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Analyse comparée de l'usage de la modélisation d'accompagnement pour faciliter la gestion adaptative de l'eau agricole au Bouthan

JURY

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CONTENTS

CHAPTER 1

INTRODUCTION

Sustainably managed and fairly distributed natural resources (NR) can form a major source of national income and prosperity. However, mismanaged and unjustly shared NR can be a major cause of conflict and instability (Peters, 2004). As in most countries, Bhutanese have for centuries depended on natural resources for their livelihood, culture and well being (NEC, 1998). The traditional norms and well-established relationships among users constituted a broadly respected customary regime of natural resource management (NRM), which has resulted from blending of appreciation for the value of natural resources and recognition of their dependence. Over the years with economic development, and rapid transformation in social values, local institutions and traditional perceptions (FAO, 1999), there is over exploitation of natural resources. As Bhutan opened itself to modern development in mid 1990s, the age old traditions and customary norms to manage NR faced greater challenges to cope with threats from variety of developmental sources like urbanization, industrialization, and commercialization (Gurung and Turkelboom, 2000). As Holling (1978) illustrates, the concept of adaptive management recognizes that a complex social agro-ecological system requires flexible, diverse strategies, and regulation, as well as monitoring procedures leading to corrective responses, and experimental probing of the ever changing reality. Because management of NR revolves within ecological, economic, and social background it makes a complex system (Berkes, et al., 2006). In view of NR governance being complex due to the multiplicity of stakeholders and arrangements to govern their use and exploitation, there are no one-size-fits-all solutions to handle NRM issues. The cautious move to embrace development is vivid in the words of past Bhutanese Planning Minister, "*We will not be rushed into an uncritical adoption of all things that are modern: we will draw on the experience of those who have trod the path of development before us and undertake modernisation with caution, at a pace that is consistent with our capacity and needs*" (NEC 1998). With 69% of the kingdom under forest, NR (forest, water, minerals, land and biodiversity) form a principal source of revenue for supporting development of the country. Therefore, there is a strong commitment to conserve the NR and strike a balance between economic development and environmental conservation by looking for "The Middle Path" (PCS, 9th Plan Document).

1.1 Justification of this research

Rising from the North-eastern plains of India at 100m elevation to 7550m in the North, Bhutan is characterized by high mountains and deep narrow valleys resulting in extreme variation in climate, geography and biodiversity. The 69% of forest cover with its associated resources represents a large and valuable pool of NR for the country. Being landlocked with more than 80% of the population dependent on small-scale mountain agriculture and livestock farming (Duba, et al., 2006), use of NR remains an essential component in livelihood and culture of Bhutanese people. Patterns of resource use have historically reflected low population density, low technology, subsistence use, and isolation from international trade. From among the NR water resource occupies an important position for the nation, as Bhutan considers harnessing water resource for hydropower as the principal development avenue (NEC, 1998). Despite the abundance of water resources, its location and distance poses a daunting challenge for using it. As such water scarcity in Bhutan can be classified as economic water scarcity[1] (IWMI, 2008), which is impacting on agricultural production and fast becoming a critical issue for most farming communities. The steep precipitous slopes dominating the topography of the country give rise to multiple watersheds of various sizes which drains into four major river systems (Figure 1.1).

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[1] Indicators of water scarcity: **(i) Little or no water scarcity**. Abundant water resources relative to use, with less than 25% of water from rivers withdrawn for human purposes, **(ii) Physical water scarcity** (water resources development is approaching or has exceeded sustainable limits). More than 75% of river flows are withdrawn for agriculture, industry, and domestic purposes (accounting for recycling of return flows). This definition—relating water availability to water demand—implies that dry areas are not necessarily water scarce, **(iii) Approaching physical water scarcity.** More than 60% of river flows are withdrawn. These basins will experience physical water scarcity in the near future.
(iv) Economic water scarcity (human, institutional, and financial capital limit access to water even though water in nature is available locally to meet human demands). Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists.

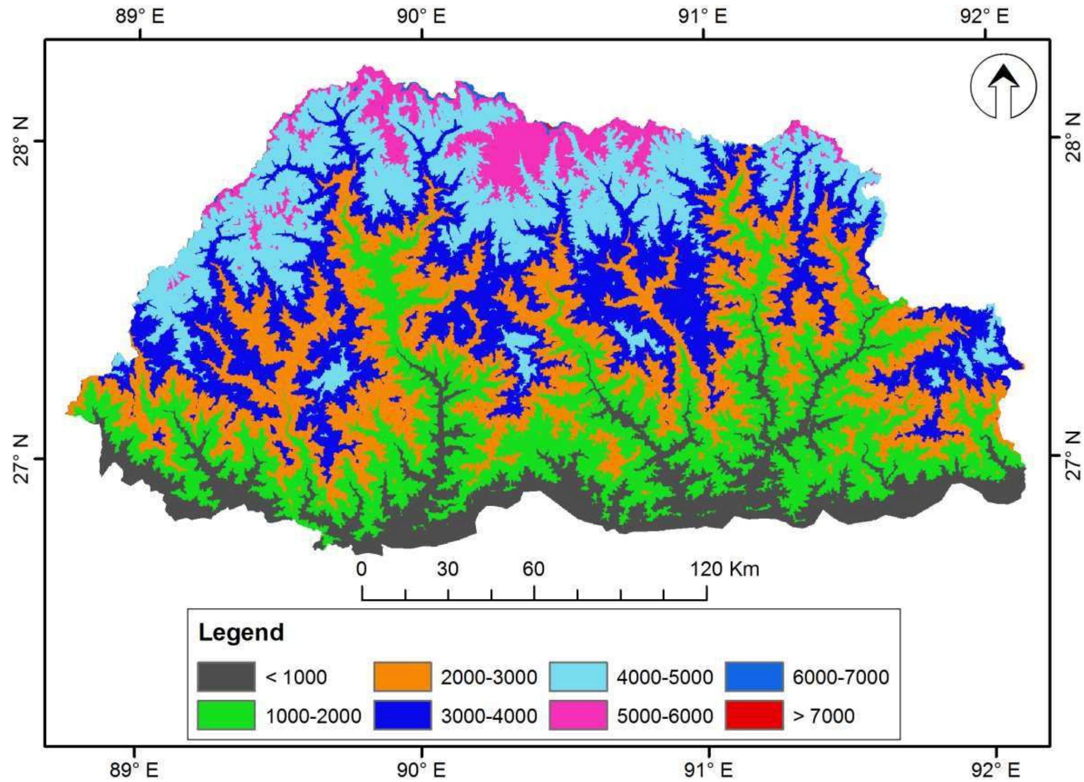

Figure 1.1. Altitudinal zones and the four major river basins in Bhutan.

The annual discharge from the four major river systems is estimated at more than 50,000 million cubic meters with hydropower potential of 20,000MW (MoA, 2002). The annual per capita water availability of 75,000m^3 of water (BWP, 2003) projects a false water security, as in reality the country is often challenged with localized and seasonal water shortages for drinking and agricultural purposes. Today only 78% of the population has access to safe drinking water and only about 27% of the arable land is irrigated (GNHC, 2008), water scarcity is expanding and fast becoming pervasive. The issue of water scarcity is related to the location of settlements in uplands and inaccessibility of water from major river systems as they flow in deep gorges (Figure 1.2), the uneven distribution of precipitation, the high cost of developing and maintaining irrigation systems in mountainous terrain, landslides and flash floods. In the lower valleys and plains, it is further aggravated by competing water demands from urbanization and hydropower projects, and the lack of legal and institutional arrangements to regulate water distribution.

Figure 1.2: Perennial river (Mochu) flowing through a deep gorge in Gasa District, west-central Bhutan.

According to the International Water Management Institute (IWMI), Bhutan falls under economic water scarcity zone where water resources are abundant to meet human demands but lack human, institutional and financial capital to access water (IWMI, 2008).

The inaccessibility to water has impacted on the basic household water need, livestock productivity and crop productivity. Every summer, rice farmers in Bhutan face acute shortage of irrigation water to cultivate their paddies due to declining water supply and competing usages, while their counterparts in the uplands struggle to satisfy their household water demand as sources dry. For instance decline in stream discharge and drying up of natural lakes are a common phenomena (Refer to chapter 4). Such state of affairs can be seen as the emergence from the complex interactions between natural and social dynamics. Water scarce situation may further reflect social, political and economic inequities. Given that all water bodies in Bhutan are state property (Forest and Nature Conservation Act 1995), water resource principally is a common-pool resource facing the problem of free riding, over harvesting and crowding (Ostrom, 2002). In the absence of definite legal provisions, the traditional practices of water resource management and conflict resolution system prevails. Most recently, with water related woes pouring in from across the country, most policy makers are pointing to the lack of water law as the culprit. As reported by a national newspaper “Bhutan’s traditional water sharing system is corrupt, unjust, feudal and exploitative, not taking into account ground realities of land and number of households" (Kuensel 26 July, 2008). Realizing the dearth of legislation on water resources, the Government of Bhutan initiated the formalization of a Water Act and a Water Policy in 2003. In July 2010 the Water Act was enacted by the National Assembly and the National Environmental Commission was subsequently assigned to be the focal agency to implement the Water Act (Water Act 2010). Until water policies are formalized and implemented, many issues related to water resource management will continue to escalate.

In the wake of uncertain administrative and legal footing, stakeholders manoeuvre within a fuzzy property rights thereby avoiding conflicts. Installing property rights including access, withdrawal, management, exclusion, and separation would facilitate better management. In any management regime, it is the resiliency of the resource base which becomes the prime objective. If resilience is the capacity of a system to absorb disturbance and reorganize while undergoing change to sustain its function, structure, identity and feedbacks (Walker et al. 2004), users have a definite role to influence the degree of resiliency. Therefore, it is of paramount importance to innovate by relying on participatory approaches to engage resource users, enhance their capacity to communicate, initiate collective decisions and actions fostering on higher system productivity, equity and resiliency.

1.2 Choice of research approach

The natural resource management system characterised by multiplicity of resources and resource users, power relations, scale, non-linearity, uncertainty, emergence, and self-organization presents a complex situation to comprehend (Berkes, et al., 2003). The ability to respond to such issues depends on information, governance, social processes and structure (Adams et al. 2003). It merits a methodological approach which can appreciate systems emergence. Among several approaches, collaborative modelling is seen as a promising way to foster integrated natural resource management (INRM) and decision-making processes. One among such collaborative modelling approaches, Companion Modelling (ComMod) with its feature of knowledge integration and ability to capture and represent different point of views provides an innovative posture, methods and tools for INRM. Its theoretical basis relies on the science of complexity, the constructivist epistemology, post-normal science and adaptive management. Its combined use of role-play games and computer agent-based models makes it versatile to facilitate shared learning and collective decision making. Its flexibility in sequencing the application of tools according to the context, and progressively iterate the cycles to incorporate new issues and understandings further makes it adaptable as it proposes very intuitive representations of actual situations. Considering the shallow understanding of the water resource issues often associated to declining resource and management problem and rapidly emerging as one of the critical NRM issue in the country, it is anticipated that ComMod approach can be adapted to current NRM context of Bhutan.

1.3 Choice of study sites: natural resource management context

Apart from harnessing water resources for hydropower generation for export earning, the essential use of water is for domestic use (safe drinking water and sanitation), agricultural use (irrigated rice, vegetable, orchards, and livestock), and cultural use. In agriculture, with only 28% of arable land being irrigated, there is always a strong drive to generate maximum output from the limited water resource. This competition for every declining water volume due to irregular rainfall pattern and drying up of source, often results in water sharing conflict. Correspondingly the drying up of upland natural springs and perennial streams have drastically impacted on the availability of safe drinking water both at rural communities and urban centres. From among different locations badly hit by the above situation (i) rice-based community in Lingmuteychu watershed where water sharing conflict for irrigated rice has become a perpetual problem, and (ii) maize-based upland community in Kengkhar where drinking water has become the scarcest resource are the two discussed cases in this dissertation.

The Punakha-Wangdi valley (Figure 1.3) where Lingmuteychu is located in the west-central part of the country is known for its local varieties of red-pericarp ("*map*") and white-pericarp ("*kaap*") rice. It is also the site where modern rice varieties have been extensively tested and modern semi-dwarf rice varieties like IR64 and IR20913 are widely cultivated. Although a major river system (Punatshangchu) drains the valley, all rice fields are irrigated with water from small seasonal streams flowing into Punatshangchu.

Figure 1.3: Terraced rice fields in Punakha-Wangdi valley.

With 90% of households from seven villages in Lingmuteychu dependent on rice farming and operating within a traditional arrangement of water sharing, local rice growers often encounter conflicting situation that sometimes escalates into physical fights. Indeed every rice transplanting season it is common to see farmers from Lingmuteychu attending legal cases in district courts following disputes on irrigation water sharing. In the absence of a legal framework and water resource management system, as the users increased amidst declining water resource, irrigators have been manoeuvring through the age-old customary norms. Over the years as the number of users increased, cropping systems changed, and competition for irrigation water expanded; the traditional water sharing arrangements became irrelevant and conflicts beyond water resource emerge between villages that impinge on broader social fabrics.

Correspondingly the Eastern part of the country is predominated by upland environments farmed with maize-based cropping systems (Figure 1.4). The landscape in the Eastern region is highly incised by swift flowing rivers resulting in steep slopes and gorges.

Figure 1.4: Ploughing a dryland farm with Mithun bulls in Eastern Bhutan.

As lower stretches of hills are mostly steep and rocky they are not suitable for cultivation, most farmlands are located in upper half of the hills where slopes are gentler (Figure 1.5). Eastern landscapes are also devoid of natural water reservoir (or lakes) that could possibly feed the slopes. As such one of the most limiting natural resource is water for both domestic use and agriculture. While eastern people mostly depend on maize, water for irrigating crops is not very important. However, access to potable water is challenged by distance and cost of building and managing water supply schemes.

Figure 1.5. Location of human settlement.

One of the communities severely affected by dwindling drinking water is Kengkhar in Mongar district. People of Kengkhar for ages have depended on natural spring ponds for drinking water. However, as natural spring ponds gradually reduced from 30 two decades ago to just 4 now (Own survey, 2007) people with the support of Government agencies tried different alternatives to resolve the water scarcity. Attempts to bring piped water from distant sources could not be sustained due to frequent breakdown and high maintenance cost. At one time people were even proposed to resettle to a lower reach in Jimjorong where water is in plenty.

Manoeuvring in the resource scarce situation confined within the customary norms, resource users have often looked at the government support of physical intervention to address the issue. Apart from direct material support to build canal and drinking water supply schemes, there is no record of well intended consultative process or community engagement focusing to build their collective capacities to comprehend the issue and also stimulate them with capacities to initiate collective action locally.

Considering the two principle uses of water and the common problem related to it, these two sites provide an opportunity to test the ComMod collective modelling approach to involve users in addressing their local long standing water resource management issues.

1.4 General research question and general hypotheses

In view of the two contrasting contexts and water management issues in the research sites, the general research question was framed as: Can the ComMod approach facilitate in building social capital[2] to enhance equitable water sharing and management? Based on this general question, more specific and complementary questions to be investigated are as follows:

- How communities in contrasting (spatial, social, economic and political) settings have been adapting to water resource management in recent years marked by accelerating economic change?

[2] Social capital is the feature of social organization such as networks, norms, and social trust that facilitate coordination and cooperation for mutual benefit (Putnam 1995).

- How does social capital enhance the resiliency of the water resource thus contributing to higher system productivity, equity, and stability?
- Can the ComMod approach enable shared understanding and collective ability to better comprehend the local situation?
- What are the effects and impacts of ComMod processes in these two sites and can they be systematically compared?

The associated hypotheses for this research are as follows:

- Enhancing the social capital in the community can enrich the local competence in managing water resources by enabling them to self-organize and set up innovative institutional arrangements for adaptive water management.
- Shared new learning on conflict situation helps in building trust and collective understanding leading to the emergence of networks both at the community level (bonding) and across multiple levels outside the community (bridging) for adaptive water management.
- The network of resource users and public infrastructure in association can enhance the efficiency of water resource management.
- ComMod processes generate and sustain effects and impacts that promote shared communication and learning, collective action and self-organization.

1.5 Research objectives

The general objectives of this research followed the two main objectives of ComMod processes implemented to support collective decision-making on resource management as follows:

1 To enhance understanding of water resource use and management dynamics by developing shared representations of the water systems and collectively exploring them with the resource users.

2 To improve shared communication and learning, adaptive capacity, to facilitate collective decision making in water resource management.

The following specific objectives were pursued:

1 To study the dynamics of water resource use and management and how farmers address the issue of water sharing conflict.
2 To understand how stakeholders adapt their decision-making process under constrained water resource situation.
3 To develop conceptual models of integration of water resource, its uses and collective management.
4 To construct and implement a family of Multi-agent models (computer-assisted Role-Playing Games-RPG and Agent-Based Models-ABM) to validate the conceptual model with stakeholders, and for further sharing scientific and indigenous knowledge on the issue being examined.
5 To identify and simulate co-management scenarios identified by the stakeholders in order to facilitate communication among them and to support the inclusive and creative negotiation of agreed upon collective action acceptable to the parties to mitigate the current conflicts.

1.6 Thesis structure

The dissertation is structured in four main parts namely (i) Situational analysis at multiple scales to understand the specificities of the Bhutanese context, (ii) Conceptualization of research and implementation, (iii) Comparative analysis of findings at the two contrasted sites, and (iv) Discussion and conclusions.

Following this brief introduction of the context and rationale in chapter 1, chapter 2 provides perspectives of how NRM systems have been mainstreamed at different levels in Bhutan. It comprehensively provides a historical perspective of NRM, issues related to natural resources, traditional institutions associated to NRM, and effects of NRM policies and institutions - on environment and livelihood. An attempt has been made to present the Gross National Happiness (GNH) policy in relation to sustainable development and the selected social-ecological framework. Alongside a detailed enquiry of water resource from social, cultural and economic dimensions is presented to better understand the issue. Chapter 3 provides an overview of agrarian systems in Bhutan with a detailed analysis of their evolution in the midst of the changes in governance. An attempt has also been made to relate how commercialization and globalization has influenced the agricultural development in Bhutan. The analysis of policies from the perspectives of sustainable development is also included in the chapter. Chapter 4 provides an overview of water resources in the country and their key role in national development. A short description of the cultural perspective of water is also provided to enhance understanding of its value. A detailed presentation of water bodies and watersheds in the country is made for better understanding of their distribution. It also presents policies related to water resources and its evolution in the country.

The second part of the dissertation discusses the use of ComMod to facilitate change in water management. Chapter 5 presents the state of the art on governance, institution, resource management and social capital. It focuses on the complexities of social-ecological systems and their management. The trend in integrated water resource management research and development is also presented. Chapter 6 provides a description of the state of the art in collaborative modelling and how it has been used in NRM and more specifically on water resources management. The review converges on the use of ComMod in NRM. It also provides a theoretical background of the research in relation to the science of complexity, post normal science, and the constructivist epistemology. Chapter 7 provides details of the research methodology. It also links to the past research done in both sites. In particular, in the case of Lingmuteychu the present application of ComMod is the up-scaling of a previous more limited intervention in the two uppermost villages. The detailed steps and sequences of the two ComMod processes are presented for better understanding of the reflexive progression.

Part three includes result presentation in Chapter 8 (Lingmuteychu) and 9 (Kengkhar), where a detailed analysis of the processes, effects and impacts at the two sites are presented. It is attempted to make specific analyses of how and why certain patterns emerge. Evolution of the ABM constructed from the RPG and their use in laboratory experiment is also presented.

Part 4 is composed of chapters 10 and 11 providing a discussion of the research findings, and a conclusion and perspectives section for further research and/or application.

PART I: SITUATIONAL ANALYSIS AT MULTIPLE SCALES TO UNDERSTAND THE SPECIFICITIES OF THE BHUTANESE CONTEXT

CHAPTER 2
BHUTAN: MAINSTREAMING NATURAL RESOURCE MANAGEMENT

2.1 Introduction

In the Eastern Himalayas, land-locked between China in the north and India in the south, east and west lies a nation state Bhutan covering an area of 38,394 square kilometres (Figure 2.1). The land rises from an elevation of about 100 metres in the south to over 7,550 metres in the north, providing a characteristic land feature of the country. The characteristic high mountains and deep valleys results in extreme variation in climate, geography and bio-diversity (MoA, 1996). With pristine condition of nature and strong policy for nature conservation, Bhutan holds the greatest potential for conservation of unique Eastern Himalayan ecosystems[1]. With 60% of the total land to be preserved as forest and its associated natural resources (water, flora and fauna), it represents a large and valuable pool of natural resources for the country.

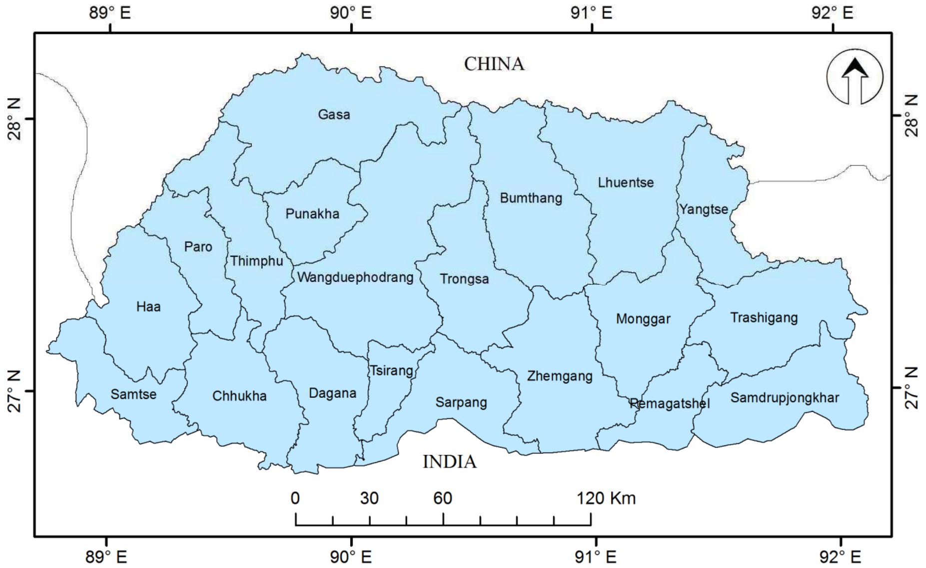

Figure 0.1: Map of Bhutan with international boundaries and twenty districts.

[1] The Eastern Himalayas are recognized as one of the global hotspots for biological diversity. It is reported that Bhutan Himalayas harbour over 100 species of wild mammals, over 620 species of birds and over 5400 species of vascular plants (300 of which are used in traditional medicine). About 46 species of rhododendrons and 600 species of orchids have been recorded so far (BAP, 2002).

Bhutan is largely an agrarian country with 79% of the total population of 634,982 inhabitants in 2008 depending for their livelihood on small-scale mountain agriculture and livestock farming (PPD, 2008). Due to the rugged terrain and altitudinal variations, total agriculture area is estimated at 8% of the total land in the country (Table 2.1). With average landholding of 1.2 hectares which are mostly marginal land, around 29% of population fall below the poverty line[2] (NSB, 2007). The low crop productivity forces the rural population to depend substantially on off-farm livelihood sources. Therefore the use of natural resources, especially forest resources (including pasture within forest areas), remain an essential component in most Bhutanese people's livelihood and culture.

Table 0.1. Land cover in Bhutan.

Category	% Total (38,394 sq. km)
Forests	72.5
Agriculture	7.9
Pasture	3.9
Settlements	0.1
Others	15.7

Source: PPD, 2008.

In recent times Bhutan has been experiencing the pressure of increasing population and demand on its small natural resource base (27,835 sq. km of forest area). For instance, timber consumption increased by 20% during 1997 to 2006 (PPD, 2008). The overharvesting of natural resources in the fragile environment influenced by rugged terrains and incessant rains during the wet monsoon increases the vulnerability to soil erosion, landslides and flash floods (PCS, 1999).

2.2 Historical perspectives on natural resource management

The land-locked and inaccessible mountainous terrain and forest cover isolated Bhutan from the outside world for centuries leading to the construction of a distinct pattern of civilization, social, economic, religious and political institutions (Hasrat, 1980). Within the regime of self-imposed isolation, ensuring the integrity of forests, rivers and soil was vital for the

[2] Poverty line= Euro 11.29 (1 Euro=Nu. 61) per person per month which is estimated to meet the cost of a food basket providing the nutritional requirements of 2124 calorie per person per day.

survival in inhospitable environments, which forged unique social-ecological relationships that ensured sustenance of near-pristine environment (NEC, 1998). As the livelihood revolved around the surrounding forests and renewable resources thereof, the locally defined roles and rules to regulate access to and use of these natural resources evolved over generations. Such local management regimes existed within communities and between users from different communities. In some situations, there were clearly defined boundaries for resource utilization and means to resolve conflicts; in other situations, competition for renewable resources was regulated by temporal arrangements. These indigenous community-level responses resulted from a combination of appreciation for the value of the natural resources and recognition of the need to prevent overuse (MoA, 2002). In the absence of formal national policy and legislations associated to NRM, local practices and traditions constituted customary regimes of NRM to achieve social and ecological objectives. Traditionally the farmers operated in self-contained subsistence farming within the limits of available natural resources, production capacities of the arable land, and bartering among the neighbourhood. Prior to the 1960s when systematic planning and development was launched, the forest and natural resources were privately owned either by individuals or the village community.

The landmark in the history of natural resources policy, legislation and management in Bhutan is the enactment of the Forest Act in 1969[3] and the subsequent nationalization of forests[4]. In nationalization of forest within the framework of the Forest Act 1969, all the natural resources[5] on public and private lands came under the jurisdiction of the state. According to Namgyel and Chophel (2001), the nationalisation of forest resources in Bhutan was influenced by the forest legislation in India that continued the British colonial policy of centralization of forest resources to serve the primary interest of the state. Although the intent of state to nationalize was to ensure protection and sustainable use of forest (RGOB, 1969), the principle flaw was disregard to the local capacities to manage resources within a given socio-ecological context. As the responsibility and control of forest and natural resources shifted to the state, it led to the disappearance of many of the indigenous knowledge systems and community-based

[3] The most critical dimension of the Act was definition of Forest as "forests means any land under forest which no person has acquired a permanent, heritable, and transferable right of use and occupancy" and it was declared as Government Reserved Forest. Further the Act invalidated the customary laws and instituted prescriptive norms.
[4] Government Reserved Forests include all land that no person has acquired a permanent, heritable and transferable right of use and occupancy.
[5] Resources within forest included trees, Non-Timber Forest Products (NTFP), water, wildlife, stone and sand.

regimes for NRM as communities lost their customary rights and control over local forest resources (Messerschmidt et al., 2001). In a situation where the state was not able to take the full control of the nation forest and in the absence of community based norms, natural resource degradation due to human and consequently natural factors became a major problem (Namgyel and Chophel, 2001).

As the natural resource mismanagement became rampant, in 1974 the first National Forest Policy was ratified to ensure forest management, development and utilization of forest resources and maximize revenue. Further to minimize the forest degradation due to over harvesting, the policy stipulated to maintain at least 60% of the total size of the country under forest cover. To broaden the scope of policy, it was revised in 1991 to include (i) protection of the land, its forest, soil, water resources and biodiversity against degradation, such as loss of soil fertility, soil erosion, landslides, floods and other ecological devastation and the improvement of all the degraded forestlands, through proper management systems and practices; (ii) contribution to the production of food, water, energy and other commodities by effectively coordinating forestry and agriculture; (iii) meeting the long-term needs of Bhutanese people for wood and other forest products by managing the production forests sustainably; and (iv) contribution to the growth of national and local economies, including exploitation of export opportunities, through fully developed forest-based industries, and to contribute to balanced human resource development, through training and creation of employment opportunities. It was the National Forest Policy 1991 that introduced the concept of scientifically prepared forest management plans with the objectives to conserve fragile environment, ensure sustainable supply of timber and NTFP for local consumption, and to promote value-added forest based industries.

The revision of Forest Act 1969 in 1995 was a key turning point in the way forest and the NRM regimes evolved. The Forest and Nature Conservation Act 1995 emphasized the protection and sustainable use of forests, wildlife and related natural resources for the benefit of present and future generations. The Act also introduced the concept of social forestry and community forestry which aims at building on the engagement of people in management of forest. Subsequent to revision of Forest Act, rule and regulation for social forestry was framed and as of May 2008, Ministry of Agriculture and Forests have approved 72 community forestry schemes covering 9,099 hectares managed by 3,940 member households (PPD, 2008).

2.3 Natural resources – distribution and dynamics

Forest resources are important for economic and ecological sustainability. An over-riding policy of maintaining 60% of land under forest cover ensures the sustenance of resources. For the purpose of this study, natural resources are grouped into four groups as timber, non-timber forest products (NTFP), water resources are presented here leaving aside biodiversity and minerals which are equally important, if not more.

2.3.1 Timber

Forest in Bhutan can be roughly classified into chirpine forest in temperate zones representing 29% of forest, transition zone where chirpine and broadleaf species cover 4% of forest area, and the sub-tropical zone characterised by a humid climate with extensive broadleaf forest covering 67% of forest area (Table 2.2).

Table 0.2: Distribution of forest area by type of forest in four regions of Bhutan in 2004 (hectares).

	Regions				
Type of forest	Western	West-Central	East-central	Eastern	Total
Coniferous[6]	37008	19672	7438	8221	72339
Bluepine	17235	3817	4247	838	26137
Chirpine	719	10062	230	5850	16861
Fir	3068	994	201	170	4433
Mixed conifer	15986	4799	2760	1363	24908
Conifer/Broadleaf	2591	3637	1743	3282	11253
Broadleaf	56897	39738	23297	48471	168403
Total	96496	63047	32478	59974	251995

Source: PPD, 2008.

These forests act as pool of natural resources. Timber and timber products are inevitable to Bhutanese livelihood as they use it for building houses, prayer flags, firewood for cooking, fencing farm land, and woodcraft. As per annual average consumption of number of trees for 2004 to 2007, Bhutanese consume 38 trees per head annually (NSB, 2009). Traditionally, Bhutanese architecture is timber intensive with intricate sculpturing on it, except for the wall which is generally built with rammed clay or chiselled stone, all other parts of the building including roof are made from wood (Figure 2.2). The culture of hoisting 108 prayer flags for

[6] Coniferous group: Bluepine (*Pinus wallichiana*), Chirpine (*Pinus roxburghii*), Fir (*Abies spp.)*

every death and varying numbers for different religious purpose is a common use which consumes substantial amount of timber. Further the practice of using log splits as fence in high altitude villages result in high timber consumption.

Figure 0.2. A typical Bhutanese house.

Table 2.3 provides an overview of timber products used from 2003 to 2007, a general trend of reduction in consumption of some products is due to the use of alternative construction materials which are now available. The abrupt increase in the use of firewood is linked to opening of several institutions like schools with boarding facilities, monastic institutions and training institutions across the country. These establishments run mess with improved wood stoves which are gradually being replaced by electric ones. In five years there was an increase of 272% in consumption of logs which is the principle revenue generator.

Table 0.3. Quantity of forest products supplied by type from 2003 to 2007.

Product Type[7]	Unit	2003-04	2004-05	2005-06	2006-07
Standing Tree	Nos.	22921	18316	26955	12465
Shinglep	Nos.	2593	2565	2260	13
Cham	Nos.	67113	45893	65103	19864
Tsims	Nos.	33048	26401	51373	11884
Dangchung	Nos.	24831	37256	41084	4393
Flag post	Nos.	42457	39483	40255	28569
Fencing post	Nos.	20728	33080	39990	24422
Fuel wood	M^3	34737	32491	29900	1462614
Logs	M^3	15883	32346	38132	59137
Sawn timber	M^3	722	145	1101	195
Bamboo	Nos.	419182	447572	628870	479549

[7] Singlep=1.5m long planks for roof, Cham – Baton, Tsims and Dangchung - planks

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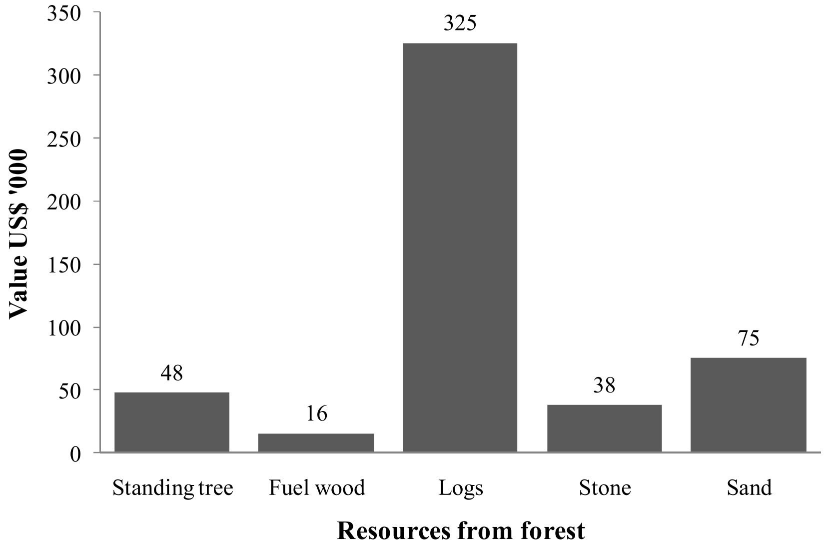


Figure 0.3. Average annual revenue generated by selling different resources from forest in Bhutan, (2003-2007).

According to the Department of Forest and Park Services (DoFPS), the total log production potential for 2014 is projected as 105,900 m^3 (PPD, 2008). To ensure sustainable forest resource utilization, a forest resource development programme has been initiated. Under the program there are 15 Forest Management Units in operation covering 127,362 hectares.

2.3.2 Non-timber forest products

As in many developing countries, NTFP continue to play a significant role in the economic and cultural lives of virtually all rural households in Bhutan. Bhutan's NTFP resource base is rich and includes a broad range of products (Thinlay, 2004) from medicines to dyes, oil seeds and nuts, incense, forest vegetables, fruits and nuts, bamboo and cane, spices, resins and high value mushrooms (see details in appendix 1). Among the species used as wild food, yams, orchids, bamboo shoots, mushroom, ferns and fresh water algae are the most popular. They are even sold in urban centers by farmers and generate substantial income (Figure 2.4). As a part of daily diet, Bhutanese use prickly ash (*Zanthoxylum spp.)* in the form of spice. As mushroom cultivation is not common, most mushroom consumed are harvested in the forest. From around 94 mushroom species, some of the commonly consumed mushrooms are "jilli namcho" (*Auricularia auricula*), which grows on rocks and rotten logs; "jichu kangroo" (*Calvaria spp.*); "ga shamu" (*Clitocybe odora*); "sisishamu" (*Cantherellus cibarius*); "taa shamu" (Polyporus spp.); and "sangey shamu" (*Tricholoma matsutake*). Of the entire mushroom, matsutake is the most prized (US$ 13/kg – in Bumthang during 2010 season) and is even exported to Japan (11 tones in 1998 which has drastically reduced by 70-80% now due to poor quality control systems).

Figure 0.4. Ferns and wild mushroom sold in local markets.

Locally woven clothes are still popular among the population. While the fabrics are imported from India, dyeing is done using local vegetable dyes available in the wilds. There are specialized weavers who can formulate quality dyes from leaf, bark, flower-fruit, and stem and root. Making of baskets and containers from wood, bamboo and cane are very popular artistry (Figure 2.5). All the craftsmen derive raw materials from the forest. Indeed, there are communities whose livelihood depends on handicrafts. They also use latex from trees to glue wood and bamboo crafts.

Figure 0.5. Weaving, cask making, and curving wooden mask are important artistry in Kengkhar.

Associated with the Buddhist culture, Bhutanese use large quantities of incense in household altars and community temples. Incense is locally made using plant species (*Nardostachys jatamansi, Tanacetum tibeticum, Juniperus spp., Rhododendron, anthopogon, Rhododendron, setosum, Abies densa, and Delphenium brunonium*) found in high mountains.

Among the all the NTFP, cordyceps[8] (*Cordyceps sinensis*) is the most priced commodity as it is exported to USA and Taiwan believed to be used as aphrodisiac. With annual production capacity of 700 kg, in 2007 a kilogram of cordyceps was sold at US$ 10,000 a highest ever reported. In Bumthang, Wangduephodrang, Thimphu and Paro farmers devote substantial time and resource to harvest cordyceps in 4000-4500m altitude sites.

2.3.3 Water resources

Situated in the Eastern Himalayas, the northern part of the country is under snow cover almost year round. The glaciers which feed rivers in Bhutan cover around 10% of the total land area. There are 2674 glacial lakes (Mool et al., 2001) that serve as a perennial source of water for the four major river systems in the country: the Drangme Chhu; the Puna Tsang Chhu; the Wang Chhu; and the Amo Chhu (Figure 2.6).

[8] *Cordyceps sinensis*, commonly called cordyceps or caterpillar fungus (locally known as *dbyar-rtsa-dgun-bub*), is a rare and highly prized medicinal ingredient that grows at altitudes of 4000 – 4500 masl. The body of a dead caterpillar jointed to a fungal stroma at the head is 3-5 cm long, 3-8 mm in diameter and has 20-30 annulations. Head is reddish brown with two bright red conspicuous eyes. There are 8 pairs of feet and the stroma is 4-7 cm long and 3 mm in diameter. Odour is fleshy and the taste slightly sweet. In Bhutan, Cordyceps sinensis is found in Lingshi, Laya, Lunana, Menla Karchung (Bumthang), Dagala and Trashi Yangtse.

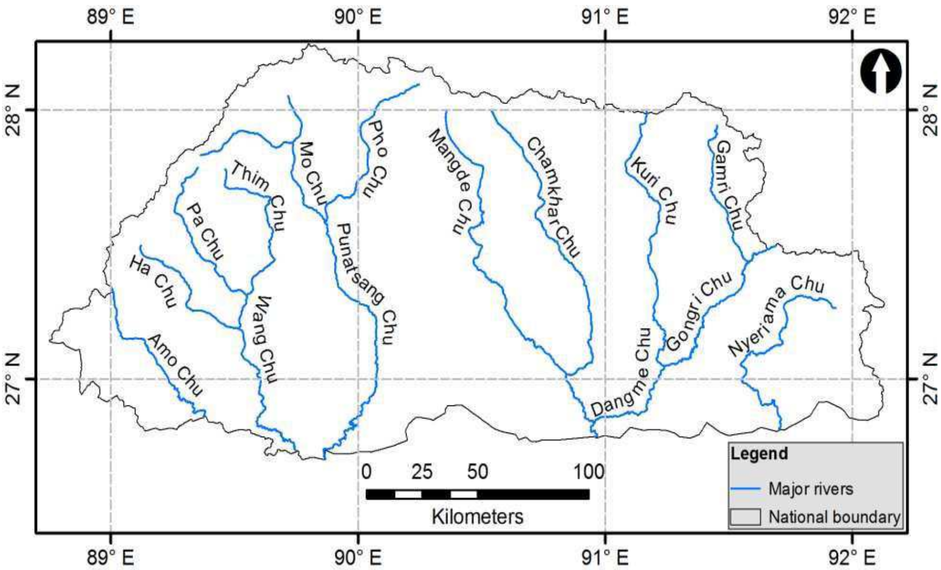


Figure 0.6. Main river systems and in Bhutan.

All these river systems swiftly meander through deep gorges and narrow valleys to drain into the Brahmaputra in India, dropping from an altitude of above 5500 m to 200m within a distance of 250 km (Figure 2.7).

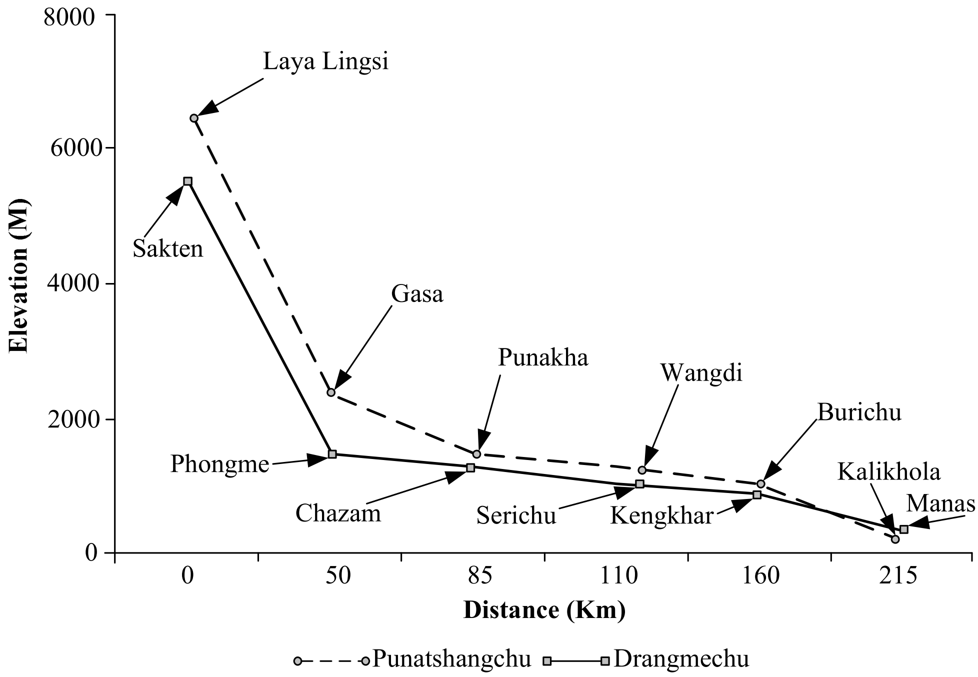


Figure 0.7. Schematic representation of the profile of two major river systems – Punatshang chu and Dangme chu – in Bhutan.

The quick drop within a short distance provides tremendous hydropower potential of around 30,000 MW (GNHC, 2008a). The hydropower sector generates around 60% of the national revenue and contributes around 19.1% of the GDP in 2008 (NSB, 2009). Apart from revenue generation, the electrical power sector has hastened the development in all sectors such as industry, education and health services. The rural electrification program which aims at the electrification of all settlements by 2020 (GNHC, 2008a) will help in the reduction of fuel wood use, improve hygiene and health, increase working time in the evenings, introduce electrical appliances thereby support in poverty alleviation. It is estimated that agriculture utilizes 54% of the water for irrigating crops followed by domestic use accounting for an extra 36%, and industries which are gradually coming up takes up 10% of water volumes (EarthTrends, 2003).

As the main rivers flow swiftly down south at the bottom of deep gorges, their water is rarely used in agriculture. In addition to its accessibility problem, low temperature from glacial melt makes it harmful to crop production. As such small season streams and spring ponds are used for domestic and agriculture purposes. The annual renewable freshwater resource per capita is estimated to be 58,930 cubic metres (PCS, 2007) and seems insufficient with increasing demand from rapid industrialization and urbanization. In agriculture, there are 19,522.81 hectares of wetland where irrigated rice is cultivated (Figure 2.8). Only 40% of the wetlands are fed with 591 km of concrete lined irrigation canals built by the Department of Agriculture (GNHC, 2008b). Remaining wetland fields are either irrigated with the help of earthen canals built by communities or depend on rainfall.

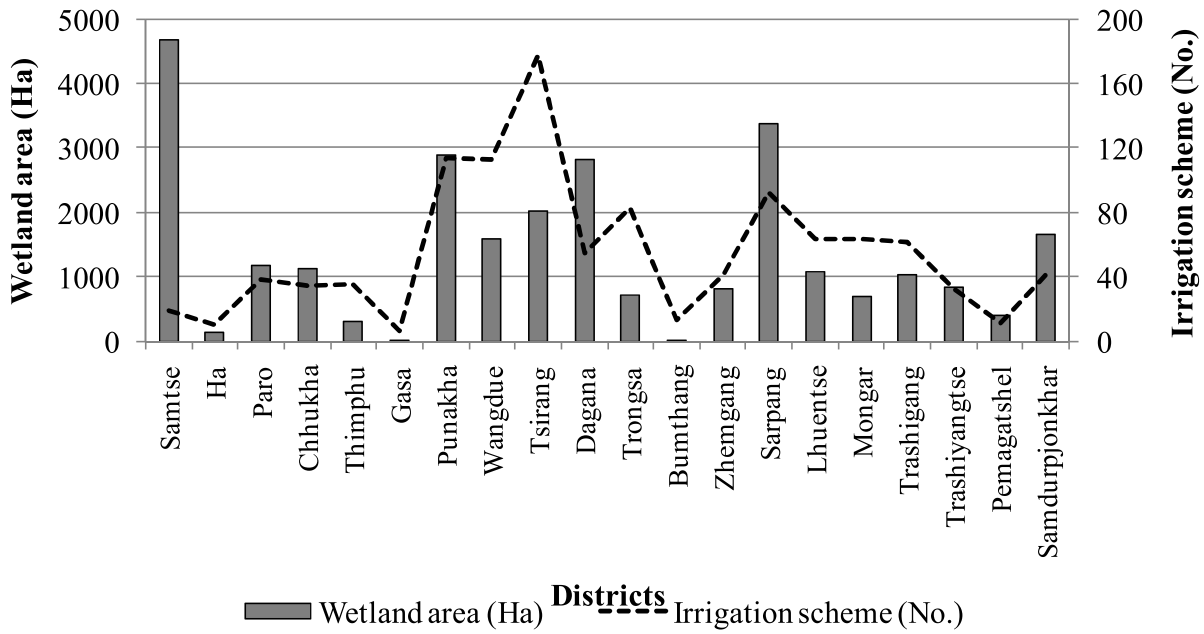


Figure 0.8. Wetland area and corresponding number of irrigation schemes in each districts of Bhutan.

For domestic use water from natural spring and stream is collected, filtered and treated to supply urban centres. In rural areas the Rural Water Supply Scheme (RWSS), a government program construct simple concrete tanks to collect and supply piped water in the village by constructing tap stands in the village. Although (Figure 2.9) official reports indicate population access to safe drinking water as 80.5% (NSB, 2007) there are many situations where schemes have been rendered non-functional due to drying up of water sources (e.g. Kengkhar in Mongar). Similarly many drinking water sources have been washed away by land slides and flash floods in Tsirang, Samtse, Phongme and Mongar, depriving the communities of safe drinking water.

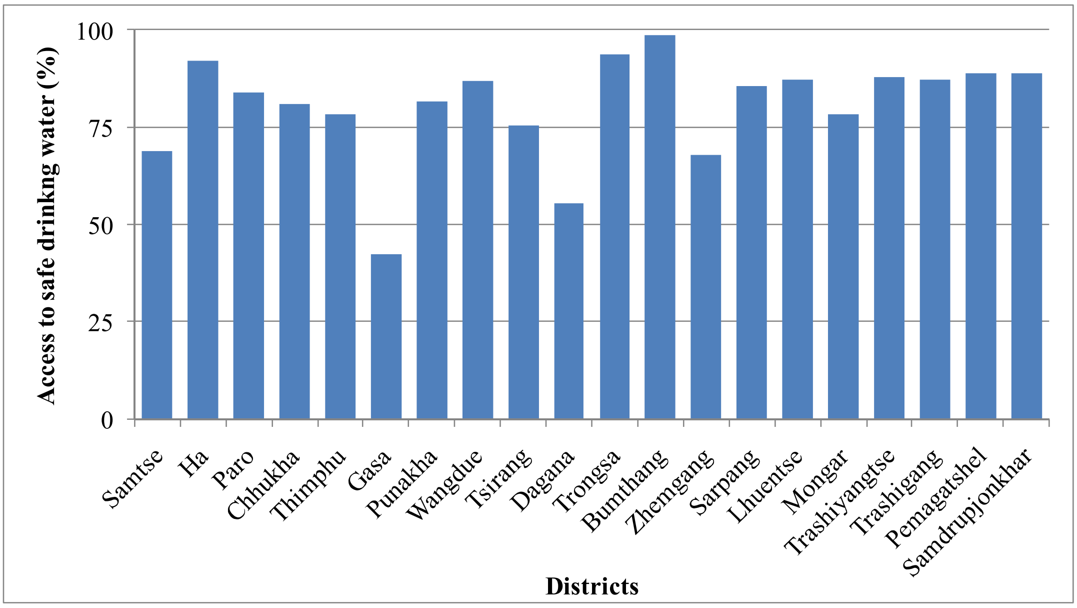


Figure 0.9. Percentage coverage of safe drinking water by districts in Bhutan.

2.3.4 Natural resource dynamics

Natural resources use and management is increasingly becoming complex with the inevitable interactions of biophysical, economic, ecological, and social aspects . The dynamics of natural resources in Bhutan can be best represented as illustrated in Figure 2.7, which is built on the theory of "induced innovation" and "Homma's model of extractivism" (Homma, 1992).

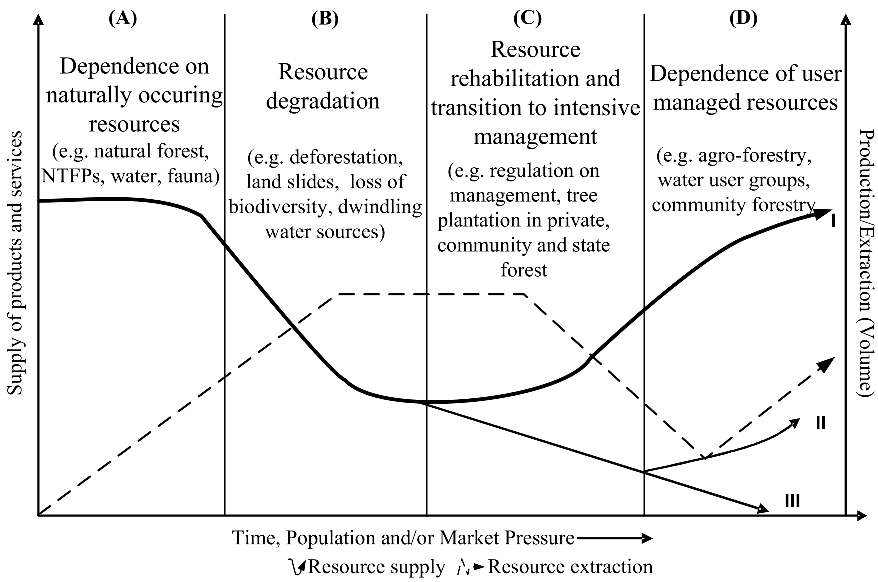


Figure 0.10. Induced innovation in natural resources management (adapted from Kerr, 1998).

The four phases correspond to the social, political and institutional development in the country. Phase A represents the period until the mid 20th century, when the country was isolated from outside influences, people fully depended on naturally occurring resources for almost all purposes from food to cloths. In absence of centralized governance of natural resources communities managed it within the customary norms that minimized unscrupulous extraction of natural resources. Phase A can be equated to the "expansion" phase of Homma's model during which extraction rapidly increases as the resources are in abundance.

The second phase (B) coincides with the registration of land, nationalization of forest and introduction of a taxation policy in the country. As the state took over the forest and the resources therein, rampant extraction of forest resource took place leading to severe degradation of resources and the ecosystem. Realizing the disadvantage of the nationalization policy and the way it was implemented which led to severe damage of the natural environment; the government introduced the concept of management plans for sustainable harvesting of the natural resources. The involvement of stakeholders in forest management was re-considered. As such resource rehabilitation became a primary focus of the phase. Starting in the mid of phase B to mid of phase C, a balance between supply and demand seemed to be attained due to increasing prices. This phase also saw the approval of 31community forest plantations (Beukeboom and Temphel, 2006) across the country that transferred management responsibilities and ownership to community members. These initiatives led to the last phase D wherein natural resources are managed by users to the extent that NTFP like *Swertia chirata*[9], orchids, star anise, and mushroom are being domesticated. In this process of management regime change, several species in the flora and fauna[10] are either endangered or lost. In the absence of detailed previous studies on the effects of such management regimes on natural resources, one of the noticeable

[9] It is one of the most important medicinal plants found in Bhutan. In Shingkhar Lauri (East Bhutan) people use this species to treat different human ailments such as fever, fungal infections, coughs and colds, worms, body pain, malaria, gout and headaches. Locally it is known as "Khalu" due to its bitter taste.

[10] Globally Threatened Mammal Species found in Bhutan: Pygmy Hog *Sus salvanius,* Golden Langur *Trachypithecus geei,* Capped Langur *Trachypithecus pileatus,* Dhole/ Wild Dog *Cuon alpines,* Red Panda *Ailurus fulgens,* Bengal Tiger *Panthera tigris tigris,* Snow Leopard *Uncia uncial,* Asian Elephant *Elephas maximus,* One-horned Rhinoceros *Rhinoceros unicornis,* Asiatic Water Buffalo *Bubalus bubalis,* Hispid Hare *Caprolagus hispidus,* Ganges River Dolphin *Platanista gangetica*

landmarks is the increased occurrence of degraded forest and deep ravines in the different parts of the country.

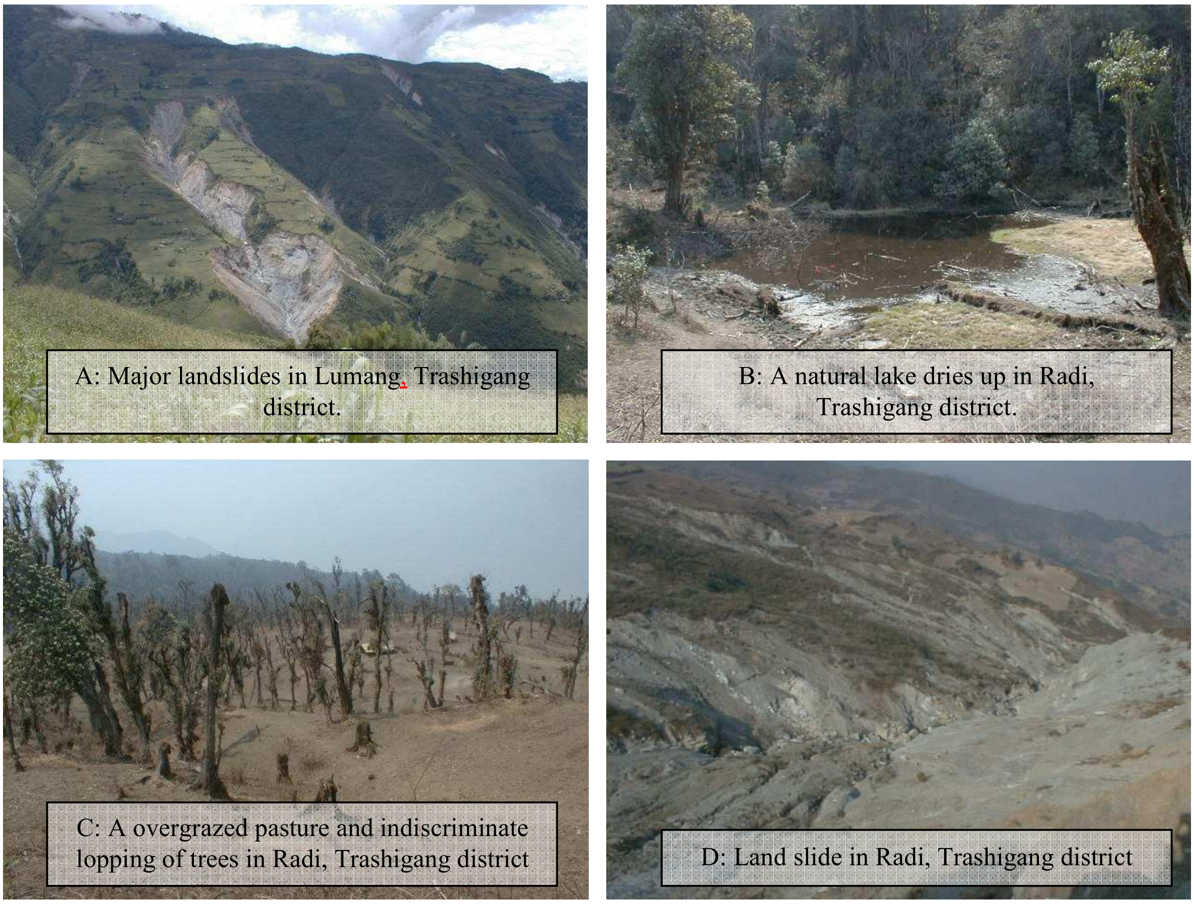
2.4 Decentralisation of natural resources management

Traditionally the livelihood of Bhutanese people was intimately associated with their natural environment that ensured the integrity of forests, rivers and soil for survival in the high valleys of the Eastern Himalayas (NEC, 1998). This association forged over centuries within the local norms helped in sustaining the resource base. Abundance of resources, low population, self-reliant subsistence societies, and lack of national policies resulted in commonly accepted traditions and social relationships among users. Such traditional norms collectively comprised the customary regime of NRM which ensured collective benefits. Within the customary regimes, societies designated oldest trees, rock, natural spring, source of streams, and pass as holy and seat for local deities. The local prescriptions to avoid littering the natural lakes, feel trees, and make undue noise, actually helped in preserving the niche ecosystem. For instance, eutrophication of lakes is avoided as there is a local belief that littering the lake can result in dreadful curse from the local deities.

Resource use rights play important roles in determining how natural resources are used, by defining who has rights to use and the relationships among individuals and groups as they benefit from the resources. A number of different types of use rights can be recognised as (Schlager and Ostrom, 1992):

- Access: The right to enter, exclude and alienate a defined physical property and how the right may be transferred.
- Withdrawal: The right to obtain the products of a resource.
- Management: The right to regulate internal use patterns and transform the resource by making improvements.

Traditional rules based on the user rights concepts significantly ensured sustainability of the natural environment until recent times. However, during the 1960s when forest and all natural resources within forest were brought under the purview of the National Forest Act, the traditional rules were rendered obsolete. Since then the forest became a state property, access to which was highly regulated. In a highly regulated situation with minimum or no monitoring in the field, the forest around the settlement were completely stripped off and overgrazed leading to severe land degradation (Radi, Phongme, Lumang in Trashigang districts are some of the examples) Figure 2.11.



A: Major landslides in Lumang, Trashigang district.

B: A natural lake dries up in Radi, Trashigang district.

C: A overgrazed pasture and indiscriminate lopping of trees in Radi, Trashigang district

D: Land slide in Radi, Trashigang district

Figure 0.11: Land degradation in Trashigang district in the eastern region of Bhutan.

In 1981, when the civil administration introduced District development committees with the objective of decentralizing the decision making process, and subsequently block development committee in 1991 to empower and promote local socio-economic development strategies, it provided an impetus to also engage users in forest management. This decentralization drive, also influenced to enact the Forest and Nature Conservation Act (FNCA) in 1995, provided provisions for establishment of community forests. Up to 2008, there were 72 community forests covering an area of more than 9,000 hectares (PPD, 2008). In conjunction to this, people are also allowed to develop and maintain private forest areas.

To formalize the decentralization process, bylaws for district and block[11] development committee were passed in 2002. These bylaws specify the role of development committees and village head in managing the natural resources in their jurisdiction. Indeed the responsibilities to delineate critical watershed and catchment, approval for timber harvesting and other resource uses for the rural population were transferred to the block development office.

2.5 Policy environment

With 72.5% of the country under forest cover and a population density of 16 person/sq. km, there is no apparent menace to the natural resource. But the policy environment stresses the sustainable management of natural resources for all times to come. The commitment of Bhutan to maintain 60% of the country under forest covers (PCS, 1999) provides an overriding policy setting that favours NRM. Some of the broad policy frameworks that touch upon NRM are briefly detailed below.

2.5.1 Development philosophy: Gross National Happiness

Gross National Happiness (GNH) is the development philosophy of Bhutan which stresses development as a process which seeks to maximize happiness rather than economic growth alone (PCS, 1999). Unique to Bhutan the concept emphasizes that development has several dimensions other than those associated with the Gross Domestic Product (GDP). Analogous to Buddhist principles of containment, in the words of Frederick Keonig, "We tend to forget that happiness doesn't come as a result of getting something we don't have, but rather of recognizing and appreciating what we do have."[12]. Thus GNH places the individual at the centre of development efforts, in recognition of the spiritual and emotional needs of that individual, in addition to the material needs. The four pillars of GNH are the preservation and promotion of culture, sustainable and equitable development, promotion of good governance, and conservation of the environment (Thinlay, 1999). They holistically emphasize on sustainability and equity issues comparable to sustainable development concepts, except that GNH also stresses the spiritual needs of human beings and advocates achieving a harmonious balance between the material and non-material dimensions of development (GNHC, 2008a).

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[11] Block (locally called as Geog) is the cluster of villages and the lowest administrative unit. The block is headed by a elected headman (Gup) who serve as chairman of the Block development committee.

[12] http://thinkexist.com/quotes/frederick_keonig/

These elements give a tangible expression to the central tenets of GNH and embody the guiding principles related to the independence, sovereignty and security of the country. The concept of GNH rejects the notion that there is a direct relationship between wealth and happiness.

2.5.2 Constitution of Bhutan

The constitutional reforms initiated with the establishment of the National Assembly of Bhutan in 1953 and transforming the country into a constitutional monarchy was the first step to the adoption of democratic principles of governance (Hasrat, 1980). Subsequently the decentralization policy of 1981 further strengthened grassroots participation in governance. The enactment of the Constitution of the Kingdom of Bhutan in 2008 and successive launch of democratically elected government was a land mark in engaging people in governance. Within the constitution, there is a specific mention in Article 6 which relates to the environment and elucidates the maintenance of 60% forest cover for all time to come and the role of Bhutanese citizen to protect their natural environment, and conserve biodiversity (RGoB, 2008). As an overriding decree, it provides enabling background for sustainable management of natural resources.

2.5.3 Environment and forest policies

As a custodian of state forest, the DoFPS operates within the broad policy framework as prescribed in the Acts related to forestry. While rights and concessions were given, the Forest Act of 1969 makes special mention that concessions are permitted within the limits of protection of the environment and public property (MTIF, 1969). In 1974, the Department of Forest under the Ministry of Trade, Industries and Forests formulated the National forest policy of Bhutan with the objectives of forest conservation, utilization, and revenue generation (DoF, 1974). The strong point of the 1974 policy was the conservation – where the need to maintain 60% forest was already envisioned. Further the inclusion of watershed management and domestication of NTFP highlights the commitment to NRM. The comprehensive forest policy of 1974 was more holistic and encompassing than the provisions of the Bhutan Forest Act 1969. Realizing the mismatch between Act and policy, the Forest and Nature Conservation Act was enacted in 1995 (FNCA) superseding the 1969 Act. FNCA broadened the scope of the Act and introduced the concept of management of forest and natural resources by state and stakeholders. While conservation through national parks and biological corridors was maintained within the Act, soil and water conservation was included giving the impetus to watershed/catchment management. To effectively deliver the services within the FNCA 1995, Ministry of Agriculture formulated the Forest and Nature Conservation Rules of Bhutan in 2006. It details procedural aspects supported by series of administrative forms to facilitate implementation (DoF, 2006).

The National Environment Commission (NEC) as an autonomous agency of the Royal Government of Bhutan oversees all issues related to environment in Bhutan. To curtail the ill-effects of development projects and avoid environmental harm, the Environmental Assessment Act was enacted in 2000. It requires all projects to acquire environmental clearance certificate from NEC prior to implementation (NEC, 2000). Considering the need to maintain or enhance health, diversity and productivity of environment and natural resource for the future generation while maximizing the benefit now, the National Environmental Protection Act was enacted in 2007 which ordained that all Acts and regulations governing the use of land, water, forests, minerals and other natural resources shall be in coherence to this Act (NEC, 2007).

The long awaited policy framework on water resource was finally cleared by the fifth session of Parliament in July 2010 as the "Water Bill of Bhutan 2010". The Act is aimed at ensuring the protection, conservation and management of water resources in an economically efficient, socially equitable and environmentally sustainable manner (Ref Water Bill).

2.5.4 People participation

The participation of people in decision making and governance dates back to 1953 with the installation of the National Assembly as the highest decision making body constituted by people's representatives and government officials. Although decentralization started in 1981 when District development committees were instituted, the working modalities were formalized only in 2002 after the District development committee bylaws (*Dzongkhag Yargay Tshogdu Chathrim*) and the Block development committee bylaws (*Gewog Yargay Tshogchhung Chathrim*) were approved. The responsibilities of committees and rural people in managing natural resources were clearly pronounced. More specifically the involvement of people in management of water resources started when the irrigation policy was launched by the Department of Agriculture in 1991, wherein the concept of water users association was applied to involve the users in managing the irrigation schemes. Similarly rural people were given the responsibility to manage forest through social and community forestry program since its inclusion in 1995 FNCA. The above development committee bylaws have been superseded by The Local Governments' Act of Bhutan, 2007 to facilitate direct participation of the people in the development and management of their own social, economic and environmental wellbeing through decentralization and devolution of power and authority.

Participation of people in commercialization of agriculture could not materialize due to low economy of scale. Thus to provide opportunity for people with common farming interest and economic objectives to come together, the Cooperative Act was approved in 2001. As enshrined in the Act, communities can organize in groups to manage, harvest and market certain natural resources from the locality or even operate group business. There are already small groups of farmers specializing on *chirata* (*Swertia chirata*) in Samdrupjongkhar, *pipla* (*Piper longum*) in Pemagatshel, *amla (Emblica officinalis)* and Lemongrass in Mongar. In line with the cooperative act, area development projects like the Agriculture marketing and enterprise promotion program (AMEPP) in the Eastern region provide financial grant to support micro-initiatives on agri-business. To further promote people participation beyond rural communities, the Civil Society Organization Act was enacted in 2007 to support organizations that work on mutual benefit and public benefit principles.

2.6 Institutional environment

2.6.1 Government institutions linked to NRM

Institutional transformation in Bhutan has been motivated by strong cultural heritage which serves as a powerful, unifying and integrating factor of social harmony and cohesiveness. This gradual institutional change has over time fostered Bhutanese society to gain more control over their own destiny, and orient the development pace within the internal capacity of resource endowment and absorptive ability. Some of noteworthy initiatives in institutional development related to natural resources are presented in Table 2.4. These institutions aim at enabling the NRM initiatives and engagement of population in sustaining the efforts.

Table 0.4. Introduction of institutions related to natural resource management in Bhutan.

Year	Institutions	Roles and comments
1952	Department of Forest as the first department of Government was established	Regulate forest resource use
1953	*Tshogdu* – National Assembly was established by 3rd King	Highest legislative body
1961	Department of Agriculture and Department of Animal husbandry were established under Ministry of Development	Technical department with implementation responsibilities
1961	Geological Survey of India establish mineral exploration program in Bhutan	Inventory of minerals
1963	*Lodey Tshogday* – Royal Advisory Council was established	Advices the King on matter of national importance, acts as bridge between governments and people, ensures implementation of laws and decisions of National Assembly.
1968	High Court was established	
1968	Cabinet (*Lhengye Zhungtshog*) was established	Highest executive body
1969	Department of Trade and Industries was established	Forest Act 1969
1981	20 *Dzongkhag Yargey Tshogchung* (DYT) (or District Development Committee) with 572 elected members nationwide was established	To promote people's participation in the decision making process.
1991	201 *Gewog Yargey Tshogchung* (GYT) (or Block Development Committee) with 2614 elected members at the national level was established	To promote local socio-economic development strategies and initiatives by empowering the people to make decisions on their plans and programs.
1991	Bhutan Trust Fund for environmental conservation was established	To sustain financing of environmental conservation
1998	Council of Elected Ministers	Devolution of full executive power
1998	National Biodiversity Centre was established	Implement biodiversity action plan
2008	Democratically elected government with 47 constituencies and 20 member National council	Democratic governance
2010	Department of Agriculture Marketing and Cooperative established	Implement Cooperatives Act

Considering the need to regulate forest and natural resources in the country, the Government instituted the first department as the Department of Forest. The management of forest and natural resources were gradually centralized and regulated as state property. As the department it could play a critical role in positioning the forest resources in overall development policies and processes. With the highest decision making body, the National Assembly consolidated the people's voices and put together the Forest Act in 1969. To provide greater impetus to the Department of Forest, it was put under the Ministry of Trade and Industries so that forest resources including water could become vital economic commodity. The indiscriminate exploitation of forest resources leading to widespread degradation following the nationalization led to gradual decentralization of natural resource management responsibilities. Decentralization was formalized through enactment of District and Geog development committees and their associated bylaws. In parallel as the check-and-balance mechanisms, non-government agencies like National Environment Commission played the role of coordinating NRM initiatives.

The institutions associated with natural resources can also be identified at three levels where they operate and regulate. Looking at seven major natural resources, it is vivid that while at macro levels there are different agencies involved in specific resource there are only few institutions at the micro level (Table 2.5). There are even cases where a single institution covers all the three macro, meso and micro levels. Such differences have created misunderstandings by misinterpreting the policy or inability to fully deliver the services when required.

Table 0.5. Natural resources and associated institutions at different levels in Bhutan.

Resources	**Macro**	**Meso**	**Micro**
Forest (State, community, social, and private)	Department of Forest, National Environment Commission	Territorial forest office	District forestry extension, Range/Beat office, Geog extension office
Water resource (including watershed, major rivers, glaciers)	Department of Agriculture, Department of Energy, National Environment commission, Department of Forest, Department of Geology and Mines	Regional Research and Development centers, Territorial forest office	District agriculture extension, District environment office, Range/Beat office, Geog extension office
NTFPs	Department of Forest, ITMS, National Mushroom Centre	Territorial forest office, Regional Research and Development centers	District Forest extension, Range/Beat office, Geog extension office
Wildlife	Department of Forest, World Wildlife Fund	National Parks, Territorial forest office	District Forest extension, Park, Range/Beat office, Geog extension office
Biodiversity (Flora and Fauna)	National Biodiversity Centre, Department of Forest, Royal Society for Protection of Nature	Territorial forest office, Regional Research and Development centers, Parks	District Forest extension, Park, Range/Beat office, Geog extension office
Minerals	Department of Forest, Department of Geology and Mines	Territorial forest office	Range/Beat office
Natural pastures	Department of Forest, Department of Livestock	Territorial forest office, Regional Research and Development centers	District Livestock extension, Geog extension office

2.6.2 Traditional institutions associated to NRM

Prior to nationalization of forest in 1969, the resources used for collective benefit were managed by age-old institutions which had been tested over centuries. The most prominent ones related to the study are presented in Table 2.6. Although there is no written operational mechanism, the system has been passed over generations with minor changes.

Table 0.6. Traditional institutions related to natural resource management in Bhutan.

Local Institution	Resource	Boundary	Role	Sanction	Status
Reesup (Village forest guard)	Forest	Village	To ensure all households have adequate firewood and timber, apply ban to access forest "*reedum*" during specific period.	Yes	Replaced by Forest guard
Meesup (Forest fire watcher)	Forest	Village	Monitor forest fire, and mobilize community is case of forest fire	No	Do not exist
Chusup (Drinking and irrigation water watcher)	Water	Irrigated field	Ensure access to drinking water and proper distribution of irrigation water	Yes	Formalized in the Land Act and still in practice
Shingsungpa (Agriculture crop damage arbitrator)	Agriculture crops	Village	Protect crop from cattle damage and arbitrate crop damage disputes	Yes	Formalized in the Land Act and still in practice

Among the four institutions mentioned in Table 2.6, *reesup* or the village forest guard was the most common and every village in the country had it. Considering the forest as the primary source of most resources community depended on, *reesup* had a crucial task of protecting it from intruders, internal exploitation, and equitable allocation of firewood and timber. Associated with *reesup* was the forest fire watcher (*meesup*) who had the difficult role to watch for any forest fire during dry seasons and mobilize community in fire fighting. While the *meesup* had no authority to penalize the defaulters, the *reesup* had the power to penalize them in the form of free community labour and to abandon one's provisions. This may be because the management responsibility is collective impinging the whole community, which indirectly helps in minimizing intentional fires. Further it also promoted collective monitoring.

Next two categories of traditional institutions are related to farming. In all villages where rice cultivation is practiced, community designated on an annual rotational basis a member of the community as water guard (*chusup*). *Chusup* had to ensure equitable distribution of water for drinking and irrigation. Traditionally, villages used water from the irrigation canal for drinking until very lately when rural water supply scheme introduced piped water supply. As irrigation water had to be conveyed in an open earthen canal, it needed a regular maintenance. *Chusup* had to organize seasonal canal cleaning and repair prior to the rice growing season. Whenever a canal collapsed or went dry, the *chusup* rapidly mobilized users to attend to the problem. In addition, every community had a person with high integrity and respect who served as agriculture crop damage arbitrator (*shingsungpa*). The *shingsungpa* had the role of ensuring that crops were not damaged by domestic animals. In view of scattered settlements and proximity of fields to forest, wild animal damage was inevitable. Therefore, the *shingsungpa* also had some role in monitoring the crop damage by wild animals. The principle responsibility of the *shingsungpa* was to arbitrate the crop damage compensation in a just manner.

The above institutions functioned under close guidance and scrutiny of village elders, who generally acted as village council. Even if they appeared informal, people cherished the time when community managed resources locally. With the enactment of the Bhutan Forest Act in 1969, the *reesup* and *meesup* were rendered obsolete and all forest management responsibilities were taken over by department of forest. However, in 1985 the Department of Forest realized that the *reesup* could play a key role in providing local knowledge and information, interpreting the concept of sustainable forest management, and developing useful institutional links with the local people in managing the forests. The responsibilities of the *reesup* was reinstated with additional responsibilities of explaining government policies, rules and regulations regarding sustainable forest management, and supporting in monitoring of forest (Wangchuk, 1998).

Similarly when the national irrigation policy was launched in 1991, it was built on the concept of farmer managed irrigation systems operating in the country. Within the policy, the *chusup* was included to play a crucial role in making water users association functional. The *shingsungpa* too was formalized in the Land Act 1979 and is still in practice. Its role in crop damage assessment has become more important with the crop devastation becoming a regular phenomenon.

2.7 Effect of NRM policies and institutions on environment and livelihood

As enshrined in the Constitution of Bhutan 1953 (Hasrat, 1980), all decisions on nation building are to be done through a consultative mode to achieve the happiness and prosperity objective. Within this premise all the policies and institutions enacted and instituted largely maintained the welfare and were people centred as the basis. Despite the benevolence, due to the social, cultural and economic differences the effects of policies and institutions have been varied, mostly planned but many unexpected.

The four traditional institutions explained in Table 2.6 which emerged from within the community were valued and abided by all. While one person was assigned of the duty, the whole community took collective responsibilities as it is them who identify the responsible person and even prescribe the rules. The well intended formal NRM policies and institutions could not harness wholesome commitment of the community members. Table 2.7 presents some effects of policies as experienced by people.

Table 0.7. Successive policies related to natural resources and their effect on environment and livelihood in Bhutan.

NRM Policies	Year	Environment	Livelihood (Agriculture)
Forest Act	1969	Commercialization of timber and inability to monitor led to rampant clearing of forest and extraction of timber. (Namgyel and Chophel, 2001).	Access to resources became highly regulated, dependence of sedentary agriculture increased.
Forest policy	1974	Designation of wildlife sanctuary, commercialization logging in broadleaf forest area.	Commercialization of natural resources in accessible areas leads to decline in NTFP supplies.
Land Act	1978	*Sokshing* (forest to collect leaf litter) and *tsamdo* (grazing land) used beyond carrying capacity, sign of decline in many areas.	Land ceiling and access to land for all secured the livelihood of people. Supply of forest litter for composting declining, population dependent on livestock faced with grazing problem.
Forest and Nature Conservation Act	1995	Scientific extraction and management helped in sustaining the resource base, reforestation of logged areas.	Community involvement in forest plantation and management assured better access to resources, litter, water, timbers and grazing areas.
Ban on shifting cultivation by 70th Session of National Assembly	1995	Damage by uncontrolled forest fire reduced and forest cover increased.	Shifting cultivators deprived of their livelihood source, agro-biodiversity loss, population shift to off-farm employment.
Bhutan 2020	1999	Integrated management approach to environment put in plan.	Sustainable development of agriculture.

Table 2.7 (Continued) Successive policies related to natural resources and their effect on environment and livelihood in Bhutan.

NRM Policies	Year	Environment	Livelihood (Agriculture)
Environmental Assessment Act	2000	Saved fragile environment and ecosystems from major development work.	Protection from environmentally unfriendly projects and technologies.
Forest and Nature Conservation Rules	2006	Increased forest cover through reforestation and regulated use.	Ownership of trees from community forestry acts as source of income for the community.
Land Act	2007	Increased forest areas as natural pastures and forest used for collecting litters were nationalized, centrally manage degraded areas.	Uncertainty for livestock dependent farmers, source of organic matter may be curtailed
Local Government Act	2007	Environmental management activities at village and block level gets priority.	Management of crop and livestock predation by wild animals initiated in bigger scale
Civil Society Organization Act	2007	Awareness program and environmental campaign helped in restoring environment (RSPN, NEC, WWF).	Livelihood support program in remote poverty stricken communities, handicraft promotions, and small agro-based businesses.
Constitution of the Kingdom of Bhutan	2008	Environmental management is a constitutional responsibility.	
Cooperatives Act (2001 revised in 2009)	2009	Minimize individual exploitation of natural resources (NTFP).	Maximize profit from agri-business and NTFP, as an alternative source of livelihood.
Water Bill of Bhutan	2010	Water resource management in holistic manner, watershed management in place.	Equitable water sharing and agriculture water prioritized second only to domestic use.

The drive to nationalize forest drawn from colonial India was flawed by lack of state's capacity to monitor and manage such an unexplored extensive forest (Namgyel and Chophel, 2001, and Wangchuk, 2005). In the process the public property became state property exposing itself to indiscriminate exploitation. There are several landmarks like overgrazed pasture in Radi (Gurung et. al 1999), land slides in Lumang (Wangchuk and Turkelboom, 2010), ravines in Lingmuteychu (RNRRC Bajo, 1996), flash flood in Bomdeling (TDA, 2008) which are reminders for policy makers. Such devastations consequently led to the loss of agricultural land (eg. Rice fields in Radi and Bomdeling, dryland fields in Lumang) and deprivation of pasture in Radi, Phongme and Songphu. It hit the livelihood of several resource-poor farmers (Levaque, 2005). The Land Act with the noble idea of land reform secured the livelihood of landless and tenant farmers. The designation of natural pasture and woodland used for collection of leaf-litters (*sokshing*[13]) as Government Reserved Forest and giving only the user rights without management responsibilities resulted in excessive use. The Forest Act and policies indeed broaden the gap between resource users and the government institutions responsible for NRM (Wangchuk, 2005). In spite of the withdrawal of provisions to practice shifting cultivation by Forest Act 1969, people continued to make a living from this type of farming. However, when the 70th session of National Assembly imposed complete ban on shifting cultivation in 1995, people were left without any alternative which deprived them of the basic livelihood source. The revision of Land Act in 2007, completely took over the pasture and *sokshing* to be let on leasehold arrangement. Forest and Nature Conservation Act of 1995 and its related rules introduced scientific management of forest and engagement of people in managing forest and natural resources. Even the most recent Water Bill 2010, reaffirms the reinstating of *chupeon* (water guard-same as chusup as described in Table 2.6) and involvement of beneficiaries in management of water resources and related infrastructures.

The development of institutions had far reaching effects on the environment and livelihood. It seems the effects of institutions were more far reaching than the policies, due to variations in translations of policies by different institutions during implementations (Table 2.8). For instance, shifting cultivation practices which were banned in 1969 still continues in remoteareas, may be with slight changes (Kerkhoff and Sharma, 2006). Similarly the conservation policy on wildlife which prohibit killing[14] of wildlife is applied differentially. Further the conflict in policy of conservation and crop production makes it practically difficult for implementing agencies.

[13] A oak forest in the periphery of a community is used exclusively for collecting leaf litters to make compost. It can be individually or collectively owned with only user right. Such woodlots are locally termed as *sokshing*. They form an important source of organic nutrient for farming.

[14] Chapter VII of the Forest and Nature Conservation Act 1995 (FNCA 1995).

Table 0.8. Institutions related to natural resources and their effects on environment and livelihood.

Organization	Institutions	Environment	Livelihood (Agriculture)
Department of Forest	Community forestry, Social forestry, *reesup* and *meesup,* Watershed management committee, Community based NRM group (Chirata, Pipla, Bamboo-cane).	During 1950-70 there was indiscriminate logging leading to widespread deforestation, after which conservation and protection of forest.	Nationalization of forest in 1969 deprived people of NTFPs and also timber, however gradually people friendly policies gradually brought back people to forest management, provision to domesticate and scientifically harvest high value NTFP enhanced livelihood, stringent wildlife conservation policy hit hard on people (still a major issue).
National Environment Commission	Environmental clearance committee.	Mainstreaming of environmental issues in government policies and programs helped in environmental management (NEC, 1998).	Ensure sustainability of livelihood program.
Department of Agriculture	Water users' association, self-help group, *chusup*, Community based NRM group (MAP-lemongrass).	Expansion of farming in fragile areas and continuation of shifting cultivation lead to severe land degradation (Upadhaya, 1988), construction of farm road and irrigation structures in fragile areas initiated degradation (Gurung et. al., 1999; PCS 2002).	Support crop production by promoting technological options, inputs and credit, commercialization of farming, poverty alleviation (MoA, 2007).
Department of Livestock	Dairy development groups, community based pasture development.	The pastures in high altitude areas are heavily overgrazed with consequential damage to forests and erosion of soil (Jambay, 1993).	Modern livestock management systems, pasture development, and better livestock breeds helped in enhancement of livelihood (GNHC(b), 2008).
Department of Agriculture Marketing and Cooperatives	Farmer groups and cooperatives.	As a unified group, exploitation of environment is drastically reduced.	Protecting farmers and provide an effective response to market forces, enhance household income (GNHC(b), 2008).
Ministry of Home and cultural Affairs	District and Block development committee.	Local decision to manage environment by prioritizing the activities ensures sustenance.	Environmental management programs linked with the livelihood support systems (bamboo-cane in Zhemgang area, Bohemeria in Kengkhar, lemongrass in Mongar.

After two decades of failure in managing the environment and natural resources, reinstating the traditional institutions within the new policy framework was a positive move. The *reesup, meesup, chusup*, and *shingsungpa* incorporated in different policies helped in bringing back the community in environmental management. As these traditional institutions were either not found in all communities or operated in different modes (Wangchuk, 2005) the blanket application of the concept may not be uniformly accepted. Since the launch of the community forestry program, water user association, management committees and producer-marketing groups it has gradually enhanced the capacity of community as well as government's role in managing the environment. It can also be observed that formalizing the institutions have facilitated mainstreaming the environmental management principles.

2.8 Perspective of national development philosophy and NRM

Following the argument that global is associated with "capital, space, history and the power to transform" and local being " place, labour, tradition and, not infrequently, women, indigenous people, peasants and others who are 'still attached to place", it imply subordination of latter (Dirlik, 1998). Subordination can also be an internal phenomenon as lack of education was considered as a factor for backwardness in Bhutan, as mentioned in the preambles of Constitution of Bhutan 1953 (Hasrat, 1980). To avoid subordinations, Bhutan borrowed ideas from developed nations, initially for education and later for governance. Although it is said that only in global partnership nations can achieve integration of environment and development to fulfil basic needs (UN, 2009), experiences of western development in developing nations has led to the dissolution of indigenous cultural, political, and economic systems leading to increased inequalities in livelihood systems and access to natural resources (Porter and Sheppard, 1998). Bhutan, despite its prior self-imposed isolation, was swirled into the development pathways by the regional and global movement after 1960s. Realizing the development as a double-edged sword, Bhutan took cautious and proactive measures to ensure development as mutually inclusive of socio-economic, environmental, and cultural integrity for long term viability (NEC, 1998, Pommaret, 1998). Based on this premise of development, the fourth King of Bhutan, His Majesty Jigme Singye Wangchuck, articulated the concept of Gross National Happiness (GNH) as soon as 1972 (NEC, 1998). Since then GNH has been the development philosophy of Bhutan.

2.8.1 Gross National Happiness policy and its relationship to sustainable development and the social ecological systems framework

Within the Bhutanese value system where development is equated to knowledge acquisition and self containment as the goal, the GNH concept comprehensively relates to all spheres of social welfare. It is possible to identify common ground between the GNH principles posited as a development philosophy in Bhutan with the movement of sustainable development[15] based on United Nations' Agenda 21[16] and Social Ecological Systems (SES)[17] framework. From a narrow perspective, the elements of these three concepts can be presented through their economic, social, environmental and institutional components (Figure 2.12).

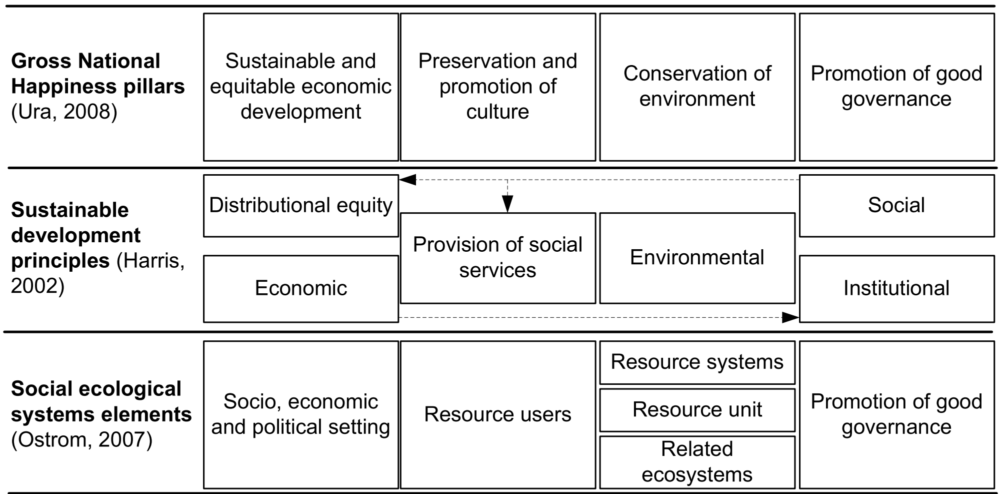

Figure 0.12. Relationship of Gross National Happiness (GNH) to sustainable development and Social Ecological Systems (SES) concepts.

All concepts emphasize sustainability and equity issues. Their focus on mainstreaming marginalized and disadvantaged groups is another common concern. Cultural plurality and promotion, social freedom, political stability and strength of traditional institutions are common features of all these three concepts. The environment is a central tenet to all of them as all emphasize nature and biodiversity conservation, and sustainable environmental management. Finally collective-choice rule and collective decision making, broad based participation, political accountability and transparency are some of the shared aims of governance. To a large extent, their common principles focus on welfare and sustenance:

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[15] Sustainable development is development which meets the needs of the present without compromising the ability of future generations to meet their own needs.6 (World Commission on Environment and Development (1987).

[16] Agenda 21 is a comprehensive plan of action to be taken globally, nationally and locally by organizations of the United Nations System, Governments, and Major Groups in every area in which human impacts on the environment. Agenda 21, the Rio Declaration on Environment and Development, and the Statement of principles for the Sustainable Management of Forests were adopted by more than 178 Governments at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janerio, Brazil, 3 to 14 June 1992.

[17] A SES is an ecological system intricately linked with and affected by one or more social systems.

- Gross National Happiness - Maximise happiness of all to enable them achieve full and innate potential as human beings.
- Sustainable Development - Fulfill needs of the present without compromising the ability of future generations to meet their own needs.
- Resilient Social ecological systems - Prevent an SES from moving into undesirable configurations

2.8.2 Commercialization of natural resource and its impact at different levels

Depending on the resources from the wild for ages, it has become a traditional practice of harvesting natural resources for domestic use. Extraction and use of natural resources like leaf litter, wild vegetables, medicinal plants and bamboo are intimately associated with traditional culture, that many are still in practiced even if there is little or no economic rationale for their use. There is a steady rise in commercial demand for wild vegetables (*damroo – Elatostema spp*., fresh water algae – *Ulva spp*., ferns and mushroom) and some medicinal plants like *chirata*, *pipla*, and *cordyceps*. Likewise the traditional culture of using wooden mask (*bap*), wooden bowl (*dapa*), wooden cup (*phop*), cane basket (*bangchung*), and wooden cask (*palang*) for day to day use at home and public functions is still a common practice. As there is no factory locally, villagers extract raw materials from forest and manually develop into different products and sell them in local markets. While the domestic demand is steady, the demand from the tourism sector is overwhelming. The natural resources commercially exploited can be broadly grouped into two, first as timber and timber-based products and second as non-timber forest products. Since 2003 on an average Bhutan earned revenue of US$ 568,400 annually from the sale of natural resources, but this figure rose to almost a million dollar in 2006-07 (NSB, 2009). In terms of proportion, timber product dominates with 74% of revenue generated with only 26 % coming from non-timber forest products (Figure 2.13).

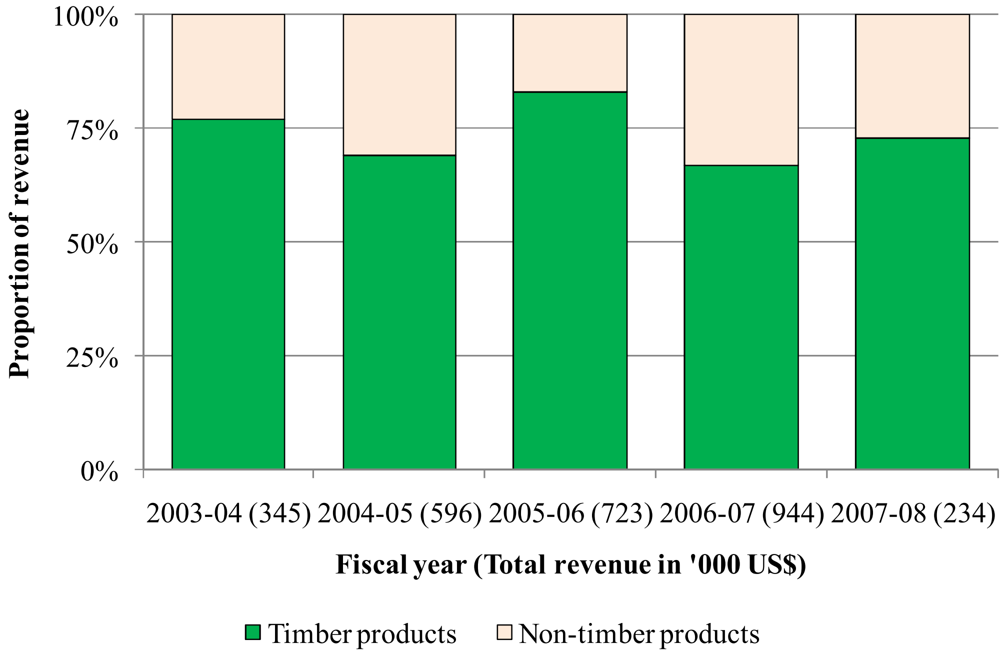


Figure 0.13. Proportion of revenue generated by sales of natural resources (July 2003 to June 2008).

There are around 33 natural resources that are commercialized and for which records are available, of which 10 are timber based products, 13 being NTFP and the remaining 10 are minerals which are mined (Appendix 2).

2.9 Issues related to natural resources

Since 1969 when systematic commoditization of natural resources to generate revenue at macro level was initiated, the country has passed through dynamic changes and emerged as a nation fostered on strong policy foundation. However, on the NRM front there are several issues the country is grappling with now.

- *Tragedy of commons*: When the state took over the responsibility to manage the forest in 1969, it did not realize the extent of forest and corresponding human resource to stringently protect it. Bhutanese territory being pristine and historically known for its wealth of medicinal plants and rare animals, resources were always at risk of being poached. To protect such valuable wealth with very limited manpower and regulatory tools, it became the inherent problem. When the ownership of natural resources was taken over from the community and in the absence of consistent monitoring, resources were indiscriminately exploited leading to the well known "tragedy of the commons" paradigm (Hardin, 1968). Subsequent to realization of the weakness of nationalization of forest, painstaking efforts have been initiated to bring back people into management regime. There are numerous cases in point to illustrate the inability of policies to bridge people and national policies. The poaching of prominent endangered species like tiger, musk deer, black bear, and Chinese caterpillar (*Cordyceps sinensis*) is a flourishing business generally influenced by demand from outside the country.

- ❖ Resource degradation: Provision of free access to natural resources in the Government Reserved Forest by any Bhutanese citizen actually led to over-exploitation. Further the building of logging roads in virgin mountain environment changed the landscape which in many instances was the starting point of land degradation (Figure 2.14). The scar such roads leave in not just the road, but as it disturbs the waterways and faunal feeding routes, it changes the ecosystem. Further down the slope damage due to rolling stones and dumping of debris are irreversible.

Figure 0.14. Fresh scar from the construction of farm road.

- ❖ Governance: In the absence of monitoring mechanisms, rapid change in SES, limited social network in relation to the resource, and free access to outsiders resulted in ineffective governance of the natural resource (Dietz et al., 2003).
- ❖ Breakage of social fabrics: The society whose tradition and culture has evolved through generation of association with nature is characterised by multitude of norms (Choden, 2008) that acted as bonding force for small societies amidst vulnerability. The nationalization of

forest and disregard of customary rules created a society without a functional social network. Within the state property regime, the secret sites of local deities in the forest, mountain, rock and rivers became irrelevant. People and society were disconnected from the vital resource they had depended on and mimicked the forest ecosystem to adapt agriculture and livelihood system. The detachment from the forest and natural environment, the need to frequently interact and organize community teams to go to forest for harvesting resources did not arise (Dietz et al., 2003), it became more costly to individually harvest resources. All these slowly disintegrated the social capital that kept the society moving forward. The attempt to reintroduce and recreate a community role in forest through community forestry program did not quite serve the purpose due to the uncertainty of rights to use the products from the community forest.

- *Frequent change in rules*: In the process of regulating and deregulating forest and natural resources, there are more than ten Acts and several policies associated to natural resources. The frequency and plurality of policies suggest the importance and sometimes perverse feature of the natural resource. This link to governance change adds on to the confusion. While it is reasonable for a remotely located farming community not to be aware of new policies, but it is an irony that even some of the implementers too are unaware of new policies. Such discrepancies arise from the frequent policy changes and poor policy dissemination, which leads to manipulation and mismanagement of natural resources.
- *Conservation policy*: In pursuit of sustaining the pristine environment, Bhutan has crafted conservation policies which are globally applauded (Wang, 2008). Notwithstanding the positive impact the conservation policy has perpetrate, it has also hindered development in some areas. For instance, the strong environmental conservation policies have affected the pace of implementing energy projects due to the lengthy procedures such as environment impact assessments and securing road clearances (ADB, 2008). The conservation of wildlife and increased crop production has also been in conflict for years.
- *Institutional coordination*: The assortment of policies and legislations related to natural resources are mandated to various institutions depending on their main function. Viewed for their respective national mandates, the NR policies are either implemented in piece-meal or interpreted differently by different implementing agencies. For instance the Land Act is responsibility of National Land Commission, while Forest Act with Department of Forestry,

Mines Act with Department of Geology and Mines, Nature conservation with Nature and Conservation Division (NCD), Biodiversity Act with National Biodiversity Centre, Water Act and Environmental Protection Act with National Environmental Commission. The coordination among these institutions would not only simplify the implementation of vital policies but most importantly clarify and enhance grassroots' understanding of the policies which would facilitate implementation.

2.10 Synthesis

In spite of the prudent policies and timely interventions, the nationalization of forest and outright control over forest by the state during a decade put the customary resource management regime in absolute disarray. Looking through the NRM regime can be segregated into three main phases, each characterized by distinct problems and opportunities. Until the 1950s the main NRM regime was mainly a common property one with some individually-owned and jointly-owned private property. From 1952 to 1974, with absolute control of the state over forest and natural resources, the state property regime became dominant. It was during this period that over exploitation of renewable natural resources was rampant. The present period (1974-till date) characterized by people participation in most functions through integrated programs can be broadly designated as public property regime with occurrence of all other forms of regimes.

Although the current forest cover is much higher than the 60% threshold set as an eternal target, the natural resource degradation is widespread and its consequences as flash floods, land slides and water scarcity have become a serious threat to livelihoods. In this context, natural resource degradation, pollution and loss of biodiversity are detrimental because they increase vulnerability, undermine system health, and reduce resilience.

CHAPTER 3
AGRICULTURAL TRANSFORMATIONS IN BHUTAN AS SEEN FROM TWO STUDY SITES

The evolution of agriculture from ancient form of gathering from the wild to a highly specialized form is indeed a result of evolving ecological and economic conditions of the farmers (Trébuil and Dufumier, 1993). To establish a well founded understanding of an agrarian system and its transformation, a holistic analysis that provides scope to investigate within a time-scale the social, economic, and ecological factors and their interactions is crucial. Among such tools, the agrarian system diagnosis methodology which combines agro-ecological zoning, historical profile and analysis of recent transformations, classification of production systems into farmer typologies has been extensively used in understanding successions of agrarian systems at a given place (Trébuil, 1989; Trébuil and Dufumier, 1993; Dumrongrojwatthana, 2010). Most of the data presented in this chapter were generated either by using structured questionnaires, focused group discussions and key informant surveys in two sites, one in Western and other in Eastern part of the country.

3.1 Bhutanese agriculture

Bhutanese agriculture is still largely based on the traditional subsistence oriented mixed farming systems that integrate cropping, livestock rearing, and use of forest products. It has evolved over a long period of time characterised by diversity of ecological conditions and a high degree of self reliance. The unique mountain agriculture system characterised by diversity, variability over time and heterogeneity over space has led to the development of diverse farming systems specific to different localities. The integration between forest, crop and livestock system is built on the principle of input-output relationship (Figure 3.1). In the centre of the web, the farm household manipulates the level of resources appropriated from one system to the other to optimize the benefit. The two basic factors that influence the resource flow are the physical environment and the socio-economic, cultural and institutional environment. Operating in a closely integrated production system, Bhutanese agriculture is largely organic with low use of inorganic fertilizer and pesticides. Agricultural production is basically sustained with application of organic fertilizers at the average rate of 10-12 tons/ha (RNRRC Bajo, 2008) in the form of farm yard manure and compost.

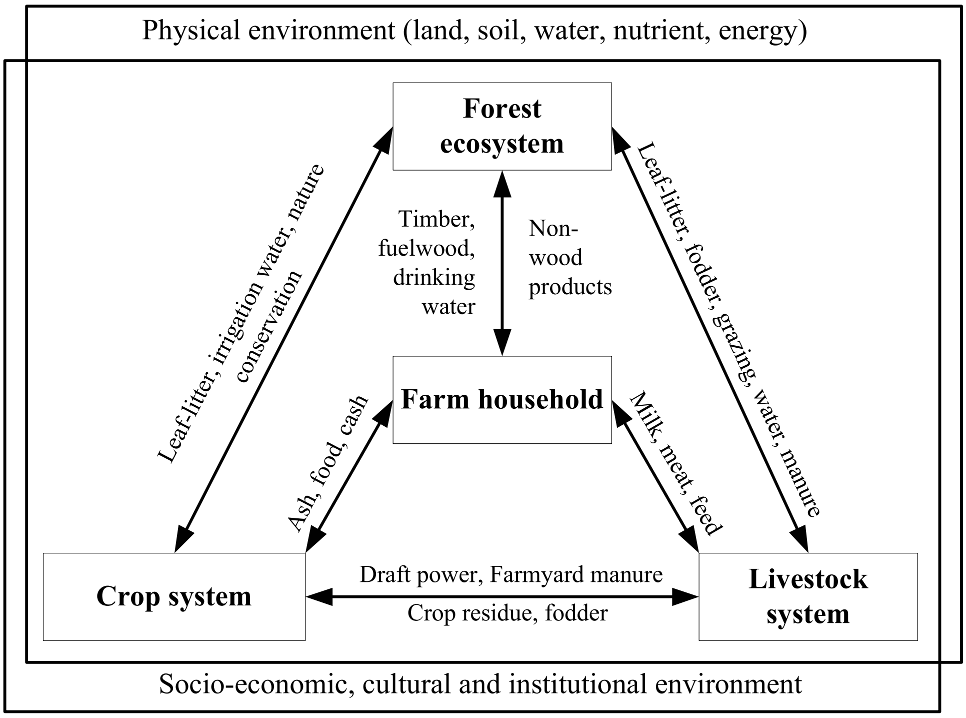


Figure 3.1: Key interactions in integrated farming systems in Bhutan.

Farmers painstakingly sweep the floor of designated woodlot from where leaf litters can be collected (*sokshing*), use them as animal bedding and heap it for composting. The semi-decomposed compost is applied in the field (Figure 3.2).

Figure 3.2. Leaf litter in the *sokshing*, farmer bringing home a load of leaf litter, and heaps of farmyard manure in paddy fields in Lingmuteychu, Punakha district.

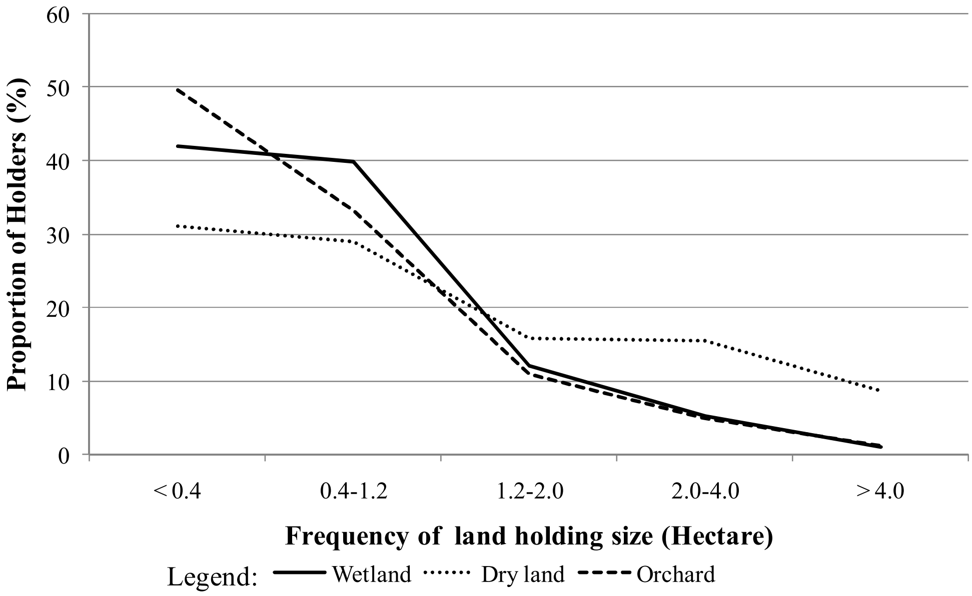
In Bhutanese agrarian society land is the primary asset in the composition of wealth. Despite rapid socio-economic development land ownership is still a valuable indicator of wealth or poverty (PCS, 2002). Fragmentation of land is highly influenced by inheritance and encroachment of arable land by infrastructure development. Nationwide, about 14 percent of farm households own less than 0.4 ha of arable land. Around 55% of farm households (HH) own 0.4 to 2 ha (MoA, 2002). Owing to the 16% arable land at the national level and difficult terrain, the potentiality of the agriculture land is marginal. Low productivity and small land holdings inflicts poverty in Bhutan, as such land is considered as main indicator of poverty. After the revision of Land Act 2007 and subsequent nationalization of pasture land (*tsamdro*) and woodlot for collecting litters (*sokshing*), individual land ownership is only on three land categories (Table 3.1). From among three land categories, dryland account for 62% of the total area followed by 28% for wetland and 10% for orchards.

Table 3.1. Agriculture land use categories, acreage and number of holders, 2009.

Land use types	Area (ha)	Households
Wetland	36,326	11,000
Dry land	79,096	49,000
Orchard	12,367	12,367

Source: RNR Statistics, 2009.

On average around 75% of land holders own below 1.2 ha of arable land (Figure 3.3) and only 3.6% of the population own more than 4 hectares of land (MoA, 2009). It is the population owning less than 1.2 ha/HH who represents the majority of the farming population. Farm parcels are small, numerous and scattered making it difficult to fully commercialize agricultural production. Around 25% of dryland holders own more than 2 ha, mainly because of the recent reclassification of shifting cultivation into dryland. Majority of Bhutanese farmers are small and marginal and thrives on 1.66 hectares of farm land.



Source: RNR Census 2009

Figure 3.3. Distribution of land holding sizes in Bhutan, 2008.

Agriculture in Bhutan is labour intensive with relatively low intensity of use of external farm inputs. An annual average of 27 kg/ha of chemical fertilizer is used on farm land by 38% farmers and 7 kg/ha of commercial pesticides by 20% of farmers predominantly involved in growing potato, apple, and citrus (MoAF, 2009). Although the overall share of agriculture contribution to GDP has been declining from 26% in 2001 to 19% in 2008 (NSB, 2009), agriculture remains to be one of the most important sector of the Bhutanese economy. The 7.8% of the total land area used as agriculture serves as the major source of livelihood to about 80 percent of the rural population. Further, a majority of the farms are located at a distance of roughly five to six hours walk from the nearest road head (MoAF, 2009).

The Bhutanese farmer subsists by growing crops ranging from rice, wheat, maize, buckwheat, potatoes and barley depending on the climatic conditions. Livestock rearing is integral part of the farming life, as it supports food, draught power and nutrient recycling. The major crops cultivated in Bhutan include paddy, maize, wheat, barley, buckwheat, millet, potato and mustard. In acreage terms maize and paddy accounted for the largest share, covering around 27,227 hectares and 19,356 hectares respectively (Table 3.2).

Table 3.2: Crop area and production in Bhutan, 2008.

Crops	Area (Hectares)	Production (x1000 Kg)
Paddy	19,356	77,314
Maize	27,227	66,780
Wheat	3,189	5,647
Barley	1,314	2,051
Buckwheat	3,438	5,138
Millet	3,519	5,024
Potato	5,560	52,959
Mustard	1,940	3,580
Chilli	3,826	7,313

Source: RNR Census 2008, MoAF 2009.

Rice based systems dominate irrigated terraced land up to an altitude of 2,500 m (Figure 3.4), while maize and potato based systems are commonly practised on upland slopes (Figure 3.5). At altitudes between 2500-3000m, buckwheat, wheat, and barley are the traditional crops. Rice and maize are the main cereals grown in all zones except the western cool temperate zone where wheat, buckwheat, barley, mustard and potatoes predominate. Wetland crops in winter include wheat, mustard and potatoes. Mustard is also grown under dryland conditions which occupy the largest cropped area. The only new basic food crop is the potato being cultivated in the temperate zone mainly for export purposes. Current production levels account for only 50, 65, and 59 percent self sufficiency in rice, wheat, and oilseeds respectively (DoA, 2008). The deficit is met through imports. The gap between domestic production and national requirement is widening as consumption rates increase due to increasing preference for agricultural commodities not produced in the country like oats, wheat, palm oil, sunflower oil and changing food habits to fast food, vegetable, and legumes.

Figure 3.4. Typical rice-based farm and ladies threshing paddy and drying the straw in Gasa.

Figure 3.5. Maize and potato-based farms in upland environment in eastern region of the country.

Owing to the improved communication facilities in the country, there is an increasing tendency to cultivate cash crops like apples in the temperate north; oranges, areca nut and cardamom in the subtropical south (Table 3.3). Other cash crops that are exported include ginger, chillies and various kinds of vegetables.

Table 3.3: Fruit production and households with orchards in Bhutan, 2008.

Crops	No of plants (‘000)	Production (x1000Kg)	Households (%)
Apple	245	5410	9
Mandarin orange	1123	38183	39
Areca nut	487	4082	11
Peach	31	961	20
Pear	18	1204	13
Plum	85	414	9
Walnut	13	338	11
Mango	17	610	10

Source: MoAF, 2009.

The farm production is supplemented by keeping different kinds of domestic animals such as cattle for draught and milking purpose, chicken for eggs and pigs for meat etc. Among the livestock, 24% of the households rear Mithun[1] and Mithun-cross cattle both for dairy and

[1] The Mithun (*Bos frontalis*) is a bovine species indigenous to the south-eastern parts of the Himalayas and the adjacent mountain ranges in north-east India. This bovine species, which is very little known elsewhere, is believed to have originated from the Gaur (*Bos gauris*). Mithun is the pride animal called as ‘Cattle of Hilly Region’ of north-eastern hilly region of India and tropical rain forest of China.

draught power (Figure 3.6). Jersey and Brown Swiss cattle introduced through the Swiss Cooperation during 1960s are popular dairy cattle.

Figure 3.6. Mithun bulls kept for ploughing.

Poultry as a source of egg has become very popular as egg is considered to be an auspicious item for gifts, around 16% of rural households raise poultry (Table 3.4). At higher altitudes, yaks and sheep are the principal source of livelihood (Figure 3.7). High altitude yak herders still practice a migratory pastoral system where the family moves along with their yak herds before the winters in September to warmer area below 2000 m. For instance herders from Merak and Sakten in Trashigang, eastern Bhutan migrate to Radi, Phongme and Khaling in winters. While the yaks graze on natural pastures in warm areas, herders move around the villages to barter the cheese, butter, and meat with grains and chilli.

Figure 3.7. Yak a principal source of livelihood for high altitude people.

Table 3.4: Livestock population and proportion of households raising them, 2008.

Livestock	Population (No.)	Households rearing (%)
Nublang[2] cattle	184,014	24
Poultry	197,766	16
Jersey cattle	50,443	9
Mithun cattle	68,885	9
Horses and mules	22,335	6
Pigs	18,963	6
Goats	34,176	5
Sheep	12,116	1
Brown Swiss	5,253	0.67
Yaks	40,482	0.65
Other cattle	1,476	0.17

Source: MoAF 2009.

Livestock products like cheese and butter are part of the Bhutanese diet with key dishes like "*ema-datshi*" (chili cooked with cheese) and drink like "*suja*" (butter-salt tea). With the support of MoAF, milk cooperatives supply urban centres, making it one of the important commodities marketed (Table 3.5). Egg is another commodity which can be remunerating as imported eggs are highly regulated due to avian-flu outbreaks in neighbouring countries. Most of the commodities are locally sold without proper processing and packaging.

Table 3.5. Livestock products produced and sold in Bhutan, 2000-2008.

Livestock products	Unit	2000	2005	2008
Milk	Liters	24,837	19,927	25,840
Butter	Ton	1,316	1,552	1,727
Cheese	Ton	2,172	4,790	2,029
Beef	Ton	1,409	547	477
Pork	Ton	186	1,649	248
Mutton	Ton	35	54	34
Wool	Ton	11	31	10,552
Fish	Ton	0	0	16
Chicken	Ton	21	151	90
Egg	′000 Dozen	5,718	5,397	459

Source: MoAF, 2009.

[2] *Nublang* is the traditional cattle breed of Bhutan since its presence dates back to time immemorial. It is a *Bos indicus* breed of cattle which is believed to have originated from the Sangbay geog of Haa in the western part of the country. The *Nublang* is a priority breed for conservation since it is facing numerous threats to its existence such as the introduction of high yielding exotic breeds in the country and restricted forest grazing.

3.1.1 Distribution of agricultural production systems

Bhutan can be divided into six main agro-ecological zones (AEZs) based on elevation, annual rainfall and air temperature (Table 3.6). These AEZs are further influenced by the mountainous terrain and valleys (Figure 3.6). These diverse agro-ecological conditions and topographic features have direct bearing on the farming systems practiced in each of them.

Table 3.6: Main agro-ecological zones of Bhutan.

Agro-ecological Zone	Altitude Range (m.a.s.l)	Annual Rainfall (mm)	Average annual Air Temperature		
			Max °C	Min °C	Mean °C
Alpine	3600-4600	<650	12.0	-0.9	5.5
Cool Temperate	2600-3600	650-850	22.3	0.1	9.9
Warm Temperate	1800-2600	650-850	26.3	0.1	12.5
Dry Subtropical	1200-1800	850-1200	28.7	3.1	17.2
Humid Subtropical	600-1200	1200-2500	33.0	4.6	19.5
Wet Subtropical	150-600	2500-5500	34.6	11.6	23.6

Source: MoA/ISNAR, 1992.

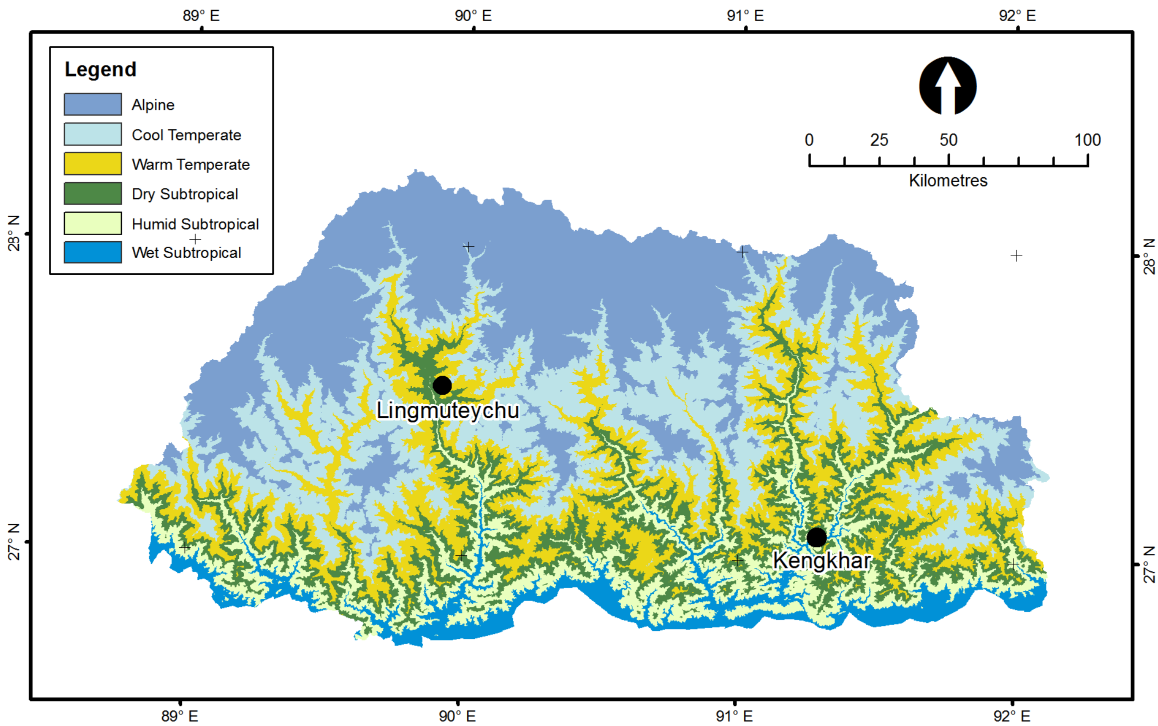


Figure 3.8: Distribution of the main agro-ecological zones of Bhutan.

A simple classification of crop, livestock and NTFP across these main AEZs provides a clear differentiation and understanding of the diversity of agricultural production systems (Table 3.7). The interaction of crop-livestock-forest resources and topography in different social systems leads to further niche production systems even within the same AEZ. For instance in the humid zone, while the farming system in Tsirang is an irrigated rice-based system, farmers in Pemagatshel and Zhemgang depend on maize-based and swidden farming systems. Similarly in the dry zone a difference can be seen between Mongar and Wangduephodrang: irrigated rice-based systems dominate in Wangduephodrang and Mongar is predominantly rainfed maize-based. The difference in production systems is also closely associated with the livelihood system and cultural background of people. The diversity of production systems of each AEZ is briefly explained in the following paragraphs.

Table 3.7: Major crops, livestock and NTFP in different agro-ecological zones in Bhutan.

Agro-ecological Zone	**Crops**	**Livestock**	**NTFPs**
Alpine	None	Yak, Sheep	Cordyceps, *Nardostachys, Jatamansi, Rhododendron, Anthopogon*
Cool Temperate	Barley, mustard, wheat	Yak, Sheep	Cordyceps, *Nardostachys Jatamansi, Rhododendron, Anthopogon*
Warm Temperate	Barley, buckwheat, wheat, mustard, apple, pear, peach, plum, vegetable	Nublang, Mithun, Jersey, Jersey-cross, pigs, poultry	Mushroom, orchids, asparagus, dyes.
Dry Subtropical	Rice, wheat, mustard, millets, orange, banana, guava, vegetable	Nublang, Mithun, Jersey-cross, pigs, poultry	Rattan and cane, ferns, mushroom, staranise (*Illicium spp.*) used as spice.
Humid Subtropical	Rice, wheat, maize, mustard, millets, ginger, areca nut, orange, large cardamom, Guava	Cattle, goat, pigs, poultry, buffalo	Rattan and cane, ferns, mushroom, chirata
Wet Subtropical	Rice, wheat, maize, mustard, millets, ginger, areca nut, orange	Cattle, goat, pigs, poultry, buffalo	Ferns, bamboo shoot, mushroom, Nettle grass[3], Pipla, chirata

In the alpine and cool-temperate zone (above 3600m amsl), semi-nomadic communities (*Brokpas*) practise a pastoral production system with yak rearing as the main source of

[3] Three species of nettle grass is found in Bhutan - *Girardiana palmate*, *Laportea terminalis*, and *Urtica dioia*. Their tender leaves and inflorescence is consumed as vegetable. While from the matured shoots, fibre can be extracted for weaving cloths and making rope.

livelihood, lately they also rear small herds of sheep. They grow crops like high altitude barley, buckwheat (Figure 3.9), mustard and few short season vegetables during the summer season in their backyard in areas below 3000m. During winter when they migrate to warmer valleys, it is common to see yak herders in their traditional attire visiting houses to barter their cheese, butter, meat and wool with rice, chilli, and beans (Figure 3.9).

Figure 3.9. Yak herders from Lunana in their winter camp.

In the cool temperate areas, livestock rearing is still dominant with more cropping than in alpine zone. Farmers rear both cattle and yaks besides other livestock types like sheep and mules. Cattle graze the pastures in summer and yaks in winter. Higher proportions of people engage in farming and grow buckwheat, barley, wheat and potato in dryland (Figure 10). Farmers in this zone maintain large tracks of natural pastures where they paddock their livestock.

Figure 3.10. Buckwheat field in Bumthang valley and buckwheat pancake a delicacy in high altitude community.

The warm temperate zone is comparatively more fertile than other zones, as most mid altitude valleys like Thimphu, Paro, Ha, Punakha and Wangdue are drained by river systems that deposit alluvial soil in the flat floor valley (Figure 11). Fertile soil and mild climate favours cultivation of different crops like paddy in irrigated terraced areas, mustard, chilli and wheat as second crops. Potato and barley are major crops in dryland fields. This zone also represents the major temperate fruit growing area (apple, pear, peach, plum and walnut). Livestock is another important component of the farming systems, particularly as a source of draught power and manure. Lingmuteychu is located in this zone.

Figure 3.11. Punakha-Wangdue valley with Punatshangchu river in foreground and rice fields in the background.

Predominated by maize cultivation, the dry sub-tropical zone provides an upland farming environment where mostly rainfed crops are grown and irrigation water is the most limiting resource to crop development (Figure 12). Crops like millets (finger millet and fox-tail millet are the most common), and beans (phaseolus beans, kidney bean, soya beans) are the most popular ones. Potato is fast spreading as a cash crop. Lemongrass is found in abundance as undergrowth of chirpine and is extensively harvested, distilled and sold. With low productivity of land people still practices slash and burn agriculture with shorter fallow periods of 2-3 years. Burning also helps in new flush of grass including lemongrass, thus used as a management tool. Cattle, mules and pigs are other important sources of income.

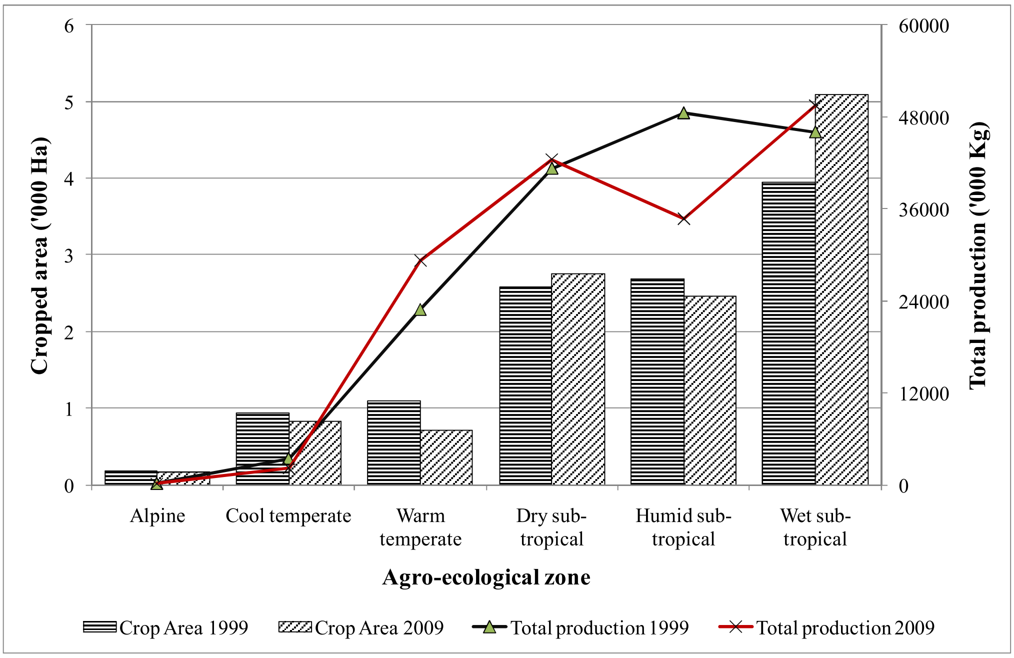
Figure 3.12. Typical upland maize field in the eastern region.

The zone with altitudinal range of 150 to 1200m amsl receives annual rainfall of 1200-5500mm is classified as humid and wet sub-tropical zone. With abundance of water, irrigated rice production in terraces is the dominant cropping practice. Growing pulses on rice bunds, mustard and wheat after rice are common practices. This zone also represents the major mandarin orange production belt. Large cardamom, although wiped out by wilt, used to be an important cash crop. In the low foothills, areca nut and ginger are extensively grown and generate substantial income. Local breeds of cattle, goat and poultry constitute livestock which helps in household income and farmyard manure.

Figure 3.13. Cowpea grown of rice bunds and areca nut in the background a common feature in the southern foothills of Bhutan.

3.1.2 Trends in agricultural area and production in AEZ

During the last decade (1999-2009) there has been some significant change in crop areas and production across these AEZ (Figure 3.7). Except in the dry sub-tropical and humid sub-tropical zones, there has been a dramatic decline in cropped area. Maximum decline of 30% and 24% in cropped areas was observed in the wet sub-tropical and cool temperate zones respectively. Although empirical data is absent, this decline may be linked to encroachment of arable land for infrastructural development in temperate zone and lack of agricultural infrastructure like irrigation canal and crop predation by wild animals. An increase in cropped areas of around 7% in the humid sub-tropical and 5% in dry sub-tropical may be associated to the conversation of shifting cultivation land to dry land and the opening of farm roads in remote settlements. Similarly a drastic decline in total crop production ranged from 15% in the alpine zone to as high as 35% in the cool temperate zone. Reduction in crop production, particularly in the cool temperate zone, may be associated to the continuous use of local varieties of buckwheat, barley and wheat under poor crop management practices. A substantial production increase of 28% in the warm temperate zone is associated to the use of improved crop varieties, farm mechanization, irrigation development, and more access to support services.



Source: MoAF, 2000; MoAF, 2009.

Figure 3.14: Trend in cropped area and production during 1999 - 2009 in the main agro-ecological zones of Bhutan.

3.1.3 Linkage between AEZ

The fact that these six AEZs specialize in particular production systems which is exclusive from the others, results in inter-dependence between these zones. While there is an apparent up-stream and down-stream linkage between communities, their basic linkage is related to livelihood systems (Table 3.8). For instance people in the alpine zone are handicapped with the harsh climate and solely depend on yak rearing and produce excess of dairy products during summer. In winters when herders migrate to warmers areas with their yak herds, they carry along butter and cheese to barter with grains and cloth. Yak herders move down as far as the dry sub-tropical zone and trade their goods. This age old trade network is vital to maintain the social system in the different zones. When the alpine dwellers move down in winters, they also bring rare high altitude herbs widely used in traditional medicines and incense. Similarly there is also a close inter-dependence between communities of temperate and sub-tropical zones. The dependence is based broadly on crop products like red rice, potatoes, and apples from temperate zone and maize, citrus and vegetables from the sub-tropical zone.

Table 3.8. Dominant farming systems, representative communities, major products and their linkages in the main agro-ecological zones of Bhutan.

AEZs	Dominant farming systems	Representative community	Major products	Flow of products
Alpine	Pastoral farming systems	Gasa (Layap and Lunaps), Trashigang (Brokpas)	Yak cheese, butter, wool, and meat	
Cool Temperate	Agro-pastoral farming systems	Shephu, Gantgey, Bumthaps	Buckwheat, cane mat and baskets, cheese, butter, and sheep wool	
Warm Temperate	Farming systems dominated by food crops and temperate horticulture crops	Thimphu, Paro	Red and white rice, Apple, chilli	
Dry Sub-tropical	Farming systems dominated by food crops and slash and burn cultivation	Wangdue, Punakha, Zhemgang, Mongar, Trashigang	Rice, vegetables, maize and potato, woven clothes	
Humid Sub-tropical	Farming systems dominated by orchards and sub-tropical horticulture crops	Tsirang, Dagana	Citrus, ginger, rice and maize	
Wet Sub-tropical	Farming systems dominated by rainfed agriculture	Samtse, Sarpang, Samdrupjongkhar	Areca nut, ginger, mustard, rice	

The seasonal variations in these different AEZ also force people to move during harsh winters from high altitude areas to warmer valleys and foothills. As the temperature rises during March-April they migrate back to their villages. This practice of seasonal migration resulted in most of the families having summer and winter homes. The migration to south during winter is also forced as pasture are barren and covered with snow, taking their animals to south gives them access to grazing areas. There are even situations where western farmers of Paro, Thimphu and Ha districts own grazing land in Chukha. As people move their house, even today the monastic body maintain a winter base at Punakha Dzong and during summer the monk body resides in Tashichodzong in Thimphu. This movement of population between different AEZ has helped in maintaining close social networks between different ethno-cultural groups. For instance, the close linkage between herders from Ha and farmers of Dorokha in Samste and Sambeykha in Ha is well known.

3.2 Agricultural policies

Since the launch of planned development in the form of five year plans in 1961, agriculture has been the priority sector. In the first five year plan, three Departments of agriculture, animal husbandry, and forest were established to demonstrate new crops, animal breeds and improved production technology and expand the production base. Conservation of forest and judicious utilization of forest resources was emphasised. In the subsequent plans, the development objective of the farm sector focused on enhancing self-reliance in food production and conservation of natural resources (Table 3.9).

Table 3.9. Development objectives of the farm sector in Bhutan, 1961-2013.

Five year plans (Period)	Development objectives
First (1961-66)	- Promote and increase fruit and vegetable production area, conservation of forest, livestock production development
Second (1966-71)	- Policy to increase food production through regional specialization of crops, conservation of natural resource
Third (1971-76)	- Improving crop production and cooperative marketing, conservation of natural resource
Fourth (1976-81)	- Major emphasis on development of agriculture and animal husbandry, conservation of natural resource
Fifth (1981-87)	- Self reliance in food production, conservation of natural resources
Sixth (1987-92)	- Self reliance in food production, enhancing rural income, conservation of natural resources
Seventh (1992-96)	- Self reliance in food production, enhancing rural income, conservation of natural resources
Eight (1996-2002)	- Self reliance in food production, enhancing rural income, conservation of natural resources
Ninth (2002-2008)	- Enhancing rural income; achieving national food security; conserving and managing natural resources; and generating employment opportunities.
Tenth (2008-13)	- Poverty reduction, income generation, employment generation and environmental conservation

Source: Hasrat, 1980; GHNC, 2008a.

Roughly, the succession from first to tenth plan can be categorized into three phases. First the humble beginning of providing people with land rights and production technologies when the focus was on subsistence farming. A second phase of semi-subsistence economy emerged and consequently cooperative marketing promoting people to produce surplus and state run auction and bulk marketing were launched. From the 1990s, when beneficiaries were charged for the production inputs like seed and planting materials, fertilizer, chemicals, tools, and machineries, the objective of maximizing income became the priority of farmers. Coherently, since the 1990s the farm sector development focused on cooperative or collective based large-scale production, development of post-harvest processing, enterprise development and marketing, thus leading to semi-commercial farming. The policy of the farm sector therefore clearly indicates the trajectory from traditional subsistence farming to specialized commercial farming in the years to come.

The policy of food self sufficiency was debated for more than a decade, and concluded that it was un-realistic (FAO, 1991). Subsequently a 70% food self sufficiency goal was adopted in the seventh five year plan (1992-96). As the goal has been far-fetched, it has been maintained even in the current tenth five year plan to increase national food self sufficiency level from 50% to 70% (GNHC, 2008a). The concern over food security and self-sufficiency stems from the increased reliance on the importation of staple foods, particularly due to the growth in urban consumers and increases in the general level of income. The ultimate goal of specialization and commercialization is challenged by the limited scale of production and the resource capacity of the farmers. To enhance and sustain food production capacities, the protection of wetland and consolidation of land use types into wetland and dryland (Land Act 2007) promotes landuse options to farmers. The provision of rural credit for commercial farming by the Bhutan Development Finance Corporation has significantly facilitated farmers' capacity to purchase agricultural inputs and farm machinery. While all had access to rural credit only 15% of the farmers availed the credit (PCS, 2007). Electricity, roads, piped water, and rural credit are considered as the four most effective interventions in improving household incomes (PCS, 2007). Similarly irrigation development, improvement of agricultural marketing facilities, and cooperative development are expected to boost the farmers' capacity to increase crop production.

As indicated in Table 3.9 the strong hold of development policy has been the conservation of nature. An impact assessment study by Planning Commission has revealed a mixed opinion on the impact of conservation policy. While some gave credit to nature conservation policy for forest regeneration and increased availability of NTFP, there are many who opined that the stringent forest rules have prevented their access to valuable natural resources which supported their livelihood (PCS, 2007). The crop and livestock predation by wildlife is a major problem encountered by farmers.

3.3 Participatory diagnostic studies

The initiation of research in both sites was based on requests from the community. In Lingmuteychu it was a case of up-scaling of the initial ComMod process carried out in two upstream villages in 2003 where participants requested for inclusion of all seven village communities in the sub-watershed (Gurung, 2004). While in the case of Kengkhar, the community appealed the district administration to help them in resolving the acute shortage of drinking water. With this backdrop and water being a multifunctional resource connected to all facets of the SES, a detailed diagnoses of the problem situation was conducted by using the agrarian systems analysis methodology (Figure 3.8).

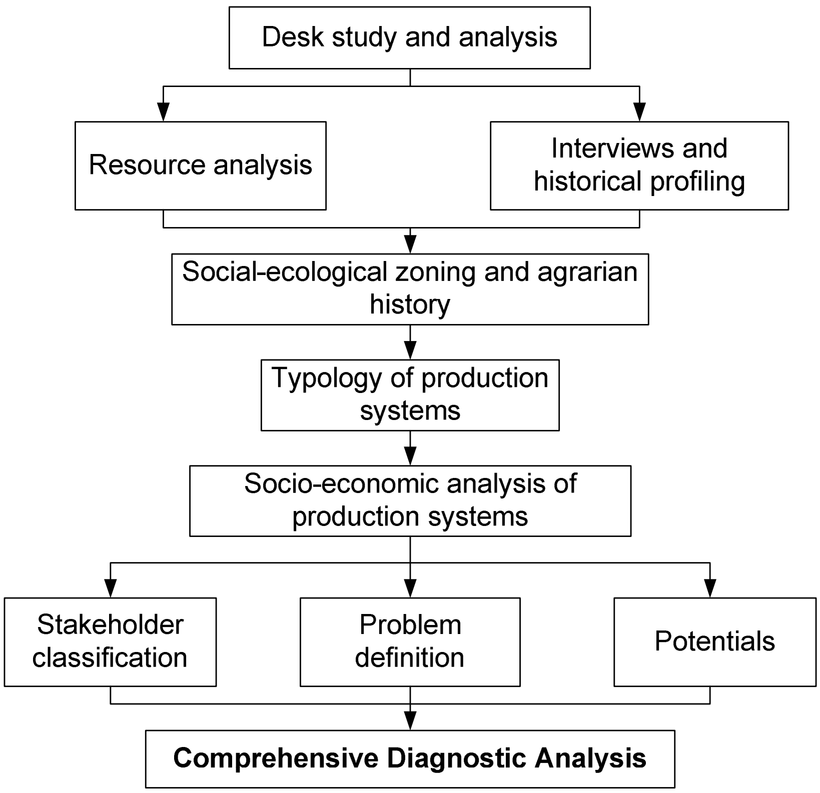


Figure 3.15. Agrarian systems diagnosis in Lingmuteychu and Kengkhar (based on FAO, 1999).

3.4 Agrarian systems analysis

The way farmers exploit the environment within the limits and ability to reproduce by using the relations and interactions that occur between all of its social and physical components, can be considered as an agrarian system (Sacklokham and Baudran, 2005). The agrarian system[4] takes into account the relationships between the production systems and the general social and economic organization of the whole society. This concept takes a historical perspective by taking dynamically into account ecological and social systems and other interactions and provides a better understanding of the complexity of the present dynamics, the socio-economic structures and the mode of exploitation of the ecosystem. Different types of production systems in interaction co-exist in a given agrarian system (Figure 3.9). Although agrarian system analysis can be conducted in different ways, broadly it can be implemented in four distinct steps: (i) agro-ecological zoning, (ii) analysis of recent transformations, (iii) in-depth farm household survey and construction of a farmer typology, and (iv) economic analysis of each main type of production system (Trébuil and Dufumier, 1993; FAO, 1999).

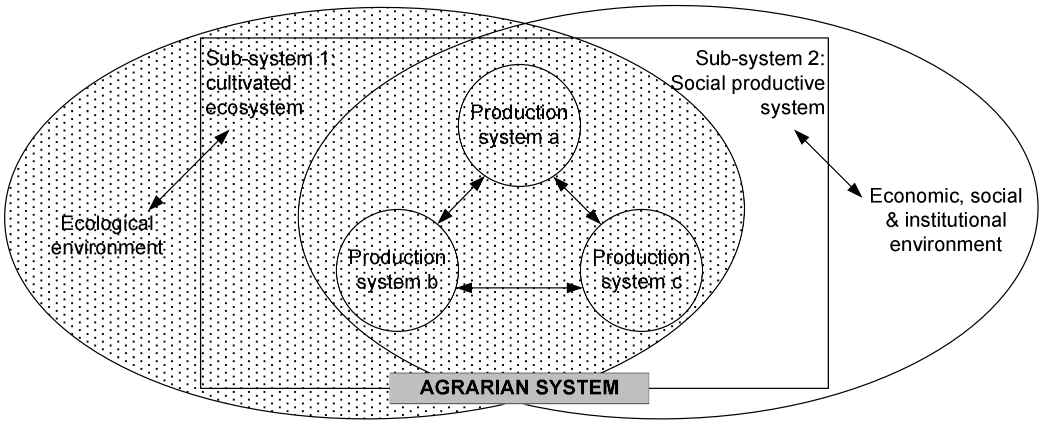


Figure 3.16. The agrarian system: a complex open system, made of two main sub-systems (FAO, 1999).

Compared to the concept of SES originating in the field of ecology, the agrarian system is emphasizing agricultural production and the economic survival of its different types of production systems. But there are many similarities between these two concepts such as the focus on interactions between agro-ecological and social and economic dynamics, the

[4] Prof. Mazoyer (1985) defined an agrarian system as “a mode of exploiting the environment historically created and sustainable, a system of production forces adapted to the bioclimatic conditions of a given space and responsive to the social conditions and needs of the moment”.

importance given to processes of adaptation to change and transformation (change from one system to another one having a different domain of viability and functioning rules), the use of key indicators or performance, thresholds and tipping points for example.

3.5 Participatory zoning and general description of water problems in two agrarian systems of western and eastern Bhutan

As geo-databases are not well developed for these two sites, participatory mapping was used in the form of resource mapping and delineation of areas for specific purposes. Zoning was done based on local knowledge and field observations. It was done to segregate areas into units of similar characteristics to identify and localize agro-ecological and socio-economic constraints and potentials. Apart from agro-ecological zone and resource maps prepared based on key informants and transects, an important demarcation illustrated in both sites (Figure 3.8) is the irrigation water network and user groups in Lingmuteychu which is based on local knowledge. Similarly in Kengkhar zoning was prepared to show how villages share natural spring water (Figure 3.10 B).

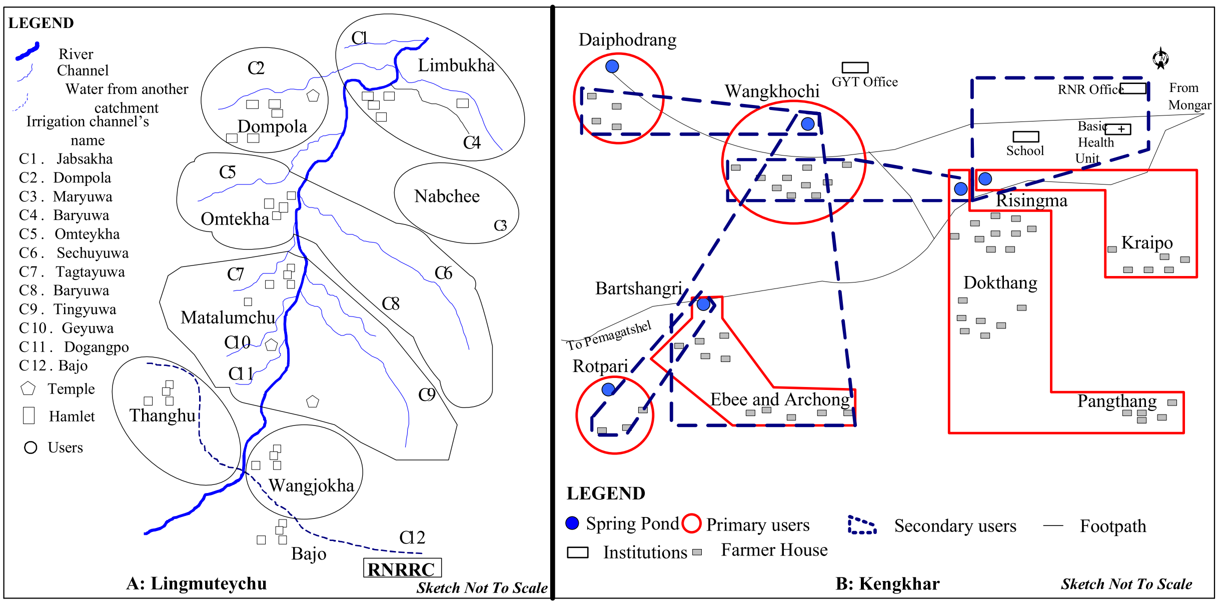


Figure 3.17. Zoning of water users in (A) Lingmuteychu and (B) Kengkhar.

Farmers in Bhutan are experiencing localized and seasonal water shortages for drinking and agricultural purposes. The present water resources management by different sub-sectors hinges on water utilization or abstraction rather than the integrated management of water, land and related resources. Further poor data scenario on water resource limits good planning and management strategies (Jamtsho, 2002). Considering the priority of water use set by the government (Water Act, 2010) this study identified water for domestic use and agriculture use as issues for research. To this effect the issue of irrigation water sharing of Lingmuteychu in Punakha district and drinking water crisis of Kengkhar in Mongar have been perpetual concern. Following a preliminary research in two upstream villages of Lingmuteychu in 2003-2004 (Gurung, 2004), a proposition to upscale the ComMod process to all the seven villages of the sub-catchment to address the issue of irrigation water conflict between up-stream and down-stream communities justified the continuation of this research. The issue in Lingmuteychu is further compounded by the administration boundaries, governance and institutional gaps. According to 9th Plan document of Mongar Dzongkhag, Kengkhar geog is reported to have acute water shortage which is affecting the livelihood of people as it limits crop yields, livestock productivity, sanitation, and health (Mongar Dzongkhag, 2006). The looming water resource ever became more severe, despite continued efforts to resolve it. The past efforts to built water supply scheme by different agencies in 1986 have not yielded enduring solutions. As small initiative on water harvesting by research team in Wengkhar in 2004 was considered feasible, people requested to continue the idea (Mongar Dzongkhag, 2006). In view of the contrast on use of water and social-ecological differences, these two sites were selected for this research (Figure 3.11).

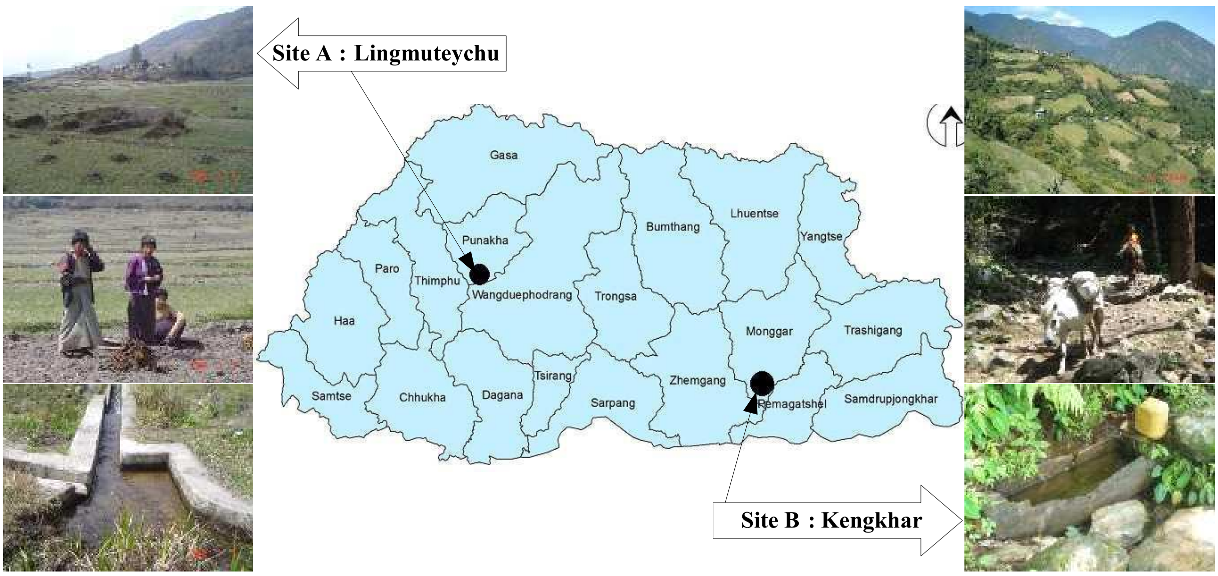
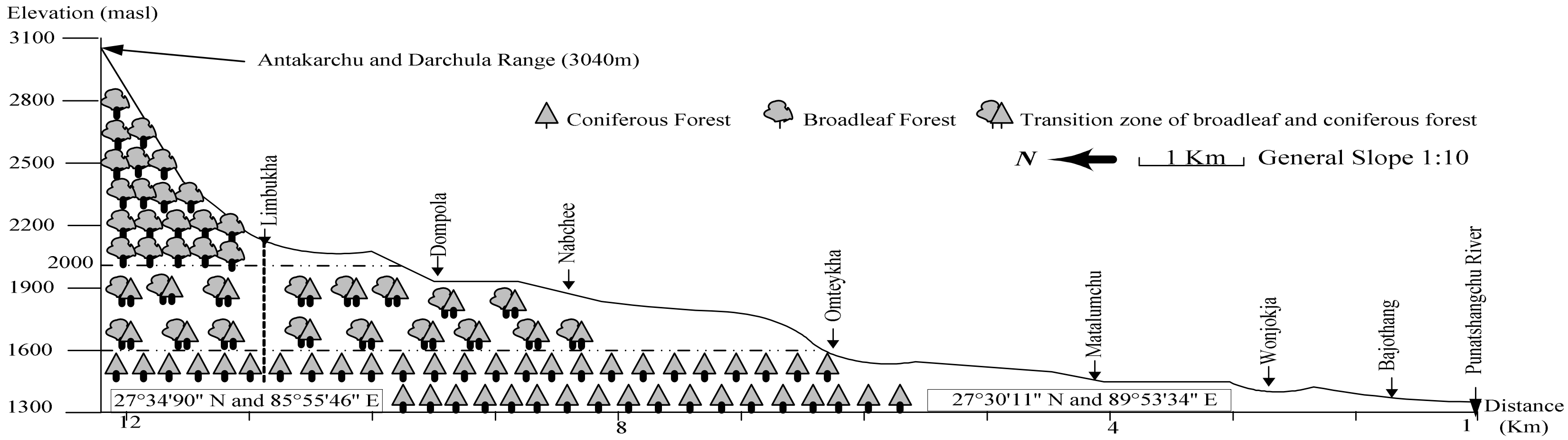


Figure 3.18. Location of the two research sites in western and eastern Bhutan.

3.5.1 Lingmuteychu sub-watershed

Lingmuteychu is a small sub-watershed, occupying an area of 34 km^2 located at on the east bank of the Punatshangchu river in west-central Bhutan. It is located in Limbukha block of Punakha district. It is drained by an 11 km long Limtichu stream that originates as a spring from a rock face at an altitude of 2,400 m north of Limbukha village (Figure 3.12). It is a rainfed stream since the Antakarchu and Darchula ranges that confine this sub-watershed are below the snow line. The stream serves five irrigation systems supporting 11 irrigation channels that irrigate about 242 ha of terraced wetland belonging to 206 households of seven villages (Own survey, 2009). While six villages share irrigation water from Limtichu stream within a broadly respected customary regime, the seventh lowest village use water from another catchment. Until 2008, four villages (Limbukha, Dompola, Omtekha, and Nabchee) fell under Limbu block of Punakha district, two villages (Matalangchu and Wangjokha) under Baap block of Thimphu district, and one (Bajothangu) under Thetsho block of Wangdue district. This administrative jurisdiction further added to confusion of water resource management. In 2008 when the democratic process was launched at the national scale constituency for election were delimited. In the process two of these villages under Thimphu district were merged with the Limbu geog while the last and the lowest one which used water from another catchment continued to belong to Wangdue district.

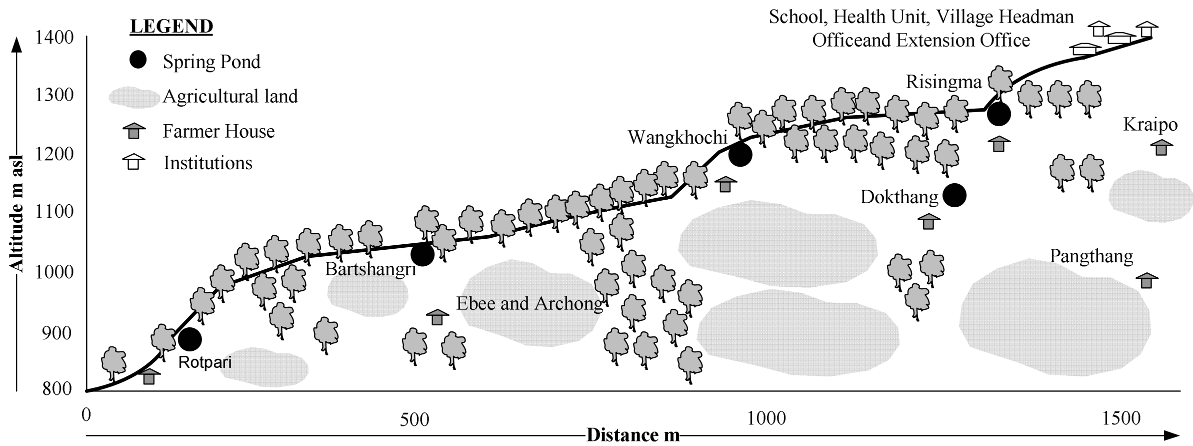


District	Punakha				Thimphu		Wangdue	Whole catchment
Villages	Limbukha	Dompola	Nabchee	Omteykha	Matalumchu	Wangjokha	Bajothang	
Altitude (masl)	2170	2100	1870	1600	1500	1300	1300	1300-2170
Vegetation	Broadleaf forest				Coniferous forest			Clay to sandy loam
Access to forest (distance)	Good	Moderate	Good	Poor	Poor	None		
Soil Type	Dark brown clay	Dark brown and sandy loam	Shallow and deep brown sandy loam				Sandy loam	
Irrigated rice land (ha)	38.46	28.97	4.24	40.08	49.58	33.97	47.06	242.36
Dryland (ha)	6.75	7.48	7.00	1.83	1.99	14.80	6.03	45.88
Major Crops	Rice, potato	Rice, maize, wheat, vegetable	Maize, Rice	Rice, mustard	Rice, Wheat, mustard	Rice, Wheat, mustard		Rice, wheat, mustard
Households	35	31	22	24	27	18	49	206
Main income source	Potato, Rice	Vegetable, Rice	NWFP, Maize, vegetable, off-farm within watershed	Rice, Vegetable	Vegetable, Rice	Rice, Vegetable, off-farm		Rice and vegetable
Problems	Wild animals	Water shortage and wild animals	Wild animals and water shortage	Water shortage	Water shortage and market	Irrigation water shortage	Irrigation water shortage	Irrigation water shortage
Potentials	Potato and rice production	Rice and vegetable production	Maize, potato and vegetable production	Rice, mustard and vegetable production	Rice, wheat, mustard	Rice, mustard, wheat	Rice, Wheat, mustard	Increased crop production

Figure 3.19. North-South longitudinal transects line of Lingmuteychu sub-watershed in west-central Bhutan. December, 2009.

3.5.2 Kengkhar

Kengkhar is a small highland settlement located on the confluence of Kurichu and Gangrichu in Mongar district. It is one of the remote block without motorable road access and electricity. It takes 8 hours of brisk walking to reach this village from the nearest road head at Gyelposhing. The block spreads over an area of 156 km^2, with a population of 380 households clustered in 7 hamlets. The altitude ranges from 860m to 2400m and the area experiences cold winter and warm summer. Kengkhar is popularly known for intricately carved wooden mask (*bap*) cask (*palang*), and altar (*tsho-sam*). The study site comprised of four hamlets: Munma, Aring, Drongphu and Kengkhar (Figure 3.13).



Village	Munma	Aring	Drongphu-Sherkong	Kengkhar
Vegetation	Mixed broadleaf			
Problem of water	Severe	Severe	Medium	Medium
Soil type	Sandy loam			
No. of household	20	12	27	30
Dryland (Ha)	8	5	10	12
Major crops	Maize, mungbean and mandarin orange			
Income source	Mandarin orange and handicrafts			
Problems	Land degradation, water shortage	Water shortage		
Potentials	Sustainable land management	Mitigation of water shortage by networking spring ponds		

Figure 3.20. Transect line of Kengkhar in Mongar district, eastern Bhutan, 2009.

3.5.3 Socio-ecological landscapes

The complexity of SES, uncertainties and nonlinearities arise from internal feedbacks and interactions with structures and processes operating at other scales (Gunderson and Holling, 2002), resulting in multiple alternate stable states (Scheffer and Carpenter, 2003). Further intricacy is induced by the complex mixture of ecosystem goods and services, each with their own set of stakeholders (Walker et al. 2002, Lebel, 2004). Uncertainties blend to form key features of social ecological landscape (Lebel et al., 2006). Resource use and interacting SES steer the function and patterns of landscapes (Brunckhorst, 2005). As such the SES landscape can be a basis to understand complexity as it provides a useful conceptual context for integration.

3.5.3.1 Lingmuteychu

The social-ecological landscape of Lingmuteychu is illustrated is Figure 3.21 by using the three main elements of rural socio-ecological systems (Schouten, et al., 2009). Physically Lingmuteychu can be represented by two steep slopes draining to a seasonal stream – Limtichu forming a narrow (approximately 11 km long, 1.5 km wide) valley (Figure 3.14).

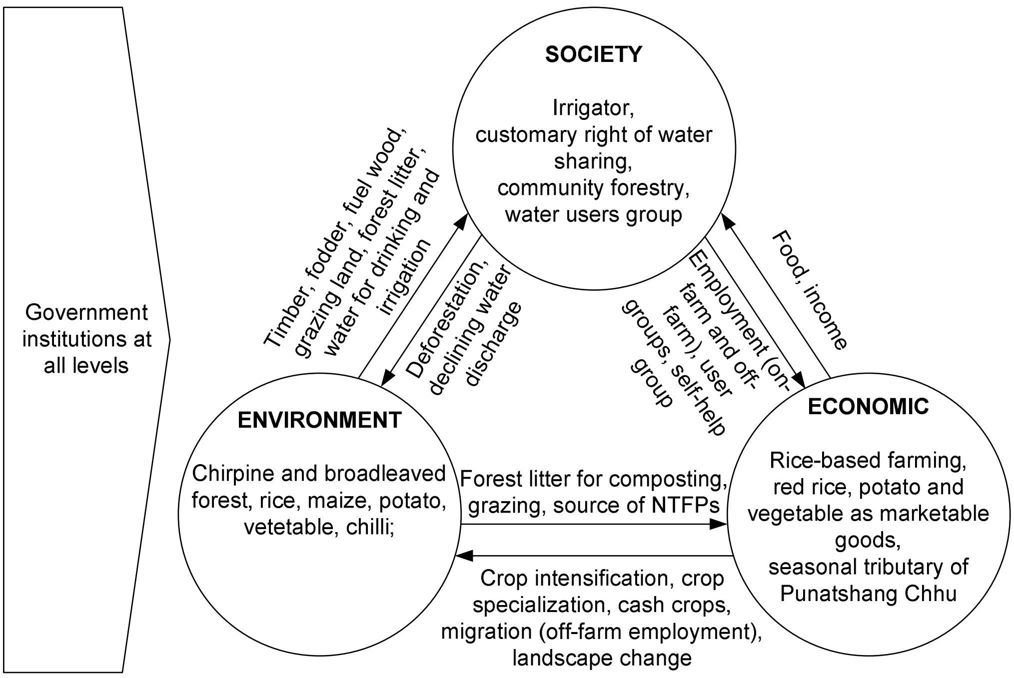
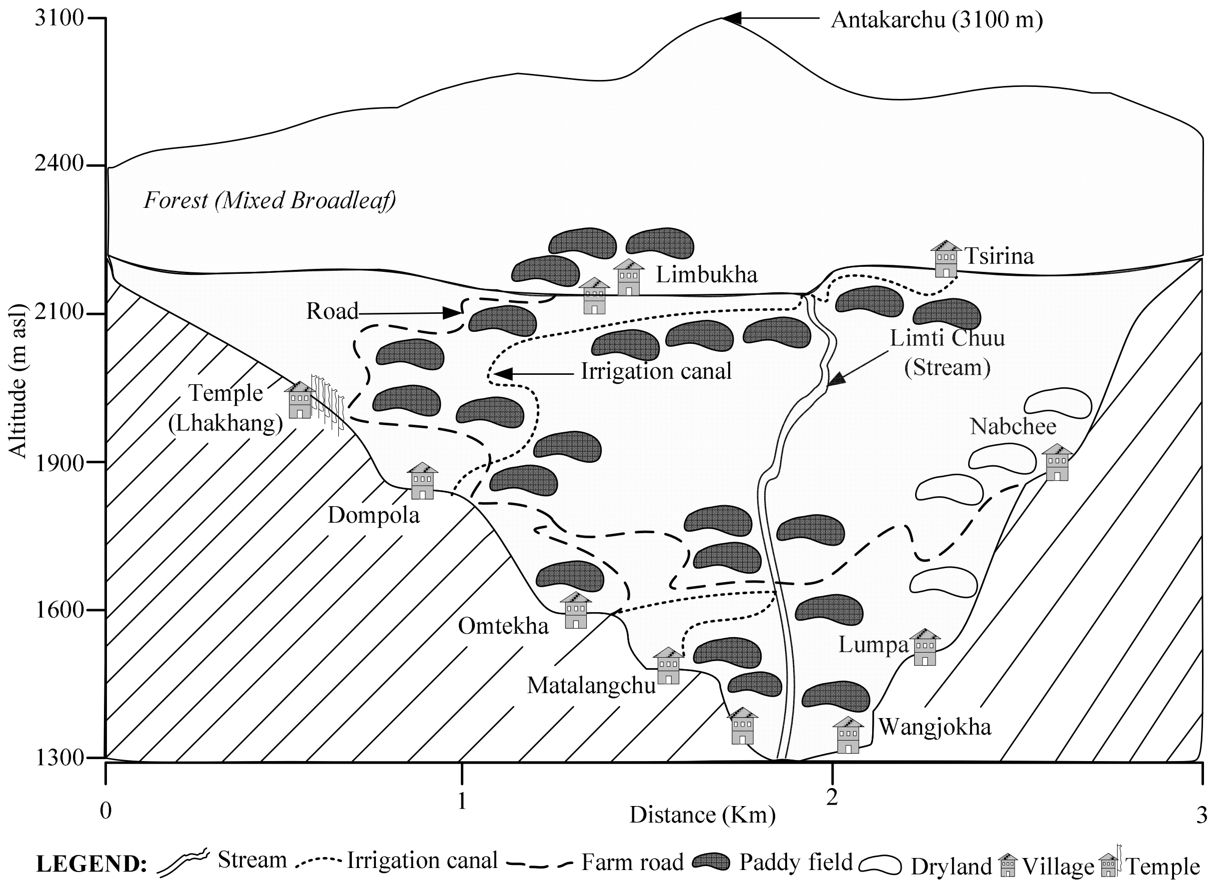


Figure 3.21. Components of the rural socio-ecological system and their interactions at Lingmuteychu in west-central Bhutan.

The altitude ranges from 1300 to 3100m amsl which provides agro-ecological features of warm temperate and dry sub-tropical zones. There are basically two types of forest vegetations: broadleaf forest above 1600m and coniferous forest below. Together they cover 69% of the sub-watershed area. A detailed longitudinal zonation of the sub-watershed along a transect line, locating the vegetation types, soils, and altitudinal differences influencing crop choices and other land-use decisions is provided in Figure 3.22. There is a small stretch of highly degraded barren land in the lower reach of the sub-watershed, which results from over grazing and poor forest regeneration (Gurung, 2004). Irrigated wetlands covering 242.36 ha predominates land use.



Source: Own survey, 2009

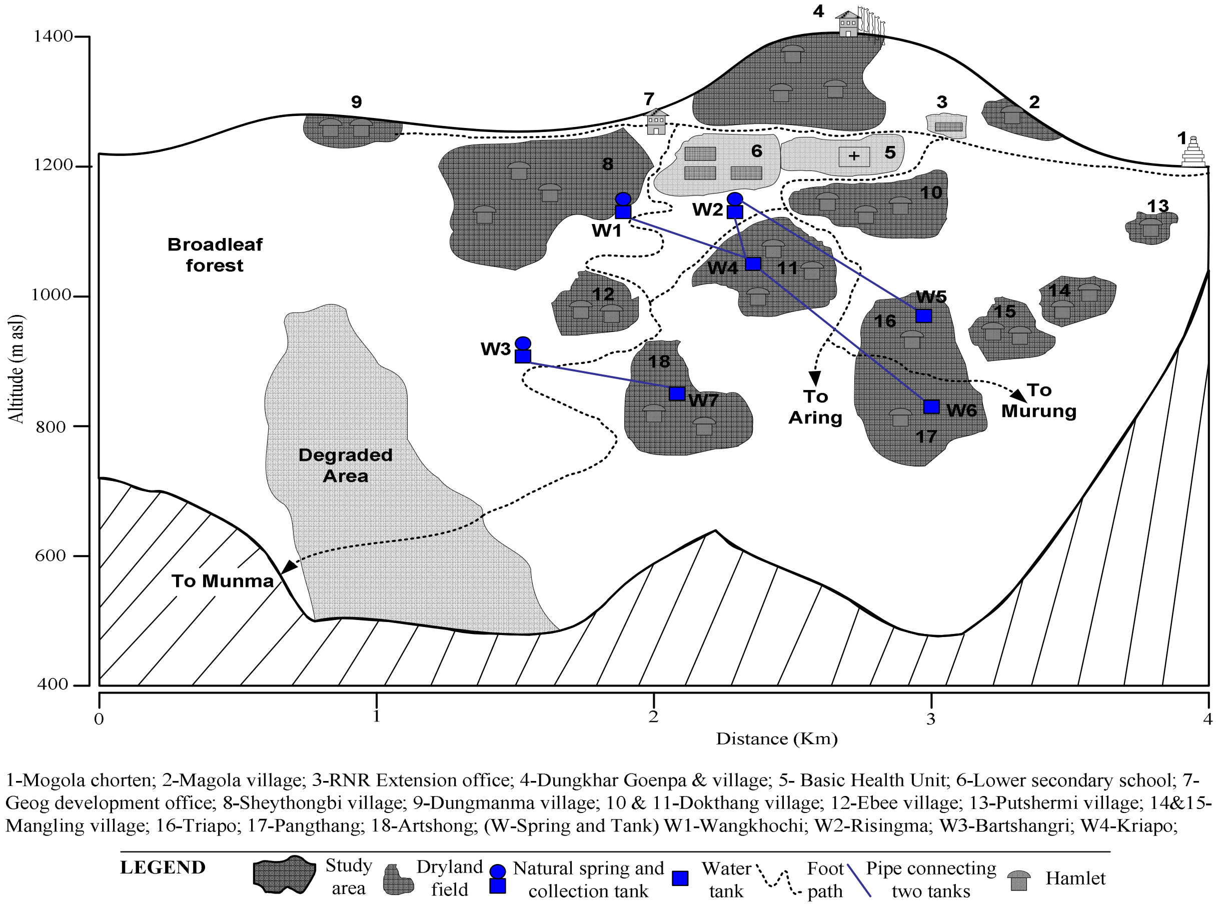
Figure 3.22. Schematic representation of landscape profile at Lingmuteychu site, west-central Bhutan.

Farmers divert water from Limtichu stream for irrigating the rice fields. From the early days the local communities have framed customary norms to share and manage water from this seasonal river. The customary rights created during a time when the resource was abundant with few users is still in practice and are found to be feudalistic and unfair (Kuensel, 2008). For instance, the well-off families who own large land holdings have greater say over the resource allocation. Major income sources can be categorized into three categories: (i) agricultural commodities (rice, potato, mushroom, dairy products, and NTFP) (Figure 3.23), (ii) off-farm employment (construction, skilled and semi-skilled work), and (iii) remittances (family member employed in public and corporate sectors). Lingmuteychu has most of the basic amenities in place (school, health unit, electricity supply, telephone connectivity, piped water supply, and dirt road), and the community has rapidly transformed from subsistence to semi-commercial farming (see below for details). Being accessible, people are aware of most of the policies of the government.

Figure 3.23. Rice and puffed rice as important commodity of trade from Lingmuteychu.

3.5.3.2 Kengkhar

The landscape of Kengkhar is representative of the eastern region of the country which is dominated by dryland. The study site is a south-east facing slope covering 30% of the Kengkhar block at an altitudinal range of 600 to 1400m amsl. Figure 3.24 provides a sketch of Kengkhar area with dryland concentrated and dominating one-half of the area. The community has a temple (Dungkhar Goenpa) overlooking the settlement and considered as the residence of a guardian deity. All the government service centres, including the local government office is located in the study area, making it a hub of the block.



Source: Own survey 2008 and 2010.

Figure 3.24. Schematic representation of the landscape profile of Kengkhar, eastern Bhutan.

Demographically, it is a small settlement with around 50 households, the family size ranging from 5 to 10 members. It is basically a homogenous *Tshangla* (language of eastern Bhutan) speaking community who migrated mostly from Lhuentse and some from Trashiyangtse districts located in the north-eastern part of the region. With the government support citrus was introduced and now forms an important cash crop (Figure 3.25). Despite the severe short supply of water, this community has devised a customary water sharing system that promotes collective access to this crucial resource. There is no report of conflict on water sharing so far. Another peculiarity is the absence of amenities like road and electricity. Therefore, in the absence of any motorable road so far, portaging is a major off-season employment for which almost all households maintain few stocks of mules. With skill of wood carving and painting, many people move to urban centre for employment.

Figure 3.25. Mandarin orange as important cash crop of Kengkhar.

The interactions among the three components of the local socio-ecological system are displayed in Figure 3.26. While a detailed study was not done, community members too perceive the decline of natural spring water and land degradation as an effect of indiscriminate harvesting of timber. So much that, as they cannot find suitable timber in the community, the craftsmen bring the timber from the neighbouring Pemagatshel district (a 6 hours walk toward the south) to make their famous wooden casks.

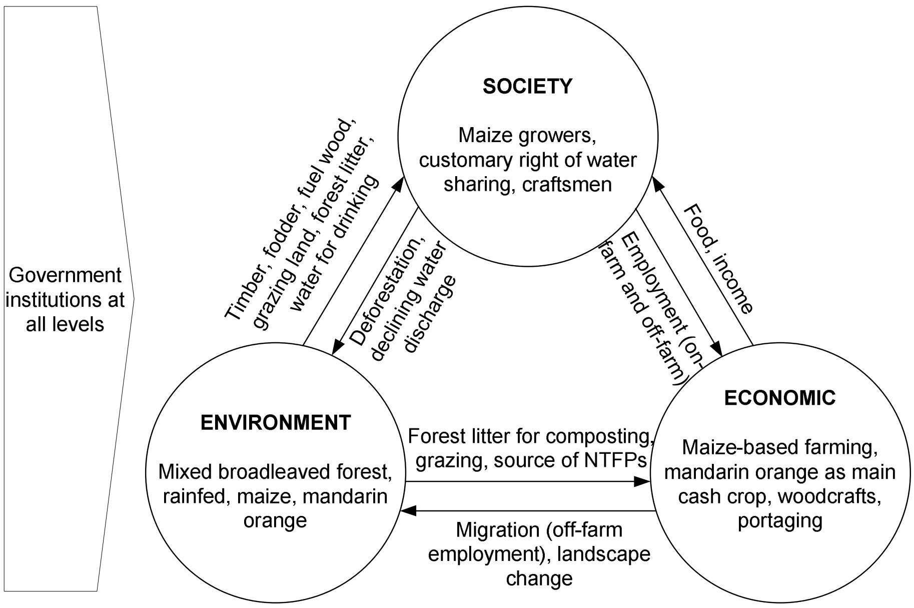


Figure 3.26. Components of the rural social-ecological system and their interactions at Kengkhar site in eastern Bhutan.

3.5.4 Natural resources, their interactions and management

3.5.4.1 Lingmuteychu

The natural resources available in the study can be broadly grouped into three groups: as forest, crop production, and livestock based. The status of natural resources in Lingmuteychu is presented in Table 3.10. It is evident from the status that people have abundance of arable land and livestock compared to resources derived from the forest. Among the natural resources NTFP, *sokshing*, and grazing land are scarce, while timber and water are moderately available. It was revealed from the survey that the main cause of loss of timber was the nationalization of forest in 1969 when anyone with a permit could access the forest and harvest trees. From the total sub-watershed area of 34 km^2 only 6.3% is arable land and the remaining falls under the government reserved forest (GRF). This GRF area actually represents scrub forest and vast barren land. The broadleaf forest in the upstream looks fairly healthy.

Table 3.10. Status of natural resources in Lingmuteychu.

Natural Resources	Abundance	Threat	Subsistence usage	Commercial usage	Community rules
Timber	xx	xxx	xxx	-	x
Communal *sokshing*	x	xxx	xxx		xx
NTFP	x	xx	x	xx	x
Communal pasture	x	xx	xxx		x
Water (irrigation and drinking)	xx	xxx	xxx		xxx
Community forests	x		xxx	x	x
Arable land	xxx	x	x	xxx	xx
Field crops	xxx	xx	xxx	xx	
Horticulture crops	xx	x	x	xxx	
Feed and fodder	x		x		
Cattle	xxx	x	xxx	xxx	
Poultry	xx	xx	xx	xxx	
Piggery	x	-	xxx	xxx	
Horses	x	-	x	x	

Scale: blank = non-existent, x = low, xx = medium, xxx = high.

Dwindling water resource has been a perpetual problem of the community. One of the reasons for declining discharge of water is associated with the small catchment area. NTFP is also an important natural resource that support livelihood, as household depend on ferns, mushroom, orchids and wild fruits for domestic consumption. The provision to use designated areas in the forest as source of leaf litter "sokshing" for composting and area for grazing “tsamdrog” has been withdrawn after the revision of Land Act (Land Act 2007). Without the legitimate access to grazing land and leaf litter there could be a major impact on the farming systems. The revised provisions of leasehold will take sometime to operationalize. As both agriculture and livestock resources are predominantly used for commercial purpose, resources derived from the forest acts as inputs to the other two components.

3.5.4.2 Kengkhar

The natural resources available in Kengkhar are identical to those of Lingmuteychu except that types and uses vary. For instance, water is the most scarce resource in the area and used only for domestic purposes. This deprive people to irrigate their crops, thus leading to only dryland farming. Timber (soft wood) particularly for carving is a valued resource which has been completely exhausted. NTFP like wild vegetables (mushroom, orchids, ferns and asparagus) supplement the household requirements (Table 3.11).

Table 3.11. Status of natural resources in Kengkhar.

Natural Resources	Abundance	Threat	Subsistence usage	Commercial usage	Community rules
Timber	x	xxx	xx	xxx	
Communal *sokshing*	x		xxx		xx
Wild mushroom	x	x	xxx	-	-
Water for domestic uses	x	xxx	xxx		xxx
Community forests	x		xxx	x	xxx
Arable land	xx	x	x		xx
Field crops	xx	xx	xxx	x	
Horticulture crops	xx	x	x	xxx	
Feed and fodder	x		x		
Cattle	xx	x	xxx	xxx	
Poultry	xx	xx	xx	xxx	
Horses	xxx	-	x	xx	

Scale: blank = non-existent, x = low, xx = medium, xxx = high.

All the natural resources are limited causing hardship to the community. To this effect, respondents ponder if resettlement to another area would be a better option.

3.5.4.3 Interactions among natural resources and their management

The dynamic interactions among these three groups of natural resources are influenced by the household that regulates the interplay. Within a household, three elements of food, shelter and income as basic needs can be theoretically linked to different resources to represent these interactions are shown in Figure 3.27. All resource flows into household from where it flows out of the system to market to generate income and fulfil other needs. Although it could not be accurately quantified, it is evident from the representation that forest is a primary source of resources that feed the other sub-systems.

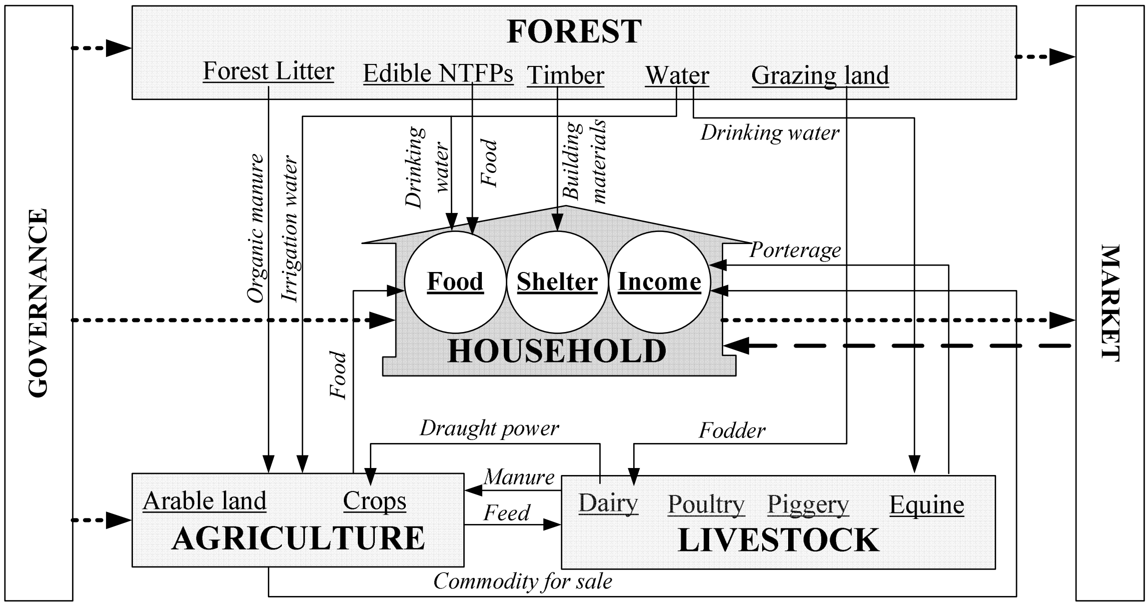


Figure 3.27. Natural resources flow and interactions in Lingmuteychu and Kengkhar farming households.

Broadly there can be three management regimes depending on the resource involved. In the case of Lingmuteychu and Kengkhar, resources are mostly under the state management within the prescribed rules (Table 3.12). At both sites there are forestry officials to regulate the use. As these officials have no litigation responsibilities, the resource sharing conflicts are addressed by local government offices (represented by the Block headman). Severe cases are reported to the District court. For example farmers of Lingmuteychu have to often attend such legal cases, the most recent one was in August 2009, when a group of irrigators from Omtekha village dismantled the irrigation weir. Despite such rules, customary rights on water and NTFP are duly considered (Water Act, 2010). Agriculture and livestock resource although privately owned, they are protected from exploitation by policies. Particularly the protection of wetland from being used for other uses (Land Act 2007).

Table 3.12. Natural resource management regimes in Lingmuteychu and Kengkhar.

Resources	Management regimes		
Forest based	State management	Community management	Private management
Timber	Chapter V of the Forest and Nature Conservation Rules, 2006 specifies the allocation of timber		
Bamboo and cane	Chapter V Article 54 (5) of Forest and Nature Conservation Rules (FNCR) 2006 permits access and use	Community regulates the schedule to access forest areas	
Sokshing (Woodlot for collecting forest litter for composting)	Chapter 11(Use of *sokshing*) of the revised Land Act 2009 withdraws rights from both individual and community and declared as Government reserved forest, thereafter it is allowed on leasehold basis		
Wild mushroom	Chapter 3 Article 15 (c) allows individuals to harvest mushroom for domestic consumption without permit	Community based management approaches are applied	
Communal pasture	Chapter 10 (Article 235 - Use of *tsamdro*) of the revised Land Act 2007 withdraws rights from both individual and community and declared as Government reserved forest, thereafter it is allowed on leasehold basis		
Water for irrigation and drinking purposes	Water Act 2010 provisions right to access water for domestic and agriculture use on priority basis. FNCR, 2006 have special provisions to protect and manage catchment areas	Customary rules and rights to access water supply	
Community (& plantation) forests	Chapter 4 of FNCR 2006 promotes community involvement in forest management		
Agriculture based			
Arable land	Land Act 2007 is the overriding legal framework that protects land		
Crops	Provision for development support	Planting and harvesting schedules	Primary decisions to raise crop and management levels
Livestock based:			
Domestic animals	Provision for development support	Migratory schedules and track	Individual decision to raise livestock and management levels

3.5.4.4 Land holding in Lingmuteychu and Kengkhar

As any typical Bhutanese community, Lingmuteychu and Kengkhar are also sparsely populated communities living within the realms of traditional cultures (Figure 3.28). Lingmuteychu is predominantly a rice growing community with around 84% arable land devoted to irrigated wetland. While Kengkhar represents a distinctive dryland environment with 88% of arable land used for dryland cultivation (Table 3.13). There is no wetland in Kengkhar and similarly Lingmuteychu community has not invested in orchards.

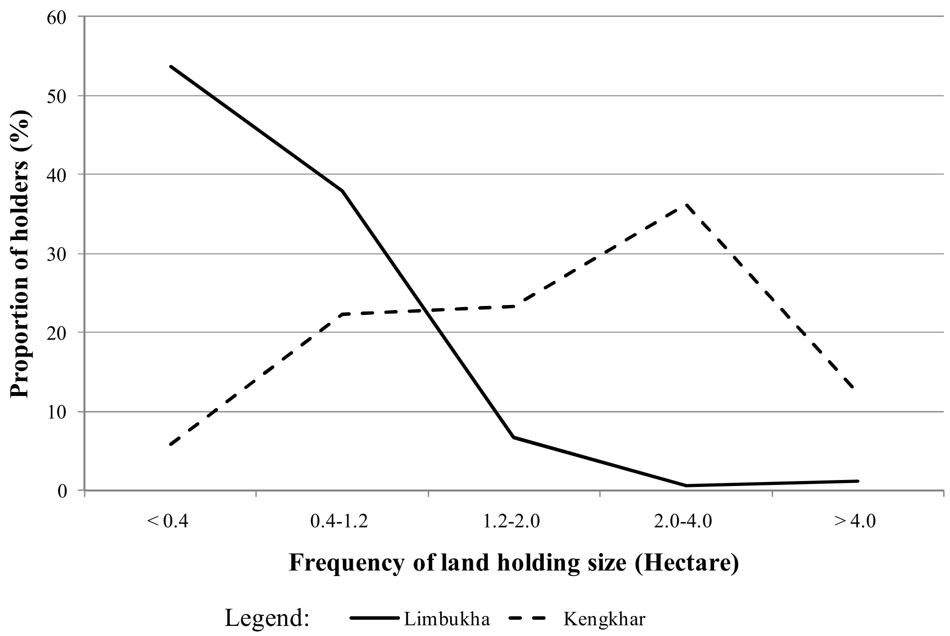
Figure 3.28. Lady (in red shirt) from Lingmuteychu offering tea, while lady from Kengkhar (in blue Tego) offers ara (locally brewed alcohol) to guest.

Table 3.13. Landuse and households at Lingmuteychu and Kengkhar study sites, 2008. (Hectares).

Study sites	Wetland	Dryland	Orchard	Households
Lingmuteychu	242	45	0	206
Kengkhar	0	53	7	52

Source: RNR Census 2009.

The land distribution between the two study sites is contrasting (Figure 3.29). Distribution in Lingmuteychu is equitable as around 92% of the farmers own less than 1.2 ha of arable land. Just 1% of the population has more than 4 ha. In the case of Kengkhar, more than 71% of the farmers hold more than 1.2 ha., with only around 6% owning less than 0.4 ha.



Source: MoAF, 2009.

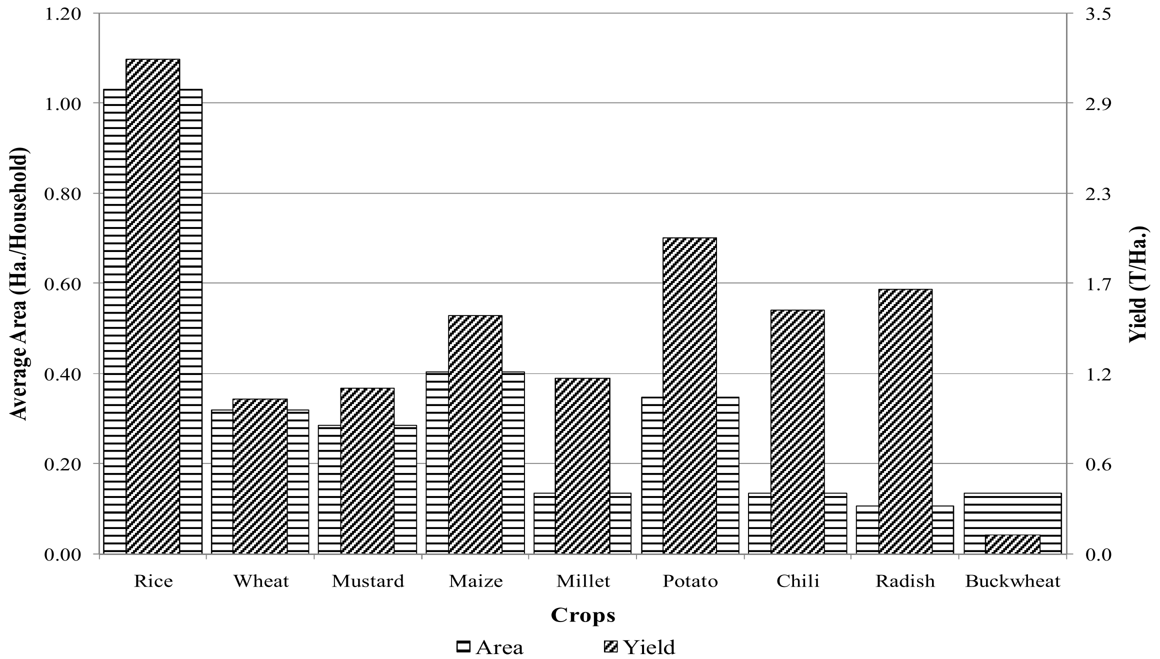
Figure 3.29. Distribution of land holding size in Lingmuteychu and Kengkhar.

3.5.4.5 Crops and cropping patterns

In view of the differences in land use at these two sites, it is useful to present the crops and cropping patterns separately. Further, as seven upstream to downstream villages are involved in Lingmuteychu, it is better to show their cropping patterns individually to understand the overlaps.

Lingmuteychu

All farmers in the seven villages of Lingmuteychu sub-watershed grow different varieties of rice (local red rice, local white rice, IR64, IR20913) on average in 1 ha/HH. In general people grow 5 cereal crops and 3 vegetables (Figure 3.30). Maize is mostly grown by Nabchee farmers. Potato is fast becoming a popular cash crop, although it was started only in 2003 by Limbukha farmers as a pre-rice crop, now downstream communities have also introduced potato before rice. Chili and mustard are other crops which are grown in small plots by most farmers.

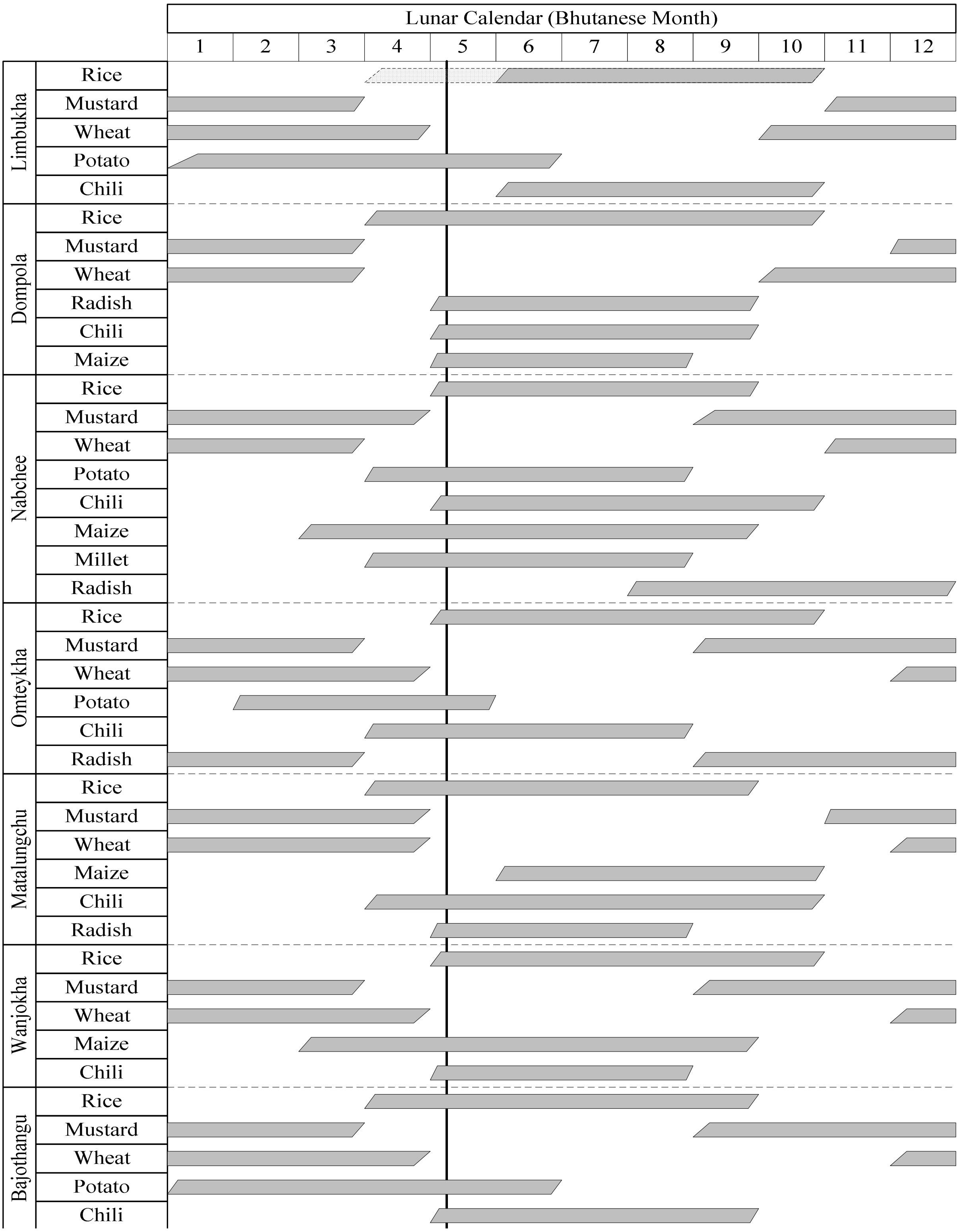


Source: Own survey, 2009.

Figure 3.30. Crops grown in Lingmuteychu and their productivity.

As a potential rice growing area, the yield levels of rice and millet are 13% and 11% higher than the national average yields[5] respectively. The cropping calendars presented in Figure 3.31 provide a glimpse of how seven communities implement their cropping activities on a village basis but under the influence of other upstream communities.

[5] National average yield (t/ha) over nine years: paddy=2.8; maize=2.4; wheat=1.2; barley=1.3; buckwheat=0.9; millet=1.0; and potato=10.2 (Source: MoA, 2009)



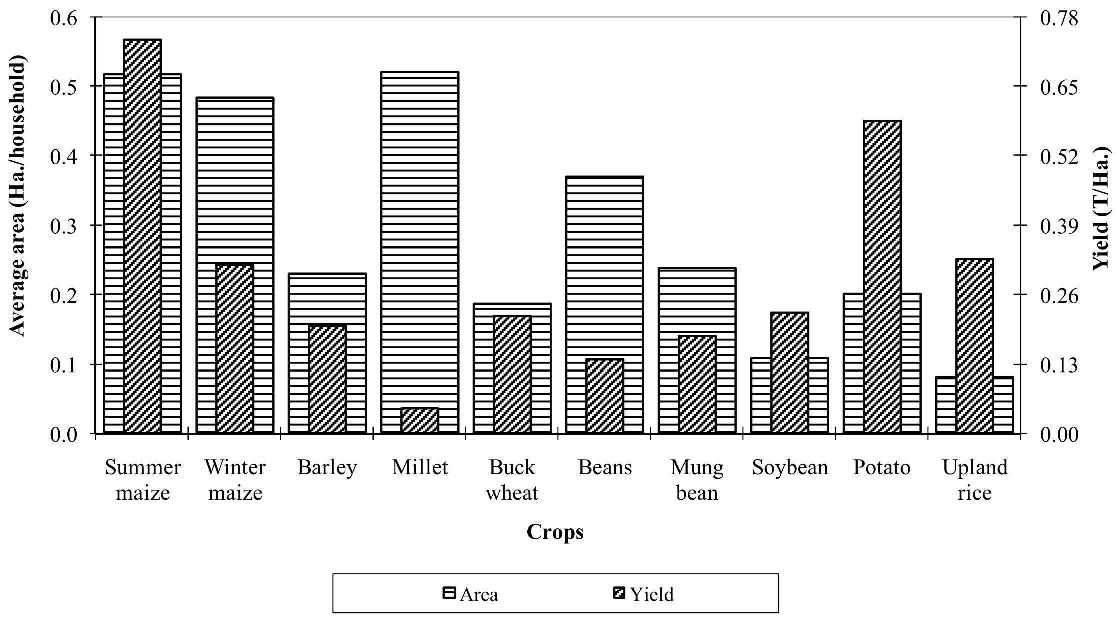
Source: Own survey, 2009.

Figure 3.31. Cropping patterns of seven villages in Lingmuteychu sub-watershed.

The most glaring case is rice transplanting time which is almost the same for all the villages. The limited time within which rice has to transplanted and harvested before 11th month (to avoid cold spells during flowering) poses competition for irrigation water. In the past the uppermost village (Limbukha) used to transplant rice in the 4th month and by the 10th day of the 5th month it would release water for next Dompola village. With the introduction of potato before rice in Limbukha as a lucrative crop, rice transplanting has been delayed to the 6th month which further puts pressure for downstream communities as water may be released later than usual. Three villages (Dompola, Matalungchu, and Bajothangu) have adopted a strategy to transplant one month before the immediate upstream village. This could have reduced the pressure on water and thereby conflict. However, as water is required in different stages of the rice growth and development cycle, early planting actually does not solve the whole gamut of the water conflict.

Kengkhar

Kengkhar farmers grow assorted crops like maize, millet, and legumes that suit the dry upland environment. Being a staple crop in the area, all households grow maize in half a hectare land (Figure 3.32). Cereals like millets, barley and buckwheat in addition to supplementing household food requirement; they are also widely used for brewing home-made alcohol. Upland rice is traditionally grown in small plots (not more than 20 m^2) and the rice harvested is solely used for religious offerings. However, with support from MoAF farmers are accessing better and high yielding varieties which could be grown in larger plot as supplementary food.

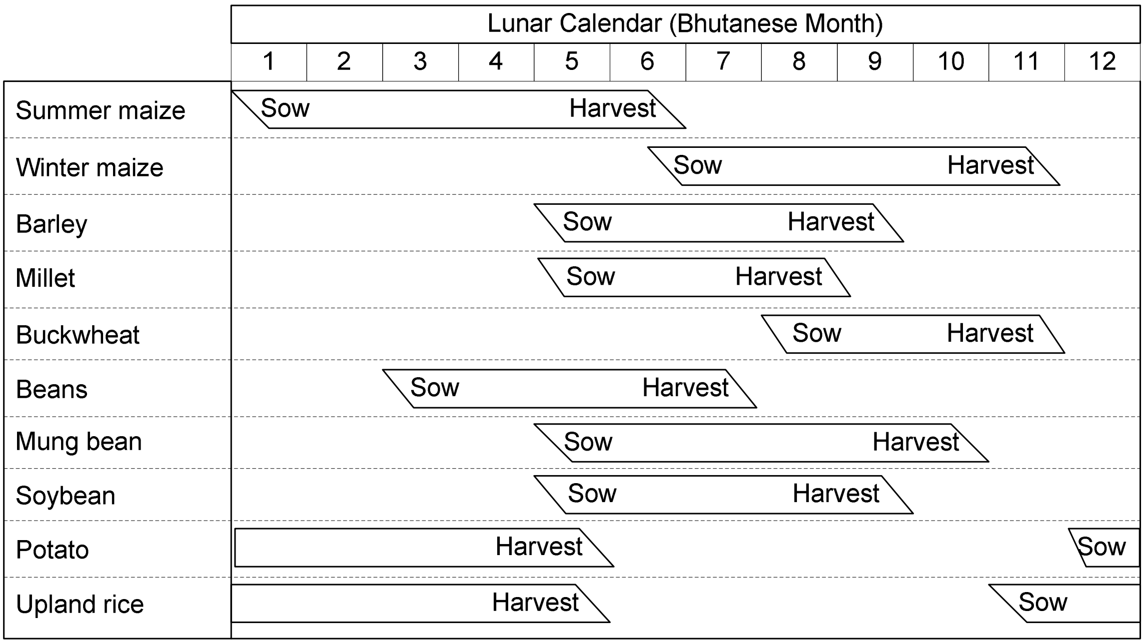


Source: Own survey, 2009.

Figure 3.32. Crops grown in Kengkhar and their productivity.

While potato is planted as a sole crop and pulses/legumes (*rajma-Phaseolus vulgaris*, field beans-*Vicia faba*, soybean-*Glycine max*, and mungbean- *Vigna radiata*) are popularly cultivated as intercrops in maize. Potato and beans are sold in nearby towns to earn cash income. The yield levels of all crops are extremely low, for instance the maize yield is around 70% lower than the national average and the potato yield is almost 90% lower.

The cropping calendar (Figure 3.33) provides a general understanding of how maize cultivation takes most of the farmer's time in crop production. There seems to be lots of overlap, which could be one reason for poor crop yields. It also provides a sense of subsistence farming and food security with short cycles of multiple crops continuously providing some food diversity for the household.



Source: Own survey, 2009

Figure 3.33. Cropping patterns at Kengkhar.

3.5.4.4 Livestock

Livestock system serves an important role to supplement household with animal protein, in addition to the vital draught power and manure it provides to farming. In addition to the wealth indicator, people maintain large herds of livestock as a source of farm yard manure (FYM) which is applied in large quantities on the fields. For instance, farmers apply 7 to 10 tons of FYM/hectare/year in Lingmuteychu, while Kengkhar farmers apply 5-6 tons of FYM/hectare/year and tether their cattle in the field. Farmers rear eight types of livestock in both sites (Table 3.14).

Table 3.14. Livestock types and their population in Lingmuteychu and Kengkhar in 2008.

	Mithun	Nublang	Jersey	Brown Swiss	Mule	Goat	Pig	Poultry
Lingmuteychu	90	680	85	0	66	11	7	281
Kengkhar	572	918	182	3	166	9	30	799

Source: RNR Census, 2009.

Cattle form the most important group with four different breeds (Mithun, Nublang, Jersey, and Brown Swiss), followed by poultry. Farmers in Kengkhar maintain more local cattle (Mithun and Nublang) for the purpose of ploughing fields (Figure 3.34). In Lingmuteychu ploughing is done by the 10 power tillers available in the sub-watershed (Figure 3.34). Most households in Kengkhar own mules to transport goods as the community is still not connected by road. In contrast although there is a motorable road in Lingmuteychu, some well-off households still own mules which are used for transporting FYM from homestead to fields.

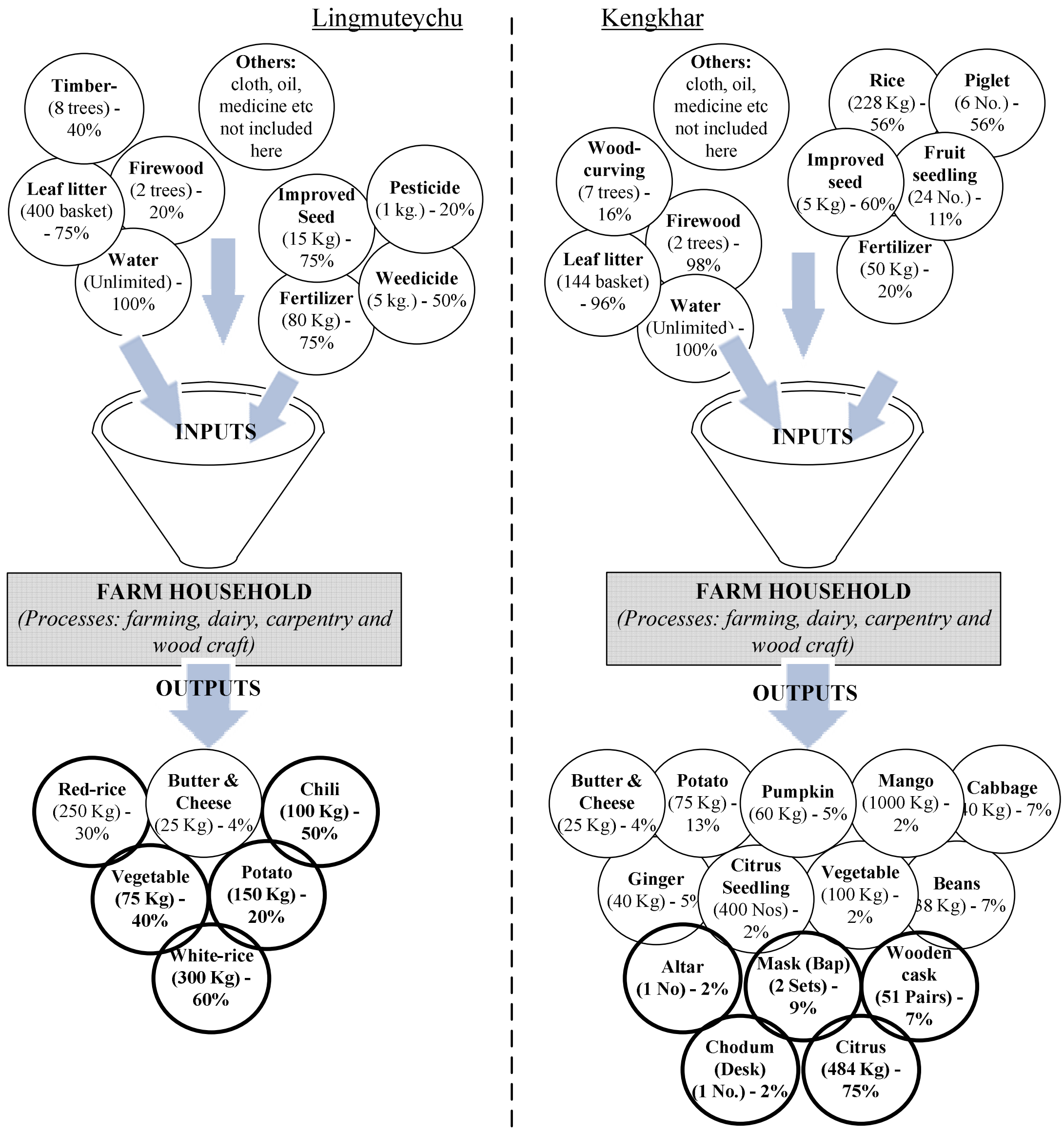
Figure 3.34. Ploughing the field with power tiller in Lingmuteychu and use of Mithun bulls in Kengkhar.

Until the year 2000, they used mules for transporting goods to the nearby town of Wangdue. Raising few cockerels in every home is a traditional practice; however poultry farming is of recent introduction by MoAF's initiatives. Currently many households rear more than 10 improved breed of layers supplied by the Department of Livestock, which is a supplementary source of income from selling eggs.

3.5.4.5 Livelihoods, constraints and opportunities.

Lingmuteychu and Kengkhar provide contrasting strategies for livelihood adopted by communities in two different situations. A simple schematic representation of resource inflows and outflows describe the livelihood sources of the two communities in Figure 3.35. The inputs for both cases are almost similar, except that they vary in terms of volume and proportion of households using them. The inputs come from two sources: from the forest and from external sources like the market. Kengkhar farmers consider rice as an input to the system, as they fully depend on it from external sources. In Lingmuteychu, to operate the intensive rice farming, farmers heavily depend on chemical fertilizers, pesticides and herbicides. Further they consume higher proportions of forest produces like leaf litter and timber.

The outflow from the system indicates a rice and potato specialization in the case of Lingmuteychu. The products are specially targeted to the market and produced in large quantities. In comparison, Kengkhar farmers produce several items in small quantities, which may be sold. From 14 items, Kengkhar people consider woodcrafts and citrus as the prime products that are targeted for the market. Fundamentally it can be deduced that livelihood of Lingmuteychu is based on semi-commercial rice production system, while in Kengkhar livelihood depends on semi-subsistence farming supplemented by micro wood-based cottage industry.

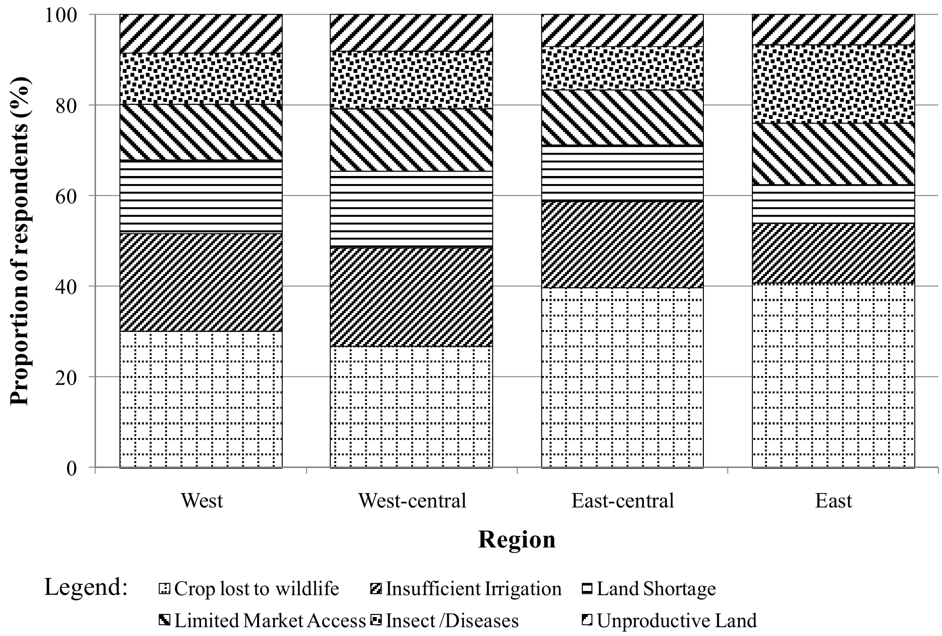


Please note: Figure in parenthesis represents quantity of resource used/produced by household annually and percent represents proportion of households involved with the particular resources (n=50 in Lingmuteychu and n=55 in Kengkhar). Those outputs with bold circles represents the priority outputs.

Source: Own survey, 2009.

Figure 3.35. Farming household resource in-flow and out-flow in Lingmuteychu and Kengkhar.

At the national level the principal limiting factor in the farm sector is crop damage and livestock predation by wildlife (Figure 3.36). 34% of the respondents in a nation wide agricultural census raised wildlife as the most important issue. It was most prevalent in the eastern region and lowest in the west-central region. It was followed by insufficient irrigation water (19%) which made difficult to cultivate rice. The issue of irrigation water was more prevalent in the west and west-central regions where rice is a dominant crop. Shortage of arable land was raised as a limiting factor to crop production by 14% of the respondents. Access to market, pest and diseases, and unproductive land are also constraining agricultural development.

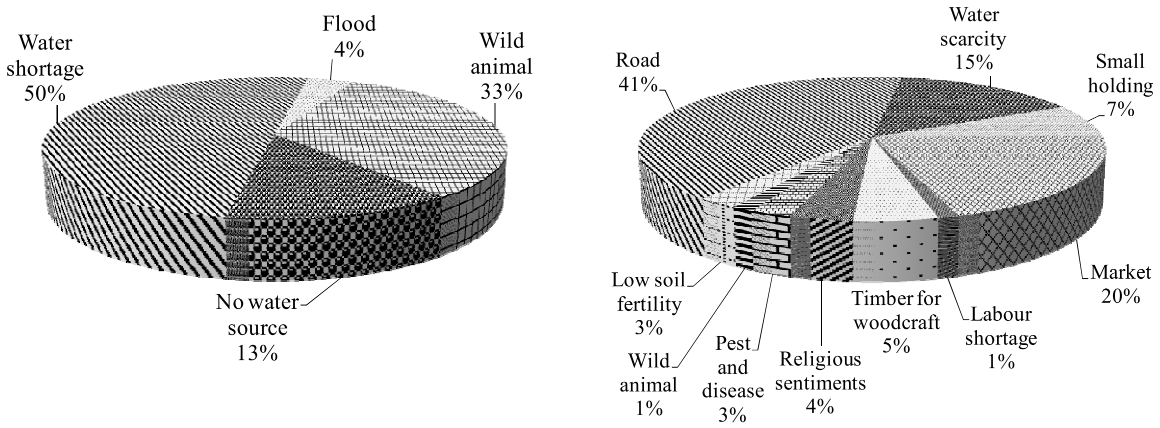


Source: RNR Census 2009.

Figure 3.36. Constraints to agricultural development in Bhutan, 2009.

The constraints at our two study sites correspond to the national scenario with the water issue as a primary concern in Lingmuteychu and access as main limiting factor in Kengkhar (Figure 3.37). In Lingmuteychu 67% of respondents (n=50) indicated the water issue as a major constraint followed by wild animal damage in upstream villages. Flood during the wet monsoon from the Punatshangchu river is a problem in Bajothangu lower village. Farmers in Kengkhar seem to be surrounded by numerous problems ranging from labour shortage to access. About 41% of the respondents (n=52) pointed the lack of road as a major constraint of the community.

With a motorable road now under construction, access to market can be improved in the near future. Drinking water scarcity was also raised as an issue by 15% of them.

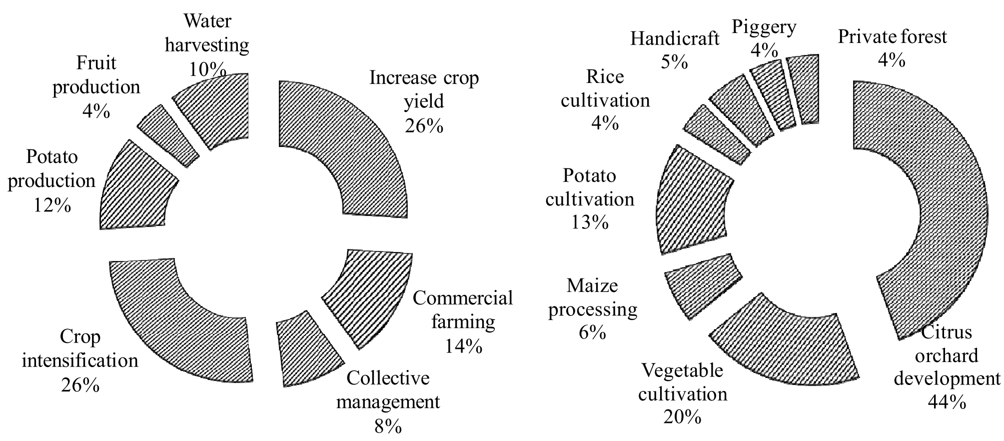


A: Lingmuteychu **B: Kengkhar**

Source: Own survey, 2009.

Figure 3.37. Problem definition in (A) Lingmuteychu and (B) Kengkhar.

Despite the problems, opportunities exist which can facilitate development of these communities. In Lingmuteychu cropping intensification and improvement of crop yields are major opportunities. 14% of the respondents considered that commercialization of agriculture through the expansion of potato cultivation (12%) have a high potential in the area. To address the issue of water shortage, there is a potential for collective management of the resource and water harvesting particularly in Nabchee area (Figure 3.38).



A - Lingmuteychu B - Kengkhar

Source: Own survey, 2009.

Figure 3.38. Opportunities for agricultural development in (A) Lingmuteychu and (B) Kengkhar.

Similarly, in Kengkhar, cultivation of citrus, vegetable and potato are opportune interventions. People consider the future new highway linking Gyelposhing to Nanglam that will connect the area to Assam, India and the farm road being built in the study area as motivation to expand cash crop cultivation. Although woodcraft is an important livelihood source, only 5% of the respondents considered it as an opportunity because other thinks that it is highly dependent on the availability of timber which is already in short supply and has to be imported from a neighbouring province.

3.6 Recent agricultural transformations at the two study sites

Ever since the country was unified in 1907, there has been a chain of socio-economic and political events either planned or incidental that led to transformation of agro-ecological conditions. From a sparsely inhabited and self-contained farm families migrating with herds of livestock and practicing shifting cultivation, in two decades it evolve into the present landscape where farming is driven by income generation objectives and people competing for (both local and external) renewable resources. 55 farmers in Lingmuteychu and 40 in Kengkhar were consulted to generate historical profiles to document and understand the evolution of the local socio-economic contexts and their associated influence on agro-ecological conditions. Respondents felt comfortable to share information on events that occurred only after the early 1950s when serfdom and feudalism was abolished. Some reasoned that few powerful people controlled the socio-economic system. Based on the historical timeline, the agrarian transformations in both sites summarized in Tables 3.16 and 3.17 can be grouped into three main phases as (i) 1950-1970: Subsistence farming by predominantly shifting cultivators, (ii) 1970-1990: self-subsistence to part-commercial, and (iii) 1990-2009: Semi-commercial farming dominate.

3.6.1 1950-1970: Land reform and subsistence farming

Prior to the 1950s, slavery and serfdom prevailed in Bhutan and it was only in 1952 when a land ownership ceiling was set at 10-12 hectares per individual, serfdom abolished and King granted land to landless people (Hasrat, 1980) leading to the emergence of an independent household based mode of farming free of the bondage (Table 3.15).

Lingmuteychu: a wetland dominant community

Despite the land allocation and entitlements, farmers followed the traditional method of cropping and production systems just for the subsistence purpose. People practised a shifting cultivation system (locally termed as *tseri*) as it suited best for households who had to migrate with their livestock herds seasonally. As they followed long fallow periods (more than 12 years) *tseri* helped rebuilding the soil production potential and ensured better harvests especially by controlling weed infestation. With the abundance of forest resource and open barren lands, farmers used them as grazing land and source of timber and firewood indiscriminately. Within the predominantly rice-growing farmers, in 1952 few families from the eastern part of the country were resettled in Nabchee, who brought along maize cultivation into the sub-watershed; even today Nabchee farmers still depend on maize. During early 1960s, Government provided subsidy for terracing their field and conversion of dryland to rice fields. In 1969 when taxation was changed from kind to cash, farmers started growing a larger diversity of crops (like chilli, cabbages, radish, beans and rice) that could be easily sold to civil servants in Punakha and Wangdiphodrang towns. People narrate of long early morning treks in the nearby forest to harvest ferns, orchids and mushrooms which fetched little income. It was evident from the discussion with the respondents that no one took responsibility of degraded forest on the top of Antakarchu mountain which is a primary catchment for the Limtichu stream that drains the watershed. Elderly respondents expressed how freely and irresponsibly people harvested resources (timbers, litter, and NTFP). The fragmentation of fields as large as 25 acres into smaller individually owned fields as small as a *langdo*[6] led to division of irrigation water shares to multiple users.

[6] *Langdo* is a local unit of land which is a piece of land than can be generally ploughed by a pair of bullock in a day. It is roughly 0.1 Ha.

Table 3.15. Evolution of socio-economic conditions and related agro-ecological transformations in Lingmutechu watershed, Punakha District, West-central Bhutan.

	Agro-ecological transformations	Year	Socio-economic changes
Subsistence[7] farming	- Abundance of primary forest and natural resources	- Before 1950	- Feudalistic, scanty villages and migratory population
	- Few land owners with large land holdings, producing local red rice varieties - Shifting cultivators producing meagre maize and millets	1952	- Abolition of serfdom - Land ceiling up to 10-12 ha per household - Resettlement of people in Nabchee from eastern Bhutan
	- Crop diversification – maize, millets, legumes, vegetables - Clear felling of forest in Nabchee and start of maize	1969	- Start of taxation in the form of cash - Nationalization of forest and natural resources
Semi-subsistence[8] farming	- Production of varieties of crops for the market to generate income. - Indiscriminate felling of trees	1979	- Implementation of Land Act which standardized land ownership and tenancy - Irrigation development programs
	- Increased cropping intensity in rice-wheat system - Conversion of dry land into terraced wetland - Competition for water resources	1984	- Community participate in rehabilitation of irrigation canals (Maryuwa and Baryuwa channel in 1984 and Omtekha channel in 1986) - Agriculture research centre in Bajo established
	- Efficient water diversion and conveyance to farms - Introduction of high yielding rice varieties	1987	- Households received technical and material (inputs) support from donor funded projects - Farmers have access to rural credit with low interest to expand agricultural production
	- Cropping intensity and rice yields increase by 30% - Vegetable production expands to all villages	1991	- Empowerment of people to make decisions on their community plans and programs - Implementation of national irrigation policy
Semi-commercial	- Farmers take responsibilities to manage the local irrigation scheme - Plantation of community forestry in barren land	1997-99	- Construction of feeder road to Limbukha - Renovation of Limbukha-Dompola irrigation canal - Abolition of free labour contribution for development activities (*gungdawoola*)
	- Delayed rice planting in Limbukha delays water availability to lower catchment villages - Potato introduced as important cash crop	2003	- All households get electric power supply through the rural electrification program

[7] A subsistence farm is one that produces food mainly to feed the farm family, with very limited surplus for sale or barter.

[8] A semi-subsistence farm is one which produces surplus beyond family's needs, to sell for regular income (McConnell and Dillon, 1997).

	before rice -Chilli and beans cultivated for market -Farmers engage in off-farm employment outside the community		
	-Use of firewood drastically reduced, saving many trees	2005	-All seven villages of the watershed agree and constitute a Watershed management committee to address the management issue of water resources
	-Irrigation canal to Lumpa village restored leading to cultivation of 1.6 Ha. of rice fields -Check dams build in all villages to recharge aquifers and enhance water harvesting -Runoff reduced resulting in stabilization of gullies and degraded land	2007	-Community receive financial support from UNDP to operationalize the watershed management activities
	-Water harvesting tanks constructed in all villages -Rehabilitation of degraded areas done	2008	-Government initiates democratization -While upstream conflicts are resolved, latent conflicts in between down stream communities are re-emerging
	-Dismantling of irrigation canal and weirs due to water sharing conflict led to indiscriminate water overflow and poor conveyance	2009	-7 villages continue to share the water from Limtichu, supplemented with water harvesting tanks and check dams. New solutions have rekindled old conflicts.

Kengkhar: a dryland community

As Kengkhar has been a traditional North-South trade route for people of Lhuentse, Pemagatshel and Samdrupjongkhar[9], the early settlers as per the historical profile were the descendents of Dungkhar Cheoje[10] (*Clan*) from Dungkhar in Lhuentse who gradually opened up forest areas for cultivating maize and millets. People in Kengkhar are proud to report the visit of the First King of Bhutan sometime in 1919 and the subsequent construction of the Dungkar Goenpa Lhakhang (*Temple*) located on the top of the village (Figure 3.11). In 1950, Kengkhar was made a sub-district of Mongar (*Drungkhag*) with a Sub-Divisional Administrator (*Drungpa*) who implemented the policies of the government in the three blocks of Kengkhar, Thangrong and Chaskar. In 1952 when land ceiling and taxation in cash were introduced in the country, the household with land holdings of less than 0.1 Ha., were exempted from land taxation (Table

[9] There are elders in Menbi, Lhuentse district who narrate stories of how they along with people from Pemagatshel, Samdrupjongkhar and Mongar went to Tibet to bring salt in exchange for chilli and products from India. Traders used the Mongar-Deprong-Kengkhar-Denchi-Yangbari-Nanglam route.
[10] Dungkhar Cheoje:The father of the First King of Bhutan Sir Ugyen Wangchuck, Jigme Namgyel belonged to the Dungkhar Cheoje dynasty (Hasrat, 1980, P118).

3.16). It was during this time that people from Trashigang, Trashiyangtse and Lhuentse came and settled in Kengkhar, which the respondents related to people escaping the tax and free labour contribution to the development activities in their original domicile. It was during this time that forest was cleared in several areas and scattered settlements were built. People harvested bamboos to build houses from bamboo mats, and opened up forest areas for cattle grazing. In 1960, two monks[11] started making wooden cask (*palang*) from a locally available tree (locally named *Dongtshushing*): *Boehmeria regulosa*) and wooden mask[12] (*bap*).

Table 3.16. Evolution of socio-economic conditions and related agro-ecological transformations in Kengkhar, Mongar District, East Bhutan.

	Agro-ecological transformation	Year	Socio-economic changes
Subsistence agriculture	-Abundance of primary forest and renewable resources (including water)	Before 1950	-Feudalistic, few households, shifting cultivation, few crops with low yields
	-Few farmers own large land holdings -Large tracks of forest being cleared and burnt for cultivation	1952	-Land ceiling up to 10-12 ha per household -People from Trashigang starts to settle in Kengkhar
	-Clearing forest for cultivation, opening large tracks for cattle grazing -Pressure on water source	1960	-Start of craft cottage industry
	-Wood carving leads to felling of trees	1963	-School was built in Kengkhar
	-Cultivation of crops like maize, millet, nigerseed, chilli, legumes in parcels less than 0.1 Ha. -Cultivation in fallow dryland with maize	1969	-Start of taxation in the form of cash -Nationalization of forest and natural resources
Semi-Subsistence agriculture	-Started production of crops like kidney beans and field beans for the market to generate income -Indiscriminate felling of trees for woodcraft and house building -Land slide near Ebee village damaging spring pond and agriculture land	1979	-Implementation of Land Act which standardized the land ownership and tenancy -Rural water supply scheme implemented under development programs
	-Multiple land use systems to maximize crop production	1980-1984	-UNICEF grant for the supply of drinking water
	-Neglect of catchment area for natural ponds -Landslides expands in Ebee damaging more forest area -Expansion of citrus plantation	1990	-Citrus marketing in Pemagatshel started

[11] Tiku Rinzin from Murung and Tiku Mindu from Shaytongbi started making palang and Lopen Phujay initiated painting in Kengkhar.

[12] While the best mask is made from *Bombax ceiba*, it is commonly made from chirpine (*Pinus roxburghii*) and in that matter any softwood is used for making mask.

Semi-Commercial agriculture	-Cultivation of citrus in dryland and along the farm boundaries, enhance better vegetative cover -Landslide in Mogola – piped drinking water defunct as landslide damage the spring pond and pipes	1998	-Construction of Basic Health Unit in Kengkhar
	-Appreciation of local healing practices, complementing with modern treatments. -Water share with health facility	2000	-Water source protected, introduction of high yielding maize and vegetable variety, more human resource in the geog
	-Protection and rehabilitation of all natural spring ponds in the catchment	2002	-Extension office constructed -Initiated water harvesting using large ponds and plastic drums
	-Access to extension advice and guidance in cropping and renewable resource management -Few check dams/ponds were dug-lined with plastic sheet to collect roof water during rainy season -People contribute labour to construct 17Km long Larjap Water supply: it is unreliable and non-functional	2005	-Small shop started in Kengkhar
	-Neglect of natural spring ponds within the village and catchment area degraded as people fell trees	2007	-Community collectively request to District administration for support to address water supply problem
	-Construction of 6 concrete tanks and connecting them with HDPE[13] pipe as network to transfer water -Catchment protection for all operational spring ponds.	2008-2009	-Peer pressure to Block development committee to mobilize people to develop and manage the new tank network -6 member tank network management group led by a monk is established -Community has access to clean water supply scheme

The wooden mask and cask is the trademark of Kengkhar now and forms a major livelihood source for households. Around same time a local monk, Lopen Phujay started painting of wooden mask and altar (*Choesum*). With the start of woodcraft, people indiscriminately fell trees. In 1963 with the construction of a school in Kengkhar, many children were forced to the school as parents did not readily enroll them for fear of loosing farm labour. Most predominant agro-ecological change was the opening of new farm land and the introduction of new upland crops like finger millet (*Eleusine coracana*), nigerseed[14] (*Guizotia*

[13] High density polyethylene (HDPE) pipe.
[14] *Guizotia abyssinica* is an annual herb grown for its seed to extract edible oil and pickling.

abyssinica), Perilla or Chinese Basil (*Perilla frutescens*), upland rice, mustard by the resettled populations.

3.6.2 1970-1990: Government initiatives to agriculture development and semi-subsistence farming

In the agricultural development of Bhutan this period was the most crucial as enacted of Land Act and nationalization of forest occurred during the 1970s. Further development of irrigation occurred, and rural credit and technical support for agricultural production were also launched during the 1980s to the 90s.

Lingmuteychu: Crop production increase and income generation

The nationalization of forest (Forest Act, 1969) and start of taxation in cash during 1969 induced a major socio-economic change as the (both individual and collective) responsibility to manage forest resources in and around watersheds as the responsibilities to protect, manage, and control access to forest was transferred to the forestry department (Wangchuk, 2005). It was reported that indiscriminative felling of trees and access to forest resource by outsiders[15] was the starting point of forest degradation and intrusion of primary catchment areas. As rice growing area, when irrigation development programs were launched by Department of agriculture (DoA) in 1979, farmers terraced and built bunds in most of the dryland areas under the terracing program supported by DoA and converted dryland slopes into wetland. During the 3rd Five year plan (1971-76), DoA implemented soil conservation program that promoted terracing and bunding. Farmers were provided financial support (Nu. 300 for every acre terraced-bunded. This resulted into expansion of rice cultivation in all six[16] villages except Nabchee where resettled families depended on maize cultivation in dryland fields. Along with rice cultivation, farmers started cultivating pre-rice chilli in down stream villages and radish and turnip in upstream villages. Respondents also reported the introduction of rapeseed-mustard and wheat by DoA as winter crop after rice. With the expansion of paddy fields in the watershed, a major rehabilitation of irrigation schemes (Maryuwa, Baryuwa and Omtekha canals) involving beneficiaries for

[15] Within the provision of Forest Act 1979, people from down-stream communities fell trees of their choice based on the permit issued by the forestry officials. Outsiders here imply people/community previously not included as users of the forest resource.

[16] Limbukha (including Sirina), Dompola, Omtekha, Matalungchu, Omtekha and Thangu are the villages within the watershed.

labour and materials from DoA were done in 1984 which helped in improving the irrigation water conveyance. The rehabilitation of major canals (Figure 3.11) resulted in diverting all the stream water during rice transplanting season virtually drying up the stream. As people diverted most water into their rice fields and in absence of tail end water management, the overflow of irrigation water opened up several gullies leading to land degradation. Even today one can see the Wangdi-Sengana road blocked by red soil flowing down from Omtekha area. With irrigation development, provision of technical and material support from DoA and opening up of local markets, farmers gradually targeted their production to market thus income objective was driving the agriculture production.

Kengkhar: Sedentary semi-subsistence farming

As woodcraft became popular, timber in the locality became the most sought after resource. Some respondents related the excessive felling of trees from catchment areas and on the upper reach, both for construction of houses and woodcraft, as a possible cause for the drying up of natural springs in Kengkhar. The Land Act 1979 was a major incentive for the farmers in remote place like this as it provided the legitimate rights to the plots they were cultivating, and it was during this time people started fencing, protecting and regularly cultivating their fields. Even today it is a common feature to see live fences with Jatropa (Physic nut: *Jatropha curcas*) or other commonly found shrubs. However, as people only had dryland fields, they grew local varieties of maize, chilli and beans. Household maintained 2-3 cattle heads, cows for milk and ox for draught power. In Kengkhar farmers use powerful Mithun bulls to plough field with 3-4 males helping the ploughman (Figure 3.39).

Figure 3.39: Mithun bulls used for ploughing sloping land in Bhutan.

As the number of households permanently residing increased people started to feel the insufficiency of drinking water. In 1980, the government, through the rural water supply scheme, provided materials (pipes and cement) to tap water from Mogola. Under this program, a network of tap-post was constructed. However, 2-3 years later the source was washed away by land slides and the scheme became non-functional. People abandoned the scheme including the tap-post (their remains can be seen in several locations now). The network of pipe water supply scheme in the area made people complacent, and they tend to ignore the natural springs and their catchment conditions. Some respondents reported of complete degradation of catchment above Rotapari spring pond when a land slide washed away the pond in 1983; even now the area has not been stabilized.

3.6.3 1990-2009: Semi-commercial agrarian systems

This period saw major social, political, and economic changes in the country. Among them the decentralization and empowerment of community to make decisions at local level gradually changed the way people managed their farms and resources. While people were made responsible to manage natural resources, government took up infrastructure development like building roads, irrigation schemes, schools and hospitals. With modernization and introduction of television, internet and mobile phones, the need to generate income from farming became a primary objective. Depending on the location, communities started specialized farming targeting the market. Another fundamental development during this period was the democratization of the governance and involvement of local population is decision-making processes.

Lingmuteychu: Semi-commercial farming under resource constrained situation

In 1991 coinciding with the start of Block development committee, DoA launched the National Irrigation Policy (NIP) which transferred the responsibility of managing irrigation schemes to the beneficiaries. Under NIP, water users associations (WUA) were created for each irrigation scheme. In the case of Lingmuteychu watershed, WUA never actually took off due to critical shortage of irrigation water, confusion on administrative jurisdiction[17], and the still prevalent traditional water sharing rules which suited dominant social groups in the uppermost village. Under the NIP some communities, like Omtekha, started community plantations with chirpine saplings to protect degraded areas in the catchment. Local Thangu and Wanjokha communities participated in WUA of Bajo canal[18] which was one of the active WUA in the country and managed the scheme optimally. Although there may not be a formal WUA today, beneficiaries of Bajo canal still function in a coordinated manner. Despite the severe problem of irrigation water, agriculturally the sub-watershed has a high potential for crop production within its diverse agro-climatic zones covering 34 km^2. Farmers with large land holdings (more than 2 hectares per household) during this period, coinciding with the technical support in crop production and marketing, started producing crops for markets, while the small farmers sold their surplus in the local market. Among the cash crops, potato was introduced in the sub-watershed and farmers grew it as a pre-rice crop. The 18 km long feeder road from Samthang (diversion from Wangdi-Shengana road at 6 km from Wangdi town towards Punakha) to Limbukha commissioned in 1997 provided an impetus to commercial production of crops like rice, potato, chilli, beans and dairy products (Gurung, 2004). Further with the electrification of all households in the sub-watershed in 2003, the working time was extended by almost 3 hours in evenings and most

[17] Among the 7 villages in the sub-watershed, Limbukha, Dompola, Nabchee, Omtekha are under Limbu geog of Punakha district; Matalumchu, and Wangjokha under Baap geog of Thimphu district, and Thangu under Thetsho geog of Wangduephodrang district.

[18] Bajo canal brings water from another catchment 9 km east of Wangdi town with its command area in Phangyul, Bajo, Wanjokha and Thangu. As water is hardly ever left in the Limtichu stream during the rice transplanting season, these two lower villages access water from Bajo canal, an arrangement in existence since a long time (no one could give us a rough idea on when and how it started).

importantly it drastically reduced the consumption of firewood as people switched to electrical home appliances. During the same period, to take advantage of the market demand, farmers formed self-help groups and growers association to produce mushroom and market the produce collectively. As the conflict in water sharing was escalating, seven communities came together to institute a watershed management committee (See Chapter 8) which took the initiative for community mobilization for collective actions to address the watershed management issues (Gurung, et al. 2006). Some of its noteworthy activities are the rehabilitation of a canal in Lumpa which had been defunct for more than 10 years, while the construction of check dams and water collection tanks in all villages have revitalized the community for collective responsibility. The watershed also received financial support from UNDP in 2007 to implement collective activities. In 2008, when the government launched the democratic process and delimitation of constituency, Matalungchu was included under Wangduephodrang district while Omtekha was clubbed into Limbu geog of Punakha district. While this union helped in consolidating the voters for the democratic process, the latent water sharing conflict between the two villages reached the highest point with farmers dismantling the water distribution weirs and chasing out the researchers who were assigned by the district administrators to help resolve the issue (Kuensel, 2009).

Kengkhar: Woodcraft and citrus as major income sources

The south facing slope of Kengkhar is best suited for cultivating mandarin orange. The traders market oranges from Kengkhar in Pemagatshel. With the production potential and marketability of orange, DoA distributed free orange seedlings to the farmers. During 1990 almost all households took 5-10 seedlings to plant in their homestead. With the promotion of citrus, woodcraft and citrus became the principal livelihood sources for the *kengkharpas* (people of Kengkhar). Even today, the lack of a motorable road has not deterred the people to painstakingly take orange in horseback to Pemagatshel and Mongar where they fetch substantial income. A major blow to the drinking water came in 1998 when the Mogola land slide completely washed the water source and pipes. With the land slide in Mogola and Rotpari, people had to go back to the natural spring ponds which were only used for livestock. With declining spring discharges, the water became a scarce resource as local farmers, government establishments and students had to depend on the same source. In 2002, agriculture research initiated rain water harvesting, wherein people constructed large tanks lined with plastic sheets to harvest rain water and people were trained on roof water harvesting in plastic jars. As a key development need for the community, Mongar district helped community to tap water from Larjap which is 17 km away. Due to its length and the course it follows along the ridge, the scheme was irregular with frequent breakdown putting pressure on people for maintenance. This massive investment did not ease the water problem and once again people had to go back to their old spring ponds. The democratic process initiated in 2008 provided an opportunity to people to collectively seek support from research and development agencies to resolve the issue. In 2009 the research centre in Wengkhar (near Mongar district town) helped the community to build concrete tanks to collect spring water and share it among the tanks by linking them in a network. This effort has also helped people to collectively restore the catchment areas for respective spring ponds and manage it sustainably. With the dwindling water resource, people of Kengkhar had raised their practice of upland cropping and citrus have become a definite saviour for them which generates substantial household income.

3.6.4 Characterization of water resource management systems in two sites

These successions of three agrarian systems provide a scope to characterize the water resource management systems and their evolution in these two sites.

Lingmuteychu: Irrigation system as a lifeline

As in most irrigated systems, prior to the nationalization of forest and institutionalization of a national irrigation policy, people operated open earthen gravity-fed canals to divert stream water to their fields within a logic of ‘first-come-first-serve” (Jamtsho, 2002) meaning the early settlers had greater access and rights to water. The traditional water sharing system framed when water was plenty and users few appeared sound (Brand and Jamtsho, 2002). Based on field survey, until 1970 there were only around 75 households in Lingmuteychu cultivating roughly 100 ha of irrigated rice which rapidly increased to 166 households looking after 179 ha of wetland terraces in 1996 (RNRRC, 1997), and 206 household cultivating 242 ha of rice in 2008 (Table 3.17).

Table 3.17. Evolution of irrigation systems in Lingmuteychu, 1950-2009.

Variable Components	1950-1979	1979-1996	1996-2009
Resource user size (Households)	75	166	206
Command area - Ha (Ha/HH)	100 (5-10)	179 (1-5)	242 (0.5-1)
Conveyance systems	Earthen canals, in some points wooden troughs and bamboo splits	3 major irrigations canals (10 km): concrete canals with metal flumes, some earthen canals	All canals with cement and metal flumes, except Omtekha canal which is earthen
Construction and maintenance	Farmers constructed canals collectively, maintenance by tenants	Government financed construction of irrigation canals, major maintenance by government and seasonal/regular maintenance by users	
Accessing rules	"first-come-first serve" early settlers get priority, more access to those who invested in canal construction, upper catchment villages has full rights to divert water, Matalungchu village have access to water that seeps from Omtekha canal, Wangjokha and Thangu use water from another sub-watershed		
Institutions related to irrigation systems	Water guard (*chusup*), assigned annually on rotational basis, monitored irrigation canal and water distribution.	Water user association for each canal was established with government initiative. (but it did not last long)	Water guards per village (or canal), block development committee; in 2005 a Watershed Management Committee (WMC) was put in place
User categories	4 categories (*Thruelpa, cheep, chatro*, and *lhangchu*)[19] in Limbukha and Dompola; in downstream villages thecategories are based on investment in canal construction and early/late settlers		
Conflicts	Except for water stealing at plot level no major issue	Multiple users lead to regulated system delay by one user had multiplier effects to subsequent users, water holding and non-release on time. Reduced stream discharge and complete diversion by upper-catchment villages effects lower villages	
Conflict resolution systems	Village headman and elders	Water user association (did not function well in the upper sub-watershed), Block development committee, District court and High courts relying on customary laws	

[19] They are four water sharing categories is Lingmuteychu :*thruelpa* is entitled to half the flow in the canal (½ of canal flow); *cheep* is entitled to half of *thruelpa* (¼ of canal flow); *chatro* is entitled to half of cheep (1/8 of canal flow), and *lhangchu* has no entitlement and has to beg for water from other categories.

State interventions	Irrigation development program and nationalization of forest and natural resources (including water)	Construction of Maryuwa and Baryuwa channels in 1984 and Omtekha channel in 1986, initiation of water user association	Concrete lining of all canals and installation of concrete weirs for water distribution from source and water gates at intake point for secondary canals
Constraints related to water	High conveyance loss and land degradation due to poor tail end water management	Water stealing and inequitable water allocation	Upstream-downstream conflict in water sharing, poor coordination and in-efficient water use systems

This boom in rice cultivation is associated with the support provided by the government in the form irrigation development, farm mechanization, technological support, and road construction. With the expansion of the rice area and number of users, the demand and conflict on irrigation water intensified to a point that communities had to spend long hours of water guarding as physical damages of irrigation structures occurred. Some respondents associate the rivalry for water to the social structure that prevailed in the past (Gurung, 2004), and the nationalization of irrigation systems disregarding the traditional arrangements which were crafted to suit the local context. For instance until the 70s, irrigation systems were managed locally by community assigned water guards who were rotated annually among all households. While village to village water sharing was managed by groups of village elders, disagreements were resolved amicably within the sub-watershed. However, with the introduction of the NIP, farmers felt detached from the responsibility of managing the systems and waited for the government assistance to rehabilitate the scheme, as in the case of the Lumpa irrigation canal during the last decade[20] (Gurung *et. al.*, 2006.).

Kengkhar: Drinking water system

The crisis of drinking water in Kengkhar became apparent when several natural springs dried up due to land slides and poor maintenance of the catchment. As the population increased from around 72 inhabitants in 1950s to 310 inhabitants in 2009 the settlement area expanded to a point where the catchments of some natural springs also came into cultivation, while in some cases trees were fell for house construction leading to degradation of forest and subsequent land

[20] Lumpa is a small hamlet under Omtekha village with approximately 2.8 Ha. of paddy fields. The 4 km irrigation canal became non-functional after the discharge at source reduced to bare minimum and the canal started to crack in several points, the paddy fields had been left fallow for last 10 years.

slides. Considering the small size of the user group there is no social strata in terms of accessing water and all have equal rights to access water from any tank (Table 3.18).

Table 3.18. Evolution of drinking water system in Kengkhar.

Variable Components	1950-1970	1970-2000	2000-2009
Resource user size	12 farming HH, 3 officials HH, 100 school children	30 farming HH, 9 officials HH, 175 school children	52 farming HH, 20 officials HH, 350 school children
Resource supply system	20 springs with open ditch or wooden trough next to natural spring pond	10 natural springs, Piped water supply (dysfunctional after 3 years), check dams and open tanks to collect rain water	5 natural springs, 17 Km piped water (unreliable, frequent breakage and costly to maintain), concrete tanks and network after 2009
Command population	184 persons + 60 livestock	391 persons + 150 livestock	742 persons + 260 livestock
Conveyance systems	Fetch from the spring pond and livestock drink directly from the pond	Fetch from the pond. In Kriapo used pipe to take water from private pond, rural water supply scheme	Collect spring water in concrete tank and use tap, tanks are connected to share water from upper to lower tanks
Construction and maintenance	Open access, dug a pond to trap spring water, in some places wooden trough used to collect water	Government financed construction of water supply scheme, major maintenance by users	Government project financed construction of water tank and its network, managed by a 6 member user group
Accessing rules	Open access and rely on the"first-come-first serve" rule		
Institutions related to water supply systems	None		Management group with support from RNR office and geog administration
Constraints related to water	Difficult to fetch water, long hours of wait and walk	Spring ponds drying and water brought in pipe from distance places become non-functional and costly to maintain	

However, a general norm which people follow is first to visit the tank closest to the respective hamlet and go to the next in case the first one is dry. While customarily everyone is supposed to directly access from the spring pond there is one household in Kriapo who owns a private tank next to his house connected to a spring pond some 500m away. The lack of durability of different interventions in the past was attributed to the non-involvement of beneficiaries in finding solution and assignment of management responsibilities. In the most recent case of the 17 Km water supply scheme originating from another block, beneficiaries are faced with the problem of the long length of pipe to maintain through difficult terrain. In the process of bringing water from distant locations outside the community in the past, people neglected the natural spring ponds and their catchments within the community.

3.6.5 Extent of socio-economic differentiation among households

The transformation of these two agrarian systems from a feudalistic period in the 1950s to self-managed semi-commercial farming after the 1990s has led to the emergence of distinct categories of farmers characterized by discrete socio-economic features.

Lingmuteychu: productive assets and income differentiation

Socio-economically the present farming households can be classified into four distinct types which have influence on the way the water resource is used and managed. Based on common criteria, 50 households (survey sample) can be categorized into four main types as follows:

Type A: This group represents the resource poor farmers who own 0.5 ha of land of which wetland area vary from 0 to 0.3 ha (Figure 3.40). They have 1 to 3 farm labour to work and a meagre herd of 2 heads of cattle to operate their small farm. There is one household in the group who does not possess both land and cattle, this household is dependent on Type A and B. The livelihood sources of these households depend predominantly on crops (62%) and off-farm employment (19%). Remittances from in-laws working outside the district account for 13% of their total income. Sale of dairy products, ferns and mushroom harvested from the wild provide roughly 3% of the overall income. Households grow seven different types of crops, using local varieties and traditional methods which lead to lower physical productivity. In general they devote 51% of the arable area for irrigated rice cultivation and 26% for maize. Other crops are raised as preceding or succeeding crop to rice or maize. 25% of the farmers in this group lease in on an average 1.7 ha of rice field on a share cropping basis. The one landless member in this group always leased in 1.2 ha of wetland from a Type D farmer. 16% of the HH belong to this type.

Type B: With 44% of the farmers in this group, it is a common category in the sub-watershed with small farms and multiple owners depending on the water resource. This group also owns less than 1 ha of total arable land and irrigated rice fields. On average they rear 3 cattle for milk and draught power. Growing eight types of crops, and selling them in local market generates 70% of the average annual household income of US$ 560. As Type A, they also engage in seasonal off-farm employment in nearby construction sites and earn around 15% of the annual income for this source. There is one household who weave to earn extra income for the family. Smaller income is also generated by sale of dairy products and NTFP. More than 45% of farmers from this group lease in wetland from Type C and D and share crop 1.1 ha of rice on average. As most land owners prefer it, the sharecroppers grow quality rice, and they sell their share fetching substantial income.

Type C: They represent economically stable group with larger land holding ranging from 1.2 to 1.9 ha. This group has maximum farm labour of 3 to 7 heads who work in their farms. 85% of the household income comes from the sale of crops like rice, wheat, maize, potato and mustard. With larger parcel size, adequate cattle herd (average of 5 heads per household), and working hand they try to maximize their agricultural production. According to the respondents of this group, among all groups their productivity levels are generally higher compared to others as they have animals to produce farmyard manure and the workforce to take care of the crops. They also generate household income from off-farm employment (6%), remittance (4%), sale of wild ferns and mushroom (3%), and dairy products that contributes 2% of their total annual income averaging US$ 585. Even in this Type C, there are 20% of the farmers involved in share cropping. Type C comprise of 24% HH in the sub-watershed.

Type D: With 16% of the farmers in the group, they represent the most affluent group of the locality. They are traditional elite families who have large land holdings (3 to 6 ha of wetland) and herds of cattle (7 to 12 heads of cattle) which are traditionally associated to the wealth of the household. With higher proportion of wetland, they grow rice in almost 70% of their arable land and the remaining is devoted to other crops. Their average annual income is US$ 815 which is predominantly generated by selling rice (80%). As they cultivate only 0.7 to 3.8 ha of wetland per household, the remaining wetland is leased out to sharecroppers. It was reported that most of the grain received from sharecroppers are either directly sold as rough rice from the field or milled and marketed in Thimphu, Punakha or Wangdue markets.

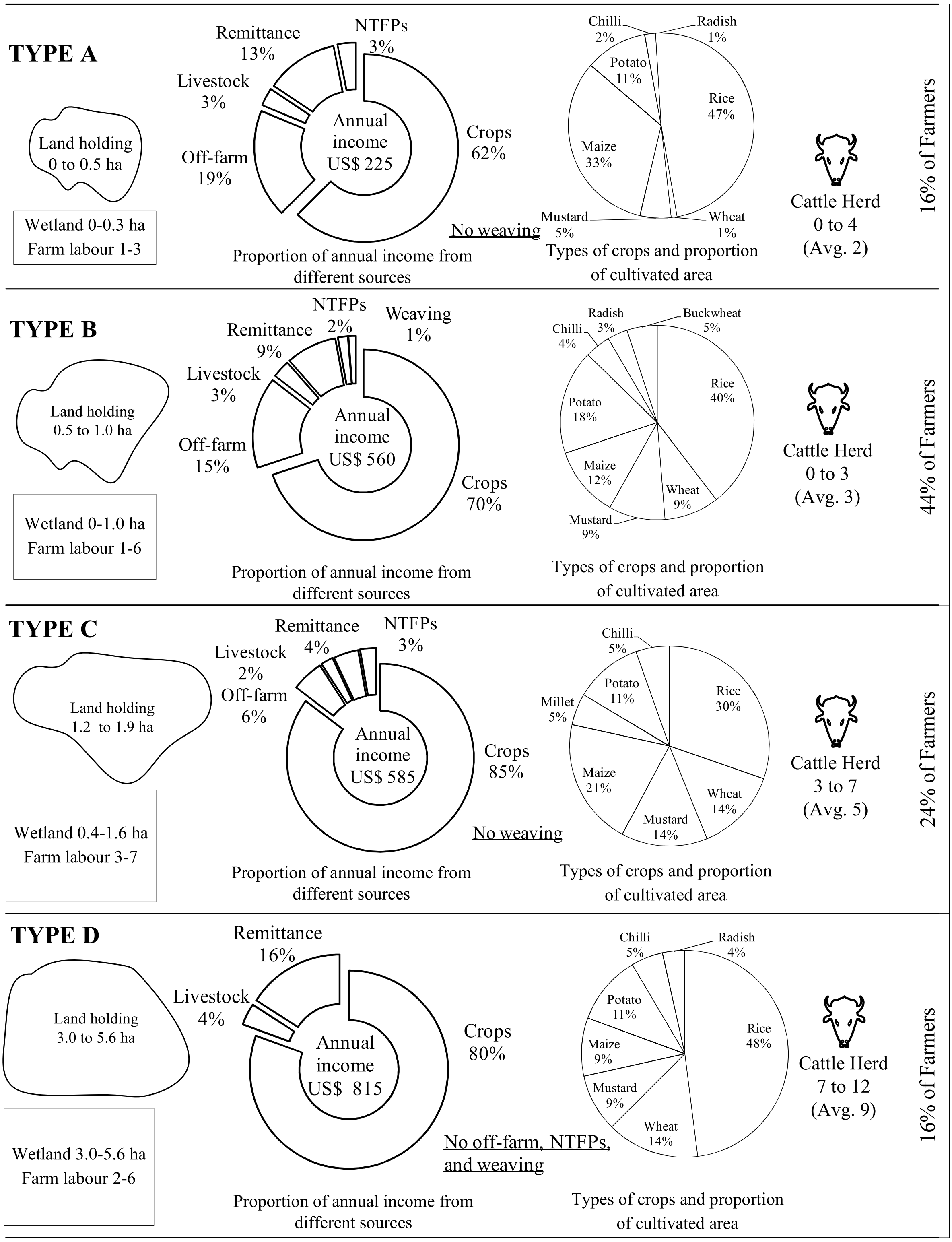


Figure 3.40. Present farmer typology in Lingmuteychu, 2009.

Kengkhar

Based on the semi-structured questionnaire survey of 55 villagers and household visits, the present households can be categorized into three main socio-economic types as follows:

Type A: Majority of farmers (45%) fall within this group (Figure 3.41). They represent the resource poor group who farm less than 1 ha of land. With maximum family size of 2 to 7 they earn 42% of their annual income by transporting goods from Kengkhar to Gyelposhing, a distance of 12 hours of brisk walk. Carrying a load of 20 kg they earn US$ 3 for one-way, which is equivalent to one day wage. Second most important source of income is woodcraft contributing 40% of their average annual income of US$ 383 (minimum of US$36 and maximum of US$ 1357). Many of them do carpentry and make altar and cabinets. Some sell vegetable and citrus generating 10% of the income. While all farmers own and operate dryland fields, only 39% of them have planted citrus orchards.

Type B: Type B farmers are more skilful in making wooden mask and cask, which are sold at US$ 34 a pair, and earns 43% of the annual income of US$ 433 on average (minimum of US$22 and maximum of US$ 2776 They also have small land holding (0.1 to 1.2 ha), but all cultivate dryland and 62% of them own citrus orchards. As in the case of Type A farmers, the sale of crops contribute only 10% of their annual income. As they own mules and 2-5 family members residing in home, portering form a second important income source generating 26% of total income. 32% of the local HH fall into this type.

Type C: They are the prosperous group owning 2 to 4.5 ha land of which 60% is dryland, 26% *tseri* and 10% planted to citrus orchard. Only 23% of the local farmers fall into this group, whose principal sources of income are crops (oranges for 53%) and remittances (38%). As they own mules, while they transport their goods to market, they also transport goods on payment. Portering earns them 9% of their average annual income of US$ 506 (minimum of US$265 and maximum of US$ 745). As in Type A and B, all farmers in this group own and operate dryland and 89% of them also have citrus orchards.

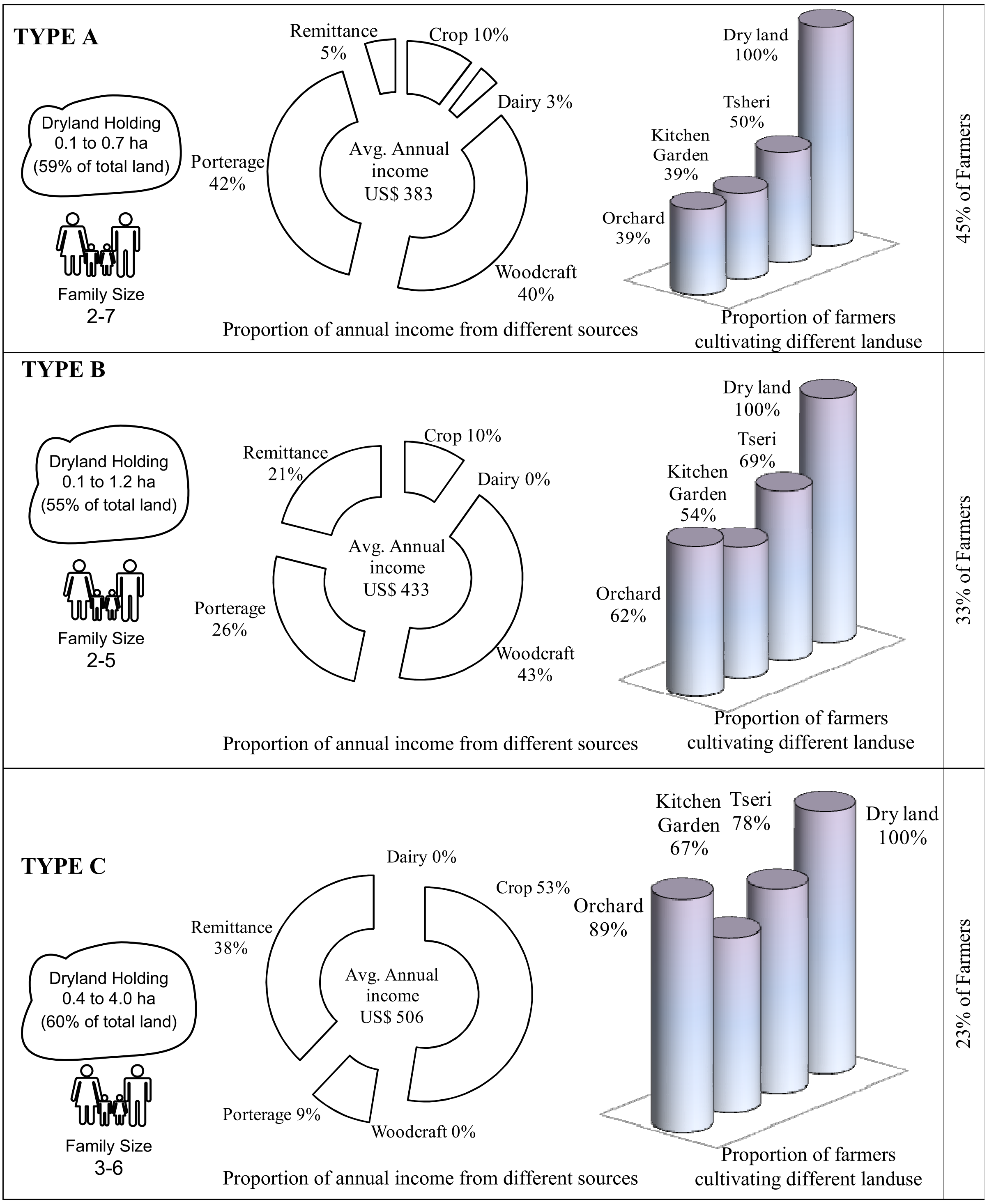


Figure 3.41. Present farmer typology in Kengkhar. 2009.

3.6.6 Sequences of agrarian systems in both sites

The pace at which the transformations of the agrarian systems occurred over the last 6 decades in these two sites varies considerably. Prior to the 1950s, in the midst of primary forest, people practiced shifting cultivation and reared large herds of cattle. After government initiated official enumeration of population and registered the land they tilled, people gradually started sedentary farming using local varieties and traditional practices. The progression from subsistence farming to semi-commercial farming has primarily happens to satisfy the social needs (Trébuil, 1989) influenced by the changing social, ecological, economic and political environment.

Lingmuteychu: three successive agrarian systems leading to increased farmer differentiation

A small sub-watershed with sparse population was endowed with abundant natural resources and fertile land. Elders, like Ap Sigey, narrates of the time not very far into the past, when there was no tension on use of water or accessing forest resources. With the increase in population and commercialization, there is competition in accessing resource, producing best quality, and securing the maximum price and income. People narrate that the shift from use of traditional method of crop production and animal rearing systems to modern methods happened so rapidly that some farmers are trapped in the absence of old systems and cannot afford modern farming methods.

Although a majority of the farmers operated subsistence farms, they were self-sufficient in food. With basic food produced within their farms dependence to external sources was rare. As the market opened in nearby towns and need for cash to pay tax, buy clothes and household items, the subsistence farming evolved into semi-subsistence during the 1970 (Table 3.19). With the objective to produce more (surplus), people started looking for production techniques which could enhance their productions. The support from government in terms of free seed, chemicals and advisory services gave thrust for the change from subsistence to semi-subsistence. To maintain the income people increased the cropping intensity, which lowered the productivity level of the farm. With decreasing livestock population and reduced farm yard manure, people depended on chemical fertilizers to improve soil fertility. In the 1990s, with the farm road constructed in the area and access to subsidized farm tools and machineries, the drudgery of farming was greatly reduced. However, as the dependence on external inputs and services intensified the need for cash to pay went up. Therefore to generate higher income, there was a gradual move to semi-commercialized agriculture. Farmers introduced crops like potato and vegetables which could be sold readily and fetched high prices. They even started to grow low yielding local rice (red pericarp and white japonica type with mild aroma) specifically for niche markets. While the local red rice cost around US$ 1/Kg imported common rice cost only US$ 0.6/Kg. As they fetch high price, there are instances when farmer sell all the traditional rice and buy cheaper imported rice for their daily consumption, this is a strategy adopted to supplement the income gap.

Table 3.19 Sequence of agrarian systems in Lingmuteychu sub-watershed, West-central Bhutan.

AS Variable Components	**1970**		**1990**
	Subsistence	**Semi-subsistence**	**Semi-commercial**
Ecological events	Extensive prime forest with tracks of wetland in flat areas and dryland in gentle slopes	Expansion of cultivation areas into forest, conversion of dryland into wetland, diversion of stream	Patchy forest area, reduced stream discharge, degraded areas, and barren land
Means of production	Local varieties, manual tools, draught animals, earthen canal/wooden trough, farmyard manure, traditional methods	Local and few modern varieties, farmyard manure supplemented with chemical fertilizer, manual tools, draught animals, concrete canals	Improved varieties with few local varieties, farmyard manure with chemical fertilizer, chemicals, hand tractors, improved hand tools, few draught animal
Techniques applied	Integrated crop-livestock-forest systems, slash and burn in dryland fields, irrigated rice-fallow systems	Use of modern varieties and recommended production practices, rice-wheat /vegetable cropping system, fertilizer and pesticides used	Mechanization of farm (Power tillers for ploughing and transportation, electric operated rice mills), semi-wet bed nursery and poly-tunnel nursery for rice.
Production	1 rice crop a year in irrigated field and 1 crop of maize in upland fields and chilli, dependence on wild vegetables, roots and fruits	Wheat, oats, mustard, vegetables as new crop following rice and maize	Potato and vegetable crops like cabbage, beans, lettuce following rice in irrigated field and after maize in upland fields.
Demographic pressure	13 inhabitants/Sq km (75 HH estimate by village elders)	29 inhabitants/Sq km (166 HH in 1996)	36 inhabitants/Sq km (206 HH in 2009)
Marketing conditions	Bartering, family exchange	Use of mules to carry rice, wild vegetables and fruits to local markets in Wangdue and Punakha towns	With motorable roads buyers come to the village, rice and vegetable taken as far as Thimphu and Phuntsholing, even participate in auction of vegetables in Phuntsholing
Farm supplies	Forest litter and compost	Inputs supplied by District	Inputs (fertilizers, seed) sold

(inputs, equipment)	carried manually/mules, farm tools locally made by village craftsman	agriculture extension	by agriculture commission agents, pesticides by extension staff, tools and machinery by agriculture machinery centre
Rural credit patterns	No monetary credit system, exchange of input with labour	Individual rural credit system supported by BDFC (Bhutan Development Finance Corporation), available at district	Agricultural credits available from different financial institutions/banks, easy access for group lending
Land tenure patterns	Large land holding by elite families operated by serfs or tenants on fixed rents	Most own land but there is disparity, higher proportion of wetland to dryland, sharecropping (50:50, or 75:25)	Share cropping by those having farm labour; mechanization (power tiller) helped in reducing labour requirement
Labour market	Family labour of the tenants, community labour during peak season (group operation in turns)	Hired labour used for transplanting and harvesting rice	Hired machinery and labour
State interventions	Eradication of serfdom, introduction of land ceiling, land grants to those landless and resettlement	Training, supply of new crop varieties, fertilizers and pesticides, marketing support, subsidy	Subsidy, marketing support, credit and institutionalization of collective/cooperative farming, link with tourism
Farmer income, productivity	Non-monetized production, self sufficiency	Rice production predominantly subsistence, vegetable for market, some surplus rice being sold in local towns.	Red rice and potato as principal income sources fetch (US$ 1/kg of rice and US$ 0.5/kg of potato), off-farm employment lucrative
Extent of farm differentiation	Very low	High	High

Kengkhar: Gradual agrarian system change

In contrast to swift change over in Lingmuteychu, the transformations in Kengkhar were gradual (Table 3.20). In the early 1950s when the national level registration of citizens was done, elders narrate the presence of scattered households in most gentle slopes close to the natural spring ponds. In the middle of thick mixed-broadleaved forest there used to be 10-12 open space where people built houses and did farming. The practice of slashing and burning large tracks of forest during January to April was common. Now in his 70s, an elder respondent expressed with excitement the blazing fire line spread he watched at night. As the productivity of shifting cultivation was low, farmers looked for fertile patches in the forest, cleared and did farming there. Moving around with large herds of cattle, everyone produce enough to sustain their livelihood. With nationalization of forest and land reform policy, the operational space for the community drastically reduced, and they gradually started cultivating their designated plots with low yielding traditional crop varieties. As the productivity of land was low and access to modern technology limited, people expanded the woodcraft trade and currently around 80% of households depend on woodcraft for their livelihood. With the small boom of the woodcraft industry linked to the expanding tourism industry at the national level, the major effect has been over harvesting of trees from the nearby forest. Opening the forest area in such terrain has accelerated drying of spring ponds and in some fragile areas land slides washed away spring ponds. As upland crops like maize and millets yields were low, with the support of the Department of Agriculture they introduced mandarin orange during the early 80s, which has now become the principal cash crop in Kengkhar. Currently 83% of households grow orange in areas ranging from 0.1 to 0.8 ha per household. Although there is no road connection to Kengkhar, yet people tirelessly bring their orange on mules to Mongar and Pemagatshel markets. Apart for economic benefit from orange, extension officials in the area say that orange plants have helped in increasing the tree cover. With the two principal sources of income, people now operate a semi-subsistence farm all striving to produce surplus for market. In the early 2000s, when the government decided to develop a major North-South national highway between Gyelposhing and Nanglam[21] (GNHC, 2008a) which passes along the Kurichu river at the lowest reach of Kengkhar, the community submitted a petition to the District requesting a farm road. Subsequently the area development project[22] agreed to support its construction in the 9th plan (2002-2007). As the construction of the national highway got delayed by 2-3 years, the construction of the farm road could only start in 2009. The success of citrus production and the established market for woodcraft are boosted with the approval of road. In fact since 2000, orange plantation on a small scale was taken up by all households. There is one progressive farmer, who has devoted most of his area into a commercial nursery for citrus and *Boehmeria regulosa* (tree species for making top quality *palang*-cask). As farmers operate semi-commercial farming systems, there is going to be two major differentiation features between those dependent of woodcraft (Type A and B) and those specializing in citrus production (Type C) who currently earn 53% of their annual income from mandarin oranges.

[21] Nanglam is a Sub-district of Pemagatshel district and is an important town connecting to Assam in India.

[22] An area development project under the MoAF – Agriculture Marketing and Enterprise Promotion Program (AMEPP) sponsored by the International Fund for Agriculture Development (IFAD) support most agriculture development activities in the Eastern region (6 districts in the East).

Table 3.20 Sequence of agrarian systems in Kengkhar, East Bhutan.

AS Variable components	**1970**		**2000**
	Subsistence	**Semi-subsistence**	**Semi-commercial**
Ecological events	Predominantly mixed-broadleaf forest with patches of grazing land and shifting cultivation plots	Conversion of forest areas into dryland fields. Shifting cultivation continue to exist. Many natural springs dry up	Land slides in 3 sites, forest density drastically reduced
Means of production	Local varieties, manual tools, traditional methods, burning of forest debris	Local and few improved varieties, farmyard manure, manual tools, draught animals	Mostly local with few improved varieties of citrus, maize and vegetables, farmyard manure, tools, draught animal
Techniques applied	Slash and burn in dryland fields, long fallows	Slash and burn with short fallow, mono-cropping of maize, fruit plantations	Double cropping of maize, citrus orchards and vegetable in dryland
Production	1 crop of maize (low yield) and millets (fox tail, and finger millets), supplemented with wild tubers and vegetables	Maize, citrus, millets and vegetables	Maize, potato, citrus, beans, chilli, mustard and radish
Demographic pressure	24 inhabitants/Sq km (12 HH estimate by village elders)	60 inhabitants/Sq km (30 HH in 1996)	104 inhabitants/Sq km (52 HH in 2009)
Marketing conditions	Bartering, family exchange, sell small amount of vegetable and fruits in the village		Use of mules to transport oranges, vegetables and wood crafts to Mongar and Pemagatshel
Farm supplies (inputs, equipment)	Forest litter and compost carried manually/mules, farm tools locally made by village craftsman	Inputs supplied by District agriculture extension	Farm yard manure, improved seed supplied by extension staff, tools purchased from Samdrupjongkhar or Mongar
Rural credit patterns	No monetary credit system, exchange of input with labour		Agricultural credit available from BDFC
Land tenure patterns	Shifting cultivation plots self managed, user rights for grazing land	Large land holding by early settlers while small holding of resource poor farmers	
Labour market	Family labour, collective work in slashing and burning	Family labour still dominates; rarely wage labour from within community	
State interventions	Introduction of land ceiling, land grants to those landless and resettlement	Technical advice and material support from Agriculture Extension. Extension office in block. Drinking water supply	Subsidy, marketing support, credit and institutionalization of collective, construction of water supply and tanks
Farmer income, productivity	Non-monetized production, self sufficiency	Maize production predominantly subsistence, surplus commodities usually exchanged or bartered	Maize production predominantly subsistence, citrus, potato and vegetable for market
Extent of farm differentiation	Homogenous	Medium	Medium

Comparison of agrarian system changes in two sites

In Lingmuteychu change from fully subsistence to semi-subsistence system was much more rapid than in the case of Kengkhar, where it took more than 15 years for all farmers to make the change. State interventions and access to supports helped the speedy change in Lingmuteychu while the remoteness constrained the shift in Kengkhar (Figure 3.42). As the decentralization was launched, a motorable road was built and electricity and telephone connections came to Lingmuteychu while the commercialization of crop production started. In fact the road was the principal driver for the change. While the market demand for wooden mask, cask, altar, and late season citrus from Kengkhar is high, the lack of road and reduction of porters are deterrent to shift over a semi-commercial system. Although gradual the trend is picking fast, as government has approved a 5 Km farm road from Jimjurung to Tongla from where it is gentler and takes only 3 hours on foot to reach Kengkhar.

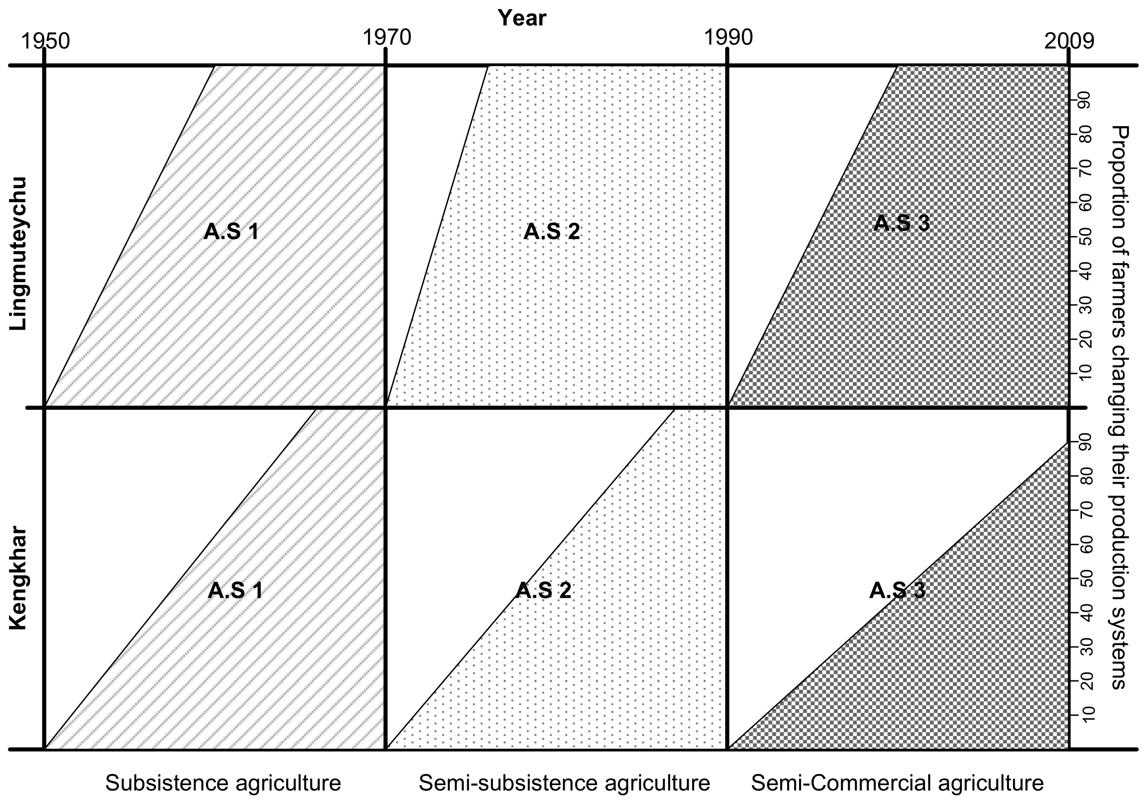


Figure 3.42. Comparison of chronological change over of agrarian systems in the two sites.

As stated in an earlier section, change-over is also influenced by accessibility to information and external inputs/services. For instance farmers in Lingmuteychu benefit from prompt support services and are more equipped to swiftly react to the market forces. Being next to the satellite town of Wangduephodrang and the capital, people are more aware of the policies within which they manoeuvre to maximize their objectives. In other words they have higher bargaining power. In contrast, people in Kengkhar are deprived of the opportunity of access to services and information. When farmers are not confident on the outcome of development efforts, they continue to maintain old practices. Some glaring examples are (i) 63% of the farmers still practice shifting cultivation despite the ban introduced in the 1980s and exclusion of this land use type in the record from 2007, and (ii) the presence of wooden trough next to the natural spring pond. The sequence was also different in the two sites, mainly because livelihood sources vary between them, rice in Lingmuteychu and woodcraft in Kengkhar.

3.6.7 Importance of the water resource issue and corresponding relevance of different types of stakeholders

Consultation with different stakeholders to outline their relative importance and influence to the problem of water (Figure 3.43) helped in eliciting the position and role each stakeholder could take. The stakeholder with the highest stake are the Type C and D farmers in Lingmuteychu and all farmers in Kengkhar, as the resolution of the problem lies on how they organize and manage the resource. In the case of Lingmuteychu, Type A and B farmers have small wetland holdings and do sharecropping, although the issue is highly important, they have low influence to address the issue. Similarly, downstream farmers are most affected by the conflict however they have low influence as they represent late settlers in the sub-watershed. In both sites, research and development agencies that have been playing a mediator role too have very minimum influence, rather they are considered as source of support for development activities.

While the government institutions do not appear as stakeholder in Lingmuteychu, all such establishments in Kengkhar have substantial influence on the issue. For instance the health unit through their hygiene and sanitation program can enhance the awareness on how clean water enhances hygiene and sanitation. Similarly, RNR extension collectively can mobilize farmers in scientifically managing catchment areas and enhance aquifer recharge. The travellers, for whom the issue in not important, have a tremendous influence on it as respondents often blame travellers for dirtying or damaging the natural springs. In fact after the construction of tank and network, breakeage of several taps were blamed to the travellers. The newly formed watershed management committee in Lingmuteychu, is expected to have high influence on the issue. With the mandate of water resource, the National Environment Commission through enactment of Act and Policy has significant influence on how such issues on water are resolved.

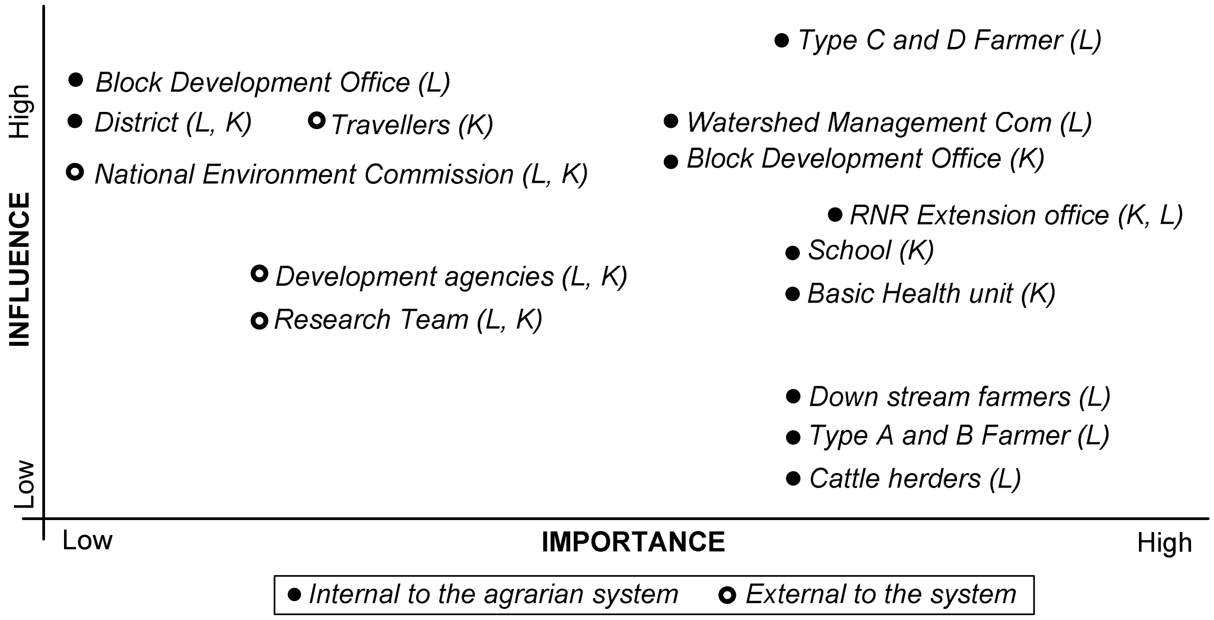


Figure 3.43. Importance of resource issues and corresponding relevance of different stakeholders.

While the resources at stake in two sites are the same, the purposes are different. While water is a direct input to the household in Kengkhar, it is used as a mean to produce irrigated rice on terraces in Lingmuteychu, providing two critical perspectives of water as a multifunctional resource. The differentiation among resource users in Lingmuteychu are discrete and traditionally ingrained in the society, which acts as a barrier for negotiation. Further the single source of resource poses yet another issue of jurisdiction. To add to the complexity, there is a traditional rule that favours few “powerful” households which the favoured group always tussle to uphold. In contrast with no clear differentiation among farmers in Kengkhar which directly influence the resource in question, it is a case of collective problem. As water needs for Kengkhar farmers is basic, the issue impinges directly to their livelihood. Looking for solutions outside and in different watershed has lured away the focus from managing the vital resource base (natural spring and aquifer) within the community. Even after investing a huge budget to bring water from distant places, in the absence of beneficiary responsibility to manage the supply scheme and catchment, it has become a temporary and short lived achievement.

The analysis and lessons of past agricultural transformations in these two sites provide a prospect for application of a broad-based and all-inclusive research approach. Broad based as it should encompass all issues arising from the renewable resource in question and inclusive to include all stakeholders within the context. To further enhance the understanding of water resource and its management issues a broader SES in integrated water resource management is considered beyond agrarian systems centred on agriculture. A detailed analysis of water resources status and prospects is presented in the following chapter.

CHAPTER 4

BHUTAN: WATER AS VITAL RESOURCE – CHANGING DYNAMICS

Water for a Buddhist is more an element of life than a mere infinite renewable resource. Buddhists believe that the nature is composed of four elements (*jung-wa-zhi*) which are revered: soil (*sa*), water (*chu*), fire (*mey*) and air (*luung*) (RSPN, 2006). As a revered abundant renewable resource, water has not only helped the nation to sustain its cultural heritage but also helped in earning much needed capital for nation building, a true lifeline for Bhutan. Thus water has an explicit significance to ecological, social, cultural, economic and political spheres of Bhutan. The detailed accounts on the cultural perspective of water are given by Zürcher and Choden (2004) in their book *Bhutan-Land of spirituality and modernization: Role of water in daily life*.

4.1 Multi-functionality of water

Socio-cultural function

Water forms an integral part in the belief systems and rituals of both Vajrayana Buddhism and Hinduism in Bhutan. As a natural resource accessible to all including the poorest of the poor, water is especially important as a symbol of offering in household altars and temples. In a Bhutanese household the day starts with water offering in the altar and ends with emptying the water bowls. Water offerings in seven bowls represents water for washing face '*argam*', water for washing feet '*pangden*', flower '*peupey*', incense '*dugpoe*', light '*alokey*', perfume '*gyendhen*', and food '*niuti*' (RSPN, 2006). Culturally water is considered as a medicine and is associated with cleansing and purification (Zurcher and Choden, 2004). The age old tradition of sprinkling water with the peacock feather in all religious proceedings in both Buddhism and Hinduism to signify consecration is still practised. In today's globalized technology driven world affairs, Bhutanese still associate water with divinities, spirit, and demons (ibid.). For instance, the myth of serpent (*lu*) in lakes and water bodies as a Buddhist belief and the Hindu belief of water sources and springs as site of deities (*devithan)* are innately woven in the social systems. One of the common uses of free flowing water is to turn the prayer wheels (Figure 4.1) which are a common sight in rural areas. The sight of brightly painted water driven prayer wheels often with a sound of brass bell that hits every rotation the wheel makes, add sanctity to the environment. The reverence of water has indirectly helped in building a society and nation that is conscious and invests in the conservation of renewable resources.

Figure 4.1. Prayer wheel driven by free flowing water – a common sight in rural Bhutan.

The country is also known for its hot springs (*tshachhus*), hot stone baths (*menchhus*) and clean spring water (*drupchhus*) for consumption (Figure 4.2). The local residents use these hot springs as part of their traditional treatment for diseases and physical ailments. The well known hot springs in high demand are found in Gasa, Punakha, Lunana, Bumthang, Gelephu, Zhemgang and Trongsa (not functional) Dzongkhags. There are also a number of hot stone baths using spring water in various places that are popularly used by the locals for healing purposes including rest and restoration.

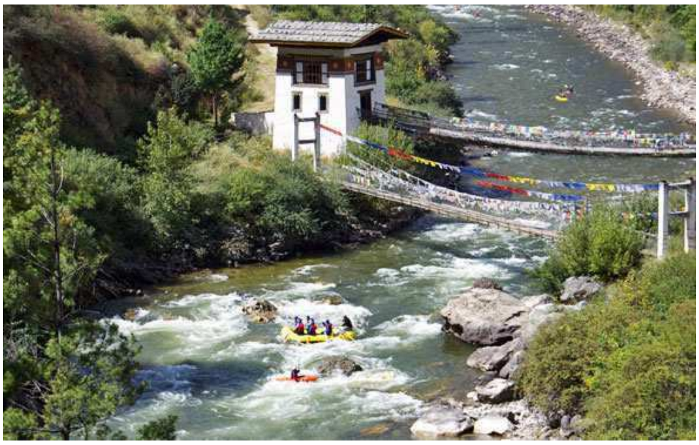
Figure 4.2. Hot spring in Gasa, hot stone bath in Punakha, and clean spring water in Bumthang.

Economic aspects

A landlocked nation opened only to the rest of the world in the early 1960s started the pace of development with pristine forest and traditional society. Bhutan has been blessed with abundant water resource which has accelerated the pace of development. With only 17.7% of arable land suitable for irrigated agriculture and 20% of population cultivating irrigated wetland (PPD, 2009), water acts as a vital resource for irrigated rice growers. Rice being the staple crop and with only 50% self sufficiency at the national level, increase in rice production has been a farfetched vision of the agriculture sector (GHNC, 2008b).

With limited use of the water from the major river systems in agriculture, the role of water in hydro-power generation is indeed the most alluring and pragmatic use for Bhutan. Apart from providing cheap electricity to people, hydropower projects earn about US$ 234 million in 2008 from export of electricity to India (NSB, 2009).

The rivers flowing through a narrow meandering course and with limited accessibility offers adventurous locations for recreational kayaking and rafting. Tourism is an important revenue earner (US$ 29 Million in 2007) in the country (GNHC, 2008a). With the plan to increase its share in the national revenue, water sport is considered as a new and potential product to attract tourists (Figure 4.3).



Source: North West Rafting Company, 2011.

Figure 4.3. Water Rafting in Paro chu in Bhutan.

Bottled spring water is fast becoming a lucrative business. Currently mountain spring water is bottled in Thimphu by Bhutan Agro Industries and Kurje Drubchu bottled in Bumthang by Himalayan Dew. Although there is no data on production and marketing of bottled water mainly due to the import of bottled water, with the availability of natural springs and demand for bottled water its production is expected to increase.

Bio-physical aspects

Originating from glacial lakes in high Himalayas the major river systems have incised the country into deep gorges (Figure 4.4) with narrow valleys through which it meanders down South to drain into the Brahmaputra in India. In addition to the four major river systems (Figure 4.11), small perennial and seasonal streams too have changed the landscape. Traditionally watersheds have been used to demarcate regional and district boundaries. It is also remarkable to note that each district has a major river system flowing through it, probably it would not have been done deliberately but it gives a sense of delimitation of administrative jurisdictions based on natural resources.

Figure 4.4. Meandering river in Trashigang district, Eastern Bhutan.

The water bodies, particularly marshy wetlands in high altitudes serve as habitat for wildlife. The Phubjikha and Bumdelling valleys are breeding grounds for globally threatened black-necked cranes *Grus nigricollis* roost in large numbers during winter. Although it has not been properly assessed, there are 50 freshwater fish species in Bhutanese rivers. The main indigenous fish species include the Himalayan trout *Barilius spp* and *mahseer tor tor* (MoA, 2009).

In the highlands, during the rainy season runoff velocity rapidly builds up resulting into frequent flash floods and landslides (Figure 4.5) which have become a principal natural force for landscape change. For instance the 2004 flash flood across the country left behind major scares in the landscapes. Similarly the glacial outburst in 1994 in Punakha and 2004 flash flood in Trashigang have drastically changed the land features of the area (Figure 4.6).

Figure 4.5. Major landslide affected area in Lumang in Trashigang district.

Figure 4.6. Village settlement in Lungtenzampa and rice terraces damaged in Udzorong by a flash flood on Radi, Trashigang district.

4.2 Water resource and its distribution

The World Resource Institute estimated the per capita renewable freshwater resource in Bhutan at 43,214 m^3 per person signifying its richness, compared to per capita availability of 1822m^3 in India, 8703m^3 in Nepal, 8444m^3 in Bangladesh, 1384m^3 in Pakistan (Earth Trends, 2003). To reiterate, among all the natural resources, water surpasses all in terms of the benefit the country derives from. Currently with four hydropower projects around 86% of electricity generated is exported to India which earns around 60% of the annual export earning (Table 4.1) making it the highest ranked export commodity.

Table 4.1. Top ten commodities exported from Bhutan, 2008.

Commodity	Million US $
Electrical energy	234.74
Ferro-silicon: containing weight more than 55 % of silicon	59.82
Pozzolana cement	21.82
Carbides, whether or not chemically defined: of calcium	18.14
Other: refined copper wire	16.37
Manganese and articles thereof, including waste and scrap	13.19
Vegetable fats and oils and their fractions	11.22
Other of free cutting steel	8.52
Other (semi finished products of iron or non alloy steel)	7.47
Total	391.27

Source: NSB, 2009.

4.2.1 Water bodies and watersheds

Bhutan stretched over 340 km East to West and 175 km North to South with altitudinal variation of 200 to over 7000 m amsl, with around 20.5% of its total area above 4200 m amsl (MoA 1997). Most of the area above 4200 m amsl is covered by the perpetual snow and ice forming the glaciers and glacial lakes (Figure 4.7). Based on ICIMOD[1] study (Mool et al., 2001) it is reported that there are 677 glaciers and 2674 glacial lakes covering an area of 1317 km^2 and 107 km^2 respectively. The glacier forms a mighty ice reserve of 127 km^3 which is a perpetual

[1] ICIMOD - International Centre for Integrated Mountain Development is a regional knowledge development and learning centre serving the eight regional member countries of the Hindu Kush-Himalayas – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and is based in Kathmandu, Nepal. It aims to assist mountain people to understand these mountain ecosystem changes, adapt to them, and make the most of new opportunities, while addressing upstream-downstream issues.

and crucial source of water for most river systems in the country and downstream in India and Bangladesh.

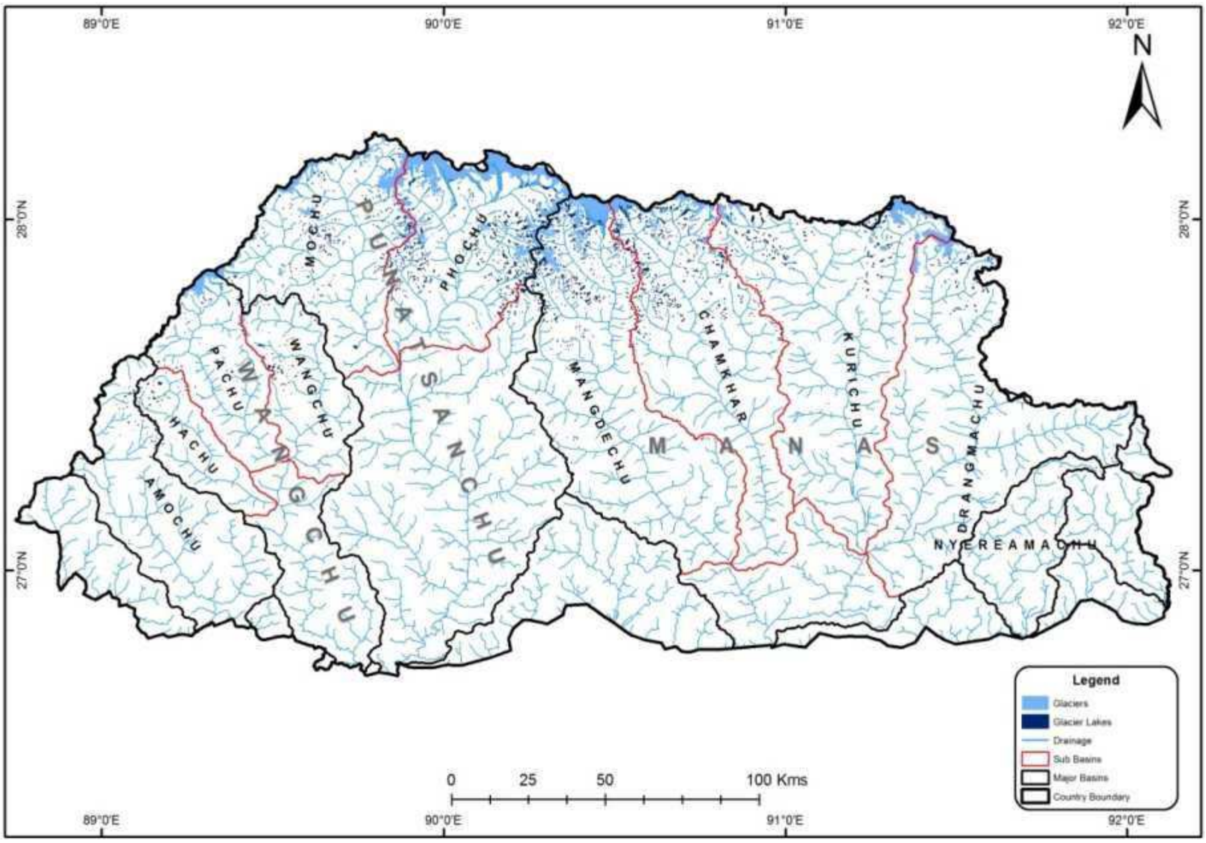


Figure 4.7. Distribution of glaciers and glacial lakes in Bhutan.

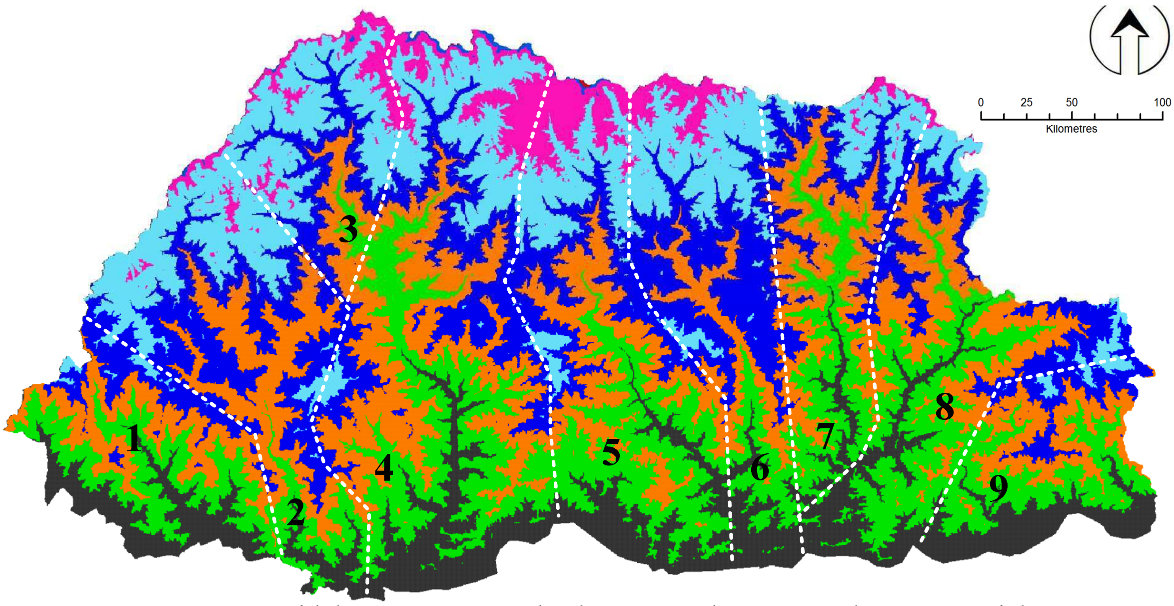
Global climate change has caused the shrinkage or retreat of glaciers resulting in the formation of a large number of glacial lakes, many of which can become unstable as their volume increases or they are subjected to surge waves as a result of ice and rock avalanches striking their surface that cause them to overtop their end moraine dams (Ives et al., 2010). A number of glacial lake outburst floods (GLOF) have occurred in Bhutan in recent years and have caused considerable damage (Table 4.2).

Table 4.2. Known glacial lake outburst flood events in Bhutan.

Year	River basin	Lake	Cause of GLOF
1957	Pho chhu	Tarina Tsho	Unknown
1960	Pho chhu	Unnamed	Unknown
1960	Chamkhar chhu	Bachamancha Tsho	Unknown
1997	Pho chhu	Luggye Tsho	Moraine collapse

Source: Ives et al., 2010.

From the mosaic of numerous sub-watersheds, broadly nine main watersheds (Figure 4.8) can be defined running West to East (FAO, 1999). The perpetual stock of water in the form of glaciers in the Northern part and 72% of forest cover ensure healthy watershed status. The sudden rise from 100 m amsl to over 7000 m amsl and mountainous terrain intensify drainage during rainfall resulting in rapid swelling of streams. Such events of swift swelling of streams sometime lead to flash flood causing severe damage.

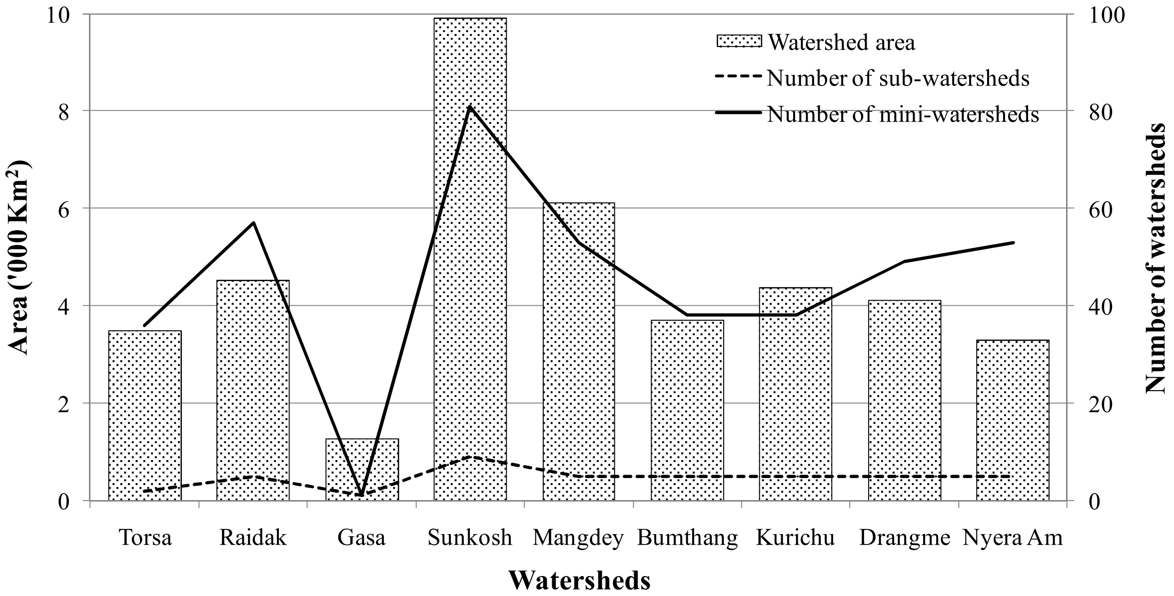


Legend: 1-Torsa; 2-Raidak; 3-Gasa; 4-Sunkosh; 5-Mangdey; 6-Bumthang; 7-Kurichu; 8-Drangmey; 9-Nyeraam

Source: FAO, 1999.

Figure 4.8. Nine principal watersheds in Bhutan.

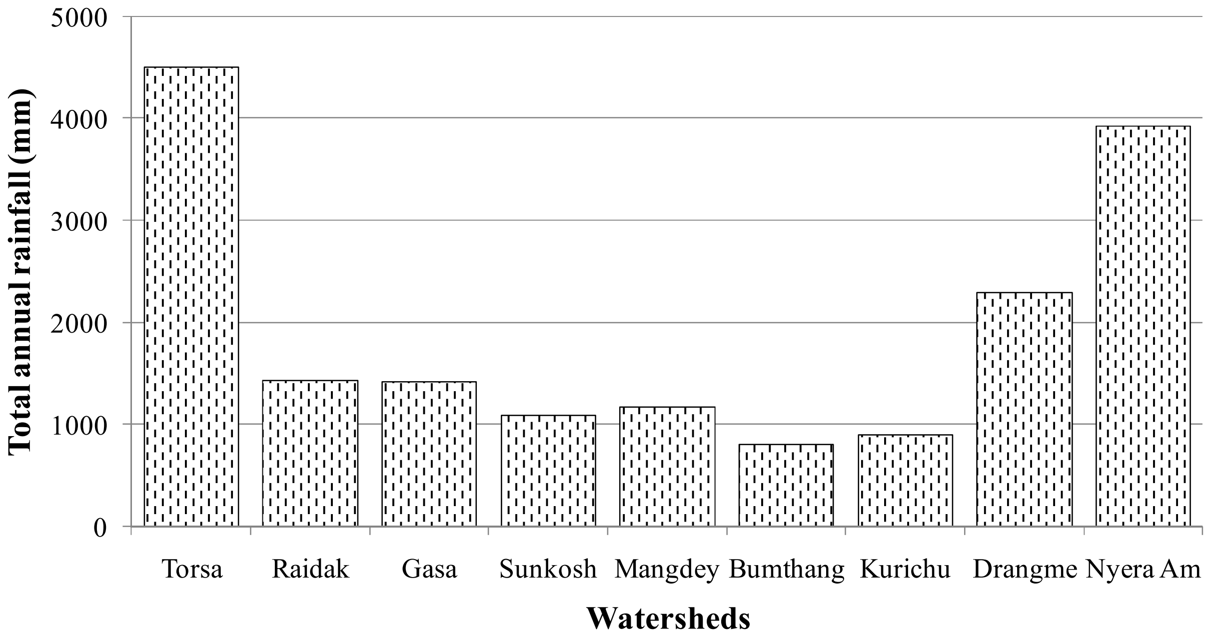
Among the nine main watersheds, Sunkosh, which is drained by Phochu at Punakha, Dangchu and Phobjikhachu in Wangdue, Burichu in Tsirang is the biggest watershed spreading over 9892 Km^2 followed by Mangdey basin covering an area of 6110 Km^2. Sunkosh has the highest number of sub-watersheds and 81 mini watersheds. Other watersheds are fairly uniform with area ranging from 3290 to 4520 Km^2. Gasa is the smallest basin with only 1260 Km^2 and only 1 sub-watershed (Figure 4.9).



Source: FAO, 1999.

Figure 4.9. Bhutan nine principal watersheds spread and their secondary and tertiary watersheds from West to East.

Based on meteorological data over 4 years (2004-2007), the two watersheds Torsa in the West and Nyeraam in the East receive the highest amount of annual rainfall of 4500mm and 3900 mm respectively (Figure 4.10). Rainfall in other basins ranges from 800 to 1400mm. Rainfall significantly contributes to watershed discharge and base flow of the streams. In many places in the highlands, rainfall is the only source for seasonal streams like in Lingmuteychu and natural springs which serves a primary source of drinking water like in Kengkhar study site. Incessant rain often is a threat as it causes major landslides and flash floods. During 2004 heavy rains lead to swelling of Gamrichu in Trashigang and Kholongchu in Trashiyangtse that ravaged large areas of paddy field in Rangjung and Bumdeling respectively, including lives (Figure 4.11).



Source: FAO, 1999.

Figure 4.10. Average annual rainfall in nine watersheds of Bhutan (2004-07).

Figure 4.11. Paddy fields damaged by flash flood in Bumdeling, Eastern Bhutan in 2004.

4.2.2 Profile of major river systems

As presented in Chapter 2 (Figure 2.3) the network of streams and rivers has been clustered into 8 major river basins, from west to east they are Amo Chhu (Torsa), Wang Chhu, Puna Tsang Chhu (Sunkosh), Drangme Chhu (Manas), Samtse, Gelegphu Area, Samdrup Jongkhar, and Shingkhar-Lauri (Table 4.3).

Table 4.3. Main river systems of Bhutan.

Main river basin	Tributaries	Basin area (km^2)	Glacier number	Glacier area (km^2)	Ice reserve (km^3)
Amo Chhu (Torsa)	-	2,400	0	0	0
Wang Chhu	Thim Chhu, Pa Chhu, Haa Chhu	4,689	36	48.92	3.55
Puna Tsang Chhu (Sunkosh)	Mo Chhu, Pho Chhu, Dang Chhu, Daga Chhu	10,355	272	503.11	43.28
Drangme Chhu (Manas)	Mangde Chhu, Chume Chhu, Chamkhar Chhu, Kuri Chhu, Kholong Chhu, Gongri Chhu	16,599	310	376.95	28.77
Samtse	multi-river	962	0	0	0
Gelegphu Area	multi-river	1,956	0	0	0
Samdrup Jongkhar	multi-river	2,279	0	0	0
Shingkhar-Lauri	multi-river	779	0	0	0
		40,019	618	929	76

Source: Water Resources Management Plan, Department of Energy, 2003.

The orientation and agro-ecological settings of the watersheds have greatly influenced the human settlement and land use patterns in the country (FAO, 1999). For instance, the Sunkosh watershed (or Punatshang chu) represented in Figure 4.12 is one of the biggest watershed traversing the country North to South from Lunana to Kalikhola. It provides a fair representation of how watershed bio-physical features have affected the land use and settlement. Pho chu originates from the numerous glaciers in the Lunana valley fed by Tarina and Lunana glaciers. Right at the upstream, a narrow valley is occupied by a small settlement of yak herders who depend on pastoral farming systems. After draining Lunana valley, Pho chu flows through deep gorges and rugged terrain to join Mo Chu immediately south of Punakha Dzong to form Punatsang chu.

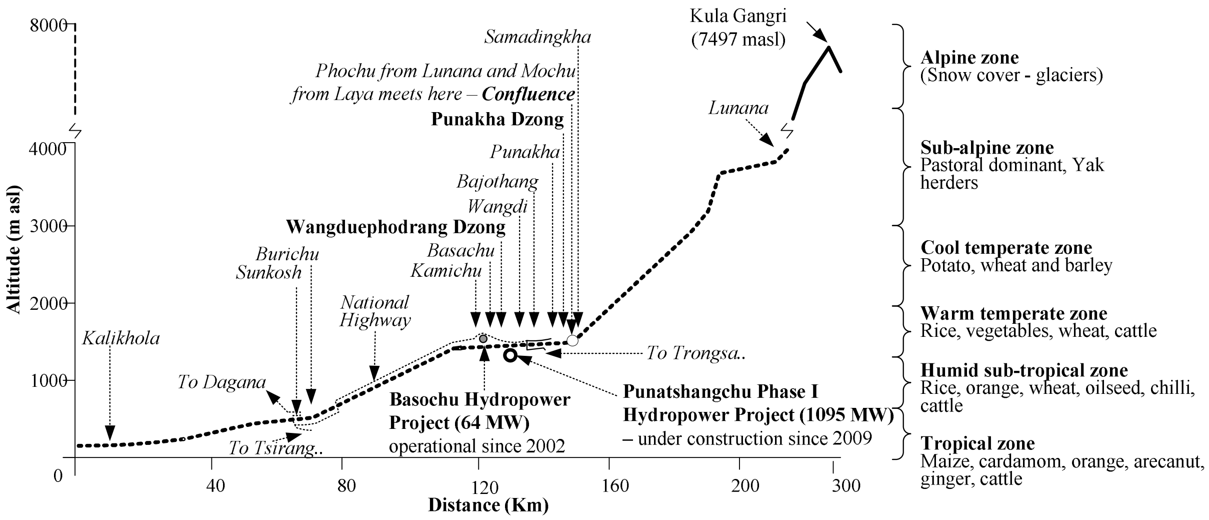


Figure 4.12. Schematic representation of Sunkosh watershed with agro-ecological features, settlements and infrastructures, Pho chu (Punatshang chu).

As Pho chu reaches Samadingkha it opens into the widest valley in Bhutan which stretches around 30 km long and 5 km wide to form Punakha-Wangdue valley a major rice growing area in the country. As it leaves the valley at Hesothangkha (just below Wangduephodrang Dzong), a 1095 MW hydropower project “Punatshang chu Phase I” is being constructed since 2009. From the point where the dam is built to Kalikhola, a length of around 100 km, Punatshang chu flows in deep gorges without any settlement except few restaurants along the Wangdue-Tsirang highway. At 120 km point a 64 MW power plant has been built on the right bank of Punatshang chu utilizing water from two tributaries: Baso chu and Ruri chu. As Punatshang chu reaches Kalikhola, it is called Sunkosh which spreads in the plains of the southern foothills draining the tropical Manas Wildlife Sanctuary. The profiles of four other river systems in different regions of the country are presented in Figure 4.13 and described below.

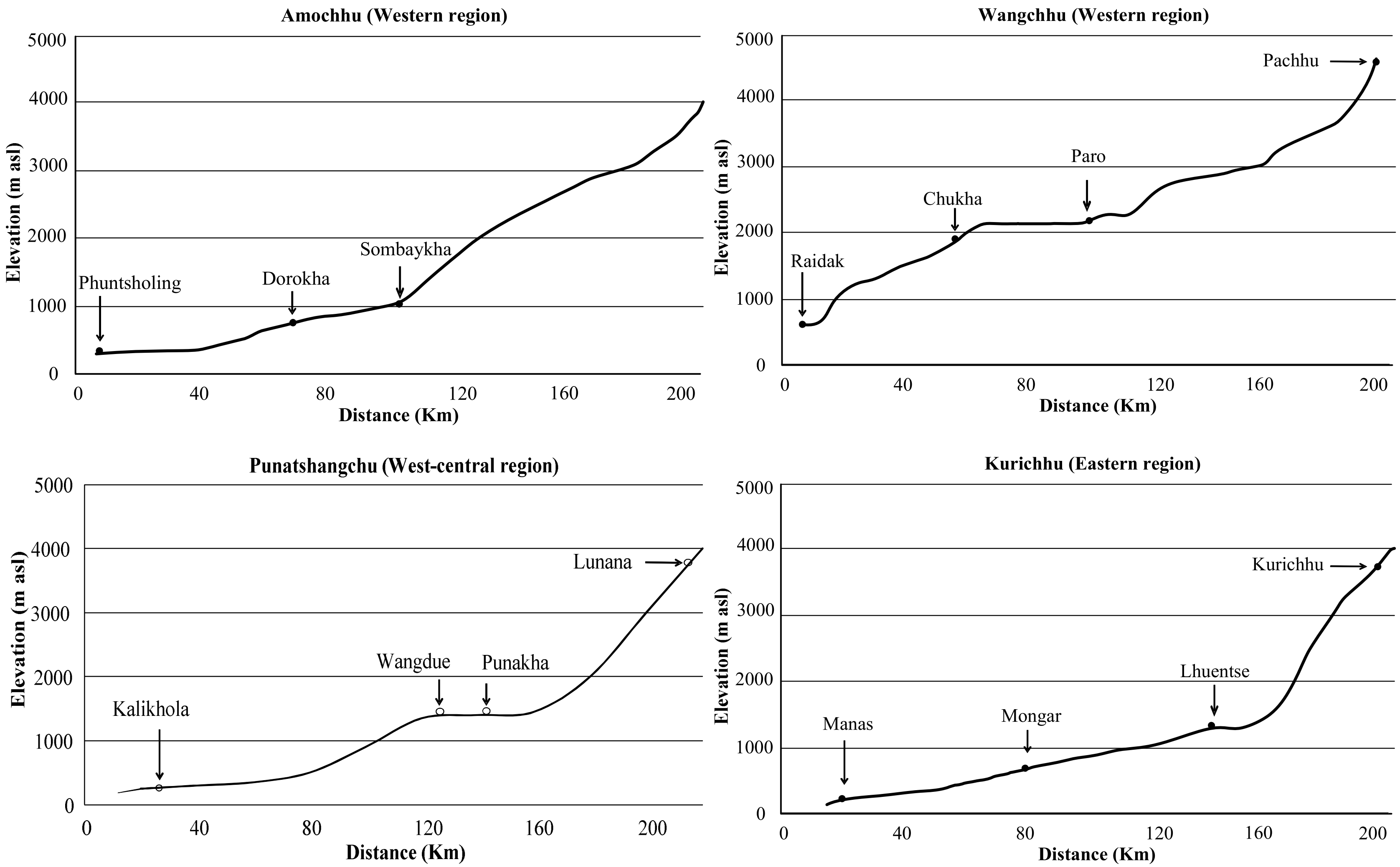


Figure 4.13. Profiles of four major river systems in Bhutan.

Amo chu : One of the smallest river systems (NSB, 2009) originates in Chumbu valley in China (Tibet) and enters into Bhutan from Yatung. Within Bhutan it does not have any tributaries other than seasonal drainage during the wet monsoon. The river mostly flows in Samtse district covering around 170 km of deep gorges and spreads out in Phuntsholing as Torsa and flows in the plains of West Bengal before draining its water into the Brahmaputra. Within Bhutan its water is not used for any purpose.

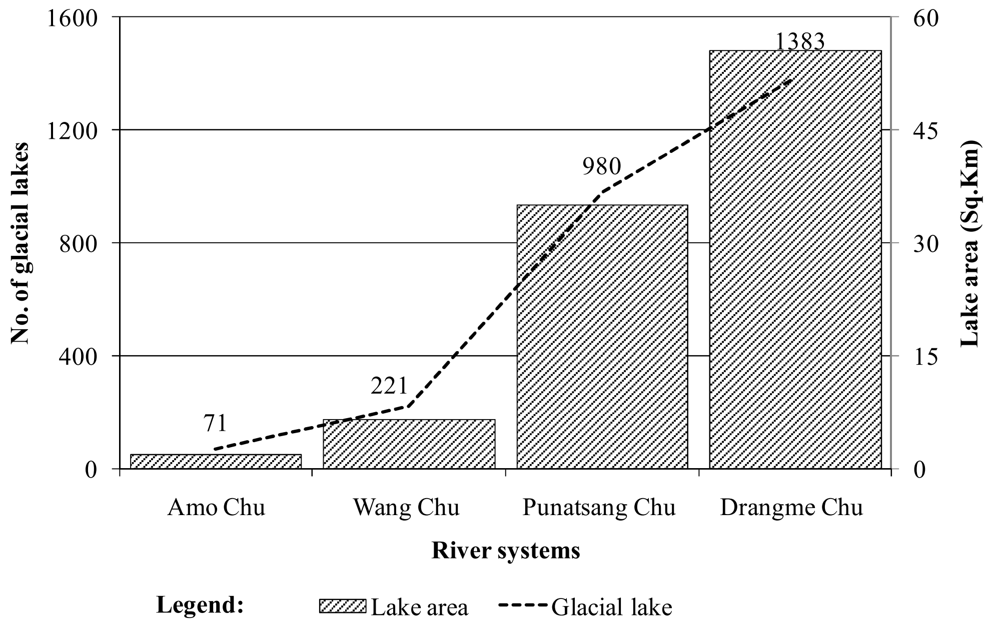
Wang chu: Wang chu is one of the most important river systems as it serves two major hydropower projects (Chukha and Tala dams) commissioned in 1988 (Chukha) and 2007 (Tala). Wang chu has 3 tributaries, which drain through the 3 important districts of Thimphu (Capital), Paro (Airport), and Ha (Army Training Institute), and are named Thimchu, Pachu and Hachu based on the main towns they pass through. Thimchu and Pachu meets at Chuzom (*Confluence*), both have narrow valleys where high altitude rice can be grown. With warm temperate climate this area is also best suited for apples, peach and plum which are cash crops in the region. The two rivers join with Hachu to form Wangchu. Along the Hachu there is only one settlement at Ha where the Ha Dzong and army training facilities are located. Wangchu has a total basin area of 2865 km^2 with 48.92 Km^2 of glaciers that feed the rivers. Its mean annual discharge is recorded as 76 m^3/sec (Table 4.4). As it flows swiftly, its water is tapped through tunnel and used for operating two hydropower projects. Other than the use in hydropower it is not used for agriculture purposes. Wangchu also drains into the Brahmaputra after exiting from Raidak in Southern Bhutan.

Table 4.4. Annual discharge of water from river systems.

River system	Principal tributaries	Discharge recording site	Altitude (m)	Catchment area (Km2)	Mean annual discharge (m3/sec)
Wang chu	Hachu	Damchuzam	2,690	336	10.6
	Wang chu	Tam chu	1,990	2,520	65.7
Punatshang chu	Mo chu	Yebsa	1,230	2,320	116
	Pho chu and Mo chu	Wangdi	1,190	5,640	291
	Sankosh	Dubani	263	8,050	387
Drangme chu	Chamkhar chu	Kurjey	2,600	1,350	53.7
	Mangde chu	Bji	1,860	1,390	65.7
	Mangde chu	Tingtibi	565	3,200	150
	Gongri chu	Uzorong	570	8,569	256
	Kuri chu	Kurizampa	540	8,600	293

Source: Mool et al., 2001. No data for Amochhu.

Punatshang chu: The longest river in Bhutan measuring around 250 km (Mool et al., 2001) and formed by the merger of Pho chu (*male river*) originating from Kula Gangri in Lunana with Mo chu (*female river*) flowing in from Zhomolhari in Laya. With its catchment area of 16,010 km^2 and ice reserve of 43.28 km^3, its mean annual water discharge is recorded as 794 m^3/sec (Table 4.4), it is one of the mst important and dependable source of water (Figure 4.14). It is considered important as it drains the important rice growing areas and dependable as it is fed by tributaries originating from the glaciers. It drains out of Bhutan from the Southern town of Kalikhola.



Source: Mool et al., 2001.

Figure 4.14. Four major river systems, number of corresponding glacial lakes and their sizes.

Drangme chu: the largest river system covering nine of the 20 districts and spreading over almost 43% of the country (38,394 km^2). There are 310 glaciers that account for 44% of the area under glacier in the country. In the West, Mangdechu which originates from Gangkar Punsum peak is the main river of Trongsa district that joins with Chamkhar chu coming in from Bumthang. While there is hardly any flat area in Mangde chu basin, Chamkhar chu has a wide and beautiful valley in Bumthang where the district headquarters and popular Buddhist temples are located. Its catchment area extends to 23109 Km^2 and discharges 768 m^3/sec of water annually, making it a potential target basin for hydropower projects (Table 4.4).

There are four rivers flowing in from the Eastern region: Kuri chu in Lhuentse, Kholong chu and Gongri in Trashiyangtse and Gamri chu in Trashigang that join with Mangde chu in Pangbang to form Drangme chu. Except a small stretch (10 km long and 2 km wide) of flat area in Gyelposhing along Kuri chu where the Kurichu Hydropower Project is located, the rest of the river flows in deep gorges and narrow valleys until it exits in the plains of Manas in the South from where it drains into India.

Others: The remaining four basins (Samtse, Gelephu, Samdrupjongkhar, and Shingkhar Lauri) are small river systems not connected to the main above mentioned ones. There are multiple seasonal streams fully dependent on the wet monsoon rains and some are formed by consolidating seepages from natural springs and drainage. Among them, Samdrupjongkhar river system, also called Nyere Ama Chu basin has the biggest basin of 2279 km^2 and a 185m long glacial lake (Mool et al., 2001). It drains out into the plains of Assam in Daranga causing chaos during wet monsoon. The remaining three are completely dependent on rainfall. While most of them are dry during winters, they turn into violent rivers with incessant monsoon rain causing rampant destructions. Unlike the four principal river systems, these seasonal rivers form a major source of irrigation water for rice cultivation in the Southern foothills from Sipsu in Samtse to Daifam in Samdrupjongkhar.

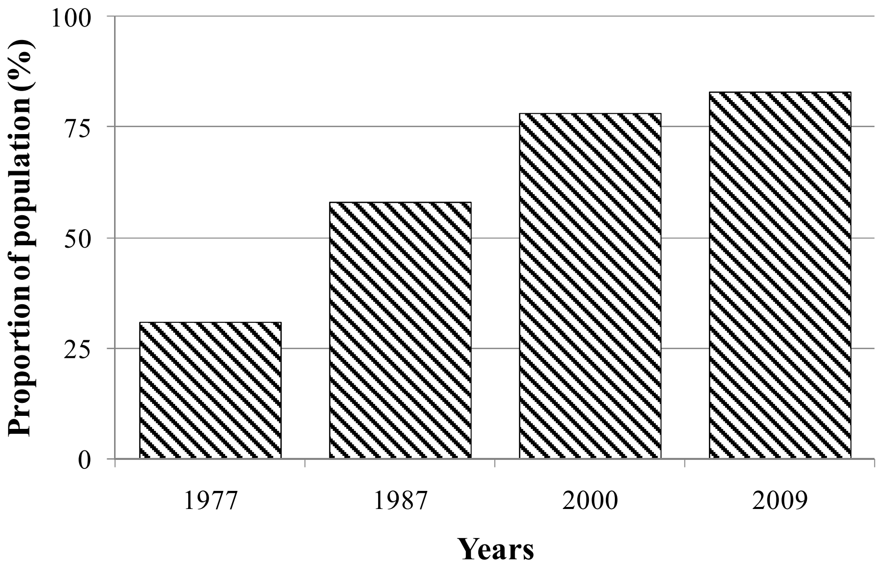
4.3 Water in development

Bhutan has a narrow economic base and the main support for economic growth should come from the exploitation of hydropower and establishment of natural resource-based industries that make use of cheap power (ADB, 2005). The driving forces for rapid development of Bhutan since 1961 are the rich resource endowments such as water and environmental biodiversity (Ura, 2004). Water is considered vital for social and economic development of the country, which is vivid from the priority placed in accessing water. Despite the abundance of water resources, the national policy prioritizes water access in the order of (i) drinking and sanitation; (ii) agriculture; (iii) energy; (iv) industry; (v) tourism and recreation; and (vi) other uses. This aptly captures the four prominent uses highlighted by Her Majesty the Queen Ashi Dorji Wangmo Wangchuck (Zürcher and Choden, 2004). The following sections present the use of water as a key resource in national development.

4.3.1 Domestic use : changing scenarios

Water is the principal renewable natural resource which has influenced the human settlement and early civilizations in the Indus valley. In Bhutan too the important seats of religion and royalty have been in fertile valleys with perennial river flowing as a lifeline for the settlement. For instance, Thimphu, Paro, Punakha, Wangdue, Bumthang, and Ha are the most important settlements from where development emanated in Bhutan. Prior to 1960s people used water for domestic purposes directly from canal, streams and ponds by carrying it from long distances (Zürcher and Choden, 2004). In rural Bhutan, domestic water use comprise of drinking/cooking/washing (47%), animal feeding (28%), and irrigation (25%) (Domang et al., 2007). While in urban areas almost all the water is used only for drinking, cooking, and washing.

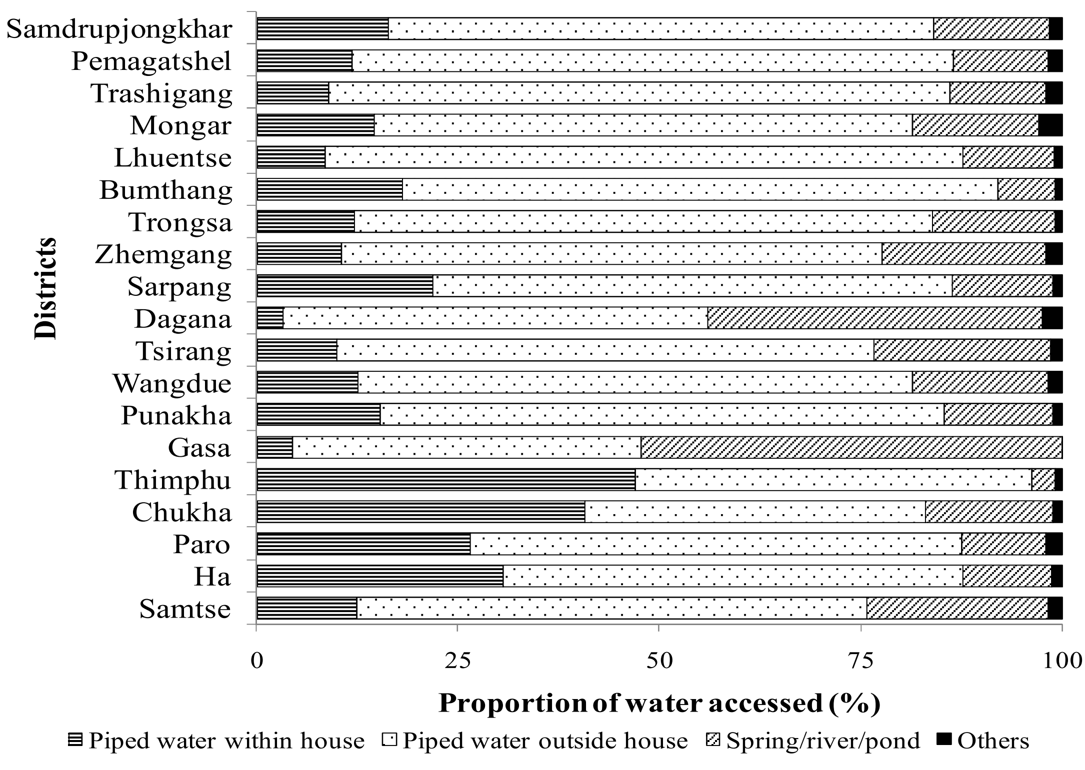
In view of the close association of incidence of infectious diseases like diarrhoea, typhoid and cholera to drinking water, the provision of safe drinking water to improve the health status of the population has been a priority since development began in the 1960s and targets for universal access for safe drinking water and the total sanitation is targeted by 2013 (GHNC, 2009a). It is evident from the gradual development that universal access seems an attainable goal (Figure 4.15).



Source: PCS, 1999; GNHC, 2008; NSB, 2009.

Figure 4.15. Proportion of population with access to potable water, Bhutan, 1977-2009.

While the figure looks convincing there is a drastic difference between situations in urban and rural areas. With 69% of the population still based in rural areas, access to potable water to the rural population continues to be a concern in most remote areas. Although water is abundant in Bhutan, it is limited by distance and seasonality. In 2005, while 54% of the urban population had piped water within their houses, only 9.2 % of rural folks had access to it. In contrast, 69% of rural households had access to piped water outside their house. It is also interesting to note that almost 22% of the rural population depended on natural springs, rainfall and tube wells (NSB, 2008). The use of water from open sources may be the reasons for the prevalence of water borne diseases (MoH, 2009). The disparity is also obvious across the districts (Figure 4.16), where districts with remote geogs, like Laya in Gasa, Drujeygang in Dagana, Dorokha in Samtse, Patalay in Tsirang, Goshing in Zhemgang, Kengkhar in Mongar, and Bjena in Wangdue, households still depending on water from natural springs, streams, ponds, and wells (OCC, 2006).



Source: OCC, 2006.

Figure 4.16. Proportion of households accessing drinking water from different sources by districts in Bhutan, 2005.

Despite the priority and focus on enhancing access to safe drinking water, studies have shown that 30% of rural water supply schemes (RWSS) are either poorly managed or non-functional (MoH, 2009). In many cases dysfunctional water supply schemes are due to source drying up (Domang, et al., 2008) while poor maintenance is another main cause.

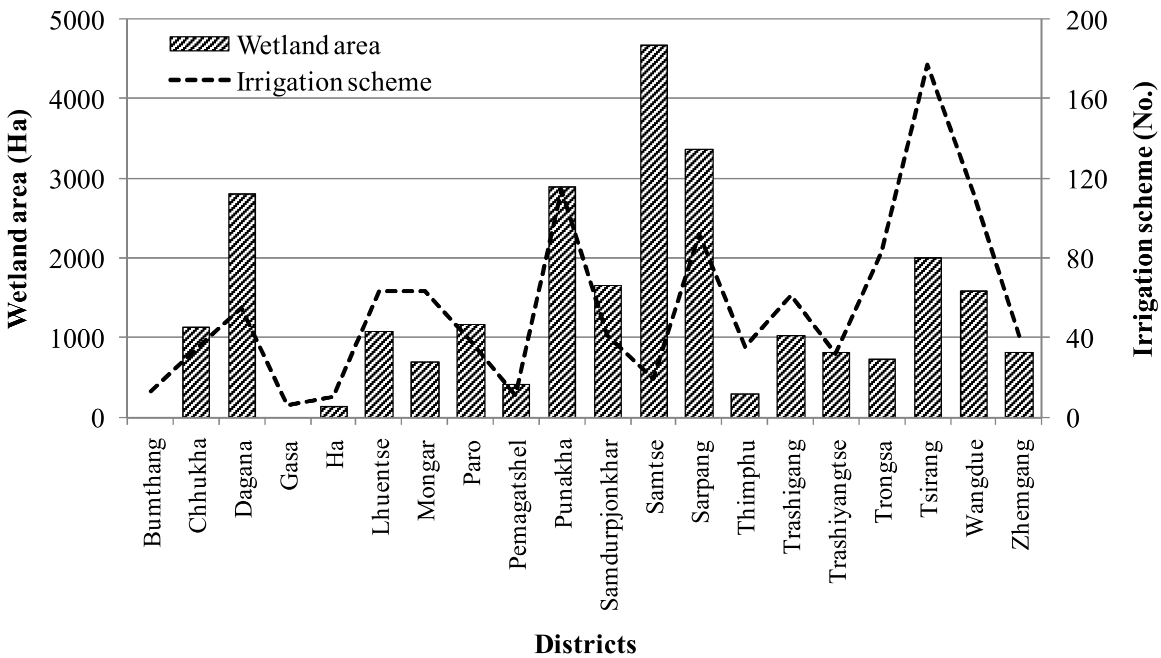
Water in the early days was a free and abundant renewable resource, and even when planned development was launched in 1961 government took all the responsibilities to develop and manage safe drinking schemes. As the population increased, water sources dwindled, and use of water diversified from household use to irrigation, hydropower generation and industries, competition for water increased rapidly. To sustain a safe drinking water program, water is metered in urban areas, while in rural areas community members participate in the construction and maintenance of the schemes.

4.3.2 Agricultural use: irrigation systems and their evolution

The farm sector uses the largest share of water (54%) followed by the domestic sector (36%) and industry (10%) (Zürcher and Choden, 2004). In 2008, approximately 19,274 ha of agricultural land was irrigated and cultivated with rice. (MoA, 2009). As explained above, the profiles of the river systems that follow deep gorges do not permit its water to be used for irrigation. Even in valleys, as bulk of the river water comes from snow melt its temperatures are below 10-12°C which could be harmful to crops. Further some attempts as in Bajo, Wangduephodrang to pump water from Punatshang chu and storing it is large open reservoirs to increase its temperature prior to use, has come out to be expensive, but it works. This leaves only with seasonal streams sustained with rainfall and underground aquifers to be used for irrigation.

Prior to 1969, when the National Forest Act was enacted and forest nationalized, farmers had free access to water resources (DoF, 1969). Wealthy families constructed private irrigation canals named after them diverting water during rice seasons. For instance Thapa kulo in Tsholingkhor, Tsirang in 1910, Bawanikulo in Barshong, Tsirang in 1921, and Churalum in Guensari, Punakha in 1950 (Communication from Irrigation Division, DoA, 2010). Similarly, in areas like Lingmuteychu in Punakha, early settlers contributed resources (labour, food and materials) and constructed irrigation canals (Litmus Consult, 2002). Depending on the investment to construct irrigation canals, local water distribution arrangements were established. In Peljorling village of Samtse, where the 5 km long *Diwan Kulo* diverts water from Sipsukhola, it is first used by the owner and subsequently the tenants and other villagers. In addition a quarter of the water flow was always reserved for the owner. In a collectively built canal as in Limbukha village in Punakha, four distinct classes of irrigators: Thruelpa, cheep, chatro, and lhangchu. They persist today (Gurung, 2004).

Much before nationalization of forest in 1969, the Government supported the construction of irrigation canals in potential rice-growing areas. In 1946 two canals in Senghe village of Sarpang district were constructed by the government to support rice cultivation in the plains. The canals were named as Mazan and Baral canals and are still functional today. Since then the government has constructed 968 irrigation canals across the country totalling a length of 2590 km. In general the lengths of irrigation canals in different districts have been in relation to the extent of wetland areas (Figure 4.17). However, the distinct difference in Samtse is mainly due to the facts that they practice rainfed lowland and not irrigated rice.

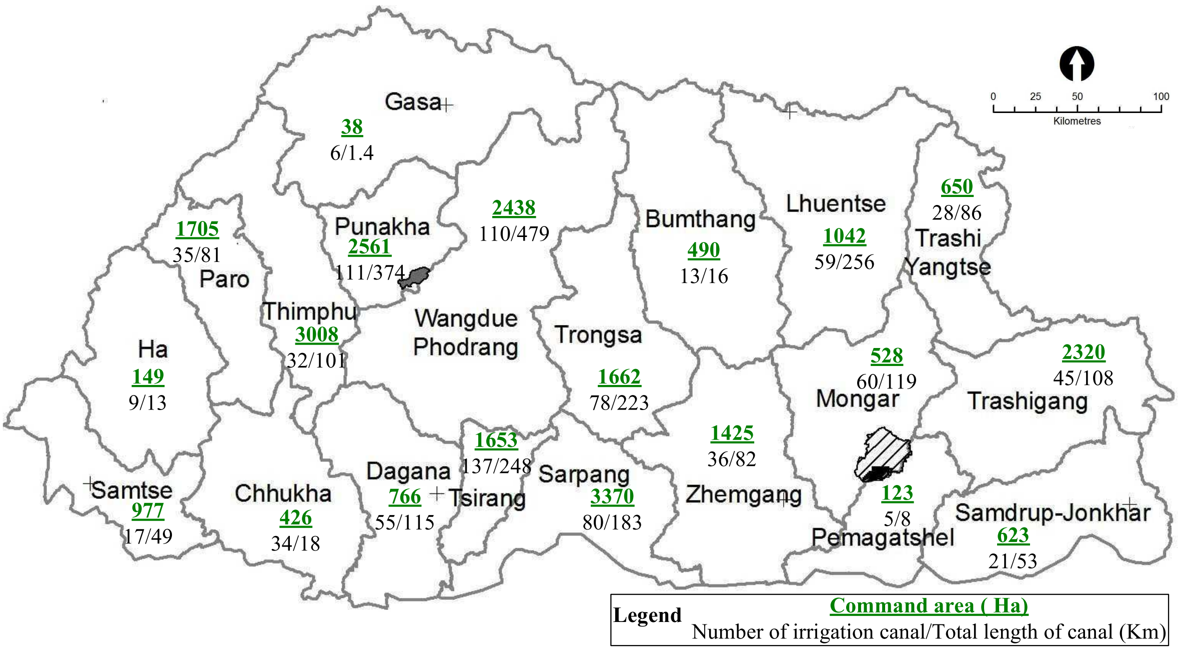


Source : DoA, 2010.

Figure 4.17. Wetland areas and total length of irrigation canals in different districts of Bhutan, 2010.

In total there are 1101 canals measuring a total length of around 3022 km of which only 971 canals are functional (Table 4.5). Although the potential command area is 25,956 hectares

(Figure 4.18), effectively may be only 40% of the total wetland is actually irrigated (DoA, 2010). The government is the principal investor in irrigation development with the construction of 69% of the 1101 canals (Figure 4.19). There are 15 donor assisted projects which helped in the construction of 11% of the canals, among them 50 were built in the eastern region of the country by IFAD funded area development projects (FEZAP, SEZAP and AMEPP)[2] over a period of 15 years. In addition 10% of the canals were built by communities and the remaining 10% privately. The poor canal management and on farm water management is the primary reason for the failure of many irrigation schemes in the country. This is further aggravated by the absence of canal management institutions. According to the Irrigation Division of DoA, presently only 24 water users associations (WUA) are functional despite the initiative of this Irrigation Division in 1991 when the National Irrigation Policy was enacted. Only Trashiyangtse, Samtse, and Samdrupjongkhar have 12, 11, and 1 WUA respectively managing their schemes efficiently.



Source: DoA, 2010.

Figure 4.18. Functional irrigation canals and their command areas against the constructed canals, Bhutan, 2010.

[2] IFAD – International Fund for Agriculture Development which provided soft loan to support FEZAP-First Eastern Zone Agriculture Project, SEZAP – Second Eastern Zone Agriculture Project, and AMEPP – Agriculture Marketing and Enterprise Promotion Program.

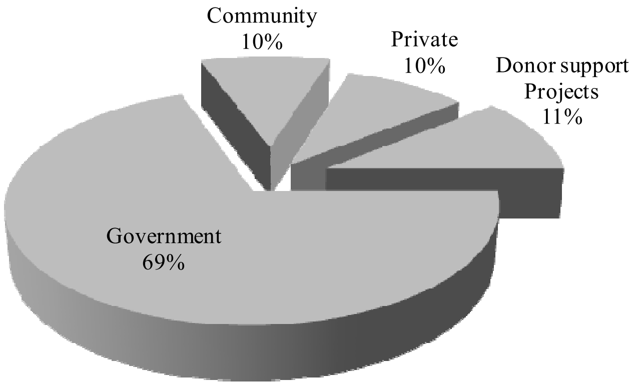


Figure 4.19. Construction of irrigation canals by different agencies in Bhutan.

Table 4.5. Water users associations (WUA) in Bhutan, 2010.

Dzongkhag	No. of WUA	Name of the Irrigation Scheme	Length (Km)	Command Area (Ha)
Samdrupjongkhar	1	Rekhey	1.5	6
Samtse	11	Ugyentse, Tendruk, Sipsu, Chengmari, Yoseltse, Chengmari, Chargharey, Tading, Biru	32.3	272
Trashiyangtse	12	Tshalign Daksa, Nangkhar, Buyang, Wangningmo, Shami, Mangtey chu, Manchu, Phuyang, Yalang, Rollam, Namthi, Bayling	42.3	88

Source: Irrigation Division, DoA, 2010.

4.3.3 Hydropower: potentials and current status

The rich endowment of water resources and typical profile of Himalayan river systems following the narrow gorges makes it ecologically, technically, and economically friendly to harness river for hydropower generation. Bhutan has an estimated hydropower potential of 30,000 MW with an average development potential of 781 kW in a square kilometer of catchment (Tshering and Tamang, 2005). Similarly the hydropower potential of Nepal and India are 43,000 MW and 120,000 MW respectively. Although the Power System Master Plan identified 91 potential hydropower sites with a capacity of more than 10000 MW, in 2002-03 the feasibility capacity for exploitation was estimated to be more than 23000 MW (ADC, 2005). The first hydropower plants built during the first plan (1961-66) were in Khasadrap chu in Thimphu and Shari in Paro with installed capacity of 400 kW each. At the same time 250 kW on daily basis was imported from India for Samtse and Phuntsholing (Hasrat, 1980). As these 3 sources tremendously boosted the local development, the government rapidly expanded the construction of micro and mini (10 to 1500 kW) hydropower projects in different districts and remote settlements as shown in Table 4.6.

Table 4.6. Micro and Mini hydropower projects in operation across Bhutan, 2005.

Year	Hydropower project	Location (District)	Installed capacity (kW)
1966	2	Gidakom (Thimphu), Sari (Paro)	400, 400
1974	5	Hesothangkha (Wangdi), Chumey (Bumthang),Khalanzi (Mongar), Chenary and Rangjung (Trashigang)	300, 1500, 1350, 750, 2200
1975-2004	16	Thinleygang, Lingzhi, and Jungina (*Thimphu*), Chachey (*Tsirang*), Darachhu (*Dagana*), Surey, Kikhar and Tingtibi (Zhemgang), Bubja and Trongsa (Trongsa), Ura and Tamshing (Bumthang), Rukubji (Wangdue), and Gangzur and Rongchu (Lhuentse), Khaling (Trashigang)	30, 8, 360, 200, 200, 70, 20, 50, 30, 50, 50, 30, 40, 120, 200, 600

Source: Tshering and Tamang, 2005.

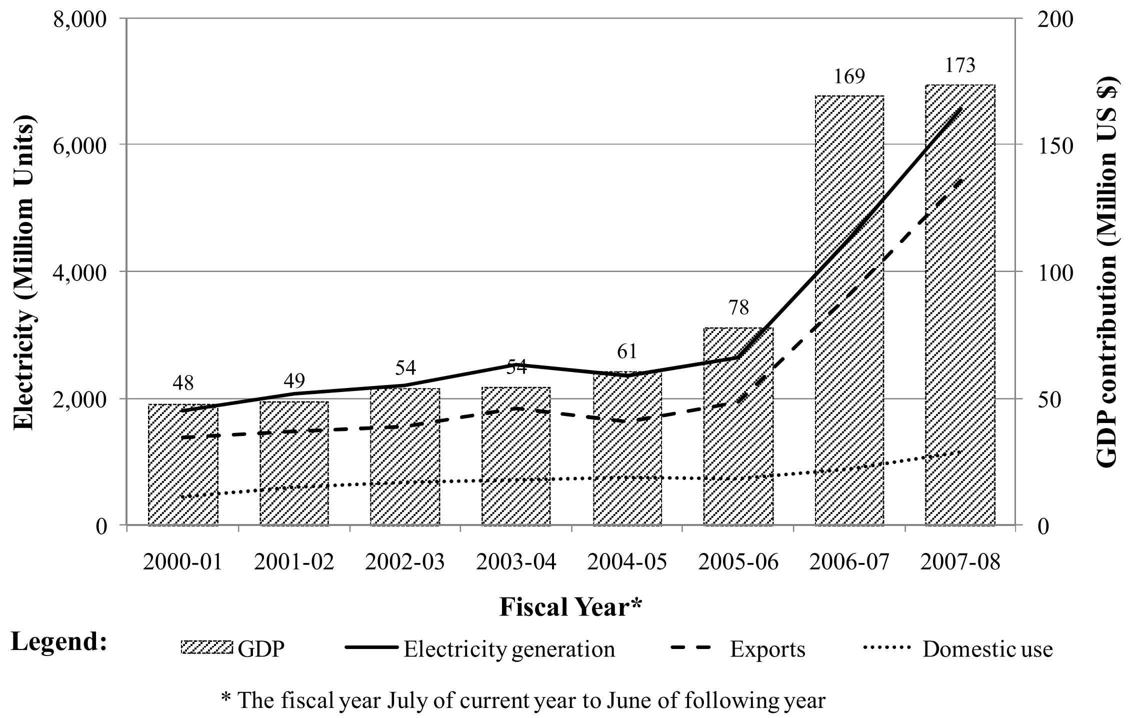
With its low population and limited electricity dependent industries, Bhutan's domestic electricity demand and consumption will remain much below the production potentials. The surplus energy can be easily absorbed by the enormous demand in India providing Bhutan with much needed foreign exchange to finance its development (NVE, 2009). In 1974 the government conceived the plan to harness the hydropower generation capacity of Wang chu for export. In 1986 the first mega hydropower project was commissioned with installed capacity of 336 MW. Most of the energy generated by the Chukha Hydropower Project (CHPP) is exported to India making it a net earner (DGPC, 2009). Hydropower projects in operations are detailed in Table 4.7.

Table 4.7: Hydropower Projects in operation in Bhutan as of 2010.

Hydropower Project	Rivers	Installed capacity (MW)	Power Generation (Million Unit)	Year installed
Chukha HPP	Wang chu	336	1800	1986-88
Kuri chu HPP	Kuri chu	60	400	2001-02
Baso chu HPP	Baso chu and Ruri chu	64	290	2002-05
Tala HPP	Wang chu (Downstream of Chukha)	1020	4800	2006-07

From the successful commissioning of CHPP, 3 more hydropower projects were constructed. A dam along the river Kuri chu was constructed in Gyelposhing in Mongar to install the Kuri chu Hydropower Project with capacity of 60 MW. It caters to the whole of East and Central Bhutan. During the peak power generation season, over 60% of the power generated from the plant is exported to India (DGPC, 2009). Subsequently, with the support of the Austrian Government a 64 MW hydropower project at Baso chu in Wangduephodrang was commissioned in 2005. In the down stream of Chukha HPP, Tala Hydropower Project (THPP) was commissioned in 2006. It is the biggest hydropower plant in Bhutan with installed capacity of 1020 MW and the total energy from THPP is fully exported to India.

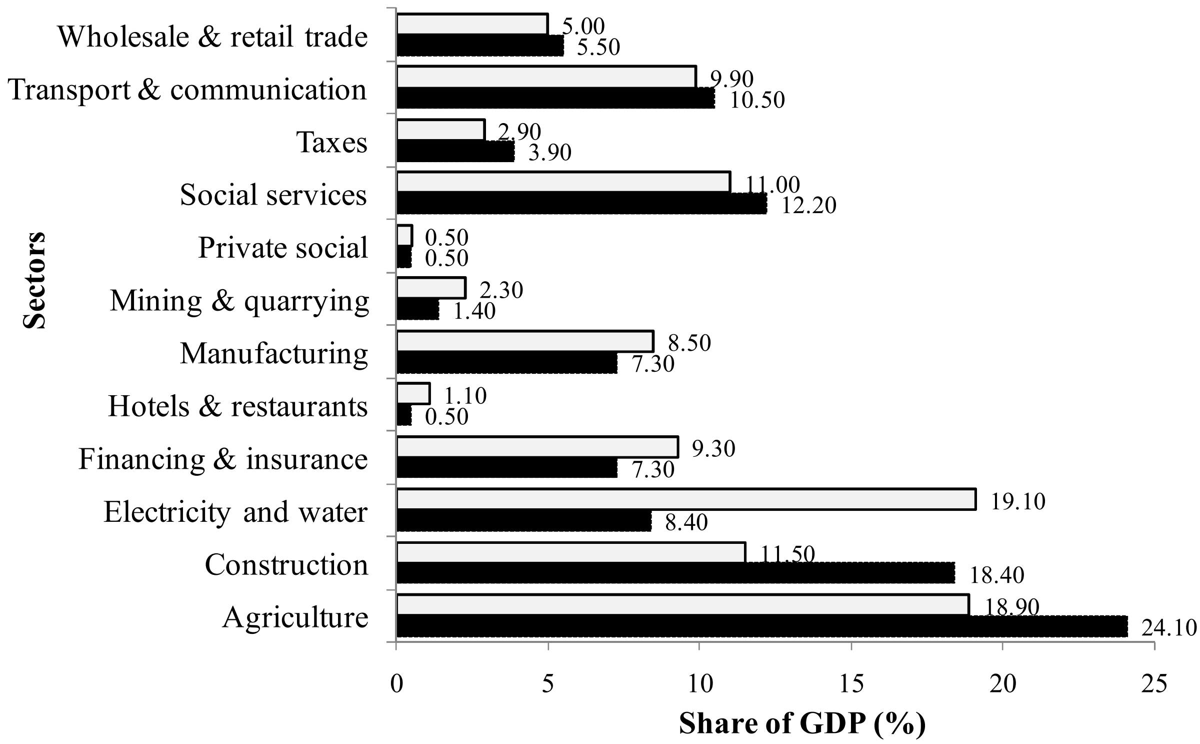
From the total electricity generated on an average, only 26% account for domestic use and the remaining is exported to India. After Chukha and Kuri chu HPP were commissioned more than 1300 million units are exported earning around US$ 50 Million per year. After Basochu HPP came into operation it released energy from Chukha and Kuri chu HPP for export further adding more than US$ 20 Million. The export earning increased by more than twofold from 78 to 178 million (based on 2000 price) after the 1020 MW Tala HPP was commissioned (Figure 4.20).



Source: NSB, 2009.

Figure 4.20. Electricity generation, domestic consumption, exports and their contribution to GDP in Bhutan, 2000-2008.

Until 2004 the farm sector (agriculture, forest and livestock) dominated the GDP with a 24% share followed by construction, social services, and transport. The hydropower sector then contributed a meagre 8.4%. However with the installation of mega hydroprojects, in 2008 electricity and water sector surpassed all sectors by contributing 19.1% of GDP as shown in Figure 4.21.



Legend: □2008 (1152) ■2004 (665)

Figures in parenthesis represents annual GDP at current price - Million US$

Source: NSB, 2009.

Figure 4.21. Share of GDP by different sectors in Bhutanese economy, 2004 and 2008.

With 8 projects are planned, with some already under construction (Table 4.8), it is expected that hydropower projects will dominate the foreign exchange earning for many decades to come. Energy is an essential input for all socio-economic development activities in Bhutan. Like every other developing country, energy is recognized as a priority sector in Bhutan for poverty reduction and sustainable development. While industry has been an engine of growth in the past, growth has been singularly dominated by the hydropower sector (GNHC, 2009a), and it appears that in the future hydropower will become the backbone of the Bhutanese economy.

Table 4.8. Planned hydropower projects in Bhutan.

River basin	Project name	Installed capacity-MW	Construction period
Punatshang chu	Punatshang chu I HEP	1095	2007-2014
Mangde chu	Mangde chu HEP	670	2009-2016
Punatsang chu	Punatsang chu-II HEP	990	2009–2016
Amo chu	Amo chu HEP	500	2010-2018
Nika chu	Nika chu HEP	210	2010-2018
Drangme chu	Kholong chu	485	2014-2020
Bumthang chu	Chamkar chu-I	670	2014-2020
Bumthang chu	Chamkar chu-II	570	2017-2022
Cumulative capacity by 2022		5190	

4.4 Policy on water resource

Culturally, Bhutanese consider water as god-gifted and life giver, the purest of all and revere it as divine. However, socially water is considered as a common resource with free access. Traditionally as there was no written policy or norms for water management, communities crafted water accessing and sharing systems that best suited them. The traditional oral system passed through generations has evolved as social culture which people still respects and follows. Even after the advent of planned development and emergence of several policies water is still basically managed by traditional institutions, norms, and rules (Litmus Consult, 2003; Ministry of Agriculture, 2002b). As Buddhists, people conscientiously follow the religious perspective of hydrological cycles and plan cropping systems, by referring to monks and lunar calendars.

4.4.1 Evolution of policies on water (provisions in draft policies)

If the definition of "Forest" *means any land and water body, whether or not under vegetative cover, in which no person has acquired a permanent and transferable right of use and occupancy."* (FNCA, 1995) holds true, water resource in Bhutan was nationalized in 1969 following the enactment of National Forest Act 1969 (MoTIF, 1969). Since 1969 there has been series of Acts and policies linked to the water resource, which distinctly show the commitment of the government to manage the resource and sustainably use it for the development of the country (Table 4.9). Corresponding to the commitment, the state had very limited (financial, human and physical) resources to effectively implement the legislation. Withdrawal of local customary rights and the absence of regulatory mechanisms led to open access resulting in mismanagement and over exploitation of the resource in a case of "tragedy of the commons".

Table 4.9. Act and policies related to water in Bhutan.

Year	Act/Policy	Provision
1969	National Forest Act	- Conservation of catchment areas of streams reserved for supply of water for drinking and hydroelectric projects.
1974	Forest Policy	- Whole country was declared as catchment area for all rivers originating either from China or inside the country - Watershed management and riparian protection
1992	National Irrigation Policy	- Set the foundation for a sustainable approach to irrigation development through the effective participation of the water users
1995	Forest and Nature Conservation Act	- Introduced the concept of critical watershed for protecting the supply of water for drinking, irrigation, flood control and hydroelectric project - Prohibition of blocking and diverting water courses, polluting water bodies, felling of trees within 100 feet from river bank - Soil and water conservation measures
2003	National Water Policy	- Priority of water use, domestic use as first followed by irrigation Emphasised on water resources management within river basins and aquifers, including both upstream and downstream water users - Assured access to adequate, safe and affordable water to maintain and enhance the quality of their lives
2006	Forest and Nature Conservation Rules	- In addition to above provisions, it permitted watershed management to be included in the community forest plan
2008	Forest Policy	- Watershed as source of high quality water for domestic use, irrigation and hydropower project included in policy - Participatory watershed management approach to enhance ecosystem services and local development - River basin planning as an organizing concept
2010	Water Act of Bhutan	- Ensures that the water resources are protected, conserved and/or managed in an economically efficient, socially equitable and environmentally sustainable manner - Assign institutions to address the issue of water resource

The change in the regime affected irrigation water the most. During the same period government constructed many irrigation schemes across the country to expand rice cultivation. In 1990 when the irrigation program was evaluated, it was found that irrigation development did not make the desired impact on agriculture production (DoA, 1992). This review resulted in enactment of a National Irrigation Policy (NIP) which in principle, aimed at assigning the responsibility for operation and maintenance of irrigation schemes to the beneficiaries. It also emphasised the need for water users to take ownership and engage in decision-making processes in scheme operation and maintenance (DoA, 1993). However, the recent report on irrigation schemes by DoA indicates that only 24 WUAs are in operation. Some of the reasons farmers give for the discontinuation of NIP-WUA are its prescriptive nature, non-legal status of WUA, drying of water sources, and limited capacity to build fund from membership to invest in canal maintenance. With the failure of WUA, farmers retracted to the traditional system of organizing themselves based on the age old protocol, often guided by a village elder and managed by local water guard (*chusup* – see chapter 3). Within the scope of the United Nations initiated Global Water Partnership (GWP) which was founded in 1996 to foster integrated water resources management (IWRM), the Bhutan Water Partnership (BWP) was launched in 2001 to coordinate all programs related to water resource management (RGoB, 2003). Through its inter-ministerial body, it formulated the Bhutan's Water Policy which was released in 2003. It assures access to adequate, safe and affordable water to maintain and enhance the quality of people lives. It also highlights the status of water as the principal resource for the country and the need for its management within river basins and aquifers, including both upstream and downstream water users (RGoB, 2003).

Forest and Nature Conservation Rules of Bhutan released in 2006 introduced the concept of watershed management within the community forest which prompted communities to take initiatives to manage catchments. It broadened the functional understanding of community forest as a source of timber to the concept of natural resources. In 2008, MoAF took yet another initiative to revisit and revise the Forest Policy through a wider consultative process. It was warranted with the change in governance and start of democratic governance. Further as enshrined in the Article 5 of the Constitution of the Kingdom of Bhutan that "*Every Bhutanese is a trustee of the Kingdom's natural resources and environment*" (The Constitution of the Kingdom of Bhutan, 2005) it was deemed necessary to revise the Forest Policy which is an umbrella policy for natural resources and environment. Forest Policy 2008 further reiterated watershed as source of quality water for domestic, agricultural and hydropower project but it introduced the participatory watershed management approach to enhance ecosystem services and local development (MoA, 2008).

The status of water resources in Bhutan was finally acknowledged when the 5th Session of the First Parliament endorsed the new Water Bill in July 2010. The Water Bill 2010 proclaims the state as the sole authority of water resource and ensures access to safe, affordable and sufficient water for basic human needs for which the state will protect, conserve and/or managed water in accordance to IWM principles. While the policy is silent on the customary rights, it is explicit that policy encourages formation of WUA which can be federated into Basin Management Committee and promotes equitable sharing of water. At the macro policy level, it emphasises payment for environmental services (PES), particularly to generate funds to invest in watershed management activities in upstream areas. Operationally it was only in November 2010 that a Yakpugang sub-watershed in Mongar was formally declared as PES pilot site. Under the agreement between Yakpugang community and Mongar municipality, the municipality annually pays around US$ 1,100 to the community for sub-water management.

The 10th Five Year Plan period 2008-13 derives essence of natural resource management from the above policies for operational plans. For instance one of the five specific policy objectives of the 10th Plan is to "Conserve and promote sustainable commercial utilisation of forest and water resources". In line with this policy objective, different agencies are implementing activities to better manage water resources (GNHC, 2008b). For instance, the 10th plan program of Ministry of Agriculture include development of watershed management plan and sustainable management of water resources, , Ministry of Health Services emphasises strengthening advocacy for conservation and safe utilization of water resources , while Ministry of Economic Affairs stresses sustainable water resources development and management and safeguard against water related hazards .

In the country where GNH is the development philosophy, a natural resource which is woven so intimately into social and cultural aspects of Bhutanese life deserves the highest commitment from the people and government to conserve it. Without access to clean water the very basic social chore of praying in the morning with offering of seven water bowls get disturbed. Further, the globalization and the development drives to achieve higher socio-economic goals, water in abundance used for electricity generation has become the most important source of export earnings. As widely recognized, water is the principal natural resource that will drive the economy of Bhutan.

Although the commitment of government in sustainably managing the water resource is vivid in the policies and Acts, there are signs of imbalances in the implementation. One of the prominent scenarios is the collapse of irrigation systems along with its associated institutions which has hampered irrigated rice cultivation, in contrast to the expansion of hydropower projects getting higher priority. If not for all the hydropower sites, the current displacement of around 100 farming households from upper Gaselo in Wangduephodrang district by Punatshang chu Phase I is a conflicting action. The disregard of customary rights/norms and traditional social systems, could cause heavy damage to the nation as the generation old understanding and strategies for NRM is lost.

While the policy instruments seem right, the limitation may be lack of manpower and institutional mechanisms to systematically flow through the implementation. Sometime poorly implemented policy (and regulations) may lead to greater damage than operation in informal setting within a broad consensual arrangement. The rapid depletion of forest resources in the 1960s and 70s was a case of poorly implemented policies. The efforts of government to re-engage people in management of natural resources is legitimate, however the half-hearted devolution may be futile. Here people with their best traditional practices should be taken on board rather than simply as subjects to follow the prescriptive guidelines.

Within the premise of changing social, ecological, and political environment vis-à-vis globalization, water as a basic renewable resource has emerged as a primary revenue earner to support national development. As the water evolved as a multi-functional resource, it has escalated complexities in competition and conflict over water resources. Such evolution demands the need for congruent and enduring social capacities, institutions and governance systems. In chapter 5 a detailed review on the state of art on resource governance, institution and water management in proposed to enhance a better understanding about how they can cope with the evolution of water resource management.

CHAPTER 5

STATE OF THE ART ON RESOURCE GOVERNANCE, INSTITUTIONS AND WATER MANAGEMENT

The rapidly changing political environment, socio-economic conditions, climate change, and globalization are escalating complexities in competition and conflict over natural resources demanding for reforms in the social institutions which govern these resources in Bhutan (GNHC, 2008a). Causes for failure to preserve ecosystems are poor correspondence of scale of human system and ecosystem, failure to introduce governing institution, and lack of appropriate knowledge (Cutler et al., 1995). Although grounded in the ecological science (Holling 1973), resilience[1] has increasingly been tested and applied by natural and social scientists to examine a range of communities linked into social–ecological systems (Berkes and Folke, 1998; Berkes et al., 2003; Gunderson and Holling, 2002) and institutional and organizational arrangements (Folke, 2006).

5.1 Governance of a common property resource

Social-ecological systems (SES) are complex adaptive systems in which heterogeneity, multiple scales, multiple domains of attraction, surprise, and fundamental uncertainty of the functioning of the ecosystem prevails. The proposition of panarchy[2] in resource and environmental management (Holling et al., 2002) has brought in a shift from reductionist, command and control science and management to a more integrated, adaptive, systems-based approach (Berkes and Folke, 1998). Therefore, such integrated management concerns must be tackled by complex array of political, economic, institutional and social processes by which society govern an SES (Moench, 1999), otherwise governance.

The management of a Common property resource (CPR) is a widely discussed topic, ever since Garrett Hardin remarked that "*Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons*" in his

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[1] Resilience is the ability of the ecological systems to absorb changes of state variables, driving variables, and parameters, and still persist (Holling, 1973).

[2] Panarchy is the hierarchical structure in which systems of nature and humans, as well as combined human–nature systems and social-ecological systems are interlinked in never-ending adaptive cycles of growth, accumulation, restructuring, and renewal (Holling, 2001).

seminal article titled “The Tragedy of the Commons” (Hardin, 1968). According to him when property rights to natural resources are absent or unenforced, i.e. when there is open access, no individual bears the full cost of resource degradation. The result is 'free riding' and over-exploitation, what Hardin termed the 'Tragedy of the Commons'. He insistently put forth that the state control and management is a solution to ‘tragedy of the commons’. This notion of state control and disregard on local management strategies has led to widespread and long lasting controversies. Cox (1985) and Berkes (1989) disagree to the Hardin’s proposition and relate the decline of resources to the breakdown of existing commons systems due to disruptions that have originated externally to the community. Similarly, Dove (1993) and Berkes (1989) associated the tragedy of the commons to institutional failure to control access to resources, and to make and enforce internal decision for collective use, which could be either due to the inability to coordinate internally or due to an incursion of outsiders. While the privatization of the commons was considered as a means to increase efficiency of their management (Demsetz, 1964 and 1967), decentralized collective management of CPR by their users was found to be an appropriate means to avoid such 'tragedy of the commons' (Berkes, 1989; Wade, 1989; Jodha, 1986; Chopra et al. 1989; Ostrom, 1990, 1994). For a successful CPR regime, congruence of ecosystem and governance boundaries, specification and representation of interests, matching of governance structures to ecosystem characteristics, containment of transaction costs, and establishment of monitoring, enforcement and adoption processes at appropriate scale is necessary (Eggertsson, 1990; Ostrom, 1990; Bromley, 1991; Hanna, 1992). As an effective means to govern and manage CPR, Schlager and Ostrom (1992) proposed “bundle of rights” as follows:

- Access—a right to enter a defined physical property,
- Withdrawal—a right to harvest the products of a resource such as timber, water, or food for pastoral animals,
- Management—a right to regulate the use patterns of other harvesters and to transform a resource system by building improvements,
- Exclusion—a right to determine who else will have the right of access to a resource and whether that right can be transferred, and
- Alienation—a right to sell or lease any of the above for rights.

Through governance individuals and groups articulate their interests, mediate their differences and exercise their legal rights, obligations and mediate their differences for which decision-makers are held to account (UNDP 1997; Plumptre et al, 2000; Leach et. al. 2007; Moktan et al., 2008), implying the interplay of various forms of power that suits top-down control paradigm (Olsson et al., 2006). However top-down control of renewable natural resources has been said to stimulate unsustainable use of the resource (Janssen et al., 2004).

In such situation, the involvement of local resource users in decision making, and how local government is accountable to these users, influences the effectiveness of local government in natural resource sectors (Agrawal & Ostrom, 2001; Blair, 2000). Engaging users creates new spaces for citizen involvement as the 'owners', and to some extent the 'makers and shapers', rather than simply 'users and choosers' of services (Cornwell et. al., 2001) which enhances the efficiency of management regime. To sustain such initiatives, Agrawal (2001) suggested four factors as critical enabling conditions: (i) resource system characteristics, (ii) group characteristics that depend on resource, (iii) institutional regimes through which resources are managed, and (iv) external forces and authorities such as market, state and technology. However, as management of natural resource revolves within ecological, economic, and social background (Berkes, et al., 2006), the ability to respond to resource management issues depends on information, governance, social processes and structure (Adams et al. 2003).

Similarly the environmental problems which cannot be dealt with conventional science and management require alternative management and resilience thinking (Folke et al., 2002). Perhaps the ability to manage resilience may influence the form of governance (Lebel, 2006). Resilience is about system (social and ecological) flexibility in the face of change (Berkes et al. 2006). This flexibility in turn depends on the degree at which the system can self-organize and build its capacity to adapt. For building resilience and adaptive capacity, Folke et al. (2003) identified four factors that interact across temporal and spatial scales necessary for dealing with nature dynamics in SES. They are: (i) learning to live with change and uncertainty, (ii) nurturing diversity for reorganization and renewal, (iii) combining different types of knowledge for learning, and (iv) creating opportunity for self-organization toward social-ecological sustainability. Based on studies in Nepal, Hemant et al. (2008) suggests that the challenge of achieving equitable governance of renewable natural resources is related to the ways through which diverse knowledge systems come into deliberative interface to transform or reproduce relations of power and rules of practices. Sharp differences in power and in values across interested parties make conflict inherent in environmental choices. Beyond power and rules, Putnam (1994) suggested that higher levels of trust and co-operation which is self-reinforcing and cumulative leading to reciprocity, civic engagement and collective well-being facilitates better governance, which he terms as social capital. Many authors distinguish factors of social capital formation especially trust, reciprocity and collective learning (Ostrom 2003; Sobel 2002; Valentinov 2004; Putnam 1993). Social capital is conceived as possession of a durable network of institutionalized relationships of mutual acquaintance or recognition (Bourdieu, 1985), social life, norms and trust (Putnam, 1995), and as rules that reduce transaction costs of monitoring and enforcement of these rules (Ostrom and Ahn, 2003).

Governing the commons is always a struggle as effectiveness of rules change with constantly changing SES and when human drives to evade the rules. Therefore, rules should evolve for successful governance (Dietz, et al., 2003). Developing trust and reciprocity is crucial to build the social capital needed to create workable property rights (Ostrom 1998; Ahn and Ostrom 2008). In addition to trust, Heinmiller (2009) identified common preferences, shared knowledge, collaborative experiences, focusing events and expectations of future interactions as factors affecting the success of CPR governance.

5.2 Institutions

The evolutionary nature of the concept of Institution is well presented by Holling (1986), comparing institutions to ecosystems which become "brittle" over time, triggered by resource crises leading to breakdown (release) and reorganization building resilience. Resource management institutions have been extensively discussed in the literatures (Uphoff, 1986; Rungs, 1992; Ostrom, 1992) and broadly considered as a set of formal and informal norms, laws, rights, sanctions and conflict resolution mechanisms, designed to manage resources. In a SES, patterns of interrelations, sets of norms and rules and systems of values that control and organise the natural resource have evolved over generations and have shaped patterns of behaviour giving rise to unique institutional arrangements. Institutions are therefore considered as enduring regularities of human action in repetitive situations structured by rules, norms and shared strategies constituted and reconstituted by human interaction, as well as the physical world

(Crawford and Ostrom 1995), or simply a set of working rules (Ostrom, 1986) and a formal means to manage pluralism and power relations (Leach et al. 2001). Thus institutions that shape social behaviour and transported by various carriers, such as cultures, structures, and routines over generations can facilitate collective action and the solution of common pool resource problems thus avoiding the "tragedy of the commons" (Ostrom 1990). Such social behaviours evolve into formal (policies and law) or informal (social norms) prescriptions that forbid, permit, or require some action or outcome (Ostrom 1986, Crawford and Ostrom 1995). Ostrom (1990) in her book "Governing the commons: evolution of institutions for collective actions" introduced design principles of institutions for governing sustainable resources, as follows:

1. *Clearly defined boundaries:* The boundaries of the resource system (e.g., irrigation system or fishery) and the individuals or households with rights to harvest resource units are clearly defined.
2. *Proportional equivalence between benefits and costs:* Rules specifying the amount of resource products that a user is allocated are related to local conditions and to rules requiring labour, materials, and/or money inputs.
3. *Collective-choice arrangements:* Most individuals affected by harvesting and protection rules are included in the group who can modify these rules.
4. *Monitoring:* Monitors, who actively audit biophysical conditions and user behaviour, are at least partially accountable to the users and/or are the users themselves.
5. *Graduated sanctions:* Users who violate rules-in-use are likely to receive graduated sanctions (depending on the seriousness and context of the offense) from other users, from officials accountable to these users, or from both.
6. *Conflict-resolution mechanisms:* Users and their officials have rapid access to low-cost, local arenas to resolve conflict among users or between users and officials.
7. *Minimal recognition of rights to organize:* The rights of users to devise their own institutions are not challenged by external governmental authorities, and users have long-term tenure rights to the resource.

For resources that are parts of larger systems:

8. *Nested Enterprises:* Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises.

Although the design principles are neither a panacea nor abstract concepts, the validity of the framework has been studied at several sites and found legitimate in design of the institutions for governance of CPR. From 33 such studies, 75% of the cases are either moderately or highly supportive of the usefulness of the design principles (Ostrom, 2008). However, as CPR may or may not have formal or informal property rights, balancing the multiple interests and property regimes often is a major concern in management (Steins and Edward, 1999). Thus the absence of an institutional framework and top-down approach in management of CPR gives rise to co-management initiatives (Röling, 1994) which regards management issues from perspectives of common understanding of resources, joint actions and cooperation by stakeholders. Introduction of nested platforms for resource use negotiation is considered a way forward to deal with the management of CPR (Steins and Edward, 1999, Gonzalez, 2000). The key aspect of such platform is the concept of "social learning" emerging from complex interdependent stakeholder relationship in a multiple property regime. It is also suggested that important issues for collective actions through such nested platforms are:

- Ability of the individual user groups to influence decision-making within the platform,
- Influence of the collective choice and legislative institutional frameworks on the effectiveness of the platforms,
- Role of social learning, and
- Need for a third party to facilitate nested platforms.

The property regimes are not static but tend to appear and disappear and change in form and function in correspondence to SES changes (Ostrom, 1990), this shift can be considered as institutional capital (Ostrom 1994). Such change helps to maintain a balance between vertical (federal) and horizontal (local) control by dispersing across stakeholders the capacity (e.g., knowledge, power, and resources) to solve complex problems (Imperial, 1999). Analyzing the governance system of the wetland landscape of Kristianstad (Figure 5.1), Hahn et al. (2006) suggests 6 key characteristics for a successful collaboration within a social network of dynamic horizontal and vertical interactions:

- A flexible ‘bridging organization’ and ‘adhocracy’ (*an organization that does not have a fixed bureaucratic structure and can adapt to changing circumstances or a model of management or decision-making in which various groupings of individuals reach consensus by responding in an ad hoc fashion to frequently changing priorities*),
- Leadership through trust-building and conflict resolution,
- Generating and communicating SES knowledge,
- Collaboration and value formation conditional on fixed objectives, and
- The interplay between formal and informal institutions.

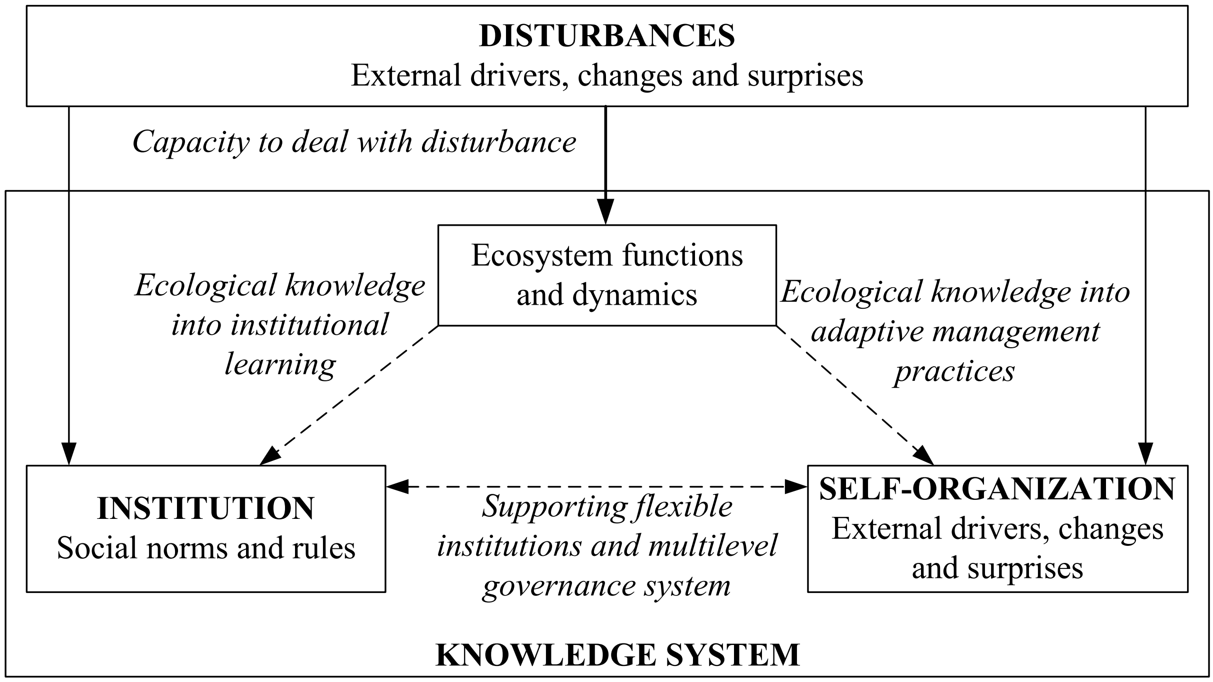


Figure 5.1. Successful adaptive approaches for ecosystem management.

(Adapted from Hahn et al., 2006)

After the failure of nationalized management approaches to CPR, the involvement of communities has strongly come forth as a pragmatic management regime. This decentralization by empowering local communities enhances the capability of local-level institutions to learn and develop to respond to environmental feedbacks faster than do centralized agencies (Berkes and Folke 1998), as centralized system delays or blocks information from the resource in the form of feedbacks (Holling et al., 1998). Even in situations where local institutions did not historically exist for a particular resource, new institutions may evolve over time, especially if higher-level institutions provide a social and political environment conducive to such development (Berkes, 2000).

Similar to the design principles of Ostrom, from multiple empirical studies Deitz et al. (2003) identified two broad principles for robust institutions managing localized resources as (i) *regional and global principles*: analytical deliberation, institutional variety, and nesting, and (ii) *local principles*: rules congruent with ecological conditions, clearly defines boundaries, accountability mechanisms, graduated sanctions, and conflict resolution. These principles are meant to satisfy governance requirements as provision of information, conflict resolution, compliance rules, infrastructure, adaptation and change. In human institutions the knowledge-power linkage is enacted, contested and resisted in governance practices (Lusthaus et. al. 2002). The treatment of knowledge in isolation of power gives an incomplete view of learning and innovation systems. Institutions are often influenced by cultural norms and customs that include a society's habits, ways of thinking, values, and informal unwritten standards. Further these socio-cultural forces operate at local, regional and national levels, and have a profound influence on the way organizations conduct their business and what they value in terms of outputs and effects. The institutional transformation linked to the concept of "social learning" and "innovation systems" results from the interaction among multi-layered sources of knowledge.

According to Röling (2002), social learning aims at a transformation from reductionism to holistic perspectives, from a positivist to a constructivist perspective to tackle complex problems as the outcome of human activity and critical thinking. As the concept of social learning implies knowledge sharing among stakeholders as a key mechanism for building sustainable societies, it is compatible with the idea of soft systems thinking (Checkland, 1981; Röling and Wagemakers, 1998) and the concept of adaptive management (Holling, 1995).

Knowledge and organisation have been identified as the most important aspects of farmer empowerment, that form a basis for establishing higher-level farmers' organisations that could represent their interests in the local government and influence national policy (Friis et al., 2008). Within this organized engagement, there is learning from sharing of diverse perspectives and experiences to develop a common framework of understanding and creation of collective action thereby building institutional learning (Schusler et al., 2003). When institutional learning happens within networks there is a change in mutual norms and institutions. The degree of consistency and collaboration among the networks influences the usefulness of interactions between institutions at different organizational levels (Young, 2002). Favourable interactions enable adaptive co-management[3] within the existing social capacity to understand and respond to environmental feedbacks over time and space, and to sustain and enhance ecosystem resilience (Berkes and Folke, 1998). In relation to the idea of existing social capital, Ostrom (1990) demonstrated that communities have relied on institutions resembling neither the state nor the market to govern some resource systems with reasonable degrees of success over long periods of time, implying that functional local arrangements and institutions existed within communities. However, in a highly globalized world, broad influences of global trade and multilateral institutions like World Trade Organization, the World Bank, and International Monetary Fund have increasingly influenced environmental governance institutions (Dietz, et al., 2003).

5.3 Water resource management

Water sustains life and all social and environmental processes, yet it is one of the endangered natural resource (Simonovic, 2009) which raises the question of ownership, management, and technological development (Coopey et al., 2005). Globally, around 70% of water withdrawals are for agriculture, with remaining 30% for domestic, industrial and leisure uses depending on access, quantity, quality and socio-economic conditions. Overall, global water consumption has increased almost tenfold from 1990 to 2000 (FAO, 1993). Growth in population, increased economic activity and improved standards of living lead to increased competition for and conflicts over the essential but limited freshwater resource (GWP, 2000). Basically human actions bring about water scarcity in three ways: through population growth,

[3] "adaptive management" stands for learning from deliberate experimentation and "co-management" is collaboration among local actors as well as with higher level organizations and institutions.

misuse and inequitable access (FAO, 1993). Freshwater which is inevitable for human, agriculture, industries and natural environment has become scarce (WWF, 1989) and is a full-scale emergency (UNEP, 1999).

The International Water Management Institute (IWMI) highlighted the issue of access to safe and affordable domestic water supply and sanitation, and the perceived physical scarcity of water as the most widely discussed issues on water (IWMI, 2004). According to the comprehensive assessment of water for agriculture, a third of the world's inhabitants now face physical water scarcity[4] and economic water scarcity[5]. One-quarter of the world's population now live in river basins where water is physically scarce and around one-sixth inhabit catchments where water is economically scarce (Comprehensive Assessment, 2007). Water resource management is influenced by the limits of biophysical, socio-political and economic processes to meet goals like production and especially food security, its profitability, risk aversion and wider community goals such as poverty alleviation, welfare of future generations, and environmental conservation (Campbell et al., 2001). All NRM systems involve multiple stakeholders, with multiple perceptions and objectives operating through interacting mechanisms. The interactions in water management can be considered as upstream-downstream relations, farm level trade-off, food security, risk aversion, environmental conservation, thus posing complexities for management. Such complexities arise from (Campbell et al., 2003):

- Multiple scale of interaction (from the field to the watershed levels),
- High frequency of non-linearities, uncertainty, and time lags in complex systems,
- Multiple stakeholders with often contrasting objectives,
- Context specificity of INRM sites, and
- Problems of maintaining integration in the face of numerous components and interactions.

As a water resource system comprises of individual, organization, society and environment, it is very closely associated with the social system in a given ecological context. Within this complexity, neither regulation nor economic incentives, nor education or shifts in

[4] where there is not enough water to meet human and environmental demands
[5] where water may be plentiful in nature but there is insufficient investment or human capacity to satisfy demand for water

property rights, is the "right" management strategy. The challenge for the water resource manager is to manage these elements within the environment and across individuals, organizations and the society to achieve sustainable management (Simonovic, 2009). Further, against the backdrop of above complexities, management effectiveness will always be limited by incomplete knowledge and understanding of dynamic interactions between natural and social systems. The knowledge which stakeholders use to define the problems of resource use falls into three realms: knowledge of the empirical context; knowledge of laws and institutions; and beliefs, myths, and ideas (Adams et al., 2003). The variation in knowledge and understanding results in inherent conflict which needs to be taken into account for developing strategies to address NRM issues (Bullock, 2008). Through irrigation technology, societies controlled and manipulated natural water supplies to improve crop production. The result was often reliable and ample food supplies were produced which led to the creation of stable agricultural villages and nation states, the division of labour and economic surpluses (FAO, 1993). Water resource use and management has evolved through generations of stewardship, control and technologies. For ages water resources have been appropriated and used for benefit of humanity, which is best explained by "*Water is the patrimony of mankind"* (GCWC, 1998), as adaptation of water use and management in an evolutionary context over generations.

It is evident that past initiatives on water management (drinking, irrigation, flood control, land reclamation) mostly came from the state in the form of structural interventions like reservoirs and canals (Table 5.1). Among several traditional water management schemes, one is the primary pond (*Sayama-Ike*= mother pond), secondary and tertiary field ponds interconnected with canals near Osaka, Japan. Technological innovation has helped in restoring the system which is still in use. The water sharing among the users is done through water users associations and their federation. In 1980, the Japanese government enacted the Irrigation Association Law which promotes the federation of water users for sustainable water use (Coopey et al., 2005). Many countries actually used the approach of river basin committees to manage water resources to address local management issues. In China as the resource and system is owned by the state, users have to pay a water rent which curtailed mismanagement and ensured sustainable use. France adopted a centralized public utility model of water allocation where its "*Agences de bassin*" (Basin Agencies) were assigned with the responsibility to develop long term plans and manage water resources sustainably. India from the very early age used water tanks to collect rain water and well to draw ground water, to manage the network of tanks, village committees and water user associations were established. However, water diverted from multipurpose dams is regulated by the state. From the above cases (Table 5.1), it is evident that efforts to equitably allocate water and sustainably using it had been an everlasting strategies in all countries, otherwise a scenario of supply driven management systems. However, dwindling water volumes and increasing users pose multiple challenges in providing sustainable and equitable water services. In 1994, experiencing the increased freshwater stress due to rapidly increasing demand worldwide, the UN Commission for Sustainable Development conducted the Comprehensive Assessment of the Freshwater Resources of the World. The study concluded that a complex web of physical, social, economic and political interrelationship is necessary to enhance the efficiency of water systems to support both strategies of health and sustainability. It reiterates the need to increase understanding of water related problems and potentials (Kjellén and Mcgranahan 1997).

Table 5.1. Examples of water management systems in different countries.

Country	Management system	Reference
Chile	- Comprehensive water allocation system that establishes tradable property rights. - *Chile's water law*: allows trade between and among economic sectors; protects third party rights; establishes compulsory water user associations and a national water authority to resolve conflicts; and allows for judiciary solutions to those conflicts not resolved by water user organizations or the water authority. Water transfers require authorization at two levels : those of the local water user associations and the national water authority.	FAO, 1993b.
China	- River basin committee (6 for the Yangtze, Yellow River, Huaihe, Songliaohe, Haihe, Pearls and Tai Lake) that manage water resource management at the national level. - Water resource bureau at prefecture and county level. At district level irrigation districts and field canal committee manages the local schemes.	Liao et al., 2008
France	- Centralized public utility model of water allocation (River Basin Committee – RBC- and Basin Agency) - The RBCs approve 20- or 25-year water development plans and, every five years, establish action plans to improve water quality. They also set two fees to be paid by water users: one for water consumption and the other for point source pollution. The fees provide incentives for users and also form a fund to encourage better water use through grants or soft loans. The RBCs include representatives from national, regional and local government administrations as well as individuals from industrial, agricultural and urban interests.	FAO, 1993b.
India	- Tank systems, developed ingeniously and maintained over the centuries, have provided insulation from recurring droughts, floods, vagaries of the monsoon, and offered the much needed livelihood security to the poor living in fragile semi-arid regions. - Use of village council: supervisory and regulatory task for equitable water sharing. - Water User Associations.	Sakthivadivel et al., 2004
India	- Institutional arrangement (i) 'collective choice situations' that may involve decisions about planning, development and management of the resources and sources, (ii) 'entry' and 'exit' rules that concern exclusion of potential beneficiaries and seek to regulate access and use of the village water resources and sources, (iii)'operational rules' that regulate the use and day-to-day maintenance of the water sources.	Singh, 2006
Iran	- In 2000 BC village councils were formed to assign water rights of village inhabitants for irrigation and other purposes.	Marjanizadeh et al., 2009
Japan	- Use of Sayama-Ike (mother tank) and secondary and tertiary tanks to share and use water for irrigation is a worthy example of use of technology to enhance access of water (*River Act 1896).* - Federation of water users association (*Irrigation Association Law 1980*).	Hatcho and Matsuno, 2005
Nigeria	- River basin development authority and Water users association – cooperative management of public sector scheme.	Bala et al., 2005
Australia	- Relatively decentralized and based on entitlements or rights to specific quantities of water.	FAO, 1993b.
The Netherlands	- Reclamation of land with dykes since the 14th century. Establishment of water boards to develop better local and regional water management. In the 21st century established a State Committee for Water Management.	Bruin et al., 2005
United States	- "First in time, first in right", private individuals cannot "own" water but have "usufructuary" rights. The state retains ownership and determines which uses are beneficial.	FAO, 1993b

According to the World Water Council the pressing issues related to water resource are access to safe and affordable water, destruction of wetlands and its biodiversity, limited use of water conservation technologies, exploitation of ground water, and the sectoral management of water (WWC, 2000). The first 'Conference on the human environment' forum is 1972 included natural resources (air, water, land, flora and fauna) in its declaration as one of the principles and urged in safeguarding it for the benefit of present and future generations through careful planning or management (UNEP, 1972). Subsequently, the International Conference on Water and the Environment (ICWE, 1992) highlighted the serious risk posed by the mismanagement and scarcity of fresh water, and drew the following four principles for management of freshwater as: (i) freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment; (ii) water development and management should be participatory—involving users, planners, and policy makers at all levels; (iii) women are central to providing, managing, and safeguarding water; and (iv) water has an economic value in all its competing uses and should be recognized as an economic good. These principles came to be known as the Dublin Principles which form the heart of the integrated water resource management (IWRM) concept (ICWE, 1992) as is became widely accepted that the water crisis is associated to many interacting trends in a complex system for which real solutions require an integrated approach to water resource management. The three primary objectives of IWRM (WWC, 2000) are to:

- Empower women, men, and communities to decide on their level of access to safe water and hygienic living conditions and on the types of water-using economic activities they desire and to organize to achieve them.
- Produce more food and create more sustainable livelihoods per unit of water applied (more crops and jobs per drop), and ensure access for all to the food required for healthy and productive lives.
- Manage human water use to conserve the quantity and quality of freshwater and terrestrial ecosystems that provide services to humans and all living things.

IWRM can be considered as the way in which water can be managed to contribute to the achievement of the objectives of sustainable development (GWP, 2009). It is an approach that reflects the need to achieve a balance among the three Es of IWRM: Environment, Equity and Economy (Figure 5.2).

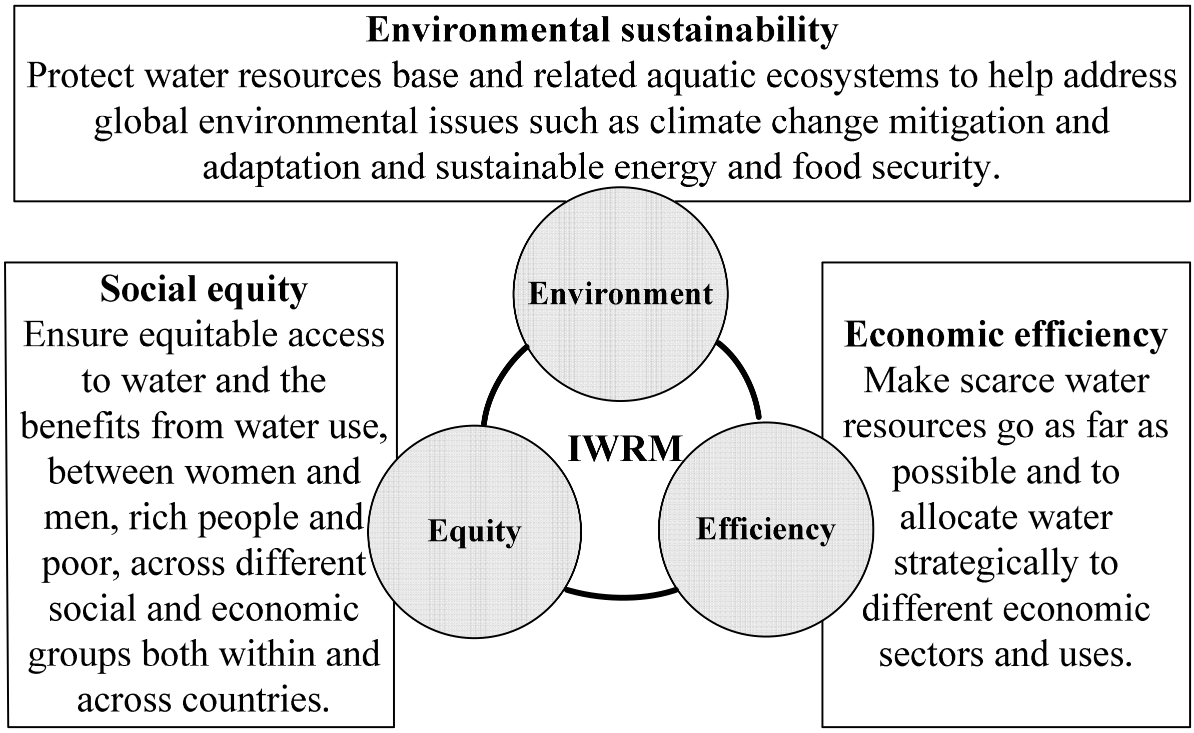


Figure 5.2. Three Es of Integrated Water Resource Management (Adapted from Ker Rault and Jeffrey, 2008).

Various initiatives by international organizations resulted in founding the Global Water Partnership in 1996 to foster IWRM which is defined as the coordinated development and management of water, land, and related resources in order to maximize economic and social welfare without compromising the sustainability of vital environmental systems (GWP, 2010). GWP operates through its 13 regional networks[6] and 74 Country Water Partnerships which provide a neutral and multi-stakeholder platform for dialogue and facilitating change processes. They manage and govern themselves, and bring about solutions that are tailored to local conditions and informed by local experiences.

[6] They are the Caribbean, Central Africa, Central America, Central and Eastern Europe, Central Asia and Caucasus, China, Eastern Africa, Mediterranean, South America, South Asia, Southeast Asia, Southern Africa and West Africa networks.

The fundamental goal of water resource management seems to assure fair distribution of the resource, promote user participation in management, and ensure sustainability of the resource. However, as the management of renewable resources involves the interactive roles of a diversity of stakeholders characterized by different perspectives, experiences, knowledge and interests in the management of the resource to be shared, they have varying level of access to and control over, decision-making, and specific knowledge about NRM processes. This difference often leads to power relations between stakeholders which are negotiated over space and time depending on various factors in the local context (Cornwall, 2000). Based on these principles, something resembling a standard package of water reforms to national water policy and law has been developed in most countries.

The study of water governance in the Mekong region (Williams and Weale, 2006) revealed that IWRM has been applied as a 'blueprint' and one-size-fits-all approach without considering the diversity of the social, political, and ecological contexts. As a result the relevance of water policies are questionable. The prescriptive approach of IWRM in situations where watersheds overlap with other jurisdictions like administrative and political ones makes it difficult to implement (Butterworth et al., 2010). Williams and Weale considered IWRM as 'off-the-shelf' generic reforms that may not work in local situations. The lessons from implementing IWRM in South Africa (Anderson et al., 2008) highlights the need for a concerted effort towards identifying implementation mechanisms and approaches rather than debating on the definition of IWRM. As IWRM over emphasised policy and legislations, it hardly brought any tangible change or promoted poverty reduction at the grassroots level. South African cases indicated a long gestation period which disillusioned people leading to reversal to old practices. They showed that IWRM is most effective when initiatives actively empower disadvantaged groups through their involvement in projects that serve to improve the livelihoods and well-being of communities. While the benefits exist, the implementation has been slow, due to uses of a 'command and control' regime to manage water demand across a river basin by IWRM approach (Lankford and Hepworth, 2010).

The three objectives of IWRM are conflicting and difficult to achieve together (Figure 5.2). As a result, the entire process appears to be naturally steered by the state leading to paternalistic, technocratic and bureaucratic top-down approaches (Molle, 2008). This author found that efforts to improve water management, for instances through the introduction of irrigation management transfer (IMT) in Sri Lanka, tradable water rights in Sri Lanka, Bolivia, Ecuador and Peru, participatory irrigation management (PIM) in Pakistan, irrigation water pricing in Thailand, have not actually picked up, instead citizens have resisted. According to him the beneficial impact of the IWRM movement has been to disseminate socially and environmentally sensitive concepts and, perhaps, to inspire a new generation of water professionals. Butterworth et al. (2010) reason out that the vagueness of the concept itself could be the primary cause for delayed achievement of impacts from IWRM implementation. Further non-inclusion of concerns of poor and marginalized people in IWRM projects is often a cause for grievance (Merrey, 2009). Some of the common criticisms on IWRM (Butterworth et al., 2010) are listed below:

- Vague concept: in terms of what aspects to be integrated, how, by whom,
- Not sufficiently people-centred and limited stakeholder participation,
- Non conformity to adaptive management principles,
- Ignorance of customary/traditional/local water management strategies, and
- Over emphasis on legitimacy.

GWP substantiates the drawbacks of IWRM to application as the blueprint does not deliver concrete benefits. As there is the risk of linking too many variables without clear objectives which can stall IWRM processes (GWP, 2009). However, the effectiveness of the IWRM approach can be enhanced by uses of the right mix of hard and soft tools. Despite the criticisms, GWP claims that social and economic life is more secure in areas where IWRM is implemented than it otherwise would have been, as an outcome of better water management (GWP, 2009). GWP also enlisted the key lessons from the review of the case studies as follows:

- IWRM is not a one-size-fits-all prescription and cannot be applied as a checklist of actions. Pragmatic, sensibly sequenced institutional approaches that respond to contextual realities have the greatest chance of working in practice.
- Water resource planning and management must be linked to a country's overall sustainable development strategy and public administration framework.
- Water management must ensure that the interests of the diverse stakeholders who use and impact water resources are taken into account.

- Approaches to water resources management will evolve as the pressures on the resource and social priorities change. The challenge is to develop institutions and infrastructure that can adapt to changing circumstances.
- While the river basin is an important and useful spatial scale at which to manage water, there are often cases where it is appropriate to work at smaller sub-basin scale or at a regional multi-basin level.

The command and control approach in NRM does not work, even for water. A top-down approach, without a shared legitimacy of decision over water, indeed leads to non-compliance of rules and over-exploitation of resources (Lankford and Hepworth, 2010). Multi-stakeholder platform (MSP) is a negotiation approach which helps in legitimizing, at least in part, by demonstrating a high-quality process. To do so requires attaining and maintaining high standards of deliberation, facilitation, inclusiveness, information exchange and communication with the participants and wider constituency (Dore et al., 2010). Not discerning the well-tested approaches, the three basic types of "water rights" systems will always prevail and are: (i) riparian - only those owning the land in physical contact with a natural watercourse have a right to use it; (ii) prior appropriation - based on beneficial and actual use; and (iii) public administration - a public authority authorizes water distribution and use. Prior appropriation and public administration are the most common systems in use throughout the world (FAO, 1993).With uncertainty of IWRM impact and basic water rights systems, concepts which are more decentralised, local based, collectively owned and oriented to locally agreed standards have been proposed. Among them Polycentric WRM appears to be a pragmatic management approach with micro-catchments as sub-units of basin built of legal framework of customary laws and reflexive law which is self-regulating, self-referenced and rationale. It is also more self-regulating compared to IWRM which is less open to a decentralised, modular and informal mode, on to which more formality and federalisation may be associated in the future (Lankford and Hepworth, 2010).

Water resource management poses both challenges and opportunities. The challenges arise mostly from two aspects. The first one is related to “power and control” over the water resources. The challenges further arise from the way the state operates a centralized regulatory approach to manage the resources and when the bureaucratic process ignores local institutions, and norms, there is always a tension of non-compliance of legal frameworks. Further any well intended interventions of the state are considered as top-down and have the problem of legitimacy. Secondly the mismatch between the global and local issues and strategies could be a major hurdle in many developing countries as local capacities vary extremely. In addition when the governments of developing countries agree to global movements of natural resource management like IWRM, Participatory irrigation management (PIM), and Irrigation management transfer (IMT) the issues consolidated at the global level often do not have local essence. Therefore the strategies too are inconsistent to the local issues.

In parallel the water management issue provides opportunity mainly as it can vertically be linked from local to regional to national, and now global, which can provide a prospect to enhance citizen engagement in governance within the principles of polycentric governance. As a broad-based planning platform polycentric WRM helps in realizing the multifunctional nature of water resources, its linkages and influences which broaden the scope, relevance and ownership of the intervention.

This review provides a better understanding of the need for generating knowledge, capacities (social and institutional), and communication through trust building, collaboration and value formation. This new found social capital should lubricate interplay between formal and informal institutions and bridge them to promote adaptive management. It is also evident that within the constantly changing SES there will always be a need for adaptive management systems, vibrant institutional arrangements, and polycentric governance which too evolves. Chapter 6 will examine if and how collaborative modelling can help in generating such knowledge, capacities , communication, trust building, collaboration and value formation as the way forward in water management.

CHAPTER 6

STATE OF THE ART IN COLLABORATIVE MODELLING

Social-ecological systems (SES) are often referred as complex adaptive systems with heterogeneous domains and functional diversity (Janssen *et al.,* 2004) and the ability of society to respond to resource management issues depends on information, governance, social processes and structure (Adams et al., 2003). In such situation, it is important to enhance communication by reducing complexity to help people find meanings and shared understanding (Sierhuis and Selvin, 1996). Models have been used to simulate the human process of learning in systems thinking and practices to communicate complex interrelationships, communicate concepts, search for new insights about how systems functions, and evaluate scenarios (Wilson and Morren, 1990). Models also have the ability to represent the system structure and dynamics in a simplified form to enhance understanding of social and bio-physical processes (Kolfschoten et al., 2008). Because models developed by researchers only are little used, collaborative modelling approaches are needed to effectively share and generate new knowledge, and relate information for better understanding of the systems and guide management decisions (Costanza and Ruth, 1998). Importantly collaborative modelling helps segregate factual conflicts from value conflicts aiding to build trust in the analysis and to arrive at a shared vision of how the system can work. Collective shared understanding of key factual issues enables beneficial debate on the issues. Collaborative modelling also fosters learning among stakeholders and decision makers about both the system and the stakeholder's needs (Lorie and Cardwel, 2006).

6.1 Collaborative modelling and NRM

The scope of NRM is so wide that no single institution has jurisdictional responsibility (Bellamy et al. 2002, 2005). NRM takes place in complex human landscapes with multiple stakeholders such as local people, various levels of government, non-governmental organizations, and private sector actors who have different perspectives, interests, entitlements, knowledge, capabilities, values and power (McDougall and Braun, 2002). Often the NRM policies are vague, persistent, socially constructed and often disputed for being top-down (Rittel and Webber, 1973). Such complexities pose difficulty to comprehend the issues in a holistic manner and conceive relevant management strategies. Modelling as an approach to simplify SES structures and dynamics for better understanding has been widely used. Although local knowledge is a vital source of indigenous knowledge, it alone is not sufficient for rural development (Ostrom et al., 1993). Traditionally, models were constructed by experts and scientists who are much more detached from the decision-making process than the actors who have a stake in the NRM issue that is decided upon. In contrast collaborative or participatory modelling approach is one means to integrate knowledge of local stakeholders in the modelling process to elucidate the interrelationship between users and resources (Van Walsum et al, 2007; Institute of water resource, 2009, Carmona et al., 2008), and the common understanding it develops helps to set up sustainable management strategies (Loucks, 2006). This implies that a NRM model should represent the physical aspects of the resource, the social aspects of its utilization, and the interactions between these aspects (Bots and van Daalen, 2008). While a collaborative modelling process is a positive way for stakeholders to express their views and interests in managing a resource, and encourage collaborative learning through participation (Purnomo et al., 2003), there is always a mismatch between what models can deliver to what is expected by the participating stakeholders. Sometime the time taken to process the data may wane off participants. As specified by Bots and van Daalen (2008) the outputs of models deal with six different purposes: research and analysis, design and recommend, provide strategic advice, mediate, democratize, and clarify arguments and values. Therefore in participatory modelling, model applicability, accessibility and accuracy needs to be evaluated and understood by participants and modellers (Johnson, 2009). The success of the collaborative modelling exercise will depend on the choice of the model, the integration of participants' knowledge and opinion, the transparency of the process, the continuity of participation, application of model by the local stakeholders and the efficiency of the modeller (Johnson, 2009; Purnomo *et al.,* 2003).

Vavinov and Bousquet (2010) posits participatory modelling as a powerful tool to enhance stakeholders knowledge and understanding of a system and clarify the impacts of solutions to a given problem to support decision making, policy, regulation or management. Their elaborate review on modelling with stakeholders listed group model building, mediated modelling, companion modelling, participatory simulation, and shared vision planning as some of the modelling tools where stakeholders are engaged. Based on the, Companion Modelling is one of the collaborative modelling approach that supports generic principles of good participatory modelling (Table 6.1).

Table 6.1. Some generic principles of good participatory modelling.

- Flexible and focused on the process rather than the product.
- Open and evolving
- Promote adaptive management and adaptive decision making
- Maintain societal and scientific openness, and transparency of methods and models.
- Rely on collaborative research, and open source models
- Always be aware of social and group dynamics, special interests, power and hierarchies
- Facilitate and encourage learning from each other and the process
- Supports iterations
- Accommodate uncertainty and non-traditional metrics of success

(Source: Vavinov and Bousquet, 2010)

6.2 Origin of Companion Modelling

The management of SES characterized as a complex ecosystem has shifted from reductionist, command and control science and management to a more integrated, adaptive, systems-based approach (Berkes and Folke, 1998; Holling *et al.,* 2002). Similarly during 1970s the analytical tools also shifted from static to dynamic systems. To handle the complex dynamics of SES and its interactions, Multi-agent systems (MAS, also referred as agent-based modelling) are considered as promising tools (Janssen, 2002). Computer MAS provide an innovative perspective to represent human agents in modelling by making use of the cellular automata technology to represent agents[1] as computerised independent entities capable of acting flexibly (goal-directed, reactive, and interacting with other agents) and autonomously in a common environment having its own dynamic.. A MAS is an assembly of agents[2] with specific goals capable of perceiving, communicating, interacting and acting in an environment with other agents (Ferber, 1999) (Figure 6.1).

[1] Minimal definition of agent and MAS: An agent can be a physical or virtual entity that can act, perceive its environment (in a partial way) and communicate with others, is autonomous and has skills to achieve its goals and tendencies. It is in a multi-agent system (MAS) that contains an environment, objects and agents (the agents being the only ones to act), relations between entities, a set of operations that can be performed by the entities and the changes of the universe in time and due to these actions (Ferber, 1999).

[2] Three different kinds of agents can be distinguished: humans who differ in mental maps, goals, locations, and abilities; non-humans such as animals and plants; and passive agents such as non-living entities (Janssen, 2002).

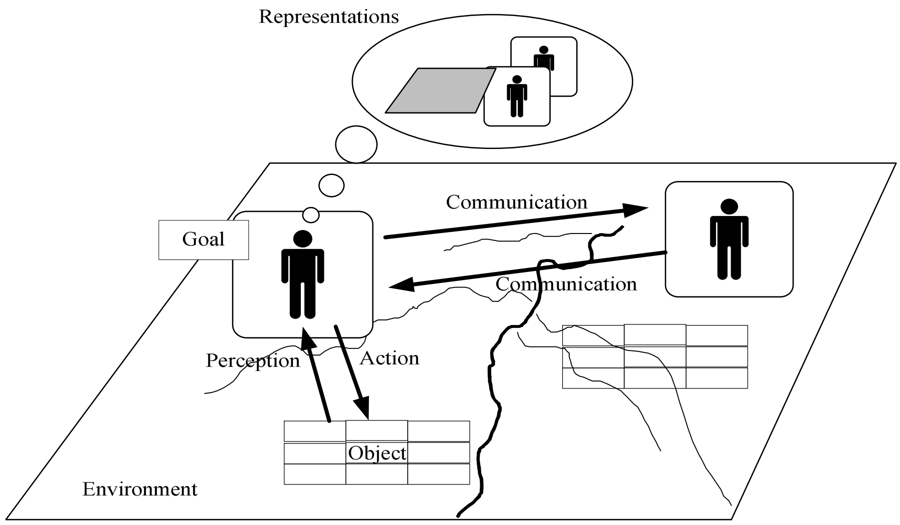


Figure 6.1. Multi-agents system general organization and principles (adapted from Ferber, 1999).

The potential for increased understanding of how changes in individual behaviour affect the behaviour of the SES at larger scales is part of the motivation of what has come to be called multi-agent modelling in the resource management and ecological economics literature (Janssen, 2002). MAS also bring a radically new solution to the very concept of modelling and simulation in environmental sciences by offering the possibility of directly representing individuals, their behaviour and interactions (Ferber 1999). In resource management, the underlying principle of MAS as the interaction between agents provides potentials to understand the relationships among agent behaviours, their interactions, and the resulting dynamics at different levels of organization (Barreteau *et al.,* 2001; Anderies, 2002; Bousquet *et al.,* 2002). MAS with the capacity to create virtual societies can be used to simulate dynamics and associated feedbacks in resource systems.

Based on the constructivism theory, people construct reality within their capacity of experiences, and knowledge (Roling, 1996). This theory broadened the scope for the collective creation of a common artificial world as a shared representation to stimulate and explore scenarios (Bousquet, et al., 2002). This premise led in particular to the development of a modelling and simulation tool called CORMAS – Common-pool Resource and Multi-Agent Systems (Bousquet *et al.,* 1998, http://cormas.cirad.fr). Further, ideology of exploitation and conflict in common-pool resource (Hardin, 1968) paved the way to adaptive management

(Holling, 1978) and co-management (Berkes, 1997) which are compatible with the principles of 'patrimonial[3] mediation[4]' (Borrini-Feyerabend *et al.,* 2000). In the direction to integrate theoretical concepts of constructivism and patrimonial mediation, Bousquet et al. (1999) suggested coupling of role games with computer Agent-Based Models (ABM) because of their complementarities (Table 6.2) in simple representations of complex realities. A role-playing game (RPG) can provide a suitable methodological framework to build a communication enhancing and negotiation support tool (Etienne, 2003). The engagement of scientist/modeller as associate to the local stakeholders in thinking process and decision making by series of simulation tools adapted to their successive needs introduces the social dimension of companion to simulate the co-evolution of the social-ecological interaction. In 1996, a new approach called Companion Modelling (ComMod) to examine complex natural resource management issues was formalized by the GREEN (Management of renewable resources and environment) research unit at CIRAD, France (Trébuil, 2008).

Table 6.2. Complementary features between agent-based models and role-playing games.

Agent-based models	Role-playing games
agents	players
rules	roles
interface	game set
simulation	game session
time step	turn

As per the ComMod charter (Barreteau, *et al.,* 2003), this approach is designed to deliver an improved understanding of the complex processes through a mutual recognition of collective representation of the issue at stake to enrich the decision-making process in terms of technical information and social aspects. A general feature of ComMod is that the models are designed and refined in a process involving the participation of stakeholders and experts (Scott, 2008). Based

[3] Patrimonial is defined as 'all the material and non-material elements that work together to maintain and develop the identity and autonomy of their holder in time and space through adaptation in a changing environment' (Ollagnon, 1991).

[4] Mediation is a negotiation method that brings in a third, neutral party in order to obtain agreement among the parties involved in the process; it is an approach in which each party's views on the issue or problem are translated for the others (Babin and Bertrand, 1998).

on the above principles, the most important theoretical foundation of ComMod are the science of complexity, post-normal science, and the constructivist epistemology.

6.3 Theoretical background

6.3.1 Science of complexity

Complexity refers to a simple event at micro level leading to the emergence of complex phenomena at macro level (Jiggens and Röling, 2002). Complexity elaborates how physical and social phenomena persist to exist within the constant order and disorder displaying multiple equilibrium and with interactions between elements. Thus complex systems are potentially unstable but also unpredictable (Urry, 2005). The complexity of living systems of people and nature emerges not from a random association of a large number of interacting factors but rather from a smaller number of controlling processes (Holling, 2000). The concept of complexity is the notion that "*any complex whole is more than the sum of its parts*" (Hyanes, 2003). A complex system is one in which numerous independent elements continuously interact and spontaneously organize and reorganize themselves into more and more elaborate structures over time, as small set of critical processes create and maintain this self-organization (Holling, 2001). In other words, complex systems are characterized by emergent structures on a macro scale influenced by interactions between micro level agents (Janssen, 2002). Within this frame, SES can be seen as complex adaptive systems (Janssen *et al.*, 2004). Social and natural worlds are interdependent and co-evolving, subject to discontinuities and shocks stemming from various dynamic sources. As such social science emphasizes the complex, self-organizing, non-linear characteristics of social, technical and natural interactions (Urry, 2005).

The 10 key concepts of complexity science and their key characteristics put into three sets by Ben *et. al.* (2008) provide a way of better describing and understanding dynamics and processes of change found in a range of physical and biological phenomena. (i) systems – *interconnected-interdependent elements, feedback processes, and emergence*, (ii) change – *nonlinearity, sensitivity to initial conditions, phase space, chaos and edge of chaos*, and (iii) agency – *adaptive agent, self-organization, and co-evolution*. These characteristics of complex systems also lead to uncertainty in outcome therefore poses difficulty in modelling (Holling, 2001). The SES with its complexity features has self-reinforcing mechanisms that prevent shifts into other configurations (Folke *et al,.* 1998, Gunderson and Holling, 2002) which will be important to understand and capture. The emergent phenomena of the complex SES can be studied and predicted (Bradbury, 2002) as it provides insights as to how simple local rules lead to emergent macro-level structures (Janssen, 2002).

Considering the diversity of stakeholders (agents) and spatial settings (distribution of resources in an environment), MAS is a promising approach that focus to understand persistent emergent phenomena arising from context dependent, non-linear interactions of the objects and rules (Janssen, 2002; Holland, 1998). In the SES, the local individual actions generate emergent global dynamics, and modelling individual behaviour of interacting heterogeneous agents to understand changes in collective NRM inspired MAS applications (Marty, 2002).

6.3.2 Post-normal science

In search of scientific means to enquire phenomena (or processes) of biological organization and human interaction, Gregory Bateson first made reference of a new kind of science in 1958 which later came to be known as 'post-normal science' (Tognetti, 1999). The management of natural resources in a rapidly changing environment is not straight forward, as social factor loom large (Wilson and Morren, 1990). Further the difficulty arises from the tendency of ecosystems to change over time in an unprecedented manner, more so when the resource is under pressure. In an overexploited ecosystem change is rapid and outcomes are unpredictable both quantitatively and qualitatively (Holling, 1986; Gunderson *et al.,* 1995). This unpredictable emergence further adds to the complexity of SES. To fully understand the complexities of uncertainties, plurality of legitimate perspectives, and their services have been considered beyond the realm of science (Watzold and Schwerdtner, 2005; Hulme 2007; Francis, 2009). Conventionally a system is defined based on its elements and their interaction from the researcher's perspective (in economics, forestry, hydrology, etc.) disregarding others as simply systems noise (Waltner-Toews *et al.,* 2003), implying that inability of normal science to capture holistically. In situation where "facts are uncertain, values in dispute, stakes high and decisions urgent", post-normal science is an appropriate methodology for managing complex issues (Funtowicz and Ravetz, 1991, Funtowicz and Ravetz 1992, 1993; Futures, 1999). Post-normal science also provides a means of enquiry of the relationship between humans and environment in a hierarchical framework of systems (Tognetti, 1999), thus engaging stakeholders impacted by decision and the process as in the case of SES (Hemmati, 2002).

Collaborative modelling draws the essence of using local knowledge from the theory of post-normal science. This is in contrast with normal science, characterized as an extension of laboratory, puzzle-solving approaches that externalize uncertainty and are not appropriate for addressing complex global environmental problems. The key challenge in post-normal science is the need for reflexive discourse in the decision process that allows for diverse kinds of knowledge and perspectives to facilitate mutual learning among public officials and other stakeholders as to what the trade-offs and uncertainties are, including how they are distributed (Tognetti, 1999).

The ComMod approach which involves stakeholders from conceptualization to model building, to gaming and scenario simulation is built on the ambition to support multiple and diverse perspectives, broadening the frame of reference and view problems in a larger context. It also promotes reflexive discourses to establish shared learning and to enhance collective decision-making process.

6.3.3 Constructivist epistemology

Jean Piaget's concept of the ability to accurately represent the world and perform logical operations on mental representations of concepts grounded in interactions with the world was decisive to introduce the theory which Glasersfeld (1985) formulated as 'constructivism'. Constructivism, unlike nativist[5] and empiricism[6] theories asserts that we construct our cognitive abilities through self-motivated action in the world. Two principles dominate the theory of constructivist epistemology as (i) radical constructivism: knowledge is actively built by cognizing subject, and (ii) cognition is adaptive: it serves the organization of the experimental world and not the discovery of ontological reality (von Glasersfeld, 1985). Radical constructivism is radical because it breaks with convention and develops a theory in which knowledge does not reflect an "objective" ontological reality, but exclusively an ordering and organization of a world constituted by our experience. The radical constructivist has relinquished "metaphysical realism" once and for all, and finds himself in full agreement with Piaget, who said: "intelligence organizes the world by organizing itself." Knowledge as multiple perceptions are not the logic of reality, rather it is always the logic of your experiences (Bettoni and Eggs,

[5] which describes cognitive development as the unfolding of innate knowledge and abilities.
[6] which describe cognitive development as the gradual acquisition of knowledge through experience

2010). Knowledge is always the result of a constructive activity rather than the accumulation of propositional data (such as position and heights of mountains). In other words, constructivism shifts the focus of attention from the propositional “knowing that” to the pragmatic “knowing how.” (Riegler, 2005). Central to constructivism is its conception of learning. von Glasersfeld (1995) argues that "from the constructivist perspective, learning is not a stimulus-response phenomenon. It requires self-regulation and the building of conceptual structures through reflection and abstraction".

Chiari and Nuzzo (1996) argue that constructivism is an approach to overcome the realism-idealism dichotomy, and distinguish two broad categories of constructivism: "epistemological" and "hermeneutic". While epistemological constructivism believes that the external reality (complex systems) can be represented in several ways, hermeneutic constructivism implies that knowledge is an interpretation which can be contextually verified. Constructivist approaches demand the inclusion of stakeholders in scientific explanations and favours a process-oriented approach rather than a substance-based perspective. The cornerstone of the ComMod approach is the active participation of the stakeholders in constructing reality and developing shared representations of it to facilitate collective learning and acquisition of knowledge. It is process-oriented and integrates new learning, sharing of multiple points of view, and rely on fundamental principles and key tools to enhance the relevance of the process outcomes.

6.4 Principles and objectives of ComMod

The flexibility of the MAS approach and the versatility of the RPG tool leads to an incremental, progressive and iterative process to support inquiry of NRM in a complex SES (D’Aquino, et al., 2002). The diversity of stakeholders’ perceptions and unpredictability of the change provides opportunity for application of ComMod (Bousquet and Trébuil, 2005). As such the ComMod approach requires an enduring iterative confrontation between reality and theories (Barreteau, O., *et al.*, 2003). Therefore, the principles of ComMod are (i) a constructivist approach, (ii) an enduring iterative and engaged research process in which researchers are seen as one category of stakeholders, (iii) systematic evolution of hypothesis by field actors in a transparent way, and (iv) acceptance of all point of views as a priori legitimate ones.

Construction of an artificial world: In a highly complex world, ComMod provides a means to integrate multiple perceptions of stakeholders including those of researchers to simplify the biophysical and social environment representation the whole complexity of the system in a holistic way (Bousquet *et al.,* 2002). This posture is based on the theoretical concept of constructivist epistemology recognizing that knowledge and understandings are constructed based on the perceptions. In a ComMod process, the researcher becomes an actor of the system under study and a facilitator of exchanges among its stakeholders. The researcher's point of view is only one among other legitimate ones (Trébuil, 2008). As specified in the ComMod Charter (http://cormas.cirad.fr/ComMod/en ; Barreteau *et al.*, 2003) this approach leads to process-oriented research dealing with genuine stakes and an implementation in the field with the concerned stakeholders. ComMod considers that stakeholders' decision making processes need to be elicited to understand interactions (Bousquet and Trébuil, 2005). Dealing with the combination of complex and dynamic NRM issues, ComMod will take into account all multiple legitimate points of view. Further to ensure consistent legitimacy of research findings, ComMod emphasises conduct of fieldwork and modelling in unison (Bousquet et al., 2002) and systematic monitoring and evaluation of the effects and impacts (Trébuil, 2008).

Enduring iterative process: ComMod approach being process-oriented and dealing with SES issues characterised by complexity and unpredictability, it poses supports validation of process feedback iterative cycles (Bousquet *et al*., 2002; Barreteau *et al.*, 2003). This principle of repeated iteration between the field and the laboratory is based on the principles of having systematic refutation of all hypotheses made. The strength of ComMod lies on the several self-reinforcing sequences alternating theoretical, analytical, and modelling activities with field work (specific surveys, sensitizing activities, field workshops including gaming sessions and/or participatory simulations, plenary debates, interviews, etc.) in an iterative but evolving fashion. At the end of each loop, the conceptual model representing the system under study is revised as well as the research hypotheses. The process facilitates stakeholders' interactions to identify and scope resource management problems to be discussed and negotiated. The simulation models are used to collectively assess scenarios selected by stakeholders and may lead to new questions, new discussions, changes in the model, and so on (Barreteau, 2003). The principle can be best represented by a continuum of cyclic loops of iterative sessions of RPG and ABM simulations (Figure 6.2).

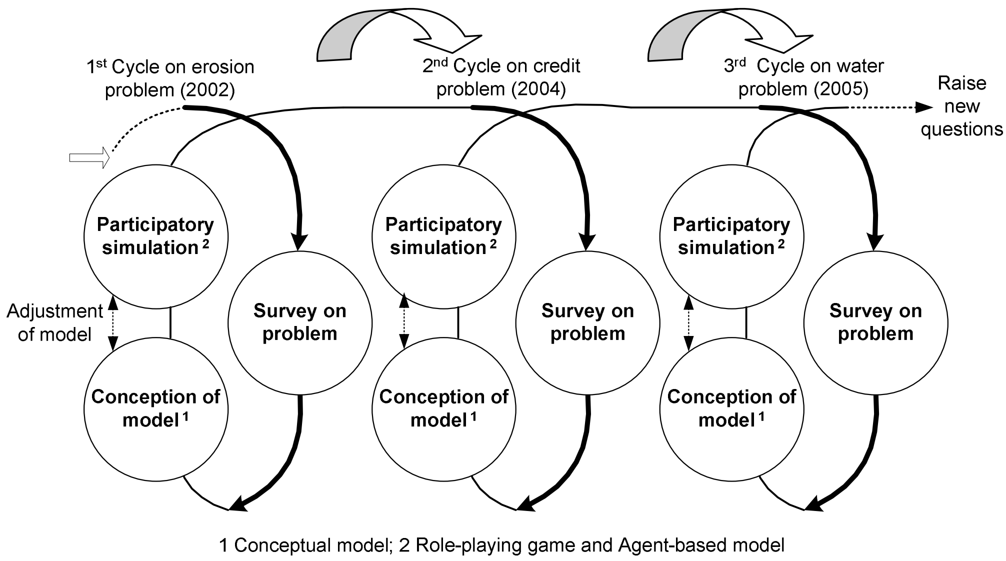


Figure 6.2. Schematic representation of a ComMod process on catchment management in Mae Salaep, Chiang Rai, Thailand (Adapted from Barnaud *et al.,* 2007).

In brief, the leading methodological principle of the ComMod approach is to develop simulation models integrating various stakeholders' point of view to use them for collective learning and decision/negotiation support in a given context and on a given concrete NRM problem (Bousquet and Trébuil, 2005).

Objectives of ComMod approach

As a modelling and simulation approach where stakeholders (people, researchers, development workers and decision makers) participation is the basis for model design, development and evaluation of scenarios, the general objectives of the ComMod approach is to facilitate dialogue, shared learning, and collective decision-making through interdisciplinary and implicated action-oriented research to strengthen the adaptive management capacity of the local community (Bousquet and Trébuil, 2005; Trébuil, 2008; Ducrot and Botta, 2009). Based on this general objective, there are two specific objectives which forms the foundation of the ComMod approach (ComMod Charter - http://cormas.cirad.fr/ComMod/en), they are:

- Understanding complex environments, and
- Supporting collective decision-making processes in complex situations.

Understanding complex environments

An important feature of ComMod is its ability to integrate various stakeholders' points of view and provide a means to identify acceptable form of simplification to better understand how a given social agro-ecological system is structured and is evolving (Bousquet *et al.,* 2002; Trébuil, 2008). This can be achieved using two perspectives, (i) researchers using a positivist paradigm to discover the objective truth to unravel the natural laws driving the system, and (ii) from the constructivist epistemology paradigm, it is assumed that people construct their own realities through learning along social processes (Bousquet and Trébuil, 2005). For centuries farmers have innovated and developed knowledge about NRM by relating to the whole system of concepts, beliefs and perceptions that people hold about the SES (Warburton and Martin, 1999). Local knowledge of natural resources is made up of three types of information: 1) accumulated cultural knowledge, 2) knowledge modified through contact with other cultures, and 3) progressive learning of the environment (Niamir, 1990). While it is vital to capture and understand such local knowledge when intervening in any society, it is necessary to be aware of possible differences and complexities in how people view the world around them, and in how they interact with each other. Without romanticizing local knowledge, a blend of formal science and local knowledge may prove to be an effective development approach (Niamir, 1990). The dialogue among researchers, the model and the field actors in the ComMod process is an iterative research one aiming at a better understanding of the system under study, particularly the interface between its ecological and social dynamics, and the various points of view facing each other in the local stakeholders' arena (Trébuil, 2008). The common vision/understanding on resource management would lead to the identification of new shared representations of the system to be improved, indicators of ecological (state of the resource) and social & economic (including equity among types of stakeholders) performances, monitoring procedures, information systems, and the negotiation of concrete alternatives for action (Bousquet and Trébuil, 2005).

Procedurally, researchers use participatory diagnostic surveys and literature reviews to collate existing knowledge (field-based and pre-connived) on the problem at stake to build a first preliminary conceptual model. The researcher's perspective in the form of a model is presented to the stakeholders most of the time as a RPG which generates new understandings and viewpoints resulting in the revision of the model to address new questions or to improve dealing with the initial one. The new version of the model is again put to the stakeholders and further generates new phenomena both in terms of model output and knowledge exchange and acquisition. This iterative process and cycles generates a family of models with specific hypotheses and objectives. It can build up into a legitimate knowledge-base to deliver improved understanding of the local socio-ecological processes (Berkes and Folke, 1998).

To support collective decision-making processes in complex situations

Managing a SES characterized by unpredictable future functions (Janssen *et al.,* 2004) poses challenge in decision-making. As such a complex and continuously changing state call for series of imperfect and adaptive decisions (Brehmer, 1992). Complex systems often display regions of extreme sensitivity to the particular assumptions, while at the same time exhibit important regularities of macro behaviour posing deep uncertainty of a type that strains the traditional[7] methods of decision analysis, vital to the systematic examination of policy alternatives (Lempert, 2002). As the complexity intensifies, decision-making at all levels must increasingly rely on their intuition and judgment (Bennet and Bennet, 2008). However, with the help of simulators, decision-makers construct insights by watching and discussing the outcomes of a variety of scenarios generated by the model and reach consensus on strategies even when the members cannot agree on the most likely future (Lempert, 2002). Through its iterative processes, the ComMod approach can significantly contribute to the stimulation of mediation and negotiation among the concerned stakeholders elucidating shared point of view (Barreteau *et al.*, 2003; Trébuil, 2008). ComMod supports both models of dynamic decision-making approach, (i) individual difference approach where behaviour of groups differing in performance is compared and (ii) experimental approach where the effects of system characteristics, such as complexity and feedback delays, are considered for dynamic decision-making (Brehmer, 1992).

6.5 Implementation of ComMod processes and tools

A ComMod process is made of three main stages which can follow iterations based on the objective of research (Bousquet and Trébuil, 2005).

[7] Traditional decision analysis rests on key assumptions about the types of information available to the decision-maker.

1. Formulation of hypothesis for modelling,
2. Modelling,
3. Simulations and assessment of scenarios.

Step 1: Formulation of hypothesis for modelling

The process starts with problem definition, review of information and literature on the issue to be studied. Based on which a team of researchers will interact with stakeholders to gather relevant information on the system under study (Bousquet *et al.,* 2002). From the premise of constructivism, stakeholders possess diversity of local knowledge, perceptions and belief system which has evolved over generations (Warburton and Martin, 1999). Knowledge can be sourced internally and externally, internal would imply the knowledge of the local stakeholders at the study site while external would mean regional, national and international sources (Svetina and Prodan, 2008). While the researchers (modellers) bring the external knowledge, the real time local realities can come from the collaborative stakeholders. Several participatory techniques focusing on agents, the resource at stake, and their interactions are used to make a diagnostic analysis for establishing hypotheses for modelling (Bousquet and Trébuil, 2005). Agrarian system diagnosis (see chapter 3), stakeholder and institutional analyses are valuable tools to be used at this stage as the challenge of the initialization phase is to enable stakeholders to express their perceptions of the present situation and of its evolution, in order to characterize the diversity of points of view in the stakeholders' arena (Trébuil, 2008). Through this process, it ensures a co-construction of hypotheses that becomes a basis for modelling and enhances the ownership of the process.

Step 2: Modelling

This step focuses on the conceptualization and co-design of models. With the shared understanding from step 1, most often researchers conceptualize the way shared knowledge can be represented in the model and submit their propositions to the stakeholders in the form of RPG for them to assess, improve or reject (Bousquet *et al.,* 2002). Actor-Resource-Dynamics-Interactions (ARDI, see also below) is a participatory technique which can facilitate the involvement of stakeholders in developing a diagrammatic shared representation and in co-designing a conceptual agent - based model related to the NRM issue to be examined (Etienne *et* *al.,* 2008). In addition to ARDI, conceptualization can be further strengthened through discussions, reviews of the existing knowledge from various sources, and specific field surveys. To elucidate agents (social, ecological, and physical types) and their interactions graphically, the Unified Modelling Language (UML[8]) can be effectively used as it facilitates elicitation and participation in conceptualization. Based on the conceptual model, a RPG can be constructed or / and a computer ABM programmed in the CORMAS platform. The model usually in the form of RPG is shared with the stakeholders to see if it adequately represents the realities as perceived by the stakeholders. To enhance stakeholder's participation and understanding, the computer ABM is translated and implemented in the form of a which is used to play with the society. The coupling of ABM and RPG tools helps in:

- Understanding the model, and more precisely the difference between the model and reality,
- Validation by examining the individual behaviour of agents and the properties of the whole system emerging from their interactions, and by proposing modifications, and
  Enabling to understand and follow ABM simulations run on the computer, and to propose scenarios to be collectively assessed and discussed following their simulations.

This process helps in the validation of the model parameters and its ability to simulate scenarios to interact with the users for joint exploration.

Step 3: Simulation

The final RPG and computer ABM are used interactively to challenge the former understanding of the system with new emergent understandings from simulations (Bousquet and Trébuil, 2005). Computer ABM have definitive advantage of generating multiple scenarios over a long range which RPG cannot handle due to difficulty in managing the players over long and repeated sessions and handling voluminous data generated from the RPG (Trébuil, 2008). Collective identification of parameters and tentative scenarios, which can be simulated over an agreed time frame helps in bridging computer model and the stakeholders, and legitimizes the scenarios thus generated. Comparing and exploring scenarios help in the generation of shared

[8] UML, or Unified Modelling Language, is a specification language that is used in the software engineering field. It can be defined as a general purpose language that uses a graphical designation which can create an abstract model.

learning that can improve communication and coordination among stakeholders to mitigate the problem at stake.

The twelve steps of a ComMod process

From the methodological perspective, a ComMod process can be further subdivided into five main phases: (i) initialization of the process, (ii) co-construction and conceptualization of models with stakeholders, (iii) implementation and validation of models, (iv) scenario identification, exploration and assessment, and (v) monitoring and evaluation. These phases are further segregated into 12 steps as shown in Table 6.2.

Table 6.3. The 12 Steps of a companion modelling process.

Step	Description
Sensitization	Introduction of the ComMod approach to key stakeholders requesting to look into a given development question, and assessment of its suitability and possibility to use it in the local context
Problem definition	Definition of the key question to be examined, by the process leaders and, sometimes, other stakeholders as well
Enumeration of knowledge	Inventory of relevant scientific, expert, and indigenous knowledge available through literature review & complementary diagnostic surveys to fill the gaps
Inquiry/Probing	Knowledge elicitation for modelling via surveys and interviews
Conceptualization	Co-design of the conceptual model with stakeholders concerned by the question being examined
Implementation of model	Choice of the tool (computer-based or not) and model implementation
Verification of model	Model verification, validation and calibration with local stakeholders
Definition of scenario	Identification and definition of scenarios with local stakeholders
Exploration of scenario	Exploratory simulations with local stakeholders
Communicating the output	Dissemination of the outputs towards stakeholders who did not participate in the process
Monitoring and evaluation	Monitoring-evaluation of the effects of the ComMod process on participants (awareness, knowledge, communication, behaviour, decision, practices, etc.)
Training	Training of interested stakeholders on using the tools produced during the collaborative modelling process

Tools used in ComMod approach

As ComMod is an action-oriented approach it heavily depends on the quality of information fed to the system. Despite the two main tools of ComMod (computer ABM and RPG), there is no fixed protocol in terms of type of tools and structure used (Trébuil, 2008; Dumrongrojwatthana, 2010). In the absence of specificity, it is important to use appropriate tools in a logical sequence depending on the situation and the issue to be examined. This is to facilitate unconditional knowledge elicitation from diverse sources to support envisioning collective consequences of individual decisions, based on which negotiation can happen to formulate a common goal and action plan based on collective decisions (Souchère *et al.,* 2008).

Actor, Resource, Dynamic, and Interaction (ARDI) technique

The ARDI technique (or any similar one) can be used to collectively identify the principal stakeholders concerned with the key question, their management entities, the resources used and the main processes driving changes affecting these resources (Etienne *et al.,* 2008a). ARDI is a participatory tool focusing on (i) principal resources of the territory, (ii) main stakeholders involved in the use and management of resources, and (iii) main processes that influence changes in resource dynamics. After the actors (stakeholders) and resources are identified, main processes that induce changes in the system (ecological, economic, and social dynamics[9]) are elucidated. Subsequently, stakeholders collectively identify interactions and linkages between resources and actors. The outcome of these four steps is a graphical representation of how stakeholders perceive the system to function – truly a shared mental model (Etienne *et al.,* 2008b).

Role-playing game

The computer ABM as explained earlier is resourceful for laboratory experiments, its full utility can only be achieved if it can be used in the field where the natural resource problem

[9] Examples of ecological dynamics are: vegetation transitions or water flow; economic dynamics (market price-changes, subsidies amount), and social dynamics (social cohesion, knowledge transfer, etc.).

exists. In this context, the use of a RPG helps to open the computer ABM black box (Barreteau, *et al.,* 2001).

While RPG is generally used as a tool in training, research or policy making (Bousquet, 2001; Barreteau, 2003), it can also be used as a communication enhancing, knowledge exchange and negotiation support tool. RPG finds its uses in creating a situation for players that is comparable to one they might encounter and from which they learn the consequences of the reactions they might have. A RPG can also be used to study behavioural patterns in contrasting situations (Barreteau, 2003). In ComMod, depending on the situation, the MAS conceptual model is simplified into a RPG to support participatory exploration and validation of the model and to identify suitable scenarios to plan simulations. In most cases, the final version of the RPG is coded into a computer ABM to allow time efficient simulations of multiple scenarios and leave enough time for the joint exploration of their outcomes.

Agent-based modelling

The trajectory of NRM models from optimal control of a simple system to an approach that facilitated progressive learning to manage the given resource base through active experimentation, was influenced by the realization that the scientific understanding necessary to define the problem sufficiently to apply control was either too costly or altogether impossible (Anderies, 2002). Considering the variety of problems, their scale, and its influence to livelihood, stakeholders will deny to experiment with their livelihood (ibid.). In such situation the principles of Cellular Automata and Agent opened up the opportunity to model social agents and virtual societies (Bousquet *et al.,* 2002; Janssen, 2002), within a prescribed rules, as in reality (Ostrom, 1994). In ComMod models, types of agents, rules, interface, time steps and protocols are collectively defined with the stakeholders, which can be derived from the ARDI exercise (Etienne *et al.,* 2008a). An abstract model is developed to study and understand the generic properties of interacting processes, based on which an applied model is formalized which is used for experimentation (Bousquet *et al.,* 2002).

Most of the ComMod processe uses the CORMAS platform as the simulating framework. It has been developed to provide a multi agent environment for simulating the interactions between heterogeneous agents and a shared environment (Bousquet *et al.,* 1998).

Monitoring framework and tools

In an attempt to formalize a monitoring process, logbooks have been effectively used to maintain chronological records of actions by all stakeholders and their effects (Dumrongrojwatthana, 2010). This dataset can precisely locate interventions and occurrence of regular tendencies or unexpected emergence. As the information maintained comes from individual stakeholders, it also ensures tracking the process and allows a detailed analysis of what happened along the way.

The Most Significant Change (MSC) technique is another participatory monitoring and evaluation tool that can be used. It is a monitoring tool as it can be applied during the process and an evaluation means as it can provide impact and outcome data to assess the performance (Davies and Dart, 2005). MSC involves the collection of significant change stories emanating from the field level and selecting (or collating) the most representative MSC story. This can be very rapidly assembled with minimum preparation and can enhance the legitimacy of the narration and verifiability of the impact.

The conscious process of incorporating multiple domains (bio-physical, socio-political, economic) in INRM (Campbell *et al.,* 2001) becomes complex owing to multiple scale of interaction; high frequency of nonlinearities, uncertainty, and time lags in complex system (Campbell *et al.,* 2003; CGIAR Task Force on INRM, 2001). Considering the complexity in INRM, impact assessment and evaluation are indispensable to play more self-critical learning roles. Such studies need to address the 'why?' questions and most importantly, what are the drivers that determine success or failure (Mackay and Horton, 2003). Often the outcomes of any interventions in INRM paradigm which happens over a period are influenced by other actors and factors (Campbell *et al.,* 2001; Douthwaite *et al.,* 2003; Springer-Heinze *et al.,* 2003). Therefore, in contrast to ex-ante impact assessment of set priorities and ex-post impact assessment of attribute, evaluation of INRM needs assessment within project cycles to support the learning of all stakeholders and supporting adaptive project management. Impact Pathway Evaluation (IPE) is a monitoring and evaluation approach that includes the processes by which stakeholders learn and negotiate based on evaluation findings (Douthwaite *et al.,* 2003).

As a given ComMod process is characterized by a sequence of tools and procedures used in an iterative mode, its monitoring and evaluation framework should capture the reflexive dimension (Jones , 2008) in order to understand why and how the approach works that foster experiential knowledge (Webler, 1999). The framework for evaluating such participatory modelling processes proposed by Jones *et al.* (2008) provides a frame to analyze change in the context due to process effects (Figure 6.3). Identifying underlying theories is based on the "theory based evaluation" model. Theory based evaluation allows an in-depth understanding of the project activities and their interactions thus identify steps to be monitored (World Bank, 2004). Thus this framework seeks to capture the espoused theory to identify the sequence of methods used and their anticipated effects. To capture the holistic understanding of the theoretical logic, both project team and participants' experiences are documented and analyzed.

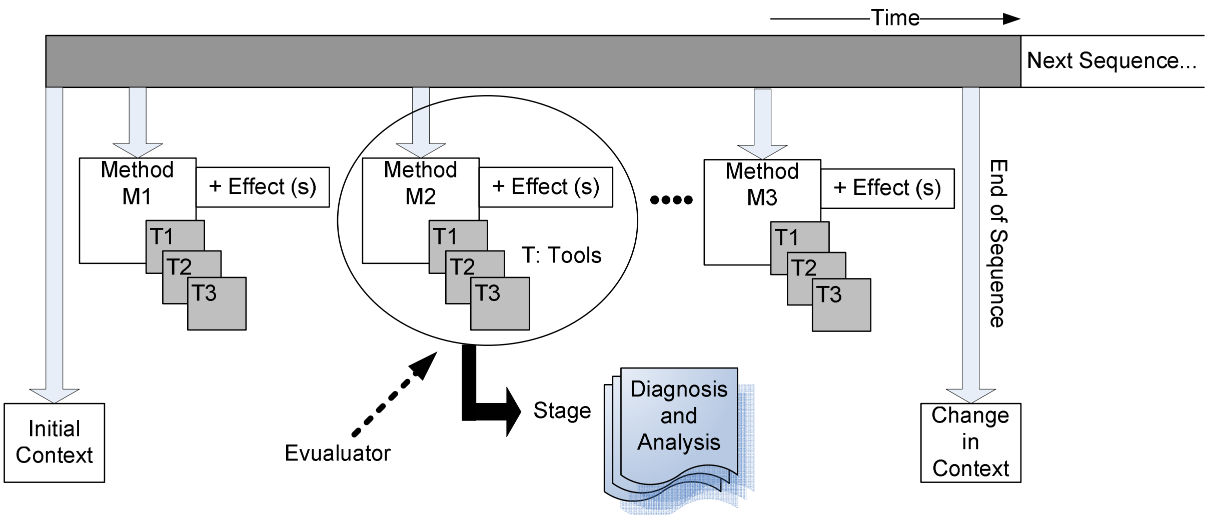


Figure 6.3. Monitoring and evaluation framework of a ComMod process (adapted from Jones *et al.,* 2008).

The multiplicity of actors with diverse perspectives, interests, entitlements, knowledge, capabilities, values and power in the management of a dwindling natural resource influenced by local and global trends, pose challenges to comprehend and envisage management strategies. The invention of high capacity computers and methodological advancement has broadened the capacity to make in-depth examination and exploration of such interactions and dynamics. The shift from top-down, command and control type of research to adaptive, knowledge-based and collaborative approaches indeed amplified the role of participatory methodologies into learning, research and policy making. The flexibility of methodologies to apply in synergy with multiple tools and their joint ability to integrate stakeholders' perceptions and knowledge has tremendously enhanced the research competency and relevance.

Among several collaborative modelling approaches, particularly in SES research, the ComMod approach has emerged as a resourceful one supporting collective shared learning based on simplification of SES structure and dynamics to focus on a given NRM problem. Its strength specifically lies on self-reinforcing theoretical, analytical, and modelling activities with field work in an iterative yet evolving fashion. While it is often said that the use of a RPG helped in opening the black box of the computer ABM, the synergy between these two key tools has indeed removed the impregnable gap between people (resource users) and science (the research team); people (citizens) and politics (policies), and act as a bridging tool.

The flexibility of the ComMod approach in terms of tools and integrating other mainframe research approaches such as the agrarian system analysis to characterize the context of a collaborative modelling process, could pose a possible problem of derailing the purpose of the planned ComMod process. Further with diversity of tools, outputs and effects from the process, monitoring and evaluation of ComMod processes still remains a challenge. In recent years, the ComMod approach has been extensively used in collaborative NRM research (Barreteau et al., 2007) and therefore its use is proposed for this study. Chapter 7 presents the detail methodology used in the research.

CHAPTER 7
RESEARCH METHODOLOGY

Water, a renewable natural resource abundant in Bhutan has truly exhibited its multifunctional nature and varying benefits at different levels. While Bhutan depends on water resources for more than 50% of its GDP at the national level, there is a dire situation of water shortage at community and household levels in some parts of the country or at some critical stages of the cropping calendar. Water shortage is further escalated by the absence of definite legal provisions, uncertain administrative mechanisms, and most importantly the recent dismissal of customary management systems. While societies have been manoeuvring within a fuzzy property rights, conflicts are inevitable when the water resource base is declining and user base is broadening. In such situation, crafting a research methodology which can take on board stakeholders to elicit local perceptions, facilitate their exchange, and integrate them with external knowledge to augment the role of stakeholders in enhancing the resilience of SES is essential.

7.1 Companion Modelling for water management

7.1.1 Use of ComMod in social change and water governance

The use of the ComMod approach in several case studies in water management has demonstrated its versatility (Barreteau and Bousquet 2000; Daré and Barreteau 2003 ; Gurung *et al.,* 2006; Barnaud *et al.,* 2007; Dung, 2008; Naivint, *et al.* 2010; Farolfi *et al.,* 2008). We identified seven case studies dealing with water management issues that used the ComMod approach from the perspective of social change[1] and governance (Table 7.1). Creating space and opportunity for reflective[2] and reflexive[3] practices are known to facilitate change in people leading to greater congruence. To become reflective and reflexive, learning and knowledge is necessary. Knowledge is a means of legitimating and communicating the acceptable and relegating less worthy knowledge, thereby stimulating positive social change (Taylor *et al.*, 2006). The ComMod approach has been widely used for examining NRM issues and often cited

[1] Process of dialogue, debate and action resulting in major shifts in social norms, and generally characterized by the highlighting and legitimating of discordant voices, particularly of those marginalized in society, and leading to improvements in their rights, entitlements and living conditions.
[2] How we see, understand and position ourselves in relation to our experience and action.
[3] How we reflect on the way we do things.

to generate new knowledge (Gurung *et al.*, 2006; Etienne *et al.,* 2008; Barnaud *et al*., 2010; Worrapimphong, 2010).

Table 7.1. Past case studies relying on the ComMod approach to study water management issues.

Case Studies	Social change	Governance	Reference
Viability of irrigated systems in the Senegal River Valley		– Tool for simulating scenarios of collective rules and individual behaviours for social organization and institution	Barreteau, and Bousquet, 2000
Negotiation in irrigated system in the Senegal river valley	– Revealed social relationships for negotiation to share irrigation water		Daré and Barreteau, 2003
Sharing Irrigation Water in the Lingmuteychu Watershed, Bhutan	– Mediation process of developing an efficient water-sharing system, leads to release of irrigation water 5 days earlier than the traditional date	– Establishment of watershed management committee with representative of all villages in the watershed	Gurung *et al.,* 2006
Catalyze collective water management in Northern Thailand (Mae Salaep)	– Collective empowerment through the creation of alliances		Barnaud *et al.,* 2007
Local water governance in South Africa	– Transformation of ethnicity based irrigation board to all inclusive water user association	– Facilitating institutionalization of catchment management agency and water user association – Develop catchment management plan	Farolfi *et al.,* 2008
Institutional engagement for land and water management in a Northern Thailand watershed (Mae Hae).	– Agreement limiting the number and size of irrigation pipes in the upstream area was achieved	– Institutional networking at all levels for negotiation	Promburom and Bousquet, 2008
Understand conflicts arising from the water demanded by rice and shrimp farmers in Bac Lieu, Vietnam	– Share knowledge, opinions on water demand; better understanding and collaboration on water management		Dung, 2008
Sharing knowledge about land, water use and labour migrations in rainfed lowland rice in Lam Dome Yai watershed, Northeast Thailand	– Labour management across broader social network		Naivinit *et al.,* 2010

Taylor *et al.* (2006) proposed a conceptual framework for dialogue which implies knowledge and learning as the core of the social change process (Figure 7.1). The framework also indicates a continuous and non-linear process which ensures change depending on the information fed to the system. This process of communicating, learning, and sharing knowledge, engaging people in their multiple roles as individuals, as part of communities, and as members of organizations can influence individual and collective behaviour, which can stimulate social change (IHDP, 2008). However, behavioural change requires not only new insights, but also the willingness to change.

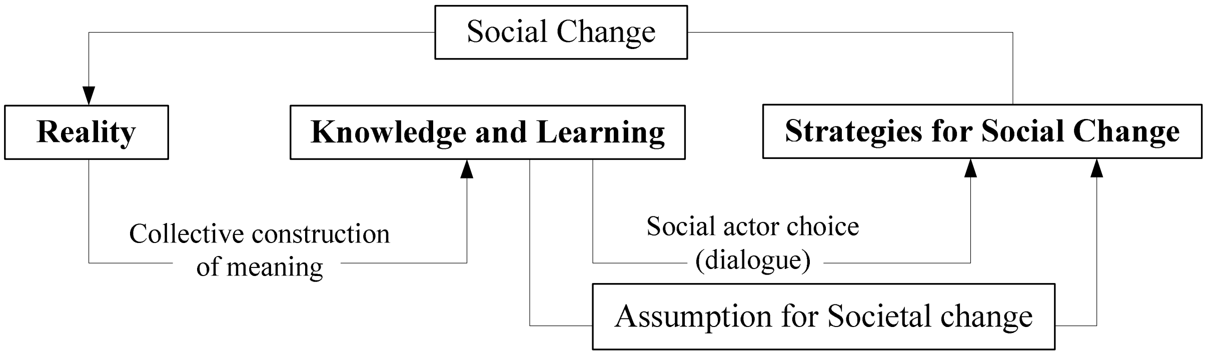


Figure 7.1. Conceptual framework of social change (Adapted from Taylor *et al.,* 2006).

ComMod by way of facilitating individual and collective learning has stimulated social change (Table 7.1). Social change has taken place in two broad categories (i) negotiated water sharing and management systems from traditionally biased systems (Daré and Barreteau, 2003; Gurung *et al.,* 2006; Promburom and Bousquet, 2008; Dung, 2008) and (ii) stakeholders creating more heterogeneous and broad based social networks from individual or ethnic based groups (Barnaud *et al.,* 2007; Farolfi *et al.,* 2008; Naivinit *et al.,* 2010).

Since the adoption of Agenda 21 and linkages among economic and social development and environmental protection in 1992 by the Earth Summit in Rio de Janeiro, Brazil, sustainable development has become a global objective. In the midst of complex SES compounded with uncertain future, the sustainable development can be approached with governance (van Zeijl-Rozema *et al.,* 2007). Governance can be considered as a shared responsibility of the state, market and civil society to address societal problems. Merging the sustainable development perspectives with modes of governance, van Zeijl-Rozema *et al.* (2007) proposed a governance framework shown in Figure 7.2. The four quadrants represent four types of governance for sustainable development: rational state, rational society, normative state and normative society.

While the hierarchical governance is featured as state led (top-down) regime, the co-governance benefits from the collectivism where state too become part of the management regime. Quadrant IV (Normative society) views governance as the way to predefined goals and outcome, as an open deliberate and reflexive process, wherein state is a part of the dynamics that is governed. The ComMod approach being an action-oriented research approach promotes reflexive governance or normative society. For instance in the Senegal river valley, it helped in testing individual and collective rules for irrigation management (Barreteau, and Bousquet, 2000). In Bhutan and South Africa, ComMod facilitated development of sub-watershed/catchment management committees including the negotiation of collective action plans (Gurung *et al.,* 2006; Farolfi *et al.,* 2008).

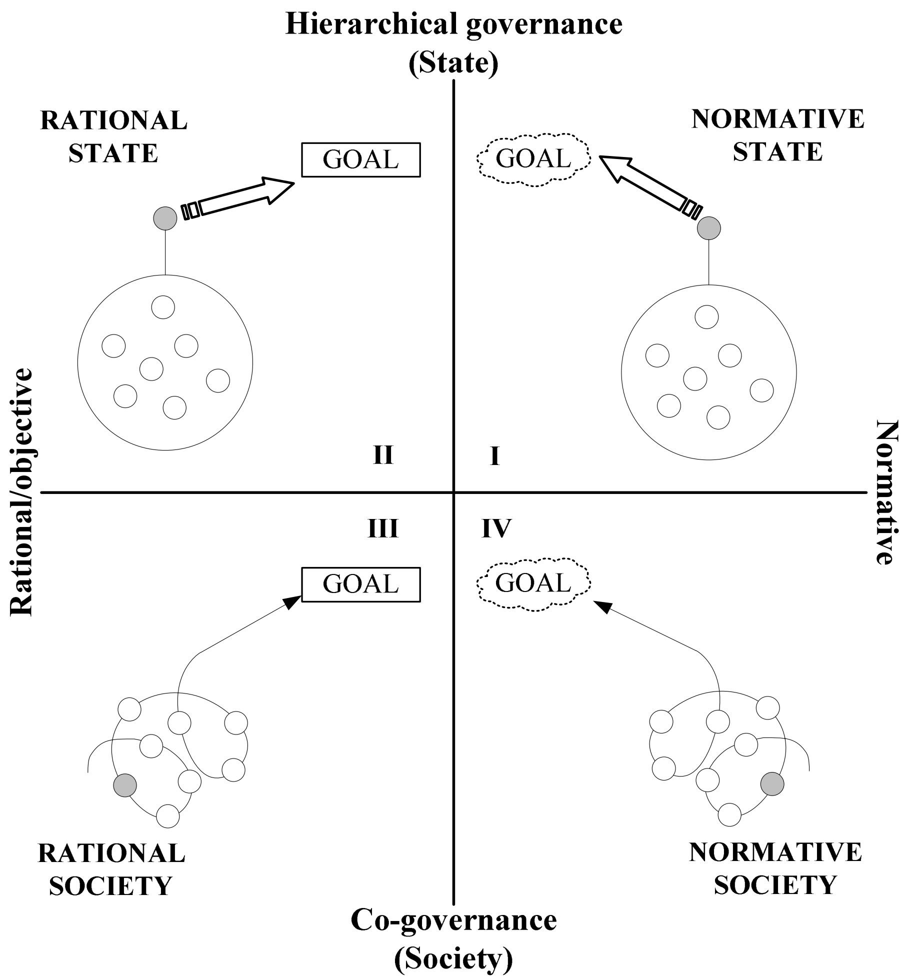


Figure 7.2. Conceptual framework of governance (Adapted from van Zeijl-Rozema *et al.,* 2007).

7.1.2 Overview-Design concepts-Details protocol for model description

Models to represent ecological dynamics are built using either microscopic or macroscopic phenomena. Balancing appropriate details to comprehensively represent the dynamics and to understand is a fundamental liability of models (Deutschman *et al.,* 1997). With the extensive application of the ABM approach in different scientific disciplines, it has become essential to use a standard protocol for the description of such models to make them easier for readers to understand (Grimm *et al.,* 2006) and to allow others to interpret and re-implement them (Hales *et al.,* 2003). Based on the two following principles (i) a general structure for describing ABM, thereby making a model's description independent of its specific structure, purpose and form of implementation, and (ii) separating verbal considerations from a mathematical description of the equations, rules, and schedules that constitute the model, Grimm *et al.* (2006) proposed the so-called Overview, Designed concepts, Details (ODD) protocol as a framework for describing ABM. The ODD protocol uses seven elements grouped into three blocks to describe the model (Table 7.2).

Table 7.2. The seven elements of the Overview, Designed Concepts, Details protocol (Source: Grimm et al., 2006).

Blocks	Elements	Explanation
Overview	• Purpose	• A clear, concise and specific information to inform about the need to build a complex model, and use of the model.
	• State variables and scales	• Enumerate entities and describe their attributes and structure including hierarchical levels if any. Describe the temporal and spatial resolution of the model.
	• Process overview and scheduling	• Describe all the processes and their effects included in the model. Explain in details the schedule of the different processes in the model.
Design concepts	• Design concepts	• Explain the model design within a broad framework of emergence, adaptation, fitness, prediction, sensing, interaction, stochasticity, collectives, and observation.
Details	• Initialization	• Detail the initial value of state variables and how the process is initiated.
	• Input	• All input data associated to state variables necessary to run the model needs to be explained.
	• Sub-models	• All sub-models for each process including the parameters are explained.

The first block called “Overview” provides the overall purpose and structure of the model by describing its state variables and scales, process and scheduling. The second “Designed concepts” block describes the general concepts of the model and interactions. The last block on “Details” comprises three elements i.e. initialization, inputs, and sub-models and provides all the information necessary to independently replicate the model.

7.2 ComMod methodological framework used at the two sites

7.2.1 Conceptual framework

Figure 7.3 displays the conceptual framework of the research composed of four main stages lay out as a process. They are (i) diagnosis and definition of the problem, (ii) collaborative modelling and simulation, (iii) collective action, and (iv) monitoring and evaluation. They are closely associated to the specific objectives of the research.

The diagnosis and definition of the problem helped to achieve objective (1) and (2) by studying resource dynamics, management and decision-making process. The second phase aimed at developing conceptual models submitted to the stakeholders as RPG for validation and simulating different scenarios fulfilling the objectives (3) to (5). The third stage related to collective actions arising from the process helping to achieve objectives (2) and (5). Finally the last stage of monitoring and evaluation served as feedback to the process and stimulated a critical reflection on it.

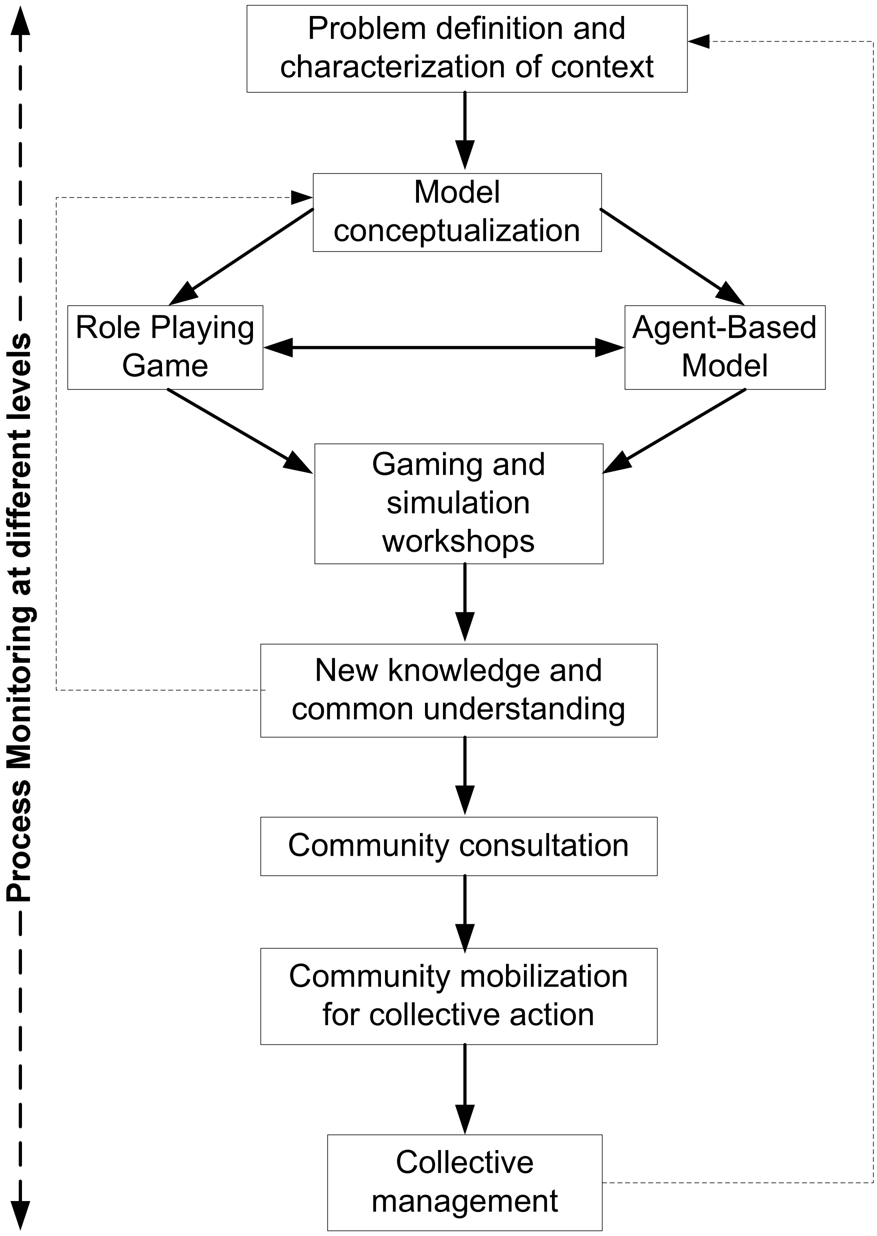


Figure 7.3. Conceptual framework of the research.

7.2.2 Conception of Companion Modelling processes for the two sites

The diagnostic study, literature review and extensive consultation with farmers and extension officials provided information to conceptualize and adapt Companion modelling processes in two sites (See chapter 3). The graphical unified modelling language (UML) was used in the model conceptualization phase as it helps in focusing and progressively construct components of the model and their interactions (Bousquet and Trébuil, 2005). It also supported the indication of the key parameters of these interactions. However, at the start of these two case studies, a simple flow diagram (Figure 7.4 and 7.5) was used to depict how people perceive and operate their particular water resource systems. Based on these descriptive flow diagrams, it was fairly straightforward to construct the different kinds of UML diagrams (class and sequence diagrams mainly) for both models.

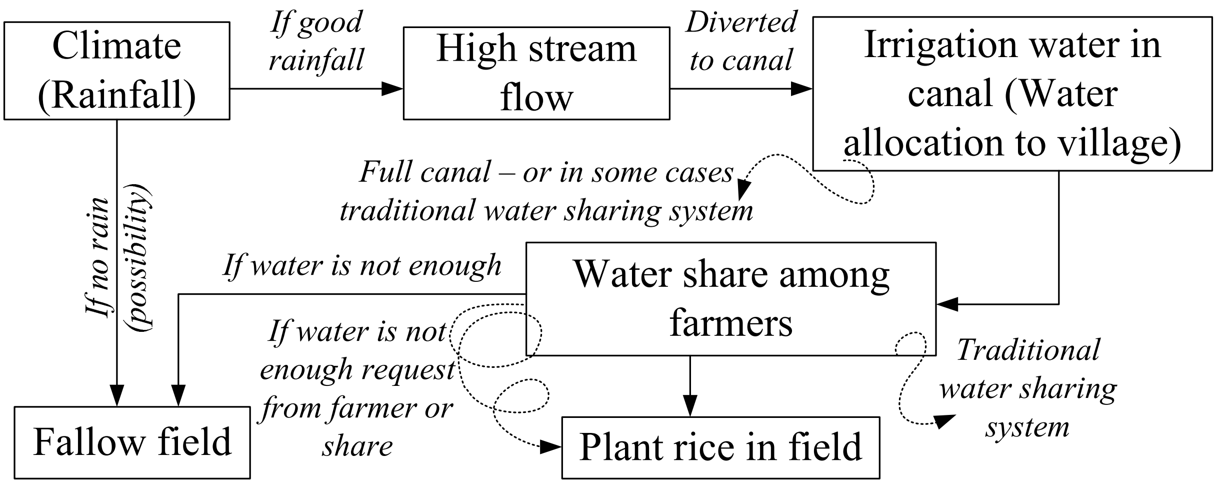


Figure 7.4. Preliminary conceptualization of the Companion Modelling process in Lingmuteychu.

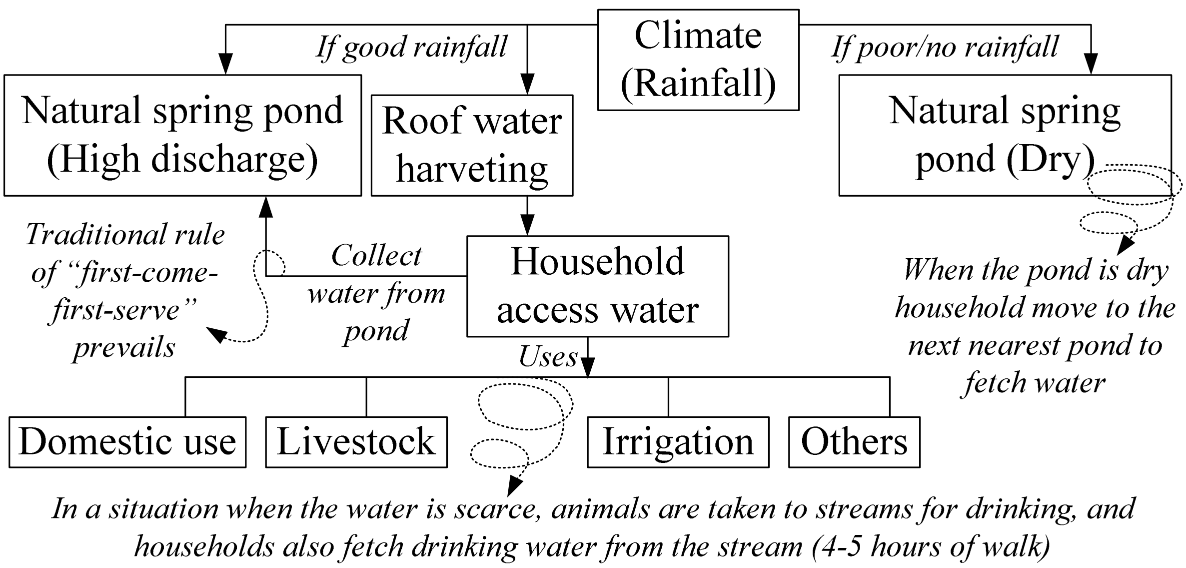


Figure 7.5. Preliminary conceptualization of the Companion Modelling process in Kengkhar.

7.2.3 Objective

The similarity of the type of resource in both sites (irrigation and domestic water in Lingmuteychu and Kengkhar respectively) and the two different (but related) issues of conflict about resource sharing in the case of Lingmuteychu and sharing a dwindling resource in Kengkhar provided a challenge to apply the research methodology to enhance understanding and facilitate improvement in these differing water management situations. In line with the objective of (i) understanding local adaptive strategies, and (ii) possibility to enhance renewable resource resilience through this research, the objectives of applying the Companion modelling approach at these two sites were as follows:

- To study the dynamics of water resource use and management and to understand how farmers either individually or collectively address the more (Lingmuteychu) or less (Kengkhar) conflicting issue of water sharing.
- To understand how different stakeholders adapt their decision-making processes to the change in water resource status.
- To develop simple conceptual models integrating the resource status, its uses and management rules.
- To construct and implement a family of MAS models (computer-assisted Role-Playing Games and Agent-Based Models) to validate this conceptual model with the concerned stakeholders, and for further sharing scientific and indigenous knowledge on the issue being examined,
- To identify and simulate co-management scenarios identified by the stakeholders in order to facilitate communication among them and to support the inclusive and creative negotiation of agreed collective action acceptable to the different parties to mitigate the current conflict or improve the present water sharing situation.

7.2.4 Role-play games and simulations

In both case studies, based on the conceptual model and systems analysis, RPG were designed by keeping the minimum number of parameters that would broadly represent the local context and features that would facilitate vibrant interactions among the players (Table 7.3).

Table 7.3. Role-game features used in Lingmuteychu and Kengkhar.

Features	Lingmuteychu	Kengkhar
Players	– Irrigators	– Household member (mainly women)
Roles	– Receive water share, plant rice, negotiate	– Access pond, share and use
Game set	– Game board representing four plots, irrigation canal – Water cubes	– Water pond/tank, water cubes, farm house, 4 containers as different water uses.
Game session	– 4 modes: individual, village wise, collective, swapped roles	– 3 modes: individually-free to access any ponds, collectively at village (group) level, and collectively at network (all groups) level.
Turns	– 5 rounds/crop year	– 6 rounds/climate year

Simple locally available artefacts were used in the game (Figures 7.6 and 7.7). RPG in both cases were pre-tested. This was done with students from the College of Natural Resources in Lobeysa in the case of the “7 Village game” of Lingmuteychu. Similarly the “Omchu RPG” used in Kengkhar was pre-tested with research assistants and farm attendants of the Research Centre in Wengkhar, Mongar.

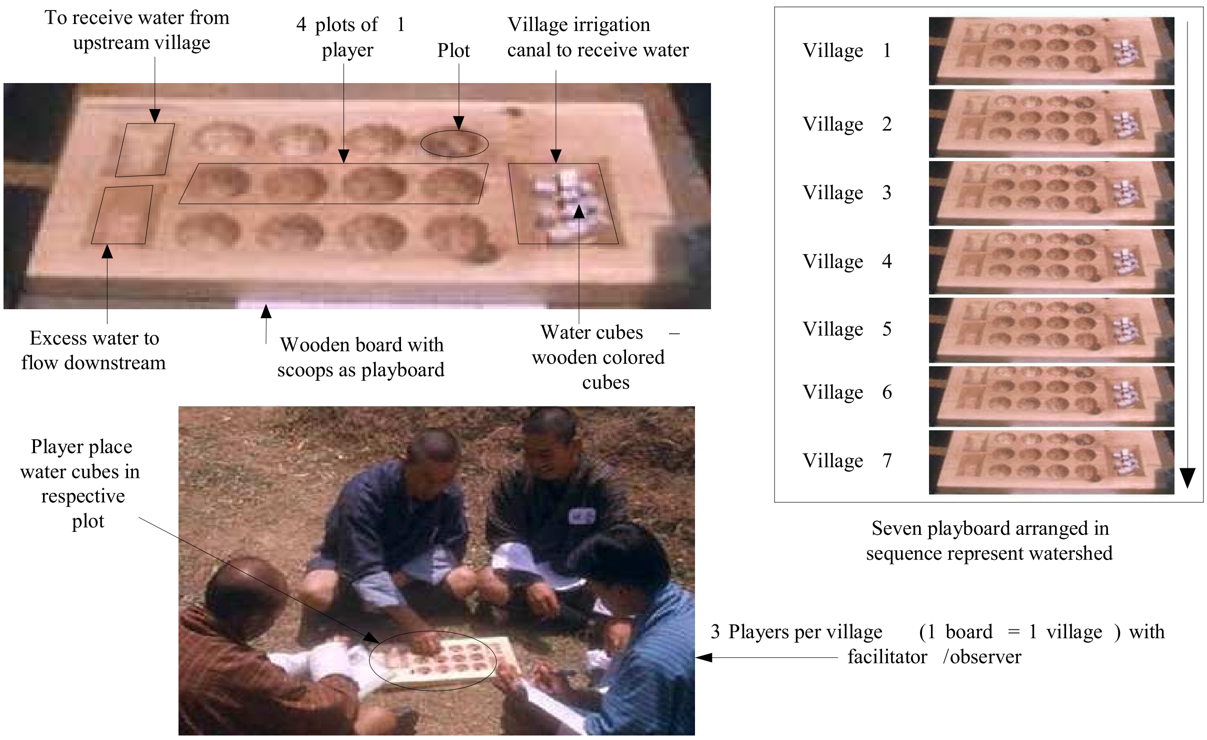


Figure 7.6. Game board used in the 7 Village role-playing game at Lingmuteychu in 2005.

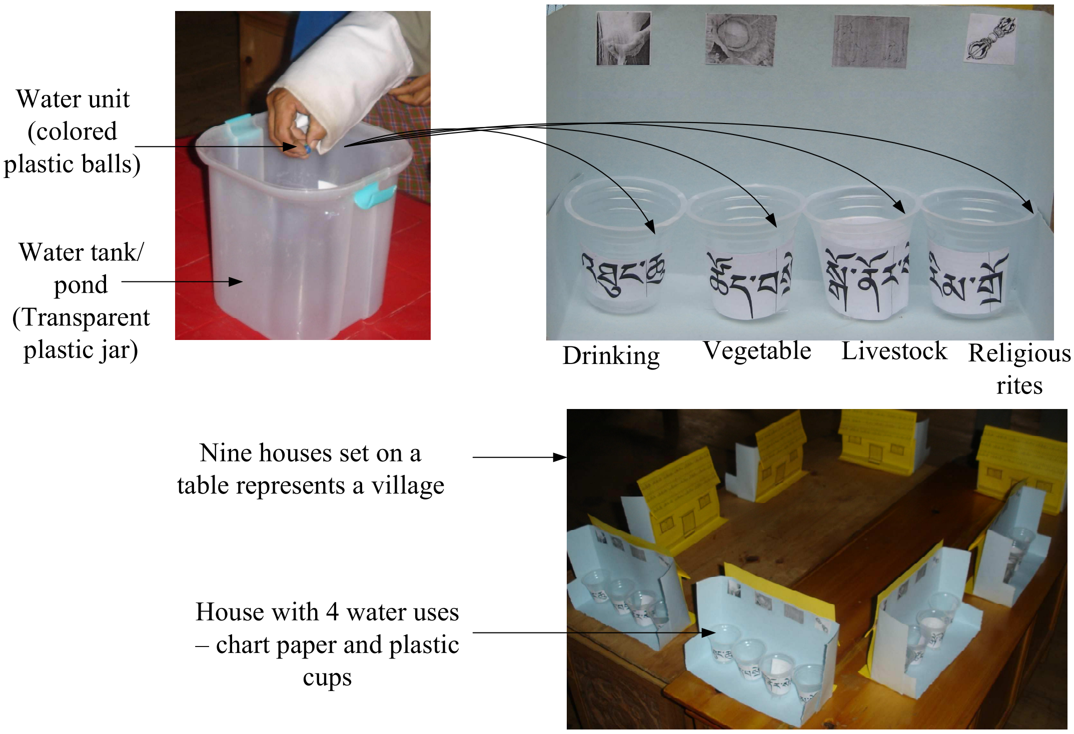


Figure 7.7. Materials used in the Omchu role-playing game in Kengkhar 2008.

In case of Lingmuteychu the traditional game "*ta-dang-no*" ("tiger and cattle") was adapted in the RPG (Figure 7.8). Because of their close relationship to the players' actual circumstances and daily activities the processes simulated in the gaming sessions was comprehensible. The process was effective and efficient in engaging participants in collectively generating unique situations as emergence from their interactions. However, this depends on the effectiveness of initialization of the process. In both situations, after a detailed briefing and introduction of the RPG setting, there was a mock session where participants tried the game for two to three rounds. The first round normally took one to one and half hour, as the players needed to get familiar with the game. After that, the rounds of plays were smooth and took only half of the initial time. As a RPG session is time consuming and cannot be repeated without player fatigue it was possible to explore scenarios for five rounds each in Lingmuteychu (Figure 7.8) and six rounds in Kengkhar (Figure 7.9).

Three players as one village in village level mode with one observer

Inter village mode located in order (village 1 to 7)

Collective mode with seven game board placed in order of village 1 to 7

Players interact actively, facilitators observes the process

Seven game boards placed in order of village 1 to 7 before the start of the game

Players interacting before making the moves, while observers discusses in the background

Figure 7.8. Glimpses of role-playing game session in Lingmuteychu.

A player collects her water share in individual mode

Players interact with facilitator ensuring she took the right water share in inter village mode

Players in collective mode allocate their water share for different uses

Players interacting before making the moves, while facilitator records the discussion

Setting for collective mode where players discuss and decide the water shareand use

Data entry done simultaneously

Figure 7.9. Role-playing game in Kengkhar.

7.2.5 Individual interviews and plenary debates

After the RPG sessions, all players were individually interviewed using a structured questionnaire (Figure 7.10 and 7.11). The interview was targeted to elucidate the actions of each player in the gaming sessions. The preliminary results from the RPG sessions and outcome of the individual interviews were presented to the plenary. The discussions in the plenary helped in the identification of scenarios of collective interest to be simulated.

Figure 7.10. Interview of individual player and plenary discussion on RPG outputs in Lingmuteychu.

Figure 7.11. Interview of individual player and plenary in Kengkhar.

7.2.6 First gaming session and participatory workshop

In both sites there was only one gaming workshop. In the case of Lingmuteychu, as it was a follow-up from the two sessions of the Dompola RPG (Gurung, 2003) it could also be considered as a 3rd session including the five new villages of the sub-watershed and adapting accordingly the rules of the game. Five rounds of play of each game were played (Table 7.4).

Three members each from seven villages were identified with the help of local extension officer. The 21 players with observers from block and district administration played five rounds each of 3 protocols of individual at village level, inter village with collective decision, and swapped collective decision. As the issue in Lingmuteychu was related to a water sharing conflict, the primary school in the sub-watershed was selected as the workshop venue that provided a common and a neutral setting. After the RPG session, a participatory workshop was organized to present the output of RPG and also to develop action plans. A rigorous consultation was organized to conceptualize and draft ideas for collective management approach, which later emerged as a watershed management committee.

Table 7.4. Proceedings of role-playing game (RPG) sessions in Lingmuteychu and Kengkhar.

Day	Lingmuteychu	Kengkhar
1	- Introduction of the RPG tool - Played 5 rounds of individual mode and 5 rounds of collective mode	- Resource persons and participants visit the tanks - Introduction of the RPG to the community and mock gaming session - Played 6 rounds as individuals with free access
2	- Played 5 rounds of swapped collective mode - During late afternoon participants, district officers, extension staff and researchers brainstormed on the development of the watershed management committee	- Played 2nd session : Free communication at group level and free flowing water - 3rd gaming session: Communication at the group level for water use and tank accessing, with water accumulation - 4th session: Collective mode with water accumulation and water sharing
3	- Research team presented the report on the watershed management committee - All participants in the gaming sessions were individually interviewed	- Individual interview of players, plenary session and closing
4	- Presentation of preliminary results of gaming sessions and recommendations - Participants and local government officials finalized a collective plan and pledged to formalize the watershed management committee	

The gaming sessions in Kengkhar were organized with 18 participants over 3 days in the Block development office. In Kengkhar it took few rounds of trial sessions and briefing before the participants felt confident to play with the RPG. As the issue in Kengkhar was more general and in absence of any conflicting situation, organizing the participatory workshop in the development office was most appropriate as it also ensured a close participation of the Block development officials.

7.2.7 Gaming and simulation processes

In contrast to case studies where RPG tools were used to simplify and validate an ABM model (Trébuil *et al.,* 2002; Barnaud *et al.,* 2008; Naivinit *et al.,* 2010; Worrapimphong *et al.,* 2010), in both case studies based on the conceptualization of our study, the RPG sessions were first organized and the RPG tools were later implemented as computer MAS models. The description of the gaming features are presented in Table 7.5.

Table 7.5. Detailed description of the role-playing game features in Lingmyteychu and Kengkhar.

<table>
<tr><th>Particulars</th><th>Lingmuteychu</th><th>Kengkhar</th></tr>
<tr><td>Situation before the RPG</td><td>- 2 Village RPG in 2003 to resolve water sharing conflict between two up-stream villages in the watershed, not resolved but suggested to include all communities in the process.</td><td>- Used water from natural spring collected in open ditch or wooden trough. Collectively construct 7 water collection tanks and their network to transfer/share water between tanks (village).</td></tr>
<tr><td>Objectives</td><td>- To facilitate exchanges among the 7 villages regarding NRM at the watershed level
- To enhance the understanding of the stakeholders and of the resource use dynamics at the watershed level</td><td>- To enhance understanding of stakeholders on resiliency of spring pond and its management as network.
- To facilitate mobilization of community for collective water resource management.</td></tr>
<tr><td>Participants</td><td>- 3 from each village (7 villages in the watershed) representing irrigator, water guard, and village representative.</td><td>- 3 from cluster of natural spring user (6 clusters of primary users of spring pond) representing female member of household, guard, and village representative.</td></tr>
<tr><td>Game settings</td><td>- 7 groups with 3 members representing were their respective villages made, positioned in distant places during individual mode and placed in close proximity in sequence as in real setting during collective mode.
- Each group has a game board
- Market place to settle the account after each time step
- Announcer of rainfall pattern and associated water quantity before each time step – randomly picked
- Allocator of village water share</td><td>- 3 groups (5 players each for group 1 and 2, and 8 for group 3) Based on the number of player in a group, they have individual miniature house placed in groups of 5, 5, 8 representing 3 villages.
- 3 plastic jar (=pond) placed away from the group but visible.
- Announcer of rainfall pattern (randomly picked) and water availability in each round.
- Market place to update water use information</td></tr>
<tr><td>Scenarios</td><td>- 3 Communication mode – individual, collective and swapped role
- 4 Rainfall patterns and 4 water shares based on rainfall
<table>
<tr><th>Rainfall</th><th>Village 1</th><th>Village 2</th><th>Village 3 to 7</th></tr>
<tr><td>severe wet</td><td>25[4]</td><td>9</td><td>13</td></tr>
<tr><td>wet</td><td>19</td><td>7</td><td>10</td></tr>
<tr><td>moderately dry</td><td>13</td><td>5</td><td>7</td></tr>
<tr><td>dry</td><td>7</td><td>3</td><td>4</td></tr>
</table></td><td>- 3 Communication mode – inter village, intra village and collective
- 2 water accumulation or collection
- 3 water uses – domestic, vegetable irrigation, livestock, religious
- 3 rainfall patterns – severe wet, wet and dry and 3 water accumulation in tanks
<table>
<tr><th>Rainfall</th><th>Tank 1</th><th>Tank 2</th><th>Tank 3</th></tr>
<tr><td>severe wet</td><td>50[5]</td><td>80</td><td>50</td></tr>
<tr><td>wet</td><td>38</td><td>60</td><td>38</td></tr>
<tr><td>dry</td><td>13</td><td>20</td><td>13</td></tr>
</table></td></tr>
<tr><td>Expected outputs</td><td>- Understanding on how players manage water in different scenario
- Observe interactions and document emergence</td><td>- To understand how drinking water scheme can be made resilient
- Identify areas for collective management</td></tr>
</table>

[4] One water unit (represented by a cube) is equivalent to the volume of water required to raise ¼ of an acre (need to convert in international unit system = ha) which is represented as one plot on the game board.
[5] One water unit (represented by a plastic ball) is equivalent to 25 liters.

In Lingmuteychu RPG, during the first scenario, three players with their game boards took position away from the other members of the group to discuss and strategize in isolation. When they got water shares, they discussed and shared water based on their own criteria. A facilitator took record of all the proceedings. After completion of the first turn, the players went to the market place (the accounting desk) to assess their crop yields. In the same manner five rounds were played to simulate the first scenario (Figure 7.12). In the second scenario (inter-village communication allowed), each group was placed in one row in order from upper to lower villages. While the internal sharing among three players was the same as in the first scenario, the group had the option to share any extra volume of water to the immediate down-stream group. Similarly, the down-stream village could request water from the upstream group. After each round, yields were estimated and the water balance recorded by the accounting desk. Five rounds were played. The final scenario was collective with swapped roles. Here the game boards were placed on a raised platform (table top) in order of upper to lower villages. All the players were systematically swapped into different groups. After rainfall and water was declared, the total water of the seven groups was released at one time at the top most canals and sequentially used and passed down. This generated different experiences and new perceptions of how the system operates for the players in another context. After the final scenario, on the following day, all the players were individually interviewed to elucidate their strategies in the game, to assess the tools used and their underlying conceptual models, and to plan the next steps of the ComMod process.

In Kengkhar, the gaming and simulation exercise was scheduled after the completion of constructing seven tanks and their networking pipes to collect spring water and share between hamlets. In view of the new infrastructure which people have not used yet, the Omchu RPG was in a way theoretically testing how the services of the scheme could be efficiently utilized. The Omchu RPG was used in four successive gaming sessions simulating as many scenarios: 1- Individual free access, 2- Free communication at the user group level with free flowing water, 3- Communication at the group level for water use and tank accessing, with water accumulation, 4 - Collective mode with water accumulation and water sharing. With a preliminary briefing and two rounds of a mock session, with lots of undecided players, the game started with drawing of rainfall pattern, announcing the water discharge, and allocation of water in three tanks (Figure 7.13). In the first scenario representing the real life situation, the players were individuals with no consultation, accessing the tanks freely as desired and not sharing water. After collecting water (balls) from the tank they allocated the water based on his/her priority in four cups designated as “domestic use”, “vegetable irrigation”, “livestock”, and “religious rites” (See section 7.3.5). The number of water units allocated by each player was recorded by group facilitators who updated the information at the accounting desk. The same sequence was played for six rounds.

Figure 7.12. The gaming and simulation process in Lingmuteychu, 2005.

Figure 7.13. The gaming and simulation process in Kengkhar, 2008.

In the second scenario, the players were allowed to discuss within the group of users on strategies about water accessing the tank, water allocation and water sharing. As in reality spring water is not collected, any water unit in the tank was taken back by the game organizer to depict free flowing. Rainfall and water discharge were announced. After discussing the players went to the tank as planned, collected water and allocated it in the user cups. Data were recorded after each round until the sixth one. In the third scenario, six rounds followed the same sequence except that water accumulation was introduced in the game (any balance water from the round was added to the discharge of the next round, and carried until the 6^{th} round). The final scenario was played in collective (merging of all three groups) mode. After the announcements of rainfall and discharge, the players discussed about tank accessing and water sharing in the whole group. On the third day all the individual players were interviewed separately to elucidate how they played in the gaming sessions and to record their views on the process, the simulation tool and its uses.

7.2.8 Dissemination of gaming and simulation results

The results of the gaming and simulation sessions were presented in different stages in both cases. On the last day of the gaming and simulation workshop, preliminary results were put together and presented as slide shows to the payers and observers with the primary objective of informing the participants on the outcome of the process and also validating these results. In the case of Lingmuteychu, this presentation of the preliminary results was attended by district officers (agriculture, livestock, and forestry) and local government office bearers. While in Kengkhar result presentation was also attended by farmers who did not participate in the gaming exercise (Figure 7.14).

A: Lingmuteychu B: Khengkhar

Figure 7.14. Dissemination of result of gaming and simulation by way of slide presentation in Lingmuteychu and Kengkhar.

Later the RPG used at the two sites was coded as ABM under the CORMAS simulation platform (7.15). These ABM were used for laboratory experiments to explore different scenarios. Upon request by the watershed management committee in Lingmuteychu, the simulated scenarios of the ABM of the "7 Village game" were presented to all the irrigators in the sub-watershed by organizing short workshops in all the seven villages. Similarly, in Kengkhar, six months after the gaming and simulation field workshop, the computer version of the RPG was also presented to the players.

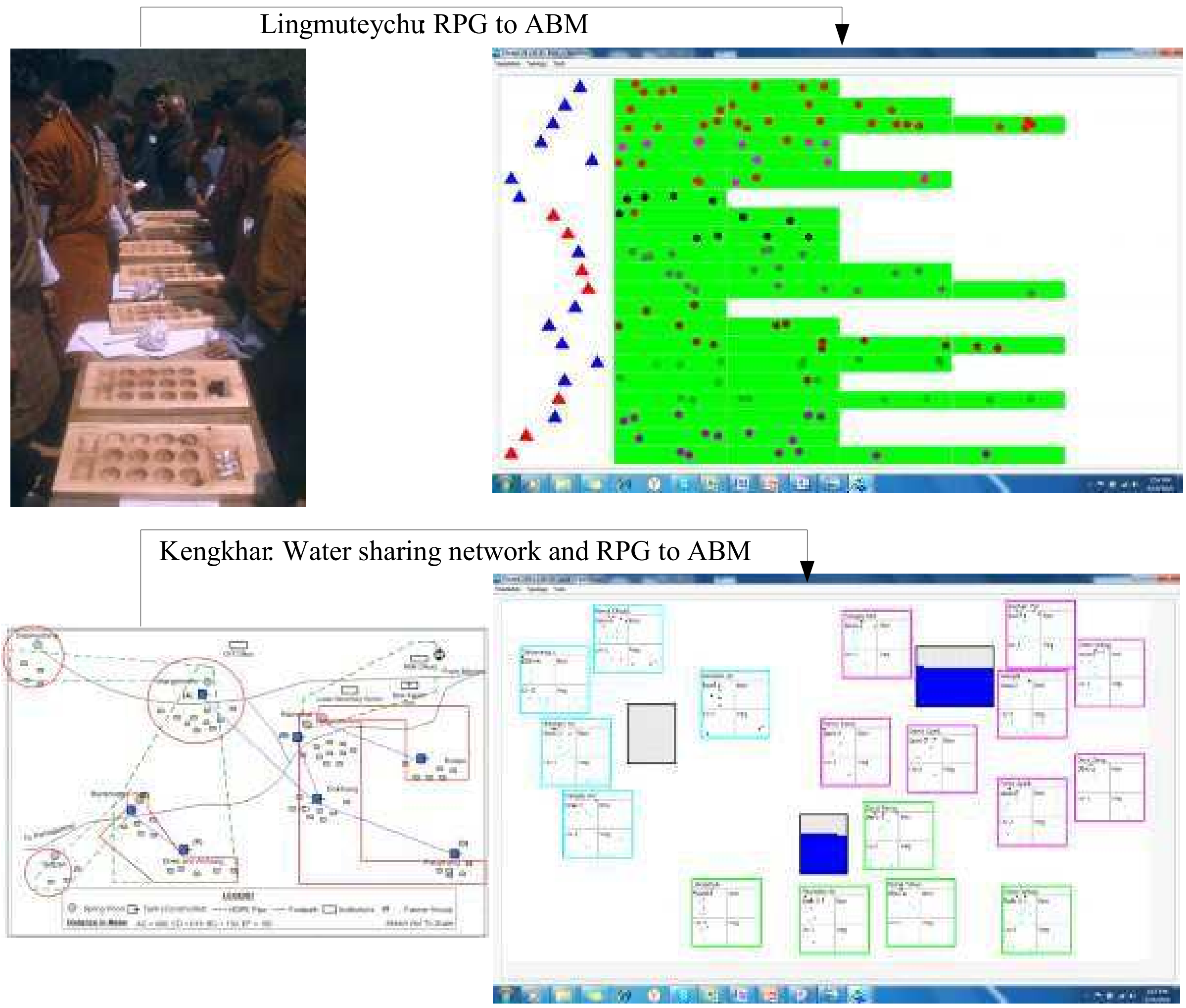


Figure 7.15. Concept for tank network, game board, village game, and agent-based model in Lingmuteychu and Kengkhar.

7.2.9 Collective action and development supports

As an action research, the ComMod approach is relevant to tackle complex and dynamic social systems sharing common resources by way of group decision support tools to promote information exchange between stakeholders (Daré and Barreteau, 2003). Further when the issue has become a long-lasting problem, there was propensity to propose collective actions. The ComMod approach that encourages information exchange and communication fosters trust to commit for collective actions (Ostrom, 2007).

In both sites after the preliminary results were presented, the participants proposed activities that could be implemented collectively for the common good of all. After long deliberations, the groups settled with few activities that urgently needed to be implemented within the following six months. In view of their limited financial resources, the participants in both sites requested the assistance of the local research centre to facilitate fund sourcing.

7.2.10 Monitoring and evaluation

As explained in earlier section 6.7, in both sites, the same evaluation framework of the participatory modelling activities was broadly used. The local facilitator (the agriculture extension officer) posted in the site continuously monitored the process and actions of the participants. A self evaluation by the site coordinator was also done using structured questionnaires, interviews, field visits, and group discussions. In Lingmuteychu a detailed external evaluation was done by external evaluators using the Most Significant Change (MSC) technique and the Actor Network Analysis (ANA) frame. While in Kengkhar an external evaluation also happened in the form of district officials and engineers visiting the tank network.

The shift in individual and collective behaviours influenced by knowledge, communication, and role can stimulate social change. Past works have indicated that the ComMod approach has potentials to accelerate social change largely by creating broad-based social networks and mediated processes. Although the synergy of RPG and computer ABM simulation tools into a ComMod processes was used only in laboratory in this research, the synergy and its ability to integrate other tools and representations have expanded the research abilities to study complex SES. Development of frameworks such as ODD protocol (Overview, Designed Concepts, Details) and evaluation framework (Grimm, Berger et al., 2006) provides an instrument to further build ComMod as a vibrant tool for understanding and co-managing complex SES. The next two chapters present the detailed outcomes and results of the ComMod processes implemented in the two sites.

PART 3: COMPARATIVE ANALYSIS OF FINDINGS AT THE TWO SITES

CHAPTER 8

COMMOD PROCESS IN LINGMUTEYCHU

This chapter provides the situational context from the renewable natural resource point of view and its associated problems. The ComMod process and its main outcomes are presented. The ABM model is also described by using the ODD protocol.

8.1 Contextual feature

8.1.1 Stakeholder diversity

There are as many as ten different categories of stakeholders in Lingmuteychu who have some relationship to the issue (Figure 8.1). The diversity of stakeholders and their stake poses both a challenge and an opportunity. They pose a challenge for the coordination and mediation, while they also provide an opportunity to consolidate the strength of each stakeholder and to create a collective momentum to initiate and sustain change.

Figure 8.1. Diversity of stakeholders in the Lingmuteychu.

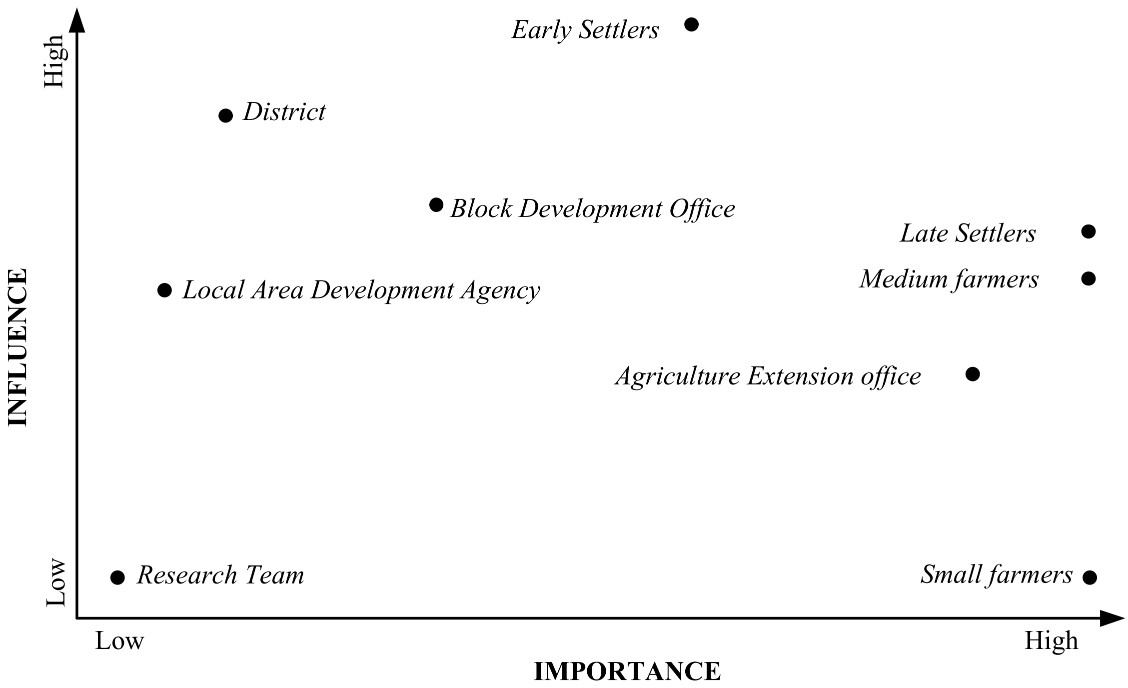


Figure 8.2. Diversity of stakeholders and their relative role in water issues in Lingmuteychu.

Categorizing the stakeholders according to their relative influence on the outcome of the issue being examined and its relative importance to them (Figure 8.2), indicates the position of farmers (a small majority in this case) highest in importance and lowest in influence. In Lingmuteychu the water resource is controlled by early settlers who are also large farmers with highest influence in water issue. But resolving the issue does not seem to be in their interest as they would be deprived of their existing benefits. In the same frame, late settlers and medium size farmers for whom it very important to resolved the water sharing issue only have partial influence on its outcome. Considering the issue of irrigation water in Lingmuteychu, the agriculture extension office and local area development projects in the region can have a substantial influence in terms of prioritizing the development agenda in the sub-watershed. The way categories of farmers are dispersed in the influence-importance matrix, it demonstrates the opportunity for coordination or networking among the farmers.

The renewable natural resources (RNR[1]) research has the lowest level of importance and influence on the resource issues. However, research being external to the problem and having limited control on the outcome, it can play a significant role in exploring the issue and evolving strategies to manage the NRM issue.

8.1.2 Water resource in Social-ecological systems

The SES from the perspectives of water resource can be represented as in Figure 8.3. It provides a holistic representation of how water is integrated into the social, economic, and bio-physical components of the system. Water for irrigating ever expanding rice terraces is primarily limited by the seasonality of the stream flow and short rice transplanting season. Irrigators who operate in a customary right that favoured upstream and richer farmers create the divide among farmers as the topmost village dictates the allocation of water resources. The intervention of the infrastructure provider, the Ministry of Agriculture and Forests (MoAF) provides financial support for the construction and renovation of irrigation schemes. The infrastructures built with modern specifications were probably flawed by the lack of operational mechanisms or scheme operations which did not correspond to the traditional water sharing systems that existed in the community. Further in a sub-watershed where farmers in upstream and downstream strategize water resource use to suit the local situation of water release (in terms of volume and schedule) from upstream community always over use water and delay in release. Such age old understanding restrains infrastructural development. In such situation, each canal and user has different water requirement and sharing system which cannot be fulfilled with standard formal rule (Gillingham, 1999). The spatial and temporal variation in water requirements even in such small sub-watershed exhibits the complexity of the situation.

[1] The Ministry of Agriculture and Forests in Bhutan is also referred as renewable natural resources sector, as agriculture, forest and livestock form the three principal component of agriculture sector.

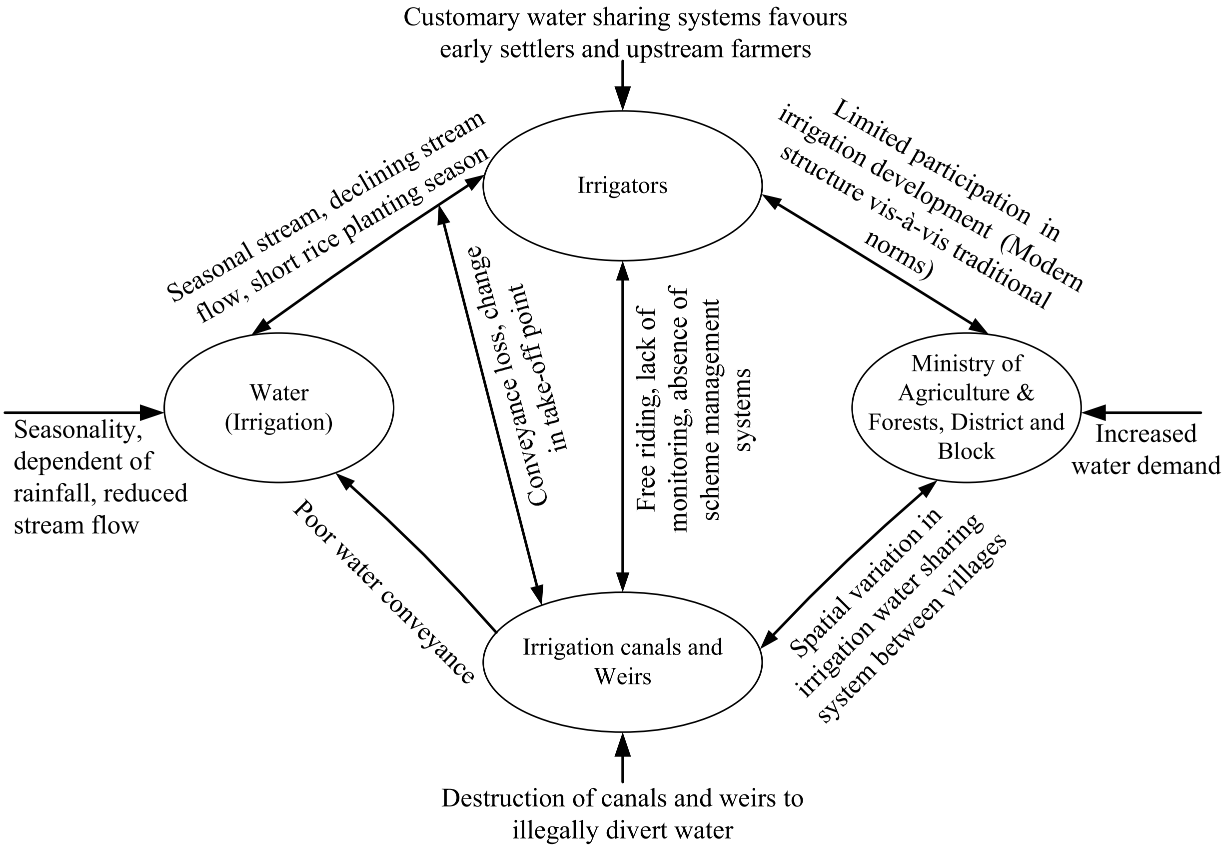


Figure 8.3. Representation of water in Lingmuteychu social-ecological system.

8.2 Analysis of the water management problem

To give a better insight of the sites in relation to water management issues, a simple framework (Table 8.2) is used to compare and contrast the two cases. The principle focus in both sites is associated to water management concern which has evolved over generations. For instance, in Lingmuteychu the issue is associated with sharing irrigation water which is very closely related to declining water, increasing users, and absence of formal legislations.

Table 8.1. Site characterization and specificity of issues in Lingmuteychu.

Topics	Features
Problem	- Irrigation water sharing for rice cultivation
Scale of the problem	- 7 villages – 206 households
Age and evolution of the problem	- Since the settlement and increasing conflict
Severity of the problem	- High for 2 upstream villages and medium among the 7 villages, most severe during the rice transplanting season
Researchers-stakeholders linkage	- Since 1987 on-farm research site, site for Community-based natural resource management CBNRM research
Origin of demand and legitimacy	- Downstream communities. Highly legitimate.
Opportunities/incentives to act	- Increased access to irrigation water leads to increased rice production, and promotes solidarity to enhance social capital

The assessment of the severity of the water problem is based on the proportion of stakeholders affected. It can be classified as high in Lingmuteychu with 89% of households affected. It was evident from the respondents that the problem has intensified every passing year. Most of the development interventions like the construction of weirs and irrigation canals in Lingmuteychu have not helped to resolve the issue. As some respondents opined, these efforts actually fuelled the problem, as with the hope of benefiting from the infrastructures, the communities neglected the existing structures and resource. The failure of public infrastructure in Lingmuteychu is the weir built in the Limti chu stream to share water between Omteykha and Matalangchu in 2009. Considering the legitimacy of the issue, research collaborated with the Lingmuteychu community since 1987 to introduce new crops and production technologies, followed by on-farm water management studies in the mid 1990s, comprehensive diagnostic study of the whole watershed in 1997, and the launch of a CBNRM research project. For instance creating a means to resolve the irrigation water sharing conflict in Lingmuteychu will have direct impact on rice production, wetland expansion, and increased systems productivity.

Eliciting the problems associated to each entity of SES further clarifies the seriousness and importance of the problem (Table 8.3). For instance, in the case of Lingmuteychu, the local rules, arrangements and institutions are well established and without including these customary regimes any intervention will be futile. Even though the new water policies may emphasize equitable water sharing, Lingmuteychu communities will and have to continue the traditional social stratifications they use beyond water. With the enactment of the Water Act 2010, many of the operational legal issues may be resolved, but an integrated approach is needed to solve issues such as in Lingmuteychu, which is entwined in the fabrics of the local society whose livelihood depends on rice for which water is a pre-requisite. Indirectly water is a determining factor of influence, power, wealth, and food security in many parts of Bhutan (Chapter 4). Therefore, the challenge is more about declining water availability rather an organizational issue.

Table 8.2. The problem of water from Social-ecological systems perspectives in Lingmuteychu.

Entities	Lingmuteychu
Resources	- Water for irrigation (declining resource and conflict in sharing)
Resource users	- Farmers cultivating irrigated rice, 4 categories – thrulpa, cheep, chatro, lhangchu - Traditional rules, stealing, mismanagement
Public infrastructure providers	- Government agencies – Agriculture - Multiple administrative jurisdiction, non-existence of water act and policy
Public Infrastructure	- Irrigation canals and distribution weirs - Local norms to use seepage water by downstream village, water stealing, low stream flow, poor maintenance
External Environment	- Policy and legal, political, administration, climate, economy - No clear legal and policy environment, focus of development programs, changes in rainfall intensity and patterns, market demand

8.3 Companion modelling process in Lingmuteychu

The process in Lingmuteychu started with situational analysis followed by conceptualization of model, gaming and simulation (Figure 8.4). Chronologically the process in Lingmuteychu started in 2002, However, the baseline study in 1997 formed the basis to apply the ComMod approach. Considering the impending conflict between the two uppermost villages (Limbukha and Dompola), two early ComMod cycles were implemented in May and December 2003 with these two villages (Gurung, 2004). The request from the participants to upscale the process to include all seven communities within the sub-watershed resulted in the development and implementation of the 7 villages role-playing game in 2005. The process resulted into the creation of a Watershed Management Committee (WMC), the renovation of irrigation canals and the construction of check dams.

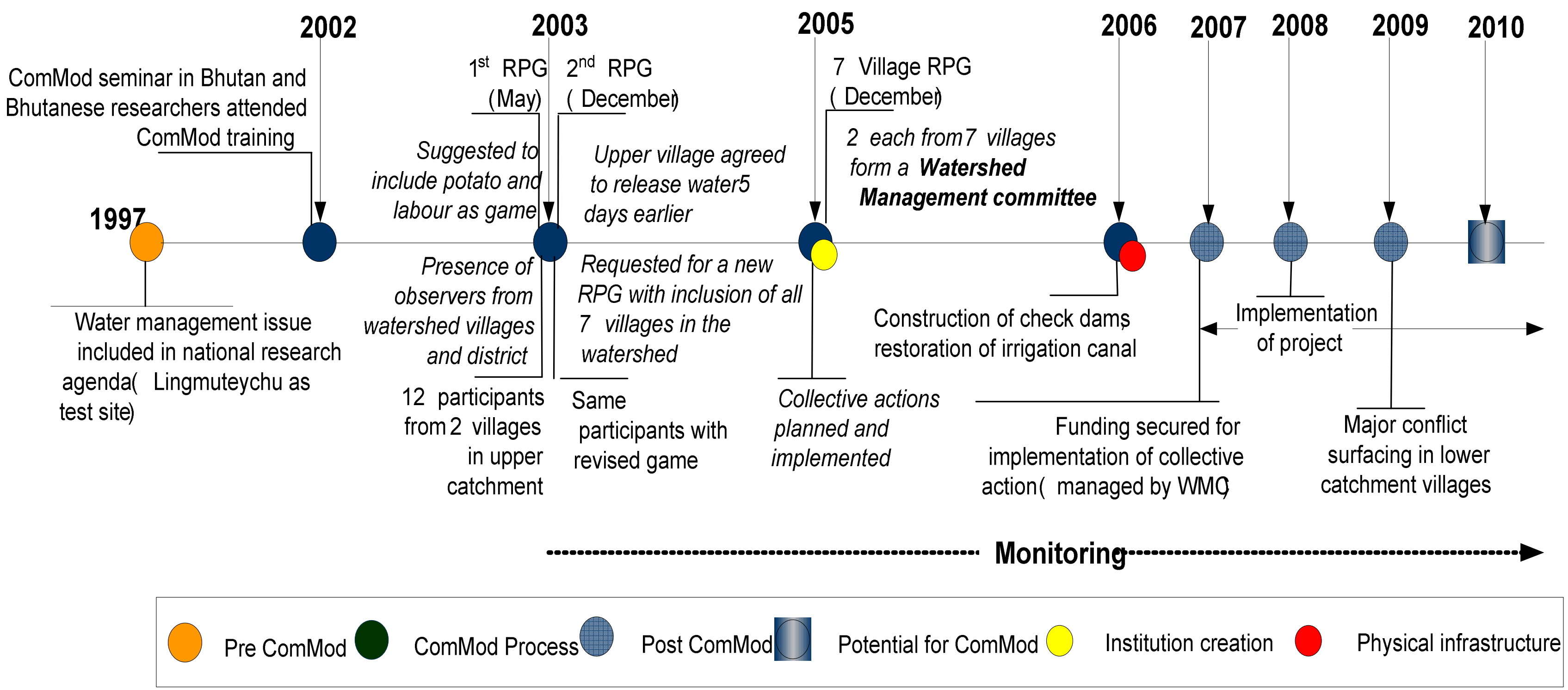


Figure 8.4. Chronology of the ComMod process in Lingmuteychu.

8.3.1 Conception of the model

Conception of the model was done initially by the local research and extension team using the information collected from the diagnostic study and literature review. The framework was discussed with farmers in two different ways. As it was up-scaling of a two-village game into a seven-village game, the basic framework of the earlier version was used with some amendments. As explained in Chapter 7, a simple diagram was used to discuss the conceptual model of the ComMod process with the Block development officer and the district extension officer. The final features of the RPG were as shown in Table 8.3.

Table 8.3. Features of the 7 village role-playing game in Lingmuteychu.

Features	**Lingmuteychu 7 village game**
Players	Irrigators: different categories, from up to downstream villages
Roles	Receive village water share, irrigate plots, share, monitor, voice
Rules of the game	Declare rainfall, allocate village water share, share among three within a village, communication according to three modes
Game sets	Playing board, with wooden cubes representing water unit
Turns (round of play)	1 year
Gaming session:	4 days

Some of the aspects, like sharing rules and the decision-making process, were left open so that the interaction among the players will be vibrant and free, allowing them to create rules as the game proceeded. The turns used in Lingmuteychu was 1 year representing a rice season. While most farmers practice double cropping of potato or mustard or wheat after rice, only rice was included in the RPG as it is the only crop linked to water shortage issue.

The first version of the 7 villages RPG was pre-tested with Natural Resources Training Institute (NRTI) students (now College of Natural Resources). Coincidently as there was one of the students in the group from Lingmuteychu, it was appropriate that he could relate the game to the reality and explain its relevance for the benefit of the group. The information generated from the gaming session was analysed using a spreadsheet which was useful to communicate to the students. The trainees expressed the need for a facilitator in each group to record observations and exchanges for further analysis. The pre-testing was also useful to calibrate the game. Based on the pre-testing, seven facilitators were introduced in the 7 village game. To develop a computer ABM based on this RPG, the entities presented in Table 8.4 were identified and UML diagrams built to conceptualize the model.

Table 8.4. Model entities in Lingmuteychu.

Entity	7 Village RPG
Social	Farmer, village, management group
Spatial	Paddy field
Passive	Climate, water, rice crop

8.3.2 The twelve steps of the ComMod process in Lingmuteychu

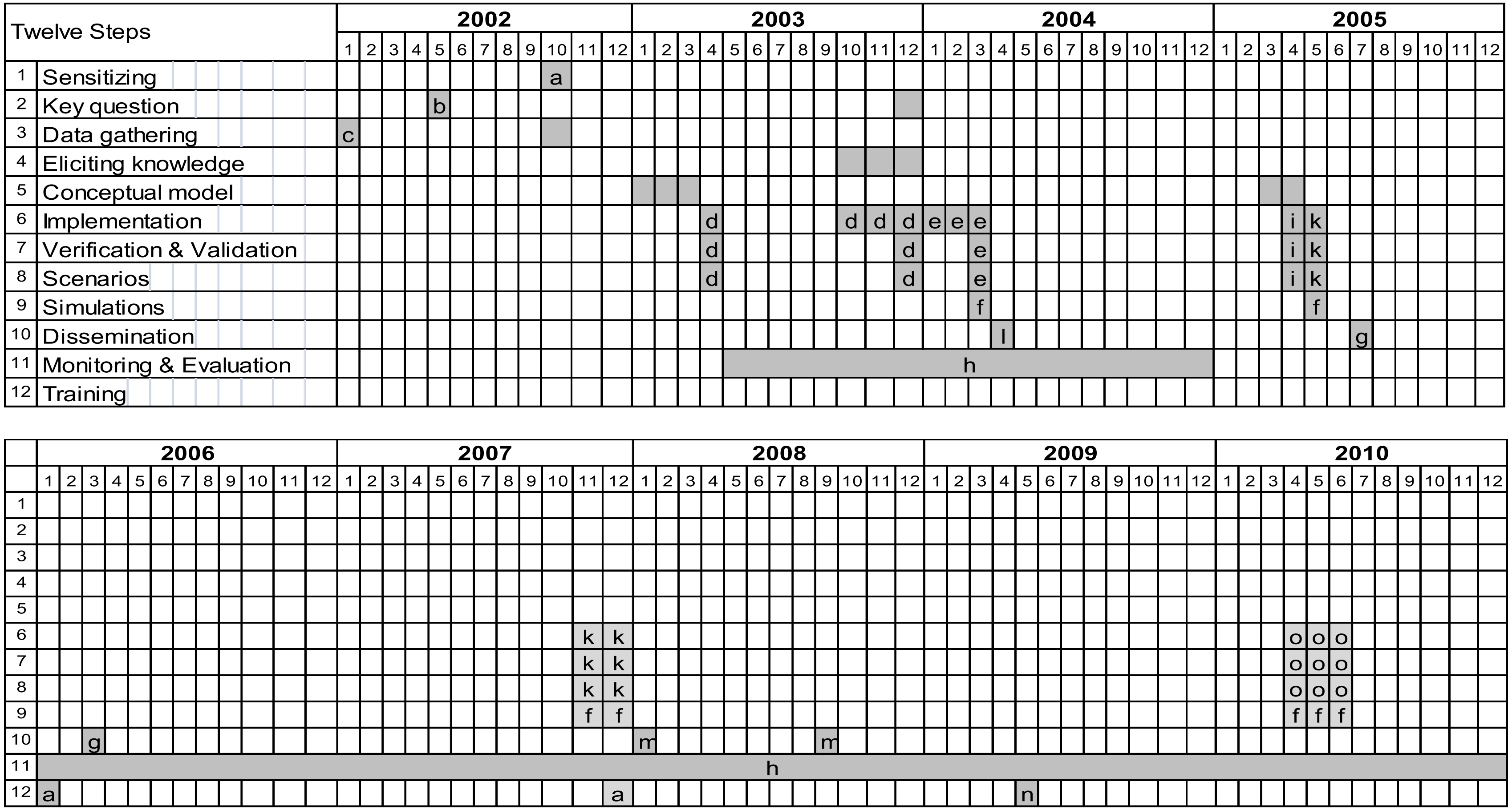
The formal sequence of twelve steps implemented in the case of Lingmuteychu is presented in Table 8.6. The sequence clearly displays the flexibility of the approach and the recurrence of steps along the process. This resembles cases implemented in the Lam Dome Yai watershed of Northeast Thailand (Naivinit *et al.,* 2010) and Bac Lieu province of the Mekong delta (Dung *et al.,* 2009) where sensitization happened after the initial field activities. Similarly, training was another step which was important as capacity development was an output of the process. In addition to enhancement of capabilities of farmers, researchers were also trained though formal training programs. Unlike in case studies in Thailand and Vietnam where the ComMod approach was used, monitoring and evaluation of the process effects was continuously conducted by an on-site researcher.

Table 8.5. Sequence of twelve steps of the ComMod process in Lingmuteychu.

Lingmuteychu
1. Data gathering (2)
2. Key question (2)
3. Sensitizing (1)
4. Eliciting knowledge (1)
5. Conceptual model (2)
6. Implementation (3)
7. Verification and validation(3)
8. Scenarios (3)
9. Monitoring and evaluation (os)
10. Simulations (4-1)
11. Dissemination (5)
12. Training (3)

NB: Figures in parenthesis indicate the number of times a given step was implemented; os = on site.

The twelve steps chronogram in Figure 8.5 also depicts the length of the ComMod process. In the case of Lingmuteychu the ComMod process actually took four years, comprising three cycles involving 2 villages and one with the whole seven villages. However, as the development of ABMs and its testing in the laboratory took much longer than initially planned, it extended to nine years. Despite the length of process, outputs were tangible. Another benefit of extended period was the possibility to do continuous monitoring and also put to test the institution established as outcome of ComMod process.



Legend: a: training, b: trip to Bhutan, c: preliminary diagnosis, d: first RPG (2 villages), e: first ABM (2 villages), f: simulations in the laboratory, g: presentation, h: monitoring by local facilitator stationed at the research site, i: second RPG (7 villages), k: second ABM (7 village game), m: presentation to all the community, n: AKB post-graduate diploma, o: third & final ABM (7 villages).

Figure 8.5. Chronograms of ComMod processes implemented at Lingmuteychu watershed to facilitate collective management of resources.

8.3.3 Description of the seven Village model

8.3.3.1 Overview

The process of companion modelling work in Lingmuteychu watershed dates back to May 2002 when first RPG between 2 villages in the upper catchment was organize to better understand irrigation water sharing conflict between Limbukha and Dompola in the watershed. A computer ABM was developed in Common-pool Resource and Multi-agent Systems (CORMAS) platform and was used only in laboratory for the purpose of generating scenarios and making comparative analysis (Gurung, 2002). During the final debriefing workshop of the December 2003 RPG, participants requested for up-scaling the RPG to 7 villages within the watershed. A 7 village RPG was organized in April 2005 with the objectives of (i) to facilitate exchanges among the 7 villages regarding NRM at the watershed level; (ii) to enhance understanding of stakeholders and of the resource use dynamics at the watershed level; (iii) to accompany the creation of a Watershed Management Committee (WMC) in Lingmuteychu; and (iv) to define the next steps toward the establishment of a formal WMC before late 2005 and to plan several short-term priority actions in NRM. Later on, the 7 Village RPG was implemented in the CORMAS platform to further explore scenarios.

Purpose

The purpose of the 7 village RPG was to bring together the seven villages in the sub-watershed to discuss and explore different strategies to resolve the long standing water sharing problem. While the computer aided ABM could not be developed immediately and applied in the field, ABM was developed to explore scenarios in the laboratory. The AMB was also used to present different scenarios to community and the watershed management committee, so that they could foresee and understand the consequences of different management options.

State variables and scale

The model uses seven variables classified into three categories of entities: spatial, social, and passive (Table 8.6). As the issue is related to irrigation, water actions are based at the plot level defined spatially as two to four plots per player. The plot can hold a maximum of two units of water and two land use features as rice or fallow. The social entities comprise of three farmers per village who are clustered into seven villages. All the villages are represented in the management committee with one member each. Each farmer owns two to four plots of land which they can irrigate and grow rice. The management committee takes collective decisions to allocate water to villages and declare awards based on the water use. Passive entities in the model are the rainfall, water and the rice crop. The climate is used to represent four rainfall patterns, i.e. dry, moderately dry, wet and severely wet, based on which irrigation water share is allocated to each village. After the water allocation, players share and allocate to their field based on the protocol. The hierarchies of entities are presented in Figure 8.6 as a UML class diagram.

Table 8.6. Variables of the 7 Village model used in Lingmuteychu.

Entity		**Parameter**	**Default value**	**Unit**
Spatial	Plot	Water use	0..2	Number
		Land use	Fallow, rice	Fallow
	Village	Households	3	Number
		Water share	7 to 25	Units
Social	Farmer	plot per farmer	4	Plots
	Management Group	Number of village	7	Villages
		Reward	1000-4000	Ngultrum[2]
Passive	Climate	Rainfall	Dry, Moderately Dry, Wet, Severe Wet	State
	Water	Water for village 1 during dry climate	7	Water unit
		Water for village 1 during moderately dry climate	13	Water unit
		Water for village 1 during wet climate	19	Water unit
		Water for village 1 during severe wet climate	25	Water unit
		Water for village 2 during dry climate	3	Water unit
		Water for village 2 during moderately dry climate	5	Water unit
		Water for village 2 during wet climate	7	Water unit
		Water for village 2 during severe wet climate	9	Water unit
		Water for village 3 to 7 during dry climate	4	Water unit
		Water for village 3 to 7	7	Water unit

[2] 1 Euro = Nu. 60.00

	during moderately dry climate		
	Water for village 3 to 7 during wet climate	10	Water unit
	Water for village 3 to 7 during severe wet climate	13	Water unit
Crop	Crop type when water cube is present	Rice	crop type
	Crop type when plot is empty	no crop	
	Maximum crop yield per plot	700	Kg
	Crop yield/plot when water is maximum	500	Kg
	Crop loss due to late planting	30	%
	Crop loss due to dry season	50	%
	Crop loss due to severe wet	40	%

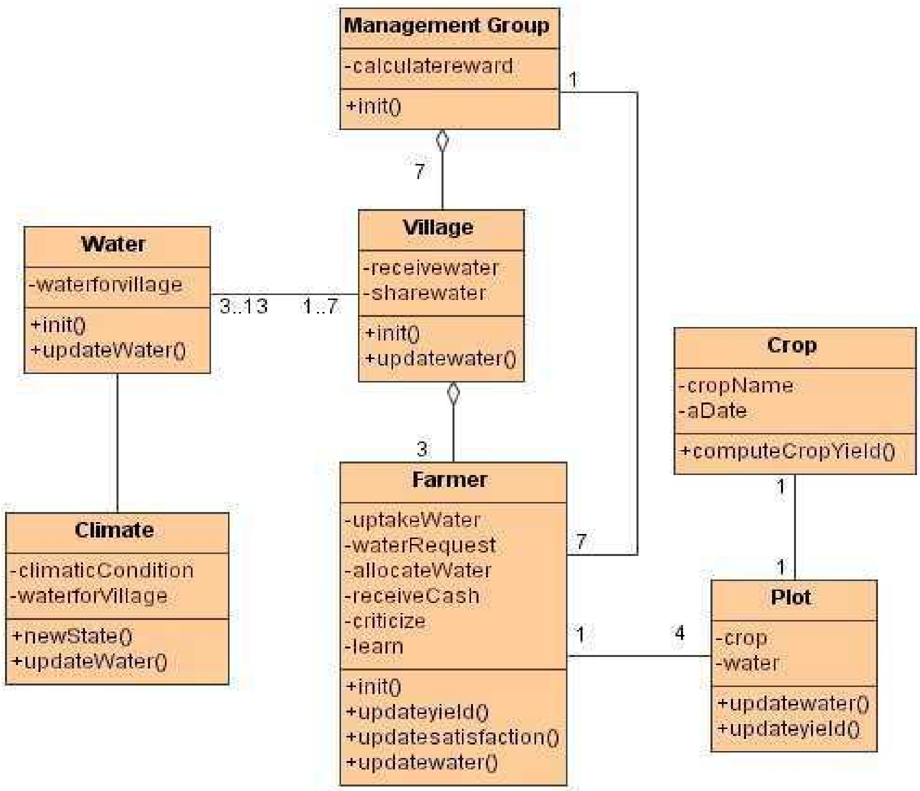


Figure 8.6: UML class diagram showing the attributes and methods associated to each entity in Lingmuteychu 7 villages model.

Process overview and scheduling

The model is scheduled on annual time step representing a rice season. Depending on the climate water share for each village is computed based on which water is shared among the farmers. The model calculates rice yield, income and the reward (Figure 8.7).

The model is programmed based on three communication and water sharing profiles as individual, village and collective (Figure 8.8). In the individual scenario, water sharing is based on the preference of the individual, which in village preference and watershed level preference is calculated for village and collective level respectively. The diversity of the farmers is represented in the model by three categories based on the number of plot each owns. Depending on the number of plots assigned to each farmer in a village, water is shared as indicated in Figure 8.9.

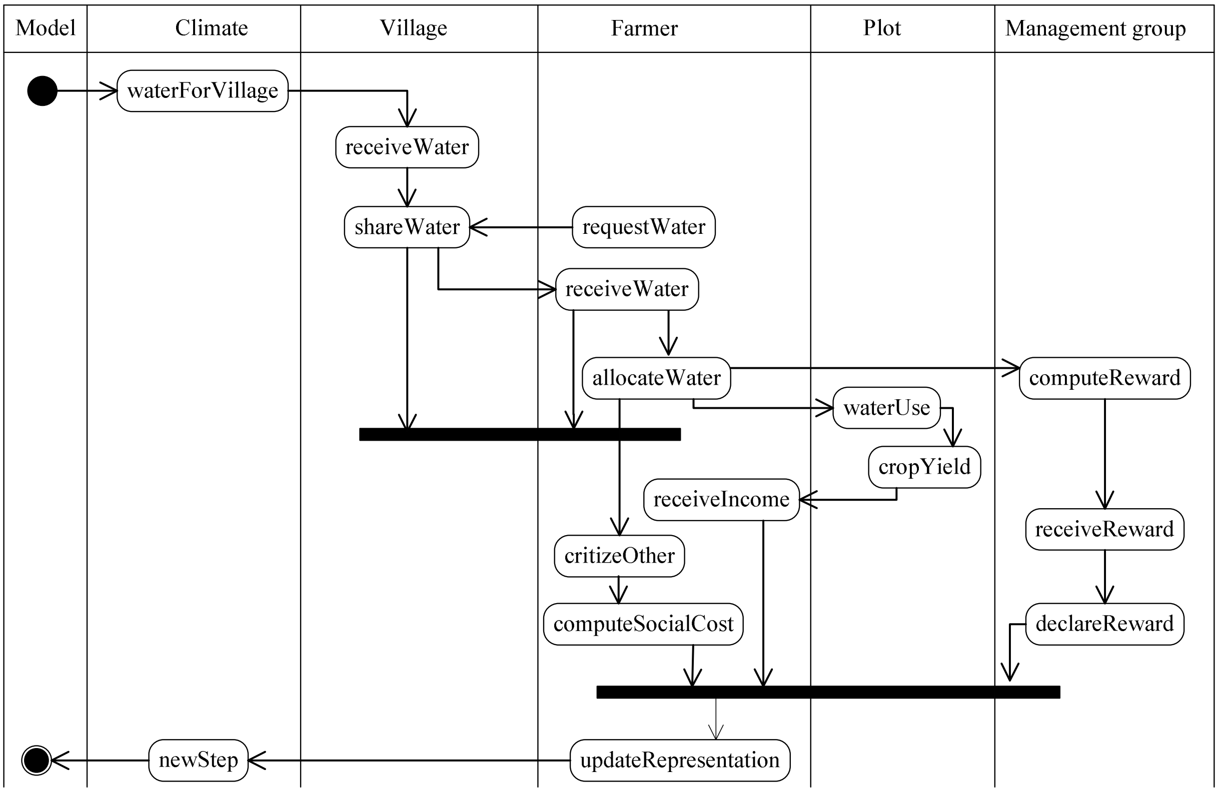


Figure 8.7: UML sequence diagram of the 7 villages model in Lingmuteychu.

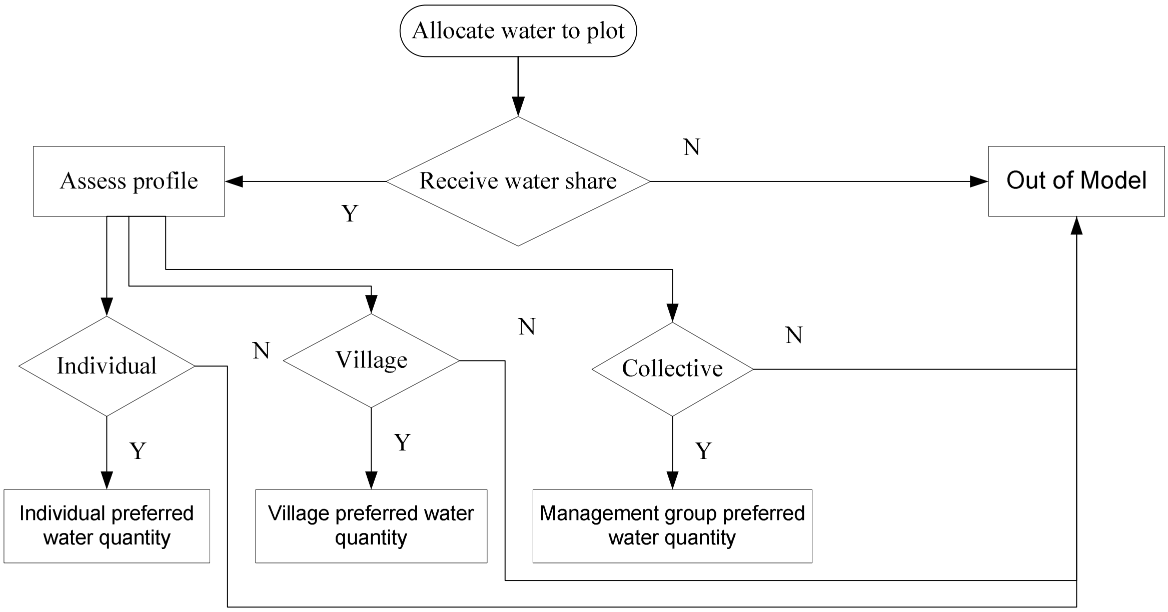


Figure 8.8~~9~~. Activity diagram presenting the decision making process to allocate water in the paddy field in the 7 villages model of Lingmuteychu.

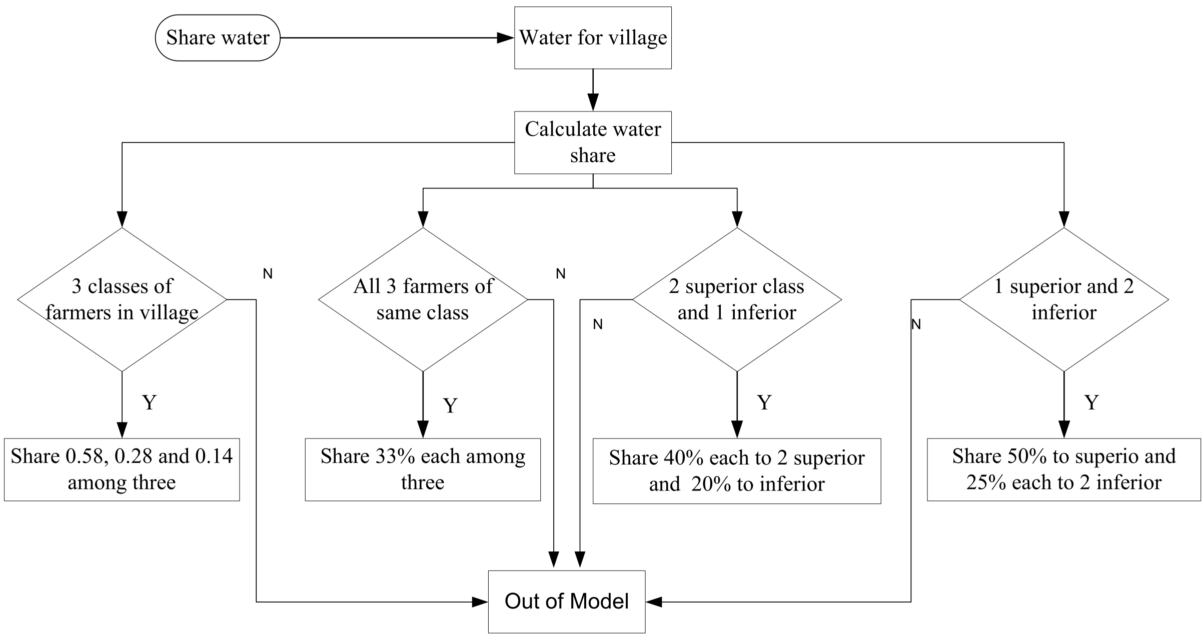


Figure 8.9~~8~~: Activity diagram displaying the decision making process to share water among three categories of farmers in Lingmuteychu 7 villages model.

The model runs with three communication scenarios (Table 8.8). First as case-as-usual where each village operates individually and choices individual preference of water units to use in plot. In the village mode it acts as a unified group with an internal water sharing system. In first scenario, there is no interaction between villages and no exchange of water. In the collective mode, all the seven groups are placed in one row sequentially represent upstream and downstream villages (Figure 7.8). Players are allowed to freely communicate between groups and even seek surplus water from upstream village. The final collective scenario with swapped roles was organized in a manner that players were randomly assigned to different villages. The seven game boards were placed in a row and the players surrounded the array of game boards to play. Players could monitor all the moves, and make suggestions for collective good.

Table 8.7. Mode of communication and scenarios used in the 7 village model in Lingmuteychu.

	Modes	Rounds	Communication modes
1	Individual	5	The decision to allocate water is based on individual choice and water-yield representation
2	Village	5	Water allocation to plot is based on village decision which is the best based on village level water-yield representation
3	Collective	5	Water allocation is based on the management committee – i.e. all village information is put together and decision is based on the collective best.

Design Concepts

The model using the three scenarios moves from the traditional (existing) system, to village level interactions, and finally to a collective mode of communication where all villages within the sub-watershed make collective decisions. The individual mode is designed to replay the behaviour of farmers who behave independently to decide amount of water for each plot and also the plot which will be cropped. The way three players strategize water use can lead to the emergence of a unique pattern, and also a common interest group and collective strategies to take benefit of the resource. It will be useful to make comparison of strategies across the seven villages on water use. The emergence may change when the agents decide collectively.

All agents have individual identity representing the real situation where irrigators are grouped into four groups based on water rights. They are *Thruelpa*, *Cheep*, *Chatro*, and *Lhangchu* (Gurung, 2004). In the model the first three are used as they have definite water allocation of 58%, 28%, and 14% respectively. The last category is not included as this group is made of generally landless water beggars. Three agents are grouped into a village sequenced from one to seven representing the communities in the sub-watershed. All the seven communities are grouped into the management institution of the sub-watershed. As such all agents have to memorize the features and their location, plot number and water share. The three agent categories and differing composition in each village that act on the water share, depending on rainfall randomly assigned, is expected to be the principal source of interaction. In view of agents behaving based on the random water share influenced by random rainfall pattern, the model can be considered as stochastic. The model was tested using multiple simulations to observe the consistency of agent behaviours. The computer ABM version was first presented to the WMC after which it was presented to all the seven villages so that all irrigators could observe the simulations and be aware of the scenarios and their consequences.

Details

Initialization

Each agent is assigned with a number from one to twenty one and is grouped into seven clusters as villages. All farmers are randomly assigned with a given farmer class (*Thruelpa*, *Cheep*, and *Chatro*). These initial features of the eighteen farmers were kept constant for all time steps and rounds to allow them to explore the varying resource level.

Every time step is initiated by randomly picking rainfall patterns as represented in Table 8.9. Four variations are used to indicate rainfall patterns as in the 7 village RPG. Depending on the rainfall pattern, a given village level water share is allocated to each village. Across the rainfall pattern, broad allocations among villages are used as village two gets 30% of the first village, and village three to seven receive 50% of the first village share.

Table 8.8. Rainfall patterns and corresponding water shares (units) for each village in the 7 village model used in Lingmuteychu.

Weather	Village						
	1	2	3	4	5	6	7
Severe wet	25	9	13	13	13	13	13
Wet	19	7	10	10	10	10	10
Moderately dry	13	5	7	7	7	7	7
Dry	7	3	4	4	4	4	4

Input

The comprehensive diagnostic survey of Lingmuteychu sub-watershed in 1997 identified four farmer categories with well defined water shares. It was also revealed that the top village (Limbukha) in the catchment, from where Limtichu stream originates. Limbukha being the first settler in watershed dominates water use with the customary rule of "first-come-first-serve". There is distinct water sharing proportions between villages followed ever since rice cultivation started.

Based on stream flow and plot water utilization measurement, a rough relation between rainfall and stream flow was established. Four rainfall patterns would result in water volume as 100 units during severe wet, 75 units in wet season, 50 units in moderately dry and only 30 units during dry, implying a base flow of 30 units. Irrespective of rainfall pattern, the water shares between the seven villages are set as 25% for the first village, 9% for the second village and 13% each to the remaining villages. The water allocations were based on the local understanding that second village gets one-third of first village's share, while the remaining five villages gets half of what first village uses. As the individual water use pattern is dependent on the profile of the agents, water allocation is also set as individual, village level, or watershed level.

Spatial configuration and interface

The spatial settings are a grid with a 24 rows x 6 columns tessellation to represent a virtual landscape on which plots (paddy fields) are located. Each row has six cells representing a space for the agent (first cell), 2 to 4 plots of rice fields (cell two to five) belonging to one agent, and the 6th cell represents the irrigation canal. There are twenty one rows assigned to as many agents. Three rows in series are grouped as a village, i.e. rows one to three make village one and rows four to six is village two and so on (Figure 8.9). A water unit is represented by a coloured circle and each village is assigned with one different colour.

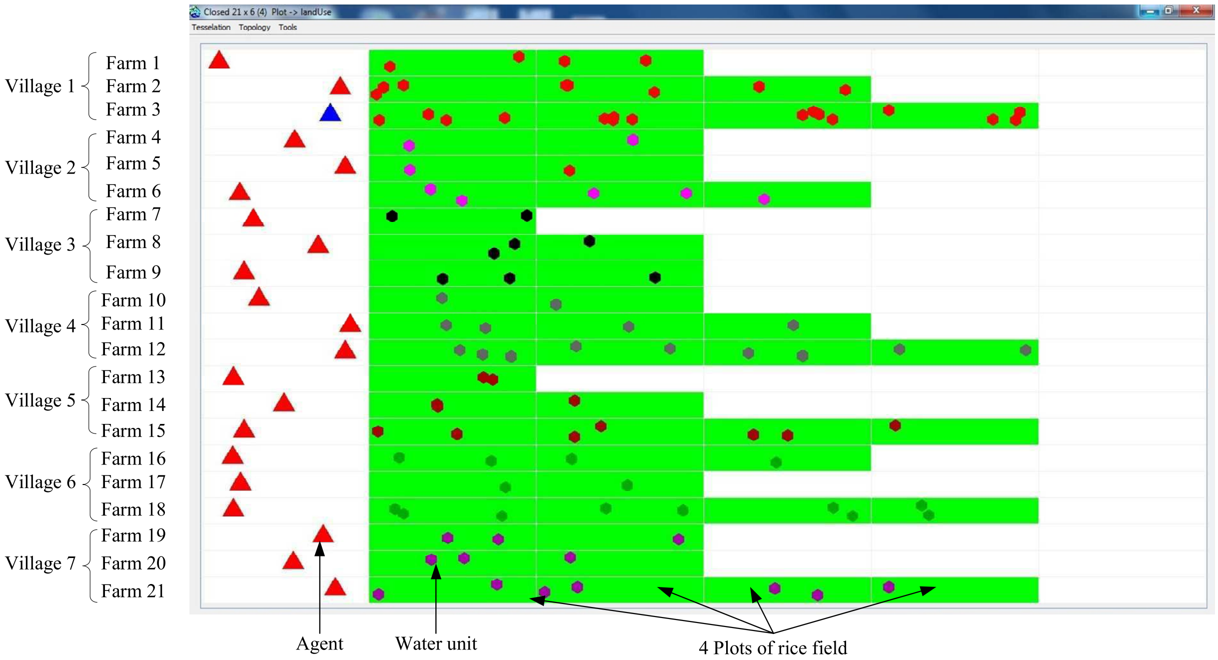


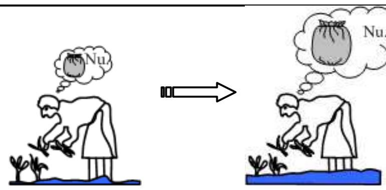
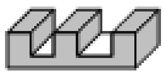
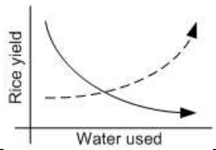
Figure 8.10: CORMAS interface of the seven village agent-based model used in Lingmuteychu.

8.4 Analysis of gaming and simulation sessions

8.4.1 Shared representation of context and participants understanding

As stipulated by the posture of the ComMod approach, the integration of points of view of all stakeholders, including those of the modeller, to construct the model enhances its relevance and use. According to the constructivist approach, reality is constructed creatively with their language, labour, and technology which is dynamic and changes as the circumstance changes (Röling, 1996). From the cognitive perspective, representations are mentally constructed using a set of symbols and logical inferences (Johnson-Laird, 1983). In the case of Lingmuteychu, three broad categories of stakeholders were identified and their representations can be simply described as given in Table 8.9

Table 8.9. Simplified representation of the mental maps or perceptions of the situation by three different categories of stakeholders in Lingmuteychu.

Site (resource)	Stakeholders	Representation	Method to capture the initial representation
Lingmuteychu (water for irrigating rice)	Irrigator		Participatory resource mapping & envisioning
	Infrastructure providers		Consultation and development plans
	Researchers		Field trials and literature reviews

The ComMod approach was efficient to recognize the shared representations of the context and use them in elucidating the details on how they manage the system and how they foresee the future. The consultative process was the first effort to create a preliminary representation which was further improved with more clarity in expressing the mental frame. The schematic representation in Figure 8.11 presents how initial individual points of view converge into a shared representation which facilitates new understanding and potentially change these individual points of view.

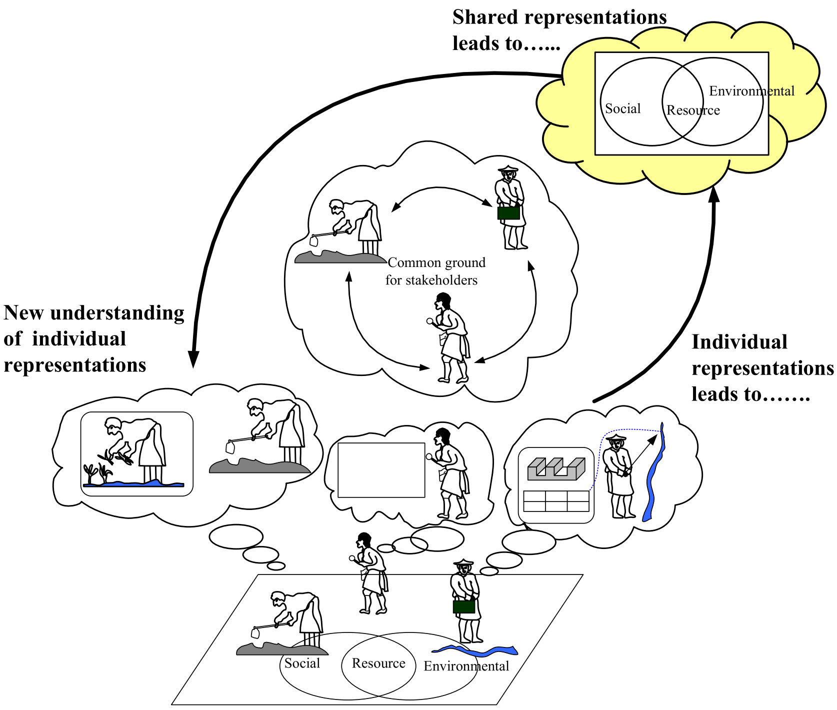


Figure 8.11. Co-designing of shared representation of the water management problem in the companion modelling process implemented in Lingmuteychu.

The study showed that farmers always perceive natural resource depletion and their marginalization despite their dream of ultimate improvement with external support. Similarly in both cases, the support service agency sees structural intervention like a network of canals and weirs in Lingmuteychu and laying pipes. The third agent in this case was the researcher who had very limited understanding of the situation, therefore used preliminary field observations and literature reviews to construct his own perception.

8.4.2 Identification of scenarios from gaming sessions

The RPG used rainfall patterns as the random factor which determined the resource endowment. Before every turn rainfall was randomly picked. While four rainfall patterns were used in 7-village game. Against the rainfall patterns, a set of protocols were used as a constant factor to induce variation in behaviour. Traditionally as irrigators interact only within the village this system was considered as a first protocol in the RPG representing the existing water sharing system. To make a comparison of different water sharing protocols, a second protocol was introduced with an open "collective" social network allowing sharing water within and between villages. The third protocol was formed by swapping the roles of each player and maintaining an open social network. The combination of four rainfall patterns and three protocols generates twelve scenarios which can be compared against parameters associated to water as shown in Table 8.10.

Table 8.10. Scenarios derived from the 7 village gaming sessions executed in Lingmuteychu.

Protocol	Rainfall pattern			
	Severe wet (R1)	Wet (R2)	Moderately dry (R3)	Dry (R4)
P1.Village wise: interaction and water sharing only within village	$S_1=P_1R_1$	$S_2=P_1R_2$	$S_3=P_1R_3$	$S_4=P_1R_4$
P2.Collective: interaction and water sharing within village and between villages	$S_5=P_2R_1$	$S_6=P_2R_2$	$S_7=P_2R_3$	$S_8=P_2R_4$
P3.Swapped and collective: open interaction and free water sharing (all irrigators operate as one single community)	$S_9=P_3R_1$	$S_{10}=P_3R_2$	$S_{11}=P_3R_3$	$S_{12}=P_3R_4$

8.4.3 Analysis of simulation results of the different scenarios

For the purpose of comparison, four aspects related to water use efficiency are analysed.

8.4.3.1 Resource stress

One of the visible parameter players considered for efficient water use system is the balance of water. The RPG was efficient to generate interactions among different players. Scenario S5 (Table 8.10) resulted in an overall water balance of almost 90 units followed by Scenario S1 with only little above 30 units of water. All other scenarios had water balances of less than 20 units. The traditional water sharing system (S_3 and S_4) and collective swapped (S_{11} and S_{12}) under the influence of moderate dry and dry situation used all the water (Figure 8.12).

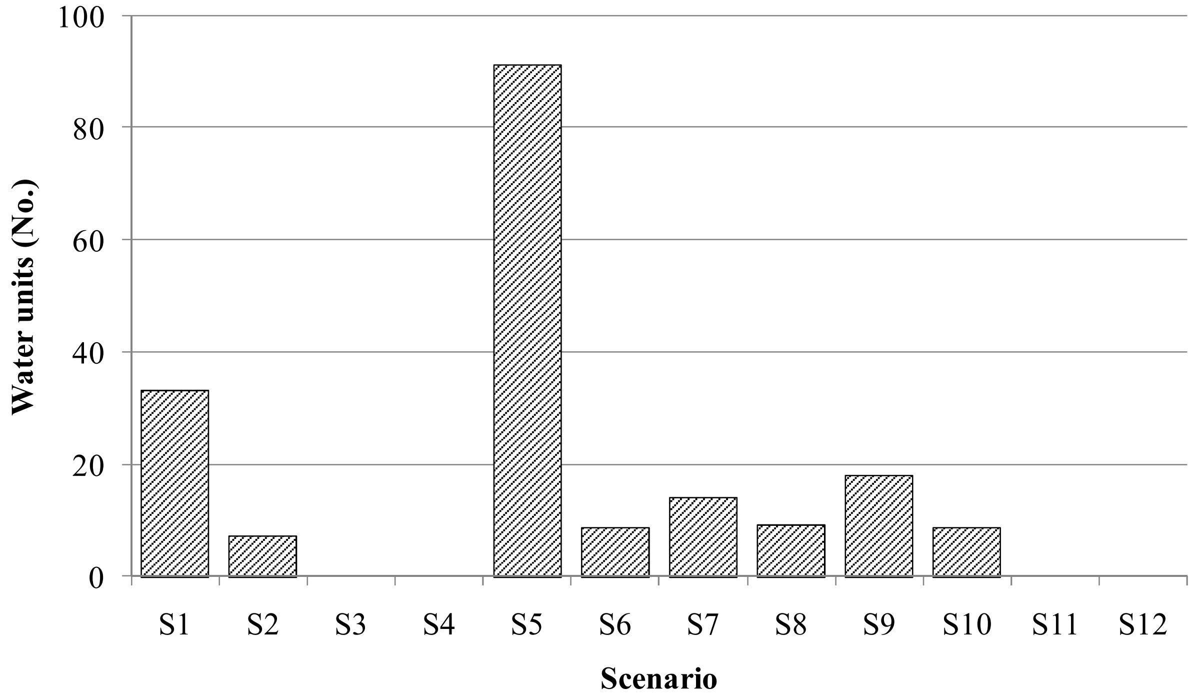


Figure 8.12. Water balance from the simulation of twelve scenarios with the 7village role-playing game in Lingmuteychu.

8.4.3.2 Equity in resource allocation

In a situation where famers are segregated using customary rules for access and sharing of natural resource, there is always an issue of inequality in resource allocation. This is further aggravated as allocations are done in terms of time and proportion of flow. In an attempt to make a comparison among scenarios simulated in gaming sessions, the Gini coefficient[3] is used to assess the way each scenario influences equity in water allocation. In such situations it is relevant to assess the balancing power any strategy can introduce. The Gini coefficient has been used in measuring water use inequality in South Africa (Cullis and van Koppen, 2007).

[3] The Gini coefficient is a measure of the inequality of a distribution, a value of 0 expressing total equality and a value of 1 maximal inequality. The Gini index is computed as follows:

$$G = 1.0 - \sum_{i=1}^{n} f_i (p_i + p_{i-1})$$

Where G= Gini index; f_i= proportion of households in interval i; p_i= the proportion of water allocation received by households in interval i and all lower intervals

In Lingmuteychu water shares among players in each scenario was evaluated and compared across the twelve simulated scenarios and the results are presented in Figure 8.13.

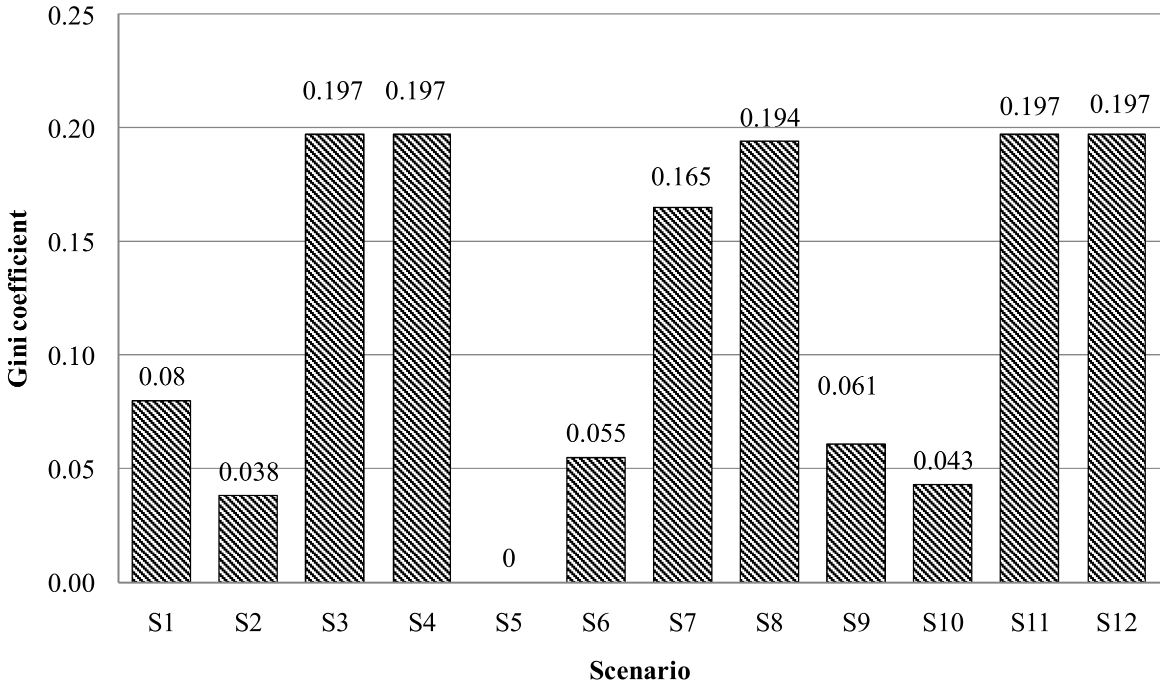


Figure 8.13. Inequality in water shares across twelve simulated scenarios in Lingmuteychu.

It appears fairly equitable in terms of water share allocations, however variations exists. For instance scenario (S_5) characterized by free interactions and sharing within and among villages fosters total equality. The remaining scenarios can be clustered into two groups (i) those below coefficient of 0.10 – S_1, S_2, S_5, S_6, S_9, and S_{10}, and (ii) those above 0.15 coefficient – S_3, S_4, S_7, S_8, S_{11}, and S_{12}. This difference can be associated to rainfall pattern, as cluster (i) closer to perfect equality represents condition of high rainfall pattern and second cluster receives lower rainfall.

8.4.3.3 Resource sharing

In the gaming sessions, vibrant exchange and interactions among players were observed. As such the exchange of water units (sharing) is an interesting indicator to compare different scenarios (Figure 8.14).

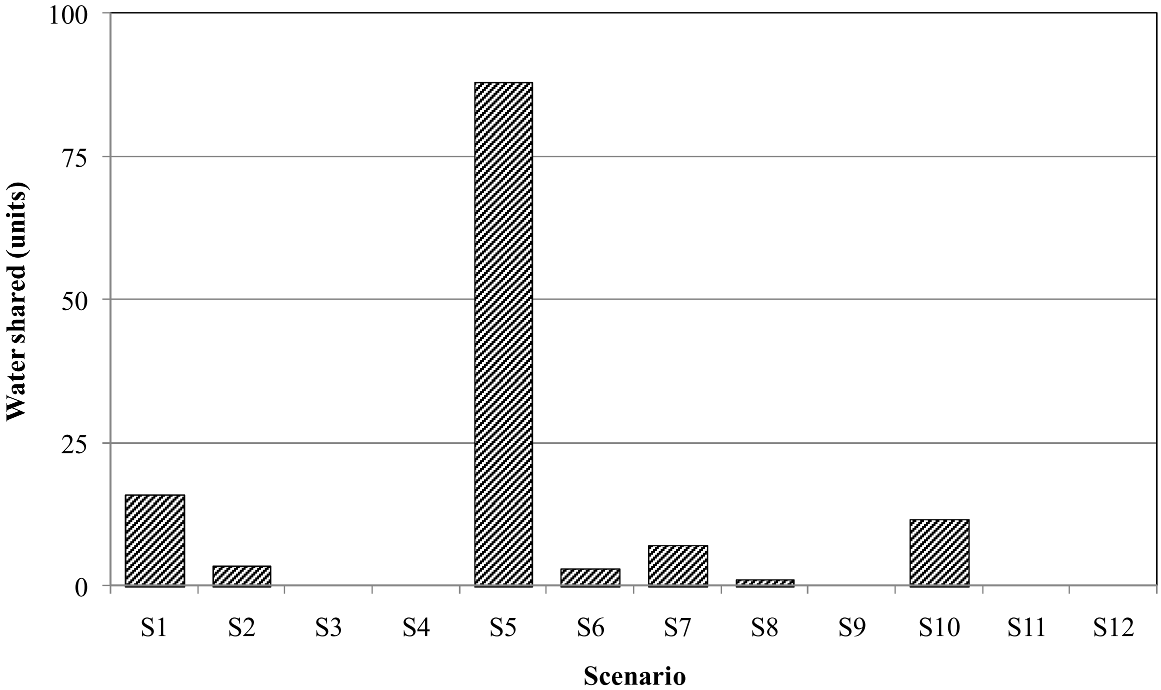


Figure 8.14. Number of water units shared in different scenarios in Lingmuteychu.

Water sharing was exceptionally high in scenario S5 where players freely interacted within and among villages and the rainfall pattern was favourable. Otherwise, exchange of water was limited under scenarios corresponding to severe wet and wet patterns, and in all other scenarios there was no exchange. This is again influenced by low water availability. The maximum water sharing in S_5 also fostered equitable distribution as indicated above.

8.4.3.4 Satisfaction of water needs

The fulfilment of water needs, both individually and collectively, is another factor players considered as a tangible effect of any strategy. Based on the outputs of the gaming sessions, a simple assessment of satisfaction level was done by (i) calculating the proportion of irrigated plots by all players in each scenario. Satisfaction level was heavily influenced by the rainfall pattern, higher rainfall giving very logically a higher satisfaction as shown in Figure 8.15.

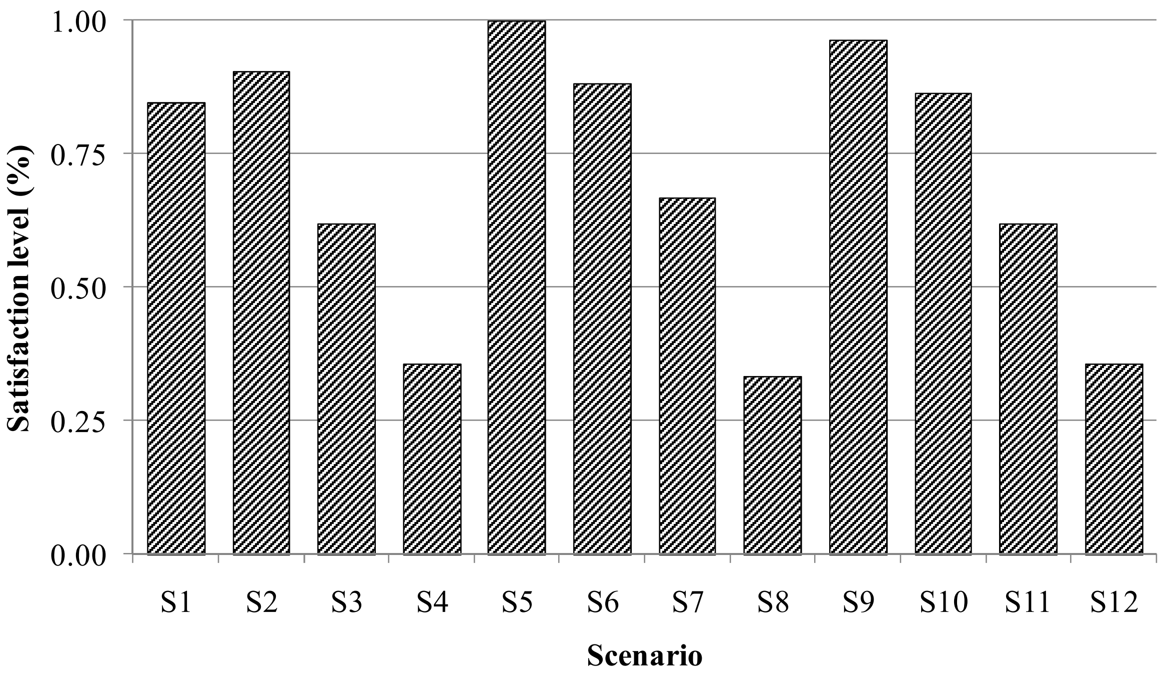


Figure 8.15. Proportion of players fulfilling their water requirement in different scenarios in Lingmuteychu.

Scenario (S_5), where collective interaction and water sharing within village and between villages happens under high rainfall pattern, was the only situation where all plots were irrigated. The influence of low rainfall was also distinct in limiting the satisfaction level below 36% irrespective of the protocol (see for S_4, S_8, and S_{12}).

8.4.4 Interview of players and new learning

At the end of the RPG sessions, all the players were individually interviewed using structured questionnaire with an objective of (i) to learn more about players' decisions regarding land use and water management, and (ii) to elucidate some of the decisions made during the gaming sessions.

After referring to the past two ComMod cycles during 2003, they considered four new learning by participating in the process. They are water conservation, collective management, sequencing (re-scheduling) of rice planting time, and learning alternative strategies from the members in the game (Figure 8.16).

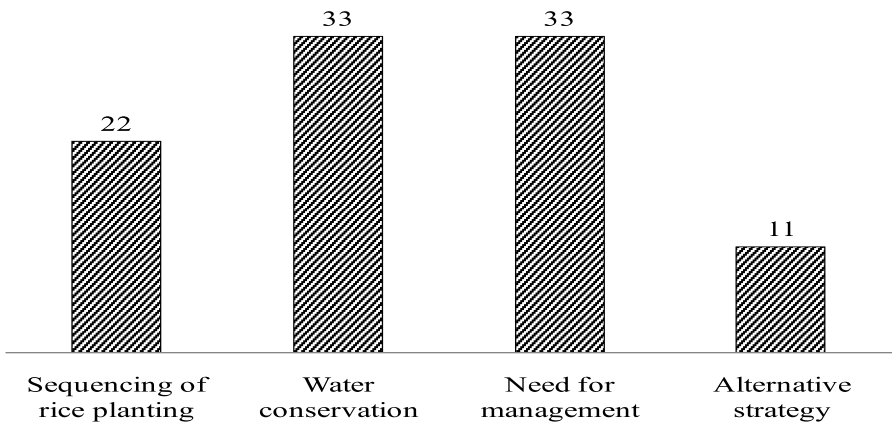


Figure 8.16. New learning by players (proportion of respondent) from RPG in Lingmuteychu (*n=21*).

While it may be tricky, the strategy of re-scheduling rice transplanting dates within the agronomic limits may be worth testing, as the rice transplanting time has been pushed further by 7-10 days with the introduction of potato in the upper catchment. Players (33% for each) considered that collective management and water conservation should go hand-in-hand for improving the water situation.

8.4.5 Collective actions

The participatory workshop and the RPG sessions brought together not only players but also several observers who saw the process converging to a point consistent to the issue of farmers. Players after rigorously debating strategies in the game felt the need and potentials for implementing few tangible collective actions. Indeed players were encouraged by the new understanding they gained from the process and choose to hold on the opportunity of developing collective approach to the issue. The last day of the participatory workshop was used to draw up collective action plan.

In Lingmuteychu the principal collective action is crafting the new watershed management committee which took lots of consultative process. Even during the role-playing session, short sessions were organized to brainstorm on the idea of consolidating the collective force in managing the issue of irrigation water. While it would take sometime to clarify and formalize the concept of management committee, develop protocols and operational plans, group suggested some immediate collective actions which could be kept on hold. The collective actions agreed by the group are given in Table 8.11.

Table 8.11. Collective actions decided in Lingmuteychu sub-watershed at the end of the ComMod process.

SL. No	What	Where	Why	When	Who	
					Implementer	Collaborator
1	Plantation in water sources (catchment)	Individual villages	To protect all water sources	June 2005 to July 2006	Tshogpa and farmers	RNRRC Bajo and Extension office
2	Rehabilitating 7 acres of abandoned wetland	Lumpa	Wetland fields in Lumpa had been abandoned due to breakdown of irrigation scheme	June 2006	Gup (Block head)	RNRRC Bajo
3	Construction of check dams	All villages	As there is no natural ponds and lake runoff is an issue, so check dams can facilitate water conservation	June 2005 to July 2007	Gup (Block head)	RNRRC Bajo
4	Institutionalizing Watershed management committee	Lingmuteychu watershed	To collectively manage NRM issues in the watershed	June 2005to July 2007	Gup (Block head)	RNRRC Bajo and Extension office

Although it took sometime to start the planned activities, all the above activities (Table 8.11) were completed by middle of 2010 as detailed below:

- The drafting of bye laws for the watershed management committee started in May 2005. The bye-law was submitted to district administration, district court, policy and planning division of the MoAF, and irrigation division of the DoA for review and approval. After the document was approved the 10 member Lingmuteychu watershed management committee institution was formally launched in early 2006 with village headman as the chairman.
- By early 2006 the irrigation canal in Lumpa which was abandoned for more than 10 years was rehabilitated bring back 7 acres of terraced paddies into cultivation.
- Re-plantation of catchment areas took time as organizing suitable planting materials was difficult. Plantation of degraded area in all villages started by 2008. Further with

community forestry plantation launched in Limbukha, the pressure to community to reforest the catchment was reduced.

- Community members under the guidance of research and extension staff dug several check dams in their village. However, the most prominent action is the construction of village level water harvesting tanks during 2008.
- All the above activities are still continuing in the sub-watershed.

8.4.6 Identification of scenarios for further computer simulations

As described earlier, the RPG sessions were efficient to support the exploration of simple scenarios within a short time frame. Although the results show definite trends and helped in generating a shared representation of the resource situation, it was not possible to introduce new parameters and test combinations with other parameters for longer periods. As highlighted earlier, the unpredictable characteristics of SES over a longer time frame cannot be modelled into a RPG. To complement gaming results, if all known factors and their parameters can be integrated, computer ABM has the ability to generate rapidly simulated scenarios over a several time-steps. After presenting the RPG-based ABM (cRPG – Computerized RPG) to the community members, different versions of the ABM were developed by incorporating new ideas which emerged from the onsite ComMod process. It was unfortunate that the ABM could not be applied on site allowing players to explore different scenarios. The inability of field application was the lack of researcher's skill to use CORMAS thereby dependence on the experts. Further the endless revisions of the parameter to make it easily comprehensible to the research team took longer time. After the model was finalized during early 2010, it was used to laboratory study for exploring the scenarios. However, the research team still hopes to use the ABM in the site and as an application to demonstrate to other communities facing similar problem of natural resource management.

8.4.6.1 Scenarios simulated with the 7villages agent-based model

Three versions of the 7 villages ABM were developed, each representing three broad concepts as (i) traditional regime, (ii) payment for environmental services, and (iii) trust and reciprocity. Each version is briefly explained and the scenarios identified for exploration are described below.

8.4.6.1.1 Traditional regime version

The traditional regime model attempts to replicate the customary regime which is characterized by agents having varying land holding and water rights. All of them operate under uniform climatic conditions of random rainfall which has a consistent effect on water availability for irrigation. As described in earlier sections, there are four categories of irrigators each having different water use rights. For instance type A has full rights over water, type B can get 50% of what type A receives, type C receives 50% of type B's share, and type D has no water allocation. Type D traditionally do not own wetland, as such no water share, but if any one owned or share cropped rice they had the rights to beg (or request) water from other users. A scenario based on a fixed configuration of plots and water share was explored over 250 time steps and with ten repetitions to study its effects on water use efficiency (Table 8.12).

Table 8.12. Number of plots per farmer and their configuration in each village in the traditional regime version of the 7 villages agent-based model in Lingmuteychu.

Parameter	Farmer	Village 1	Village 2	Village 3	Village 4	Village 5	Village 6	Village 7
Number of Plots	1	2	2	1	2	1	3	2
	2	3	2	2	3	2	2	2
	3	4	3	2	4	3	4	4
Water share	1	14%	25%	20%	14%	14%	28%	25%
	2	28%	25%	40%	28%	28%	14%	25%
	3	58%	50%	40%	58%	58%	58%	50%

8.4.6.1.2 Scenario based on payment for environmental services

In the 7 villages RPG, although there were rice yield and income as indicators for individual performances, a means to indicate collective performance was introduced by paying financial incentive based on quantity of water saved at the plot level or flowing out of the sub-watershed. Using different reward levels (0 to 10 with interval of 2.5) for both parameters under the influence of 2 sharing rules (1: Allocate water cubes looping on the farmers and giving them one cube as long as they need and as long as water remains, and 2: Allocate water to farmer based on the proportion of plots) a combination of twenty scenarios were identified as shown in Table 8.13.

Table 8.13. Scenarios use for the reward for environmental services version of the 7 village agent-based model in Lingmuteychu.

Sharing rule	Reward on plot					Reward on exit flow				
	Maximum reward									
	0	2.5	5	7.5	10	0	2.5	5	7.5	10
1	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
2	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}	S_{18}	S_{19}	S_{20}

8.4.6.1.3 Scenarios for the 7 villages agent-based version based on trust and reciprocity

The non-confrontational interactive process during the gaming and simulation sessions generates results which are not based on scientific assumptions. According to Chaudhuri *et al.* (2002) such deviations of behavioural patterns from homoeconomicus assumptions are due to trust and reciprocity. Although not explicit during the collective mode in the gaming sessions, we observed the gradual emergence of coherent community. This feature could not be tested in gaming session because of data handling limitations and the inability or difficulty to set parameters for an intangible concept like trust. In such group dynamics there ought to be a relation of mutual dependence. To check if agents are trustworthy, the idea of punishment was introduced along with the concept of reciprocity (Table 8.14). From this third version of the 7 villages ABM, the following parameters were identified to generate scenarios:

- Social network: to set social observation space of 2 representing one agent is observed or monitored by two agents (a village) and 20 signifying that an agent is monitored by all 20 agents (the watershed) (as 21 represented the whole watershed in the RPG).
- Cost to punish: all defaulters have to pay the cost of defaulting, but it also involves cost to monitor and punish the cheater. Four levels of cost (0, 150, 350, and 450) are proposed to see how it affects the total income.
- Perception rule for water sharing: two rules were used as (i) average of farmer share, and (ii) equitable sharing.

- Trust threshold: The trust (Trust = 1- number of cheaters/social observation space) levels of five (0, 0.25, 0.5, 0.75, and 1 implying 0 as no trust and 1 as full trust or no cheating) are used to assess how agents behave under different threshold.

Overall the concept of punishment and reciprocity were introduced as: if farmer has punished another agent during the last three time steps, then punisher will follow the management group rule. If the agent was unsatisfied for the last two time steps, he will follow his own perception. If the trust is greater than the trust threshold, the agent follows the prescription of the management group. If not agent follows its own perception. To ensure trustworthy behaviour, if an agent has punished another agent the counter of time for reciprocity is increased, after which it will be reset to zero. The two basic parameters of rainfall and number of plots are set at random and fixed respectively.

Table 8.14. Scenarios used with the 7 village trust and reciprocity version of the 7 village agent-based model in Lingmuteychu.

Perception rule for water sharing	Trust threshold	Social network							
		2				20			
		Cost to punish							
		0	150	350	450	0	150	350	450
1	0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
	0.25	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}
	0.5	S_{17}	S_{18}	S_{19}	S_{20}	S_{21}	S_{22}	S_{23}	S_{24}
	0.75	S_{25}	S_{26}	S_{27}	S_{28}	S_{29}	S_{30}	S_{31}	S_{32}
	1	S_{33}	S_{34}	S_{35}	S_{36}	S_{37}	S_{38}	S_{39}	S_{40}
2	0	S_{41}	S_{42}	S_{43}	S_{44}	S_{45}	S_{46}	S_{47}	S_{48}
	0.25	S_{49}	S_{50}	S_{51}	S_{52}	S_{53}	S_{54}	S_{55}	S_{56}
	0.5	S_{57}	S_{58}	S_{59}	S_{60}	S_{61}	S_{62}	S_{63}	S_{64}
	0.75	S_{65}	S_{66}	S_{67}	S_{68}	S_{69}	S_{70}	S_{71}	S_{72}
	1	S_{73}	S_{74}	S_{75}	S_{76}	S_{77}	S_{78}	S_{79}	S_{80}

8.4.7 Analysis of simulation results of scenarios with the computer agent-based model

8.4.7.1 Traditional management model

This traditional management model was a means to validate the consistency of its behaviour. With all agents fulfilling their water needs and exhausting the water completely, there were clear differences in total outcome between agents. The differences in outcomes were related to how each agent strategized water allocation (Figure 8.17).

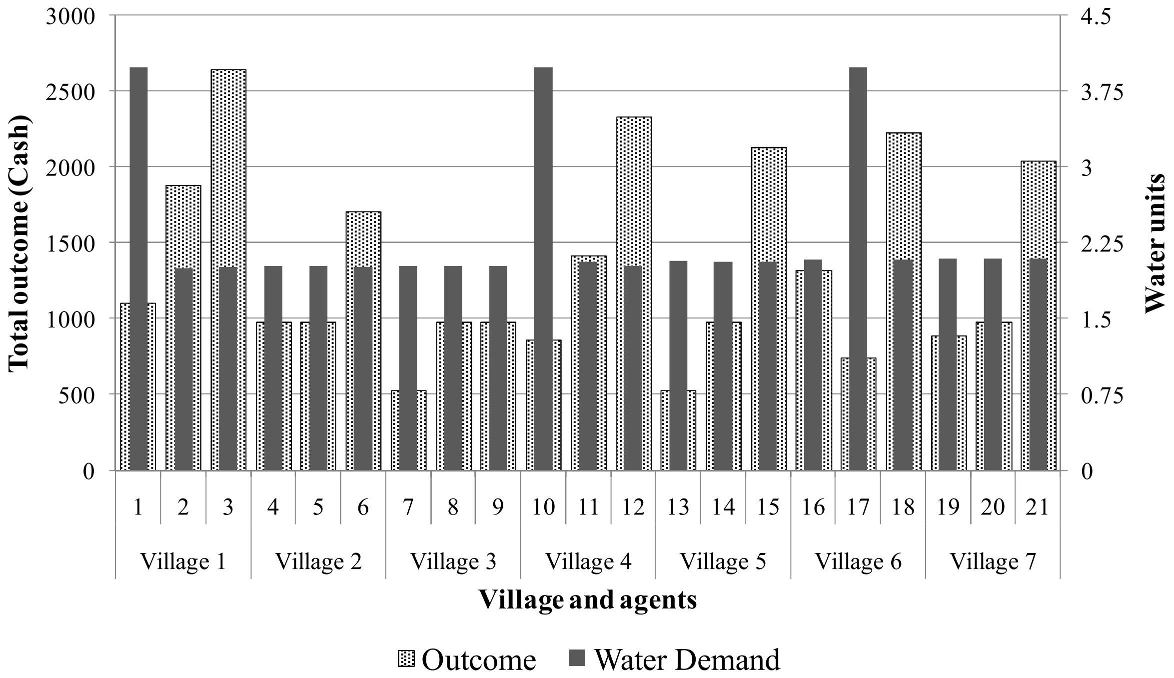


Figure 8.17. Average cash and water demand in open access individual mode simulated with the traditional management regime of the 7villages agent-based model in Lingmuteychu.

For instance agents 15, 18, and 21 although they have the same number of plots (representing village 5-agent 13, 14, 15; village 6-agent 16, 17, 18; and village 7-agent 19, 20, 21) and equal water shares, there is clear a difference in their outputs. Similarly among the villages 1, 4, and 6 having 9 plots each and equal units of water used, village 1 clearly outperforms other two in terms of total output. It indeed produces 22% and 31% higher than village 4 and 6 respectively. Agents 1, 10, and 17 who have only 2 plots each exceptionally have demand of 4 units of water (highest) while all others take only 2 units of water.

Except for three agents (1, 10, and 17) who had highest water demand which could have been influenced by random, there is a trend for balancing the water demand among the agents within a village. Although there was distinct variation in the output of farmers, it showed the village level performance. The difference in the total cash earned from cropping is dependent on plot size.

8.4.7.1.1 Reward for water saving version

The concept of rewarding for saving of water was tested at two levels, one at the plot level (reward rule 1) and the second level based on the flow of excess water from the sub-watershed (reward rule 2). Water savings at these two levels were influenced by two water sharing rules of (i) share water equally (distribute one each at a time as long as water remains) and (ii) share water proportional to plot. Depending on the water savings, reward was set at 0 to 10. Figure 8.18 displays the results of the simulation of twenty scenarios based on average cash, satisfaction and resource stress.

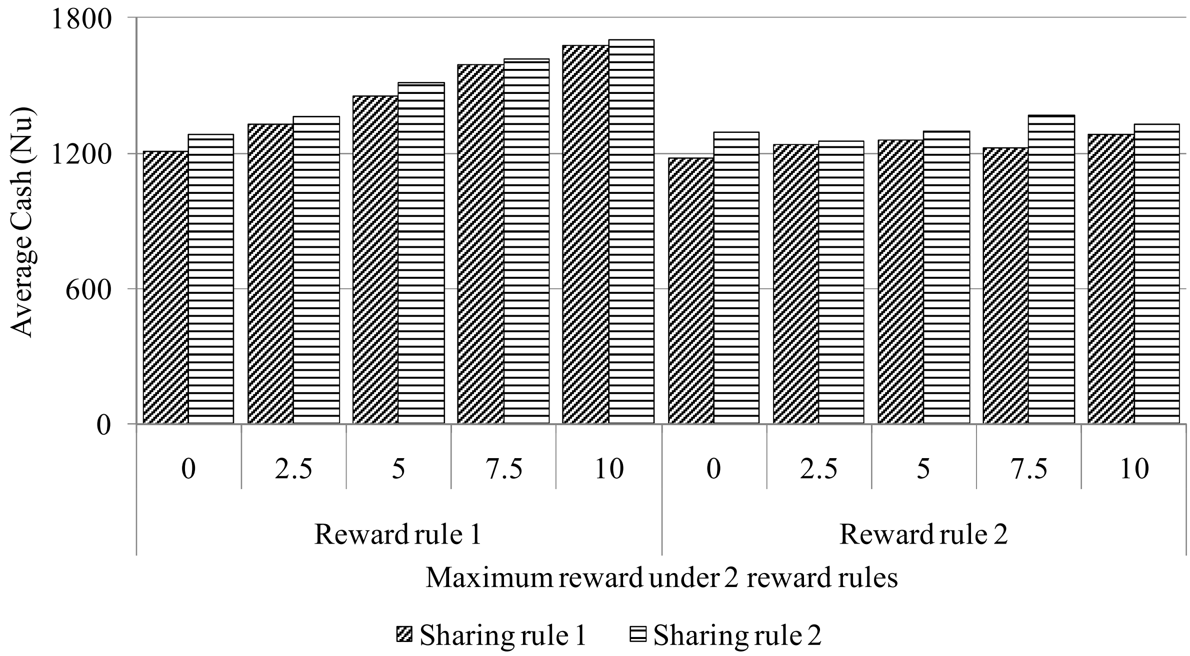


Figure 8.18. Average cash generated from 20 scenarios.

There is a distinct pattern of output between the two reward rules. When the reward is based at the plot level water savings there is a high correlation between increasing maximum reward and increase in average output (r^2=0.99). While the output based on the exit flow seems indifferent to the increasing maximum reward. There is also no significant difference between the outputs from two water sharing rules in reward rule 2.

The reward and sharing scenario seem to restrain satisfaction level to only 49 to 66% which may be due to tendency to save water thereby not fulfilling individual water requirement. There is slightly higher satisfaction level from sharing rule 1 when reward is based on plot level, and in the other hand sharing rule 2 tends to foster higher satisfaction level when the reward is based on exit flow (Figure 8.19).

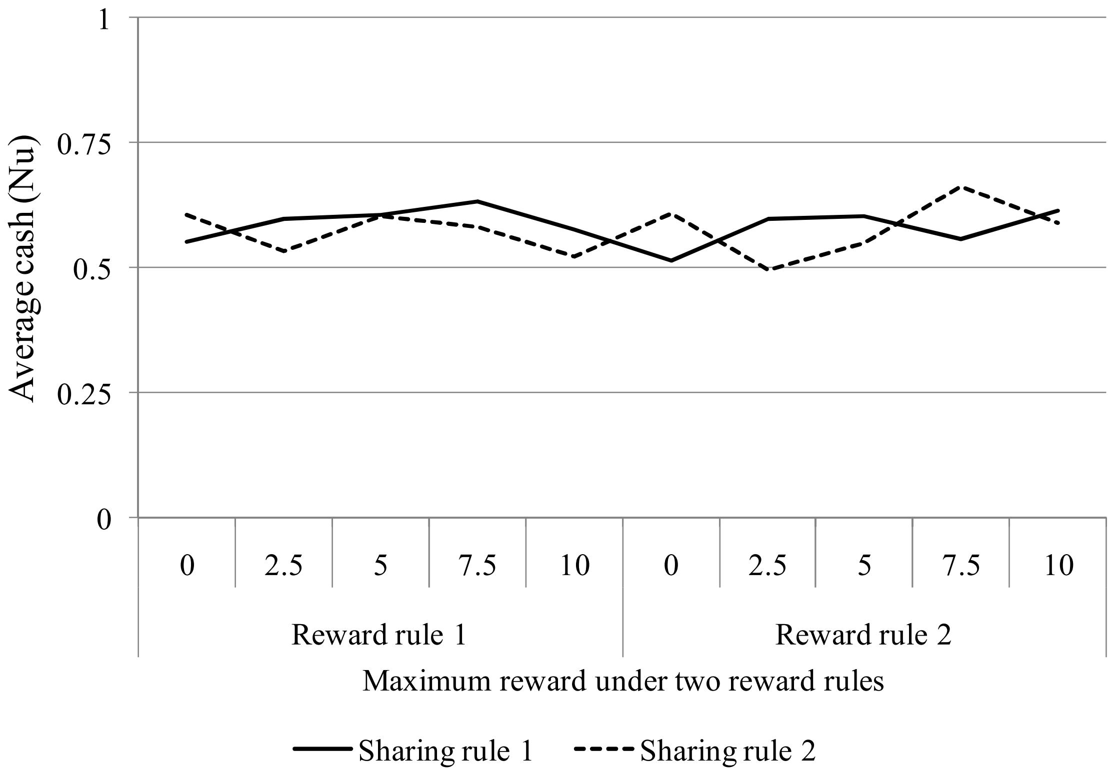


Figure 8.19. Level of satisfactions in two reward rules.

Although the satisfaction level is low, there is only around 20% water stress which seems unaffected by either the sharing rule or reward rule (Figure 8.20). In addition the balance of water ranging from 1 to 4 which is estimated here as an exit flow may actually lower the water stress if they were fully utilized. On an average across all scenarios around 2 units of water consistently remained as balance from the system. There is a clear influence of reward rule and sharing rule in water balance. For instance, rewarding based on exit flow in sharing rule 2 had the maximum water flow of 2.5 units followed by R_1S_2 and R_1S_1. The lowest exit flow of 1.4 was recorded from scenarios of reward rule 2 and sharing rule 1.

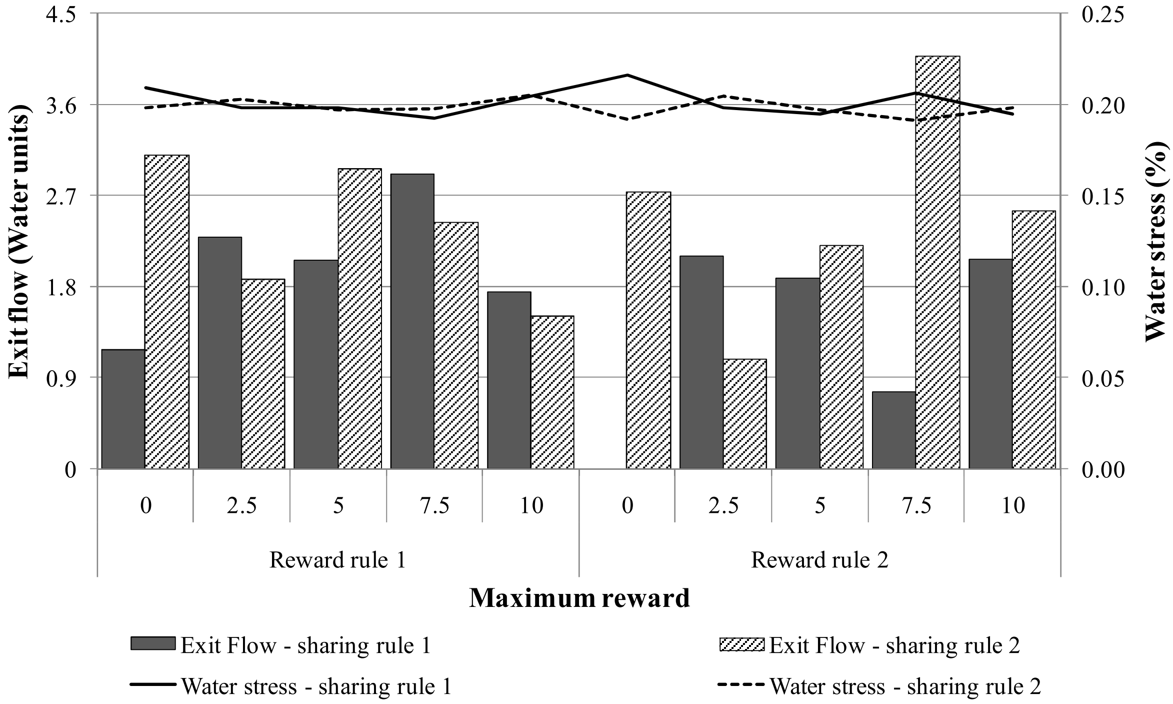


Figure 8.20. Water stress and exit flow influenced by reward scenarios.

Trust and reciprocity model

The eighty scenarios generated from two levels of perception rules and five levels of trust thresholds simulated against two network sizes and four levels of cost to punish provides a consistent influence on output and the water resource. Figure 8.20 indicates the differential influence of the two perception rules. When the management group uses average of farmer's preferred water quantity to decide the allocation of water (i.e. perception rule 1) the average outcome (or income) is about 20% higher than in perception rule 2 where available water is allocated equitably.

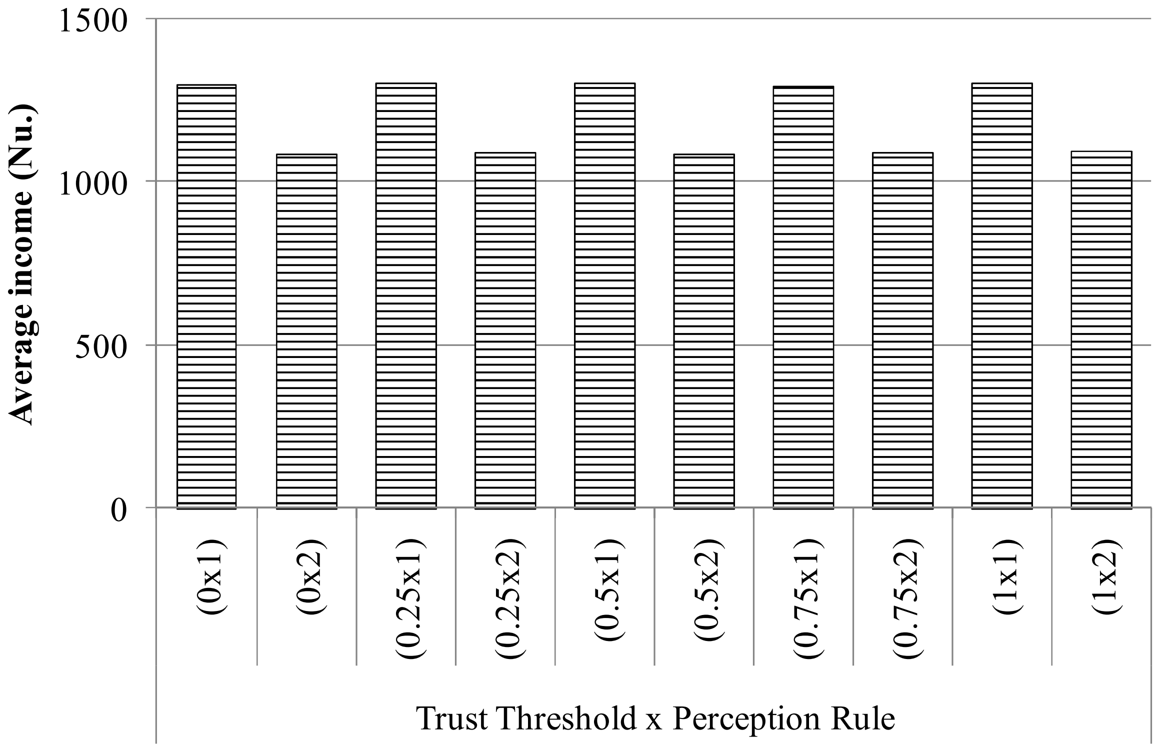


Figure 8.2120. Average income under the influence of trust and perception rule.

The pattern of influence of scenarios on level of water stress was uniform varying from 16% to 34% (Figure 8.21). The use of average water by individual farmer as a water allocation rule clearly lowered the water stress in comparison to equitable sharing of water. Initially although very small in difference, at trust threshold level of zero in both networks (2 as village network and 20 as watershed network) and without any cost to punish, seem to lower water stress in perception rule 1 and increase stress in perception rule 2. However, as trust threshold increases the village network, without cost to punish, tends to have a greater influence in reducing the water stress in perception rule 1 in contrast to escalating effect in perception rule 2.

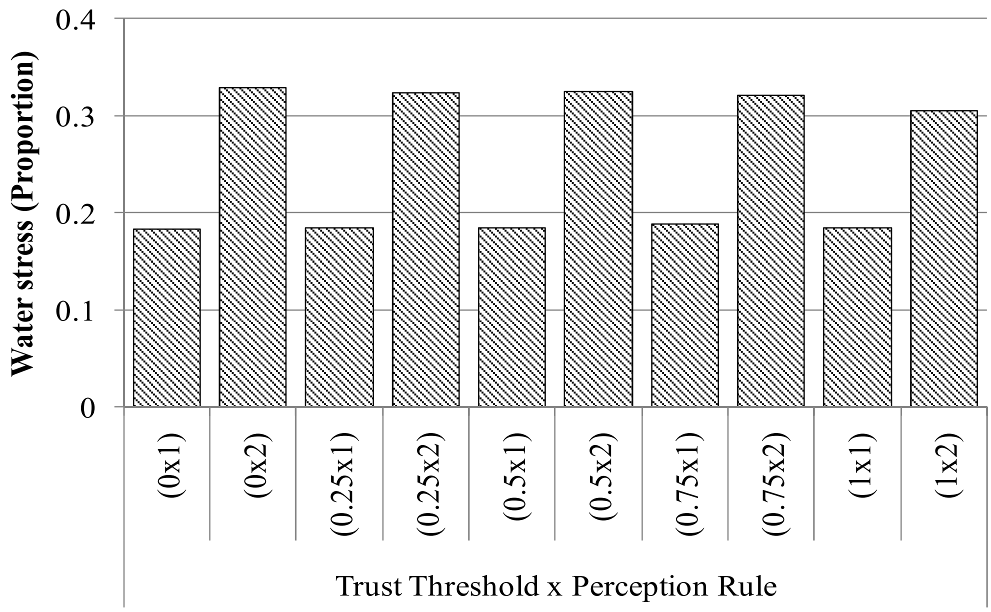


Figure 8.2221. Average water stress as influenced by different scenarios of trust and perception rule.

In contrast to the lower average income and higher water stress is influenced by perception rule 2, it actually enhances the fulfilment of water requirement (represented by satisfaction level in the model) from 6.7% at full trust level to 10.7% at trust level of zero. (Figure 8.22). While the village network had lesser influence on satisfying the water requirement under perception rule 1, it distinctly had some influence on the increased satisfaction level under perception rule 2. The overall satisfaction level in all scenarios was consistently above 75%, which corresponds to Gini coefficient of 0.043 in water distribution among 21 farmers.

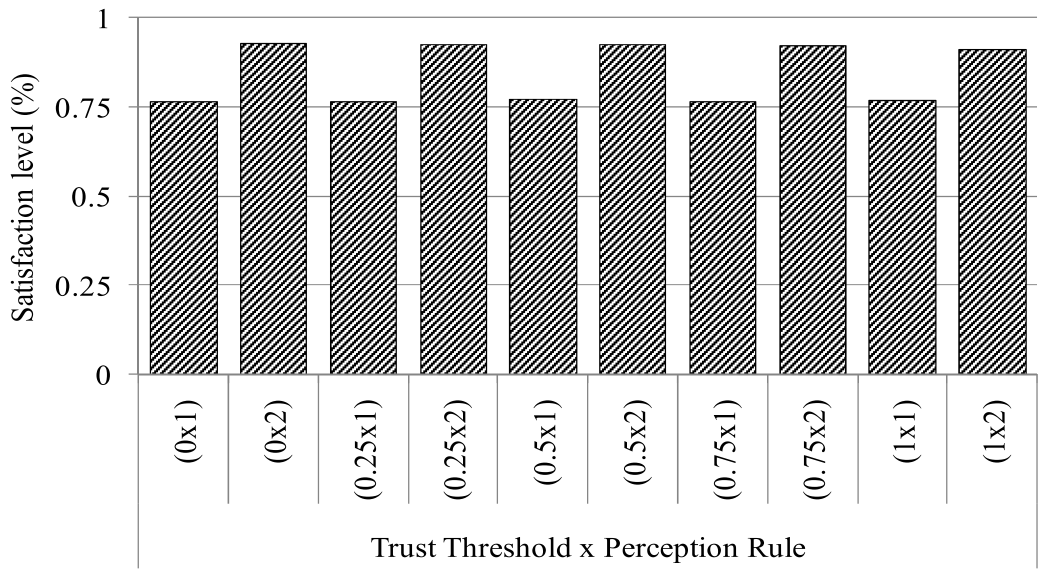


Figure 8.2322. Level of satisfaction in meeting water demands in different scenarios.

During the gaming sessions it appeared that congenial and interactive exchanges were facilitated by the trust built among the players during the ComMod process. The trust and reciprocity scenarios can have varying influences on the trust level of players. From the trust threshold of 0.25 to 75% there is almost 100% trust among the players in all levels of punishment cost and both social networks. At 100% trust threshold level the overall trust falls to minimum as shown in Figure 8.23.

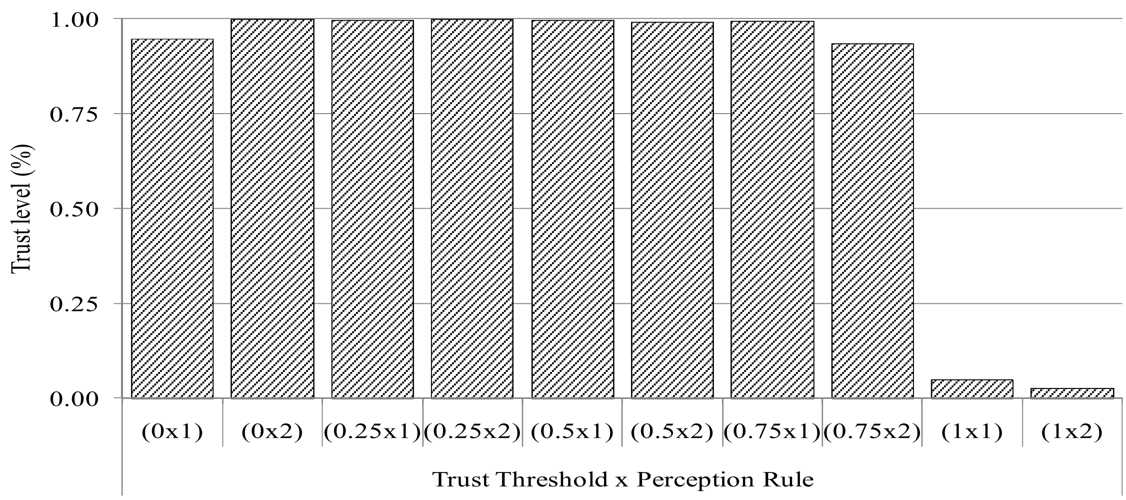


Figure 8.2423. Level of trust of players in different scenarios of trust and perception rule.

From the individual probes generated from the simulations, it was apparent that all players except player 1 all defaulted. They were also actively involved in monitoring and punishing the defaulters. Although the average trust level was as high as 95%, from the average number of punishments imposed by the players it can be concluded that there were as high 190 instances of defaulting (Figure 8.24).

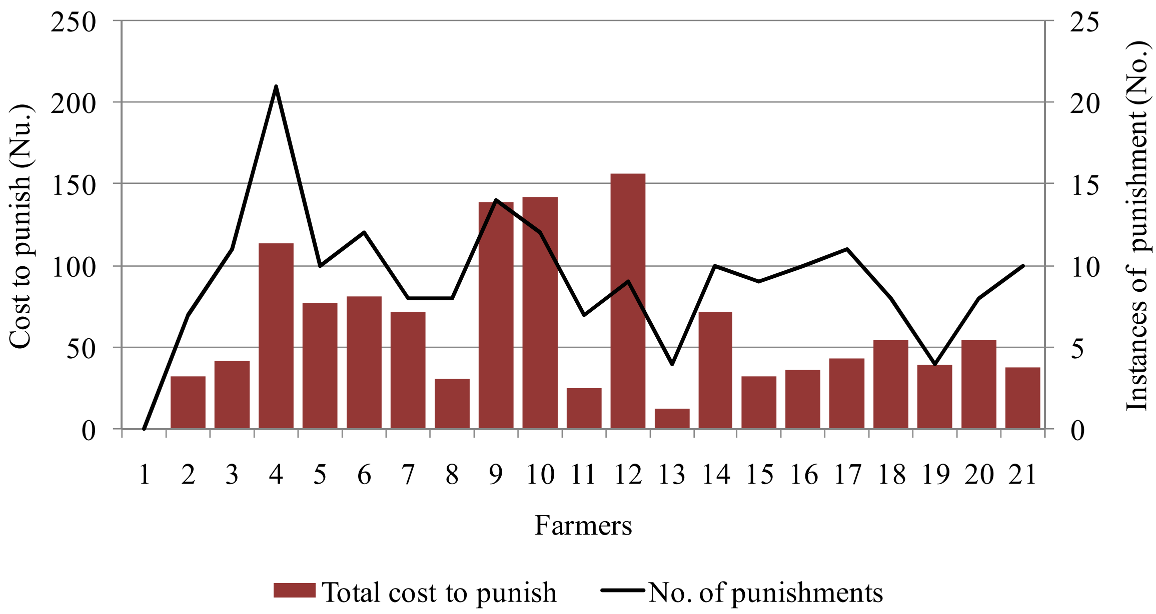


Figure 8.2524. Average number of punishment and cost to punish across 80 scenarios.

The 7 village model was able to facilitate exploration of scenarios that was beyond the ability of RPG. The testing of rewards and sharing rules helped to exhibit that collective rewarding based on watershed level water saving assured higher satisfaction level. Likewise as the trust threshold level increased there was corresponding increase the village network, without cost to punish, tends to have a greater influence in reducing the water stress. It was evident that trust level further reduced the defaulters.

Although this model was not directly applied in the field, it was used as a briefing tool to the management committee. Presenting the model to the committee and to some villagers was useful to show them the multiple scenarios and its implications on water management issues. The combination of RPG and ABM was capable to let farmer participants to compare the reality and the conceptual aspects like trust, reciprocity and rewards. The following sections presents tries to analyse the effects and impacts of ComMod process in Lingmuteychu and factors that influence them.

8.5 Effects and impacts of ComMod process in Lingmuteychu

The ComMod approach is useful to represent and facilitate the co-evolution of human-environment systems in complex SES (Trébuil, 2008). It can make problem-solving logical by dividing the necessary knowledge into subunits, by associating an intelligent independent agent to each subunit, and by coordinating these agents' activities (Bousquet and Le Page, 2004). As ComMod revolves within a co-learning process through free exchange among different actors (Bousquet and Trébuil, 2005), it is bound to have effects and impacts in different domains and at various organizational levels.

8.5.1. Direct and indirect effects

Table 8.16 provides a summary of the effects of the ComMod process in Lingmuteychu. The effects can be segregated into individual, collective, institutional and biophysical.

Table 8.1516. Direct and indirect effect of the ComMod process in Lingmuteychu.

Sites	Level of effects			
	Individual	Collective	Institutional	Biophysical
Direct effects				
	Increased awareness on managing irrigation water	Increased awareness of problem faced by other farmers	Creation of a watershed management committee	Improved channel conveyance, construction of check dams, and water collection tanks
Indirect effects				
	Individual farmer have become open to new management	Respect for the needs of other farmers	Less confrontation among the sub-watershed communities	Stabilization of slopes, increase water flow in stream

The direct individual effects in both sites are the enhanced awareness of the individual situation and strategy to improve it. It was this individual new learning that helped in establishing a shared common understanding to facilitate collective decision-making and actions. The most tangible effect at institutional level has been in the creation of a new watershed management committee established to manage the water related issues among others. The collective actions and institutional facilitation helped in the renovation of irrigation canals which improved water conveyance efficiency from earlier 30% to 60%, check dams, water tanks, and community forest plantations are some of the direct effects on the biophysical component of Lingmuteychu SES.

The concurrent indirect effects of the process are changes in individual behaviours in resource access and use. With higher level of understanding, individuals are also more open and ready to discuss the issues in a consultative mode. With the implementation of collective actions, indirectly the process also facilitated better community mobilization and social cohesion. The indirect effects on biophysical aspects can be seen in the gradual stabilisation of degraded areas due to irrigation water leakages from the canals and the extended period of water flow in the Limti chu stream.

8.5.2. Impact domains

In view of the process orientation and close interactions, the ComMod process had a significant influence on the knowledge, understanding and behaviour of the participating farmers that built trust and confidence among the stakeholders to work collectively to resolve the impending NRM issues. As such it is valuable to assess how far the approach impacts on the immediate timeframe or what can be envisioned as a longer term impact. Broadly the impacts of ComMod can be associated to four comprehensive domains: technical, individual (personal), collective (social), and external agencies (outsiders) as shown in Figure 8.25.

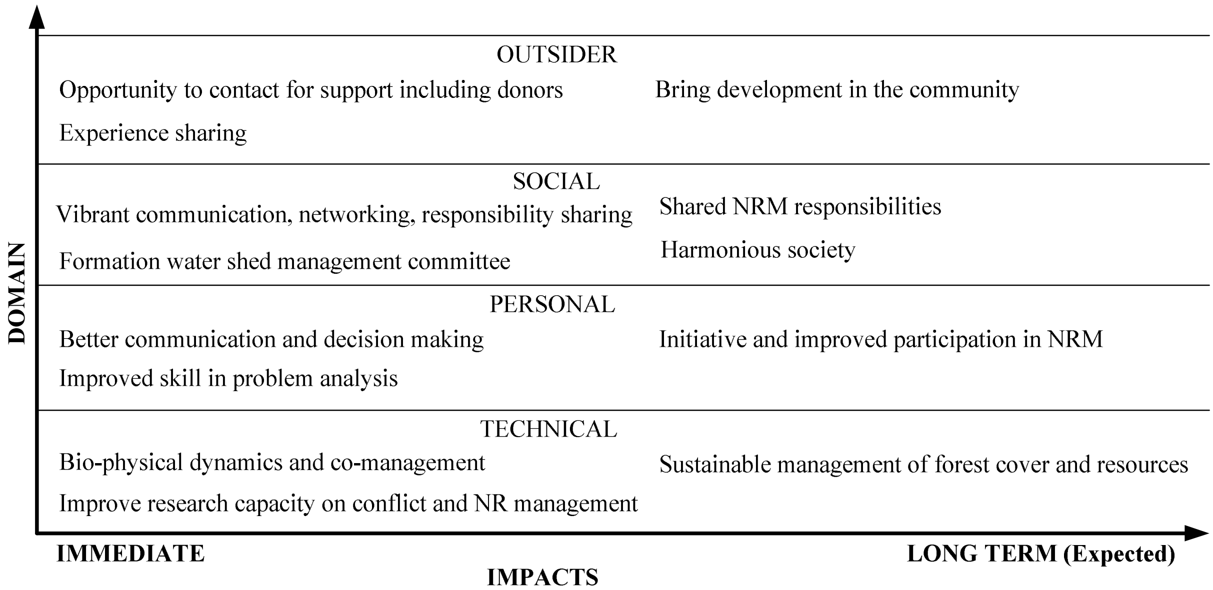


Figure 8.2625. Impact domains and impacts of the ComMod process in immediate and long term timeframes in Lingmuteychu.

Technical domain

The action research ComMod approach can use technical options related to problem issues as a basis to better understand it and develop shared representations. The integration of technologies and techniques proven successful elsewhere also provided confidence in its application. In Lingmuteychu, immediate impacts in the technical domain were adoption of technological options like new crop varieties (potato, short duration rice varieties) which spread to downstream villages to adjust with the delay in water availability, check dams, and water weirs. The understanding of bio-physical dynamics and adaptation to local circumstances, and the improvement of researchers' capacity were immediate impact which lubricated the process. In the longer term, it is expected that these village communities equipped with greater awareness of bio-physical dynamics and co-management skills will engage in a more sustainable management of renewable resources and will adopt management norms that suit the changing situations.

Personal (individual) domain

Although only a limited sample of the population was involved in the gaming and simulation exercises, the involvement of the remaining households of the study site through conceptualization, debriefing workshops, interviews, and model presentation have empowered individuals to better understand the roles of different stakeholders and their consequences on resource management. Farmers acquired improved skill of problem diagnosis and representation, better communication for equitable resource sharing and networking which was evident from free exchange of views and seeking support to develop irrigation system. With better individual capacities, it is expected that these persons will engage in purposeful monitoring of resource state and take initiatives in their management.

Social domain

The tangible immediate impact on social domain is the shared understanding of the NRM issue and vibrant communication and networking in sharing responsibilities to manage the issue. The collective initiative to build a WMC is an exemplary impact of the process. The commitment to work together and manage the highly contested water resource may in future promote harmonious society built on the principle of shared objective and collective responsibility. Over the five years after instituting WMC, the committee with support from research centre received funding to implement collective actions such as community plantation, construction of water harvesting tank, and farmers training. WMC has also been active in receiving visitors and presenting the details on the watershed management issues and actions. The local level functional institution of watershed management can be a successful model for replication in the country.

External domain

In Lingmuteychu, external agencies like research and development agencies had a decisive role in facilitating to resolve the issue. The research centre in Bajo took the lead in facilitating the process both within the community and outside mainly to mobilize donor support. The individual and social impacts that created a cohesive social network in relation to the resource in question, fostered collective bargaining power to garner donor support. The internal efforts also encouraged and attracted donors to support. It is expected that this model of community-donor collaboration can be replicated in other situations.

8.6. Factors influencing the effects and impacts of the process

The effects and impacts of this ComMod process were influenced by several contextual factors. To make clear differentiation between these factors they have been classified into internal and external segregated by their positive and negative influences in the process (Figure 8.26).

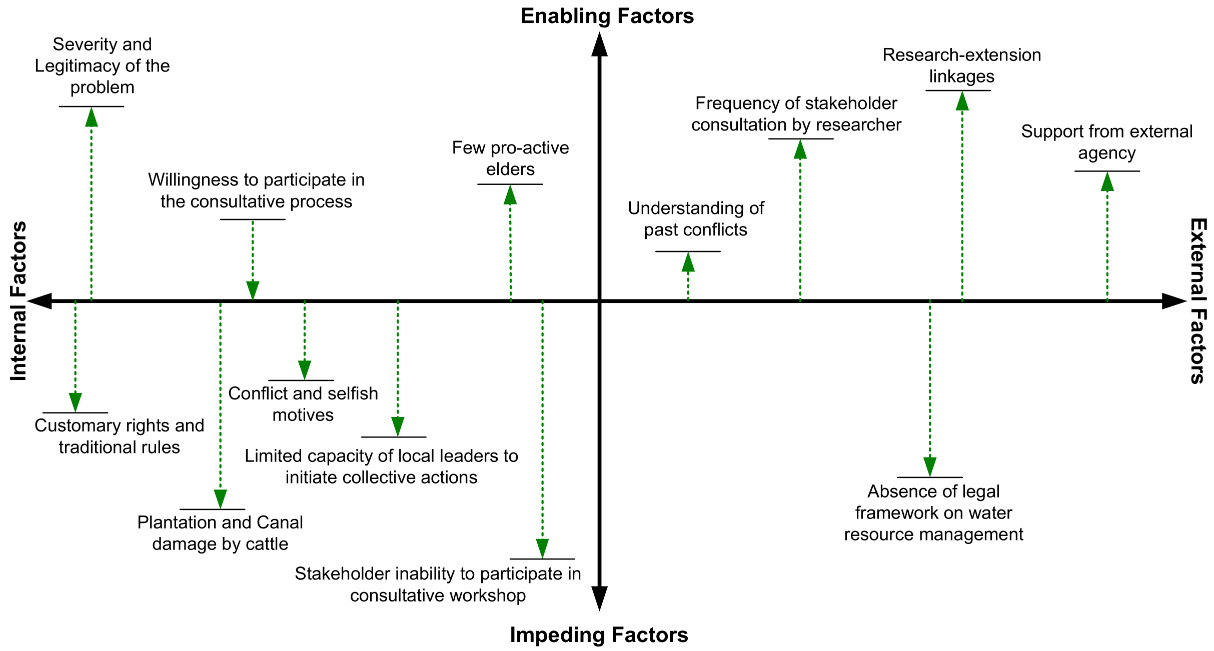


Figure 8.27~~26~~. Internal and external factors that enable or impede the ComMod process.

8.6.1. Enabling factors

The crucial enabling factors existed within the community, in the form of severity and legitimacy of the impending issue had inflicted differences leading to weakening of social fabrics. The looming worsening situation actually resulted in a willingness to cooperate by redefining the needs of water resource (Uphoff, 1986, Castro and Nielsen, 2001). The presence of few influential elders who are proactive and have genuine desires to resolve the long lasting conflict too enabled the process. Synchronized with the internal enabling factors, some of the critical external factors that facilitated the process are existing vibrant research-extension linkages which were the main channel of information flow and the initiation of collaborative research activities which fueled the process. The confidence of the community on the institution also helped in securing the process. The past involvement of research and development agencies in both sites also helped in gaining access to the community. Through the research centre, it was also easier to access support from potential donor agencies to implement collective actions.

8.6.2. Impeding factors

Alongside there were also factors that hindered the ComMod process. The presence of a very strong traditional water sharing system upheld by upper most villages and few advantaged households emerged time and again during the process. The case of destruction of weirs and blocking the canals were frequently encountered by irrigators. While the process of collectivity gradually glued people into a user network, few community members selfishly kept out of the process instigating those who were undecided. Despite the agreement to engage in collective actions, the destruction of structures by stray cattle set back the process. Two of the primary internal factor that hindered the ComMod process were the inability of all the affected households to participate in the process and the limited capacity of local leaders to follow up the process. Beside the internal factors, the absence of a legal framework for water resource management encouraged people to use the traditional norms to the advantage of few.

The ComMod process provided an opportunity to not only test the methodology but also make a real impact on enhancement of water productivity and water security. The flexibility of the process and versatility of its application in helping to comprehend the long lasting conflict situation, opened a platform for reconciliation and development of commonly agreed solutions. While the ABM could not be used directly in the field with the local actors, the gaming and simulation sessions really proved to be a resourceful tool that suited in the cultural setting of rural Bhutan to break the communication barrier and build trust to bring together the communities. The computer aided RPG or RPG-based ABM were useful to let the community understand the long term perspectives of the system to be collectively managed under different scenarios. The next chapter presents the ComMod process in Kengkhar where the NRM issue relates to dwindling drinking water resource in an upland situation.

CHAPTER 9
COMMOD PROCESS IN KENGKHAR

The chapter provides the situational context of Kengkhar from the natural resource point of view and its associated problems. The process of companion modelling and outcomes of each component are presented. The Kengkhar model is described using ODD protocol and the experimentation of model is presented.

9.1 Contextual diversity of Kengkhar

9.1.1 Stakeholder diversity

There are as many as eight different categories of stakeholders in Kengkhar having some relationship to the issue. As in the case of Lingmuteychu, the diversity of stakeholders pose challenge for coordination and mediation, while it also provide opportunity to consolidate the strength of each stakeholder and create collective force to initiate and sustain the change. Categorizing the stakeholders according to their relative influence on the outcome and importance of the issue to them indicates the position of farmers highest in importance and lowest in influence as shown in Figure 9.1.

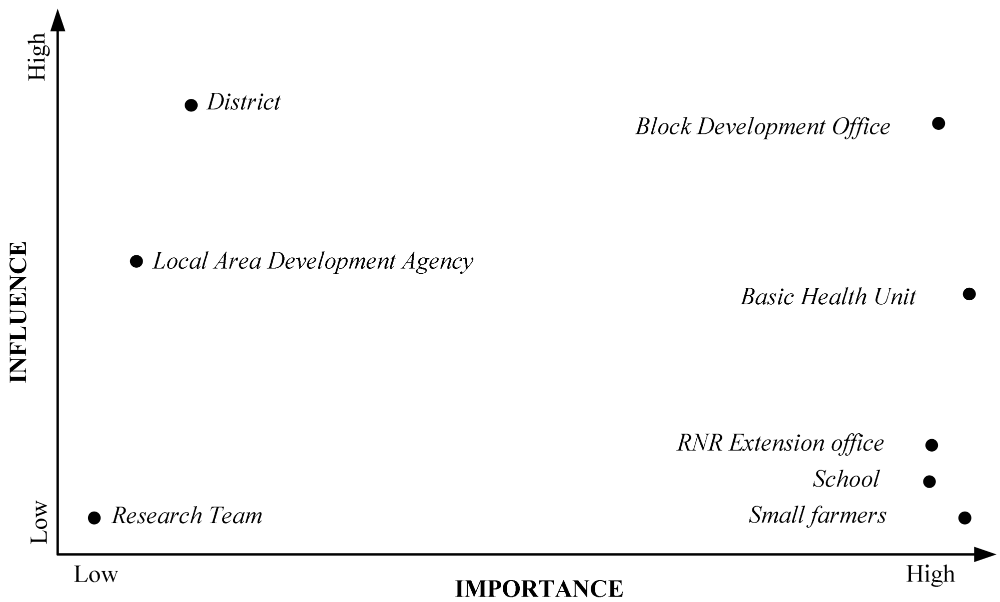


Figure 9.1. Diversity of stakeholders and their relative role in water issues in Kengkhar.

In Kengkhar all affected households expect the problem of water scarcity to be resolved but they are marginalized by their limited resource capacity and therefore have very little influence on addressing the issue. One of the principal advantages in Kengkhar is the presence of government establishment (School with boarding facility, Basic health unit, RNR extension office, and Forest range office) in the area, who also uses water from the village spring ponds and can exercise pressure to their line agencies for possible support. Among the village public offices the basic health unit with the mandate on safe water and sanitation is in a better position to influence improvement of the situation. The block development office located in the same area has the highest importance and influence to address the issue as it holds administrative power and financial resources for infrastructure development. Research centre has the least influence on the issue.

9.1.2 Drinking water resource social-ecological systems

The SES from the perspectives of water resource in Kengkhar is represented in Figure 9.2. It provides a holistic representation of how water resource is integrated into the social, economic, and bio-physical components of the system. Kengkhar with its remoteness and situated on a ridge in a dry upland site poses a desperate situation as safe drinking water has been a perpetual developmental issue (Figure 9.3). Fetching water from distant natural spring ponds has become a daily household chore for women who generally manage household and livestock. Despite the remote location, government intervention has been significant in terms of services (health, school, administration, and technical-agriculture) available in the community. This emphasis has been mainly as Kengkhar falls in the traditional trade route and served as one of the camping sites for the traders and travelers. The efforts in improving water situation are vivid from the remnants of structures in the community. As the ground water recharge system is interrupted due to indiscriminate felling of trees in catchment areas and disturbance in the close vicinity of the natural springs have resulted in drying up of spring ponds. The SES analysis provides evidence about the failure of technology and the community's inability to monitor and manage water availability.

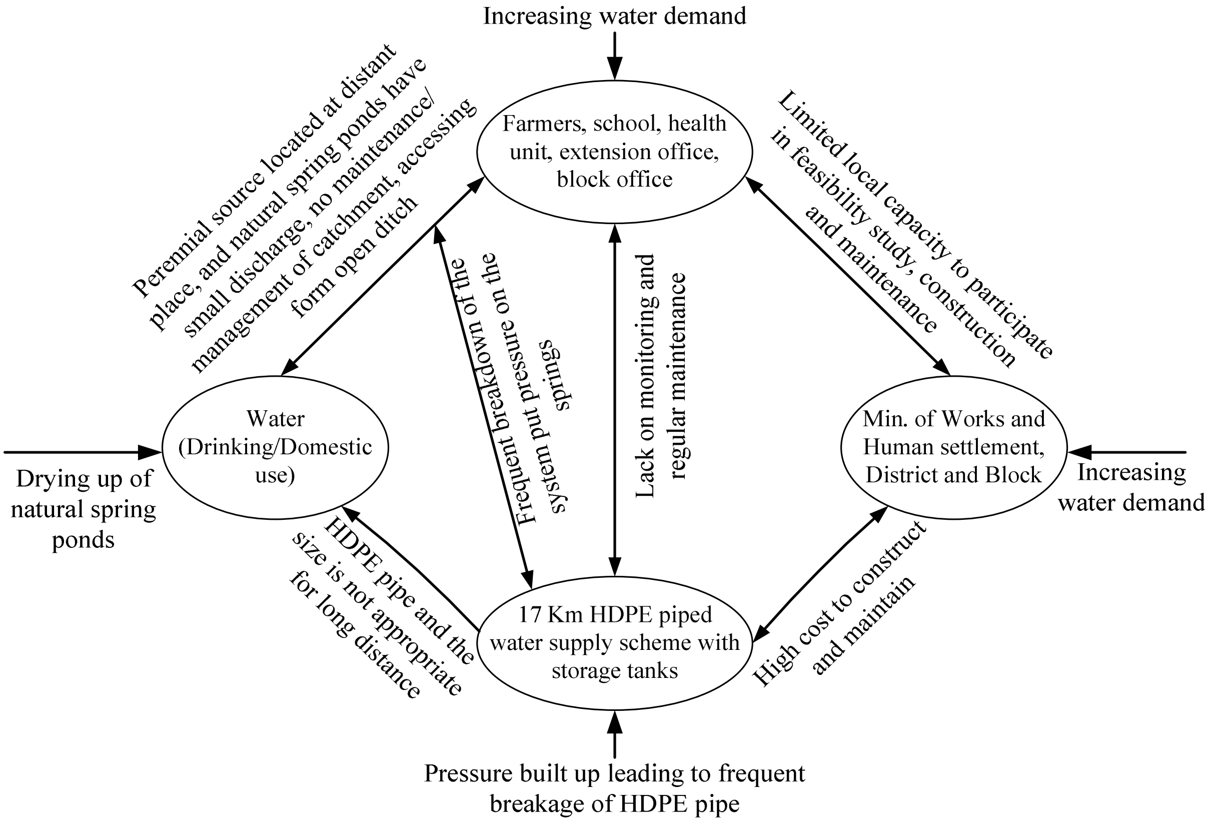


Figure 9.2. Representation of drinking water in social-ecological system of Kengkhar.

Figure 9.3. Settlement in steep slope in Kengkhar.

9.2 Analysis of drinking water problem in Kengkhar

In Kengkhar the scarcity of drinking water for six hamlets has been a major issue which is escalating as perennial water bodies are drying and there is no reliable water source in the close proximity as shown in Table 9.2.

Table 9.1. Site characterization and specificity of the water issue in Kengkhar.

Topics	Features	
Problem	-	Scarcity of water for all purpose (primarily for drinking)
Scale of the problem	-	52 households in 6 hamlets
Age and evolution of the problem	-	Ever since the population started to increase and natural forest declined roughly around 1950
Severity of the problem	-	Severe in all 6 hamlets, 4 months severe scarcity period
Researchers-stakeholders linkage	-	In 2000, researchers went to introduce the roof water harvesting technology
Origin of demand and legitimacy.	-	Highly legitimate as this issue was raised in the District development committee
Opportunities/incentives to act	-	Access to safe drinking water and networking, ensure water security, hygiene and saves time for other activities.

The severity based on the proportion of stakeholders affected can be classified as severe in Kengkhar with 100% of the households (52) being affected. It was apparent that the problem existed and has intensified every passing year. When the past efforts to install drinking water supply scheme failed, reverting to the old neglected resource base and system was difficult as the Kengkhar natural spring ponds were in dilapidated condition. The involvement of research in Kengkhar occurred much later, in 2000, when a research team visited the area to examine the issue of acute drinking water shortage raised in the District development meetings, to study the situation, and assess the potentials for introduction of rain water harvesting technologies. In Kengkhar the incentive for research exists in testing and adapting research methodology for possible replication in similar situations.

Based on problems against each entity of SES further clarifies the seriousness and importance of the problem in Kengkhar (Table 9.3). For instance, water stress in Kengkhar is severe as all past efforts to bring water from distant places have been unsuccessful. The past actions are the best lessons for Kengkhar. For instance, when UNICEF supported rural drinking water scheme which failed in 1987 people went back to the natural spring ponds. Again in 2005 when the 17 km long Largap water supply was implemented, the community ignored the spring ponds only to come back to them as the Larjap scheme could never be fully operational. With no water sources in proximity, the pragmatic approach is to invest in managing the natural spring ponds in the community. In Kengkhar although not directly linked to water, their principle livelihood source "wood craft" has probably played its toll. With the very noble intention of maintaining age old tradition of wood craft, people have tried making products from all available timber species. This has possibly led to loss of prime forest on the upper reach which ecologically served the purpose of trapping rainwater. Currently with only scrub forest with hardly any undergrowth rainfall rather poses a threat of landslides.

Table 9.2. Components of the social-ecological systems in Kengkhar.

Entities	Features
Resources	- Water for domestic use (*Drying up springs and scarcity*)
Resource users	- Farmers and public institutions (*free flowing, open access resource*)
Public infrastructure providers	- Government agencies-Works and human settlements (*No dependable water source in close proximity, high cost of maintenance*)
Public infrastructure	- 17 km HDPE pipe, 2 water reservoirs for school (*unreliable supply, exclusivity*)
External environment	- Governance, Climate (*unclear development priority, changes in rainfall intensity and patterns*)

9.3 Companion modelling process

The ComMod process in Kengkhar was little different from Lingmuteychu in respect to the sequence of intervention particularly the development of infrastructure (Figure 9.3). Following the diagnostic study conducted in early 2007 it was realized that the issue of drinking water shortage was very severe in a broadly cohesive community. The research team in consultation with the community started the process with the construction of seven concrete tanks of varying capacities to collect water from the spring ponds in early 2008. Following their construction, a participatory for gaming and simulations workshop was organized in April 2008. The objectives of introduction of ComMod process was bring together the resource users to explore and understand the water resource dynamics and introduce mechanism to better manage the water sharing network.

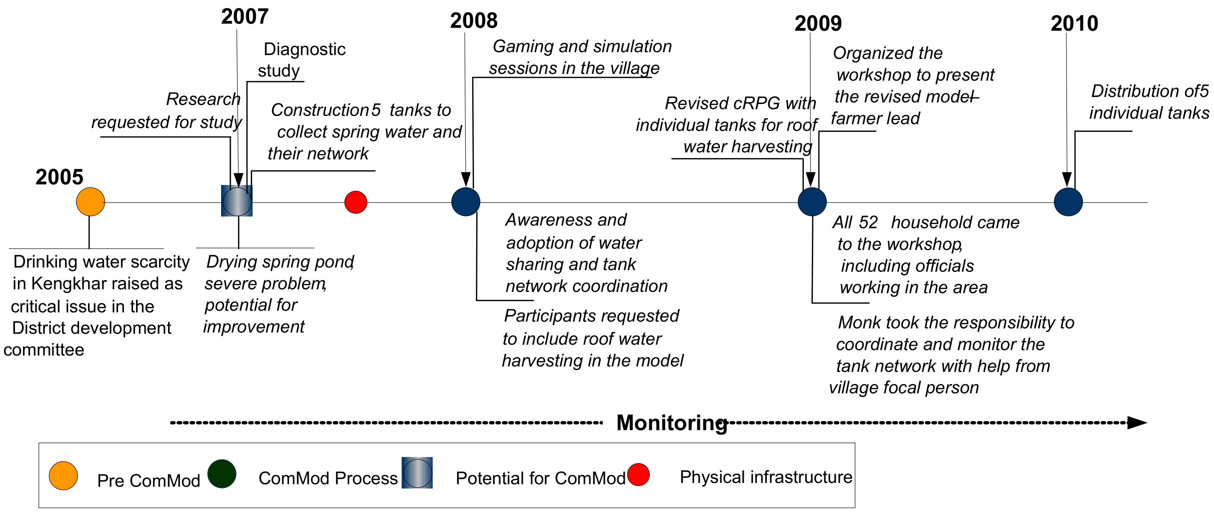


Figure 9.4. Chronology and phases of the ComMod process in Kengkhar.

9.3.1 Model conception

The conception of the model was done initially by the research and extension team using a layout plan of the water collection tanks and their network. During the discussion simple rules like quantity each individual can collect and the uses of water were established. The features of the Kengkhar model used in the construction of the corresponding RPG are given in Table 9.4.

Table 9.3. Features of the role-playing game used in Kengkhar.

Features	Details
Players	Household members (mainly women)
Roles	Access pond, draw water, allocate use, share
Rules of the game	Declare rainfall, allocate water to ponds, player access pond, allocate to uses, share, 3 modes of communication
Game sets	Pond, water units, house with 4 cups-uses,
Turns (Round of play)	1 day
Gaming session	3 days

The sharing rules and decision-making process were left open so that interactions among players would be vibrant and free, allowing them to create new rules as the game proceeded. The time step for each turn used in Kengkhar was 1 day as every water collection relates to a day's water requirement. The gaming and simulation session was scheduled for three days.

The Kengkhar RPG was pretested with farm attendants and research assistants in the Research center at Wengkhar, near Mongar. It was very difficult to explain to the players about this RPG components and its various steps as none of the test players were familiar with the spring ponds and water collection based on different needs. The steps were kept simple and straight forward and the spreadsheet used to record data and calculate the results of a session was calibrated. Based on the pre-testing, a mock session was planned to explain the characteristics and use of the RPG to the actual players.

A simple computer ABM based on this RPG was developed using household and hamlet as social entity; farm, tank, and pipe as spatial ones; and Rainfall, water source, jerrican (water), family size, water uses (domestic, animal, vegetable, *rimdo*[1]) as passive entities.

9.3.2 The twelve steps of the ComMod process

The process in Kengkhar adopted a slightly different sequence (Table 9.5) when compared to the process in Lingmuteychu (Section 8.3.2). While the core steps (4 to 9 in Figure 9.5) of modelling and simulations follow a similar sequence, sensitization, which is the key step in mobilizing the community, happened only after data gathering and finalization of the key question. In a way this gave opportunity for researchers to assess the appropriateness of the approach prior to sensitizing the community about its relevance and usefulness.

Table 9.4. Sequence of twelve steps of the ComMod process in Kengkhar.

Sequence	Steps
1	Key question (1)
2	Data gathering (1)
3	Sensitizing (1)
4	Eliciting knowledge (1)
5	Conceptual model (1)
6	Implementation (3)
7	Verification and validation (3)
8	Scenario (1)
9	Monitoring and evaluation (os)
10	Training (3)

[1] Rimdo is an annual ritual conducted by all household, where most family members gather and celebrate the annual festival.

11	Simulation (2)
12	Dissemination (2 – all)

Note: Figures in parenthesis indicate the number of times a step was implemented, os = on site, all = all households using the resource.

The twelve steps chronogram shown in Figure 9.4 also depicts the length of the relatively shorter and rapid process, as the issue was related to water scarcity that encompassed all the households in a harmonious community. Following the field data collection and identification of the key issue, the research team in collaboration with beneficiaries first constructed seven tanks to collect water from three spring ponds. Following which sensitizing for ComMod approach was done. A simple RPG imitating the tank network and rainfall pattern, helped in developing ways to manage this new tank network.

Kengkhar	2007											
	1	2	3	4	5	6	7	8	9	10	11	12
1 Sensitizing												b
2 Key question	a											
3 Data gathering								c				
4 Eliciting knowledge												
5 Conceptual model												
6 Implementation												
7 Verification & Validation												
8 Scenarios												
9 Simulations												
10 Dissemination												
11 Monitoring & Evaluation												
12 Training												

Kengkhar	2008											
	1	2	3	4	5	6	7	8	9	10	11	12
1 Sensitizing												
2 Key question												
3 Data gathering												
4 Eliciting knowledge												
5 Conceptual model												
6 Implementation				d							k	
7 Verification & Validation				d							k	
8 Scenarios				d								
9 Simulations												
10 Dissemination												
11 Monitoring & Evaluation	f											
12 Training				e								

Kengkhar	2009											
	1	2	3	4	5	6	7	8	9	10	11	12
1 Sensitizing												
2 Key question												
3 Data gathering												
4 Eliciting knowledge												
5 Conceptual model												
6 Implementation			k									
7 Verification & Validation			k									
8 Scenarios												
9 Simulations												
10 Dissemination				g								
11 Monitoring & Evaluation												
12 Training					h							

Kengkhar	2009											
	1	2	3	4	5	6	7	8	9	10	11	12
1 Sensitizing												
2 Key question												
3 Data gathering												
4 Eliciting knowledge												
5 Conceptual model												
6 Implementation						o						
7 Verification & Validation						o						
8 Scenarios												
9 Simulations												
10 Dissemination				g								
11 Monitoring & Evaluation												
12 Training					h							

Legend: a: TRG; b: discussion with site c: preliminary diagnosis; d: role playing game; e: new staff; f: onsite monitoring: local facilitator stationed in the research site; g: all water users; h: training in BKK; k: first agent-based model (replaying the game): TRG+MAS modeller; o: second agent-based model (network of water tanks): TRG+MAS modeller.

Figure 9.5. Chronogram of the ComMod process implemented at Kengkhar to create water collection and distribution systems.

9.3.3 Description of the *Omchu* RPG and conceptual Model

Overview

Purpose

In April 2008 a RPG-based gaming and simulation field workshop was organized in the village. After the gaming sessions, the *Omchu*[2] model was designed to capture the *Omchu* RPG for replay and to explore different scenarios for better understanding and communicating water collection and sharing issues in the community. The use of the simple autonomous computer ABM was developed to generate, simulate and assess scenarios with multiple tanks.

State variables and scale

The model comprises three types of entities i.e. spatial, social and passive ones. They are represented with their attributes and interactions in Figure 9.5. The social entity is composed of three hamlets designated by a number as hamlet 1, 2 and 3. Each hamlet has households ranging from five for two hamlets and eight in one hamlet. For each hamlet there is one water tank to collect water from natural spring ponds which is shared among the households. The tank has a maximum capacity of 2,308 litres and minimum of 1,375 litres (Table 9.6).

Table 9.5. Variables of the *Omchu* model used in Kengkhar.

Entity	Parameter	Default value	Unit
Spatial			
Tank	capacity	1375 to 2308	Litres
Social			
Household	Family size	2-5	Number
	Livestock size	1-3	Number
	Vegetable size	0,2	Plot
	Water use	Domestic, livestock, vegetable, *rimdo*	Type of uses
Hamlet	household	5-8	Number
Passive			
Climate	State of rainfall	Dry, wet, and very wet	State
Water			
Source	types	Rainfall, tank	Source
	Output of water	150, 350, 550	Litres

[2] Omchu means water from natural spring pond.

from Roof Collector		
Output of water from small Spring	325, 950, 1250	Litres
Output of water from large Spring	500, 1500, 2000	Litres

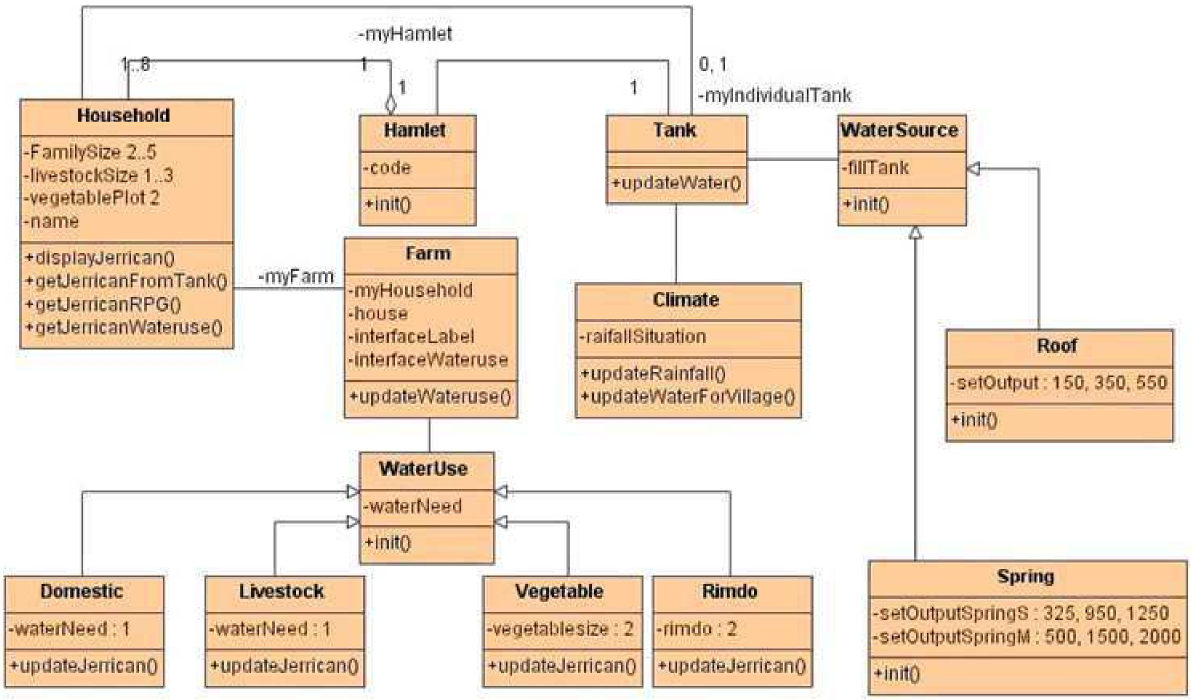


Figure 9.6. UML class diagram showing the attributes and methods associated to each entity of the *Omchu* model used in Kengkhar.

The water in tank depends on the rainfall pattern which has three states (dry, wet, and very wet). The social hierarchy is represented by three clusters of households as hamlets linked by a network for accessing water within their respective hamlet (Figures 9.7). The members of each hamlet can also collect water from tanks of other hamlets when their assigned tank dries up. Households prioritize their water use among four usages as domestic use (drinking, cooking and washing), livestock use, growing vegetable and *rimdo*.

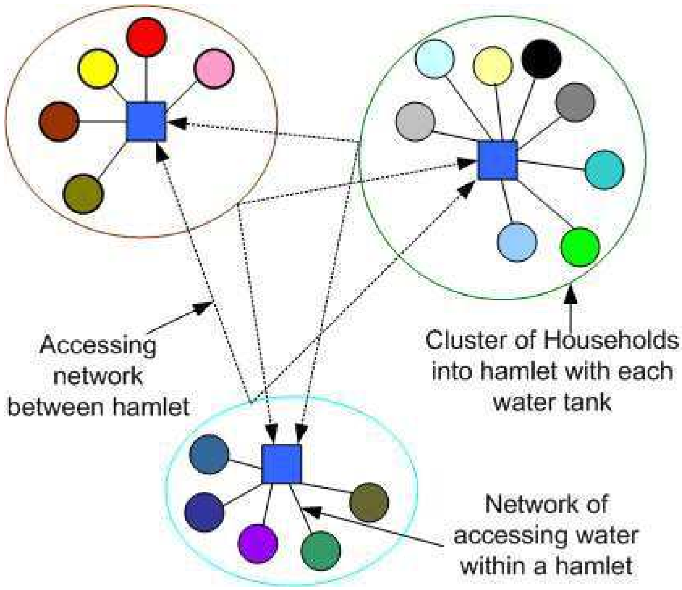


Figure 9.7. Network of households and hamlets in accessing water in Kengkhar village.

Process overview and scheduling

The model runs on a daily basis. Figure 9.8 provides a snap shot of a day in a year corresponding to a given rainfall pattern as a sequence diagram. The process in a day starts with randomly allocating one household within a hamlet that should perform rimdo. Then households to grow vegetables are decided on a random basis (Figure 9.9). It is followed by agents collecting water units based on their requirements. The collection of water is based on the availability of water in the nearest tank (Figure 9.10). Six rounds representing as many years were repeated anticipating that three rainfall patterns occurred at least twice to see their effects on water availability and use.

Once the agents collect water from tanks, they decide to allocate it based on the following sequence: if it has to perform *rimdo,* this cultural event receives the first priority. However when agents are not assigned with *rimdo*, first priority is given to domestic use followed by livestock and growing vegetables (Figure 9.11).

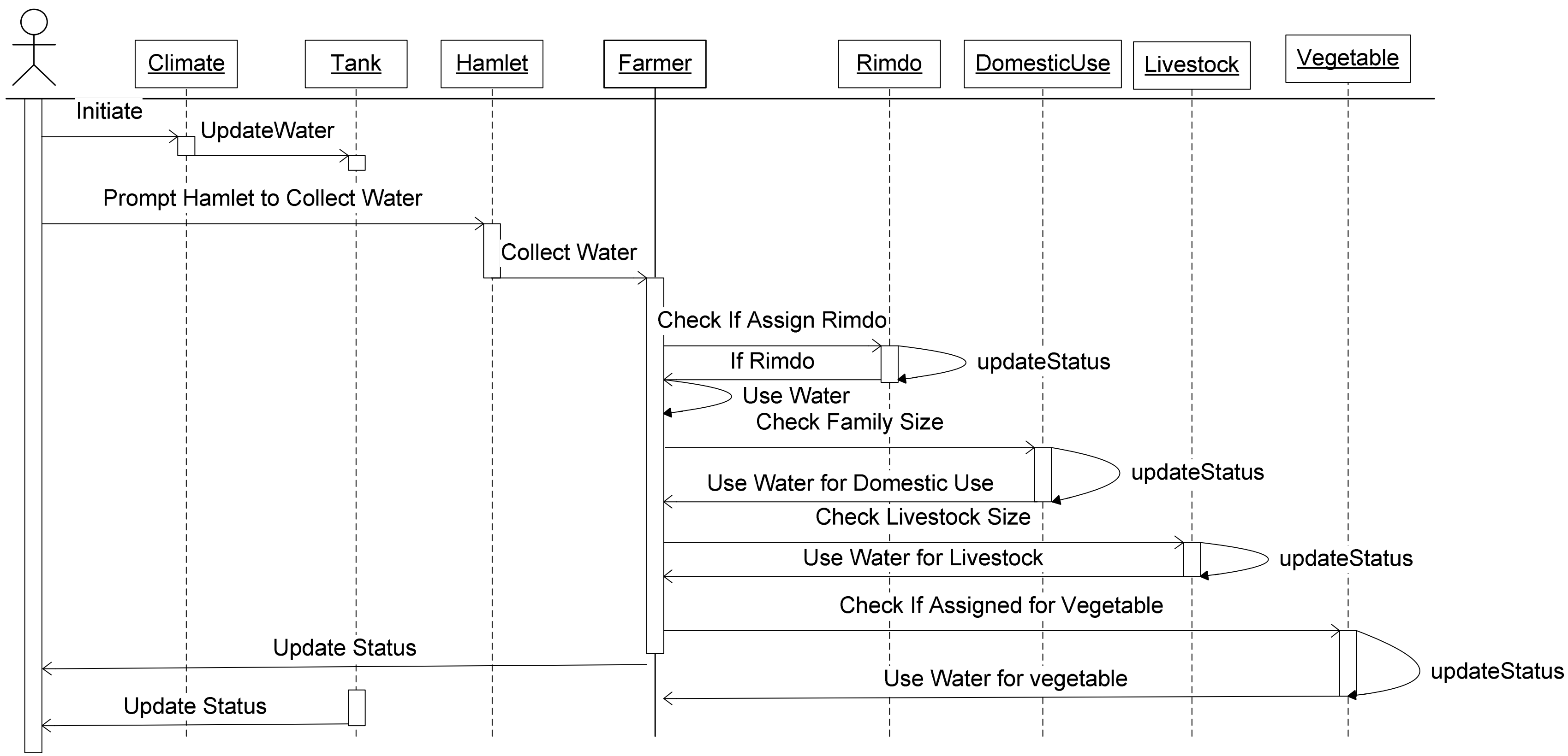


Figure 9.8. Sequence diagram of Omchu ABM.

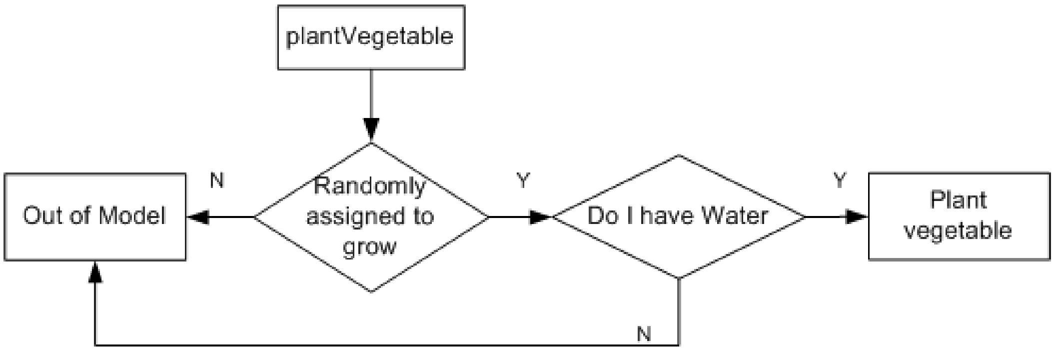


Figure 9.9. Decision to allocate water to plant vegetables.

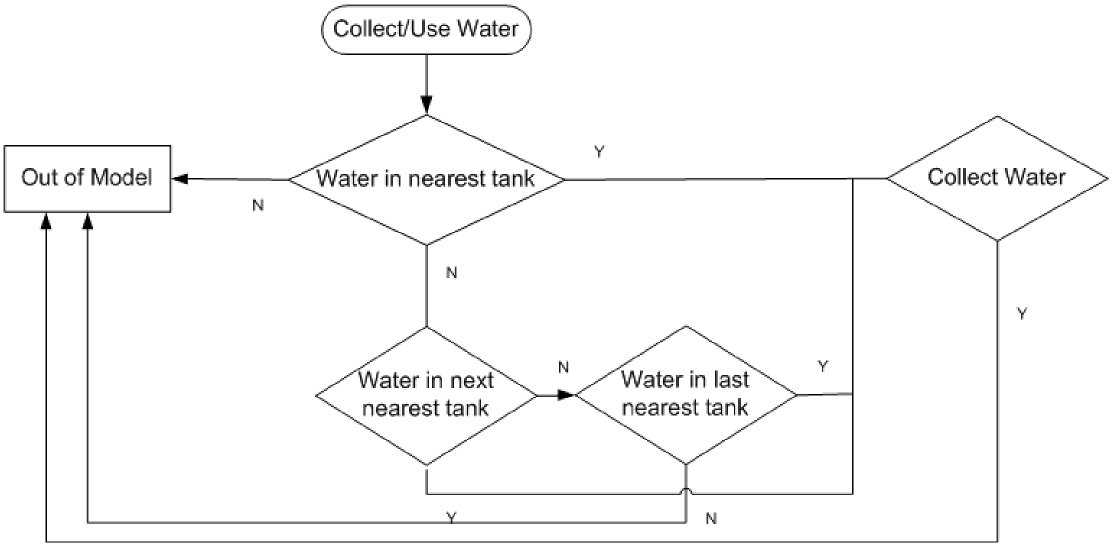


Figure 9.10. Process to collect water.

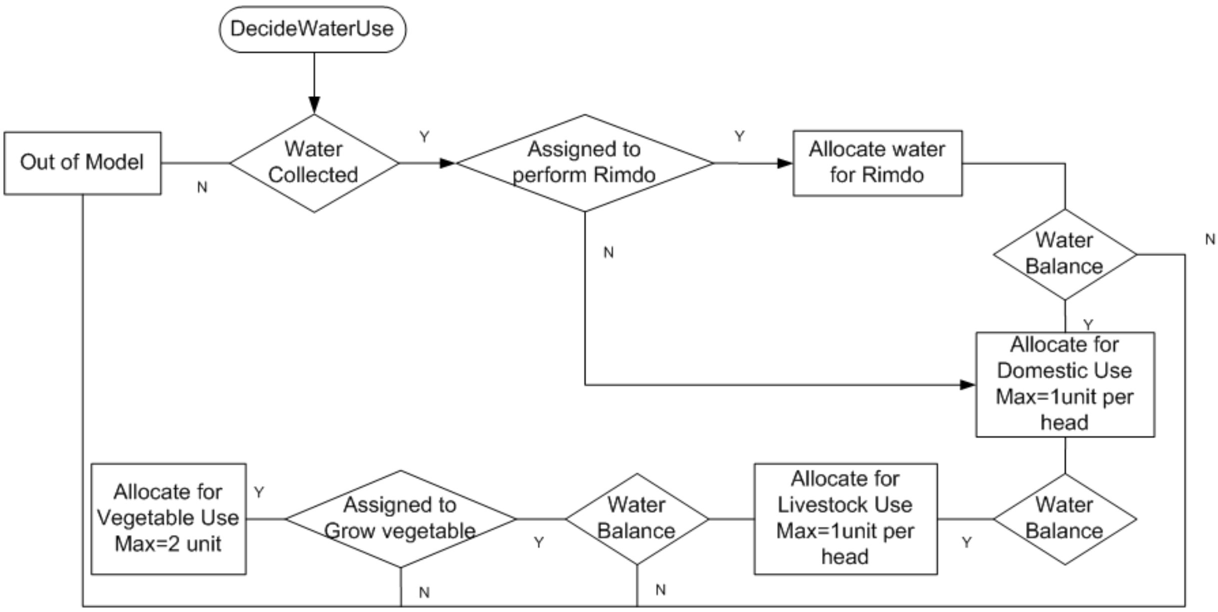


Figure 9.11: Decision to use water.

The model runs within four communication scenarios, first as case-as-usual where farmers operate on an independent mode and goes to any tank which has water. In the independent mode tanks assigned at the hamlet level also function independent of each other. In the second mode, players are allowed to discuss at the hamlet level to share water available at each round and even their movements to other tanks are discussed. In the third scenario, farmers still communicate at the hamlet level but the three tanks are networked to allow flow of water from a tank with excess water to the tank with a lower water volume. Finally, in the final scenario, all three hamlets were put as one large group where players discuss to share water at the community level (Table 9.6).

Table 9.6. Mode of communication in the scenarios used in the Kengkhar *Omchu* model.

	Modes	Rounds	Communication modes
1	Individually-free to access any ponds	6	Without any interaction, complete freedom for accessing any tank
2	Collectively at the hamlet level	6	Free interaction within hamlet
3	Collectively at the hamlet level with tank network	6	Interaction among all hamlets and collective decision
4	Collectively at the village community level and tank network	6	Inter-hamlets

Design concepts

The model is designed to represent the behaviour of farmers who behave in an individualistic manner to select tank and collect water. As some players become successful to fulfil their water demand, there is a tendency for other farmers within a hamlet to copy the behaviour of the most successful farmer. This can lead to the emergence of a common interest group and collective strategies to take benefit of the resource. Further there is also the possibility for other hamlets to see and imitate the group satisfying their water requirements.

All the farmers have to remember their hamlet group to remain within the cluster. Most importantly each one memorizes the family size and livestock size based on which they collect water and allocate it. In every time step there is a random assignment of growing vegetables and organizing a *rimdo*. At the whole system level, prioritization of water use has been set as domestic, livestock and vegetable with *rimdo* taking the first in case of farmer who has been randomly picked to perform it .

The principal interaction in the model is how players, either individually or as a group, react to water availability. There is a clear interacting effect of rainfall to water collected in tanks and subsequently its use depending on the four above-mentioned communication modes.

The model is probabilistic as it deals with the behaviour of players corresponding to randomly set rainfall patterns. Further as players visit the nearest tank with sufficient water, it is highly dependent on how the other players behave to access different tanks. Therefore with parameters set at random, the model can be considered as stochastic.

For the purpose of model testing, several simulations were run to observe the behaviour of some players if they followed some kind of pattern. The ABM simulation tool was also presented to the people who participated in the gaming sessions and farmers were quick to observe and indicate the rationale of the way they behaved in the gaming sessions which was captured by the ABM simulation.

Details

Initialization

Each farmer is assigned with a number from 1 to 18 and the participants are grouped into three clusters as hamlets as indicated in Table 9.8. All farmers are randomly assigned with a family size (2 to 5) and a livestock size (1 to 3). These initial features of the eighteen farmers were kept constant for all time steps and rounds to allow them to explore the varying resource level.

Table 9.7: Details of the farmers and their location in three hamlets of the *Omchu* model used in Kengkhar.

Hamlet No.	Farmer No.	Family size	Livestock size
1	1	4	2
1	2	3	3
1	3	2	1
1	4	4	1
1	5	3	1
2	6	2	1
2	7	3	3
2	8	3	2
2	9	3	3
2	10	5	2
2	11	4	1
2	12	5	1
2	13	2	1
3	14	4	2
3	15	5	1
3	16	5	1
3	17	4	1
3	18	5	3

Every time step is initiated with randomly picking a rainfall pattern represented by pictograms as moderately dry, wet and severe wet (Figure 9.12). Within each hamlet one tank is located that received a predefined volume of water based on the rainfall pattern (Table 9.8). Farmers collect water from the tank on the basis of water units (1 unit represents 1 Jerrican = 25 Litres). Following the discussion with the players, two additional types of tanks were introduced in the model. A collective tank with capacity of 5000 litres was added which could be used as a common tank for all the hamlets. The second type was individual tank located next to the house for harvesting rainwater from the roof.

Figure 9.12: Cards representing three rainfall patterns (Low, Medium and High rainfall) in the *Omchu* model used in Kengkhar.

Table 9.8. Rainfall pattern and corresponding amount of water (Litres) collected in different tanks in the *Omchu* model used in Kengkhar.

Rainfall	Tank at hamlet level			Collective tank	Private tank
	1	2	3		
Very wet	1250	2000	1250	5000	550
Wet	950	1500	950	3800	350
Moderately dry	325	500	325	1300	150

Nota: 1 water unit=25 Litres.

Input

Based on the interviews with stakeholders, the measurement of rainfall using a simple rain gauge over half a year, and of the water discharges measured from five spring ponds (Risingma, Bartshangri, Rotpari, Wangkhochi, and Daiphodrang springs) using the "volumetric measurement[3]" method it was roughly generalized that the three of dry, wet and very wet rainfall patterns yielded discharges of 0.01, 0.02 and 0.03 litre/second respectively. Based on the collection time of twelve hours (overnight) when water use is minimal and within three rainfall patterns, water collection in the three tanks was estimated as given in Table 9.8. In the model one of the most important inputs is the rainfall pattern which has much influence. The 2006 survey also revealed that on average, a local household used 688 litres of water on a daily basis for domestic use, livestock, and vegetable irrigation. In terms of its internal allocation, 47% of the water was used for domestic purposes (cooking and washing) followed by 29% going to livestock and 25% for garden irrigation. It was also implied that when any household has to perform a religious ceremony, all give priority to this particular use.

Spatial configuration and interface

The spatial settings of the *Omchu* model are represented by a grid with a 150 rows x 150 columns tessellation indicating the landscape on which households, hamlets, and water tanks are located. There are 18 squares corresponding to 18 farmers with 4 quadrates representing as

[3] Use a container of known volume, record time to fill the container, repeat the process three times. This method is applied to small springs (1 gallon per minute).

many types of uses of water. There are three rectangular boxes representing water tanks positioned within the three hamlets. After each farmer collects water units as small cubes (1 cube = 1 jerrican = 25 litres of water) they place cubes on the quadrate. Water units from the three tanks are identified by colours (blue cubes from tank 1, pink from tank 2 and green from tank 3). These colours help to indicate movement of water from all tanks to different households (Figure 9.13).

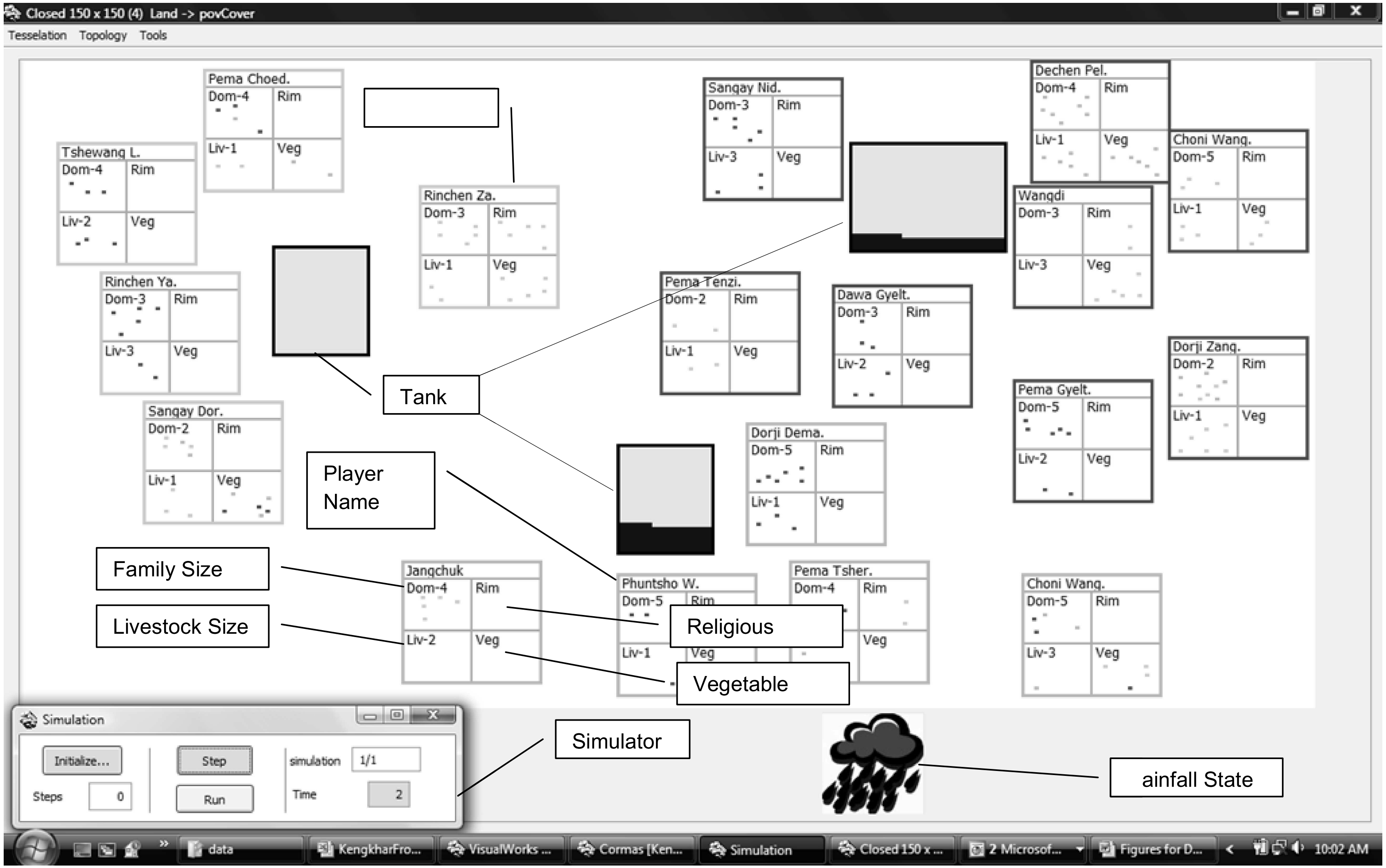


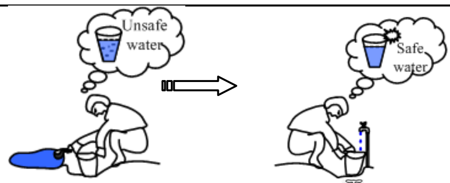
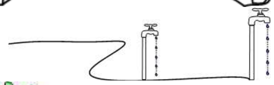
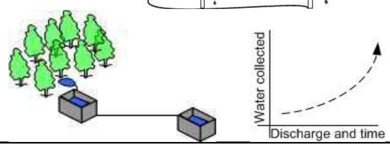
Figure 9.13. CORMAS interface of the *Omchu* model used in Kengkhar.

9.4 Analysis of gaming and simulation sessions

9.4.1 Shared representation of the context and participants understanding

As stipulated by the ComMod posture, the integration of the points of view of all stakeholders, including those of the researcher and the modeller, to construct the model enhances the relevance and use of model in Kengkhar. The co-construction of representation of such artificial world helps in creating a shared representation which forms a basis for simulating scenarios for dialogue, shared learning, and collective decision-making. In Kengkhar, three broad categories of stakeholders were identified and their representations are simply described in Table 9.10.

Table 9.9. Simplified representations of mental map or perceptions of the situation by different stakeholders in Kengkhar.

Site (and resource)	Stakeholders	Representation	Method to capture the initial representation
Kengkhar (water for domestic use)	Household		Participatory resource mapping & envisioning
	Infrastructure providers		Consultation and development plans
	Researchers		Field monitoring, discussion and literature reviews

The model conceptualization through a consultative process was the first effort to create a preliminary representation which was further improved with more clarity in expressing these mental frames. The schematic representation in Figure 9.14 provides a tentative process of how initial individual points of view evolve into a shared representation which can facilitate the emergence of new understandings and potentially change in the individuals' points of view, behaviour, decision-making and practices.

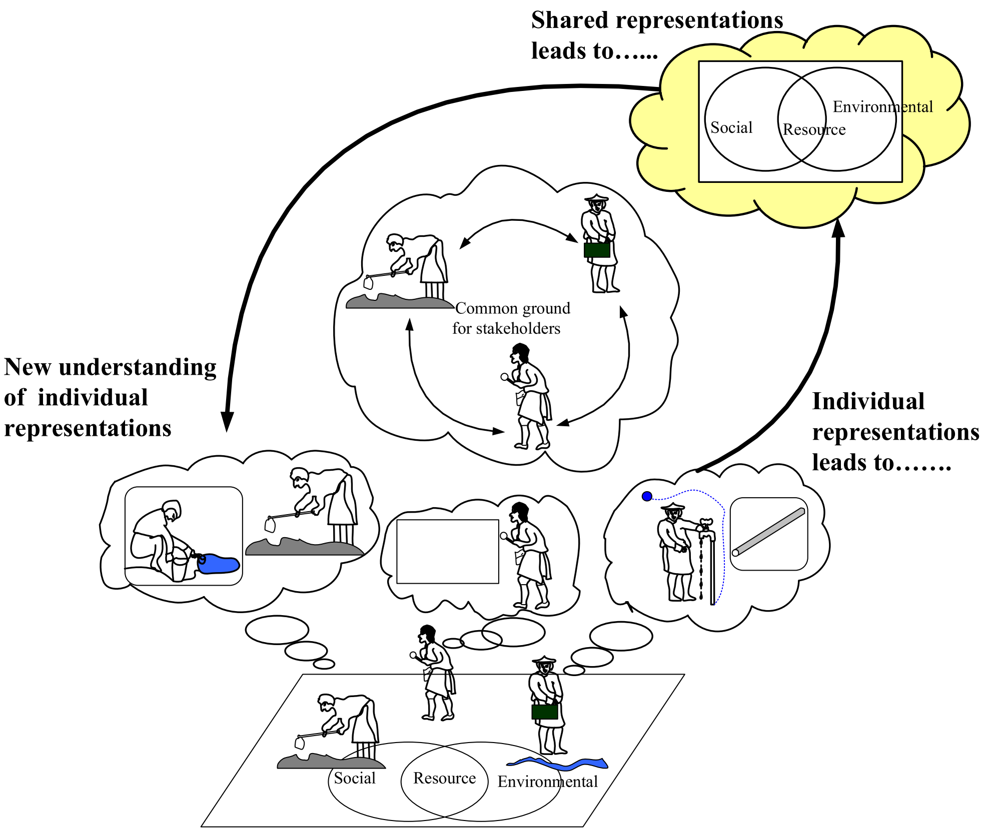


Figure 9.14. Co-design of a shared representation in the companion modelling process on water collection in Kengkhar.

Similarly the support service agency sees structural intervention like network laying pipes and installation of taps in Kengkhar as an ultimate solution. The third agent, the researcher who had very limited understanding of the situation, therefore used preliminary field observations and literature reviews to constitute a more theoretical perception.

9.4.2 Identification of scenarios from the gaming sessions

The RPG used rainfall patterns as the random factor which determined the resource volume. The interactions between the four above-mentioned protocols for communication among the players and three rainfall patterns produce twelve scenarios displayed in Table 9.11.

Table 9.10. Scenarios from the Kengkhar role-playing game.

Protocol	Rainfall pattern		
	Very wet	Wet	Moderate dry
Individual free access, no sharing and no water accumulation	$S_1=P_1R_1$	$S_2=P_1R_2$	$S_3=P_1R_3$
Communicate within group, share water within sub-group, and no water accumulation	$S_4=P_2R_1$	$S_5=P_2R_2$	$S_6=P_2R_3$
Communicate within group, share water within sub-group, and water accumulation	$S_7=P_3R_1$	$S_8=P_3R_2$	$S_9=P_3R_3$
Collective, share water and water accumulation	$S_{10}=P_4R_1$	$S_{11}=P_4R_2$	$S_{12}=P_4R_3$

9.4.3 Analysis of Scenarios

9.4.3.1 Resource stress

The water balance in Kengkhar gaming sessions were influenced by the rainfall pattern and communication protocol. The collective networking mode with free sharing and collection of water in a high rainfall situation (S_{10}) gave the highest water balance. Water accumulation and networking helped in sustaining the water which is evident from comparing S_3 and S_6 having no water balance against S_9 and S_{12} which have positive water balances. Communication and social networking also helped in more efficient water use thereby resulting balance of water as indicated by S_4 (Figure 9.15).

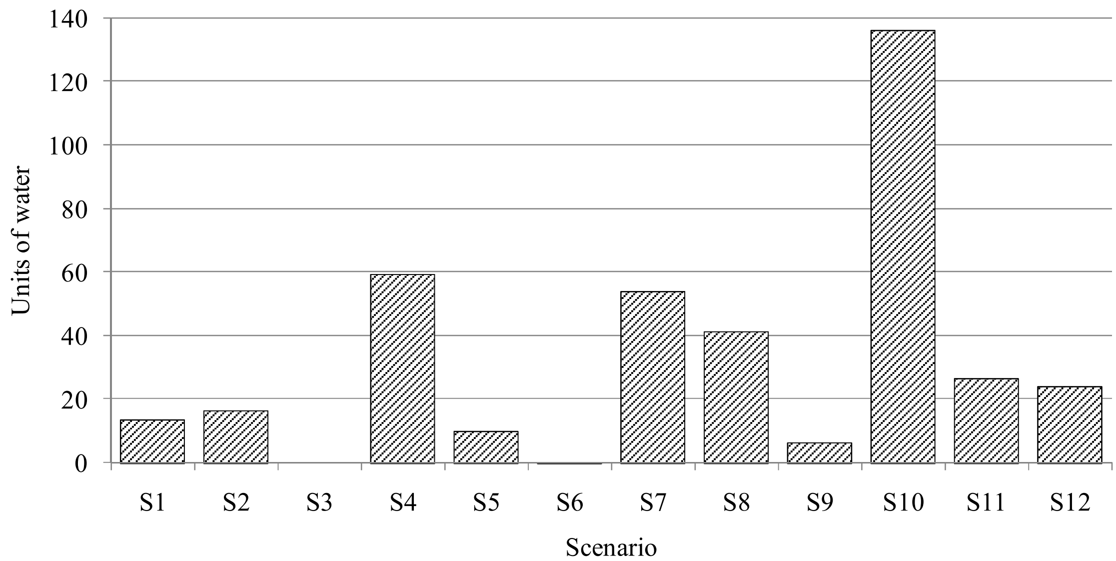


Figure 9.15. Water balance in Kengkhar RPG.

9.4.3.2 Equity in resource allocation

The issue of accessibility to looming drinking water source influence social network in Kengkhar. In an attempt to make credible comparison among scenarios, Gini Coefficient is used to assess the way each scenario influences water allocation. The inequality analysis was done on the quantity of water collected from the tank by individual players, indicating the resource distribution pattern. Compared to Lingmuteychu case, there was more variation in the coefficient and no instance of perfect equality. Scenario (S_6) with free interaction within hamlet and low rainfall caused the highest inequality (Figure 9.16). The analysis also reveals that the accumulation of water does not promote an equitable distribution, but it is the interaction (networking) and sharing which ensured equitable access to water. There is also a definite influence of low rainfall pattern leading to lower discharges that create disparity among the players, as early visitors take more within the traditional norms of "first-come-first-serve".

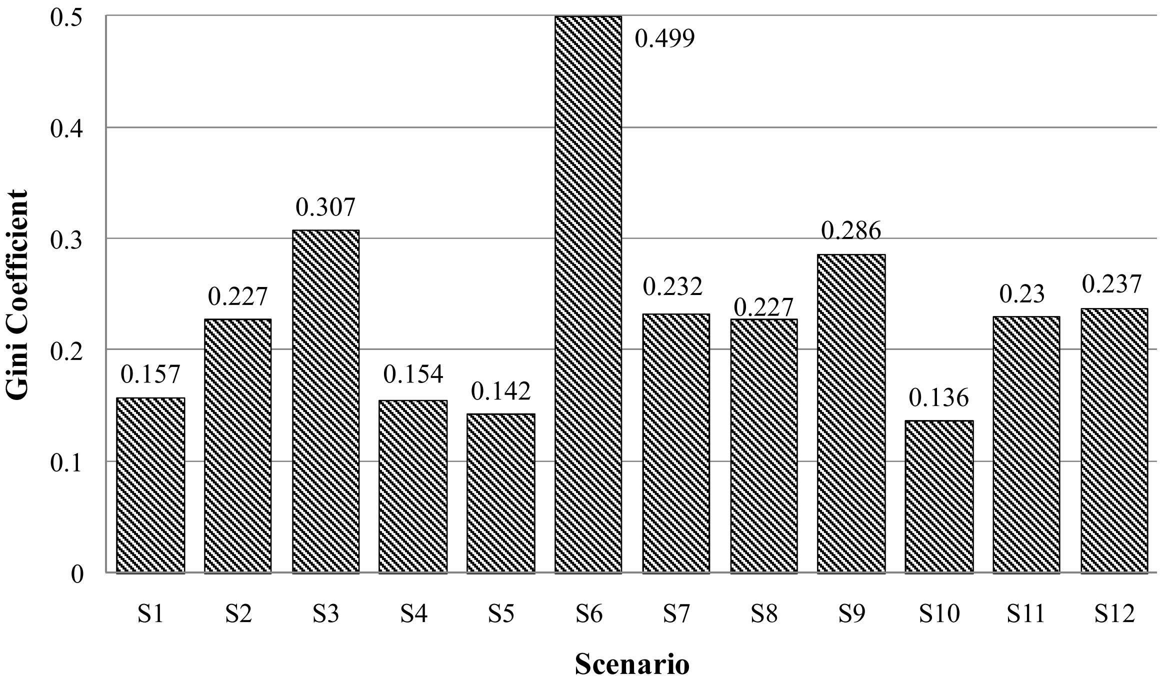


Figure 9.16. Inequality in water shares across 12 scenarios in Kengkhar.

9.4.3.3 Resource sharing

Vibrant exchanges and interactions among players were observed in the gaming sessions. As such, and as in the previous case (chapter 8), the sharing of water unit can be a useful and rather a comprehensible indicator to compare different scenarios. -During the gaming sessions exchanges were best observed in the way players visited different tanks during each turn. Although there were few instances of water sharing between players, people fundamentally in real life situation suffice their water requirements by accessing water from any tanks that has water. Therefore, to assess the efficiency of scenarios in promoting networking, a comparison of average number of tanks visited during each gaming session of six rounds by the players across the twelve scenarios was made and the results are presented in Figure 9.17. The traditional system of free access (S_1, S_2, and S3) irrespective of rainfall pattern prompted higher frequency of accessing others tanks.

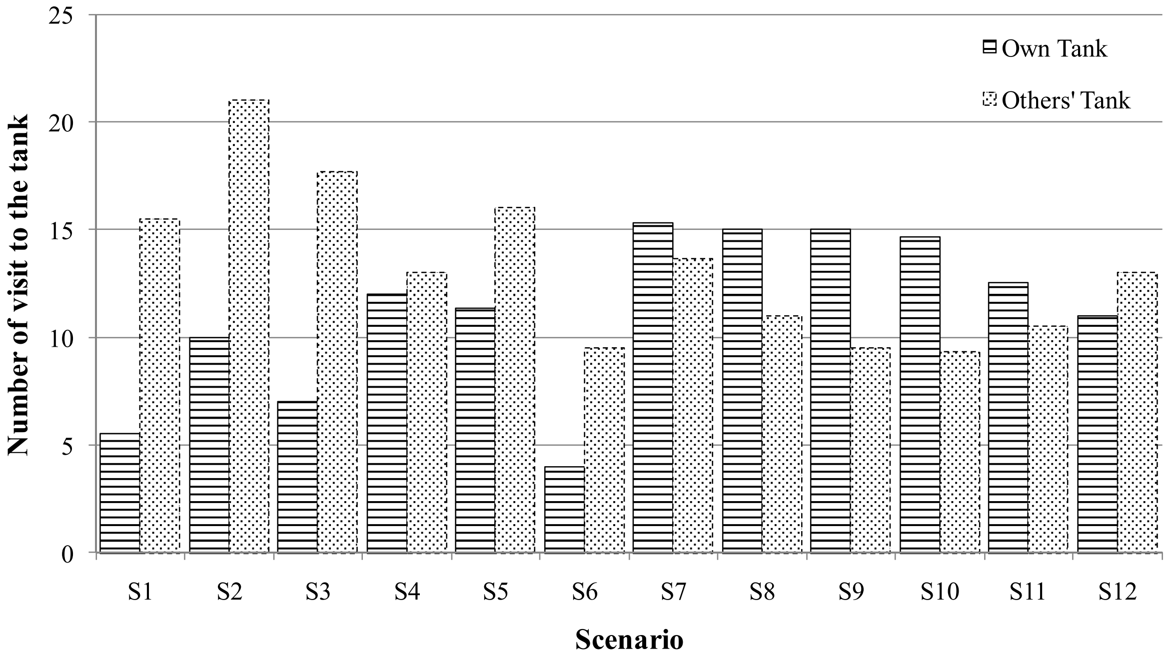


Figure 9.17. Number of time players access different water tanks in different scenarios in Kengkhar.

As sharing of water was introduced in the protocol of traditional system, the number of visits to other tanks significantly decreased (scenarios S_4 to S_6). Further the instances of accessing other tanks became lesser as accumulation of water was included in the protocol. This clearly showed the benefits of networking and water collection for natural springs.

9.4.3.4 Satisfaction of water needs

Fulfilment of water needs both individually and collectively is yet another factor players considered as a tangible effect of any strategy. Based on the output of the gaming sessions, a simple assessment of the satisfaction level was done by assessing the total water received against the requirements. It was interesting to observe the dominance of the traditional system of free access and free flowing system in high rainfall situation (S1) in Figure 9.18. The influence of low rainfall pattern in scenarios without water accumulation (S3 and S6) was prominent where more than 50% of the water requirements went unsatisfied. This indeed represented the reality where during 2 to 4 months the ponds are dry and people have a serious problem accessing drinking water. Water accumulation had a consistent positive effect in fulfilling water needs above the 95% level of satisfaction.

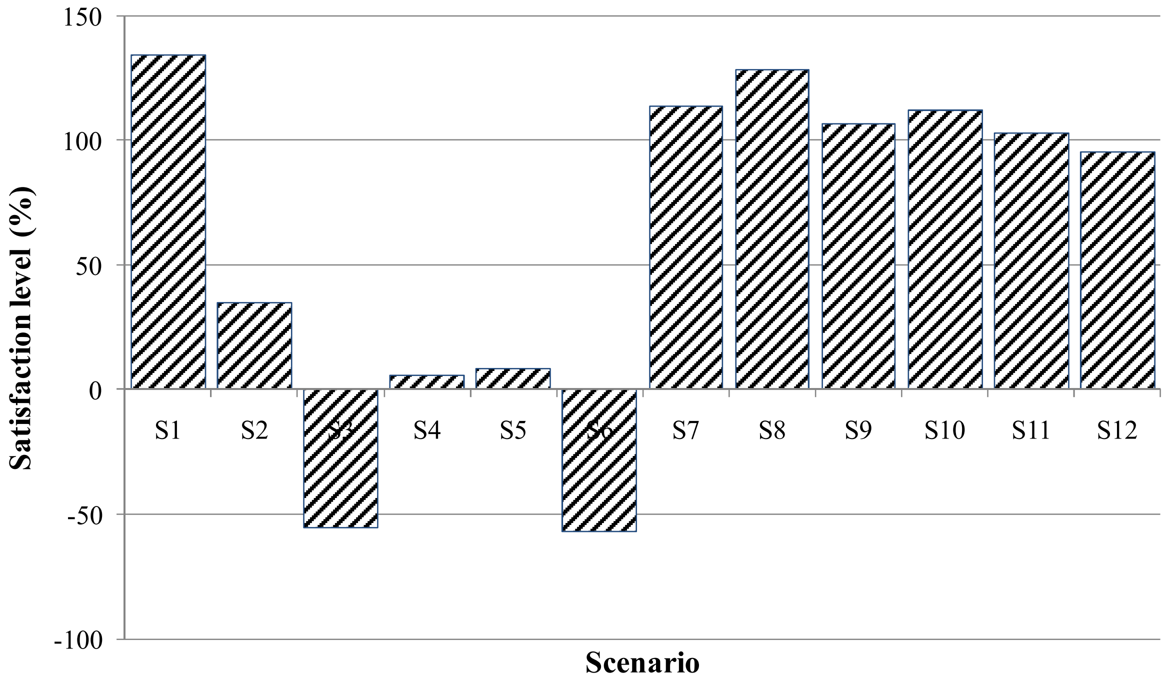


Figure 9.1819. Proportion of players fulfilling their water requirements in different scenarios of the gaming sessions in Kengkhar.

9.4.4 Interviews of RPG players about new learning

As in Lingmuteychu, all the players were individually interviewed using a structured questionnaire after the gaming sessions with an objective of (i) to learn more about players' decisions regarding land use and water management, and (ii) to elucidate some of the decisions made during the gaming sessions.

53% of the players considered water sharing by collecting and storing as a new learning as shown in Figure 9.19. Further they realized that to sustain the water resource, there is a need for proper prioritization of water use and conservation through community participation. As in reality, 56% of the players chose the tank to collect water depending on the quantity of water in it, while the remaining considered nearness to the tank as a means to decide accessing a tank. All households considered drinking as the first priority in water use, followed by livestock, *rimdo* and vegetable cultivation. A majority of the players faced a shortage of water in the gaming sessions but managed by borrowing from other players, which they considered as a possibility by seeking stored water in respective tanks. During the discussion in the gaming sessions and interviews it was time and again mentioned that sharing in reality does not happen at the individual level but that it is possible for people to visit other ponds. Players also referred to the network of tanks where water is transferred from one tank to the other as a possible strategy.

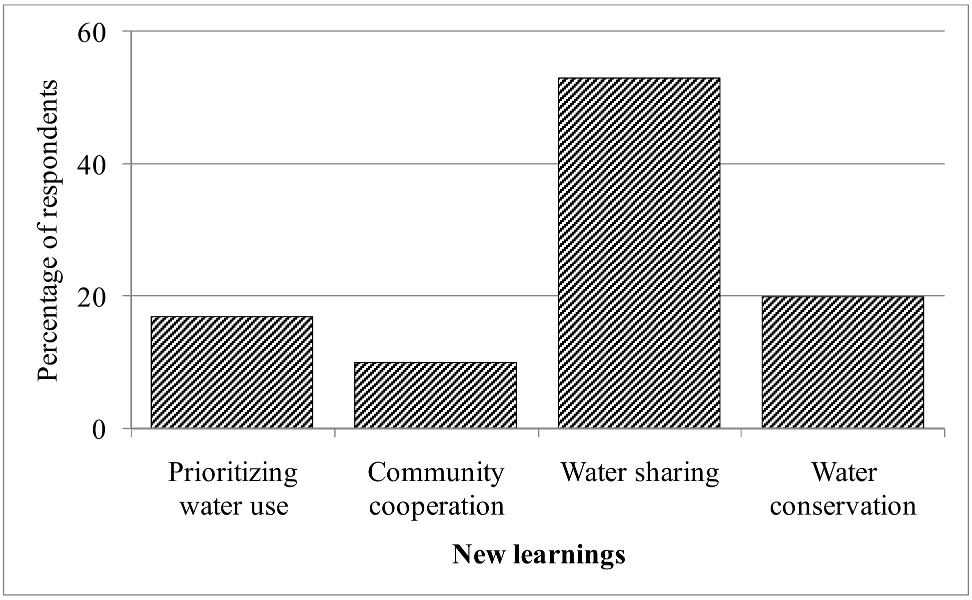


Figure 9.19. New learning by players (proportion of respondent) from the gaming sessions held in Kengkhar (*n=18*).

9.4.5 Collective actions

The participatory workshop and the RPG sessions brought together not only players but also several observers who saw the process converging to a point consistent to the issue of farmers. Players felt the need and potentials for implementing few tangible collective actions. Indeed players were encouraged by the new understanding they gained from the process and choose to hold on the opportunity of developing collective approach to the issue. The last day of the participatory workshop was used to draw up a collective action plan.

In contrast, participants in Kengkhar had several activities proposed as collective actions. It was more of an overwhelming situation with the opportunity to envision collectively. However, the joint discussion helped them to focus the plan and remain within the core issue of accessing drinking water (Table 9.11). The main advantage for Kengkhar was the completion of the important new infrastructure made of water collection tanks and linked as a network which was implemented as a collective action prior to the gaming session. Therefore most of collective actions suggested below are to maintain or sustain the structure and their network. In addition to the tanks and its network, another significant collective decision was to propose a new water source in Dochuri (Activity 6). It was encouraging to see that it has been put up to the district administration and is currently being implemented (Monitoring visit in September 2010). To ensure that all these activities are implemented as planned, the group also put in place a six member working group led by a monk.

Table 9.11. Collective actions decided at the end of the ComMod process in Kengkhar.

SL. No	What	Where	Why	When	Who	
					Implementer	Collaborator
1	Identification of catchments and looking for its critical status for management	Resingma, Wangkhochi, Bartshangri	For good water quality and quantity	May 2009	The beneficiaries of the watershed	Research, EA, Gewog
2	Maintaining sanitation of the water tanks and catchment area	Resingma, Wangkhochi, Bartshangri	Save water for drinking	Every after 3 months starting from May	Beneficiaries of the respective water source	
3	Changing the network pipe	Resingma to Kripo	Water leakage on the way	May-June	Benefiacires of the Kripo tank	Research
4	Sourcing fund	Geog yargey tshodey (GYT) (*Block development committee*)	The group is in the initial stage to support them self	May-June	The beneficiaries of the watershed will seek help from GYT	Research
5	Target to store water for all times in the water tanks	All the water tanks	To supply water for 24 hours for all communities	May-June	Chairperson of the group	EA, Research

6	Water tapping from Dochuri	For the communities of Dokthang, Pangthang, Ebee	Insufficient water from the existing spring ponds	2009-2010	All beneficiaries of the community	GYT
7	Catchment fencing by barbed wire	Bartshangri catchment	Protection from animals	May-June	Benefiacires of Ebee	Group chairman
8	Provision of cattle water drinking	Wangkhochi	No provision of tough for cattle feeding in the existing system	May-june	Benefiacires of Wangkhochi	Group chairman
9	Water harvesting from the roof	Putsturmi, Dungmanma, Dokthang, Zhorthung	Insufficient water supply and far away catchments	May-June	Beneficiaries of the respective community	Group, chairman

9.4.6 Identification of scenarios for more simulations with the agent-based model

As described in earlier sections, the RPG sessions were efficient to support exploration of simple scenarios within a short time frame. Although the results show definite trends and helped in generating a shared representation of the resource situation, it was not possible to introduce new parameters and to test new combinations with other parameters for longer periods. As highlighted earlier, the unpredictable characteristics of SES over a longer time frame cannot be modelled into a RPG. To complement gaming information, if all known factors and their parameters can be integrated, the computer ABM tool has the ability to generate rapidly simulated scenarios over several time-steps. Like in the case of Lingmuteychu, the *Omchu* ABM was used for such a purpose in Kengkhar site.

The *Omchu* RPG-based Kengkhar ABM was presented to the participants in the gaming sessions and they could easily understand and explain the movement of the agents. Compared to the RPG the ABM produced a clear visualization of water accumulation in the tanks which was convincing to farmers. As only six time steps each for four scenarios could be played during Kengkhar field workshop, this limited the analysis from long-term perspectives. Therefore using the RPG-based ABM with twenty time steps and ten repetitions of three possible combinations of parameters to generate multiple scenarios was a very complementary investigation.

9.4.6.1 Traditional regime

Farmers in Kengkhar have been following an open access water resource system, but without any resource management responsibilities. This has resulted into a mindset to use the water resource until the spring pond dries with no one really taking any initiatives to protect or restore. In the RPG, the traditional regime fostered highest satisfaction and equality in resource allocation. Therefore, the traditional scenario represented random rainfall, free flowing spring pond and accessing of ponds in order of "first visit own village pond, if there is no water move to the next nearest pond" (Table 9.12).

Table 9.12. Scenarios of the traditional regime for the Kengkhar agent-based model.

Rainfall	Water accumulation	Mine first then others
Random	No	S_1

9.4.6.1.1 Tank networking

One of the principal interventions in Kengkhar was the construction of water collection tanks and establishing a network by connecting some of them with HDPE pipe to transfer water. As per the design, two tanks (Risingma and Wangkhochi) with higher water discharge rates and located at a higher location have been designed to let flow the excess water (excess to a day's requirement of the primary users) to the immediate lower tank. As the requirement of primary user may change over time, the overflow after a certain volume collected does not appear suitable. A concept of sharing using the collective decision-making process could be a strategy for the future. Therefore a two step method of making decision was formulated as follows:

- Households agree to share: An agent agrees to share if it attained 60% satisfaction in last two consecutive time steps. This condition of sharing is included as farmers considered as drinking, washing and cooking which is the most important water need requires only around 60% of their water requirement
- Hamlet agrees to release water: If two-third of its households agree to share, the hamlet will release water to the next tank.

Using the five levels (0, 0.25, 0.5, 0.75, and 1.0) of household satisfaction and the proportion of households agreeing to share water in a situation when water is accumulated in the tank, 25 scenarios have been identified for experimentation as shown in table 9.13. These scenarios were relevant when water was accumulated in a tank, as such non-accumulation situation is not included here.

Table 9.13. Scenarios for tank networking to be simulated with the *Omchu* model used in Kengkhar.

Water accumulation	Hamlet agrees to share (proportion)	Households agree to share (proportion)				
		0	0.25	0.5	0.75	1
	0	S_1	S_2	S_3	S_4	S_5
	0.25	S_6	S_7	S_8	S_9	S_{10}
Yes	0.5	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}
	0.75	S_{16}	S_{17}	S_{18}	S_{19}	S_{20}
	1	S_{21}	S_{22}	S_{23}	S_{24}	S_{25}

9.4.7 Analysis of scenarios with the *Omchu* agent-based model from Kengkhar

9.4.7.1 Traditional water sharing

The simulation results of the Kengkhar ABM representing the traditional situation depicted the uses of water as in real circumstances with domestic use dominating water use with 48%, followed by use in vegetable cultivation (24%), livestock use took 21%, and annual household rites consumed only 6% of water. There was consistency in the proportion of water used for domestic purpose depending on family size (Figure 9.20).

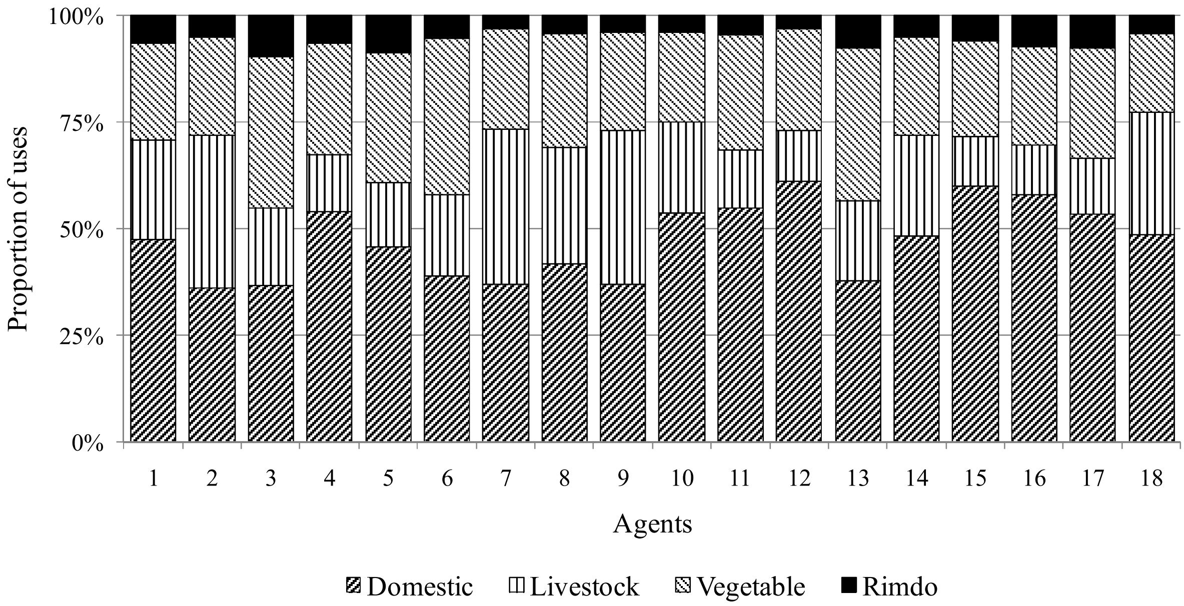


Figure 9.20. Average water uses by 12 agents over 20 simulations.

Irrespective of the rainfall pattern and water volume received by each hamlet, all farmers face shortage of water (Figure 9.21). The satisfaction level of eighteen players across twenty time steps varied from 75% (farmers 8, 9 and 10) to 90% (farmers 3, 5 and 15). This may be due the random allocation of *rimdo*.

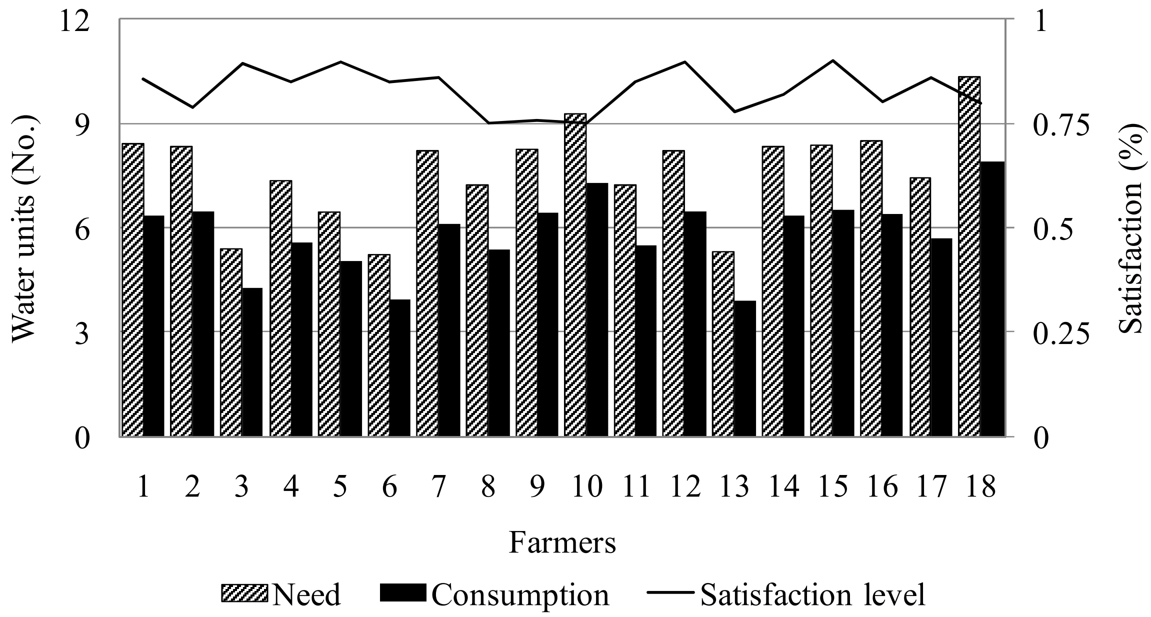


Figure 9.21. Average satisfaction level of 18 farmers in 10 simulations.

Although there is a sort supply of water and relatively low satisfaction level, the model presents a fair equality in the distribution of water over ten repeated simulations with an average Gini coefficient ranging between 0.09 and 0.13. There is also the creation of an overall water balance of about 200 to 600 units (Figure 9.22). Among the ten repeated simulations there was correspondingly a high proportion of satisfaction among the agents.

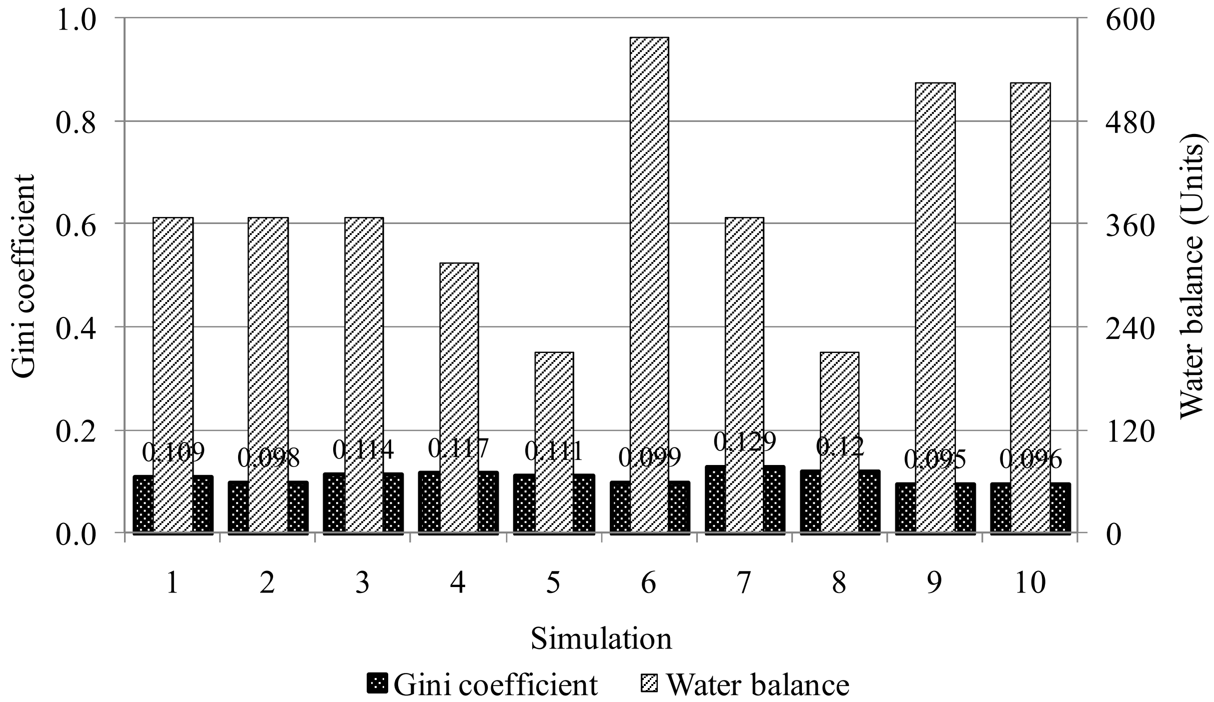


Figure 9.22. Water balance, equality in water distribution and satisfaction in Kengkhar ABM.

9.4.7.2 Tank networking

In the tank networking scenario, the 25 scenarios (five individual sharing rules by five hamlet sharing rules) provided an opportunity to generate substantial water balances. In each scenario, collectively around 126 to 152 units of water were received in the three tanks. On an average about 6.5 units were used per household achieving a satisfaction level higher than 75% (Figure 9.23). Across the 25 scenario, there was a water balance ranging from 17 to 30 units which served as a principal advantage of the tank networking.

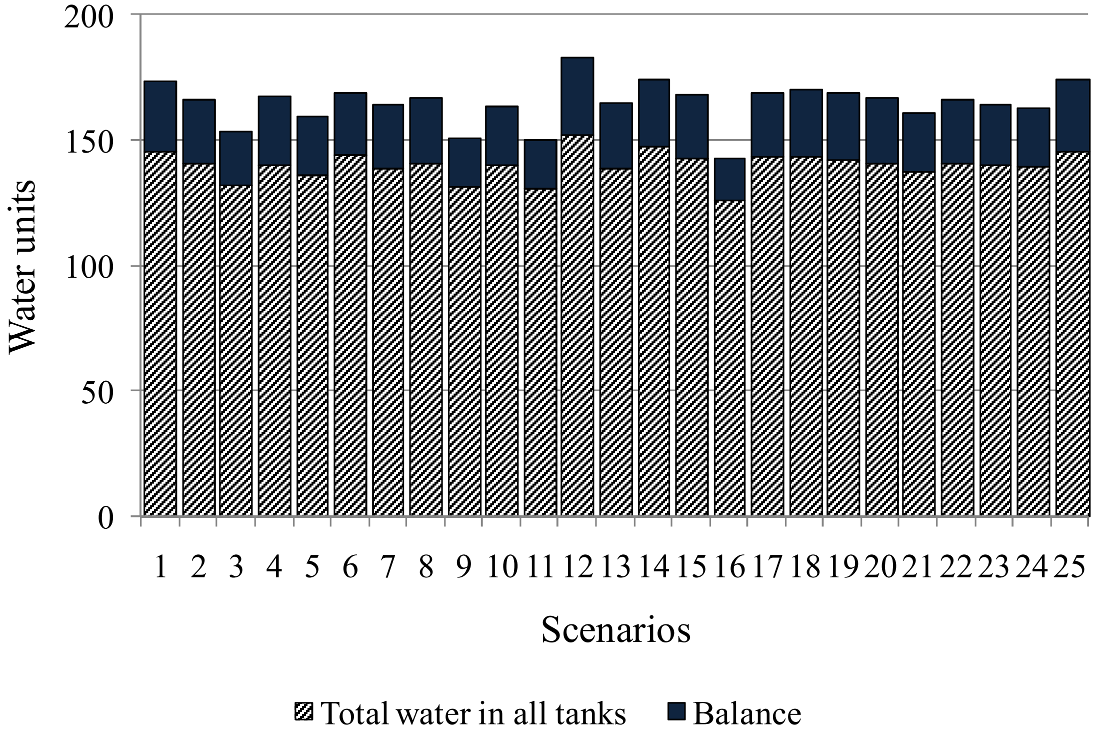


Figure 9.23. Water consumption and balance.

The balance indicated in the each scenario was contradicting the average situation each player was facing. As per Figure 9.24, all the eighteen farmers were consuming lower amounts of water than what they actually need. The gap between the need and consumption was fairly uniform across the eighteen players. Further the Gini-coefficient of 0.09 for water consumption indicated an equitable distribution. This indicated a collective saving of water, and actually corresponds to the real situation where people fetch from different tanks without hampering the requirement of all.

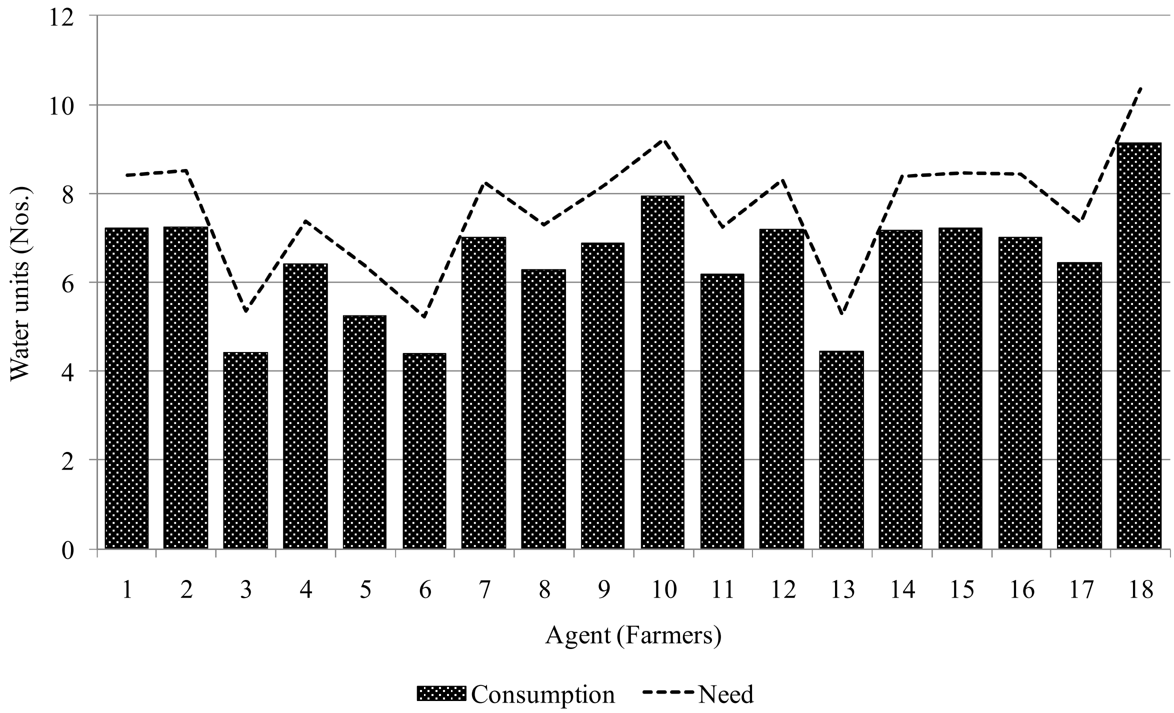


Figure 9.24. Average water need and consumption of 18 farmers.

Analysing from the total number of times each farmer do not get any water across 25 scenarios, it can be seen from the Figure 9.25 that all faced short supply of water ranging from 10% to 29% of the instances. In general scenarios (S_{11}, S_{13}, and S_{16}) corresponding to 50% and 75% households agreeing to share at 0 to 50% fulfilment of individual needs tend to have increasing water scarcity, while scenarios S_2, S_3, S_4, and S_5 that corresponds to no household agreeing to share water result in high proportions of water scarce situations. However, they do not have definitive trends. When more than 75% hamlets agree to share water irrespective of individual's agreement, scenarios S_{17} to S_{21} presents a mixed situations of water scarcity. The results do not show any definitive trend in water scarcity due to sharing.

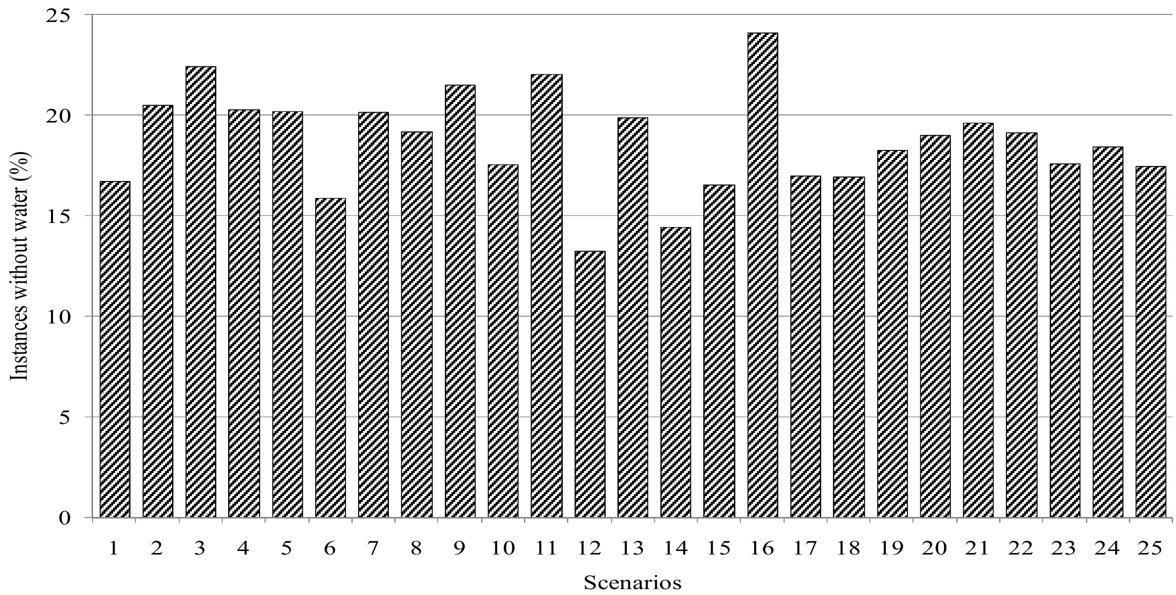


Figure 9.25. Instance when agents did not have any water at all.

Based on the water scarcity, farmers strategize differently to cope with the situation. In Kengkhar, it is based on the water use priority. As indicated in Figure 9.26 the first water use they sacrifice is the irrigation of vegetables followed by feeding livestock, and finally the domestic use, implying that domestic water need is the most important need.

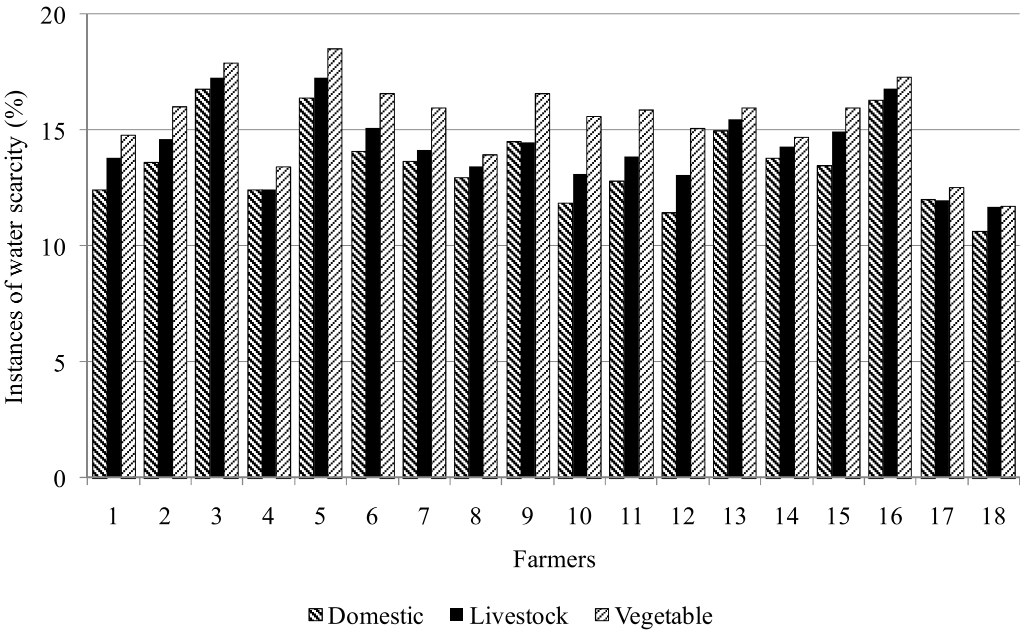


Figure 9.26. Average number of water scarcity situation for different uses.

All scenarios provide a satisfaction (consumption/need) level above 75% (Figure 9.27). Although the differences between scenarios are non-significant, household satisfaction level of 50% with 25%, 75% and 100% of them agreeing to share in a hamlet potentially provides higher overall satisfaction level. A situation where water is not shared (zero proportion of households agreeing to share) represented by the first cluster too have overall satisfaction level of 75%, which could be due to the accumulation of water in respective tanks, and agents fulfilling their requirements from their individual hamlet tank.

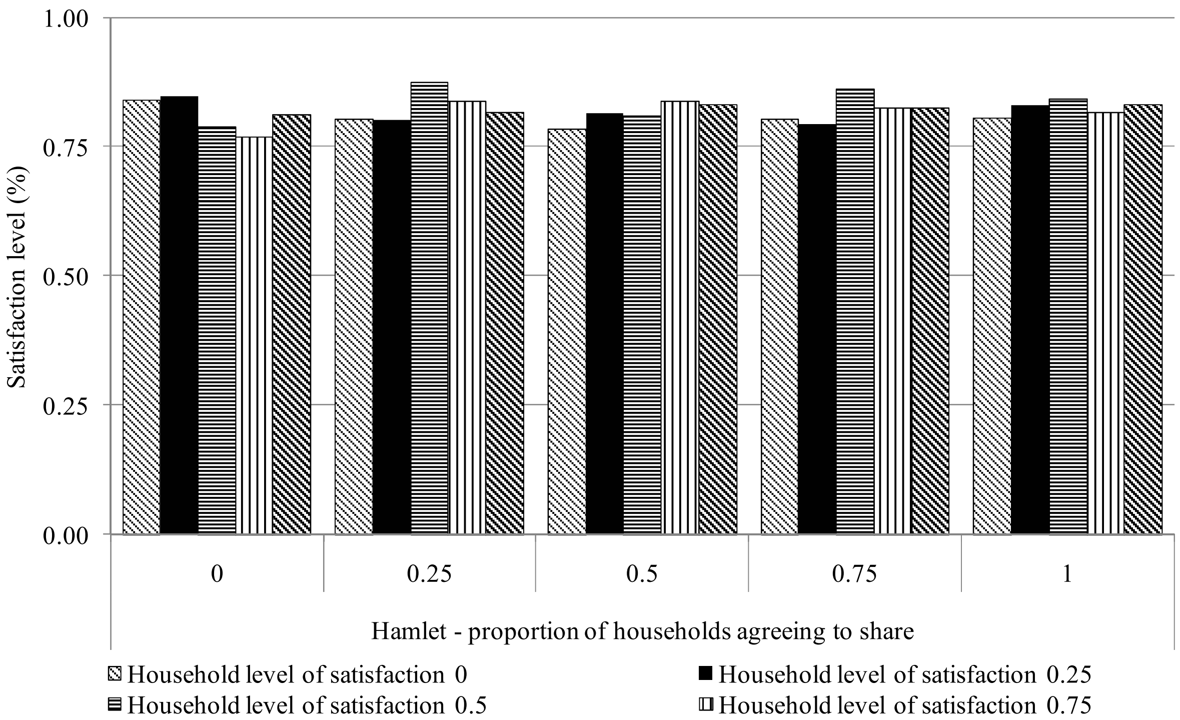


Figure 9.27. Satisfaction level based on sharing rules in different scenario.

As indicated above, water collection in tanks and networking not only satisfied the water demands, it could also facilitate water saving to a substantial level. As represented in Figure 9.28, all three tanks across 25 scenarios show appreciable amounts of water balance. The water balance ranged from 30% in tank 1, 21% in tank 2, and 10% in tank 3. The overall balance from the system is around 18%, which may be one of the incentives for networking the tanks.

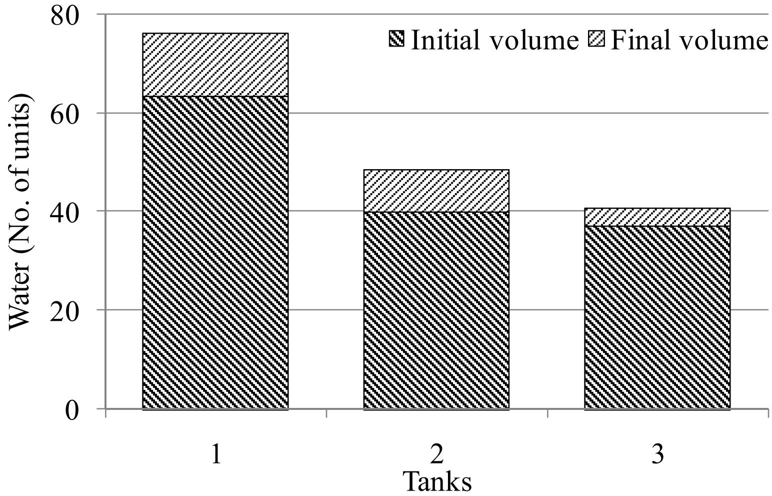


Figure 9.28. Initial and final volumes of water (in units) in the three tanks across twenty five scenarios.

The simulation of multiple scenarios provided the opportunity to display that collectively water can be saved by networking and sharing. It was also efficient to depict the existing water use dynamics like farmers accessing water from multiple tanks. The quick understanding of the model helped in one of the RPG player taking over the process of briefing non-RPG participants during the community meeting. With the successful construction of water collection tank and presentation of different water sharing scenarios, resulted in tangible effects and impacts. The details of the effects and impacts are presented in following section.

9.5 Comparison of the effects and impacts of the ComMod process in Kengkhar

9.5.1 Direct and indirect effects

Table 9.14 provides a summary of the effects of the ComMod process in Kengkhar. These effects can be segregated into individual, collective, institutional and biophysical. The direct individual effects are again the enhanced awareness of the individual situation and strategy to improve it. It was this individual new learning that helped in establishing a shared common understanding to facilitate collective decision-making and actions. In Kengkhar bringing together the institutions, like the basic health unit, school, agriculture extension office under the block development, was the prominent direct effect, and the creation of the small group to manage the tank network. The important biophysical effect in Kengkhar is the initiatives of managing catchment are and operation of water collection tanks and their networking which has improved the water availability regime.

The simultaneous indirect effects of the process are the way people started valuing the water and its quality. With the protection of the catchments, use of concrete tanks, cover and distribution system, the indirect effects on biophysical features in Kengkhar lead to an improved water recharge of natural spring ponds by catchment protection and stabilization of degraded slopes.

Table 9.14. Direct and indirect effects of the ComMod process in Kengkhar.

Sites	Level of effects			
	Individual	Collective	Institutional	Biophysical
Direct effects	Water available for 2 additional months and reliable network of tanks	Participation in consultation and collective actions	Tank network management committee formed	Catchment protection and tank networks
Indirect effects	Access to clean water, time saved from water collection	Social mobilization	Cooperation and understanding for collective action	Natural spring recharge enhanced, greening of catchment, reduced land degradation

9.5.1.1 Impact domains

In view of the process orientation and close interactions, ComMod activities had significant influence on the knowledge, understanding and behaviour of the participating farmers, that builds trusts and confidence of the stakeholder to work collectively to resolve the impending NRM issues. As such it is valuable to assess how far the approach impacts on immediate timeframe or what can be envisioned as a long term impact. Broadly the impacts of ComMod can be associated to four comprehensive domains: technical, individual, collective (social), and external agencies (outsiders) as shown in Figure 9.29.

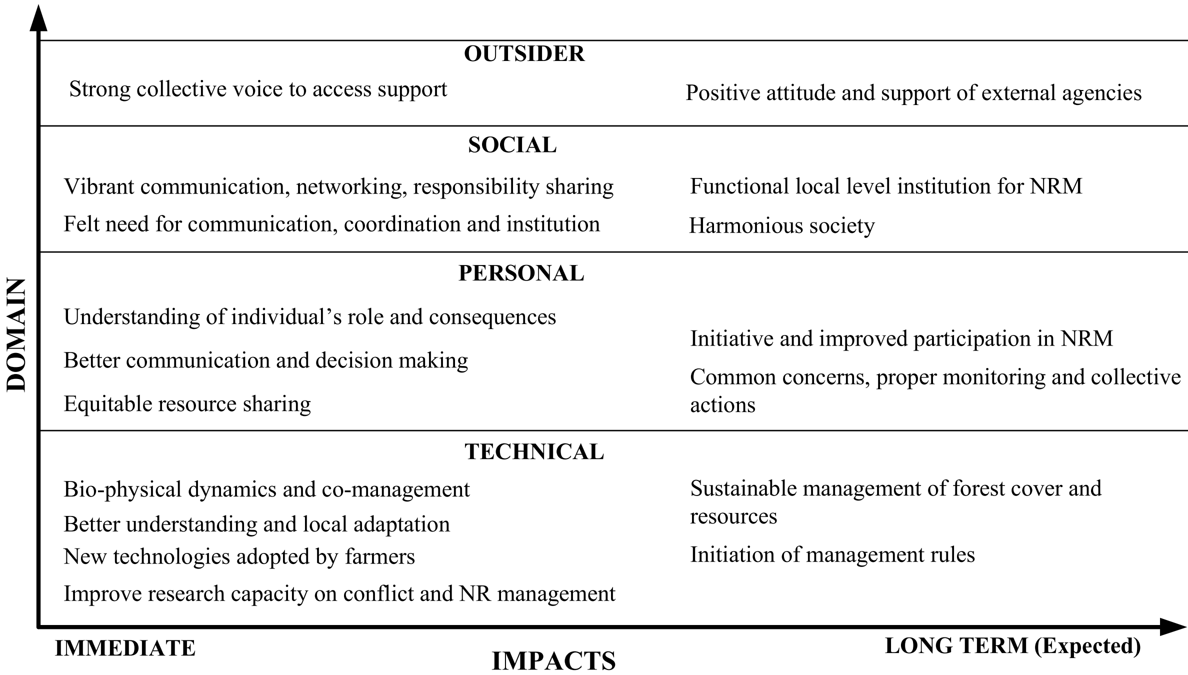


Figure 9.29. Impact domains and impacts of ComMod approach in immediate and long term timeframe in Kengkhar.

Technical domain

In view of the researcher leading the ComMod process in Kengkhar, the immediate impacts in technical domains were the adoption of technological options like water harvesting and tank networking. The understanding of bio-physical dynamics and adaption to local situation, and improvement of research capacity of research and extension staff were immediate impacts which lubricated the process. In the longer term, the development agencies including the Block development office will emphasise constant monitoring and management of the water distribution system.

Individual domain

Although only a small sample of the population was involved in the gaming and simulation exercises, the involvement of the remaining households of the study sites through conceptualization, debriefing workshops, interviews, and model presentation have empowered individuals with information on strategies and their consequences helping them to take appropriate decisions. Farmers acquired improved skills of problem diagnosis and representation, better communication and decision making for equitable resource sharing and networking. With the better individual capacities, it is expected that these individuals will engage in purposeful monitoring and taking collective initiatives to sustain the network of water collection tanks.

Social domain

The tangible immediate impact on social domain is the shared understanding of the NRM issue and vibrant communication and networking in sharing responsibilities to manage the issue. In Kengkhar the spontaneous consent to collectively build the tanks and establish a network for water sharing can have long lasting benefits. The commitment to work together and manage the water resource may promote an harmonious society built on the principle of shared objective and collective responsibility.

External domain

With the involvement of external agencies like research and development agencies in the process, local people gained confidence in consolidating their needs and put collective pressure to access support. The internal cohesion and common goal assured donor support for sustainable impact from the interventions. The Block development committee has used this small intervention as a testimony of the community to work collectively to improve water situation. The positive response on the water collection tanks and their network from the community, has attracted people from other regions to study the system for possible replication.

9.6 Factors influencing the effects and impacts of the process

The factors that influenced the effects and impacts of the ComMod process in Kengkhar are presented in Figure 9.30 with detailed explanation in following sections.

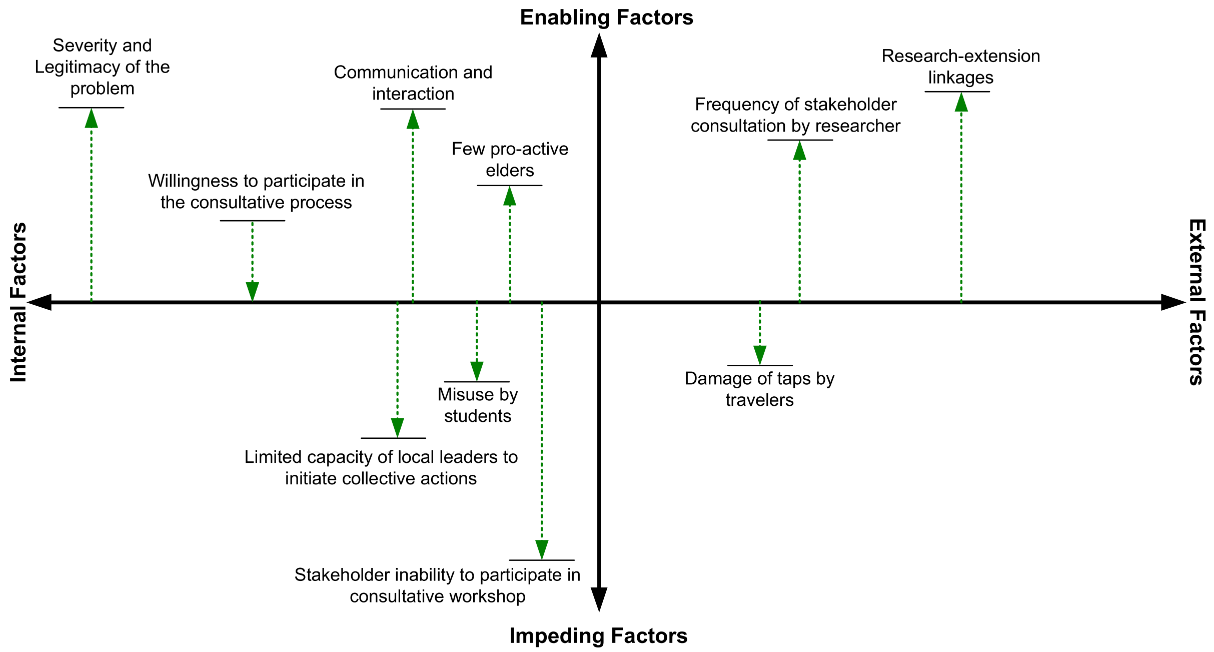


Figure 9.30. Internal and external factors that enable or impede the ComMod process in Kengkhar.

9.6.1 Enabling factors

Here too, the most important enabling factors were the severity and legitimacy of acute water scarcity in Kengkhar. The presence of influential members enabled the process. The existing water sharing systems despite the shortage, that lead to close communication and interactions was the entry point to mobilize the community in collective actions.

In parallel, some of the external factors that facilitated the process were vibrant research-extension linkages which were the main channel of information flow and initiation of collaborative research activities that facilitated the process. The confidence of the community on the institution, particularly agriculture extension, also helped in securing the process and in gaining access to the community. Through the research centre, it was also easier to access support from potential donor agencies to implement collective actions.

9.6.2 Impeding factors

Alongside there were also factors that hindered the ComMod process. Despite the agreement to engage in collective actions, damaging the tap heads and scooping water from the tank by students set back the process. Two of the primary internal factors that hindered the

ComMod process were the inability of all the affected households to participate in the process and the limited capacity of local leaders to follow up the process.

Beside these internal factors, two external factors also partially slowed down the process. In case of Kengkhar the repeated damage of tap heads and tanks by travelers almost became a disincentive to people who invested their time and energy to construct the structure.

The ComMod process positively impacted on the enhancement of water productivity and water security. Although the computer ABM tool was mainly used in the field to test scenarios, its demonstration helped in better understanding of the water tank networking concept and the players who took part in the gaming sessions were quick to conceive and explain its features and operating rules to the non-players. The detailed discussions on the analysis and findings of case studies are presented in the next chapter.

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APPENDICES

Appendix 1. Non-Timber Forest Products widely used in Bhutan.

Plant species used as food from forest

Scientific name	Local name	Parts used	Quantity available	Distribution
Dioscorea spp.	Wild yam (Eng)	Tuber	Abundant	Found in southern Bhutan
Calamus spp.	Cane (Eng)	Shoot	Abundant	Found mostly in cool, moist sub-tropical forests
Girardiana palmata	Nettle Plant (Eng)	Inflorescence	Abundant	Tropical and sub-tropical regions
Adhatoda vasica	Bashaka (Dz)	Flower	Abundant	Tropical and sub-tropical regions
Elatostema spp.	Damroo (Dz)	Stem and leaves	Abundant	Cool, moist sub-tropical regions
Ulva spp.	Algae (Eng)	Whole plant	Abundant	Found on boulders in rivers
Bambusa spp.	So (Sh) Bans (N)	Shoot	Abundant	Tropical regions
Ferns	Nakey (Dz)	New shoots	Abundant	In every district of Bhutan
Bidens spp.	Zumphirobu (Sh)	Leaves	Abundant	Sub-tropical regions
Orchid spp.	Ola-chhoto (Dz)	Flower	Rare	Sub-tropical regions

Note: (B) = Bumthap, (Dz) =Dzongkha, (Eng) = English, (M) = Medical, (N) = Nepali, (Sh) = Sharchop-kha.

Spices in Bhutanese Forests

Botanical name	**Local name**	**Parts used**	**Quantity available**	**Distribution**
Cinnamomum tamala *Cuinnamomum zylanicum*	Tezpata (N)	Leaves	Abundant	All southern districts
Piper nigrum	Pipla (N)	Fruit	Moderate	Sarpang, Samtse and Samdrup Jongkhar
Piper nigrum	Round Pipla	Fruit	Abundant	All southern parts of Bhutan
Myrica negi (small)	Tsutsusey (Sh)	Fruit	Abundant	Temperate zones
Myrica spp. (big)	Omsha tsutsusey (Sh)	Fruit	Abundant	Temperate zones
Rubus eliptica	Sergong (Sh) Ainselu (N)	Fruit	Abundant	Temperate zones
Muraya koenigii	Curry patta (Eng/N)	Leaves	Abundant	Tropical regions
Amaranthes spp.	Zimtsi (Dz) Naam (Sh)	Whole plant	Abundant	Temperate regions
Zanthoxylum alatum	Thingne (Dz)	Fruit	Abundant	Sub-tropical regions
Z. budrunga	Bokey Timbur (N)	Fruit	Fairly abundant	Sub-tropical regions

Note: (Dz) =Dzongkha, (Eng) = English, (M) Medical, = (N) = Nepali, (Sh) = Sharchop-kha.

Fruits in Bhutanese Forests

Scientific name	Local name	Parts used	Quantity available	Distribution
Juglans regia	Tashing (Dz)	Fruit	Abundant	Wangdue, Punakha, Paro, Haa, Chhukha, Mongar, Lhuntshi, Zhemgang, Trashigang, Trashiyangtse and Pemagatshel
Diplocknama butareace	Yika (Dz)	Fruit	Abundant	Rare; Punakha, Wangdue, Mongar, Trashigang, Dagana, Samtse, Sarpang and Samdrup Jongkha
Cornus capitata	Poitsi (Dz)	Fruit	Abundant	Punakha, Wangdue, Trashigang and Mongar
Cornus macrophylla	Poitsi (Dz)	Fruit	Abundant	Punakha, Wangdue, Trashigang and Mongar
Elagnus latifolia	Dangbur (Sh)	Fruit	Abundant	Found only in Montane Zone
Docynia indica	Mel (N)	Fruit	Abundant	Punakha, Wangdue, Trashigang, Zhemgang, Trongsa, Trashiyangtse, Tshirang and Pemagatshel
Aegle marmelos	Bell (N)	Fruit	Moderate	Cultivated in southern Bhutan
Zizyphus spp.	Khankarisey (Sh) Baer (N)	Fruit	Abundant	Samtse, Sarpang, Samdrup Jongkha, Trashigang and Trashiyangtse
Phyllanthes emblica	Chhorengsey (Dz) Amla (N)	Fruit	Abundant	Trashigang, Mongar, Wangdue, Punakha and Trashiyangtse
Eugenea spp.	Nasi or Nyasey (Dz)	Fruit	Fairly abundant	Punakha, Wangdue, Trongsa, Trashigang, Mongar and Lhuntshi
Fragaria spp.	Sagang (Sh)	Fruit	Abundant	Found in all pine forests
Morus spp.	Kimbu (N) Tshadey (Dz)	Fruit	Rare	Found scattered throughout all districts.
Randia spp.	Nertingaey (Sh)	Fruit	Abundant	Found in sub-tropical regions
Eleocarpus varuna	Badrasey (N)	Fruit	Abundant	Sub-tropical regions
Rhus hookeri	Tarsishing (Sh)	Fruit	Abundant	Temperate to sub-tropical alpine climates
Calamus spp.	Tikir (Sh)	Fruit	Abundant	Temperate areas
-	Thakal (N)	Fruit	Rare	Temperate areas
Solanum spp.	Khalanji (Sh)	Fruit	Rare	Tropical and sub tropical regions
Rhus chinensis	Chakashig (Kh)	Fruit	Abundant	Tropical and sub tropical regions
Machilus edulis	Guli (Sh)	Fruit	Abundant	Moist, sub-tropical regions
Spondius spp.	Lapsi (N)	Fruit	Abundant	Sub-tropical regions
Spondius spp.	Amarsey (Sh)	Fruit	Abundant	Sub-tropical regions
Artocarpus spp.	Lathar (N)	Fruit	Rare	Sub-tropical regions
Symplocos paniculata	Pangtshi (Dz)	Fruit	Abundant	Sub-tropical regions
Phyllanthus emblica	Churoo (Dz)	Fruit	Abundant	Sub-tropical regions

Note: (B) = Bumthap, (Dz) =Dzongkha, (Eng) = English, (M) = Medical, (N) = Nepali, (Sh) = Sharchop-kha.

Forest Mushrooms in Bhutan

Scientific name	Commercial name	Local name	Quantity available	Distribution
Auricularia auricula	Jew's ear	Jilli namchu	Common	Temperate regions
Amanita caesarea	Caesar's	Conngsey	Fairly common	
Clavaria spp.		Bjichu kangro	Common	
Clitocybe odora	Green milk	Ga shamu	Fairly common	
Coprinus atramentatius	Ink cap	Ruru shamu	Fairly common	
Clitocybe aggregate		Ga shamu	Fairly common	
Cantherellus cibarius	Chanterelles	Sisishamu	Fairly common	Temperate regions
Clavaria botrytis	Purple coral	Jichu kangru	Common	
Copricus comatus	Ink cap	Ruru shamu	Common	
Fistulina hepatica	Beefsteak	Chimp shamu	Fairly common	
Lycoperdon perlatum	Puff ball	Daybongthe	Common	
Lentinus edodes	Oak	Soke shamu	Common	
Peziza aurantia		Kangchu shamu	Fairly common	
Polyporus sulphureus		Taa shamu	Common	
Polyporus frondosus	Myetake	Taa shamu	Common	
Pleurotus cornucopiae	Oyster	Nakey	Common	
Pleurotus eryngii	Oyster	Nakey	Common	
Pleurotus ostreatus	Oyster	Nakey	Common	
Pleurotus sajor caju	Oyster	Nakey	Common	
Russula cyanoxantha	Green	Damsha	Fairly common	
Russula lepida		Maley sha	Fairly common	
Tremella mesentrica	Golden jelly	Tsili sha	Common	
Tricholoma matsutake	Matsutake	Sangay shamu	Common	Genekha, Ura, Isuna and Betekha (2.5 tons). Exported
Morchella esculenta	Morel	Gep shamu	Rare	Temperate regions
Schizophyllum commune	Split gill	Cinchiring (Sh)	Common	
Volvariella volvacea	Straw	Sorbang Bamu	Rare	Lingmethang; tropical to temperate regions

Source: Project Mushroom, Simtokha.

Natural Vegetable Dyes in Bhutan

Botanical name	Local name	Parts used	Colour of dye obtained	Distribution
Mallotus phillipenensis	Sinduri (N)	Powder of fruit	Red	Found in subtropical areas
Acacia catechu	Khair (N)	Heart-wood	Dark brown	Kalikhola, Samtse and Sarpang
Symplocos ramosissima	Domzim (Dz)	Leaves	Yellow	Available in every district
Symplocos paniculata	Pangtsi (Dz) Zimshing (Sh)	Leaves	Yellow	Found only in patches in western Bhutan
Strobilanthes flaccidifolius	Ram/Tsangja (Dz) Yangshaba (Sh)	Leaves	Blue	Mongar, Trashigang, Pemagatshel, and Trashiyangtse
Lacifer lacca	Jatsho (Dz) Tshos (Sh)	Encrustatio n	Red	Mongar, Trashigang, Pemagatshel and Trashiyangtse
Choenomeles lagenaria	Khomang (Sh) Mentsim (Dz)	Fruit	Mordant	Southern Bhutan, Mongar, Bumthang and Trashiyangtse
Rubia manjit	Choid (Dz) Lanyi roo (Sh)	Whole plants	Red	Trashigang, Mongar, Pemagatshel, Punakha Wangdue, Thimphu and Paro
Rhus chinensis	Bhakimlo (N)	Fruit	Mordant	Tsirang, Sarpang, Manas and Samtse
Holicia nilagirica	Potorshing (Sh) Potala(Dz)	Wood	Yellow	Found in warm, broad-leaved forests
Indigofera spp.	Indigo (Eng)	Leaves	Indigo	Thimphu, Trashigang, Paro and Mongar
Rheum emodi	Chumtsa (M)		Yellow	Alpine
Barberis aristata	Korshuen (M)			Alpine

Gums in Bhutanese Forests

Botanical name	Local name	Parts used	Quantity available	Distribution
Ficus elastica	Brongshig (Sh)	Exude	Rare	Found in tropical forest
Bombax ceiba	Simal (N)	Exude	Abundant	Samtse District. It is also found scattered throughout southern Bhutan.
Acacia catechu	Khair (N) Toeja (Dz) Jasenshing (Sh)	Heart-wood	Abundant	Bukatading, Kalapani and Pugli in Samtse District. It is also found scattered throughout southern Bhutan.
Bauhinia retusa	Semla gum	Exude	Abundant	Found in Samtse, Tsirang, Sarpang and Samdrup Jongkha

Note: (Dz) =Dzongkha, (Eng) = English, (M) Medical, = (N) = Nepali, (Sh) = Sharchop-kha.

Waxes in Bhutanese Forests

Scientific name	Local name	Parts used	Quantity available	Distribution
Apis dorsata	Mouri (N) Wagoma (Sh)	Beehive	-	Found in Tsirang, Genekha and Jimina. Also found in other districts in limited numbers.
Apis apis	Mouri (N) Mizuma (Sh)	Beehive	Moderate	
Apis sp.	Putka (N) Yingburing(Sh)	Beehive	Moderate	Topical and sub-tropical regions.

Note: (Dz) =Dzongkha, (Eng) = English, (M) Medical, = (N) = Nepali, (Sh) = Sharchop-kha.

Forest Plants Used As Incense in Bhutan

Botanical name	Local name	Parts used	Quantity available	Distribution
Juniperus spp.	Shup (Dz) Dhup (N) Shugposhing (Sh)	Whole plant	Abundant	Gasa, Thimphu, Trongsa, Bumthang, Wangdue, Trashigang, Haa, Paro, Lhuntse, Trashiyangtse and Mongar
Nardostachys jatamansi	Pang Poi (Dz)	Roots	In pockets	Alpine region
Rhododendron, anthopogon	Baloo (Dz/Sh) Sunnpatte (N)	Whole plant	Abundant	Alpine region
Cupressus spp.	Tsendenshing (Sh) Dhupi (N) Tsendey (Dz)	Whole plant	Rare; found only in patches	Kukuchhu, Lunana, Dangchhu, and Nobding; found planted in patches
Aquilaria agallocha	Agaroo (Dz) Agur (Sh)	Infected heartwood	Extremely rare	Manas and Phipsoo Game Sanctuaries and Samdrup Jongkha
Cannarium sikkimensis	Poikar (Dz) Poskar (Sh)	Exude	Extremely rare	Sarpey in Samtse, Samdrup Jongkha and Sarpang
Shorea robusta	Sal dhup (N)	Exude	Abundant	Southern low land
Cinnamomum cecidodaphne	Phagpanengshing (Sh) Malagiri (N)	Wood	Abundant	Punakha, Mongar and Samdrup Jongkha
Terminalia bellerica	Baroo (Dz/Sh) Barra (N)	Fruit	Abundant	Abundant in tropical forests

Note: (Dz) =Dzongkha, (Eng) = English, (M) Medical, = (N) = Nepali, (Sh) = Sharchop-kha.

Appendix 2. Quantity and value (US$) of forest products supplied, 2004 to 2008.

		Average of five years (2004 to 2008)	
Commodity	Unit	Volume	Value (US$)
Tree (standing tree)	Numbers	21563	44661
Shinglap (Plank)	Numbers	2374	2475
Cham (Baton)	Numbers	51337	38225
Tsims	Numbers	31482	9209
Dangchung	Numbers	24328	24473
Poles	Numbers	42188	4834
Post	Numbers	35915	4901
Firewood	Cubic Meter	343255	25573
Log forms	Cubic Feet	1040203	260536
Sawn timber	Cubic Feet	16550	1095
Bamboo	Numbers	484506	4171
Stones	Truck Load	50169	34781
Sand	Truck Load	38306	66186
Stone chips	Truck Load	9537	7400
Top Soil	Truck Load	378	302
Billet	Numbers	8347	170
Resin	Kilogram	25578	1739
Cordycep	Kilogram	194	451010
Daphne	Kilogram	6776	92
Lemon grass	Kilogram	3380	254
Leaf mould	Truck Load	253	142
Cane	Bundle	384	36

Appendix 3. Quantity of minerals produced from mines in Bhutan during 2002-2007.

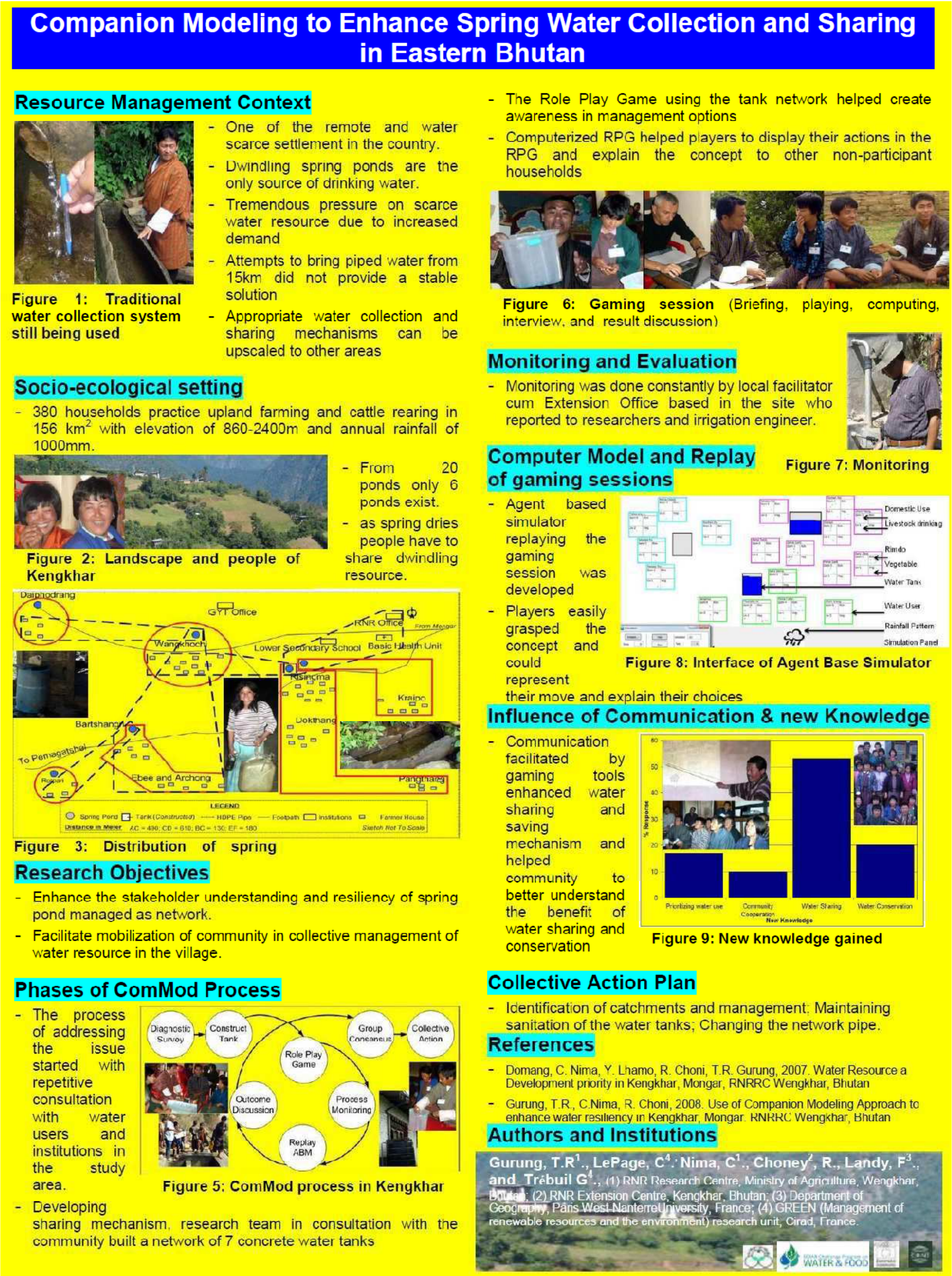
Minerals	Unit	2002	2003	2004	2005	2006	2007
Dolomite	Tons	388,056	367,402	452,336	388,711	388,711	578,552
Gypsum	Tons	105,658	122,829	131,236	150,585	150,585	189,198
Slate	Tons	6,100	57,970	126,789	2,908	2,908	105,261
Coal	Tons	88,567	66,324	29,631	85,279	85,279	12,071
Quartzite	Tons	47,464	52,058	42,599	52,694	52,694	64,049
Talc	Tons	23,118	23,101	39,797	42,791	42,791	62,015
Stone	Tons	319,702	316,068	252,207	146,767	146,767	388,721
Granite	Sq. ft	5,559	11,579	2,152	9,436	9,436	14,430
Lime stone	Sq. ft	506,268	551,525	560,807	536,030	536,030	543,964
Marble	Sq. ft	3,207	6,228	3,385	4,005	4,005	78,107

Source: National Statistical Bureau, 2007 and 2008

Appendix 4. Livestock population in Bhutan, 2008.

Dzongkhags	All Livestock Population (Nos.)										
	Mithun Cattle	Nublang Cattle	Jersey Cattle	Swiss Brown	Other Cattle	Yaks	Horses	Sheep	Goats	Pigs	Poultry
Thimphu	321	2,130	1,162	140	117	9,981	1,057	2	6	100	1,018
Paro	2,030	7,360	4,311	185	21	3,773	1,548	27	111	822	5,217
Ha	1,627	3,939	2,088	74	55	4,652	922	20	72	605	2,611
Chhukha	2,445	17,351	3,457	0	0	0	460	1,091	5,330	2,598	18,471
Samtse	749	33,504	2,394	39	427	0	433	3,556	12,266	1,840	35,925
Punakha	2,259	7,612	2,166	33	0	0	616	8	76	892	4,291
Gasa	288	426	113	158	0	5,694	994	4	4	23	339
Wangdue	4,644	16,004	2,317	505	4	2,753	1,143	2,393	156	1,347	4,982
Tsirang	399	8,487	4,727	44	236	0	243	749	5,588	1,530	23,225
Dagana	1,933	14,690	3,112	0	80	0	445	540	5,036	2,557	18,295
Bumthang	2,229	3,616	1,439	2,671	41	3,197	1,237	467	5	0	534
Trongsa	1,969	6,180	1,505	354	0	138	308	430	2	70	2,000
Zhemgang	6,167	2,945	1,400	42	0	0	1,754	0	46	864	6,074
Sarpang	2,488	18,664	4,023	54	167	0	358	954	3,920	1,264	28,306
Lhuentse	4,732	6,099	1,201	229	17	241	1,426	63	18	229	5,654
Mongar	12,526	8,818	3,972	332	0	0	2,449	40	153	1,231	14,530
Trashigang	9,594	9,779	3,272	112	165	8,780	2,927	1,528	192	1,019	10,444
Trashiyangtse	3,347	5,347	1,694	48	112	400	1,336	39	82	710	1,397
Pemagatshel	2,950	2,975	3,076	55	0	0	1,377	3	37	678	4,968
SamdrupJongkhar	6,403	7,699	2,922	73	26	0	1,268	70	942	565	9,849
Bhutan	68,885	184,014	50,443	5,253	1,476	40,482	22,335	12,116	34,176	18,963	197,766

Appendix 5. Poster on Kengkhar for disseminating the result.



Appendix 6. Abbreviation

ABM	Agent Based Model
ADB	Asian Development Bank
ADC	Austrian Development Corporation
AEZs	Agr-ecological Zones
AMEPP	Agriculture Marketing and Enterprise Promotion Program
amsl	Above mean sea level
ANA	Actor network analysis
ARDI	Actor Resource Dynamic Interactions
BAP	Biodiversity Action Plan
BC	Before Christ
BDFC	Bhutan Development Finance Corporation
BKK	Bangkok
BWP	Bhutan Water Partnership
CBNRM	Community Based Natural Resource Management
CGIAR	Consultative Group on International Agriculture Research
CHPP	Chukha Hydro Power Project
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement
ComMod	Companion Modelling
CORMAS	Common-Pool Resource and Multi-Agent Systems
CoRRB	Council for RNR Research of Bhutan
CPR	Common property resource
cRPG	Computerized Role playing game
DGPC	Druk Green Power Corporation
DoA	Department of Agriculture
DOF	Department of Forest
DoFPS	Department of Forests and Park Services
DYT	Dzongkhag Yargey Tshogdey
FAO	Food and Agriculture Organization
FEZAP	First Eastern Zonal Agriculture Project
FNCA	Forest and Nature Conservation Act
FNCR	Forest and Nature Conservation Rules
FYM	Farmyard manure
GCWC	Global Committee for the Water Contract
GDP	Gross domestic product
GIS	Geographic information system
GLOF	Glacial lake outburst flood
GNHC	Gross National Happiness Commission
GREEN	Management of renewable resources and environment research unit at CIRAD

GRF	Government reserved forest
GWP	Global water partnership
GYT	Geog yargey tshogdey
Ha	Hectare
HDPE	High density polyethylene
HEP	Hydro-electric project
HH	Household
HPP	Hydro power project
ICIMOD	International Centre for Integrated Mountain Development
ICWE	International Conference on Water and the Environmen
IFAD	International Fund for Agriculture Development
IHDP	Integrated Horticulture Development Project
IMT	Irrigation management transfer
INRM	Integrated Natural Resource Management
IPE	Impact pathway evaluation
IR	International Rice
ISNAR	International Service for National Agriculture Research
IWM	Integrated water management
IWMI	International Water Management Institute
IWRM	Integrated Water Resource Management
Km	Kilometer
kW	Kilowatt
Ls	Liters
M	Meter
MAP	Medicinal and Aromatic Plants
MAS	Multi-Agent Systems
mamsl	Meter above mean sea level
MoA	Ministry of Agriculture
MoAF	Ministry of Agriculture and Forest
MOH	Ministry of Health
MoTIF	Ministry of Trade, Industry and Forest
MSC	Most Significant Change
MSP	Multi-stakeholder platform
MT	Metric ton
MU	Million Unit
MW	Mega Watt
NCD	Nature Conservation Division
NEC	National Environment Commission
NIP	National Irrigation Policy
NR	Natural resource
NRM	Natural resource management

NRTI	Natural Resources Training Institute
NSB	National Statistical Bureau
NTFP	Non-timber forest products
Nu	Ngultrum
OCC	Office of the Census Commissioner
ODD	Overview Design Detail
PCS	Planning Commission Secretariat
PIM	Participatory irrigation management
PPD	Policy and Planning Division
RBC	
RGOB	Royal Government of Bhutan
RNR	Renewable Natural Resource
RNRRC	Renewable Natural Resources Research Centre
RPG	Role-playing Game
RSPN	Royal Society for Preservation of Nature
RWSS	Rural water supply scheme
SES	Social-ecological systems
SEZAP	Second eastern zonal agricultural project
Sq Km	Square kilometre
t/ha	Ton per hectare
THPP	Tala hydroelectric power project
TRG	Training
UML	Unified modelling language
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Program
UNEP	United Nations Environment Programme
UNICEF	United Nations
WHO	World Health Organization
WMC	Watershed management committee
WRI	World Resource Institute
WUA	Water Users Association
WWC	World Water Council
WWF	World Wildlife Fund

Appendix 7. Map of Bhutan showing places referred in the text.

Appendix 8. List of publications.

Peer-reviewed Journal articles

Gurung, T.R, F. Bousquet, G, Trébuil, 2006. Companion modelling, conflict resolution, and Institution building: sharing irrigation water in the Lingmuteychu watershed, Bhutan. Ecology and Society Vol. 11, No2, Art 36. Ralph Yorque Memorial Prize of this journal for 2006.

Other Journal articles

Bousquet, F., **T.R.Gurung**, G.Trébuil, 2005. The Game of Life – A fresh approach to the challenge of sharing agricultural resources has rice farmers playing games with scientists. Rice Today, IRRI, Philippines.

Conference proceedings/Reports

Gurung, T.R., Promburom, P., Naivinit W., Thongnoi, M., Barnaud, C. and Trébuil G. 2008. Effects of companion modeling on water management: comparative analysis across five sites in Bhutan and Thailand. Proceedings of Second International Forum on Water and Food (IFWF2), CPWF-CGRAI, 16-18 November 2008. Addis Ababa, Ethiopia.

Hoanh, C. T., Le Page C., Barreteau O., Trébuil G., Bousquet F., Cernesson F., Barnaud C., **Gurung, T. R.,** Promburom P., Naivinit W., Dung L. C., Dumrongrojwatthana P. and Thongnoi, M. 2008. Agent-based modeling to facilitate resilient water management in Southeast and South Asia. Proceedings of the Second International Forum on Water and Food (IFWF2), CPWF-CGRAI, 16-18 November 2008.p.4. Addis Ababa, Ethiopia.

Barnaud, C., P. Promburom, **T.R.Gurung,** C.L.Page, G.Trébuil., 2006. Companion Modeling for collective learning and action in water management: lessons learnt from three case studies in northern Thailand and Bhutan. Presented in International Symposium towards sustainable livelihood and ecosystems in mountain regions, Chiang mai, Thailand, 7-9 March 2006

Posters

Gurung, T.R., Ekasingh, B., Ekasingh, M., Bousquet, B., and Trébuil, G. 2004. Companion modeling to improve irrigation water sharing among rice growers in west-central Bhutan.

Gurung, T.R., Le Page, C., Dorji, L., Choney, R., and Trébuil, G. 2010. Companion modeling to facilitate understanding of grazing land conflict in Sheythimi, Radi, Eastern Bhutan.

Gurung, T.R., Le Page, C., Dorji, L., Nime, C., Choney, R., Landy, F., and Trébuil, G. 2010. Companion modeling to enhance spring water collection and sharing in Eastern Bhutan.

COMPARATIVE ANALYSIS OF USING COMPANION MODELLING TO FACILITATE ADAPTIVE MANAGEMENT OF AGRICULTURAL WATER IN BHUTAN

ABSTRACT

The customary regime of NRM in Bhutan faces greater challenges from economic development, rapid transformation of social values, local institutions and traditional perceptions on NR. Although Bhutan is projected rich in water resource for hydropower potentials, water for agriculture and domestic use is fast becoming scarcer and highly contested. As the water becomes scarce the people living in highlands are most severely affected. A detail diagnostic study of two communities, Lingmuteychu dependent on irrigated rice and Kengkhar dependent on dryland farming presents two situations of water resource issues. In Lingmuteychu the conflict of irrigation water sharing for cultivation of rice among seven villages has been inflicting resentment in all aspect of society. In contrary, in Kengkhar has been facing drinking water scarcity as the natural spring ponds dry, which forces people to walk for more than five hours to fetch water from the river. In these two sites Companion Modelling was applied to enhance understanding of water resource management dynamics and improve shared communication and learning to facilitate adaptive management strategies. The study provides a comparison of the process followed in two sites with analysis of impacts and effects from the process. The research illustrates how ComMod process helped to develop trust and commitment in the conflicting community and pave pathways to develop social capital for adaptive management of water resource. The process was able to foster shared learning and co-construct collective actions which were implementable. The research also revealed the important role of the researchers in furthering and sustaining newly achieved cooperation. The ABMs provided an opportunity to re-create different water resource management strategies which could be used as options for the community. The research also demonstrates the feasibility of applying the ComMod approach in different field of NRM.

Key words

Companion modelling, multi-agent systems, water resources, social capital, conflict resolution, Natural resource management, Bhutan.

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