USE OF MULTI-AGENT SYSTEM TO IMPROVE IRRIGATION WATER SHARING IN LINGMUTEYCHU WATERSHED, BHUTAN

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MASTER OF SCIENCE

(AGRICULTURE)

IN AGRICULTURAL SYSTEMS

GRADUATE SCHOOL

CHIANG MAI UNIVERSITY

APRIL 2004

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A THESIS SUBMITTED TO THE GRADUATE SCHOOL IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS
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Acknowledgements

First let me take this opportunity to sincerely thank all the teaching and non-teaching staff of Multiple Cropping Center, Faculty of Agriculture, Chiang Mai University for extending their support during my two years of stay in Chiang Mai.

I would like to express my sincere gratitude to Dr. Benchaphun Ekasingh, my Thesis Advisor, Dr. Methi Ekasingh, Thesis Committee member and Dr. Chanchai Saengchyoswat, Academic Advisor for their constant guidance and timely advice. I should especially thank my Thesis Advisor for introducing me to the new research methodology and supporting my participation in trainings on MAS.

Dr. François Bousquet, Thesis committee who tirelessly helped me to build the model. I would like to sincerely express my gratitude and appreciation for his effort to make me understand CORMAS and build the model. I would also like to sincerely express my gratitude for his moral, professional and financial support and encouragement provided to me in learning Companion Modeling through series of trainings I attended. Dr. Guy Trébuil, External Examiner, I would like to sincerely express my gratitude for your moral and professional support and encouragement provided. I extremely appreciate your critical comments and untiring efforts in making me understand and improve my research capacity. I will vividly remember all those educative discussions and motivating words that kept me going.

I would also like to express my gratitude to Ministry of Agriculture, Royal Government of Bhutan for allowing me to pursue my study in Thailand. My personal appreciation to Dr. Pema Gyamtsho, the then Deputy Secretary, PPD, Ministry of Agriculture and Dr. Pema Choephyel, Director, Council of Research and Extension, without whose support I would not have availed this scholarship. My sincere deepest appreciation goes to the Department of Technical and Economic Cooperation (DTEC), Thailand for providing financial support to undertake this study.

For all the support, care and guidance, I would like to express my sincere appreciation to Acharn Phrek. I would also like to express my appreciation to Khun Om for her consistent support and finding time to help all the students even when she was sick. To all my AGS friends, thank you, it has been a great pleasure to have companions like you all.

With regard to my field work, I would like to express my sincere gratitude to Sangey Duba, Program Director, RNRRC, Thinlay Gyamtsho; Aita Bhujyel; Karma Tshewang, DAO, Punakha and his staff Gyembo and Yeshi Lhamo for their support, without which it would have been difficult to conduct the field work so efficiently. To all the farmers and GYT members who tirelessly participated in Role-playing game in Dompola, I would like to express my appreciation. There are yet many more who extended their help to me along the way in past two years both personal and professional, to all of them I extend my sincere appreciation.

To my loving mother, I take this opportunity to dedicate this thesis to her for the love, care and blessings she has bestowed on me. I would not have completed my study as smoothly as I could, if my wife would not have taken all the trouble to manage our home and children single handedly. To my wife, Hari M Gurung (Ami) and sons Rihan and Nayat, let me take this opportunity to earnestly express my gratitude for being so considerate and constantly providing me the much needed moral support and encouragement. Without their support I would not have made it.

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Thesis Title Use of Multi-Agent System to Improve Irrigation Water Sharing in Lingmuteychu Watershed, Bhutan.

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Abstract

Finding a way forward in a conflict situation in natural resource management and achieving coherent strategy among communities, particularly when the rules are rooted in the traditions and dwindling natural resources, is a challenging task. The situation is particularly difficult, when local norms favor certain section of the community there are always reservations to compromise and share resources adequately. The two upstream villages of Lingmuteychu watershed in west-central part of Bhutan are experiencing this conflict situation.

This research used role-playing game (RPG) and multi-agents systems (MAS) modeling to understand decision-making process in irrigation water sharing, impacts of such decisions on resource dynamics, and finally to help improve communication between two communities to improve irrigation water sharing. The study also used the principles of agriculture production systems analysis to characterize and diagnose the watershed and farming systems.

In Dompola village, two sessions of RPG were organized in May and December 2003. Six farmers each from Limbukha and Dompola played both game sessions. The 3 scenarios used in RPG represented three mode of communication: intra-village mode of communication, inter-village communication, and swapped

roles. RPG was capable to initiate the interactive process of discussion between two villages. The research demonstrated that RPG was capable to create a non-confrontational and non-threatening environment for farmers to participate in the game. It allowed players to be an integral part of the gaming process and thus motivated them to collectively learn and evolve new rules of the game. The involvement of Block development committee as observers in the RPG also helped in legitimizing the output of the RPG. The analysis of the role-playing game indicated that inter-village mode of communication was more efficient in resource sharing and land use. On completion of second session of game, around 90% of the players realized the importance and need of managing and sharing irrigation water. This increment in shared knowledge is considered as the critical impact made by role-playing games.

Following the two sessions of role games, Common-pool resources and Multi-agents systems (CORMAS) platform was used in developing Limbukha model to facilitate integration of knowledge for better understanding of interaction among agents and the effect of decision process on resource use dynamics. The base model was found to be consistent to the output of RPG. A combination of three parameters: 3 social networks, 6 exchange protocols, and 2 rainfall patterns were used to generate 36 scenarios. The simulation results consistently indicated that network allowing communication between two villages was comparatively better in terms of resource use and income. The efficient protocol was the one where agents could give water to kin, exchange water against labor or cash, and labor against water. Maximum agent interaction for water was observed in kinship network, while exchange of labor for water generated maximum interactions among agents.

The study concludes that RPG and MAS can be an efficient combination of tools to mobilize communities to enhance their shared knowledge and facilitate knowledge-based decision-making in natural resource management.

ชื่อเรื่องวิทยานิพนธ์	การใช้ระบบมัลติเอเจนต์เพื่อปรับปรุงการแบ่งปันน้ำชลประทานในลุ่มน้ำลิงมูเตชู ภูฐาน
ผู้เขียน	นายทายัน ราท กุรัง
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บทคัดย่อ

การแก้ปัญหาความขัดแย้งในชุมชนในการจัดการทรัพยากรธรรมชาติ ยังคงเป็นสถานการณ์ที่ท้าทาย และยังคงต้องพยายามแก้ไขกันต่อไป โดยเฉพาะเมื่อมีการตั้งกฎเกณฑ์ที่สอดคล้องกับประเพณีดั้งเดิมมาใช้บังคับ ท่ามกลางความร่อยหรอของทรัพยากรธรรมชาติในระบบนิเวศ สถานการณ์ยิ่งลำบากมากขึ้น เมื่อการตั้งกฎเกณฑ์เหล่านี้เป็นที่นิยมใช้ภายในชุมชนมากขึ้น เพื่อประนีประนอมในเรื่องของการอนุรักษ์ทรัพยากรธรรมชาติ และการใช้ทรัพยากรร่วมกัน ซึ่งสองหมู่บ้านในเขตต้นน้ำลิงมูเตชูทางด้านตะวันออกกลางของประเทศภูฐานในขณะนี้กำลังประสบกับสถานการณ์ความขัดแย้งนี้

การวิจัยครั้งนี้ได้ใช้การเล่นบทบาทสมมุติร่วมกับแบบจำลองระบบมัลติเอเจนต์ เพื่อให้เข้าใจกระบวนการตัดสินใจในการแบ่งปันการใช้น้ำชลประทาน และผลที่ได้รับต่อพลวัตรของทรัพยากร ผลจากการศึกษาจะช่วยปรับปรุงให้การเจรจาเพื่อปรับปรุงการใช้น้ำชลประทานร่วมกันระหว่างสองชุมชนนี้เป็นไปด้วยดี นอกจากนี้การศึกษาครั้งนี้ยังใช้หลักการของการวิเคราะห์ระบบการผลิตทางการเกษตรเพื่อแบ่งลักษณะและวินิจฉัยระบบการทำการเกษตรในพื้นที่ลุ่มน้ำนี้

ในหมู่บ้านคอมโพลา ได้มีการจัดทำการเล่นบทบาทสมมุติขึ้นสองครั้งในเดือนพฤษภาคมและเดือนธันวาคม ปี ค.ศ. 2003 โดยมีเกษตรกรจากหมู่บ้านลิมบูก้า และหมู่บ้านคอมโพลา หมู่บ้าน

ละ 6 คนเข้าร่วมเล่นด้วย การสร้างสถานการณ์จำลองเพื่อใช้ในการเล่นบทบาทสมมุติ เพื่อใช้เป็นตัวแทนของการติดต่อสื่อสาร 3 รูปแบบ คือ การสื่อสารภายในหมู่บ้าน การสื่อสารระหว่างหมู่บ้าน และบทบาทในการแลกเปลี่ยนข้อมูลข่าวสาร การเล่นบทบาทสมมุติ สามารถทำให้เกิดเริ่มต้นอภิปรายกระบวนการปฏิสัมพันธ์ของสองหมู่บ้าน การวิจัยครั้งนี้ยังได้แสดงให้เห็นว่า การให้เกษตรกรเข้าร่วมการเล่นบทบาทสมมุติทำให้ไม่เกิดการเผชิญหน้าและไม่เกิดการบุกรุกทำลายสิ่งแวดล้อม ซึ่งการเล่นนี้จะรวมผู้เล่นเข้าเป็นกระบวนการหนึ่งของบทบาทสมมุติ และจูงใจให้ผู้เล่นเกิดการเรียนรู้ร่วมกัน และร่วมกันเปลี่ยนแปลงกฎเกณฑ์ภายในบทบาทสมมุติอย่างค่อยเป็นค่อยไป หน่วยงานที่เกี่ยวข้องกับการพัฒนาจะได้เข้ามาสังเกตการณ์ในการเล่นบทบาทสมมุติและช่วยกันสรุปผลลัพธ์ของการเล่นบทบาทสมมุติ ผลการวิเคราะห์จากการเล่นบทบาทสมมุติได้ชี้ให้เห็นว่า รูปแบบการสื่อสารภายในหมู่บ้านจะก่อให้เกิดประสิทธิภาพในการใช้ทรัพยากรร่วมกันและการใช้ประโยชน์จากที่ดิน ในการเล่นบทบาทสมมุติครั้งที่สอง ผู้เล่นประมาณ 90% ได้ตระหนักถึงความสำคัญและความจำเป็นในการจัดการการใช้น้ำชลประทานร่วมกัน ผลที่ได้รับหลังจากที่มีการเล่นบทบาทสมมุติคือ มีการแลกเปลี่ยนความรู้และข้อมูลข่าวสารกันมากขึ้น

จากการเล่นบทบาทสมมุติทั้งสองครั้ง ทำให้ทรัพยากรชุมชนและระบบมัลติเอเจนต์เพื่อการจัดการทรัพยากรร่วม (CORMAS) ถูกนำไปใช้ในแบบจำลองการพัฒนาลุ่มน้ำลิงมูเตชูเพื่อสะดวกในการรวบรวมองค์ความรู้และเข้าใจปฏิสัมพันธ์ระหว่างองค์กรและผลกระทบของกระบวนการตัดสินใจภายใต้พลวัตของการใช้ทรัพยากรได้ดีขึ้น ในแบบจำลองพื้นฐานพบว่ามีความสอดคล้องกับผลที่ได้รับจากการเล่นบทบาทสมมุติ ปัจจัยทั้ง 3 ตัว ได้แก่ เครือข่ายสังคม การแลกเปลี่ยนข้อตกลง และรูปแบบการตกของฝน จะถูกนำมาใช้เพื่อสร้างสถานการณ์จำลองจำนวน 36 สถาน-การณ์ ความสอดคล้องของผลที่ได้จากแบบจำลองชี้ให้เห็นว่า เครือข่ายทางสังคมจะช่วยให้การสื่อสารระหว่างสองหมู่บ้านมีการใช้ทรัพยากรและรายได้ดีขึ้นโดยเปรียบเทียบ ประสิทธิภาพของข้อตกลงเป็นอีกสิ่งหนึ่งที่ทำให้องค์กรสามารถให้น้ำแก่เครือญาติได้ โดยการเปลี่ยนน้ำเป็นแรงงานหรือเงินสด และเปลี่ยนแรงงานเป็นน้ำ การแลกเปลี่ยนในรูปแบบน้ำพบมากที่สุดในปฏิสัมพันธ์ระบบเครือญาติ ในขณะที่การแลกเปลี่ยนในรูปแบบแรงงานพบมากที่สุดในปฏิสัมพันธ์ระหว่างองค์กร

จากการศึกษาครั้งนี้สรุปได้ว่า การเล่นบทบาทสมมุติและระบบมัลติเอเจนต์ เป็นเครื่องมือที่ผลักดันให้ชุมชนเกิดการแลกเปลี่ยนความรู้และเอื้อต่อการใช้องค์ความรู้เป็นพื้นฐานของการตัดสินใจในการจัดการทรัพยากรธรรมชาติได้อย่างมีประสิทธิภาพ

Table of Contents

List of Tables

List of Figures

Chapter I

Introduction

1.1 Background

Bhutan is a small mountainous country in the eastern Himalayas, located between latitudes 26°45' N and 28°10' N and between longitudes 88°45' E and 92°10' E. The land rises from approximately 300 masl in the south to gigantic snow clad Himalayan mountains in the north of over 7000 masl covering a total area of 46,500 square kilometers. Physically, the country can be divided into three main landforms: the southern foothills, the inner Himalayas and the higher Himalayas (Central Statistical Organization, 2001). The country is drained by four major river systems (the Ammochu, the Wangchu, the Sankosh, and the Manas) rising from higher Himalayas and meandering down south through winding open valleys where people settle and do farming.

The country's economy is predominantly agrarian-based with 79% of the population dependent on small-scale mountain agriculture and livestock rearing for their livelihood. The primary sectors (agriculture, forest and livestock) contribute 35.39% to the GDP (Ministry of Agriculture, 2003). Bhutan has maintained 72% forest cover, rich biodiversity and plentiful water resources (Ministry of Agriculture, 1999). Mountainous terrain restricts agriculture only to 7.8% of the total area (Ministry of Agriculture, 2002a). The water from above mentioned rivers cannot be used for agriculture as they flow in deep gorges. As such seasonal streams form a principal source of irrigation water. The forest represents precious pool of natural resources for the people. The use of forest resource is an essential component of the livelihood system and is intricately woven into the Bhutanese culture (Ministry of Agriculture, 2002b).

In view of the fact that planned development started in 1961, the Royal Government under the dynamic and noble leadership, has always pursued people centered and bottom up planning approach to development (Planning Commission Secretariat, 1993). Despite the limitations of physical and socio-economic situation, Bhutan emerged into the 21st century with an intact natural resource base and strong commitment to maintain it for future generations. This foundation has been possible only with the harmonious relationship between people and the environment, forged over centuries within moral, cultural and ecological boundaries (National Environment Commission, 1998). However, the rapid socio-economic development, commercialization and globalization could become a source of risk to destroy this pristine environment and harmonious relationship.

1.2 Common pool resources (CPRs)

As mentioned above, the dependence of Bhutanese society on natural resources is very high. Table 1 presents an overview of some of the common pool resources (CPRs) and quantities harvested in 2000. CPRs such as water, wood, fodder, and non-timber forest products are regularly used directly to increase productivity through transfer of organic matter, generate income, provide shelter, sustain farming systems through nutrient recycling (Sokshing system), energy to households, and effectively supplementing privately owned resources. As such, CPRs are an important component of household and community livelihood systems.

In Bhutan, the traditional norms and ingrained relationship among users constitute a broadly respected customary regime of natural resource management (NRM), which has resulted from appreciation for the value of natural resources and recognition of their dependence on these resources. One of the natural resources that are being principally managed by traditional institutions and norms is water (Litmus Consult, 2003; Ministry of Agriculture, 2002b). However, over the years the role and efficiency of these local norms and arrangements have weakened due to the influences of economic development, commercialization, and westernization through globalization.

Table 1. Annual harvest of CPRs (wood and non-wood forest products) in Bhutan, 2000.

CPR products	Unit	Volume
Firewood	('000) cft.	25,881
Bamboo	('000) Bundles	294
Fodder	('000) Bundles	4,753
Fern tops	('000) Bundles	441
Wild mushroom	ton	96
Cane shoot	ton	5
Edible oilseed	ton	150
Lemon grass	ton	102
Dyes	ton	19
Pipla (*Piper sp.*)[1]	ton	6
Resin	ton	72
Chirata (*Swertia chirata*) [1]	ton	2

(Source: Ministry of Agriculture, 2002a).

[1] Medicinal plant

A nationwide renewable natural resources census indicated that among 60,000 farmers interviewed, 20% reported a lack of irrigation water as a major constraint to agricultural production, second only to crop predation by wild animals (42%) (Ministry of Agriculture, 2002a). The shortage of water coupled with inequitable access among users cause conflict in many communities. With increasing demand and competition for water, frequent confrontation and abuse of resources have become a major concern (Renewable Natural Resources Research Center, 1998). Such conflicts can become severe and debilitating, resulting in violence, resource degradation, the undermining of livelihoods, and the uprooting of communities. According to Castro and Nielsen (2001), if such conflicts are left unattended, they may become causes for a breakdown in social institutions and even threaten society itself.

The ratification of the Forest Act in 1969, and Forest and Nature conservation Act of 1995, showed that Bhutan was already concerned about NRM problems. These two Acts put the government in full control over forest resources, including water bodies. The centralization of forest resource management in 1969 took away the responsibility from people to manage forest resources. Over the years, following this disassociation from forest management, many of the indigenous knowledge systems and community-based regimes for natural resource management disappeared, as communities lost their customary rights and control over local forest resources (Gurung and Turkelboom, 2000; Messerschmidt et al., 2001; and Tshering, 2001). This has brought about an "open access" regime, as adequate administrative structure and resources were not in place to effectively and efficiently enforce the forest regulations (Ministry of Agriculture, 2002b). All natural resources within the bounds of forest area are considered to be under the purview of the Forest Act 1969. However, the specificity of the rules varies among the resources and in particular there is no specific policy and law concerning water resources. The water policy currently being formulated by Ministry of Agriculture is expected to address the policy, legal, and organizational framework for the fair sharing of water resources, and for effective participation, partnerships, and cooperation of stakeholders, as well as conflict avoidance (Bhutan Water Partnership, 2003). In the context of the people-centered development approach initiated by the government, Bhutan's nationalized forest management system has reoriented itself to provide people with incentives for sustainable management of forest (Dorji and Webb, 2001).

According to the decentralization policy, beneficiary participation is the primary driving force for development (Planning Commission Secretariat 1993). Further, with the ratification of Dzongkhag Yargey Tshogtshung (*District Development Committee* (DYT)) and Geog Yargey Tshogtshung (*Block Development Committee* (GYT)) governance acts, the responsibility for managing natural resources has been passed on to the communities and local institutions (Planning Commission Secretariat, 2002; Ministry of Home Affairs, 2002; and Royal Government of Bhutan, 2003a). This is specifically the devolution of decision making to the lowest level (Röling, 1999). To complement and support the devolution of NRM responsibilities, the Ministry of Agriculture formulated and released framework for community-based natural resource management in 2002 (Ministry of Agriculture, 2002b).

This brief statement of general development policies in Bhutan presents the rapidity at which changes are taking place. It is fortunate that the Royal Government has always kept strict vigilance on the process and impact of development. However, it is no time to be complacent on the progress, rather strive to find approaches to ensure harmony between society and natural resources.

1.3 Rationale

Water is a critical input in agricultural production especially in rice farming. In the present day, it has become a highly contested natural resource in Bhutan. Almost all irrigation schemes in Bhutan have been built by farmers, and are still largely managed by them (Brand and Jamtsho, 2002). These schemes are managed based on traditional water sharing systems which were framed when water was plenty and user very few. The users have diversified, command areas have increased by expansion of rice cultivation, catchment areas have shrunk due to deforestation, and demand for water has increased by many folds. The government took the initiative to rehabilitate and construct small irrigation schemes, but ensured that beneficiaries were still responsible for their operation and maintenance. In 1993, the Ministry of Agriculture introduced the National Irrigation Policy, which explicitly emphasized on a sustainable approach to irrigation development through participation of users. Much of these past interventions were driven by the assumption that irrigation systems performances were not at an acceptable level. The cause of poor performance of irrigation systems have often been largely linked to issues ranging from inadequate design and management at the farm level to inefficient upstream supply facilities, or the lack of commitment to the success of the system by users (Walker, 1989; FAO 1996). Such poor performance is always a limitation to harness full benefit from the limited resource and the investment (Chamber 1989; Satranaryana and Srivastava 1989). As Peri and Skogerboe (1979) suggested, poor performance could lead to lower crop yields per unit area and lower yield per unit of water used as well as a lower total irrigated area, lower return from irrigated crop, and bring in negative environmental effects.

In a continuously changing environment as an outcome of the system dynamics, emergent changes often lead to competition and conflict. These conflicts will escalate and increasingly surface in a society midst these changes. The scope and magnitude of change in resource management regimes and the societies of which they are part will only increase and incapacitate the development process by ripping off the community. In such a complex situation, decisions about the use of natural resources should be invariably based on interactions among stakeholders/users and their environment. More so, the exchanges of information on resource status, demand, use systems, socio-economic, and biophysical interactions should help in making such decisions.

The complexity of NRM, coordination, networking, and negotiation raises methodological questions. In the decentralized management setting, there is a need for tools to stimulate joint learning and integrating knowledge to establish shared understanding and coordination mechanisms in the context of multiple resource users and their conflicting relationships. Changes in resource use are considered to emerge from human learning, interactions and institutions (Röling, 1999), which often require considerable attention to create a common perspective of problems, diagnosis and possible solutions. As behaviour of stakeholders is determined by the goal and environment, modelling can form a stimulus-response framework, which can help in studying the system and its emergence. According to Holling (1978), integration of simulation models into collective decision-making in natural resource management (NRM) is one of the core points of adaptive management. Considering the complexity of the NRM issue, where stakeholder behaviour, actions and interactions determine much of the processes, any simulation models should have a capacity to capture the interactions through participatory means.

Since 1996, role-playing games (RPG) and multi-agents systems (MAS) platform have been used to study local land use management, water management, negotiation between foresters and breeders, and preservation of wild genetic resources by peasants (D'Aquino et al., 2002a). Among many modelling tools, multi-agent systems are increasingly used in the field of environmental and natural resource management (Barreteau et al., 2004; and Bousquet et al., 2002). MAS principally emphasize on interaction between agents and emergence from the interactions that makes it different from classical systems approaches (Ferber, 1999). Similar to any abstract representation, MAS has been used to increase scientific knowledge about ecological and social processes (Bousquet et al., 1999). MAS models can be used for collective decision making as an outcome of interactions between agents who have differential objectives and strategies. Significant advances have been recently made in simulation of social interactions with environment to address complex interactions. Among many such innovative tools, MAS have been extensively tested in many countries as suitable tools for collective learning in NRM (Bousquet et al., 1998; Trébuil et al., 2000; Barreteau et al., 2001; Trébuil et al., 2002; D'Aquino et al., 2002b; Janssen, 2002; Etienne, 2003; and Purnomo et al., 2003). Role-playing game (RPG) is yet another interactive and participatory tool which is used in conjunction with MAS. It is often used to simplify the outputs of MAS modeling with a view to produce typology of management strategies, negotiation methods and to provide a teaching aid. It can also be used to understand the systems dynamics and generate information to design MAS model (Bousquet et al., 2002).

RPG and MAS have been used extensively to understand the management of irrigation water. The three steps together are termed as "companion modeling" (Bousquet et al., 2002). The support process, involving both tools simultaneously, is as follows:

1. Stakeholders are identified, as well as their perceptions of the environment.
2. Stakeholders are involved in RPG to validate hypotheses.
3. Finally, simulations are run to show the systems dynamics generated by interactions between agents and the environment.

In view of the multiplicity of users and prevailing conflicts in irrigation water sharing, companion modelling based on the association of RPG and agent based model can be a potential tool to collectively learn the state of affairs among concerned stakeholders (including researchers) and explore potential interactions to identify more acceptable alternative strategies to resource use. Therefore, the key research question is: Can the companion modeling (ComMod) approach based on the association of RPG and simple MAS simulation facilitate:

- The understanding of farmers' decision-making processes in sharing irrigation water?, and
- The mediation of the conflict among water users in the Bhutanese context?

1.4 Objectives

The objectives of the study are as follows:

1. To understand decision-making process in sharing irrigation water by farmers at household and community level.
2. To generate scenarios with users to assess impacts of their decision on water and land use.
3. To apply MAS to improve communication mechanism in irrigation water sharing.

1.5 Scope of the study

This study focuses on collective understanding process of sharing irrigation water and its impacts on the land use changes and water use in Lingmuteychu watershed. The understanding gained from the research can be simulated to improve communication for NRM among stakeholders. If successful, the approach can be replicated in management of other common property resources in Bhutanese condition.

Chapter II

Literature review

"The paradox of any serious discussion about water is how this watery planet has increasingly become one in which there is water scarcity. Some suggest that it's not a question of scarcity but one of allocation, supply, and management. Others say it's our collective will in solving water problems that is lacking rather than the water itself. Yet some believe that water scarcity has been driven by greed."

- McDonald and Jehl (2003)

The above quote is a pertinent remark that suits to introduce this review. The review is organized into conflicts in water, institutions, participatory approaches, and use of RPG and MAS as tools to understand the issues of water sharing in Lingmuteychu watershed.

2.1 Conflicts in water use and management

Human relation theorists stipulate that conflict is a natural phenomenon, inevitable and it should be managed as it is (Reynecke, 1997, cited in Slabbert, 2004). Similarly conflict over water has become global and is further intensifying with the pressure from forces of economics development (Ostrom, 1990). It is also evident from growing number of challenges in relation to water use faced by professionals and policy makers (Coloumb, 2002). Conflict over water occurs at different scales ranging from the farm to the community and at the international level (Van Veen et al., 2003). For the purpose of this study conflict can be defined as "any relationship between opposing forces whether marked by violence or not" (Deloges and Gauthier, 1997).

Conflicts often arise when different categories of individuals and communities interact with one another in the midst of changes and discontentment. The scope and magnitude of change in resource management regimes and the societies of which they are part will only increase as the future unfolds. A conflict in resource use can be considered as an expression of discontentment either in terms of access, control or responsibility. It can also give impetus to users to organize and cooperate to assure getting at least some resources for all and to avoid violence. Thus centrifugal forces of competition can be countervailed by centripetal pulls towards cooperation (Uphoff, 1986). To some extent conflict can be useful in defining the competing needs for resources within communities and society (Castro and Nielsen, 2001). When conflict overpowers, chances of reaching agreement on solutions decline dramatically. Therefore, it is not to end conflicts, but to negotiate and find workable interventions.

Adams et al. (2003) present conflicts over use and management of common-pool resources as something beyond physical competitions. They say that it has to do with the way each user or group of them perceive the resource and also about the social structure itself. Therefore, there is a need to critically study the nature of conflict before any interventions. Further they mention that the level and differences in understanding and knowledge about the resource can also lead to conflict. If a shared understanding of the issue can be established, user can respond more positively to agreed actions.

Conventionally, conflicts are resolved in courts and many-a-times people have expressed their discontentment on the verdict. In case of Bhutan, courts rely on the traditional arrangements in absence of the Water Act (Jamtsho, 2002). In situation of condemnation of the court ruling, and alternative to litigation, people sought to negotiation, mediation and arbitration (Van Veen et al., 2003). Basic characteristics of dispute resolution techniques are summarized in Table 2.

Table 2. Characteristics of dispute resolution techniques.

Dispute resolution technique (DRT)	Definition of DRT	Attributes of DRTs	
		Strengths	Weakness
Negotiation	Process whereby two or more parties attempt to settle what each shall give and take, or perform and receive in a transaction between them	• promotes cooperation • cost efficient • promotes open process	• some parties may lack negotiation skills • power balance is not assured
Mediation	An important third party attempts to keep communication lines open, point out areas of agreement, encourage and assist disputants to resolve their differences using compromise and negotiation	• encourages participation • high degree of participant control • helps create alternative options	• process can be expensive • participants may lack skills • balance of power assured
Arbitration	Process similar to litigation but the decision of the impartial third party may or may not be binding depending on the disputants.	• results in conclusive decisions • Supported by established law and legislation	• win-lose outcomes possible • adversarial • can be lengthy
Litigation	Involves courts and a neutral third party that decides the outcome based on law.	• Conclusive decisions • Supported by law	• costly • win-lose outcomes common

Source: Van Veen et al., 2003. p. 91.

Characterization of disputes is stated to help in determining the outcome of resolution techniques. At the same time, different factors of dispute also influence outcome. Van Veen (2003) suggests four categories of dispute factors (Table 3). The factors are classified basically on specific dispute cases. In similar direction Slabbert (2004) also suggests a conflict mode instrument (matrix) that can help in assessing the outcome of the conflict depending on the degree of ability to compromise and collaborate (Figure 1).

Table 3. Dispute factor classification scheme.

Dispute factor category	Dispute factors
Background factors: *Factors that exist prior to a dispute and affects how it unfolds.*	• Past disputes between parties • Prospect of future business and/or social interaction between parties in a dispute • Attitude towards certain conflicts resolution technique due to past experience with them • Difference in parties' basic values or principles • Extent to which parties have communicated
Situational factors: *Factors that exists because of the dispute*	• Increasing personal time pressures • Number of people involved in a dispute • Involvement of parties who strongly believe in the "rightness" of their position • Parties' desires to maintain their privacy • Personality clashes between people in a dispute • Degree to which issues in a dispute can be resolved • Extent to which parties agree on the definition of the issues • Number of issues in the dispute • Presence of imposed deadlines
Capability factors: *Factor related to the ability of parties to participate effectively in the dispute resolution process.*	• Difference in financial resources available to the parties in a dispute • The potential of parties to learn unfamiliar conflict resolution techniques • Parties' abilities to use and understand technical and other forms of specialized information • Level of skill among participants in using dispute resolution techniques. • Willingness to risk an unfavorable outcome • Capacity to implement agreements
Water resource factors: *Factor of water supply and demand that affect dispute resolution processes.*	• Actual impacts of the disputed water use • Perceived consequences of disputed activity • Resource availability • Availability of temporary or permanent water supplies • How water is used • Uncertainty over scientific and technical questions

Source: Van Veen, 2003, p. 93.

The above classifications of conflicts imply that dispute, its context and resource under dispute should be intricately linked with adequate level of stakeholder participation for successful management of conflict. Although Co-management is not specified, it could be a possible approach to resource management in conflict situation. Many co-management agreements have painful births, arising out of intense conflict. Whatever the region, the resource, or the resource-using population, conflict often plays a key role in prompting the creation of co-management agreements. Nonetheless, conflict is a major factor in getting officials and other stakeholders to negotiate co-management arrangements (Castro and Nielsen 2001).

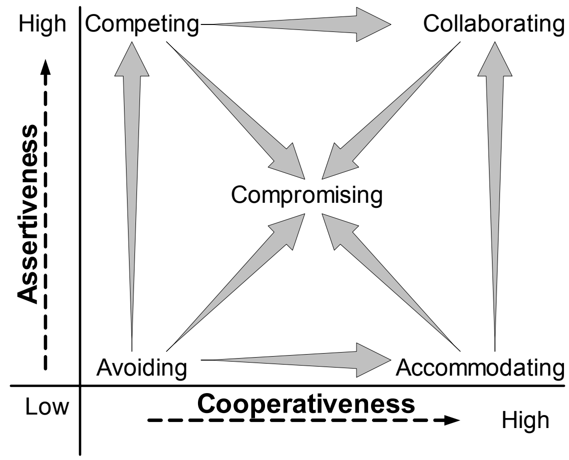


Figure 1. Conflict mode matrix

(Adapted from Thomas 1992, cited in Slabbert 2004)

The absence of a governance system at appropriate levels could further amplify the conflict. Such situation would often put environment and natural resource under threat from ravenous users (Dietz et al. 2003). However, appropriately organized institutions can facilitate sustainable use of environment. Devising effective governance system is comparable to a co-evolutionary race. With economic development, pressure on resources increase and past rules becomes redundant to current or future situations. Therefore for successful governance of commons rules should evolve in parallel with development.

In Bhutan people acquire water rights depending on their ancestral rights and more so under the doctrine of “first in time, first in right” (Jamtsho 2002). According to Ostrom (1990) in such situation junior appropriators are often victimized while senior appropriators are fully protected from encroachment on their rights. Thus conflicts in resource use can be considered as an expression of discontentment either in terms of access, control or responsibility. In conflicting situation, where users do not have face-to-face communication, the governance system cannot be successful (Dietz et al. 2003).

In management of resources, four features of society are important: relation of trust; reciprocity and exchange; common rules, norms, and sanctions; and connectedness in network and groups (Pretty 2003). They can be explained as follows:

- *Relations* of trust lubricate cooperation thus minimizing transaction cost among people. In reverse situation cooperative arrangements are unlikely to emerge.
- *Reciprocity* contributes to the development of long term obligations among people through simultaneous exchange of goods and knowledge, which help in achieving positive outcomes.
- *Common rules*, norms, and sanction (collectively termed as "rules of the game") provide individuals the confidence to invest in collective good.
- *Connectedness* (bonding, bridging and linking) is important for networking within, between and beyond ones environment.

2.2 Institutions for resource management

Institutional analysis has become a useful tool in the field of NRM for understanding how local communities manage resources, and how improvements in management could be initiated. Institutions are generally defined as "complexes of norms and behaviors that persist over time by serving collectively valued purposes" (Uphoff, 1986). They are the arrangements or 'rules of the game' which shape the behavior of local community members and include common understandings about how issues and problems are to be addressed and solved. Institutions are dynamic and respond to changes in local actors and their understanding, as well as to external power or environmental conditions, but the process of change can be difficult.

According to Ostrom (1986) an institution is a set of working rules that are used to determine who is eligible to make decision, what actions are allowed or constrained, what aggregation rules to use, procedure to follow, information to be provided, and payoffs will be provided on their actions. Institutions are imperative as they mold human behavior and their interactions and ultimately the way people use resources to attain their objectives. Resource management institutions have been extensively discussed in literature (Uphoff, 1986; Rungs, 1992; Ostrom, 1992; and Trébuil et al., 2002) and broadly considered as "*a set of formal and informal norms, laws, rights, sanctions and conflict resolution mechanisms, designed to manage resources*". Traditional resource management institutions have evolved over generations, and continue to evolve through constant negotiations among the community members with respect to the resource endowment. Ostrom (1992) highlighted that collective actions sustained over time, usually includes rules and decision-making structures. In the case of NRM, this might include rules on using (or refraining from using) a resource, as well as processes for monitoring, sanctioning, and dispute resolution.

The farmer managed irrigation systems in Nepal are often projected as more efficient than agency managed irrigation systems. The stated phenomenon is associated with the institutions built on the self-governing capacities of communities (Shivakoti and Ostrom, 2002). The basic incentive for operating such system is related to overall productivity. As Ostrom (1992) suggests, in a successfully organized systems, problems are overcome by the rules crafted by farmers themselves. For any individuals to organize into irrigation management systems they need:

- Secured land tenure,
- Capacity to relate and communicate with one another repeatedly on a face-to-face basis,
- A common understanding of the problem, cost, and benefit,
- A common understanding that they would have to enforce their rules on a day-to-day basis but could count on external authorities not to interfere in their rule-making, rule-following, and rule-enforcement activities,
- A common understanding of a range of rules that, if enforced, can effectively counteract perverse, short-term incentives,
- A common understanding that if they agree to a set of rules and follow accepted procedures to signify their agreement that each participant would be pre-

committed to follow these rules or be sanctioned by the others for nonconformance, and

- Trust that most of the farmers who agreed to a set of rules and denoted their agreement in an accepted way would actually follow these rules most of the time so that the effort to monitor and enforce these rules would not be itself extremely expensive.

It is not a mechanical process; rather in most cases it is organized in informal settings, what is crucial is that the individual long-term benefits will surpass their long-term cost. In decentralized governance system the local government can play a crucial role in mobilizing community for common property resource management (Uphoff, 1986). However, without any understanding of the vulnerability of resource poor farmers, rehabilitation of homegrown institutions (to manage CPRs) may instead act as barrier to well intended restructuring efforts. For institutional sustainability, it is vital that people accept the rules of the institution in relation to all members of the community and resource status (Ostrom, 1992). This can happen in both formal and informal settings; however Joshi et al. (2000) reported that not all formal institutions contributed to the performance of irrigation systems. Therefore, the performance of irrigation systems will depend on institutional arrangements by helping to build social capital necessary for its management. It is realized that beyond technical and design specificity of irrigation channels, social involvement is of vital importance to sustain the irrigation system (Ostrom et al., 1993; and Uphoff et al., 1991).

2.3 Participatory methods

According to Chambers (1997), participatory approaches and practices enable lower and poor people in general to express and analyze their individual and shared realities. As these realities are local, complex, diverse, dynamic, and unpredictable people living in that situation can only better express the context. Today the concept of participation has become panacea and most widely used term in development projects (Michener 1998). A process can be considered participatory when there is some form of involvement of relevant stakeholders in the change process (Pretty et al., 1995) or when the stakeholders think that they belong to the process. The process can be effective through purposeful interaction among stakeholders, which needs to be efficiently facilitated. The strategic and communicative rationality are the typical rationales behind participatory interventions (Groot and Maarleveld, 2000). Participatory interventions have become popular vehicles for both social and technical change around the globe.

The meaning of participation is numerous and has even classification systems. For instance, Deshier and Socks (1985) cited in Michener (1998) uses relative power of outsiders resulting into pseudo-participation or genuine participation. The classification of participation according to Cohen and Uphoff (1980) is more comprehensive indicating the kind of participation, who participates and how it occurs (Table 4).

Stakeholder participation in key activities of resource management in a community is crucial to ensure sustainability of the resource base. Participation is characterized by a cyclical, ongoing decision-making process, reflection and action that seek to include local people and their insights, experiences, knowledge and interests in diagnosis, planning and joint actions. Therefore, participation should be process oriented, involving people from the initial stage of problem definition to completion of the problem solving process (Narayan, 1996). According to IDRC (2003), participation increases community motivation and commitments, leading to capacity development thereby empowering the community members and ensuring greater success of actions. However, participatory methods are criticized for their inability to generate wealth of data for scientific endeavor. Rather it is considered strong to yield qualitative data (Probst and Hagmann, 2003).

Table 4. Dimensions of rural development participation.

Kind of participation	Participation in decision making Participation in implementation Participation in benefit Participation in evaluation
Who participates?	Local residents Local leaders Government officials Foreign personnel
How is participation occurring?	Basis of participation Form of participation Extent of participation Effect of participation

Source: Cohen and Uphoff, 1980

A core characteristic of participatory research approaches, is a process of interaction between local and external actors to 'co-create' innovations. Participatory methods are classified into four types to elucidate linkages between different social actors according to varying degrees of involvement in and control over decision-making in the relationship. They are contractual participation, consultative participation, collaborative participation, and collegiate participation (Table 5). The purpose of participation can be to legitimize the process or action, enhance effectiveness and efficiency of demand orientation, capacity-building and joint learning, and transformation. The process is seen to increase capacity for articulation and negotiation of interests, leadership, collective action, as well as critical consciousness, and self-esteem among marginalized social groups.

Table 5. Classification of types of participation based on the linkages among actors

Types of Participation	Features
Contractual	One social actor has sole decision-making power over most of the decisions taken in the process, and can be considered the owner of the process. Other stakeholders participate in the process according to the contacts.
Consultative	Most of the key decisions are kept with one stakeholder group, but emphasize on consultation and gathering information from others to identify constraints, priority setting and evaluation.
Collaborative	Different actors collaborate and are on equal footing. It emphasizes linkage through exchange of knowledge to make shared decisions.
Collegiate	Different actors work together as partners. All actors have equal responsibility on the action. Decisions are made on consensual basis.

Source : Probst and Hagmann, 2003. p-6.

Among many participatory methods, participatory learning and action research (PLA), helps in developing knowledge through critical reflection and experiential learning in an ongoing process of action in a real life context. This approach is thought to have several advantages. It is expected, for instance, that (i) practical knowledge and solutions can be developed which are directly useful to practitioners and people in the development process, (ii) by directly influencing the construction process of social reality, there is an increased probability that behavioral change and impact can be achieved, (iii) the people's capacity for experimentation and adaptive management can be developed, and last but not least, (iv) scientific knowledge can be generated concerning action, reaction, links, and factors that influence processes of change in a real life context (Probst and Hagmann, 2003).

In participatory learning and action research the mandate of science is no longer satisfied by scientists remaining external actors/observers developing knowledge for people. Instead, science's mandate includes helping people at different levels of social aggregation to develop knowledge (Röling 1996 as cited by Probst and Hagmann, 2003) and to enhance their capacity for adaptive management. According to Chambers (2002) cited in Probst and Hagmann (2003), great level of self-reflection, critical awareness, and continuous learning/improving on the part of researchers and other implementers is therefore a key success factor to exploit the potential of participatory approaches.

2.4 Multi-agent systems modeling and role-playing games

Models have been known to represent the systems structure and dynamics in a simplified form to enhance the understanding of the complex systems. Models play an important role in devising monitoring protocols as well as in providing a useful set of evaluation tools to assess the critical threshold of resource use. It particularly allows the explicit representation of a heterogeneous collection of agents of variable sizes, and the analysis of its evolution at both individual and collective levels. Model building is considered as prerequisite for comprehension and generating options. New modeling approaches are needed to effectively identify, generate, and relate information for better understanding of the systems. It is also needed to make shared knowledge to guide management decisions (Costanza and Ruth, 1998).

Multi-agents systems is an assembly of agents with specific goals capable of perceiving, communicating, interacting and acting in an environment with other agents (Ferber, 1999). These agents are intelligent and more or less autonomous objects in the system with specific relationships among each other and within a common environment (Figure 2) by way of different operations.

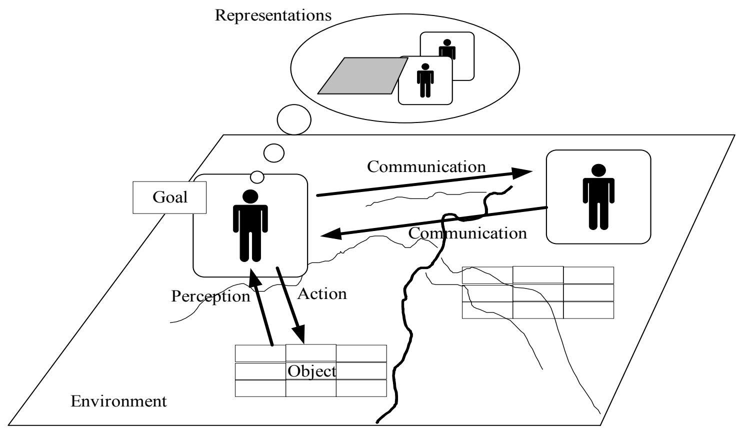


Figure 2. Multi-agents systems general organization and principles. (adapted from Ferber, 1999)

The underlying principle of MAS is the interaction between agents, which makes it useful as research tool, teaching aid, and decision-making tool (Barreteau et al., 2001). MAS can also help to understand the relationships among agent behaviors, their interactions, and the resulting dynamics at different levels of organization.

A multi-agent system (MAS) consists in a number of interacting autonomous agents. These agents can represent people, animals or organizations; can be reactive or proactive; may respond to environment; communicate with other agents; learn, remember, move and have emotions (Janssen, 2002). MAS provide simulation methods rich in potentials capable of modeling interactive processes between social and ecological dynamics (Bousquet et al., 1999). MAS can be applied for five main categories: problem solving, collective robotics, multi-agent simulation, building artificial worlds, and kinetic design of programs. According to Ferber (1999), MAS brings a radically new solution to the very concept of modeling and simulation in environmental sciences, by offering the possibility of directly representing individuals, their behavior and interactions. In resource management, MAS uses arbitration and negotiation to resolve conflicts, to stop disagreement between individuals from turning into open struggle. Thus it tries to maintain network of agents.

If used in an interactive mode, MAS can help to create a shared perspective of a complex ecosystem and to generate management scenarios which are relevant for negotiation and collective decision among stakeholders (Barreteau et al., 2001; and Trébuil et al., 2002a) to enhance the accountability and decision-making capabilities of the community. Bousquet et al. (2002) reiterates that development and use of MAS models in conjunction with role games for collective decision-making in NRM is new. Role games have been suitably used to support negotiated processes (Piveteau, 1995 cited in Bousquet et al., 2002) as well as for educational purposes (Burton, 1994 cited in Bousquet et al., 2002). However, role games need excessive resources and time for design and implementation. It is also reported that it is difficult to control parameters and to compare results of different gaming sessions. To alleviate these difficulties, Bousquet et al. (1999) suggested coupling of role games with MAS because of their complementarities (Table 6). As both proposes simple representations of complex realities, using them jointly can complement and supplement each other, towards the building of a shared understanding of the system to be managed among all concerned stakeholders.

Table 6. Similarities between role games and MAS.

Role-playing game	Multi-agent system
Players	Agents
Roles	Rules
Turns	Time step
Game sets	Interface
Game session	Simulations

Adapted from Barreteau et al., 2001.

A role-playing game can provide a suitable methodological framework to build a negotiation support tool (Etienne, 2003). If RPG and MAS tools are used in a mediation process – the social dimension of companion to co-evolve the social interaction, temporal and adaptive decision, this method is called ‘companion modeling’. Barreteau and Bousquet (2000) also summarize several studies that successfully used role-play games: For instance in studying the viability of irrigation system in Senegal MAS model "SHADOC" was developed. RPG was used to simplify MAS model to communicate the result to farmers, validate the model and used to negotiate irrigation system management; In Madagascar, integration of agro-biodiversity management knowledge was done by using RPG (STRATAGENES); To simplify MAS model used for representing sylvo-pastoral development and its impact (SYLVOPAST); RPG helped in putting the people in the virtual environment of MEJAN model, which provided appropriate setting for generation of negotiation processes in encroachment of coniferous forest. The differentiation of household under cooperative period in Vietnam was modeled in MAS (SAMBA), RPG was used to collect further information for validating the model and also to see emergence of new rules; RPG was used to generate information on sustainable land management in northern Senegal. The output from RPG was used to develop a common model implemented later into a computerized MAS model (SELFCORMAS). It is suggested that role-game and simulation models are appropriate to involve stakeholders in the exploration of scenarios simulated rapidly on the computer by using MAS models similar to RPG used with stakeholders. Bousquet et al. (2002) emphasized that MAS has considerable potential in NRM research for modeling and simulation of complex processes among stakeholders, as well as between social and ecological dynamics.

Daré and Barreteau (2003) have further shown that the association of RPG and MAS has the capability to tackle complex and dynamic social systems dealing with the sharing of common resources. The representation of reality and interference of social status in the actions during the game helps to reveal social interactions among players and communities.

Barreteau et al. (2001) stated that MAS models have the potential to facilitate the study of complex natural ecosystem management dynamics and the role of people in the system. MAS allow running repeatable and controllable scenarios for reasonable durations. However, these authors underline the need for a validation of results prior to field implementation of theories generated from MAS modeling.

As the natural ecosystem operates with multiple agents with varying objectives, CORMAS (Common-pool Resource and Multi-agents Systems) http://cormas.cirad.fr simulation platform has been developed to provide a multi-agent framework that can be used to simulate the interactions between agents and their environments. In other words, CORMAS is best suited to simulate natural resource management (Bousquet et al., 1998). CORMAS is a multi-agent simulation platform specially designed for integrating knowledge in a collective learning process on integrated natural resource management (Barreteau et al., 2001; and D'Aquino et al., 2002b). It is stated that the goal of CORMAS is not to make accurate predictions about the behavior of complex systems, but to provide framework to help people develop new ways of thinking.

2.5 Synthesis of the literature review

Conflict in natural resource management and in particular water resource is an inevitable phenomenon due to increasing demand and contestation for access. Often conflicts are expression of discontentment, inequitable access and discrimination. It is a indication of pressure on resource and also the need for change. However, if conflict bogs down, the scope to achieve a shared solution declines dramatically. In the extreme cases, it is suggested that resource conflicts can sometimes become severe and debilitating, resulting in communal riots, and more resource degradation that would undermine the society. Conflicts depend on many factors; background (factors that existed prior to the current conflict), situational factor (current state due to the conflict), capability factor (ability of the parties in conflict to participate is conflict management process), and water resource factor (supply and demand that influence resolution process). In many cases conflict also depends on the degree of cooperation and influence each conflicting society has. In view of this inter-connectedness, intricacies of conflict and its relevance to the society, a thorough diagnosis and analysis of the systems is necessary before any interventions are planned. In case of any intervention, it is suggested that conflict should be managed.

In any society, institution plays a major role is upholding the social coherence, and collective actions. Local institutions represent both formal and informal norms, which promote collective decisions and actions. It has been shown in many countries that locally managed institutions are better in productivity compared to agency-managed institutions. It highlights the ownership of the institution and their common goal, which ensures cohesion among the community members, and success of the institutions. In a successful institutional system, conflicts are overcome by the rules crafted by the farmers. Therefore, building the social capital necessary for management of natural resources will facilitate in sustaining the resources.

To ensure ownership of the social capital, institution, actions, and outcomes, participatory approaches are often hailed for its strength in harnessing local participation. Particularly, to ensure sustainability of resource base it is crucial for all stakeholders to involve in the process of interventions. As such it is said that participation should be process oriented and not one time intervention. Although participatory approaches are criticized for its inability to generate quantitative information for scientific endeavor, it is now considered to help people to develop knowledge to enhance their capacity for adaptive management. Participation increases community motivation and commitments, leading to capacity development, empowerment and success of the actions. The key factors to use participatory approaches are the level of reflection, critical awareness and continuous learning it generates on the part of all stakeholders including researchers.

The experiences in use of role-playing game and MAS models have shown a definite promise in its ability to adequately represent the environment, people and their interactions. The strength of role-playing game in enhancing non-confrontational collective interactions and discussion between conflicting communities outweigh its weakness of design complications and result analysis. RPG has definite strength to promote productive discussions and generate new rules during the gaming sessions. MAS can help to incorporate human factors in natural resource management and represent almost precisely the social interactions among users and between environments. It also helps indirectly representing individuals, their behavior, interactions and maintaining the network. It further helps in integrating knowledge in a collective learning process on NRM. As an interactive and iterative tool, RPG and MAS can creates a shared perspective on a complex ecosystem and generate scenarios, which are relevant for negotiation and collective decision. Together, they are called companion modelling, where stakeholder is involved all through the process and it is the RPG which ensures the link between actor and the MAS model.

Chapter III

Research methods

The preceding chapter succinctly presented the complexity of the issue and need for integrating different tools and approaches to study the problem of natural resource management. This chapter presents the context of the issue, conceptual framework used in the study and analytical tools. There is an elaborate description of the role-playing game and MAS, which will form the two major tools used in this research.

3.1 Conceptual framework

The study followed the conceptual framework given in Figure 3. It comprises of three distinct phases that proceeded in an iterative manner. Step 1 constitutes general diagnosis of the study area to conceptualize the issue and the context. Characterization of farming systems and users categorizations was done based on historical profile, strategy, options, constraint and potential.

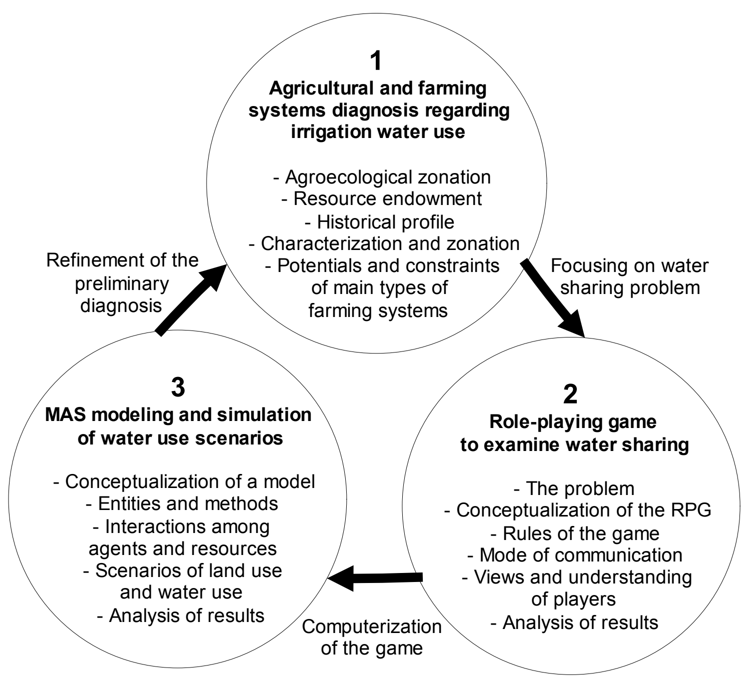


Figure 3. Schematic representation of conceptual procedure used in this study.

Subsequent step focused on role-playing game involving stakeholders in the process of collective learning by taking part in role-playing sessions. Step 2 thus helped in generating unique behaviors and actions through which greater understanding was acquired on water sharing systems in the community. The third step incorporated findings and understandings from the two earlier steps in development of agent-based models to generate scenarios of social network and exchange protocols. These scenarios helped in identifying different resource sharing mechanisms.

3.2 Setting

Common-pool resources (CPRs) play an important role in livelihoods of Bhutanese. Local demand for resources like timber, firewood, water, and non-timber forest products (NTFPs) resulted in the establishment of locally defined rules to regulate access to and use of the resources. As mentioned earlier, these local rules were derived from long-standing customs, religious traditions, and policies. Among the natural resources: wood resources, NTFPs, communal pasture, water, and communal agricultural resources are considered as critical resources (Ministry of Agriculture, 2002b). The management and use of this resource depend on the way people exercise their user-rights. Limited state capacity to effectively monitor and manage natural resources, combined with the loss of local management regimes has created an open access situation for many resources. In the process, there are signs of resource degradations and most importantly conflicts among the users are increasing. A few distinct types of degradation are:

- High demand of timbers, firewood and fodder in densely populated areas has resulted in barren forest.
- Overgrazing has affected natural regeneration of forest
- Commercialization of NTFPs such as lemongrass, cordyceps, chirata, matsutake mushroom has lead to over harvesting of the resources.
- Expansion of irrigation facilities resulted in increased option for cultivation and indiscriminate use of water leads to soil erosion. Inequitable irrigation sharing systems has led to social conflict.

Among the farming communities, access to irrigation water has always been a constraint to agricultural production. This limitation is mainly because irrigation water comes from secondary and tertiary tributaries, local streams and springs (Bhutan Water Partnership 2003). Information on water management system including water distribution and traditional rights is limited. It is important to establish adequate information and experiences on water management to help in policy formulation.

This study was conducted in a rural setting of west central Bhutan, where two communities have been in conflict over sharing irrigation water for many years. They divert water from Limtichu river into Dompola canal and share water. In Bhutan, most irrigation schemes are governed by traditional rules that were framed when demands were low and resource was in abundance. These traditional water rights are associated to the feudal past, where the original taxpayer (locally known as *Thruelpa*) has full rights over water resource. As water rights are attached to wetland and are inheritable, in the course of time other categories of irrigators (*Cheep and Chatro*) have evolved through inheritance. With the increase in population and fragmentation of land, numbers of certain categories of users has increased. At the same time resource supply declined. There are group of farmers (*Lhangchu*) who do not have water share and depend on other farmers. The detail share of water is explained in Chapter 3. In contrast, the rules on water use and sharing has not changed, which resulted in inequitable sharing of water. There are cases where upstream and downstream communities are in conflict because of disagreement in local water sharing systems. However, a greatest obstacle to mediation has been the resistance for change by those who are favored by the rules. This resistance has resulted in legal institutions upholding the principles of status quo, whenever these conflicts are reported to the district courts.

This study aims to understand the process of sharing water, its effects on resources and finally establish a communication mechanism between two communities to collectively learn and develop strategy.

3.3 Study Site

The Renewable Natural Resources Research Center in Bajo conducted preliminary diagnostic studies in Lingmuteychu watershed in 1997 as part of the community-based natural resource management research (Renewable Natural Resources Research Center, 1998). This study identified numerous constraints to low crop production in the watershed, of which lack of irrigation water during transplanting was reported as a major problem. Considering the problems and existing field experiences, the site was selected for this research.

Lingmuteychu is a small watershed located at 27°33′ N and 89°55′ E on the east bank of the Punatshang Chu river in west-central Bhutan, occupying an area of 34 km^2. It is drained by the 11 km long Limti Chu stream that originates as a spring from a rock face at an altitude of 2,400 m north of Limbukha village (Figure 4). It is a rainfed stream since the ranges that confine the watershed are below the snow line. The stream serves five irrigation systems supporting 11 irrigation channels that irrigate about 180 ha of terraced wetland belonging to 162 households of six villages (Renewable Natural Resources Research Center, 1998). These six villages share irrigation water within a broadly respected customary regime. The two villages of Limbukha and Dompola situated approximately 3 km apart in the upstream of Lingmuteychu watershed are in persistent conflict in sharing irrigation water.

The base flow during the dry months of April and May fluctuates at about 40 to 50 Ls^{-1}. The flow produced by a widespread rain in the watershed can be more than 500 Ls^{-1}. The rainfall-runoff response is quick and the stream returns to its base flow within a couple of days after the rainfall. The fluctuating nature of the stream mainly results from steep gradient of the watershed. The watershed receives an average annual rainfall of 700 mm (Renewable Natural Resources Research Center, 1998).

Regulations in terms of water diversion by different irrigation canals from the Limti Chu are based on two broad principles. The rule "first come, first served" applies, which means that existing schemes have an established water right and can prevent newcomers from using it.

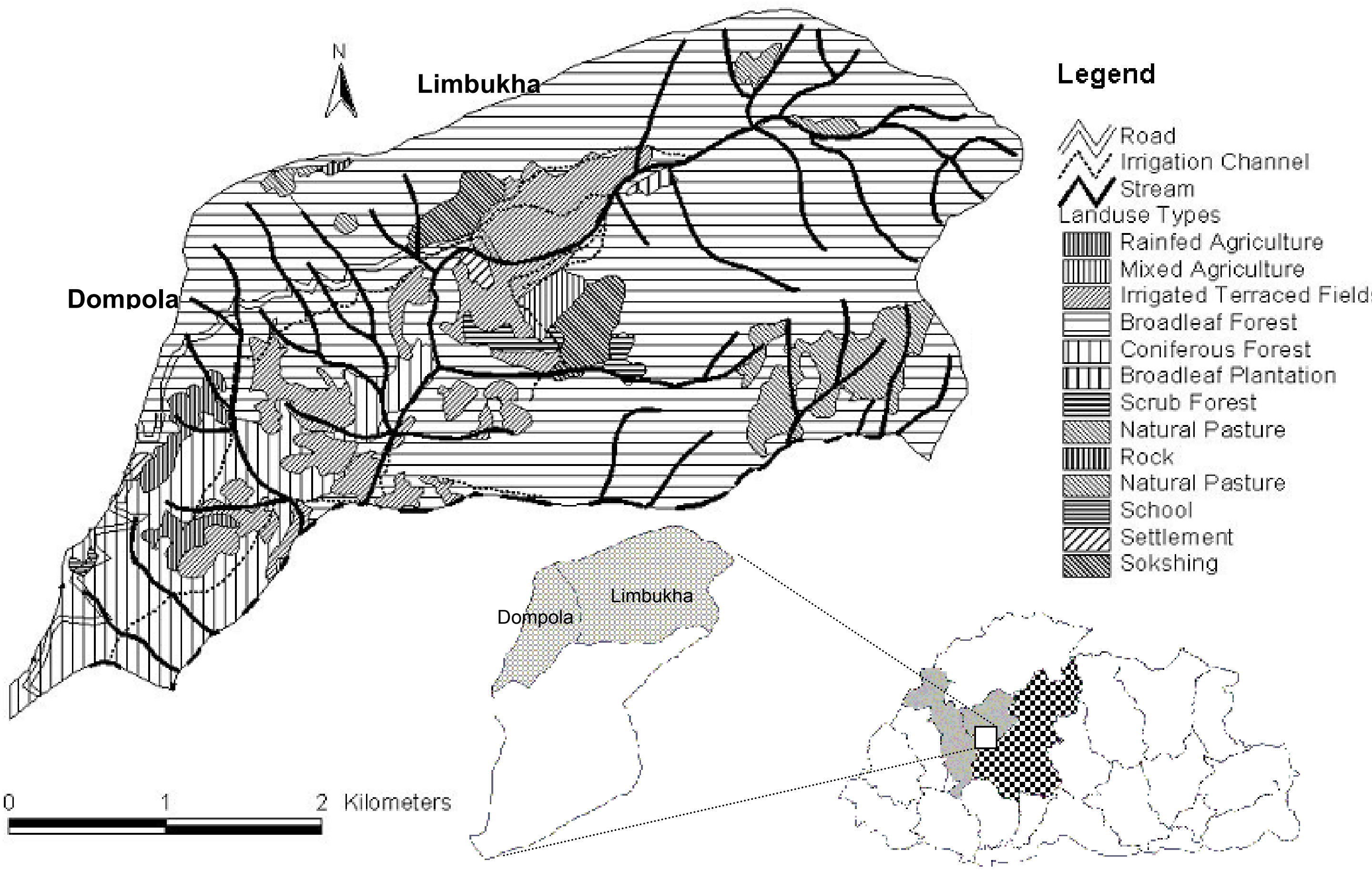


Figure 4. Map of the study area in Lingmuteychu watershed, Punakha District, West-central Bhutan.

31

For instance, Nabche (one of the villages within the watershed) is a resettled community and it does not have access to water, which prevents them from constructing an irrigation canal. The second rule can be interpreted as "more water for upstream communities." Conflicts arise particularly from these two rules. Under such water-use regime, the community in the uppermost catchment (Limbukha), close to the intake point, has absolute control over the headwater.

Ironically, Dompola, a second village in the upper catchment located approximately 3 km downstream from the intake point, does not have direct access to the stream. Dompola has to share water with Limbukha and the water release date and volume of water diverted from the stream are strictly followed. As per the traditional arrangement, Dompola gets half of the stream flow only from the tenth day of the fifth Bhutanese month every year. However, even after this date, Limbukha farmers still use water from Dompola's share to irrigate their land. As such, Dompola farmers struggle to get their paddy field transplanted. This indiscriminate use of water in the upper catchment results in conflict between two villages.

Within a village, water is shared on the basis of a rotation system locally known as "*chukor*." The rotation interval among different communities in the watershed varies from 3 to 13 days. In Limbukha and Dompola, water is shared on the basis of four categories: "Thruelpa," "Cheep," "Chatro," and "Lhangchu." These categories correspond to the following modes of access to irrigation water:

- a thruelpa is entitled to half the flow in the canal (½ of canal flow)
- a cheep is entitled to half of thruelpa (¼ of canal flow)
- a chatro is entitled to half of cheep ($^1/_8$ of canal flow), and
- a lhangchu has no entitlement and has to beg for water

As shown above, the existing water rights are not equitable. As the water resource becomes scarce, the current system has deficiencies. With differences in water rights, conflict can emerge within and between communities. It has also been shown that farmers use excessive amount of water (Ministry of Agriculture, 2002b).

This is aggravated by the introduction of multiple-cropping practices in upper villages, which have strong effects on water supply and rice productivity in the lower community (Renewable Natural Resources Research Center, 1997).

3.4 Sampling technique

The sample households were selected by using multistage sampling technique. From the 7 villages in the Lingmuteychu watershed, Limbukha and Dompola having an acute and persistent conflict on water sharing were selected. Farmers of these two villages were classified based on their water sharing category and 6 farmers from each of the two villages were randomly selected to take part in the first session of role-playing game held in May 2003 (Table 7). These 12 farmers represented four water sharing categories (as explained in section 3.2).

Table 7. Category and number of players from Limbukha and Dompola for RPG

Category	Limbukha	Dompola
Thruelpa	2	1
Cheep	2	3
Chatro	1	2
Lhangchu	1	0
Total	6	6

The same players were requested to participate in the second session of RPG organized in December 2003 in Dompola. As majority of the players during first session of RPG suggested that Block development committee members and officials from District Administration be included as observers in such exercises, all Block development committee members and District Agriculture Officer participated as observers in the second session of RPG held in December 2003.

3.5 Data collection

To fill the information gap for the study, primary and secondary data were collected. A structured questionnaire was developed based on a preliminary analysis of the secondary data and the basic information needed for designing a role-playing game. Secondary data was extracted from various published and unpublished reports, journals, literatures, proceedings, personal communications, key informants and observations. Analysis of secondary data (Renewable Natural Resources Research Center, 1997; Duba and Swinkles, 2001) helped to focus this research. Institutions like Research Center in Bajo, District and Block Agriculture Office and Planning and Policy Division (PPD) of the Ministry of Agriculture provided both formal and informal information.

Primary data were collected using formal and informal methods. The basic purpose of the primary data collection was to make systematic diagnosis of the watershed and farming systems aspects related to the problem under study and to subsequently help in designing of the RPG. Initially informal visits to the site and discussions were held with the administrators, researchers, extension staff, community leaders, and some farmers. These discussions further helped to better understanding the problem and conceptualize the study.

A formal household survey was conducted using a structured questionnaire. The questionnaire was pre-tested in Limbukha followed by a survey of 40 households from the two villages. The household survey was targeted to collect data in three major areas: general socio-economic information, social organization, and irrigation water management. The role-playing game also generated information on management strategies both during the game and from the individual interview of the 12 players after the game.

3.6 Data analysis

Watershed and farming systems diagnosis was done using the agrarian system diagnostic analysis and farming system typology methods (Trébuil, 1992, Trébuil, 1993, Trébuil et al. 1997, Capillon et al., 1993). The agrarian system diagnostic analysis is made of three main and complementary methodological tools:

- agroecological zonation,
- historical profile of the agrarian system, and
- analysis of farmer differentiation/typology.

They aim at identifying factors which steer the way farmers choose economic activities and corresponding management options. They also aim at identifying the processes through which such strategies influence the transformation of the farmer typology. The farmer typology tool follows three basic steps:

Step 1: Characterization of the general functioning of agricultural production systems (APS) to display strategies, components of the system and factors influencing the strategy.
Step 2: Grouping of similar APS in main types.
Step 3: Construction of farmer typology.

For general analysis descriptive statistics were used for comparisons of outputs. Throughout the analysis, simple graphical outputs were used for discussions with farmers. Gross margin analysis was used in the RPG to calculate farm income during the game.

While individual performances of player in RPG could be efficiently monitored by land use changes, water use and income after each time step, the overall performance of the collective system cannot be shown clearly from the summated income. Therefore, as a synchronized output from the RPG, performance of irrigated agricultural system was used as an indicator to show player the impact of their collective actions on the performance of the irrigation system. Three indicators, adapted from Molden et al. (1998) were used to compare the performance of the irrigation system in the two villages. The analysis used gross margin and cropped area generated by the RPG simulation. The three indicators are as follows:

$$\text{Output per cropped area } (US\$\ ha^{-1}) = \frac{Gross\ margin}{Irrigated\ cropped\ area} \qquad 1$$

$$\text{Output per unit command } (US\$\ ha^{-1}) = \frac{Gross\ margin}{Command\ area} \qquad 2$$

$$\text{Output per unit irrigation supply } (US\$\ m^{-3}) = \frac{Gross\ margin}{Diverted\ irrigation\ supply} \qquad 3$$

3.7 Role-playing game

3.7.1 Conception of the RPG

The RPG method was conceived as a potential tool to initiate and facilitate dialogue between the two villages and for the research-extension team to enhance their understanding of the problem. The conflict in these two villages relate to sharing of irrigation water, time of release and effect of changing cropping pattern, which further relates to the way resource is used within and between communities. In conceptualizing the game, the following features (Figure 5) were included:

▪ Players:	Irrigators - water sharing category
▪ Roles:	Play the game according to the assigned task
▪ Rules of the game:	Set of broadly pre-defined steps of the game
▪ Game sets:	Playing Board
▪ Turns (Round of play):	1 Year - (January-December)
▪ Gaming session:	3 days per session (May and December 2003)

Each turn was divided into 2 steps: January to June and July-December. In first cycle of a time step, Limbukha farmers planted potato and rice, while Dompola farmers planted only rice, based on their resources. In the second cycle, Limbukha farmers harvested potato and planted rice in their remaining plots. Dompola farmers also planted rice in the remaining plots in second cycle. There were two chance factors: rainfall (normal and low) and market price (high and low) which influenced water availability and income. Rainfall was declared after drawing a card at the start of the game, whereas the market price was declared after each round of play (crop year).

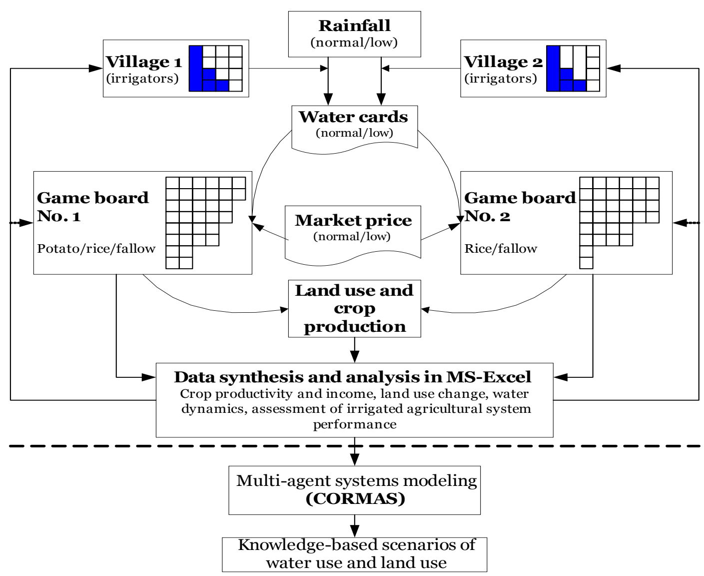


Figure 5. Diagrammatic representation of the Dompola role-playing game.

3.7.2 Game Board

Two game boards (one for Limbukha and the other for Dompola) were drawn on a 0.5 m * 1 m poster paper representing the farmers in columns and their plots in rows (Figure. 6). On the game board, columns represented six farmers. Rows represent plots, plain numbers ranging from 1 to 8 (depending on the category of the farmer). Each plot is equivalent to 0.1 ha of irrigated terraced field. Only one crop can be grown at a time. However, in the actual game, players proposed that Limbukha villagers could grow a crop of potato before any rice crop. The year and period of the game (e.g., 4/2: implying year 4 and cycle 2 of 2) were indicated in the lower right corner of the board. Players were given predefined numbers of rice fields: Thruelpa got 8 fields, Cheep got 6, Chatro got 4, and Lhangchu only 2. At the end of each crop year, the board with crop cards on was photographed and recorded to help in data analysis.

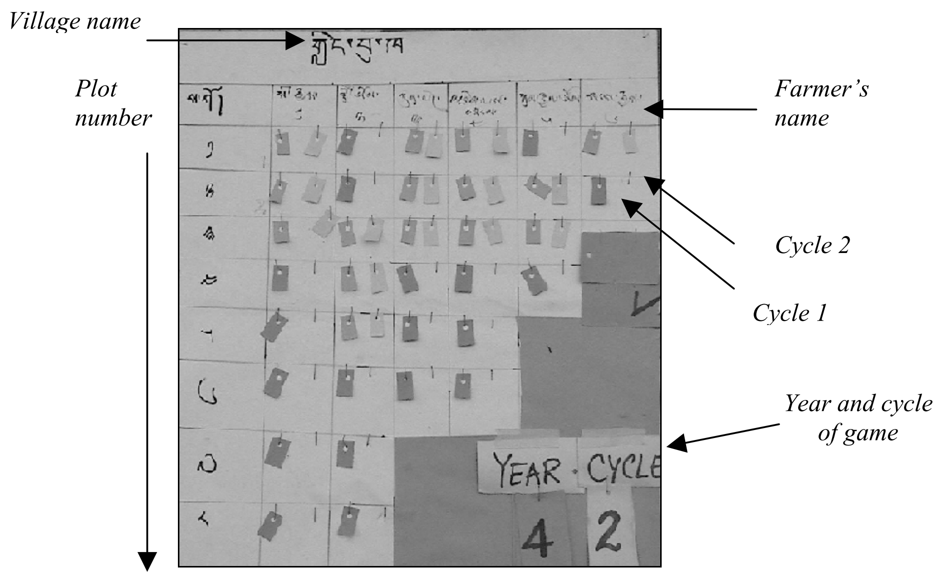


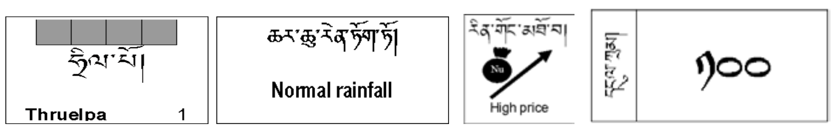
Figure 6. Game board of Limbukha village used in Dompola RPG, May 2003

3.7.4 Playing cards

Six types of cards were used as a medium in the game:

- *Name tag.* Each player was given a badge, which identified the bearer's social status and water-sharing category in public carries the name of the type of farmer and a four-squared box representing that person's share of irrigation water (Figure. 7a).
- *Cash.* Different denominations of local currency were used as cash to start farming and settle accounts after each time step. As the players introduced exchange of labor, cash was also used for labor transactions. One could borrow and lend. The card was used as an indicator of performance in terms of income. Each player received initial cash to start farming at the following rates: Thruelpa = Nu. 20,000 (US$1 = Nu. 47.10), Cheep = Nu. 15,000, Chatro = Nu. 10,000, and Lhangchu = Nu. 5,000.

- *Rainfall.* Two cards, normal (N) and low (L) rainfall for each cycle were used as chance cards to determine the volume of water available for irrigation and sharing. Depending on the rainfall pattern, the number of water received by each player were regulated to induce dynamism. Before each cropping cycle, the card was randomly drawn and declared.
- *Potato card.* Limbukha farmers received yellow cards representing potato fields. One card was equivalent to 0.1 ha of potato grown before rice. Each player could use a maximum of three cards, and could also skip a season without growing potato.



(a) (b) (c) (d)

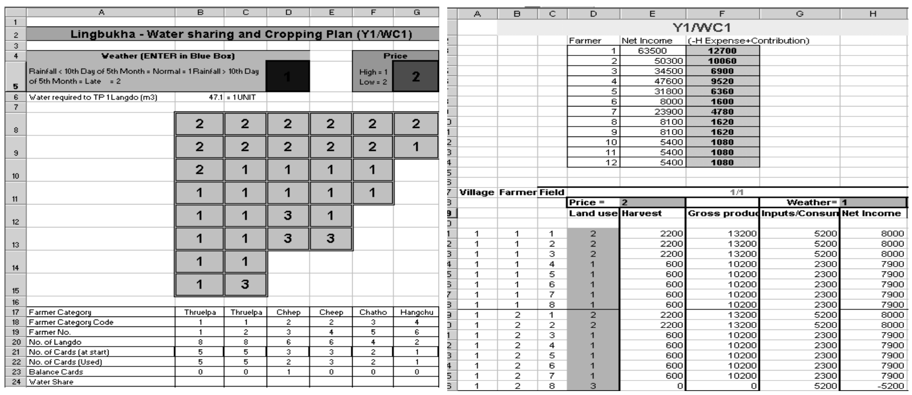
Figure 7. Cards used in the RPG in Limbukha

- *Water cards.* Pink and light blue cards were used to represent water. One pink card was used represent one unit of water, equivalent to the volume of water needed to transplant and irrigate 0.1 ha of rice. This means that farmers could place only one water card in one plot to indicate that that plot has been planted to rice. This card could be sold, exchanged, or used for transaction among villagers in a community or among farmers of the two communities. The game facilitator issued water cards in correspondence to the rainfall type. In the normal-rainfall season, Thruelpa received 5 water cards, Cheep 3 cards, Chatro 2 cards, and Lhangchu 1 card. During the low-rainfall pattern, the water provision was reduced by one unit, that is, 1 card less.
- *Market price.* Two cards representing a high and low price were used to indicate potato and rice prices. One of these cards was drawn randomly and declared after each crop cycle.

3.7.4 Spreadsheet

The data from RPG game boards were recorded in a spreadsheet (Microsoft Excel) for further analysis and synthesis. The data from the game board were transferred into a data-capturing spreadsheet (Figure. 8a) in codes (1 = rice, 2 =

potato, and 3 = fallow). The data were linked to a second spreadsheet (Figure. 8b) to calculate gross margin simultaneously. This spreadsheet acted as an interface between rounds of play (1 crop year), as it was used to calculate income from land-use decisions. Based on the results, each player was paid an income at the end of each year. Other data such as water dynamics and land-use changes were analyzed after all the gaming sessions concluded. This actually facilitated the gaming session by enabling rapid calculations and year wise comparisons if required.



a b

Figure 8. MS Excel Spreadsheet used in the Dompola RPG.

3.7.5 Pretest of the game

The game was pretested at the RNR Research Centre, Bajo, with researchers and trainees playing the role of farmers. Subsequent to the test, a few changes such as the number of plots and options for sharing water were incorporated into the game used with villagers during the following days. The test also helped to schedule the game in terms of time taken for each step. It also served the purpose of training selected facilitators and assistants before conducting RPG in the field.

3.7.6 Game sessions with villagers

In May 2003, the first gaming session was organized for 3 days in Dompola. The first day was assigned for RPG sessions. They started with a briefing about the game, the purpose, the role of the players, and the expected outputs. The game was played in three different modes of communication: village-based (intra-village), collective (inter-villages), and swapping roles. The first mode was played for 7 rounds of play (corresponding to 7 years). It represented the existing situation in which each village discussed water sharing independently at the village level and decided to grow different crops accordingly. Even the game boards were kept in distant places such that one village could not see the actions of the other village.

During the second mode of communication played for 5 rounds, farmers from both villages formed one group to discuss collectively water sharing between the two villages. The game boards were placed side-by-side to allow all players to see and discuss actions and situations on them. This was necessary to demonstrate that two villages can freely discuss and share water. During a shorter third scenario, roles were swapped between the two villages. This was anticipated to provide a better understanding of other village situations, identify any unique decisions, and bring about new understanding from swapping of the roles.

The second day was devoted to analysis of the RPG outputs and discussion among facilitators. On the third day, based on the preliminary analysis and observations, individual interviews with each player were conducted to collect views on the game and evaluate it. Following individual interviews, a plenary session was organized to present the results of RPG session to the players. The result presentation was aimed to get farmers' response to the proposed analysis in the form of simple graphs of the land-use dynamics, water exchanges, and incomes.

3.8 MAS modeling

The RPG was implemented into a simple MAS model using CORMAS to facilitate joint learning about resource use, interactions among different variables and their effects. Unified Modeling Language (UML) diagrams were built to identify different entities, components, and their interactions, sequential processes and modalities. Class, sequence, and activity diagrams were also built. These UML diagrams were used as a reference for building the model. The detail UML diagrams used in this study are discussed in Chapter 6. The rules used in the RPG were translated into simple lines of codes in smalltalk language and used in the CORMAS platform.

CORMAS is based on the VisualWorks software which is a programming environment based on smalltalk. It is available in the form of sets of smalltalk classes representing generic social entities encoding behavior exhibited by agents exploiting natural resources (CIRAD 2003). CORMAS platform is structured in three modules for the following purposes (Figure 9):

1. Designing specific entities: spatial, social and passive ones,
2. Specifying the sequence of task: control of evolution, and
3. Defining method of visualization: grid, graphs and exchange of messages.

Each module has specific steps to accomplish before the model is ready to run. They are briefly explained below. For more details please refer to CORMAS Tutorial 1 and Tutorial 2 (CIRAD 2002; and CIRAD 2003).

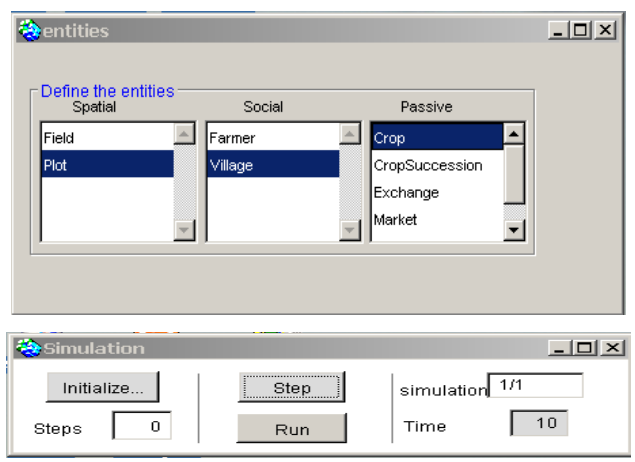


Figure 9. Structure of the main modules of the CORMAS simulation platform

CORMAS has a specific window to run simulation. The model saved in “CORMAS/models” directory needs to be loaded. Once the model is loaded, a spatial grid interface can be opened with required environment and point-of-view to visualize the simulation. Exchanges between agents can be visualized in the message window. The model has to be initialized based on selected parameters. Simulations can be run by clicking on “step” to simulate stepwise (1 time step per run) or click on “run” after inserting number of steps to allow model to simulate the assigned steps.

The simulation outputs can be exported as ASCII, MSExcel, or database files. Thereafter, data can be analyzed using any software packages. Sensitivity analysis of the model can be conducted within the CORMAS platform.

3.9 Overview of the methods

The three approaches are iteratively integrated such that they facilitate sequential flow of the information and facilitated as cumulative process of information gathering and analysis to better address the research issue. Integration of tools is also expected to facilitate analysis and achieving the objectives of the study (Figure. 3). Initially the agricultural and farming systems diagnosis helped in contextualizing the problem of water sharing, characterizing the system, and to define parameters to be used in the RPG. The RPG was built on the understanding from the first step to examine the water sharing process and observed unique behavioral patterns. As RPG has limitations to handle complexities and its use is constrained by time, CORMAS platform helped to model and simulate of different scenarios to refine our understanding of the processes. The following chapters present the findings of each approach and finally consolidate them into a general conclusion and recommendations of the study in the last chapter.

Chapter IV

Watershed and farming systems characterization and diagnosis

A watershed can be considered as an assemblage of different components interconnected by interactions and interdependences which function within a well-defined hydrological boundary to provide specific ecological, social and economic services. Watershed management involves informed decision-making in a complex array of biophysical, social and economic environments made up of processes and interactions between ecosystems, components and between human intervening in such ecosystems. Due to the complexity of issues involved in watershed management, it requires an inter-disciplinary, holistic, and integrated approach to fully understand the system.

Within each watershed, there are household-based farming systems which exhibit diversity further adding complexities to the ecosystem (Grigg 1974, cited in McConnell and Dillon, 1997). Therefore, it is appropriate to classify the diversity of farming systems based on certain typology, for instance ecologically based typology and farm management based. The typification will help in the identification and localization of agro-ecological and socio-economic constraints and potentialities that influence the dynamics of the different systems. Typologies also help in targeting extension messages and in assessing who is benefiting from the interventions.

The following sections present the diagnosis of the Lingmuteychu watershed and farming systems in the watershed. This diagnosis helps to identify and assess the diversity of situation, behaviors and actions which directly or indirectly influence resource management in the watershed with particular emphasis on irrigation water sharing.

4.1. Agroecological zonation and characterization of Lingmuteychu watershed

4.1.1. Bio-physical characteristics

Land features

Lingmuteychu watershed is characterized by mountainous terrains. The watershed is bounded by a ridgeline running down from Antakarchu and Darchula range at 3040m elevation to Punatshangchu river at 1300m elevation. Based on the altitude, watershed can be divided into 3 main zones corresponding to vegetation type and farming activities. About 59% of the total area falls above 2000m which is mostly vegetated with broadleaf forest. The predominant broadleaf species are *Michelia spp*., *Carpinus spp*., *Quercus lanata*, *Q. grifithii*, *Rhododendron sp*., and *Symplocus spp*. Coniferous forest is dominanted by *Pinus rohburghii*. Areas between 1600 and 2000m comprise 29% of the total area and correspond to a transition zone between broadleaf and coniferous forest. The remaining 12% of the area falls below 1600m elevation which is predominantly coniferous forest and rice-based farming (Figure 10).

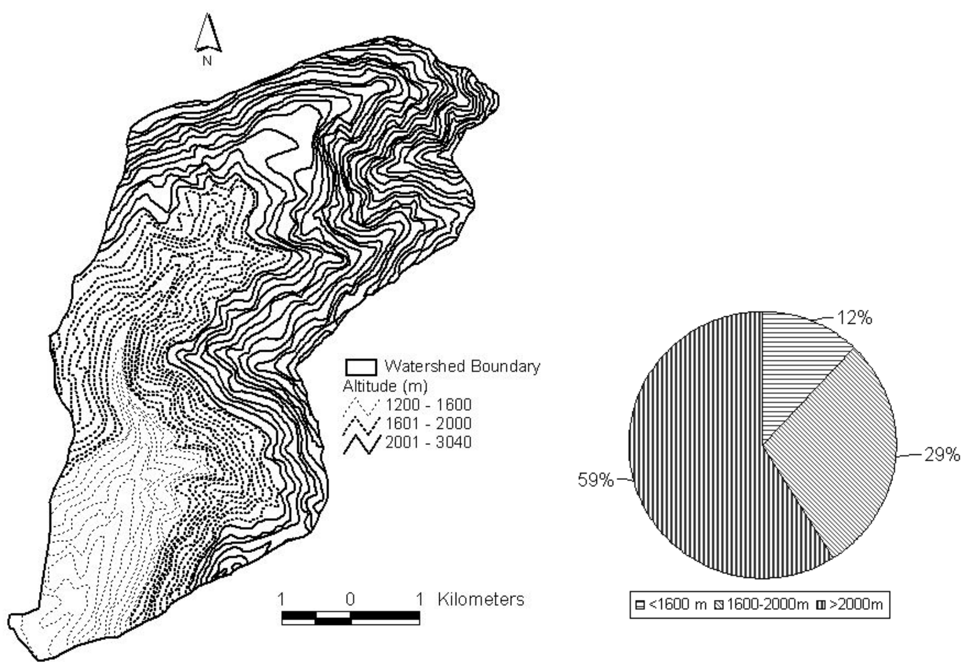


Figure 10. Distribution of watershed area by altitude.
Source: RNRRC, 2002.

There are flat areas in some pockets where people have settled and practice high altitude irrigated rice on terraces. Broadly watershed can be classified into slopy area with 57% of the total area at 25-50% slope angles, (Figure 11). Limtichu river flows in the south-westerly direction dividing the watershed into two halves and finally draining into the Punatshang river.

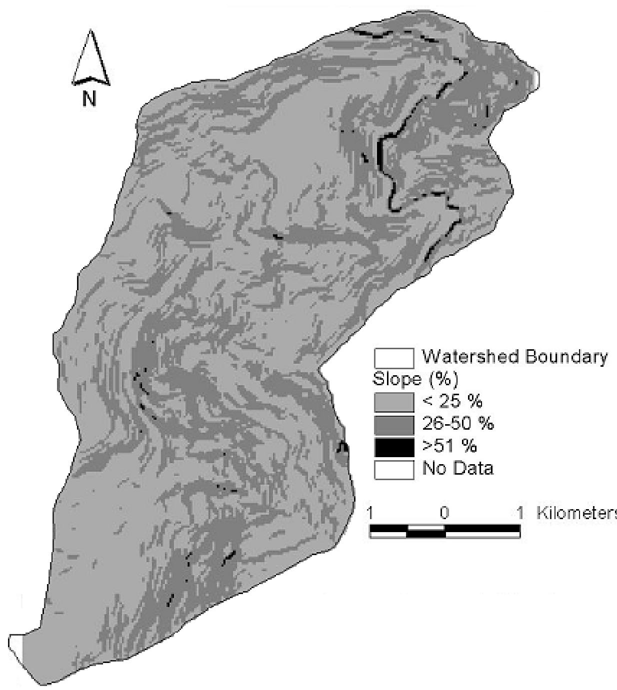


Figure 11. Distribution of watershed area by slope.

Source: RNRRC, 2002.

Major soil types

The major soil types present in watershed are given in Figure 12. This watershed predominantly has shallow and deep brown sandy loam, which covers 65% of the total area. Other soil types like sandy loam, and clayey cover 20%, 11%, and 4% of the watershed area respectively. Considering that the sandy loam type of soil is predominant in the watershed, the water retention capacity is also low, thereby leading to higher water consumption at transplanting (Brand and Jamtsho, 2002). Broadly, there is a distinct zonation between sandy loam and clayey soil according to altitude.

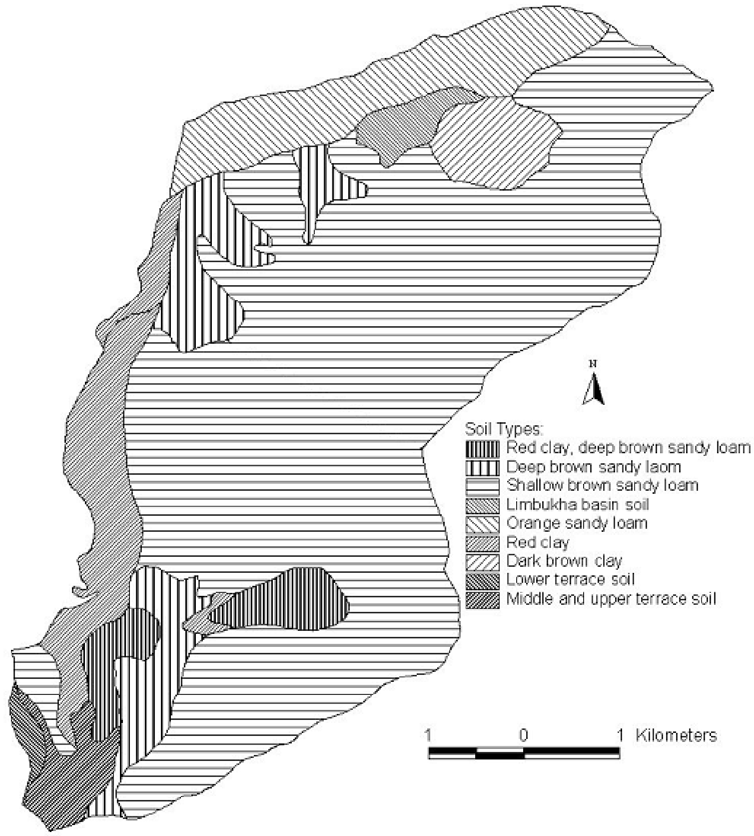


Figure 12. Soil map of Lingmuteychu watershed.

Source: RNRRC, Bajo, 2002

Climate

This watershed experience warm summer with temperature ranging from 15 to 25ºC. Winter is cool with temperatures ranging from 3 to 17ºC. Annually it receives an average total rainfall of 670mm with July and August being the wettest months (Figure 17). Based on the national agroecological zonation the watershed can be divided into two zones: a wet temperate zone (1800-2600m) and a dry sub-tropical zone (1200-1800m) (RNRRC, 2001). These zonations play a major role in crop and varietal choices. As bulk of the modern introduced rice varieties are suitable for dry sub-tropical zones, traditional white and red pericarp rice varieties dominate in the higher wet temperate zone.

Land use

From an agricultural production point of view, Lingmuteychu is predominantly a rice-growing watershed, with 180 ha of irrigated terraced paddy fields representing 64% of the total farmland in the watershed (Table 8). There are 36.5 ha of rainfed area mainly devoted to growing maize and vegetables. Forest occupies 69% of the total area. The watershed has two types of forest vegetations: broadleaf forest above 1600m and coniferous forest below 1600m. The watershed also features a stretch of barren and degraded area, due to over grazing and poor forest regeneration (Figure 13). A detailed longitudinal zonation of watershed along a transect line, locating the two vegetation types, soils, and altitudinal differences influencing crop choices and other land-use decisions is represented in Figure 14.

Upstream villages have higher forest cover associated with an easier access to forest resources. Conservation of forest in the upstream also implies protection of the whole watershed. However, the greater access to natural pastures by Limbukha, Matalumchu and Omteykha only can be a threat to forest. In contrast other four villages do not have access to grazing land and this is a pertinent example of inequitable access to resources. Except Nabchee and Bajothangu, all villages have more than 60% of land as irrigated rice terraces (Table 8). Although hydrological measurements were not made in this study, minimum flow at the tail-end of the stream demonstrates the pressure on water resources. The pressure is so high that during the peak of the rice transplanting season, there is hardly any water flowing out of the watershed (Jamtsho 2002).

Table 8. Land use by village in the Lingmuteychu watershed, 2001.

District	Village	Grazing land (ha)	Forest (ha)	Irrigated rice land (ha)	Rainfed crops (ha)	Total farmland (ha)	% Irrigated farmland
Punakha	Limbukha	64	801	34	12	46	74
	Dompola	1	316	4	2	6	67
	Nabchee	0	439	1.5	6	7.5	20
	Omteykha	19	129	42	8	50	84
Thimphu	Matalumchu	95	659	58	2	60	97
	Wangjokha	0	0	40	0.5	40.5	99
Wangdue	Bajothang	0	0	0.5	6	6.5	8
Total		179	2344	180	36.5	216.5	
Average							64

Source: RNRRC, 2002.

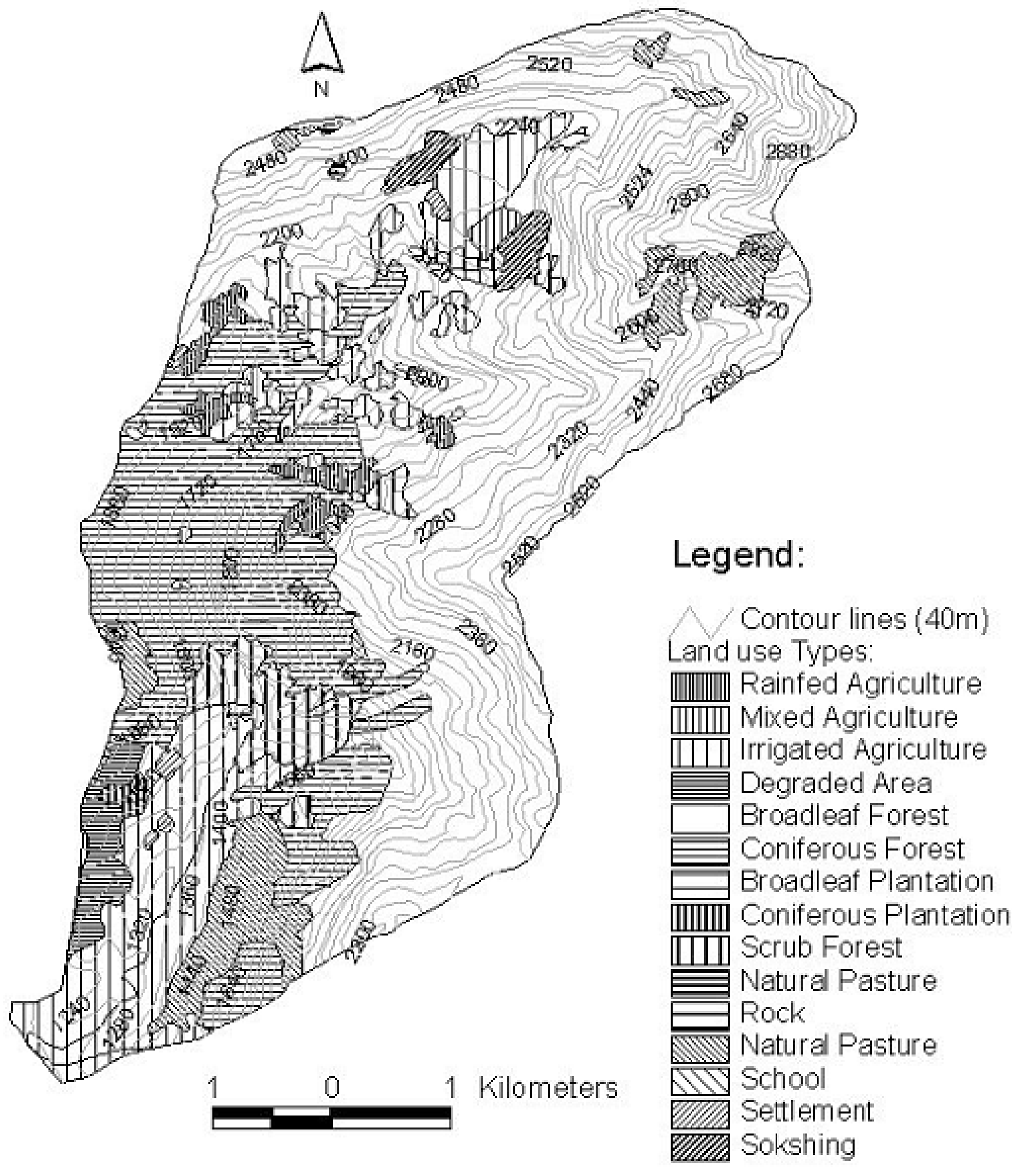
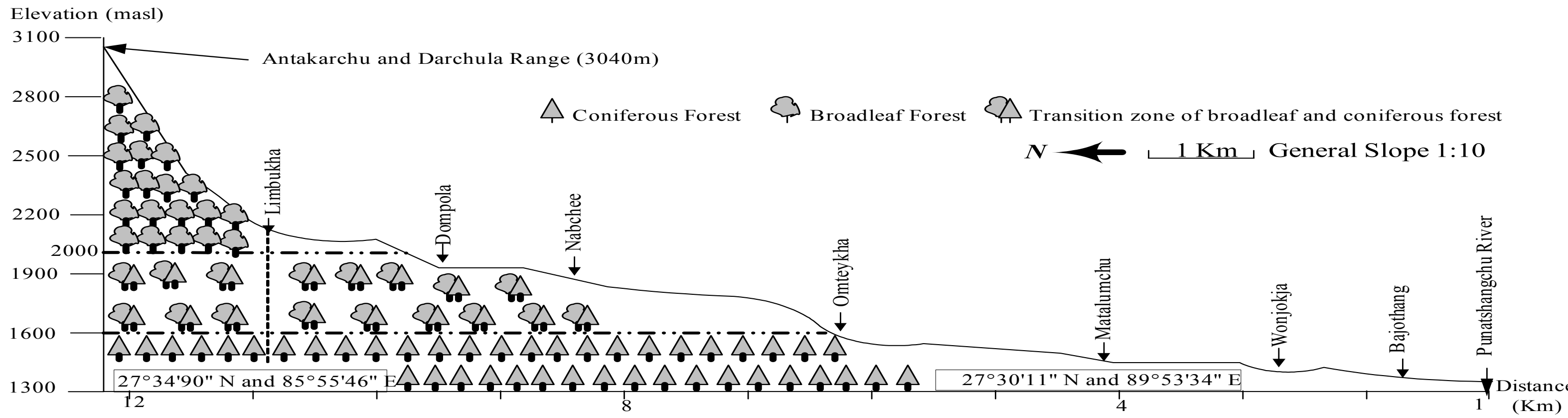


Figure 13. Land use map of Lingmuteychu watershed, 2002.

Source: RNRRC, 2002

(Note: Sokshing is a woodlot on which either individual or the community has right-to-collect for leaf litter and dry firewood).



District	Punakha				Thimphu		Wangdue
Villages	Limbukha	Dompola	Nabchee	Omteykha	Matalumchu	Wangjokha	Bajothang
Altitude (masl)	2170	2100	1870	1600	1500	1300	1300
Vegetation	Broadleaf forest				Coniferous forest		
Access to forest (distance)	Very good	Good	Very good	Moderate	Poor	None	
Soil Type	Dark brown clay	Dark brown and sandy loam	Shallow and deep brown sandy loam				Middle and upper terrace soil
Irrigated rice land (ha)	34	4	1.5	42	58	40	0.5
Dryland (ha)	12	1.5	6	8	2	0.5	5.5
Major Crops	Rice, potato	Rice, wheat, vegetables	Maize, vegetables	Rice, wheat, vegetables		Rice, wheat, mustard	
Households	36	35	20	28	20	16	15
Main income source	Potato, rice	Vegetables	Maize, off-farm within watershed	Rice	Vegetables	Off farm (Contract work outside watershed)	
Problems	Wild animals and weeds	Water shortage and wild animals	Wild animals and water access	Water shortage	water shortage and wild animals	Water shortage	Water shortage
Potentials	Potato and rice production	Enhancing water use efficiency	Dryland crops	Rice, wheat production, and access to market (Road)			

Figure 14. North-south longitudinal transect line of Lingmuteychu watershed. December, 2003.

51

Irrigation infrastructures

There are 5 major irrigation networks in Lingmuteychu watershed. They are Limbukha, Dompola, Omteykha, Matalumchu and Wangjokha/Bajothangu. The first four schemes derive water from the Limtichu stream, and Wangjokha/Bajothangu is irrigated by Bajo canal that brings water from another watershed (Figure 15). As four major channels depend on one source of water, this increases the conflict over access to the water. In principle based on traditional rules, the upstream communities have greater control over water and tend to hold water for longer time. In such situation, downstream communities have to satisfy their needs by their agreed share. However there are cases of water stealing too. As the majority of the canals are earthen without concrete lining, the conveyance efficiency of these canals are reported to be only 40%, which is extremely low (RNRRC, 1998).

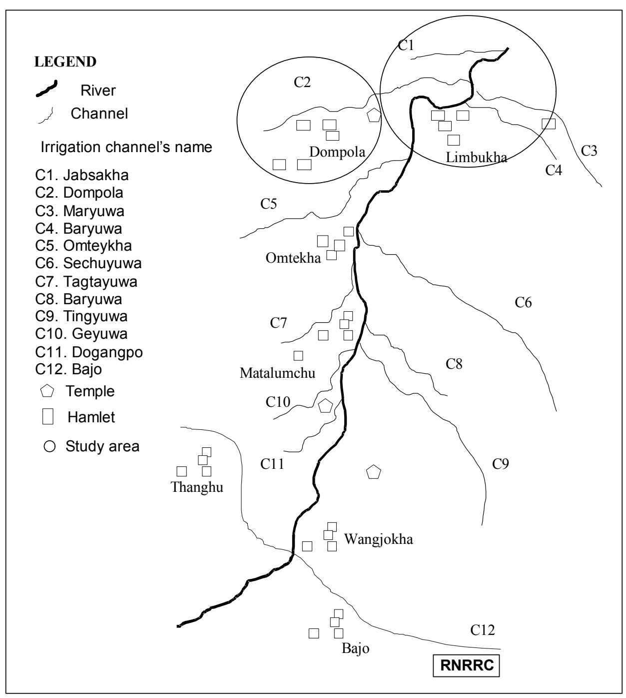


Figure 15. Sketch of network of irrigation canals in Lingmuteychu watershed. (Not to scale)

Source: RNRRC, 1998.

4.2. Cropping systems

4.2.1 Crop diversity and combinations on farms

Farmers in Lingmuteychu watershed grow diverse crops ranging from rice, wheat, potato, maize, to different species of vegetables. Almost all farmers practice rice-based cropping systems, with the exception of the Nabchee community where maize-based cropping is a more common practice. From the total cropped area of 216 ha, high altitude rice accounts for 52% of the area followed by wheat, mustard, maize and potato (Figure 16). Traditional rice with red pericarp is particularly grown at high altitude and is preferred for its special taste and social status. White rice varieties are preferred for making pop-rice and beaten rice. While rice is grown in all 7 villages, potato is grown only in Limbukha and mustard only in villages located below 1600m.

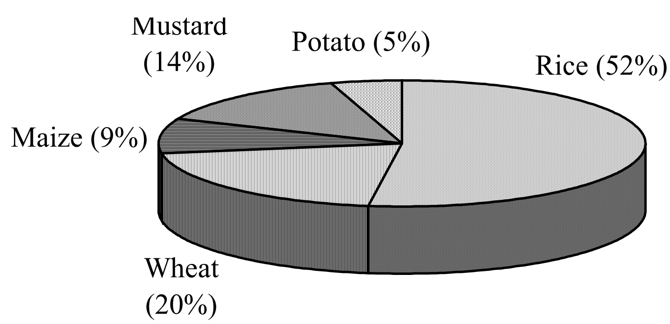


Figure 16. Crop types and share of cropped farmland in Lingmuteychu watershed in 2002.

Farmers generally use traditional varieties of all their crops, as they have special preferences for them. In Lingmuteychu, there are 4 traditional varieties of rice and 1 each of other crops. Correspondingly, there are 7 recommended varieties of rice, 5 for potato, 4 for soybean and 3 each of wheat, maize and mustard. It should be noted that farmer has grown local variety of potato for long time in dryland or kitchen gardens. The potential yields of different crops are given in Table 9.

Table 9. Crop varieties and their potential yields in Lingmuteychu watershed, 2002.

Crops	Yield (t ha^{-1})		Varieties (No.)	
	Recommended/ introduced	Local	Recommended/introduced	Local
Rice	5.1	3.8	7	4
Wheat	1.5	1.3	3	1
Maize	5.0	5.4	3	1
Mustard	0.5	0.4	3	1
Soybean	1.2	1.1	4	1
Potato	16.4	10.6	5	1

Source: RNRRC, 2002.

4.2.2 Cropping patterns

To get a better understanding of the two villages in the upper catchment, their cropping calendar was developed in relation to climatic factors. Figure 17 show 3 cropping patterns each in Limbukha and Dompola. In Limbukha potato-rice and rice-wheat is practiced in irrigated terraced fields, while maize-radish and chili as a sole crop is grown in rain-fed fields. In contrast, Dompola farmers practice rice-wheat pattern in irrigated terraced field and maize-mustard/radish and chili as sole crop in rain-fed fields. The main contrasting features between two villages is the potato crop in Limbukha overlapping rice transplantation, which is assumed to have an impact on water use in both villages. Limbukha farmers start transplanting rice in the second week of May until mid of June. Subsequently rice is transplanted in Dompola and this has to be completed in the last week of July because of the effect of cold temperature at flowering. The maximum limit of transplanting date in both villages is to avoid rice flower coinciding low temperature in September-October. The overlap in transplanting period, receding rainfall and deadline to complete rice transplanting escalates competition for water. The pressure is more severe in Dompola, as Limbukha farmers flood and hold water in their fields for a long period (RNRRC 1998).

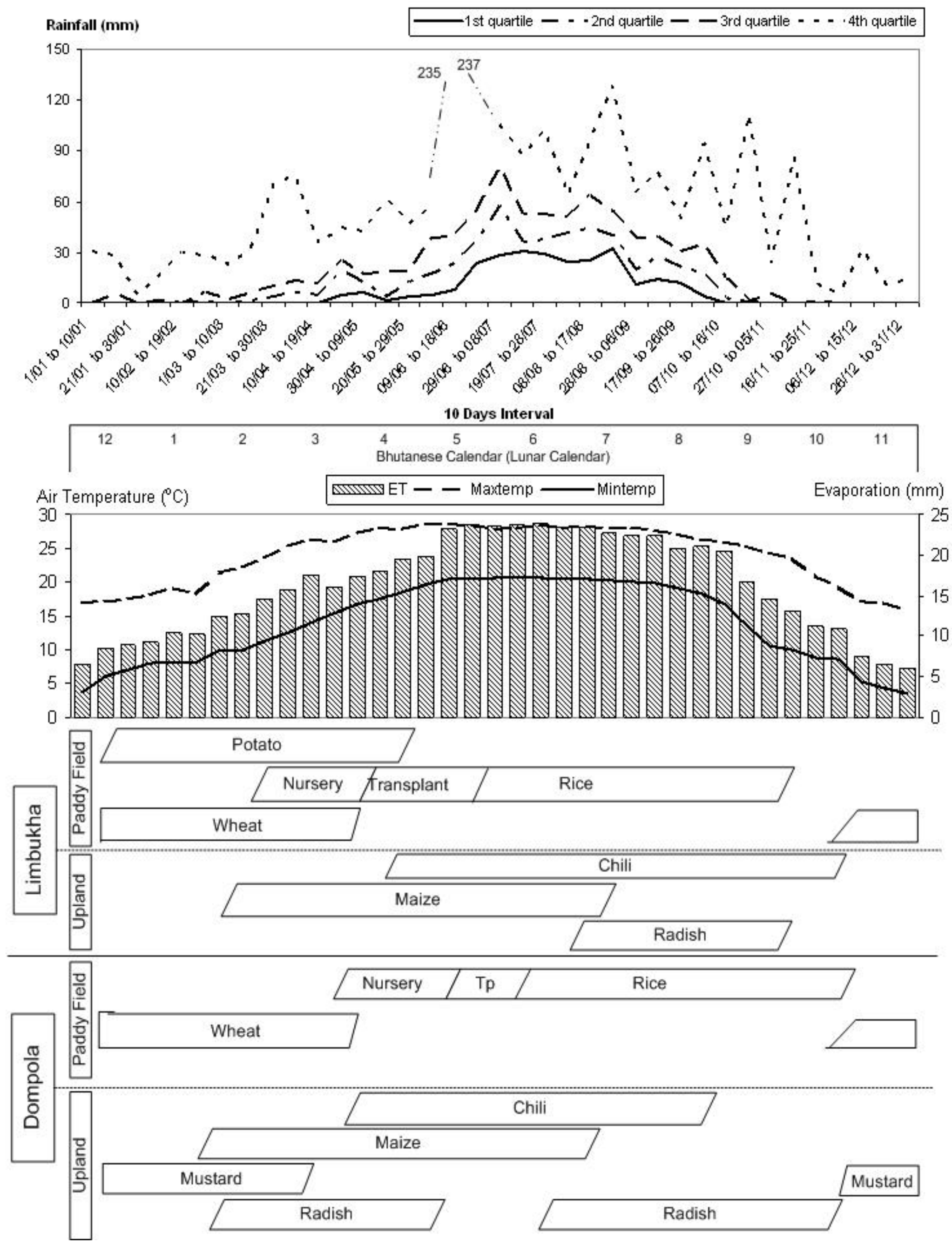


Figure 17. Cropping patterns in relation to climatic factors in two upstream villages of Lingmuteychu watershed.

N.B: Rainfall data is for 17 years (1985-2001); air temperature and evaporation for 6 years (1990-1995); 10 days interval corresponding to rainfall pattern is used for temperature and evaporation graph. Source: CORE

4.3. Socio-economic features

4.3.1 Demography

There are 162 households in Lingmuteychu watershed, with an average household size of 8 there are 1,296 people residing in the watershed. Male to female ratio in the watershed is almost 1:1 (RNRRC, 2002). To get a better insight in their educational background and occupation, 26 household from Limbukha and 21 from Dompola were interviewed. They represented 53% male and 47% female belonging to age groups between of 17 to 81 years. In both villages, high proportions of people have not attended school at all. However things are changing as 27% of Limbukha and 30% from Dompola villagers are presently studying in primary schools. Consequently, high proportions of population engage themselves in farming. According to the interviews, 53% of Limbukha and 49% of Dompola people have farming as their main activity (Table 10).

Table 10. Educational background and occupation of people in two villages of Lingmuteychu watershed, 2003

Educational Background (%)			Occupation (%)		
Level	Limbukha (n = 162)	Dompola (n = 150)	Type	Limbukha (n = 162)	Dompola (n = 150)
Nil	43	39	Farmer	53	49
High school	14	16	Civil Servant	9	9
Primary school	27	30	School children	22	30
Monk	12	9	Trader	2	1
University	2	2	Monk	7	7
Minor (<6 years old)	3	4	Village headman	1	0
			Asst. to Village headman	1	0
			Minor (<6 years old)	5	4

4.3.2 Population distribution

The population density of the watershed is 39 person km^{-2}, which is higher than the national population density of 14 persons km^{-2} (Central Statistical Organization, 2001). The Population density provides a way of measuring the impact of people on the natural environment. Intensity of resource use, transformation of the ecosystem, and conflict in access to natural resources depend on the level of population density. However, as each village operates independently in terms of resource use systems, analyzing population density at village level both against total land and farm land will provide a better understanding of the local pressure on natural resources. While the density per total village area for most villages is below 50 person km^{-2}, it is comparatively high for Wangjokha and Bajothang mainly because of the lack of forest areas (Table 11).

Table 11. Household and population density of different villages in Lingmuteychu watershed, 2002.

District	Village	No. of Households	Average HH Size[a]	Person km^{-2} of total village area	Person km^{-2} of farmland
Punakha	Limbukha	28	6.4	47	441
	Dompola	35	7.2	26	964
	Nabchhe	20	11.4	46	3115
	Omtekha	28	6.5	18	365
Thimphu	Matalumchu	20	9.7	49	323
	Wangjokha	16	7.3	117	294
Wangdue	Bajothang	15	7.3	255	1795
Average			8.0	39	576

[a] RNRRC 2002.

The population pressure on farm land is very high with an average of 576 person km^{-2} at the watershed level. Nabchee and Bajothang appear denser due to limited farm lands in these villages. Nabchee is a resettled community with limited access to land, water, and other resources. The high population densities in Nabchee and Bajothang explain that people from these two villages often engage in off-farm activities. The relatively high population density at watershed level also substantiates the pressure on resource including water, as every household tries to maximize the use of scarce resources.

4.3.3 Access and communication

The villages in Lingmuteychu watershed are linked by small meandering tracks used for mules and treks to ensure movement of goods and people (Figure 18). In 1996, a 18 km long feeder road was constructed as a diversion from Wangdue-Shengana road which provided the watershed villages with an access to the nearby towns of Wangduephodrang and Punakha and ultimately to the national east-west highway. This motorable road has facilitated cash income generation from crops like potato, rice and vegetables. It has also helped in marketing animal products like butter and cheese. While the ground distance is approximately 11 km from Limbukha to Bajothangu, it takes 5-6 hours of walk up to Limbukha from Wangjokha. The motorable road has reduced travel distance to 1 hour thus helping farmers to market their agricultural products. In return, people can take materials in bulk at much cheaper cost and in short time. The electrification and installation of satellite telephones in the watershed in 2003-2004 has further facilitated the overall socio-economic development of the community.

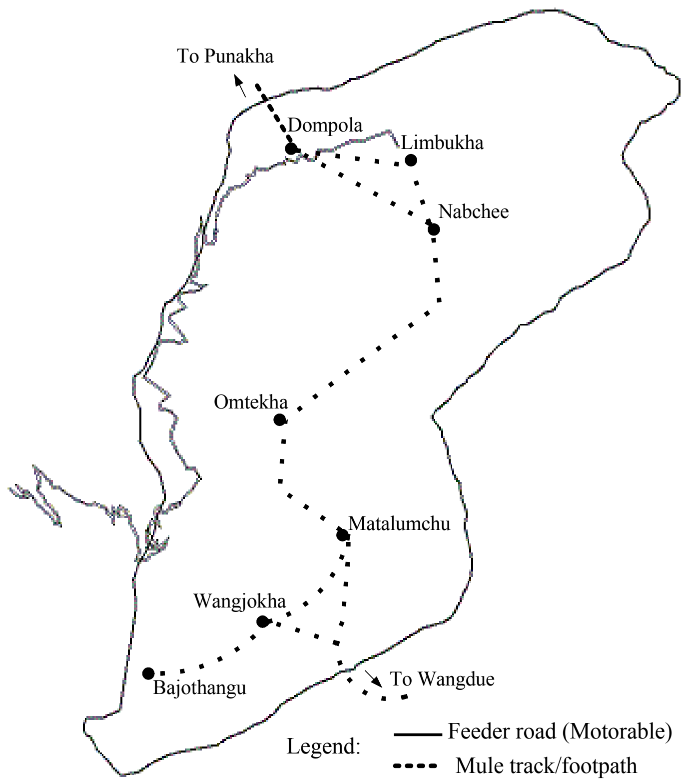


Figure 18. Sketch map of road and tracks in Lingmuteychu watershed

4.3.4 Income sources

Income sources in the watershed range from agriculture crops, dairy products, off-farm activities, and remittances from family members. The annual average income for a Limbukha farmer is US$ 2,144 and US$ 1,624 for Dompola. The 32% higher income in Limbukha is due to potato production. In both villages, remittances form the major source of income contributing 47% of total income in case of Limbukha and 36% in Dompola. Potato, rice and vegetables are major source of income in Limbukha, while Dompola farmers derive higher proportions of income from selling oranges, off-farm employment, and dairy products (Table 12).

Table 12. Sources of annual income for water sharing categories in Limbukha and Dompola, 2003 crop year (in US$).

Village	Sources	Water sharing category			
		Thruelpa	Cheep	Chatro	Lhangchu
Limbukha	Potato	386	333	222	333
	Paddy	244			
	Maize	111	11		
	Vegetables	155	244	355	166
	Butter & cheese	188	222	111	155
	Off-farm	111			
	Remittances	1079	887	1064	
	Total	2274	887	1064	321
Dompola	Beans	111	78		
	Maize		111		
	Vegetables	67	155	144	
	Orange		222		
	Peach		111		
	Butter & cheese	177	155	222	
	Off-farm	155	185	222	
	Remittances		296	887	
	Total	332	3087	1331	

There is variation in income earned among the water sharing category. For instance, Thruelpa of Limbukha earns US$ 2,274 per annum while a Lhangchu earns only a meager US$ 654 per annum. Thruelpa of Limbukha with a larger land holding and access to water, sells rice both within and outside the watershed. In Dompola, a Chatro earns higher income than other category due to higher remittances capacity and off-farm employment outside the watershed in contractual works. Thruelpa in Dompola earned 22% lower than a Lhangchu of Limbukha. This lower cash income was mainly due to limited income source, particularly absence of remittances. Another possibility may be due to limited access to water and other resource.

4.3.5 Utilization of income

In general income is spent through four major categories of expenses (Table 13). Family use utilizes above 70% of the total income and includes expenses incurred in purchase of household consumables, clothing, farming, education and other miscellaneous expenses.

Table 13. Utilization of annual income among water sharing categories of people in Limbukha and Dompola villages. 2002 crop year

Village	Category	Total Income (US$)	% of Income used for			
			Family need	Community contributions	Savings	Investments
Limbukha	Thruelpa	2274	73	10	19	0
	Cheep	1696	57	13	20	13
	Chatro	1752	87	3	10	0
	Lhangchu	654	78	7	15	0
Dompola	Thruelpa	510	65	8	28	0
	Cheep	1312	76	13	11	0
	Chatro	1475	68	13	19	0

Every household contributes on an average 10% of their income for community activities like annual offerings to the local deities, renovations of community infrastructures and community gathering. As mentioned elsewhere, there is a saving group in Dompola that encourages people to save by depositing approximately US$ 1 per month. Thus on an average they save 19% of their income, while Limbukha farmers save 16% of their income on individual basis without any saving group scheme. There was one instance of investment of remittances in Limbukha to repair/construct a house.

4.4. Differentiation among farming systems

4.4.1. Historical profile

Table 14 displays a brief historical profile of the area developed from secondary data and key informant survey to help understand the nature, origins, causes, extent of the main transformations that somehow influenced the evolution of current farming systems in the watershed. Based on the profile, it can be observed that a shift from the traditional feudal dominated agrarian system into a present tenure system emerged after 1952 with the abolition of serfdom.

Table 14. Historical profile of Lingmuteychu watershed.

Economic and social changes	Date	Agroecological and agronomic transformations
Land ceiling to 10-12 ha per household and abolition of serfdom	1952	Land ownership and household-based small-scale farms
Resettlement of villagers	1952	Clearing forest in Nabchee and establishment of settlement of people from eastern part of Bhutan
Taxation (Kind to monetary)	1969	Surplus production for generating cash income
Access to forest resource transferred from community to government lead to open access situation	1969	Deforestation due to indiscriminate harvesting leading to resource degradation
Standardization of land ownership and tenancy	1979	Increase cropping intensity
Rehabilitation of irrigation channels by the Department of Agriculture (Maryuwa and Baryuwa channel in 1984 and Omtekha channel in 1986)	1984	Efficient water diversion and delivery to farms, increased irrigation command areas
Institutionalized local development committee	1987	Resources were managed according to peoples' plan.
Construction of feeder road as a joint investment project (Machines and materials provided by government; and labor and fuel by beneficiaries)	1997	Potato as major cash crop in Limbukha, rice and vegetables as cash crop in watershed.
Renovation of the Dompola canal with government assistance	1997-98	Improved the conveyance efficiency of canal
Abolition of *Gungda Woola* (labor contribution)	1999	Increase in off-farm within and outside the watershed
Rural electrification program	2003	Forest conservation, (less consumption of firewood)

It was further strengthened in 1979 when the Land Act was ratified. A major shift in the resource management regime particularly forest and forest based resources, took place when the forest was nationalized in 1969. Subsequently forest became an open access resource for any individual to use. The pressure on resources further increased when people from remote areas were resettled in areas with higher crop production potentials and better access to social services, leading to higher concentrations of users. Introduction of taxation, construction of roads, improved access to technologies and inputs, geared farming systems towards more commercialization. With the change of policy to involve people in local development, it can be seen that people will have to learn the effect of their action and manage the resources in sustainable manner.

4.4.2. Farmers objectives and strategies

Considering that the farmers in the watershed operate in a diverse socio-economic and resource constrained situation although geographically small in extent, it is critical to understand their farming objectives, the farm environment in which they operate, their management choices, and possible improvement. As suggested by Trébuil et al. (1999), to study functioning of farming systems five aspects needs to be analyzed: (i) family situation, farming system size and objectives; (ii) farm environment; (iii) strategy for livelihood; (iv) combination of farm activities and their technical and economic performances; and (v) improvement potentials. Four farm types corresponding to FAO's farm classification (McConnell and Dillon, 1997) were identified in Lingmuteychu watershed as (i) small independent specialized commercial farms; (ii) small independent specialized part-commercial family farm; (iii) small semi-subsistence or part-commercial family farms; and (iv) small subsistence-oriented family farms. These four objectives almost precisely match with the four water sharing categories of villagers in the watershed.

4.4.3. Farming systems typology

Four distinct types of farming systems were identified for the study area based on the analysis of functioning of farming systems (Figure 19 a,b,c,d). The corresponding farm functioning diagrams clearly show that differences are mainly due to resource endowment linked to different social status. Within each type, two subclasses were identified based on the farm location. The differences in the features of these two subclasses clearly show a disparity in access to resources leading to conflict. Depending on their objectives, each type of farm has a unique choice of production and economic activities, and subsequently of management options. The environment in which they function is to a large extent, similar and characterized by a shortage in supply of water, wild animal damages, labor shortage and access to market. From the analysis of differences in the functioning of farming systems (Figure 19 a,b,c,d), key parameters were identified to distinguish fairly precisely the differences between the four types and subtypes. Major production choices, related management options and access to irrigation water were used to classify farm types. The classification of four farm types was used to further group farms of two villages (Table 15). According to the farm typology, 37% of the farms (35 in Limbukha and 2 in Dompola) can be categorized as Type 1. Similarly, Type 2 includes 26% of the farm; 28% as Type 3, and 8% as Type 4. The analysis also showed that higher percentage of farms control larger share of irrigation water particularly in Limbukha. This could lead to disparity in access to irrigation water. Considering the irrigation as one of the important inputs in irrigated rice, accessing irrigation water at right time and to right volume is of paramount importance. Farm Type 1 with full access to water and during appropriate time put them in advantage. In contrast 30% of the farms in Dompola have to share half of the irrigation flow which increases the conflict for water. The Type 4 farm which represents 8% of the farms, have to depend of other farmers for water. Basically they have to exchange water against labor, which further put the Type 4 under pressure to get water.

a/ Small independent specialized commercial farms (Type 1) in Limbukha and Dompola villages of Lingmuteychu watershed, 2002 crop year.

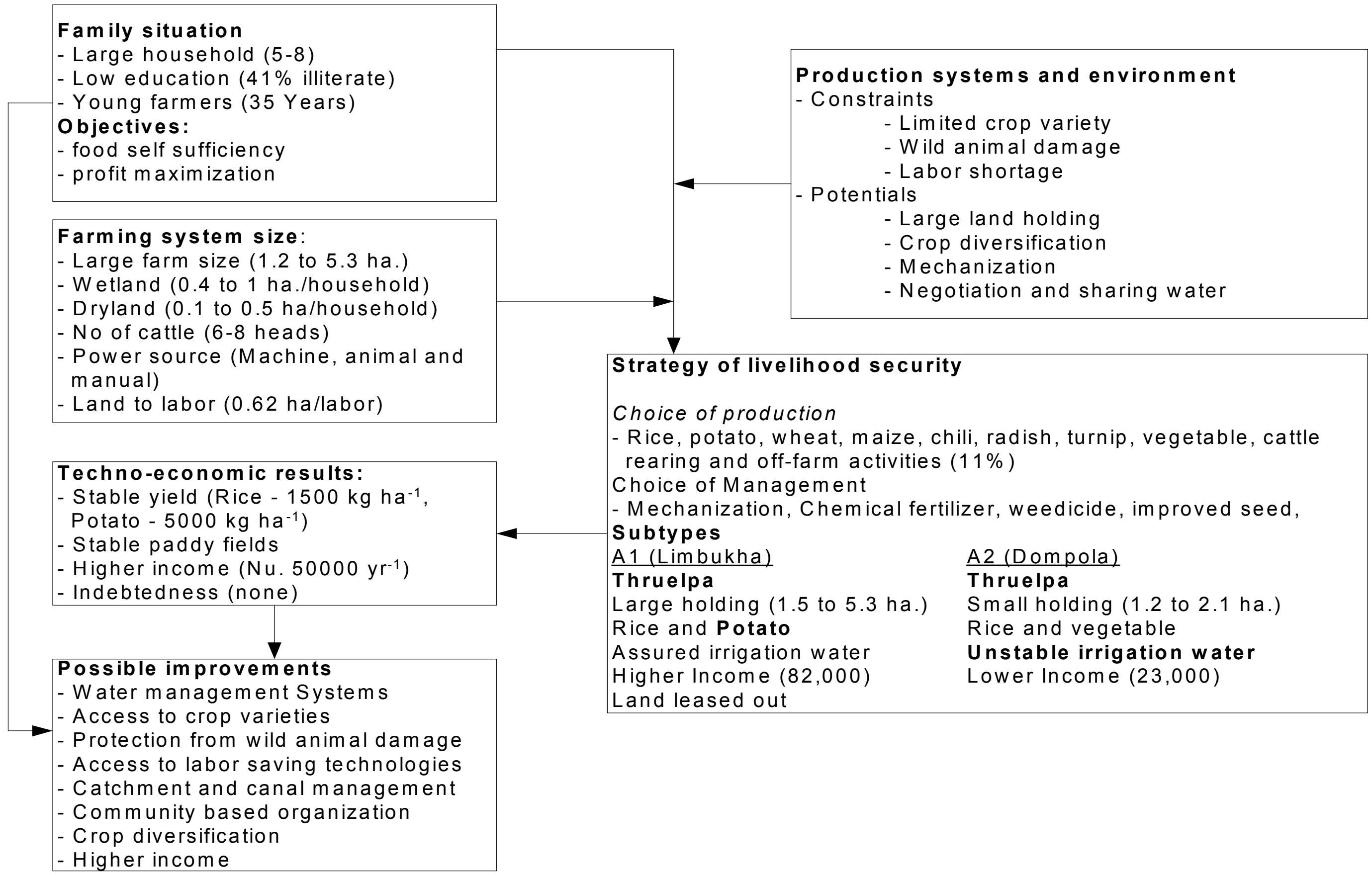


Figure 19a. Schematic representation of the functioning of four types of farming systems in upper catchment of Lingmuteychu watershed

65

b/ small independent specialized part-commercial family farm (Type 2) in Limbukha and Dompola villages of Lingmuteychu watershed, 2002 crop year.

Family situation
- Large household (4-12)
- Low education (38% illiterate)
- Young farmers (40 Years)

Objectives:
- food self sufficiency
- livelihood security
- income generation

Farming system size:
- Medium farm size : (0.3 to 2.4 ha.)
- Wetland : 0 to 2 ha./household
- Dryland : 0 to 1 ha/household
- No of cattle : 4-5 heads
- Source of power : manual and animal
- Land to labor (0.45 ha/labor)

Production systems and environment
- Constraints
    - Limited crop variety
    - Wild animal damage
    - Limited land holding
    - Limited access to irrigation water
    - Insect pest and disease problem
- Potentials
    - Yield maximization
    - Crop intensification
    - Negotiation and sharing water

Strategy of livelihood security

Choice of production
- Rice, potato, wheat, maize, chili, radish, turnip, vegetable, **citrus, mustard**, cattle rearing and off-farm activities

Choice of management
- manual and animal powered, limited chemical fertilizer and weedicide,

Subtypes

A1 (Limbukha)	A2 (Dompola)
Cheep	**Cheep**
Large holding (1.55 to 2.42 ha.)	Small holding (0.3 to 4.2 ha.)
Rice and **Potato**	Rice, vegetable, citrus and mustard
Assured irrigation water	**Unstable irrigation water**
Higher Income (15,000-55,000)	Lower Income (6,000-32,000)
Land leased out	

Techno-economic results:
- Stable yield (Rice - 1300 kg ha^{-1}, Potato - 2500 kg ha^{-1})
- Stable income (Nu. 33,000 yr^{-1})
- Nutrient and Pest Management
- Irrigation water management
- Indebtedness (None)

Possible improvements
- Water management Systems
- Access to crop varieties
- Pest and disease management
- Nutrient management
- Protection from wild animal damage
- Catchment and canal management
- Community based organization
- Crop diversification
- Higher income

Figure 19b: Continued.

66

c/ small semi-subsistence or part-commercial family farms (Type 3) in Limbukha and Dompola villages of Lingmuteychu watershed, 2002 crop year.

Family situation
- Large household (3-7)
- Low education (35% illiterate)
- Young farmers (35 Years)

Objectives:
- Food self sufficiency
- Livelihood security

Farming system size:
- Large farm size : (0.15 to 1.4 ha.)
- Wetland : 0 to 0.7 ha./household
- Dryland : 0.05 to 1 ha/household
- No of cattle : 1-2 heads
- Source of power: manual and animal
- Land to labor (0.26 ha/labor)

Production systems and environment
- Constraints
  - Limited crop variety
  - Wild animal damage
  - Limited land holding
  - Limited access to irrigation water
  - Insect pest and disease problem
- Potentials
  - Yield maximization
  - Crop intensification
  - Negotiation and sharing water

Strategy of livelihood security

Choice of production
- Rice, potato, wheat, chili, radish, vegetable, cattle rearing and off-farm activities

Choice of management
- manual and animal powered, Nutrient source: Farmyard manure, Weed control: hand weeding

Subtypes

A1 (Limbukha)	A2 (Dompola)
Chatro	**Chatro**
Large holding (1 to 1.3 ha.)	Small holding (0.15 to 1.2 ha.)
Rice and **Potato**	Rice, vegetable, citrus and mustard
Assured irrigation water	**Unstable and limited irrigation water**
Lease in Land for cultivation	Lease in Land for cultivation

Techno-economic results:
- Stable yield (Rice - 1300 kg ha^{-1})
- Stable income (Nu. 33,000 yr^{-1})
- Nutrient and Pest Management
- Irrigation water management
- Indebtedness (Owe to Cheep and Thruelpa)

Possible improvements
- Water management Systems
- Access to crop varieties
- Pest and disease management
- Nutrient management
- Protection from wild animal damage
- Catchment and canal management
- Community based organization
- Crop diversification
- Higher income

Figure 19c. Continued.

67

d/ small subsistence oriented farms (Type 4) in Limbukha and Dompola villages of Lingmuteychu watershed, 2002 crop year.

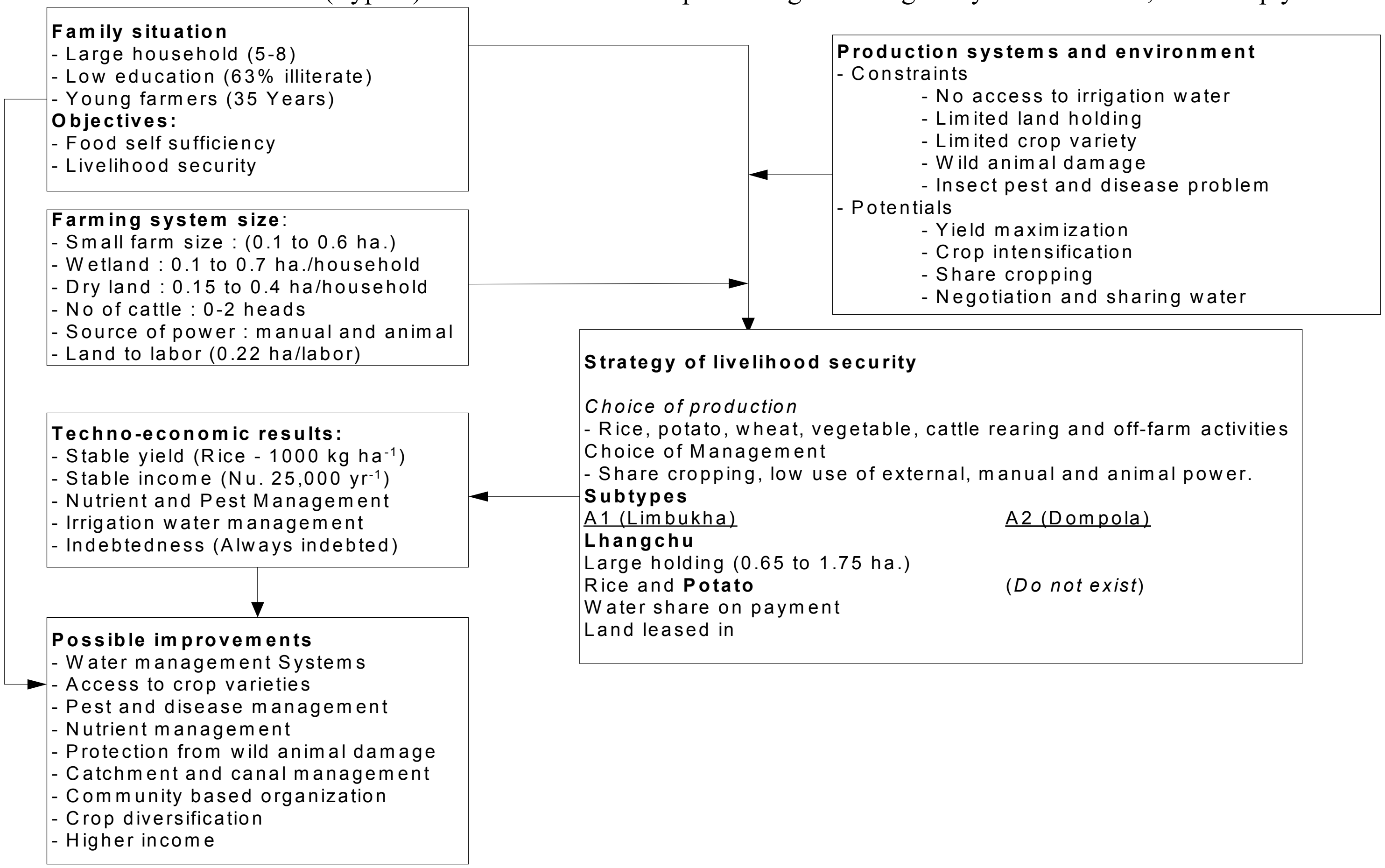


Figure 19d. End.

68

Table 15. Share of irrigation water used by different farm types in two villages of Lingmuteychu watershed.

Typology	Land holding (ha)	Water share	Income source	Management choice	% Farms (n = 49)		Farmer category
					Limbukha (n = 33)	Dompola (n = 16)	
Type I: Small independent specialized commercial farms	1.2 - 1.5	Full flow of canal	Potato and vegetables	Mechanization, fertilizer and pesticides	35	2	Thruelpa
Type II: Small independent specialized part-commercial family farm	0.3-2.4	Half of Thruelpa's share	Potato and vegetable	Manual and animal power, chemical fertilizer	16	10	Cheep
Type III: Small semi-subsistence or part-commercial family farms	0.15 – 1.4	Half of Cheep's share	Potato, vegetables, off-farm, dairy	Manual and animal power	8	20	Chatro
Type IV: Small subsistence oriented farm[a]	0 - 0.6	No share	Off farm	Share cropping, manual	8	0	Lhangchu

[a] Type IV farmers also grow potato and sell in small quantities.

69

4.5 Summary

The use of the principles of agrarian systems analysis and detail analysis of functioning of farming systems have helped in establishing a concrete understanding of the study area. The diagnosis particularly helped in classifying the diversity of farming systems and typifying them which facilitated in identifying constraints and potentials influencing functioning of the farming systems. With the understanding of the situation, the typologies will help in focusing the intervention. As the diagnosis sufficiently integrates physical, ecological, social and economical aspects of the farming systems, the knowledge generated can form as an entry point to very specific and focused interventions. As the analysis advance in hierarchical manner, from watershed to farm household, it helps in converging to the level where the problem is most critical. In doing so, it helps in relating both the potentials and constraints to different hierarchies, such that the intervention does not become a stand-alone solution. The findings of the diagnostic analysis will be vital input for designing the role-playing game.

Chapter V

Role gaming sessions in Dompola

Two sessions of role-playing games were organized in May and December 2003 in Dompola. As explained in Chapter 3, 12 farmers played both sessions of the game. The results from the game were recorded in Excel spreadsheets and hardcopy (hand records). Following the game sessions, interview of individual players was done which helped in evaluating RPG. As the game proceeded, facilitators maintained record of observation. In this chapter above information are integrated and analyzed.

5.1. Knowledge representation and its validation by the players

The first RPG session in May was conceptualized and designed by researcher based on the understanding gained from field study. The game was tested with researchers and trainees at RNR-RC, Bajo before playing in Dompola. Subsequent to the test, the number of plots and options for sharing water was incorporated in game. The second session of game played in December was basically the same game with provision for sharing water against labor and involvement of development committee members as observers of the game session. The second session was also tested with trainees at NRTI and subsequently played in Dompola.

Majority of the farmers considered that the gaming parameters represented the real situation. One farmer remarked, "It appeared like playing a game but recalling in the evening all appeared precisely real and stimulating." The players adjusted themselves to the gaming environment, after one round of play. The game board was made on a poster paper with rows and columns representing plots. 82% of the respondents confirmed that the game board represented the distribution of their fields. During the intra-village communication mode, definite patterns existed in choosing crops and fields in the first cycle of each crop year. Although it revealed that potato was planted in central plots to facilitate its protection from wild boar damages. Players said that in reality potato fields are numerous and are much scattered. All accepted the categorization of farmers in terms of access to water and number of fields. But 27% (one each from Thruelpa, Cheep, and Chatro) of them thought that the cash allocation was too high, as farmers may not be in a position to gain access to that amount in reality to start farming.

Water share, water units, and the influence of rainfall on water availability were the main features that players related to reality. Although water exchange depends on the demand from those who need it, kinship played a dominating role in the exchange of water. Whenever there was unused irrigation water, it was first given free of charge to relatives who needed water. It was stated that it is shared on the mutual basis of helping each other in times of need. Only after satisfying the demand of relatives they would exchange with other players wanting it to exchange against labor. In the first gaming session, players introduced exchange of water for cash.

Initially it was assumed that potato cultivation in Limbukha would have effects on access to irrigation water by Dompola farmers. Player said that potato is in fact harvested before the rice transplanting season starts in Dompola. Therefore, occupancy of Limbukha terraces by potato did not influence the water-share for Dompola.

Among the three scenarios, farmers preferred the second scenario as it allowed them to collectively share resources and work together, which do not happen in reality. One participating member stated, “it is more fun and interesting to work together in a community, helping each other to pull along.” Players further said that they were of the opinion that the existing water sharing system was sound and two villages could never work together due to the physical distance between them. The second scenario allowed players to exchange water against labor between two villages. Although this exchange of water between the two villages does not exist in reality, 45% of the players responded that water exchange could happen between the two villages. Further, they suggested that, when there is plenty of water at the source, it should be shared. With the increased dependence of Limbukha on farm labor from other villages and other socioeconomic dependence, this should provide a basis for cooperation and the collective decision-making process in natural resource management, primarily for water.

5.2. Improvements suggested by the players

It became evident from the game and individual interviews during first RPG session that the inclusion of labor in the game as a means for water exchange would improve interactions in the game by making it closer to reality. As farm labor is the most limiting resource in Limbukha farms, inclusion of labor as a variable in the game could produce unique reactions. It was also suggested that the number of plots per farmer category and the initial capital provided to each player might have to be revised. Prior to the start of the gaming session, more elaborate discussion on rules of the game and process with the farmers/player will help in enhancing the relevance of the game. Players also suggested during the first RPG session to include local development committee, officials from District administration and local public institutions as observers in future games.

5.3. Learning experiences

As a learning experience from the game, 36% of the players reported that it helped them to understand the benefits of sharing water with neighbors both within and between two villages, to enhance their land-use system, productivity, and income. This was evident from the discussion on the preliminary results before the plenary session in May, 2003 (Figure 20). The game also helped in understanding the valuation of water share for 27% of the respondents. This implied that, given the opportunity, a water market could emerge in the system.

Apart from the economic valuation of water, the game helped to open up new understanding of the social dependence between villages, particularly in terms of labor for water exchanges and other services. The players also believed that the RPG helped them to understand the value of maintaining farm accounts, the problems of a neighboring village, and the importance of completing farm work on time. For Dompola farmers, the game gave them the idea to attempt potato cultivation either in

Dompola or by leasing land in Limbukha where soils are more suitable to grow potato cash crop to increase their incomes.

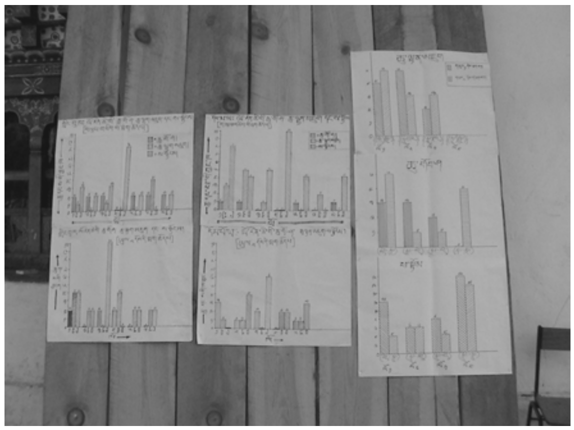


Figure 20. Preliminary results and players discussing the results, May 2003

The comparison of the lessons learned from two gaming sessions held in May and December 2003, indicates that over the period between two sessions of RPG, community members informally discussed and even assessed the impact of their decisions on resource sharing. It was unfortunate that, observations and recording of these discussions could not be done. A player from Limbukha said that they had discussions on water sharing prior to attending the second session of RPG. While there were five lessons learned from first RPG session, player reported only four lessons learned from the second session (Table.16). In both cases, importance of sharing water was the most important lesson for all players. Compared to the lessons learned from May 2003, 90% of the players (70% waters sharing, 10% canal management, and 10% on-farm water management) in December 2003 learned need and benefit of water management and sharing (Figure 21). This shared learning is an important output from RPG and it is expected that it will have dramatic influence in the way players will behave in future.

Table 16. Lesson learned by farmers from two sessions of RPG played in Dompola in May and December, 2003.

First Session of RPG	Second Session of RPG
Benefits of sharing water	Share water
Valuation of water	Canal management
Maintaining farm accounts	On-farm water management
Completion of work on time	Farm account
Water shortage problem of Dompola	

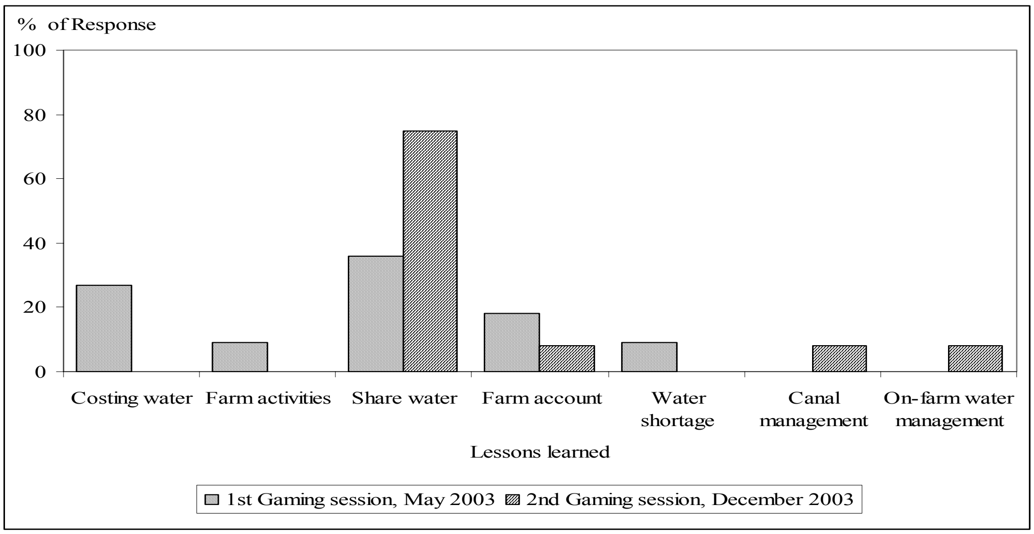


Figure 21. Lessons learned by players from 2 gaming sessions, May and December 2003

The responses of the players in the Dompola RPG on its possible uses indicated that 36% of the players considered its use for crop production problems followed by 27% who thought it useful for promoting community actions. Others thought that RPG could be used for awareness building and collective learning.

5.5. Understanding the decision-making process and its impact on resource use

The impact of the way players decide to use water and capital can be assessed from land use changes and water use dynamics. To capture the process, three different communication modes: intra-village; inter-village and swapped roles were used in two sessions of RPG. The following sections present the impact of inter-village and intra-village communication mode on land use, water, labor and income.

5.5.1. Intra-village mode of communication

The irrigation system in Lingmuteychu can be classified as a fixed system and such systems are known to be stable requiring little efforts to operate but they are also less flexible. It is the rigidity of the traditional system, which does not permit alternative approaches for managing it. Although water exchange depends on demand, kinship played a dominating role in the exchange of water in the study site. Within each village farmers held water in their fields beyond the crop requirements which deprived other farmers from accessing irrigation water. As reported by Jamtsho (2002), both villages use excess amount of water in rice cultivation which further builds on the pressure.

Land use dynamics

The most critical effect of decision on water use and sharing were land use changes over the crop years. These changes were further influenced by the rainfall pattern. In each year, two rainfall types "normal and low" were used as patterns and used randomly during the gaming session. Result in Figure 22a show that the 36% of plots remained fallow in Limbukha when rainfall pattern was low in both cycles. This validates what farmers told during interview and discussion, that water availability for transplanting rice depends on stream discharge and rainfall. In all rainfall patterns, there are fallow plots, except when both cycles have normal rainfall. It was also observed that rainfall patterns did not have any effect on number of plots planted to potato. It always fluctuated between 15 and 17.

In contrast, 39% of the plots were left fallow in Dompola, which is higher than in Limbukha (Figure 22b). It was also observed that 10% of the fields remained fallow in Dompola when rainfall pattern is either normal-low or low-normal. Similar to Limbukha, it is only during normal-normal rainfall pattern that all plots are planted to rice. The main difference in proportion of fallow plots between two villages is due to the limited exchange of water that takes places within kinship network.

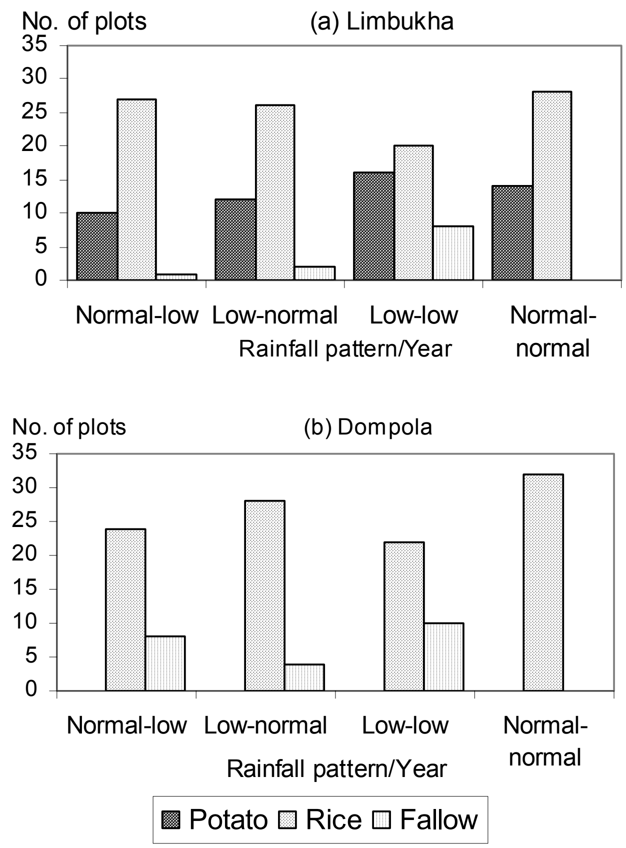


Figure 22. Land use patterns in Limbukha (a) and Dompola (b) during intra-village communication mode, May 2003

Water use dynamics

In Limbukha all 4 water sharing categories of farmers exist. Among them Thruelpa who represent 54% of the village population received full flow of water. In case of Dompola, 86% of the farmers are Cheep and only 14% Thruelpa. Water sharing is more organized and structured in Limbukha village, which could be due to shortage of irrigation water. As Limbukha village is next to source of irrigation water, they always have direct access to stream. It was reported that, Limbukha farmers face acute problem of water only when rainfall is low in both cycles. During interviews it was reported that stealing from others' share is rare in Limbukha. However, stealing of water was reported to be a problem for Dompola. Sharing of water among relatives is one of the important strategies used by both villages, to cope with shortages among some members of the communities. The kinship network was more prominent in Dompola compared to Limbukha (Table. 17).

Table 17. Kinship structure among players

Village/ Farmers		Village/Farmers											
		Limbukha						Dompola					
		1	2	3	4	5	6	7	8	9	10	11	12
Limbukha	1		s										
	2	b			n								
	3												
	4		a										
	5												
	6												
Dompola	7									b	b		
	8										i	u	
	9							s			b		
	10							s	i	b		i	
	11								np		i		
	12												

b = Brother; s = Sister; a = Aunt; n = Niece; u = Uncle; np = Nephew; i = In-law

Throughout the years played, Limbukha farmers shared on an average 5% of the total water allocated, leaving behind 6% as unused irrigation water (Figure 23a). Although Dompola farmers shared 2% of their water, they were left with only 4% of the water as excess (Figure 23b). Whenever there was unused irrigation water, it was shared within the village. In addition to sharing water according to kinship, sharing was also done by exchanging water against labor. One water turn (12 hours of discharge) was equated to 1 person-day of labor during the rice transplanting season. In the game, the players introduced a cost of US$ 2 per unit of water (equivalent to one day's wage). As this rule was not initially documented, it was not included in the RPG rules. With the increasing competition and demand for water, the cost of water and labor was raised to US$ 4 per unit. The tendency to monetize water became an incentive for players to manage it efficiently. It confirms to the behavior what Trawick (2003) stated as when resources are priced, it gives people strong incentives to use them more efficiently, and the idea of a water market is often reported to have strong appeal to economists and bureaucrats.

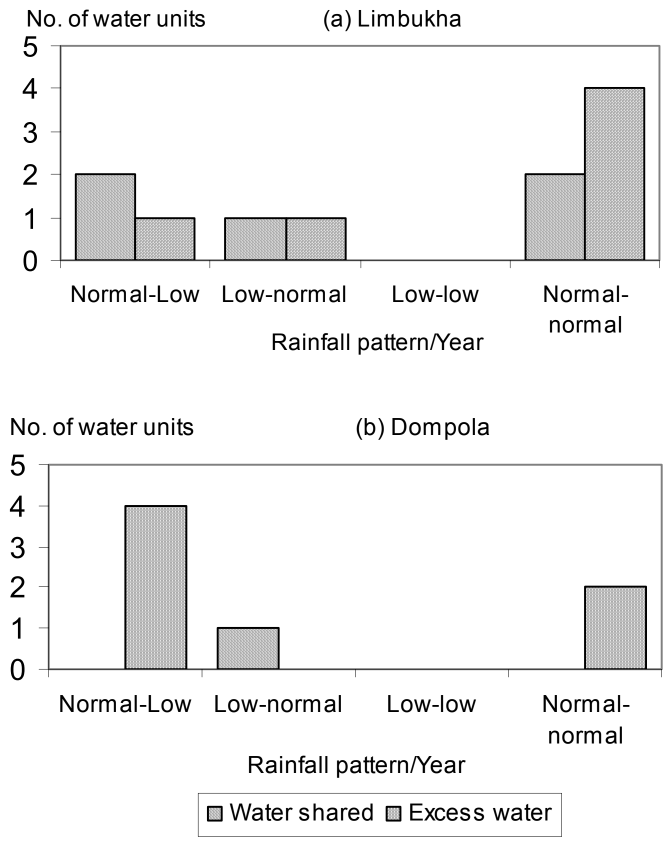


Figure 23. Water use dynamics in Limbukha (a) and Dompola (b) following intra-village communication mode

According to individual interviews, it was reported that more than 36% of the player in first RPG session and 50% in the second session shared water. One day share of water was exchanged with 1 person day of labor during rice transplanting, which was confirmed by 83% of the respondent as a actual practice. However, 75% of them expressed that kinship plays a determining role in exchange of irrigation water. Practically they would first look around if their immediate relatives have fulfilled their water requirements, after that water was exchanged with anyone willing to exchange with labor. In the game, player either paid cash or gave labor against water.

Labor use

In second session of RPG 50% of the respondents were involved in the exchange of labor. There were 42% of the players who did not get labor despite their request. The rejection was mainly because each one had pre-arranged with the ones who had excess of water. It implies that players communicate before the planting starts. As the game progressed, 33% of them did try alternative means to exchange labor either by increasing the labor wage, sacrificing the land and selling the labor or pre-arranging the exchange of water and labor. The highest number of excess labor existed in a year when rainfall pattern was low in both cycles. In the game, while Limbukha faced labor shortage, Dompola farmers were always left with 100-300 person days of excess labor (Figure 24).

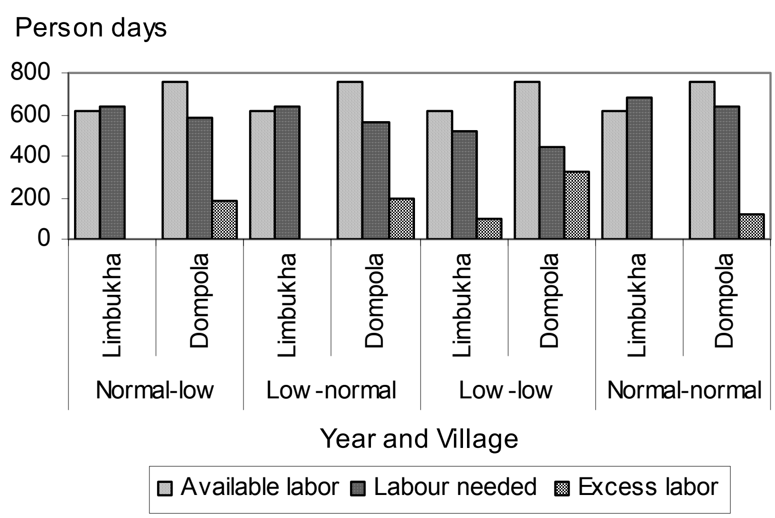


Figure 24. Farm labor use in Limbukha and Dompola during Intra-village game, December 2003

5.5.2. RPG based on communication at the inter-village level

The two communities have been in constant conflict regarding sharing water. The past attempts to bring them together to discuss and negotiate have not yielded any meaningful outcome/directions. Even in the RPG, when both villages were grouped for collective discussion on decision-making regarding water use, farmers initially flocked to their individual village cluster and exhibited unreceptive expressions. This was the initial response, but it gradually turned into a very congenial environment featured by lots of exchange of views, water sharing, and discussions on cropping and other aspects of livelihood among the villages.

Land use dynamics

There was no influence of the communication mode on land-use in Limbukha. The average percentage of plots planted to rice and fallowed were 91% and 9%, respectively, in both communication modes in Limbukha. However, in Dompola, there was a 4% increase in plots planted to rice under the collective communication mode (Figure 25a and b). This implies that when farmers communicate collectively, the Dompola farmers seem to share water more efficiently. In first RPG session, players introduced water sharing between the two villages, which benefited Dompola farmers.

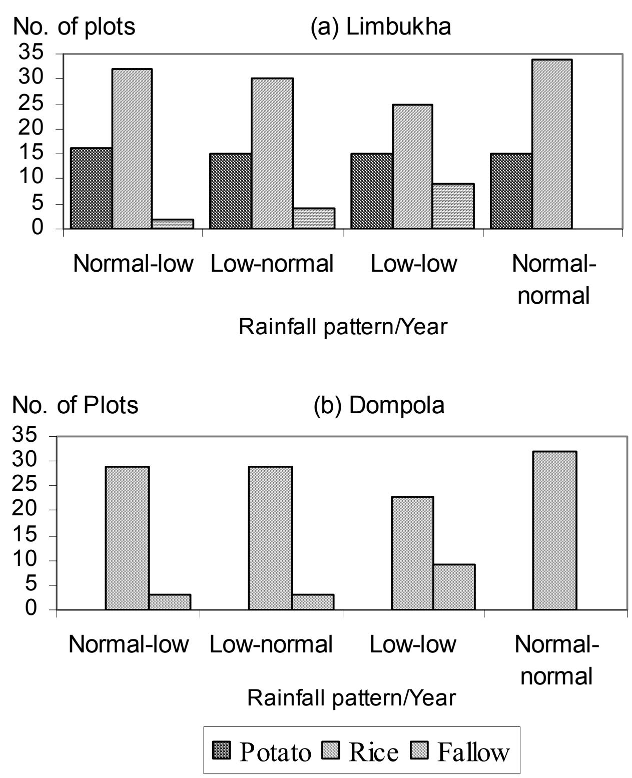


Figure 25. Land use patterns in Limbukha and Dompola under the inter-village communication mode, May 2003

Water use dynamics

In the collective mode of communication players exchanged water between two villages, thus introducing the new protocols to exchange water. Limbukha farmers found that in the collaborative mode they could sell or exchange the unused irrigation water with Dompola farmers and earn more income. Compared to intra-village communication mode, Limbukha player shared most of the water and were left with no unused irrigation water, except during normal-normal rainfall pattern (Figure 26a).

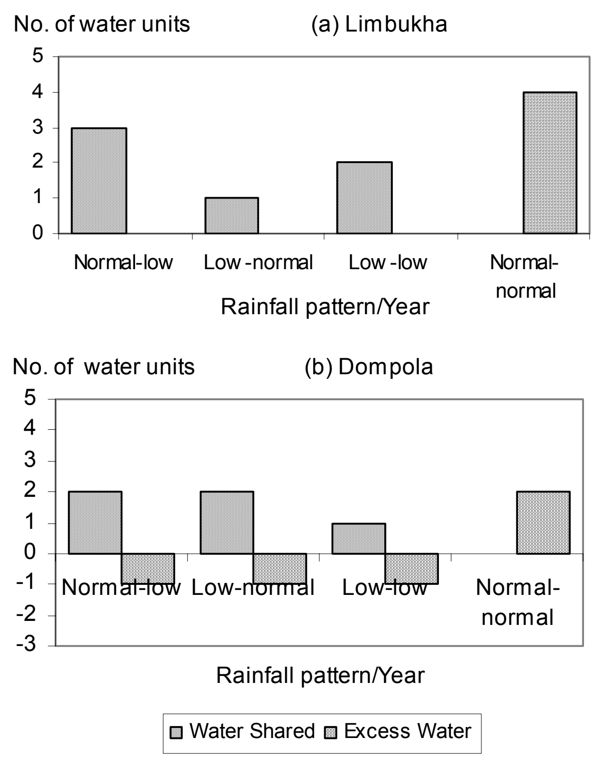


Figure 26. Water use dynamics in Limbukha (a) and Dompola (b) following inter-village mode of communications, December 2003

In the collective mode, Dompola farmers seem to benefit the most in terms of access to water. In all the years played under collective mode of communication, Dompola players received water from Limbukha. Therefore, the percentage of fallow plots declined from 16% in the intra-village mode to 11% in the inter-village mode in

Dompola. In year 1 (NL) and year 3 (LL), Dompola farmers even received water from Limbukha farmers, an example of inter-village exchange (Figure 26b). Particularly in the low-low rainfall pattern, the number of fallow plots decreased from 10 in the intra-village communication mode to 8 in the inter-village mode. It is evident that the number of fallow plots declines substantially in the collective mode. One of the reasons for this reduction is increased access to water.

Labor use

In real situation, Limbukha hire in labor from Nabche (One of the villages in watershed) to work during rice season. But in the game they could exchange with Dompola against unused irrigation water. It was designed to enhance interaction among players and see if new norms in exchange would emerge. In the game, Dompola players had excess labor in all years. In contrast Limbukha players ran short of labor during normal-normal and normal-low rainfall pattern. The negative labor in Figure 27 against Limbukha implies labor received from Dompola. It also represents that two villages readily exchanged labor against water and cash.

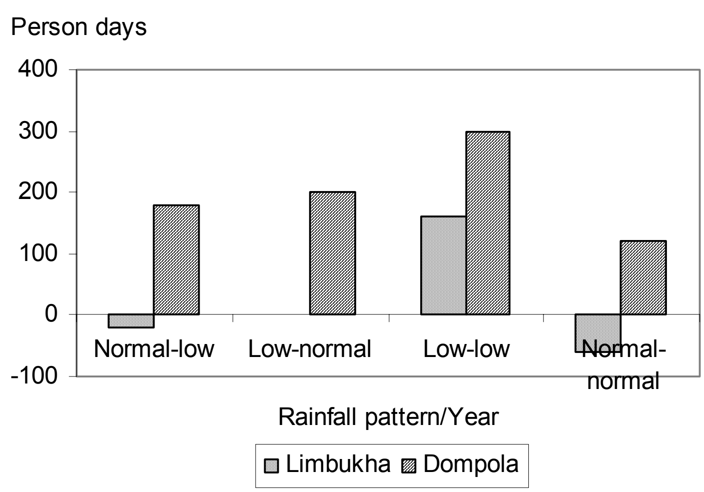


Figure 27. Excess labor in Limbukha and Dompola during inter-village communication mode, December 2003

Income

In both sessions of RPG, income was calculated and paid to the players after every time step (year of play). All the players considered income as an indicator of their success and impact of their decisions on water and land-use. This was evident as all players, after every year of play, spent some time to assess the amount of accumulated income. Income analysis showed that, overall farmers' income was 19% higher in the intra-village communication mode (Figure 28). This could be due to cultivation of potato in Limbukha that generate lots of income. Importantly, it can be seen that income is comparatively uniform in the collective communication mode than in the intra-village communication mode. When assessing the performance of different farmer categories, all categories except Lhangchu have more stable income over the years. It is also visible that, variation of income in more prominent among Limbukha farmers than in Dompola, this can also be related to choice of crop in Limbukha.

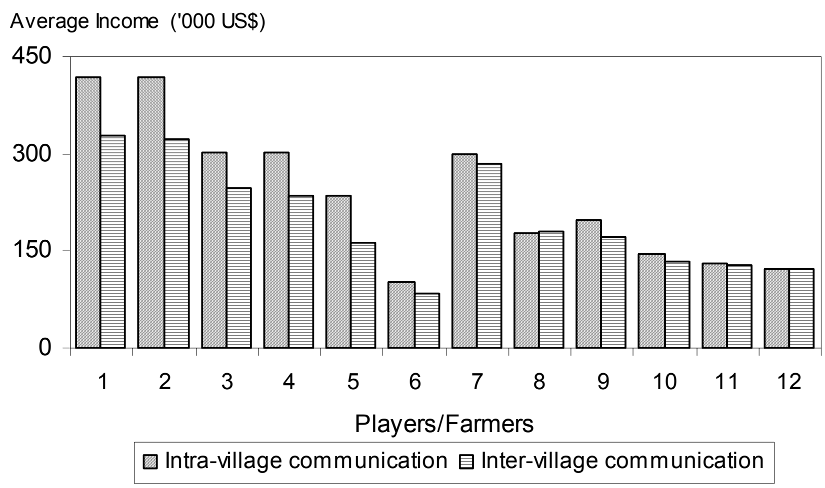


Figure 28. Income variation among farmer categories according to two modes of communication, December 2003

This implies that collective communication results a more uniform distribution of income, based on the effective sharing of resources. It also indicates that sharing of water beyond the village boundary with other villagers provides an opportunity for the villagers to sustain their production and income.

5.5.4 Swapped role between two villages

As a third scenario in the role-playing game, the role of each player was swapped with that of another village. It was swapped in the order of 1 taking the role of 7, 2 that of 8, 3 that of 9, and so on. Farmers swapped the roles as they considered it as a means to discover and experience the condition of the other village.

Similar to other studies, the pertinent benefit of the swapped game was the learning experience for both teams. There was one player who hesitated to play the role of the Dompola farmer, as his major concern was low income. We presumed that demotion in role from higher category to lower made the player discontented. The rest of the players considered the session as an opportunity to learn about the problem of Dompola farmers and the potentials of Limbukha farmers.

5.6. Performance of irrigation system

For the purpose of generating greater interactions and motivation among the players in the RPG, 3 comparative indicators out of the 9 indicators developed by IWMI were adapted and used in the study (Molden et al., 1998). The three comparative performance indicators relate output to unit of land and water used. The 3 comparative indicators are output per unit cropped area, output per unit command area, and output per unit of irrigation water diverted. Actually these comparative indicators make it possible to see how well irrigated agriculture is performing at the system, basin or national scale. However, in this study as it has been adapted to use as a tool to measure comparative performance of irrigation in two villages.

- *Gross margin per unit of cropped area*: It is the average gross income of all the players received from all the plots planted to crops. For instance, in Limbukha number of potato and rice plots together form cropped area.
- *Gross margin per unit of command area*: It is the average total gross income of all the players per hectare of command area. The total command area in the game for Limbukha is 3.4 ha and 3.2 ha. For Dompola.
- *Gross margin per unit of water used:* It is the average total gross margin received from growing crop against the unit of water used to irrigate the field.

5.6.1 Gross margin per unit of cropped plot in the game

The gross margin simulated from the RPG was used to calculate output per hectare of cropped area. The number of plots planted with potato and rice are considered as cropped area. Based on the RPG results, gross margin per hectare varied between US$ 1,035 and $ 2,042 per hectare with an average of $1,688 and standard deviation of 382 US$ (Figure 29). The gross margin per hectare of Dompola is almost at par with Limbukha during normal rainfall pattern. When the season starts with low rainfall and when both the cycles face low rainfall, output of Limbukha as a whole is lesser than Dompola. It implies that rainfall and limited supply of water affects Limbukha more than Dompola.

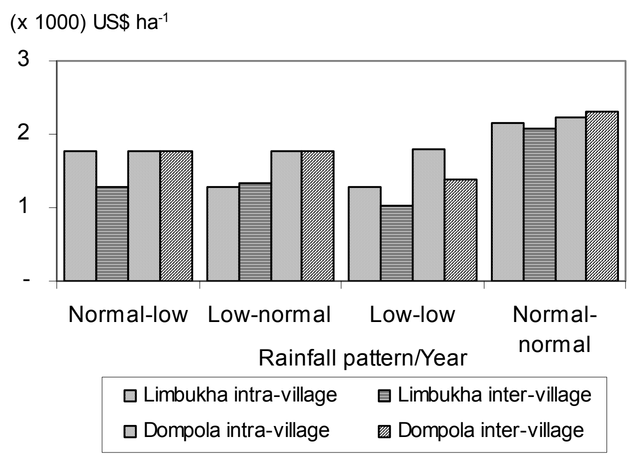


Figure 29: Gross margin per hectare of cropped area (US$ ha^{-1}) in Limbukha and Dompola generated from RPG, December 2003.

However, reduction in output during year of low-low rainfall pattern in a collective mode was more prominent in the case of Limbukha. It was also observed that intra-village mode of communication performed better compared to inter-village communication. For instance, on an average output was 12% higher for under intra-village communication than inter-village mode in Limbukha. In case of Dompola, there was not much difference between two communication modes.

5.6.2 Gross margin per unit command area in the game

In the game, crop yield depended on rainfall pattern and the crop price varied with the market state. The gross margin per unit of command area varied between US$ 992 and $ 3,150 per hectare of command area (Figure 30). Gross margin in Limbukha under intra-village communication mode was 12% higher than under inter-village communication. However, there was no significant difference between the gross margins under two communication modes. This indicates that Limbukha players are better organized and efficient in crop selection and water sharing under intra-village communication mode. But under the collective communication mode, Limbukha players shared water with Dompola, which could have lowered their income. Conversely, a higher output was expected in Dompola under collective mode, which was not the case. It was only when rainfall pattern was normal in both cycles that there was an increase of 4% in gross margin in Dompola.

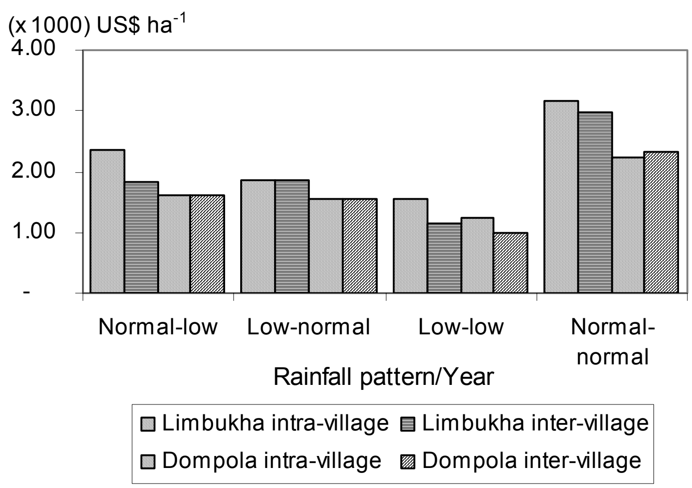


Figure 30: Gross margin per hectare of command area (US$ ha^{-1}) in Limbukha and Dompola generated from RPG, December 2003

5.6.3 Gross margin per unit of irrigation supply

Output per unit of irrigation supply in Figure 31 varies from US$ 0.7 to $ 3.7 per Cubic meter of water supplied. On an average and across both communication modes, gross margin of Dompola was 55% higher than that of Limbukha. In both the villages, there was 40% increase in gross margin when rainfall pattern was normal in both cycles. During other rainfall patterns gross margin is consistently low in both the villages. As in the earlier two indicators, in case of Limbukha on average gross margins under intra-village mode are 22% higher than in collective mode. Comparison between two villages, show higher gross margin in Dompola, in collective mode, gross margin of Dompola is 62% higher than of Limbukha. This can be associated to use of limited water appropriately.

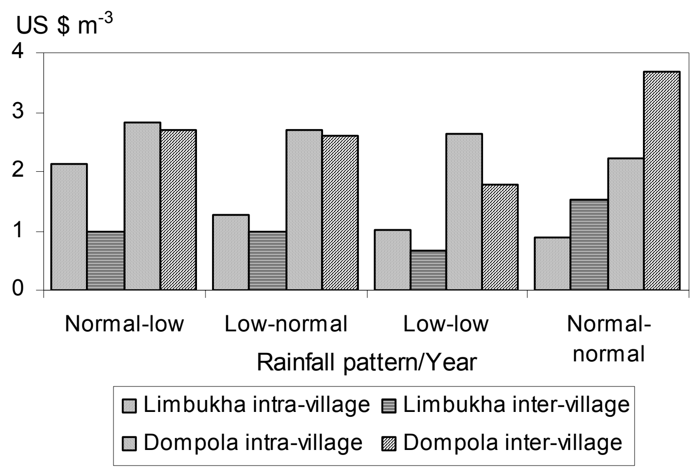


Figure 31. Gross margin per unit of irrigation water supplied (US\$ m^{-3}) in Limbukha and Dompola generated from RPG, December 2003

Based on the gross margin per cropped area and command area, irrigation canal in Limbukha perform better than Dompola canal. While the differences are not very obvious, sharing the water resource through collective mode of communication can enhance the performance of Dompola canal. However, Dompola players performed better than Limbukha players in terms of using irrigation water, which was seen from higher gross margins per unit of water used.

5.7 Summary

The farmers of two conflicting villages willingly accepted role-playing game as a means to express their concern on water sharing. The results from the game indicated that RPG has been efficient in collective learning, learning about the problem and process. The game outputs helped in better understanding the problem of water sharing and its impact. The use of three scenarios (mode of communication) created friendly environment for active interaction among the player.

From the game, it was clear that rainfall is a determining factor in ensuring the availability of irrigation. Kinship network determines sharing of irrigation water within a village. This closed sharing system is assumed to be a risk avoidance strategy when resource is limited. Within each village, players exchanged water against labor or cash. The pressure of water can be visualized by the structured and fixed water sharing system followed by Limbukha village. Dompola lacked the structured system of water sharing, which can be related to water stealing and time spent on guarding the canal. This opportunistic behavior of Dompola farmers could be related to unstable (uncertainty) irrigation supply. The game also revealed that the alternative communication mode can provide many alternatives for players to test its applicability. The unused irrigation water in Limbukha was efficiently shared with Dompola village against excess labor available in Dompola. It was also clear that monetizing water makes players more judicious in use of water. As the intra-village communication mode represented the reality, players tended to perform better even in the game. The inter-village communication mode did not influence Limbukha players in terms to resource use and income. However, it was clear that in the collective mode, Limbukha players could share all the unused irrigation water with Dompola player. Over all, Dompola players benefit more from collective communication mode.

Comparative performance indicator used in a tentative way revealed that Limbukha village performs better in term of gross margin per unit of cropped and unit of command area. Dompola performs much better in terms of output per unit of irrigation water. This is indicative information used in the game to show how individual player's performances can influence the overall performance of the village.

The dynamics used in the RPG will form a major input to the MAS model explained in Chapter VI. The role or kinship and exchange protocols will be used in generating multiple scenarios for identifying viable options for improving the situation

Chapter VI

MAS modeling in Limbukha

The information generated from the diagnostic study and role playing games were used in conceptualizing the MAS model. The objective of the model was to represent the RPG and to facilitate integration of knowledge for better understanding of interactions among agents, to explain the effects of their decision processes and facilitate communication between two conflicting communities. Subsequent to the role-playing games in May and December 2003, a MAS model was developed which was called the "Limbukha model". Although the RPG is a resourceful tool, operationally they are cumbersome, slow in action orientation, and analysis of their results is difficult (D' Aquino et al., 2002a). For these reasons, peculiarly a MAS model finds its place in associations with a RPG as it facilitates handling of numerous parameters, produce speedy results, multiple options for experimentation, and importantly visualization of results.

In the case of Dompola RPG, the gaming process was limited to 5 to 7 time steps because of time and other practical constraints. The RPG helped in understanding and creating rules, which later were used in MAS simulations. A MAS model can supplement and complement a RPG, as they share a common representation of the complexity. MAS offer the possibility to represent individuals, their behavior and interactions, thereby representing emerging collective phenomena from micro level interactions (Ferber, 1999).

This chapter briefly describes the Limbukha model and the simulations generated from the model. Based on the findings from diagnostic studies, RPG and behavior of base model, 36 scenarios have been proposed here for further exploration.

6.1 Model structure: class diagram

The entities were identified and an initial class diagram was constructed to show all the model entities, attributes, methods, and their structural relationships

(Figure 32). While the attribute characterizes the entity, methods are the task entity undertakes in the model. The basic information on the linkages was derived from discussions with farmers and researchers. They are explained in the following sections.

6.1.1 Spatial entities

Spatial entities are made of elementary spatial entities and composite spatial entities. An elementary spatial entity represents the smallest homogenous unit of the environment in the model (a cell in CORMAS environment).

Plots

In Limbukha model, the plot represents the elementary spatial entity. It is considered as the smallest homogenous unit that corresponds to the lowest land unit (1 langdo = 0.1 ha) owned by any individual in Dompola and Limbukha. The basic interactions take place at plot level. The plot is characterized by 4 attributes: *plot number*, *myblock (*collection of plot belonging to one farmer*)*, *croppingpattern* and *crop*. The possible values of these attributes in the model are presented in Table 18. This entity undertakes only one operation (task) to update the status of the plot.

Table 18. Attributes of the elementary spatial entity in Limbukha Model

Attributes	Value	Represents
Crop	1 or 2	Rice and potato
plotNumber	1 to 8	Plot numbers in each field
myBlock	1 to 12	Field of 12 players
CroppingPattern	1-2, 0-2	0 = fallow; 1= potato; 2 = rice

Blocks

Each agent has a number of plots, which are collectively represented as block. In Limbukha model there are 12 fields assigned to 12 farmers depending on their category. As the plots are components of block, the block is considered as composite spatial entity in Limbukha model.

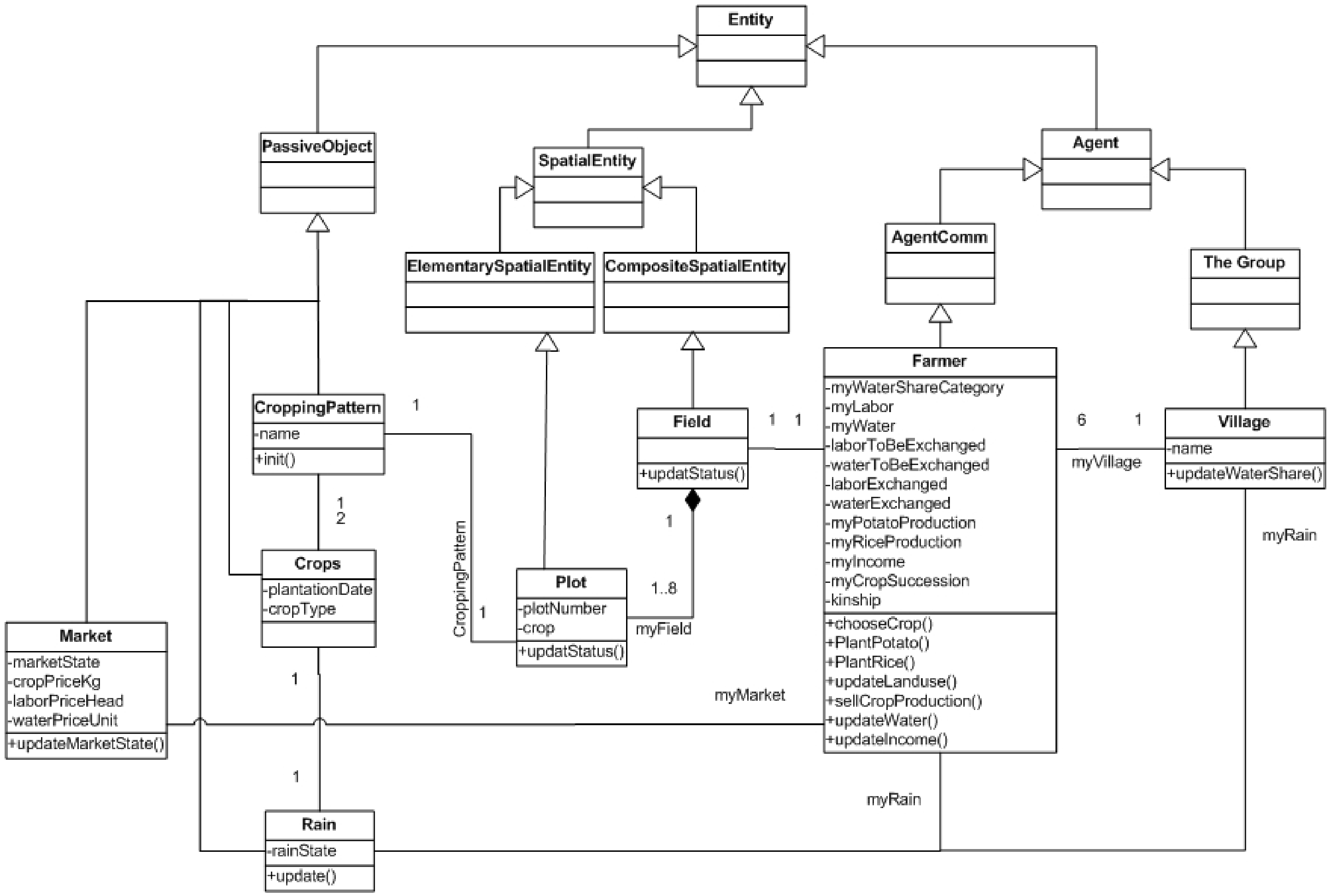


Figure 32. Class diagram of Limbukha model

92

6.1.2 Passive objects

Passive objects are collections of *exchanges* (message) of the *AgentComm* and simple objects. As the whole dynamics of the model is centered on farmer who is the communicating agent of the Limbukha model, they maintain constant interaction among farmers by way of sending the messages. In Limbukha model simple objects are *rain, croppingPattern, crops, and market.* Each simple agent has its own independent attributes and methods.

- *Rain*: the task of this object is to generate rainfall pattern for two cycles of the time step. There are two cycles in one time step, and each cycle can have either low or normal rainfall. It was done to relate the influences of rainfall on stream discharge and thereby irrigation water available.
- *CroppingPattern*: it is defined by either the potato-rice sequence OR the fallow-rice one depending on the rainfall pattern, market, and village conditions. It generates and initializes the crop succession for each time step.
- *Crops*: it is meant to define the crop type (potato or rice).
- *Market*: this object is meant to generate economic interactions. It is defined by 4 attributes (Table 19) and randomly generates market state as either low or high. It influences the economic calculation in the model and also the way players make their decisions regarding the crop succession for the next time step.

Table 19. Attributes of passive object "*Market*".

Attributes	State
marketState	It is an instance of object marketState.
cropPriceKg	It is an instance of object cropPricesKg
laborPriceHead	The wage of labor is used as US$ 2 per person day
waterPriceUnit	It is the price of water = US$ 2 per unit of water (1 day share).

- *Messages*: message is an object which helps agents to communicate and interact. In day-to-day life, it can be considered as mails (emails or any form of mails) or conversation among individuals. Any agent who needs to send message has to create an instance of a subclass of message and fulfill it. In Limbukha model there are 3 instances of message subclass and each subclass has a specific sequence of messages. For example Figure 33 shows instance: *exchangeWater* with 12 variables or types of messages. In Limbukha model messages have 3-4 attributes as explained below:

- *Sender:* it is the instance of the entity sending the message. But the entity sending the message can leave it blank (for anonymous message) or even fill it with another agent address. In Limbukha model farmer is the sender identified by their ID.
- *Receiver*: it is an instance of a class inheriting from AgentComm or GroupComm. It identifies an agent who receives the message. Every agent (farmer) has a mailbox and will be automatically registered by the channel, to receive mails from senders.
- *Symbol*: it is an attribute provided to signal the sense of communication. It can be any symbol to indicate that a conversation is taking place.
- *Amount*: it is an object describing an amount, like units of water, number of labor, and cash used in transactions.

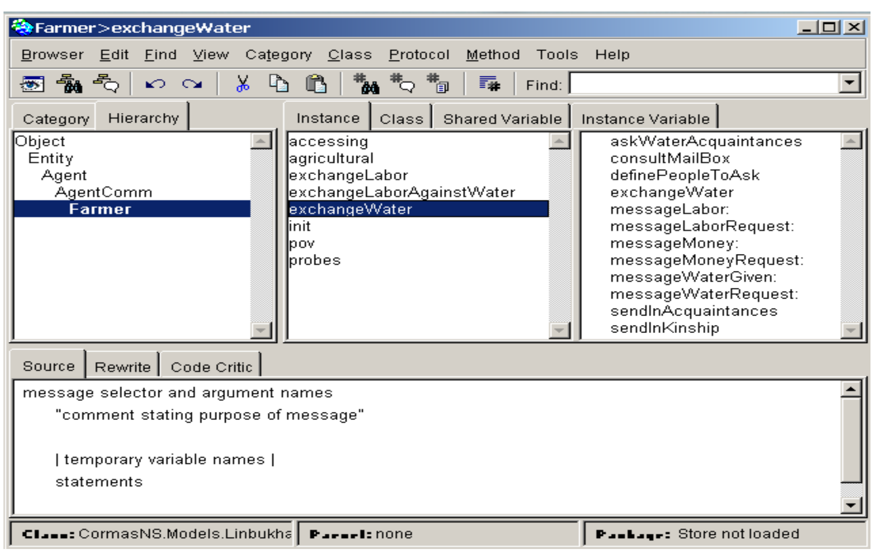


Figure 33. CORMAS window showing details of exchanges in Limbukha model.

6.1.3 Social agents

The social agents are defined by *AgentComm* and *AgentLocated*. It implies that the agents of this class can be spatially located, move to affect the environment and importantly be able to communicate with other agents. In Limbukha model, two classes of social agents are used as follows:

Farmer: in Limbukha model there are 12 farmers classified as AgentComm who communicate among agents and interact. Each agent is defined by attributes as given in Table 20. As communicating agent, farmer has to execute many tasks, it actually represents the dynamics of the model. Their tasks are presented in Section 6.2.

Table 20. Attributes of social agent (Farmer) in Limbukha model.

Attributes	Explanation
myWaterShareCategory	It is an attribute that differentiate among communicating agents
myField	Each agent has been assigned to field (1 to 12)
myLabor	Represents number of labor a agent has. Thruelpa has 60, cheep 80, chatro 180 and lhangchu has 160
myWater	It is the unit of water share each agent has depending on their category and rainfall pattern for each cycle
laborToBeExchanged	Excess labor that is available for exchange
waterToBeExchanged	Unused irrigation water that is available for exchange
laborExchanged	Number of work days received or given to *AgentComm*
waterExchanged	Number of water shares received or given to *AgentComm*
myPotatoProduction	It is the instance of potato production class
myRiceProduction	It is the instance of rice production class
myMarket	It is the instance of market class (high and low)
myIncome	It is the income gained in a year
myVillage	It is an instance of object village
myCropSuccession	It is an instance of object CropSuccession
kinship	It indicates who is related to whom, as kinship plays significant role in sharing irrigation water
peopleToAsk	List of acquaintances to ask for water
peopleToAskWater	List of all farmers to ask for water
twoCycleWaterExchanged	Sum of water exchanged in two cycles of a time step
firstCycleWaterExchanged	Units of water exchanged in first cycles of a time step
acquaintancesLabor	Labor from acquaintances

Village: there are two villages considered as *AgentLocated* in the Limbukha model. The villages are Limbukha and Dompola. The 12 communicating agents are assigned to either of the villages. Farmer 1 to 6 represent Limbukha and 7 to 12 represent Dompola, which is similar to the RPG. The village is defined by one attribute *name*: either Limbukha or Dompola. The only task it has is to update water share among villager after rainfall is initiated.

6.2 Model dynamics: behavior of agents

As explained earlier, farmers are the only communicating agent in this model. The way these agents behave and interact among themselves will influence the dynamics of the model. The behavior of agents can be classified into two broad categories as explained below.

6.2.1 Agricultural methods

In Limbukha model there are 8 tasks related to agricultural operations which an agent performs. Some of the major tasks of this model are explained below:

1. *decideCroppingPattern*: this is the first task that *AgentComm* has to do. As depicted in Figure 34, agent makes decision on the crop succession that will be used in that time step.

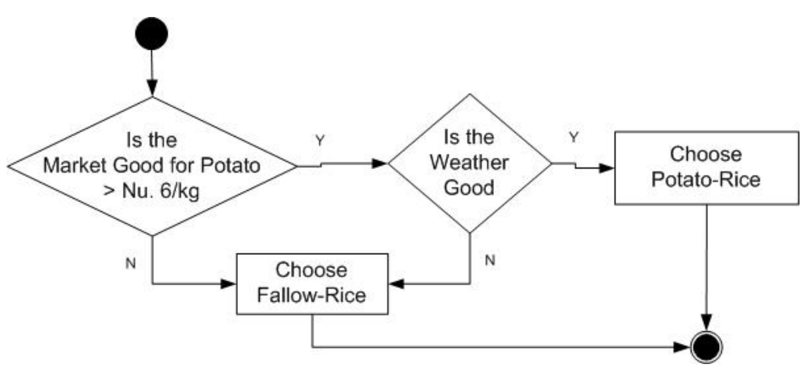


Figure 34. Process to decide a cropping pattern in the Limbukha model.

2. *calculateWaterLaborDemand*: depending on the fallow land, crop succession, water and labor allowance, agent calculates the requirement of labor and water. This task will help to find quantity of labor and water available for exchange (Figure 35).

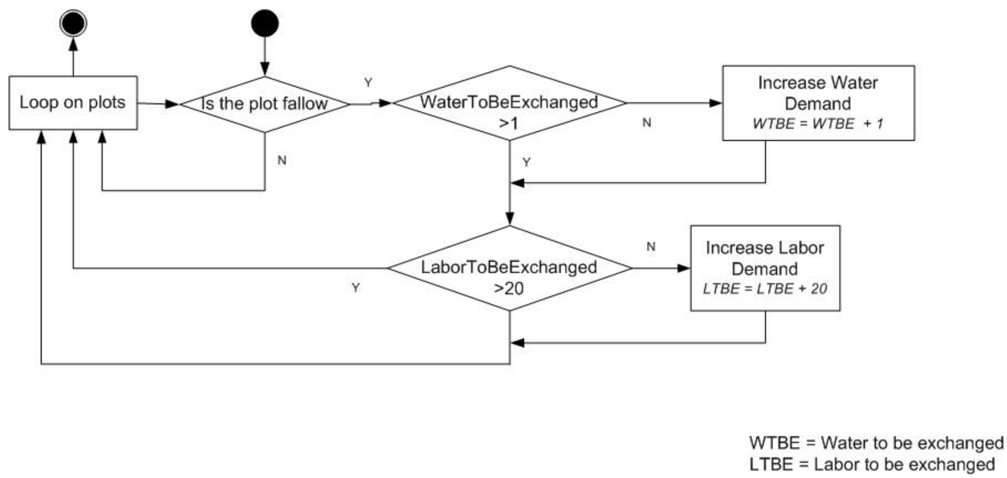


Figure 35. Process to calculate water and labor demand in Limbukha model.

3. *plantPotato*: agents of only Limbukha plant potato in the first cycle of time step (Figure 36).

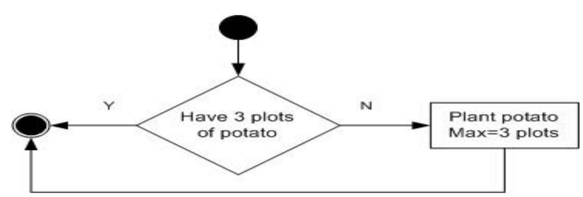


Figure 36. plantPotato task in Limbukha model.

4. *plantRice*: this task is used to plant rice in both villages in two cycles per time step (Figure 37).

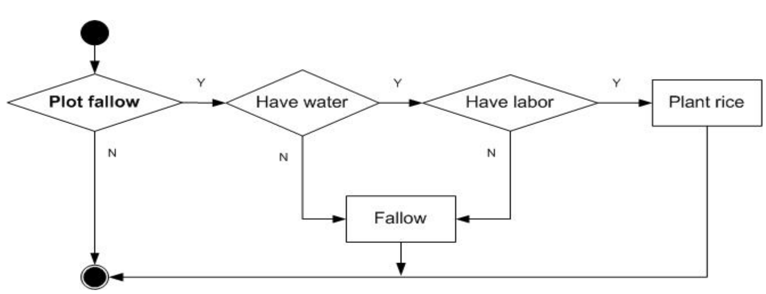


Figure 37. plantRice task in Limbukha model.

5. *exchangeWater*: in this task agent who need water send messages and interactions take place among agents. If the agent does not get water the plot is left fallow.
6. *harvestPotato*: this task is undertaken at the end of the first cycle by Limbukha farmers only to remove (harvest) potato from the plots, such that it is free for planting rice in next the cycle. In the same task, yield of potato and income of farmer is updated.
7. *harvestRice*: this task is executed at the end of the second cycle of each time step when rice planted during both cycles are removed. During the same task, rice yield is updated followed by update of income. With this task the time step (or crop year) ends.

6.2.2 Communication methods

The dynamics of Limbukha model also depend on the way agents communicate among themselves to accomplish different tasks as explained in the preceding section. Table 21 gives the detailed list of messages used in Limbukha model. Similar to Dompola RPG, three communication networks were used in the base model. Firstly, the network of kinship within a village: where an agent identifies itself as kin to another agent and gives water free of cost whenever available. Secondly, agents communicate with acquaintances of their respective village. In the last method, they were allowed to communicate with agents of the other village. A basic structure of communication method used in Limbukha model is described in the following paragraph.

Define people to ask: the first step before any request for water or labor is requested, other agents of the network are defined either as kinship or acquaintance. From the acquaintance group, each agent defines the other members as those with whom they can interact for exchange of water and labor.

Table 21. Instances of message subclass and their corresponding message used in Limbukha model

Instances of messages	Messages
exchangeWater	*askWaterAcquaintances; consultMailBox; definePeopleToAskWater; exchangeWater; messageLabor; messageLaborRequest; messageMoney; messageMoneyRequest; messageWaterGiven; messageWaterRequest; sendInAcquaintances; and sendInKinship*
exchangeLabor	*askLaborAcquaintances; consultMailBox2; definePeopleToAskLabor; exchangeLabor; messageLabor2Request; and messageMoney2Request*
exchangeLaborAgainstWater	*askLaborAgainstAcquaintances; consultMailBox3; definePeopleToAskLabor; exchangeLabor; messageLabor3Request; and messageMoney3Request*

Methods to ask: in Limbukha model three messages have been programmed to ask water or labor. Messages like *askLaborAcquaintances*, *askWaterAcquaintances*, and *askLaborAgainstWaterAcquaintances* are associated to send in request for labor to acquaintances, water to acquaintances and asking labor against water respectively. All these messages are sent to the mailbox of all acquaintances asynchronously.

Methods to answer the request: in every time step, all agents check their mailbox for any message requesting water or labor. If the receiver has excess of labor or water, the agent sends a reply to the sender. In case there is no unused irrigation water or labor the receiver will not reply to the message.

Methods to give: similar to replying to a message, the receiver sends in the requested number of labor or unit of water to the sender of the message. There are instances where receiver make return request for labor against water or even cash. The sender will pay back according to the request. Both receiver and the sender will update the account of labor, water and income.

6.3 Organization of interactions

6.3.1 Protocols of interactions

Agents may exchange either within a kinship network or among an acquaintance network. In this study 6 different protocols of interactions have been identified. The protocol that resembles reality to a certain extent is presented in Figure 38. Other protocols will be explained later. Figure 38 shows how agents "A" interact with agent "B" to get water. The process can be explained stepwise as follows:

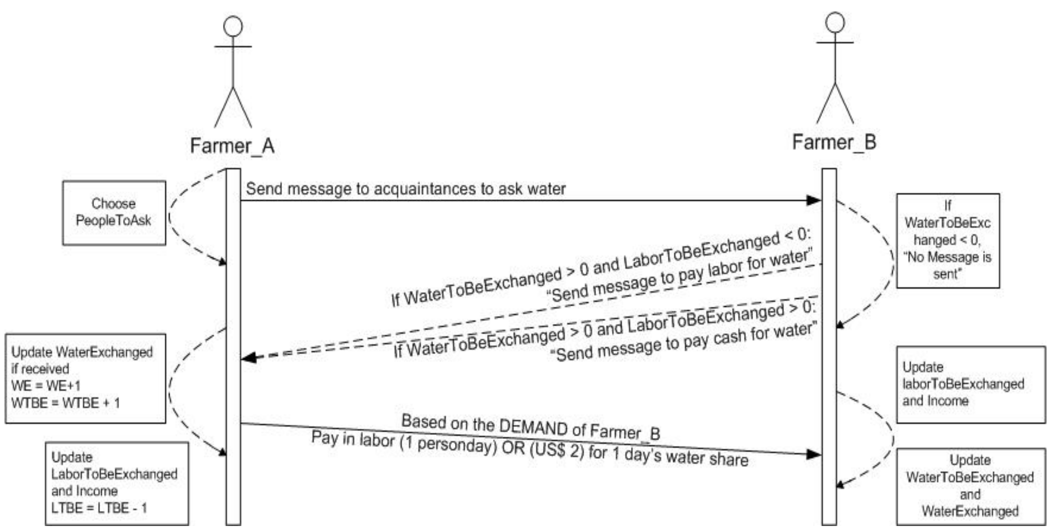


Figure 38. Protocol for exchange of water and labor in Limbukha model.

The successive steps involved in the protocol for exchanging of water and labor are as follows:

- Agent "A" identify acquaintances
- A send message to mailbox of B asking for water
- B opens the mailbox to see, if there is any request for water
- B will check his water credit or balance of water (*waterToBeExchanged*) and amount of labor available (*laborToBeExchanged*)
- If there is no credit, B will not reply to A

- Under the following conditions B will respond to A's mail:
    - If *waterToBeExchanged* > 0 and *laborToBeExchanged* < 0; B will send a mail to A asking to give labor against water.
    - If *waterToBeExchanged* > 0 and *laborToBeExchanged* > 0; B will send a mail to A asking cash for water.
- Based on the demand from B, A will make payment either in cash or labor.
- A will update *waterExchanged, waterToBeExchanged*, *laborToBeExchanged* and income.
- Similarly B will also update *waterExchanged, waterToBeExchanged*, *laborToBeExchanged* and income.

6.3.2 Overall sequence diagram for one time step

The sequence diagram shows how objects communicate with one another over time. The key idea here is to show the interactions among objects taking place in a specific sequence. The sequence takes a certain amount of time to go from start to the end of operation. The sequence diagram generally indicates schedule of different tasks performed and the entity performing the task in a given time-step. For building the Limbukha model, the base sequence was constructed using lessons learned from RPG (Figures 39 and 40). Here, one time step is equivalent to 1 year, each time step is divided into two cycles. The step-by-step tasks are listed as follows:

Cycle 1

1. All farmers decide on the crop succession based on the rainfall and market status.
2. Market price is updated to inform on the last year's market state.
3. Rainfall is initiated for the first cycle (January to mid June).
4. The information on rainfall pattern in given to the villages. At village level water is updated and allocated to each farmer based on his or her category and rainfall pattern. Each farmer calculates his water needs and exchanges with other farmers.
5. Limbukha Farmers only plant potato in their plots (maximum of 3 plots per farmer).

6. Farmers of both villages plant rice.
7. Limbukha Farmers whoever planted potato (in step 5) are activated to harvest (remove) potato and update their plots as fallow. In the same sequence they sell their potato harvest and update their incomes.

<u>Cycle 2</u>

8. Rainfall is initiated for the second cycle (mid June to December).
9. The information on rainfall pattern in given to villages. At village level water is updated and allocated to each farmer based on his or her category and rainfall pattern. Each farmer calculates his/her water needs and exchanges with other farmers.
10. Farmers from both villages are activated to plant rice.
11. Farmers from both villages harvest (remove) rice and update their plots/block as empty. In the same sequence they sell their harvest rice and update their income.

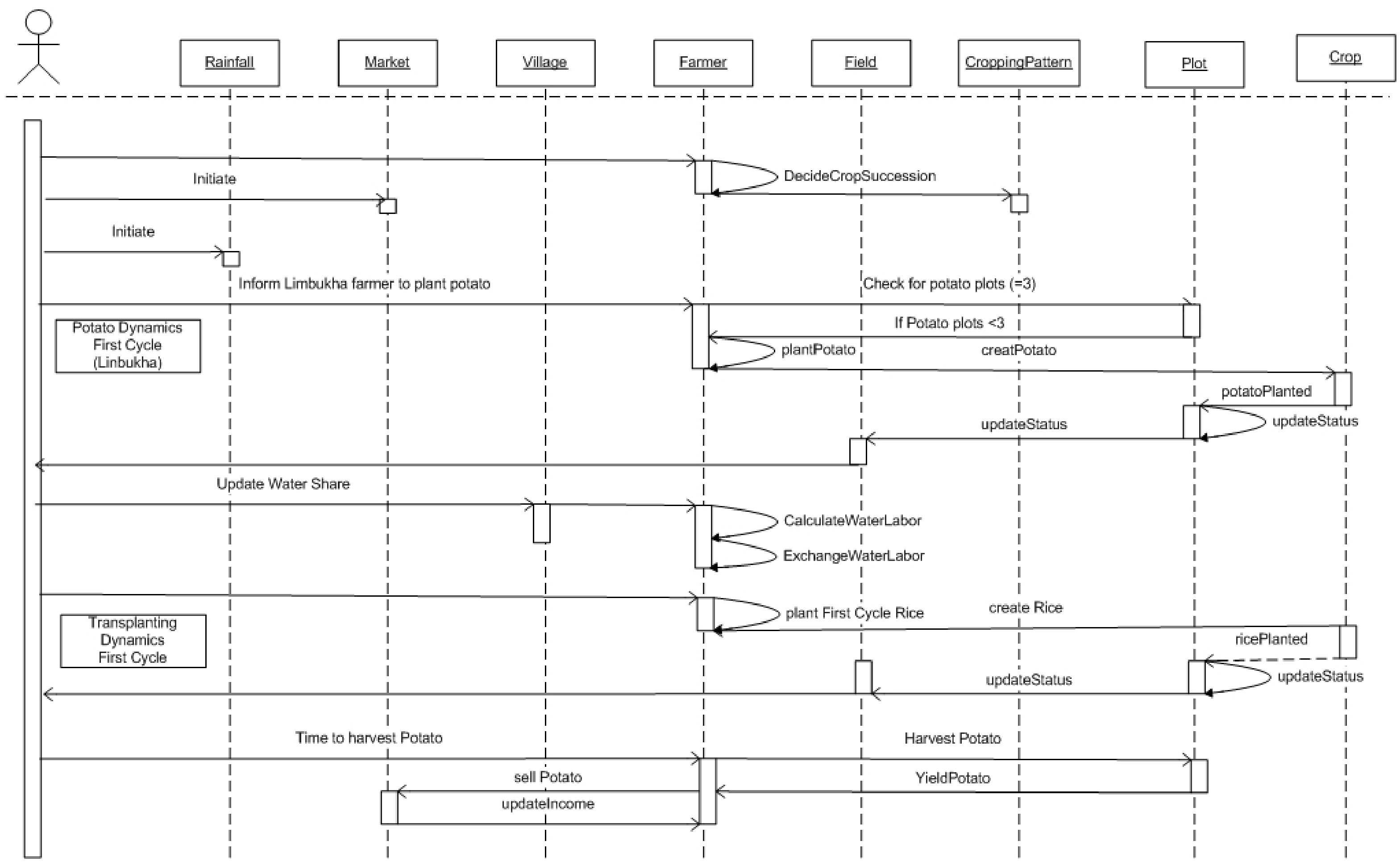


Figure 39. Sequence diagram of Limbukha model (Cycle1 corresponding to January to mid-June).

103

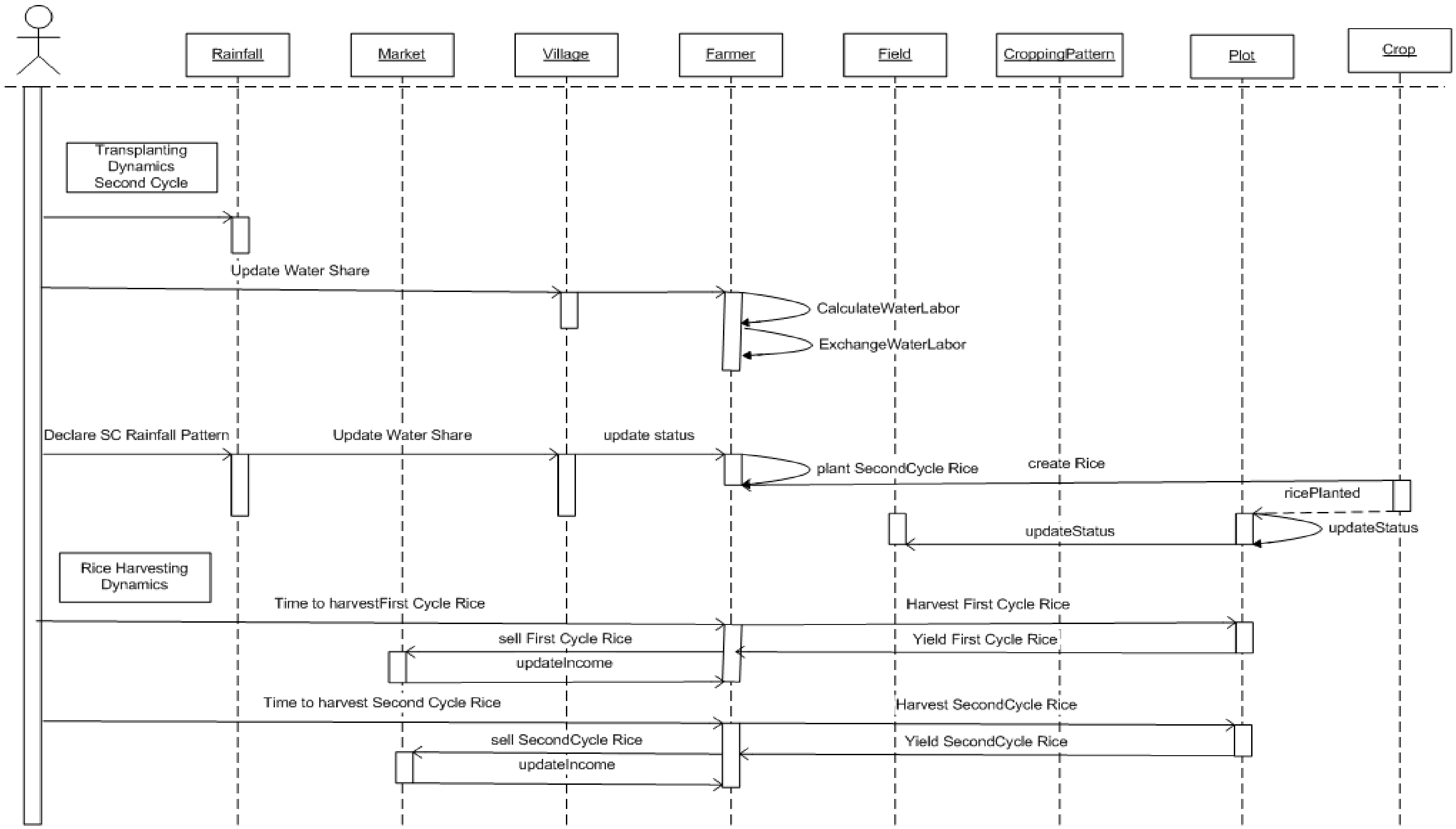


Figure 40. Sequence diagram of Limbukha model (Cycle 2 corresponding mid-June to December).

104

6.4 Data integration

Programming was done in CORMAS 2003. The codes used in Limbukha model are given in Appendix 1. The artificial environment was designed to represent plots and blocks of plots assigned to 12 farmers. For the synthetic environment an interface of 8 x 13 grid size was used (Figure 41). It was like placing two game boards (one for Limbukha and other for Dompola) used in Dompola RPG side by side. This was done to mainly maintain similarity to the game so that players will be familiar with the visualization when the model will be used to discuss the simulation outputs. Field 1-6 represents Limbukha while 7-12 represents Dompola. The allocation of fields and plots to different water sharing category is shown in Table 22. The parameters used in the base model came from both the diagnostic study and the RPG.

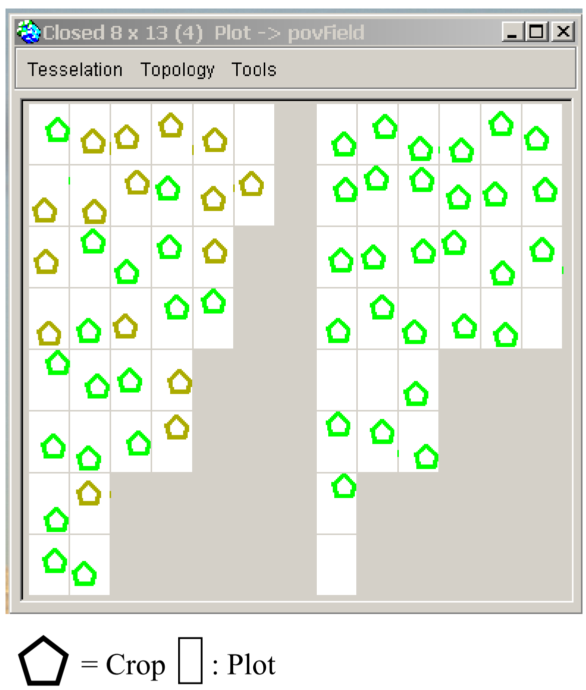


Figure 41. The artificial "Synthetic" environment and main grid interface of the Limbukha model.

Table 22. Allocation of blocks and plots to each communicating agent.

Village	Farmer No.	Water Share Category	Block No.	Total plots
Limbukha	1	Thruelpa	1	8
	2	Thruelpa	2	8
	3	Cheep	3	6
	4	Cheep	4	6
	5	Chatro	5	4
	6	Lhangchu	6	2
Dompola	7	Thruelpa	7	8
	8	Cheep	8	6
	9	Cheep	9	6
	10	Chatro	10	4
	11	Chatro	11	4
	12	Chatro	12	4

Two modes of communication (intra-village and inter-village) were tested. In each time step it was seen that all agents communicate with every agent in the environment. Figure 42 show the exchange of water between farmer 7 and 9; 7 and 10 and 4 and 2. Such interactions were very prominent in every time step.

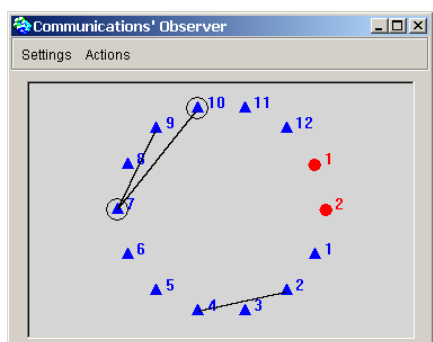


Figure 42. CORMAS Communication observer showing the exchange of water between agents in Limbukha Model (Circle represents communicating agents).

6.5 Checking the model

The scenario closest to reality was chosen to test the consistency of the model outputs. The scenario in which agent first gave water to their kins then followed by exchanges with acquaintances was used for the test run. The steps shown in the sequence diagram of section 6.3.2 were used in the base model. As Manson (2002) suggested, scenarios have been examined from a number of stylized, theoretical perspectives to see if they are qualitatively reasonable. Similarly Bousquet et al. (2002) also indicated that the validation of models could be partly done by interviewing experts. Three simulations of the base model were run to check its consistency and behavior. Each simulation was run over 20 time steps. The outputs of the simulations were captured in Excel spreadsheets and several graphs were generated. While the discussion of simulations with farmers has yet to be done, visual comparison of model outputs with that of RPG were done to assess its consistency.

The simulation outputs shown in Figure 43 indicate the similarity of base model and RPG outputs. At least they behave consistently to changes in parameters. For instance, number of plots planted to rice (Figure 43a) consistently remained within the range of 46 to 66 varying according to rainfall pattern and market states. This corresponds to the sum of rice plots in a year for the two villages in the Dompola RPG (Figure 22).

The number of plots planted to potato in Figure 43b behaved differently from RPG output. The main difference was the absence of potato in some years in the model output, while RPG results show potato being grown every year in Limbukha (Figure 22a). The reason for not having potato was the condition of market price and rainfall pattern used in making the cropping pattern decision in the MAS model. A peculiar behavior of the model was that potato plots varied between 0 and 17, indicating that there could be some weakness in the model in comparison to RPG. In any case it maintained the maximum limits of 17 plots.

Amount of unused water units in the model fluctuate between 2 and 12 depend on rainfall pattern (Figure 43c). It appeared that model over estimates the amount of unused water compared to the RPG output where the maximum numbers of unit of unused water was 6 (Figure 23). This could be due to the protocol which has to be strictly followed in exchanging water in the model. From the way the model behaves, it is considered that it is consistent in terms of its response to the parameters used in the simulations. In case of the number of fallow plots, model indicates a fluctuation between 2 and 18 (Figure 43d) which corresponds to the output of the RPG where it fluctuated between 3 and 14 (Figure 22 and 27). Here the model behaves similarly to RPG.

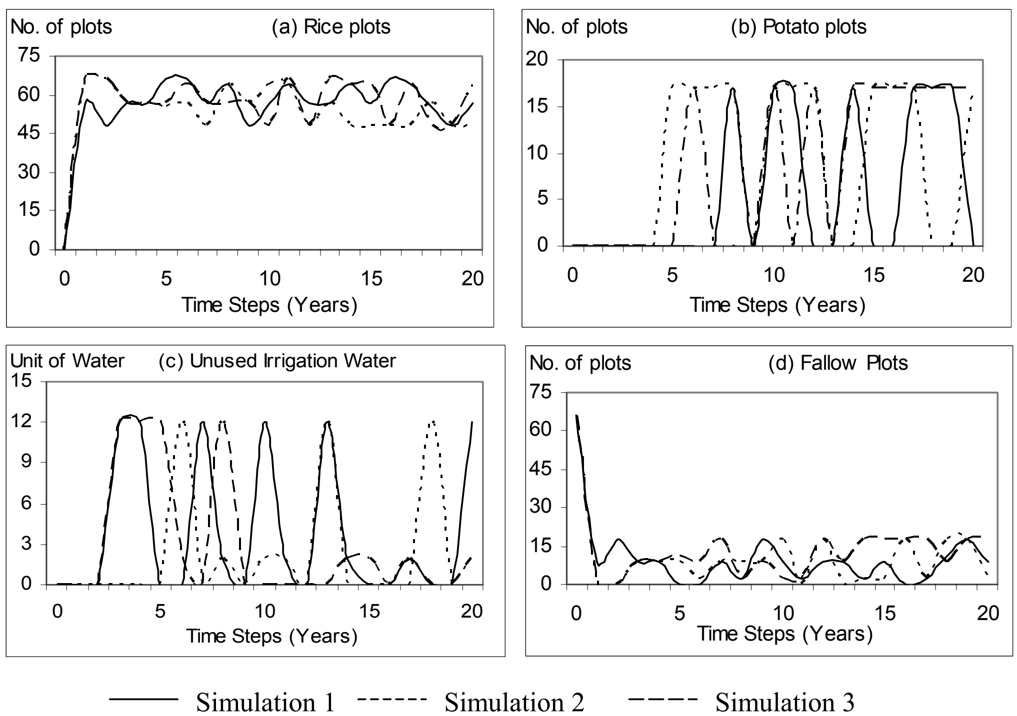


Figure 43. Test of Limbukha base model indicating (a) rice plots, (b) potato plots, (c) unused irrigation water, and (d) fallow plots generated from 3 simulations of the base model.

The total annual income of all the players ranged from US$ 4,000 to 25,000 in the model (Figure 44). The total income fluctuated more than in the RPG, where the net income varied between US$ 7000 and 18000. The wide income fluctuation in the model is linked to a greater variation of the number of potato plots between 0 and 17 in the model.

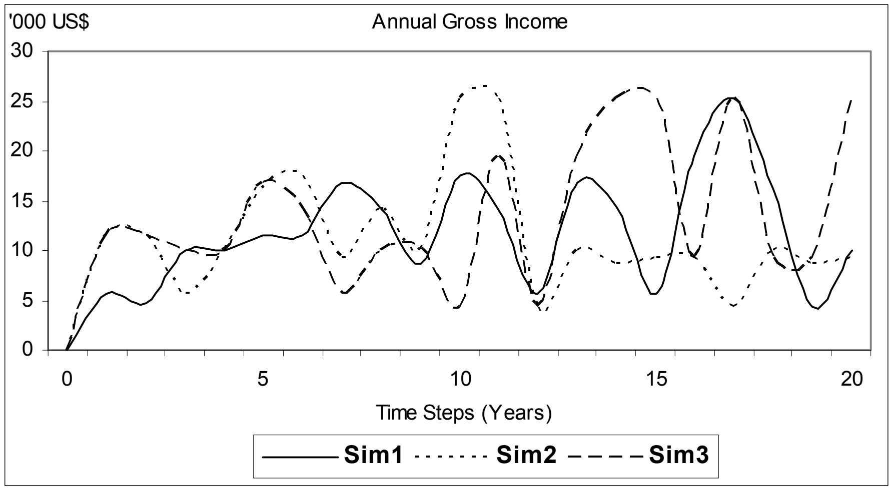


Figure 44. Test of Limbukha base model showing variations in the annual gross income from all players generated from 3 simulations.

In general the Limbukha model represented adequately the RPG except that it behaved differently in the case of potato planting. The variation in income is not a serious issue as its fluctuation is closely related to the number of potato plots. Overall the Limbukha model can be considered to qualitatively and theoretically consistent in representing the RPG. However, as part of the companion modeling approach, the model verification should be done in consultation with other experts, stakeholders, and policy makers. Considering the present state of the model, it can be used for a explorative comparative study of different scenarios.

6.6 Scenarios

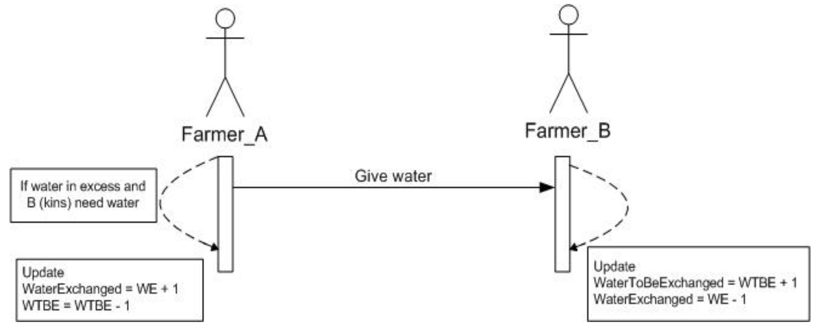
As Limbukha model was roughly able to represent the RPG it was used to generate scenarios to understand the potential effects of changes in strategies on the resource and the economic returns of irrigators. To generate multiple scenarios, three main parameters; namely social networks, rainfall patterns and exchange protocols, were identified (Table 23). Accordingly, 36 scenarios with 20 runs per scenario were produced. Data from each scenario were captured in Excel spreadsheet and the average data of 5 variables are presented in Appendix 3.

Table 23. Possible scenarios to be simulated with the Limbukha model.

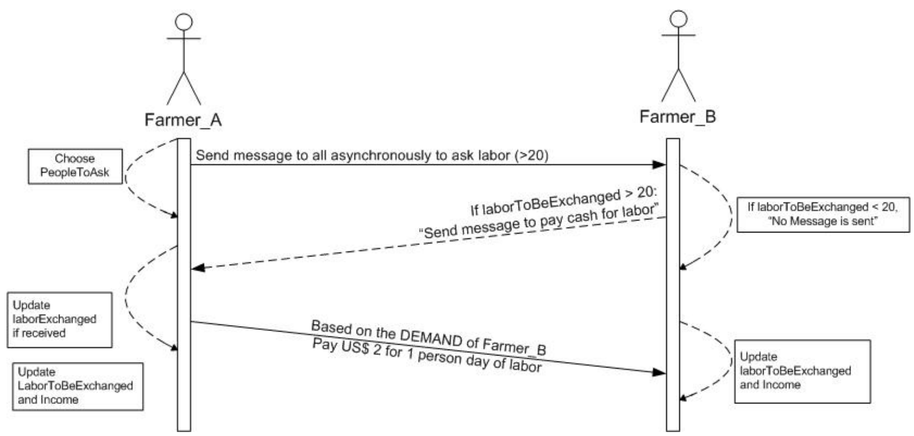
Parameters	Variables
Social network	N_1: Kinship (Table17) N_2: Among all members of same village (N1 + acquaintances in the same village) N_3: Among members of both the villages (N1 + acquaintances in both villages)
Rainfall pattern	R_1: Dominantly Low (Refer to appendix 2) R_2: Dominantly High (Refer to appendix 2)
Protocol	P_1: Give water to kinship (Figure 45a) P_2: Exchange water against labor or cash (Figure 38) P_3: N1 + Exchange labor against cash (Figure 45b) P_4: Exchange water free of charge P_5: Exchange labor against water (Figure 45c) P_6: $P_1 + P_2 + P_5$

The 36 scenarios were further classified based on their fulfillment of 6 criteria. The classification was necessarily used to categorize and identify potentially viable scenarios which can be further discussed with farmers. Threshold for each indicator were based on researcher's perception of the situation, for instance the minimum number of plots planted to rice should be 12; fallow plots should not be more than 7; there should be at least 6 potato plots; at least there should be 1 instance of exchange of unused water which total should be less than 3 units; and finally the total annual income should be more than US$ 10,000. Use of such indicators refined with stakeholders can facilitate a collective discussion and learning. In the real situation, thresholds can be identified by stakeholders to classify scenarios more realistically according to their perceptions.

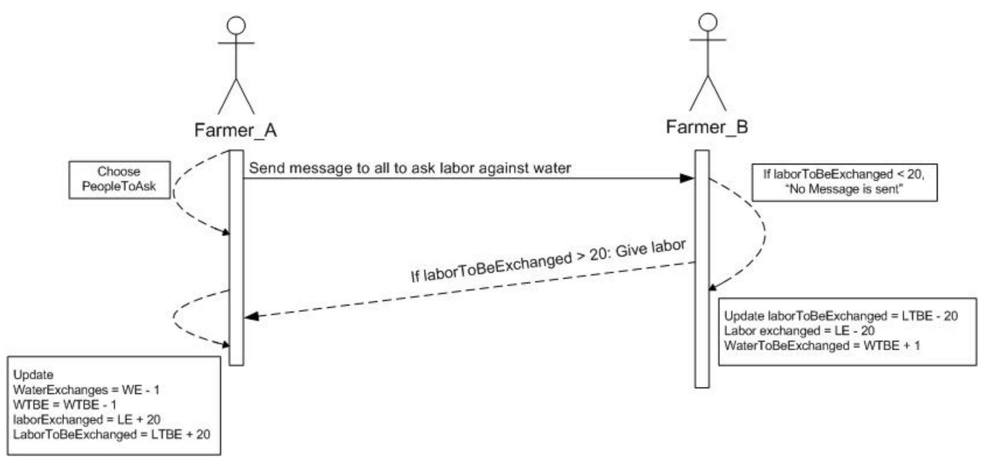
In all 36 cases, communication among agents occurred which could be seen on the "Communication Observer" visualization window of CORMAS. Out of the 36 scenarios, agents exchanged labor in 9 scenarios. The result indicated that, labor exchange was highest in exchange protocol P3 and P5. In case of water exchange in 7 scenarios social network played a major role, the result showed that N3 (Kinship + acquaintance in both villages) promoted water exchange.



(a) Protocol 1: Give water to kinship



(b) Protocol 3: Kinship network + exchange labor against cash.



(c) Protocol 5: Exchange labor against water

Figure 45. Protocols (a) P1, (b) P3, and (c) P5 used for scenario analysis in the Limbukha model.

Three measures of viability: high, medium and low were used to assess the scenarios for further exploration. A scenario was considered highly viable if it fulfilled more than five criteria and conditions displayed in Table 24. Similarly they were categorized as medium or low if they fulfilled 3-4 criteria and conditions or less than 2 criteria respectively.

Table 24. Classification of scenarios based on thresholds of six criteria and conditions.

Unused irrigation water *(< 3 units)*	Fallow plots *(< 7 plots)*	Potato plots *(> 6 plots)*	Rice plots *(> 12 plots)*	Annual income *(> US$ 10,000)*	Water exchange *(>1 transaction)*
112, 113, 122, 123, 213, 215, 216, 222, 223, 224, 225, 226, 313, 315, 316, 322, 323, 324, 325, 326	111, 114, 115, 116, 124, 126, 213, 214, 223, 226, 311, 313, 323	112, 113, 114, 115, 116, 121, 122, 125, 126, 211, 212, 213, 214, 215, 221, 222, 223, 224, 225, 311, 312, 313, 314, 315, 321, 322, 323, 324, 325, 326	All Scenarios (as minimum number of plot is 43)	111, 114, 115, 116, 121, 124, 125, 211, 212, 213, 214, 223, 226, 311, 312, 313, 314, 321, 322	212, 222, 312, 313, 314, 322, 323

N.B: 111 = First digit represent Social network (1, 2, 3); second digit represents rainfall (1 and 2); and third digit represents Protocol (1 to 6).

The results summarized in Table 25 show that 71% of the scenarios displayed viability medium. Majority of the scenarios based on interactions among kinship only are medium viable and there are no highly viable scenario. Interactions among kinship and acquaintances within and between villages resulted in 6% and 8% scenarios fulfilling more than 5 criteria respectively. It further validates the finding of the RPG that a collective communication mode facilitates a better resource use and also fulfills other socio-economic objectives. Overall, it can be seen that only 14% of the scenarios were highly viable, while 15% of them showed low viability. These variations can be due to the criteria and associated conditions in the classification. However, this result needs further discussion with the stakeholders to draw concrete conclusions.

Table 25. Proportion (%) of scenarios under different levels of viability range based on three types of social networks.

Network	Viability of scenario*			Total
	High	Medium	Low	
Kinship	0	27	6	33
Kinship and acquaintances within village	6	22	6	34
Kinship and acquaintances of two villages	8	22	3	33
Total	14	71	15	

* High = satisfies 5 indicators; Medium = satisfies 3 to 4 indicators; and Low = satisfies less than 2 indicators. Indicators are presented in Table 21.

Interdependences of parameter

Networks and protocols were classified into two income categories and three land use types. The non significant result in Table 26 indicates that income levels did not depend on social networks. Further more income levels were not dependent on exchange protocols (Table 27). However, it was the kinship network and the exchange protocol within kinship that gave a higher income compared to other protocols.

Table 26. Frequency of scenarios for test of independence between social network and income categories.

Social network	Annual income levels* (US$)		Total
	<10,000	>10,000	
Kinship	4	8	12
Kinship and acquaintances within village	6	6	12
Kinship and acquaintances of two villages	6	6	12
Total number of scenarios	16	20	36

*: Annual income implies the collective income of both villages.

Table 27. Frequency of scenarios for test of independence between exchange protocols and income categories.

Exchange protocols	Income levels (US$)		Total
	<10,000	>10,000	
P_1: Give water to kinship	1	5	6
P_2: Exchange water against labor and cash	4	2	6
P_3: Exchange water with kinship and Exchange labor against cash	2	4	6
P_4: Exchange water free of charge	2	4	6
P_5: Exchange labor against water	4	2	6
P_6: $P_1 + P_2 + P_5$	3	3	6
Total of scenarios	15	21	36

Similarly, a test of independence was also done to see the relationship between land use decisions, kinship and protocol. The results clearly indicate the independent relation between land use types and social network class (Table 28). As in the case of independence of income on protocol, there is evidence of the independence of land use types to exchange protocol (Table 29).

These results can be a point of discussion among the stakeholders. In no circumstances the result implies or predicts a definite goal; however it presents the option for discussion, a way forward.

Table 28. Frequency of plots for test of independence between social network and land use categories.

Social network	Land use types			Total
	Potato	Rice	Fallow	
Kinship	8	55	11	74
Kinship and acquaintances within village	8	53	13	74
Kinship and acquaintances of two villages	9	51	14	74
Total	25	159	38	222

Table 29. Frequency of plots for test of independence between exchange protocols and land use categories.

Exchange protocol	Land use types			Total
	Potato	Rice	Fallow	
P_1: Exchange water only with kinship	9	56	10	75
P_2: Exchange water against labor and cash	9	48	18	75
P_3: Exchange water with kinship and Exchange labor against cash	9	58	8	75
P_4: Exchange water free of charge	8	52	14	74
P_5: Exchange labor against water	8	48	18	74
P_6: $P_1 + P_2 + P_5$	7	55	11	73
Total of scenarios	50	317	79	446

Presentation of in-depth observations

Six scenarios were selected based on the classification of 36 scenarios to investigate their performance. Among them, 2 represent kinship network from medium viable scenarios; 2 were the scenarios classified as highly viable from kinship and acquaintances within village network, and the last 2 were among the highly viable scenarios from two-village network.

Table 30. Description of six selected scenarios from Limbukha model.

Scenario	Parameters	Description of scenarios
S_1	$N_1R_1P_4$	Agents can communicate within kinship network of each village. Agent gives unused water to their kins and to their acquaintances free of charge. The rainfall pattern is low.
S_2	$N_1R_1P_5$	Agents can communicate within kinship network and exchange labor against water. The rainfall pattern is low.
S_3	$N_2R_1P_3$	Agent communicates freely within ones village (Kins + Acquaintances), while they give unused water to kins only; they can buy labor from kins as well as acquaintances. Rainfall pattern in low.
S_4	$N_2R_2P_3$	Agent communicates freely within ones village (Kins + Acquaintances), while they give unused water to kins only; they can buy labor from kins as well as acquaintances. Rainfall pattern in high.
S_5	$N_3R_1P_3$	It is a full network, where agent communicates freely among all agents of both the villages. They give unused water to kins only and buy labor from kins as well as acquaintances. Rainfall pattern in low.
S_6	$N_3R_2P_3$	It is a full network, where agent communicates freely among all agents of both the villages. They give unused water to kins only and buy labor from kins as well as acquaintances. Rainfall pattern in high.

The six scenarios were compared using 5 criteria and associated conditions (Unused irrigation water < *3 units;* fallow plots < *7 plots;* rice plots > *12 plots;* annual income > *US$ 10,000;* and water exchanged >*1 transaction).* In terms of unused water Figure 46 shows that S_1 and S_2 which represents interaction among kinship results in unused irrigation water ranging between 6 to 8 units, while it was less than 2 units for other scenarios. In S_5 and S_6 there is hardly any water left as unused. It indicates that kinship network alone is not enough for efficient sharing of water. In Figure 47 it is clear that water is exchanged only in S_5 and S_6. As the exchange between kin is free, it is not accounted as water exchanged.

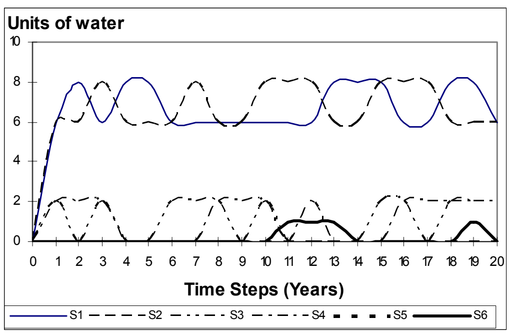


Figure 46. Units of unused water under 6 scenarios simulated by the Limbukha model.

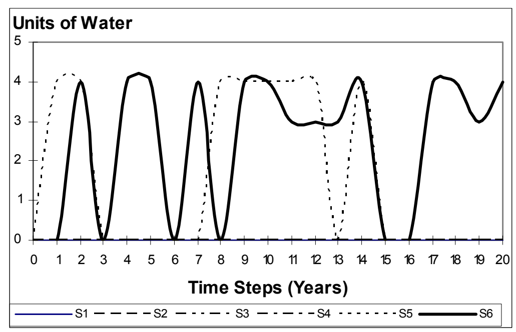


Figure 47. Units of water exchanged under 6 scenarios simulated by the Limbukha model.

In all the six scenarios plots planted to rice ranged between 58 and 66. On average, S_3 to S_6 resulted in more than 64 plots being planted, while only 60 plots were planted to rice in S_1 and S_2 (Figure 48). Correspondingly, the number of fallow plots was higher in S_1 and S_2 (Figure 49). On an average, S_3 and S_4 resulted in 1 fallow plot. It indicates that network within the village ensures minimizing fallow plots.

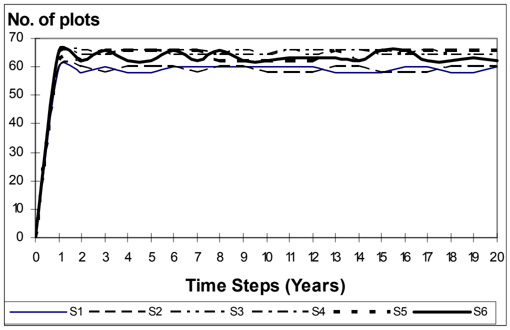


Figure 48. Number of plots planted with rice under 6 scenarios simulated by the Limbukha model.

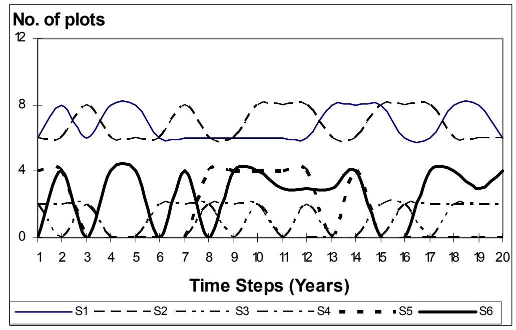


Figure 49. Number of fallow plots under 6 scenarios simulated by the Limbukha model.

The variation in annual income among the six scenarios ranged from US$ 10,000 to 25,000 (Figure 50), which is greater than the fluctuation, registered in RPG, where income ranged from US$ 7,000 to 10,000. Generally S_6 resulted in the highest income with lesser variation over the years. Result also showed that the lowest incomes were observed in the case of S_1 and S_2 with the highest variation of 32%. This indicates that kinship network extended to both villages and protocols allowing exchange between villages could ensure higher average incomes over the years.

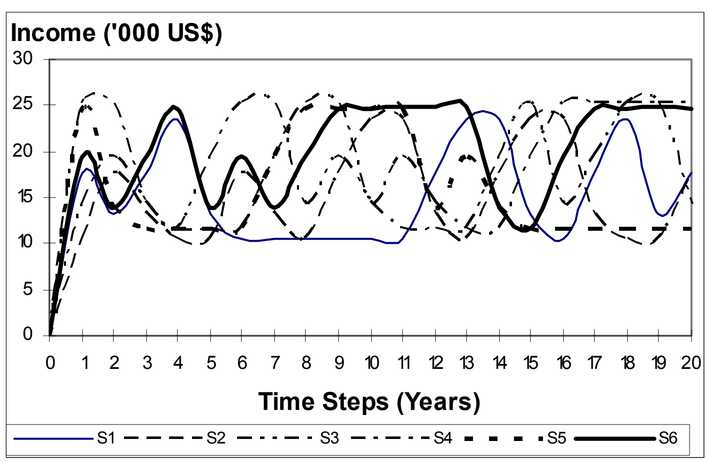


Figure 50. Annual income of 12 farmers generated from the six scenarios Limbukha model

6.7 Discussion

The experimentation with the Limbukha model provided some valuable insight in the resource use dynamics. As the stakeholders have not validated the model yet, the outputs can be considered as tentative results that can help to reorienting the next step of the process. The results consistently indicated that social network extended to both villages (N3) associated with P6 provided a better option to use resources and produced higher incomes more specifically, from the analysis of selected viable scenarios, the results showed that scenarios with kinship network led to more unused water, higher fallow plots, and no instance of exchange. Even in the case of number of rice plots, the kinship network was not as efficient as exchange protocols.

In relation to the interactions (communication) among agents, the kinship network produced maximum interactions among agents to exchange irrigation water. It may be due to the fact that water is first given free of cost to kins. In contrast, exchange of messages (interactions) for labor exchanges was highest under protocols where labor is exchanged against water. These indications justify a need for detailed analysis and understanding of the exchange protocols and social network in resource management.

The Limbukha model was able to integrate information and simulate scenarios that can be used to discuss and communicate the issue of water sharing with stakeholders. For example, the categories of viable scenarios generated from the Limbukha model can now be used as tools to generate discussion and collective learning among the stakeholders in the field.

Chapter VII

Conclusions and recommendations

This chapter consolidates the insights from the study. It is attempted to assess the benefit of the new methodology, assess if the study fulfilled the initial objectives and answered the research question. This chapter also briefly proposes further action based on the study.

7.1 Conclusion

The most important realization from this study was the awareness of the ability of role-playing game to facilitate discussion between two conflicting communities in a non-confrontational and non-threatening mode. This is considered as a vital observation because there were many reservations on communities' participation and commitment in the process of addressing irrigation water sharing issues.

RPG was efficient in facilitating collective learning and evolving shared understanding of the problem. The RPG prompted a "sense of collectiveness" and interdependence that helped in expanding the scope to explore alternative strategies to overcome water-sharing problems. The increased level of knowledge on water sharing and management from 36% in May to 90% in December has clearly shown the usefulness of RPG in collective learning and fostering common goal among the farmers.

Players through their participation in 2 sessions of Dompola RPG have increased their awareness on the issue and most critically the collective aspiration towards better management of conflict in water sharing. The following suggestions made by players during the individual interview and group discussion evidently indicate the improvement of communication between two villages. Some of the critical suggestions were:

a. Renegotiation of water release dates (e.g. pre-pond by 5 days; adjust during double months);
b. Support diversification of crops and adjustment of water allocations to the cropping systems;
c. Establish watershed level management committee to manage Lingmuteychu watershed; and
d. Strengthen local development committee to promote collective actions in NRM.

As shown in Section 5.5, at the household level water is shared principally within the kinship network. In case of sharing water with acquaintances, one-day share of water is exchanged against one unit of labor. The protocol of exchange in Section 6.3 helped in understanding the intricacies of the decision-making process. The study also highlights the inconsistency of local rules in sharing water and need for strengthening traditional institutions in resource management. The testing of different scenarios indicated that alternatives exist which can be tested to improve situation. To ensure adequate sharing of sharing of irrigation water between communities and network of irrigation canals, two communities need to organize and exchange collectively. This will enhance the exchange mechanism between two villages.

The MAS results consistently indicated that social network extended to both villages and exchange protocol allowing exchange of water between two villages either against cash or labor provides better alternative to use resources and earn higher income. This confirms the benefit of greater social connectedness to higher income and improved social cohesion (Narayan and Pritchett, 1997; Schuller, 2001).

The study further confirmed the usefulness and ability of CORMAS to facilitate integration of knowledge for better understanding of interaction among agents and explaining the effect of their decision on resource dynamics. It can also capture emergence of global phenomenon from local actions at agent level.

CORMAS helped in developing multiple scenarios using different combination of parameters and simulating them over numerous time steps. The data capturing in Excel (used in this study), ASCII and Access further facilitated data management and analysis. The graphic probes in CORMAS provide quick visualization of results. With the multiple windows, CORMAS enable learning my simulation.

The three scenarios (individual mode of communication, collective mode of communication, and swapped roles) in 2 sessions of RPG helped farmers and researchers to visualize the effects of three scenarios on land use, water use and income. According to players' response, it helped them to establish a common understanding of the value of collective water management and sharing. Using the same principles, 36 scenarios were used in CORMAS through 3 social networks, 6 water exchange norms, and 2 rainfall patterns. Effect of 36 scenarios on water and land use can be resourceful platform for stakeholder participation.

In a resource scarce situation where stakeholders tend to access the resource from individual point of view without collective concern contradictions among the user build up. Further when the intensity of resource use is influenced by external factors such as market, the complexity of the systems amplify. In such complex dynamic systems, there is always the necessity to experiment new methodologies to deal with such complex issues.

When the research intends to address collective learning and voluntary changes, there is a need for research team to be fully involved with the society and the situation as one of the stakeholders. It is only through such involvement, communication and facilitation, that discovery learning and voluntary change in behavior in the villagers can be fostered (Röling et al. 1998).

The field study also showed that the process by which information is generated to conceptualize RPG and participation of people in the game stimulates continuous and shared knowledge acquisition to hypothesize concept of development.

As ComMod process encourages active and interactive participation among the player, it motivates players to work towards identification of appropriate strategies for common good.

It is worth mentioning that organizing RPG needs specific skill in planning and facilitation. It is highly time and resource demanding tool. While RPG can facilitate conceptualization of MAS, CORMAS too demands considerable computer skills to be able to build and execute the model.

7.2 Recommendations

Irrigation water allocation is inherently and inevitably a negotiated process. Particularly in water stressed situation, the question is not of "supply management" rather it is the demand management that will make impact on resources base. As such, emphasis on negotiated approaches can contribute to better understanding and facilitation to build social capital to respond to challenges of increasing competition for scarce water resources. It will also facilitate better governance of natural resources. To keep up the aspirations of players, actions in the field should start with a minimum time lapse. The following recommendations can be drawn from the study:

As player and other members of the community have not been exposed to MAS scenarios and simulations, it would be most appropriate to present the model for validation and explaining its outputs to stakeholders. This will help farmers to validate the models and select viable options for experimentation. This experimentation can be beneficial for collective learning and joint identification of workable scenarios for improving water sharing in the community.

Using the knowledge gained from the study, the shared understanding of villager on water sharing and based on the recommendation, a collective discussion to negotiate the date of water release in Dompola canal can be re-organized. During the Dompola RPG bringing forward the date by 5 days was suggested. Now it is important to discuss and make it operational.

As it was suggested during RPG sessions, the lessons learned from the current studies should be used to establish watershed level management committee to manage Lingmuteychu watershed. This has been particularly considered as an urgent and important intervention from the point of social networking and institution building.

The exchange protocols from household level to village based to community level can be formalized to facilitate collective resource management of water resource. In the mean time, as suggested by the players and observers adjustment of water allocations and use should be done based on cropping systems

The involvement of local development committee members as observers in second session of Dompola RPG made it clear that the Block development committee needs to be strengthened to promote collective actions in NRM. Towards this action, capacity development of committee members and information exchange is expected to help in institutional development.

7.3 Further research issues

The two sessions of RPG played in this study helped in reinforcing the collective learning on water resource sharing and management. Between two sessions of the game, there was significant increase in proportion of players who thought resource sharing was important. This could have been better explained if a close monitoring on the behavioral change after the first RPG session was done. Therefore, it will be worthwhile to investigate how such changes take place. At the same time, monitoring the process of change in community is yet another interesting area of investigation. Use of spatial representation of agents, canal and field can be used to in RPG and MAS to generate more understanding of the complexity.

Comparison of ComMod with other participatory tools in similar environment for collective learning and facilitating use of knowledge based decision-making in natural resource management will enhance the applicability of the approach.

Often the scale of study using ComMod is small, especially in this study. How can the lessons learned form such exercises be scaled up to network of canals, to watershed levels or for wider scale application? A detail study on scaling up of ComMod can broaden the scope for application of the approach.

Considering the complexity of methodology, particularly the CORMAS simulation, further work towards simplification will facilitate application of ComMod in the field of NRM. It is also suggested here that capacity development of researchers in using ComMod should continue.

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APPENDIX

Appendix 1. Source Codes of Limbukha Model

1. step: t

“Simulation”

```
self theFarmers do:
        [:a | a release.
        a decideCropSuccession].
self theMarkets first init.
self theRains first init.
(self theFarmers select: [:a | a myCropSuccession name = 'potatoRice'])
    do: [:b | b plantPotato].
self theVillages do: [:a | a updateWaterShare].
self theFarmers do: [:a | a calculateWaterLabor].
(self theFarmers select: [:a | a waterToBeExchanged > 0]) do:
        [:b | b kinship notEmpty
            ifTrue:
                [self halt.
                b sendInKinship]].
self theFarmers do: [:a | a consultMailBox].
self theFarmers do:
        [:b |
        b definePeopleToAsk.
        b exchangeWater].
 [(self theFarmers
    select: [:a | a waterToBeExchanged < 0 and: [a peopleToAsk isEmpty not]])
        size > 0]
        whileTrue: [self theFarmers do: [:a | a exchangeWater]].
self theFarmers do: [:a | a plantRice].
self halt.
self theFarmers do: [:a | a harvestPotato].
self theRains first init.
self theVillages do: [:a | a updateWaterShare].
self theFarmers do: [:a | a calculateWaterSecondCycle].
(self theFarmers select: [:a | a waterToBeExchanged > 0])
    do: [:b | b kinship notEmpty ifTrue: [b sendInKinship]].
self theFarmers do: [:a | a consultMailBox].
self theFarmers do:
        [:b |
        b definePeopleToAsk.
        b exchangeWater].

[(self theFarmers
    select: [:a | a waterToBeExchanged < 0 and: [a peopleToAsk isEmpty not]])
```

```
                    size > 0]
                    whileTrue: [self theFarmers do: [:a | a exchangeWater]].
self theFarmers do: [:a | a plantRice].
self halt.
self theFarmers do:
                    [:a |
                    a harvestRice.
                    a sellProduction]
```

2. decideCroppingPattern

"Decide the crop sequence based on rainfall pattern and market state"

```
     self myCroppingPattern: CroppingPattern new.
          (self myVillage id = 1 and:
                         [self myMarket marketState = #high
                                   and: [self myVillage myRain rainState = #high]])
                    ifTrue: [self myCroppingPattern name: 'potatoRice']
                    ifFalse: [self myCroppingPattern name: 'rice'].
          self defineVisualState decideCroppingPattern
          self myCroppingPattern: CroppingPattern new.
          (self myVillage id = 1 and:
                         [self myMarket marketState = #high
                                   and: [self myVillage myRain rainState = #high]])
                    ifTrue: [self myCroppingPattern name: 'potatoRice']
                    ifFalse: [self myCroppingPattern name: 'rice'].
          self defineVisualState
```

3. plantPotato

"Plant potato and update the income"

```
                    | counter c |
                    counter := 0.
                    self myField components do: [:a | counter < 3
                              ifTrue:
                                        [c := Crop new.
                                        c cropType: 'potato'.
                                        c isMovedTo: a.
                                        counter := counter + 1.
                                        self myIncome: self myIncome - 5200]]
```

4. calculateWaterLabor

"Calculate number of labor and water units available for sharing"

```
                    self laborToBeExchanged: self myLabor.
                    self waterToBeExchanged: self myWater.
```

```
self myField components do: [:a | a crop isEmpty
        ifTrue:
    [self laborToBeExchanged: self laborToBeExchanged - 20.
    self waterToBeExchanged: self waterToBeExchanged - 1]].
self laborExchanged: 0.
self waterExchanged: 0
```

5. plantRice

“Plant rice and update income”

```
| c w l |
            w := self myWater + self waterExchanged.
            l := self myLabor + self laborExchanged.
            self myField components do:
                    [:a |
                    (a crop isEmpty and: [w > 0 and: [l >= 20]])
                            ifTrue:
                                    [c := Crop new.
                                    c cropType: 'rice'.
                                    c isMovedTo: a.
                                    w := w - 1.
                                    l := l - 20.
                                    self myIncome: self myIncome - 2300]]
```

6. harvestPotato

“Harvest potato and update potato production”

```
    | yield p c |
    self myVillage myRain rainState = #high ifTrue: [yield := 2200].
    self myVillage myRain rainState = #low ifTrue: [yield := 700].
    p := self myField components select: [:a | a crop isEmpty not and: [a crop first
cropType = 'potato']]. p
            do:
                [:a |
                c := a crop first.
                c leave.
                self myPotatoProduction: self myPotatoProduction + yield]
```

7. **harvestRice**

“Depending on the rainstate inform the yield. harvest rice and update rice production”

```
    | yield p c |
    self myVillage myRain rainState = #high ifTrue: [yield := 600].
    self myVillage myRain rainState = #low ifTrue: [yield := 400].
```

```
    p := self myField components select: [:a | a crop isEmpty not and: [a crop first
cropType = 'rice']].
    p do:
                [:a |
                c := a crop first.
                c leave.
                self myRiceProduction: self myRiceProduction + yield]
```

8. **sellProduction**

"Sell potato, rice and update income"

```
            self
                myIncome: self myIncome
                + (self myPotatoProduction * self myMarket pricePotato)
                    + (self myRiceProduction * self myMarket priceRice)
```

Exchanges (Message)

9. askWaterAcquaintances

" select someone among the acquaintances and send a message to request water"

```
            | waterRequested m a |
            a := peopleToAsk first.
            waterRequested := self waterToBeExchanged abs.
            m := Exchange new.
            m sender: self.
            m receiver: a.
            m symbol: #waterRequest.
            m amount: waterRequested.
            self sendMessageAsynchronously: m.
            peopleToAsk remove: a
```

10. consultMailBox

"check mailbox for messages and pay money or cash for water requested"

```
self mailBox do:
                [:a |
                "self id = 6 ifTrue: [self halt]."
                a symbol = #waterGiven ifTrue: [self messageWaterGiven: a].
                a symbol = #waterRequest ifTrue: [self messageWaterRequest:
a].
                a symbol = #laborRequest ifTrue: [self messageLaborRequest:
a].
                a symbol = #moneyRequest ifTrue: [self
messageMoneyRequest: a].
```

```
        a symbol = #labor ifTrue: [self messageLabor: a].
        a symbol = #money ifTrue: [self messageMoney: a]].
    self mailBox: OrderedCollection new
```

11. definePeopleToAsk

" Identify people to ask water from the list of acquaintances only and send message"

```
    self waterToBeExchanged < 0
        ifTrue:
        [peopleToAsk := Cormas
        mixt: (self acquaintances select: [:a | (self kinship includes: a)
not])]
        ifFalse: [peopleToAsk := OrderedCollection new]
```

12. exchangeWater

"Ask water to acquiantance if water is needed"

```
    self mailBox isEmpty
        ifFalse: [self consultMailBox]
        ifTrue:
        [(self waterToBeExchanged < 0 and: [self peopleToAsk
isEmpty not])
        ifTrue: [self askWaterAcquaintances]]
```

13. messageLabor: a

"Calculate labor for exchange and send message"

```
    self laborToBeExchanged: self laborToBeExchanged + a amount
```

14. messageLaborRequest: a

"Receive labor, pay wage and update the income"

```
| m |

self waterToBeExchanged: self waterToBeExchanged + a amount.
self waterExchanged: self waterExchanged + a amount.
self laborToBeExchanged > 0
    ifTrue:
    [m := Exchange new.
    m sender: self.
    m receiver: a sender.
    m symbol: #labor.
```

```
                m amount: a amount.
self laborToBeExchanged: self laborToBeExchanged - a amount]
                ifFalse:
                [m := Message new.
                m sender: self.
                m receiver: a sender.
                m symbol: #money.
                m amount: 100 * a amount.
                self myIncome: self myIncome - (100 * a amount)].
                self sendMessageAsynchronously: m
```

15. messageMoney: a

"Receive cash and update income"

```
                self myIncome: self myIncome + a amount
```

16. messageMoneyRequest: a

"Send message about the cost of each water unit"

```
                | m |

                self waterToBeExchanged: self waterToBeExchanged + a amount.
                self waterExchanged: self waterExchanged + a amount.
                self myIncome: self myIncome - (100 * a amount).
                m := Exchange new.
                m sender: self.
                m receiver: a sender.
                m symbol: #money.
                m amount: 100 * a amount.
                self sendMessageAsynchronously: m
```

17. messageWaterGiven: a

"Update water available for exchange"

```
self waterExchanged: self waterExchanged + a amount.
self waterToBeExchanged: self waterToBeExchanged - a amount
```

18. messageWaterRequest: a

"Message water received and money paid"

```
| m waterGiven |
self waterToBeExchanged > 0
                ifTrue:
```

```
[m := Exchange new.
m sender: self.
m receiver: a sender.
waterGiven := self waterToBeExchanged min: a amount.
self waterExchanged: self waterExchanged - waterGiven.
self waterToBeExchanged: self waterToBeExchanged - waterGiven.
self laborToBeExchanged < 0
    ifTrue:
        [m symbol: #labourRequest.
        m amount: waterGiven]
    ifFalse:
        [m symbol: #moneyRequest.
        m amount: waterGiven].
self sendMessageAsynchronously: m]
```

19. sendInKinship

"Send message to give water to kinship in turns"

```
| receivers waterGiven m |
receivers := self kinship select: [:a | a waterToBeExchanged < 0].
receivers do:
        [:a |
        self waterToBeExchanged > 0
ifTrue:
[waterGiven := self waterToBeExchanged min: a waterToBeExchanged abs.
        m := Exchange new.
        m sender: self.
        m receiver: a.
        m symbol: #waterGiven.
        m amount: waterGiven.
        self sendMessageAsynchronously: m]]
```

Appendix 2. Rainfall pattern used in Limbukha model

Dominantly low rainfall pattern	= 60% of the Cycle < 112mm/month
	= 40% of the Cycle > 255mm/month
Dominantly normal rainfall pattern	= 55% of the Cycle > 255mm/month
	= 45% of the Cycle < 112mm/month
1 Time step = 2 Cycles	Cycle 1 = January to Mid-June
	Cycle 2 = Mid-June to December

Time Steps	**R1**= Dominantly Low		**R2** = Dominantly High	
	Cycle 1	Cycle 2	Cycle 1	Cycle 2
1	Low	Low	Normal	Low
2	Low	Normal	Low	Normal
3	Normal	Low	Normal	Low
4	Low	Normal	Low	Normal
5	Low	Normal	Normal	Low
6	Low	Low	Normal	Low
7	Low	Normal	Normal	Normal
8	Normal	Low	Normal	Low
9	Normal	Normal	Normal	Normal
10	Low	Normal	Low	Normal
11	Low	Low	Low	Low
12	Normal	Low	Normal	Low
13	Low	Normal	Normal	Low
14	Low	Low	Normal	Normal
15	Normal	Low	Normal	Low
16	Low	Normal	Normal	Low
17	Low	Low	Low	Low
18	Low	Normal	Low	Normal
19	Normal	Low	Normal	Low
20	Low	Normal	Low	Normal

Appendix 3. Data generated from 36 scenarios of Limbukha Model

Network	Rainfall pattern + Protocol											
	11	12	13	14	15	16	21	22	23	24	25	26
	Units of unused irrigation water											
N1	6.7	3	1	6.8	6.8	4.5	7.3	3	1	6.6	7.1	4.05
N2	7.3	7.3	1.1	6.9	3	0	3	3	1.2	3	3	0.6
N3	6.9	6.35	0	7.5	3	0	7.4	3	0.2	3	3	3
	Units of water exchanged											
N1	0	0	0	0	0	0	0	0	0	0	0	0
N2	0	0.8	0	0	0	0	0	0.4	0	0	0	0
N3	0	2.2	1.6	23.5	0	0	0	0.4	2.6	0	0	0
	No. of plots planted with potato											
N1	6	9	9	6	6	9	11	8	6	5	9	7
N2	11	11	9	7	7	6	6	6	10	9	8	5
N3	7	9	6	8	9	6	11	8	11	10	6	10
	No. of plots planted with rice											
N1	59	42	46	59	59	63	59	42	46	59	59	63
N2	59	59	65	59	42	48	42	42	65	42	42	65
N3	59	58	64	53	42	48	59	42	63	42	42	42
	Annual income (US$)											
N1	14.1	6.0	6.5	15.4	15.4	17.4	17.6	6.0	5.8	14.0	16.9	17.0
N2	18.6	17.6	17.7	15.2	5.5	6.1	5.6	5.9	19.3	6.1	6.1	14.8
N3	15.6	16.7	16.0	14.2	6.2	6.2	19.1	5.8	20.6	6.3	5.4	6.3

Notes:

N_1: Only among kinship
N_2: Among all members of same village (first with kinship and then with acquaintances)
N_3: Among members of both the villages (all kinship and acquaintances)
11: Dominantly Low + Exchange water only with kinship
12: Dominantly Low + Exchange water against labor and cash
13: Dominantly Low + Exchange water with kinship and Exchange labor against cash
14: Dominantly Low + Exchange water free of charge
15: Dominantly Low + Exchange labor against water
16: Dominantly Low + $P_1 + P_2 + P_3$
21: Dominantly High + Exchange water only with kinship
22: Dominantly High + Exchange water against labor and cash
23: Dominantly High + Exchange water with kinship and Exchange labor against cash
24: Dominantly High + Exchange water free of charge
25: Dominantly High + Exchange labor against water
26: Dominantly High + $P_1 + P_2 + P_3$

Abbreviations

CBNRM	Community-based natural resource management
CIRAD	Centre de coopération internationale en recherche agronomique pour le développment. (Agricultural Research Centre for International Development)
CORMAS	Common-pool Resource and Multi-Agent Systems
CPR	Common Pool Resource
DYT	Dzongkhag Yargey Tshogtshung (*District Development Committee*)
GYT	Geog Yargey Tshogtshung (*Block Development Committee*)
ha	Hectare
IDRC	International Development Research Center
IWMI	International Water Management Institute
km	Kilometer
Ls^{-1}	Liter per second
MAS	Multi-agent system
MoA	Ministry of Agriculture
MoHA	Ministry of Home Affairs
NRM	Natural Resource Management
Nu.	Ngultrum (1 US$ = Nu. 45.01)
PCS	Planning Commission Secretariat
RGOB	Royal Government of Bhutan
RNRRC	Renewable Natural Resources Research Center
RPG	Role-playing Game
t	Ton
$t\ ha^{-1}$	Ton per hectare
US	United State of America

Glossary

Chatro:	Category of farmer who get half of Cheep's share of water
Cheep:	Category of farmer who get half of Thruelpa's share of water
Chukor:	Rotations of irrigation turns
Langdo:	Unit of land which is equal to 0.1 ha.
Lhangchu:	Category of farmer who do not have access to water.
Mixed Agriculture	Arable land used for growing multiple crops, e.g. kitchen garden where mix of vegetables is grown in small plots.
Rimdo	Annual religious ceremonies performed at household and community level
Shokshing:	Woodlot on which either individual or the community have right-to-use for leaf litter and dry firewood.
Thruelpa:	Originally tax payer in the community. Category of farmer who have full access to water.

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