Institutional Response to Biophysical and Human Induced Disturbances in Small Scale Irrigation Systems in South Asia

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Abstract

Social Ecological Systems (SESs) are facing ever increasing scale of influence from external (climate change, policy changes etc.) and contextual (users, infrastructure, resource condition etc) factors. This study looks into the institutional arrangements and resulting water rights and operational level rules-in-use to cope these changes in irrigation systems from Nepal and Pakistan. The study draws insights from new institutional economics, and apply Institutional Analysis and Development framework for analysis. The comparison of systems with variation in governance (agency managed and farmers managed), nature of water resource (perennial, non-perennial, run-off river type etc.), infrastructure (canal lining, nature of head-works etc.), and socioeconomic and policy context draws important lessons about commonly found characteristics in robust systems. The study has important policy implications about how the institutional arrangements imposed from external agencies demonstrate path dependence and fail to address new disturbance regimes as the mechanisms remain in place for longer time horizons.

Keywords
social-ecological systems, water governance, external disturbances, contextual factors**,** south asia

1. Introduction

Irrigation systems operate under the environment of pressure from several external and contextual factors. As a social-ecological system (SES), an irrigation system faces ever-increasing scale of influence of human activity. Specially, the indigenous irrigation systems are facing new threats because of openness to the new world, commercial interests of farmers, rise in cost of maintenance, increased competition of water and weakened social cohesion due to reasons including state interventions (Barker and Molle 2005; Lam 2001; Shivakoti et al. 2005). At the same time the climatic variations also pose threats to the small-scale irrigation systems.

It has been observed that irrigation systems are directly affected by a variety of disturbances like policy changes, market pressures and the changes in the biophysical context where it operates (Bastakoti et al. 2010). The social-ecological system, irrigation systems in our case, is a complex collection of human, physical and institutional entities that respond to internal and external disturbances through a diverse array of rules in different conditions (Shivakoti and Bastakoti 2006; Kamran and Shivakoti 2010). The nature of resource (mobile or stationary) responds differently to predictable and unpredictable disturbances (Janssen et al 2003). The CPR theorists consider lack of storage and non-stationary character of a resource, spate irrigation in our case, as major obstacle for collective action (Ostrom et al 1994). The strong connections of SES with large scale phenomenon pose challenges and opportunities for the stakeholders. Literature based on past performance of resource systems shows that many long endured SES have successfully adapted their institutions to these disturbance regimes (Ostrom 1990; Agrawal 1999; Shivakoti and Bastakoti 2006), while others collapsed (Baker 2005).

In this paper we focus on irrigation systems from Nepal and Pakistan. The cases in this study have also endured to known shocks of regular climate variability and floods with varying degree of success in different management regimes and resource uncertainty, and are now exposed to climate related shocks and disturbances at a pace never experienced in human history (Thornton et al. 2006). This paper looks into adaptive capacity of the irrigation systems with special focus indigenous irrigation systems, to cope with the past shocks in the form of appropriate institutions to manage external shocks (rainfall patterns, floods, droughts etc.) and the system characteristics (run off rivers diverted through indigenous structures); and to estimate chances of success to adapt to such changes. We focused our analysis on major threats and possible panaceas considering the across four first level core components of an SES *viz* resource system; governance system; resource units; resource users individually and the interaction that affect effect each other and related ecosystems (Anderies et al. 2004; Ostrom 2009).

The study is specifically focused on answering how AMIS and FMIS reflect varying degree of robustness through institutional responses to external changes in the form of flexible rules formation and adopting various coping strategies at different level.

2. Methodology

2.1. Analytical Framework for linked SES

We adopted the framework proposed by Anderies et al. (2004) that provides guideline to analyze core entities of the SES and understand interactions between them. The framework focuses on four entities that are mostly involved in CPRs harvested by people (Figure 1a). The two entities in the framework namely, 'resource users' and 'public infrastructure providers' involve humans. Other two entities namely 'resource' and 'public infrastructure' involve physical and institutional aspects. The public infrastructure consists human-made physical and institutional capital (Ostrom and Ahn 2003; Janssen et al. 2003). The 'resource' entity represents biophysical system used by 'resource users' through joint provision effort of the two human based entities in framework that is 'public infrastructure' and 'public infrastructure providers'. The internal fluctuations can result from changes in relationships between resource users and infrastructure providers and can affect various components and linkages in the framework. The arrows 7 and 8 represent the external disturbances to the ecological and social components of the SES. Other numbered arrows show the linkages and interaction between different components.

In FMIS (mostly hilly areas perennial and non-perennial systems in our case study), the resource users and public infrastructure providers are the same (Fig 1b), and the factors that affect one entity also in turn affect the other (if provision of public infrastructure is affected by some factor, the users are also affected by it). While in case of AMIS in our study, the human entities of the framework involve different actors, that is, the public infrastructure providers are mainly the state departments and officials thus affecting the infrastructure. The local communities have limited influence compared to the community-managed systems (Fig 1b).

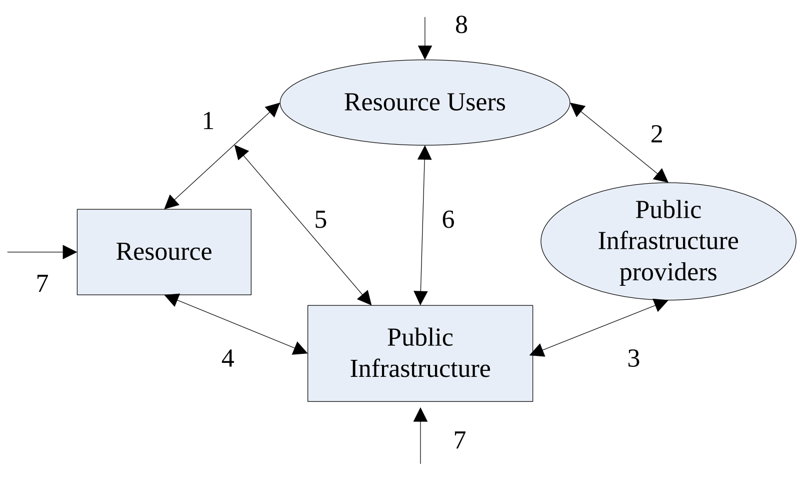

Figure 1a. Framework of Anderies et al., 2004

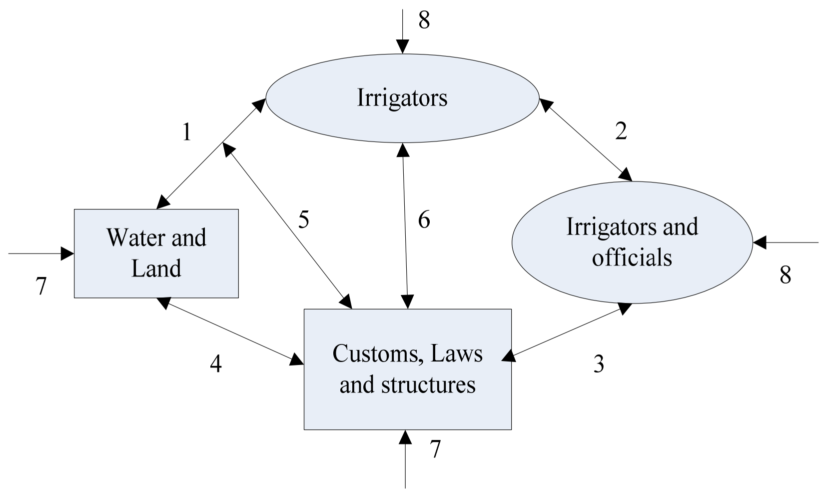

Figure 1b. Framework adapted for the irrigation systems

Figure 1 (a) A simple framework that highlights the main components of SES and their linkages (Anderies et al., 2004), (b) Modified framework for the irrigation systems

2.2. Sample and data collection

This paper is based on the extensive survey of irrigation systems from Nepal and Pakistan. Primary information was collected from the sampled irrigation systems. In addition secondary information was collected from policy documents, official reports and published literature.

In Nepal the irrigation systems were selected based on three criteria – ecological region, economic characteristics and management structure – following a series of steps. In the first step we selected major river basins across all regions of the country. In the next we focused on physical terrain: plains or hills (including undulating terrain and upland valleys). In the final step irrigation systems were selected from different strata (management structure and economic characteristics) within the identified clusters. The management structure considered were: farmer-managed; agency-managed, jointly managed and management transferred systems. A sample of 50 irrigation systems was selected covering major river basins of the country and different ecological regions. The majority of the sampled irrigation systems are farmer-managed systems.

In Pakistan we focused the study exclusively on the Spate irrigation systems only. Spate irrigation (the case study from Pakistan) systems are predominantly community managed. But variation in management ranges from completely community-managed to state-managed systems as well as semi-government type and co-managed systems around the world. In our case, we have taken traditional community-managed systems found in tribal rule (without any intervention from state in irrigation management and limited role of state apparatus in other community affairs) and state owned and managed systems (where state intervention started in British time mainly to cope tribal strength through key resource, and continued to date through changes in laws and through interventions by constructing permanent structures, involving courts and police, and appointing officials for monitoring and sanctioning). The irrigation systems from the Pakistan were selected based on nature of flow i.e. non-perennial systems (without subsequent springs after spate flow) and perennial spate (with subsequent springs after spate flow) each from community and state management.

2.3. Irrigation typology and analysis

We grouped the sampled irrigation systems considering the resource condition and institutional characteristics. The resource condition refers to the availability of the water in the source. It includes perennial (with permanent water source) and non-perennial systems (with temporary water source mainly during the monsoon season). The institutional characteristic refers to the management condition or structure of the irrigation system. It includes FMIS (irrigation systems initiated and managed by farmers) ad AMIS (irrigation systems initiated and managed by the agencies). We made simple 2x2 matrix, the subsequent analysis in the paper refer to this matrix.

2.4. Biophysical and institutional context of irrigation management

Main features of the selected irrigation systems in Nepal are presented in Table 1. Among sampled irrigation systems 50% were from plain areas and other half in the hilly areas. The majority of these selected systems were initiated and managed by farmers themselves. Out of 50 sampled systems 41 are farmer-managed irrigation systems. The remaining nine systems were agency-initiated systems, out of which three systems are under joint management and for the other six; management at various levels is transferred to users. In further discussions, we group sampled irrigation systems into ‘farmer-initiated and managed systems’ as FMIS, and ‘agency-initiated systems’ as AMIS. Out of four irrigation systems sampled from Pakistan 2 were FMIS and 2 AMIS (Table 2).

Table 1 Main features of the sampled irrigation systems in Nepal

Features	Minimum	Maximum	Mean
Age (year)	10	>200	46.0
Command area (hectare)	15	6200	501.0
Number of users (households)	28	8000	868.9
Cropping intensity at head-end (%)	130	300.0	245.5
Cropping intensity at tail-end (%)	144	300.0	238.2
Type of system			Percentage
Run-off-the-river			98.0
Pumping (incl. groundwater)			2.0
Headwork			
Temporary			30.0
Permanent			70.0

Canal lining			
Not lined			8.0
Partially lined			88.0
Completely lined			4.0
Governance system			
FMIS			82
AMIS			18

In both countries (at least the case study systems in case of Pakistan), the traditional farmer-managed irrigation systems are predominant mostly in hill/foot-hill areas. A feature of theses irrigation systems is infrastructure made from local construction materials. Such infrastructure often needed annual repair and maintenance. However, with change in government policies, many of those traditional irrigation systems have received support to improve their infrastructure.

In Nepal, many FMIS, for example, have changed their headwork to permanent concrete structures. In Nepal most of the medium and large scale irrigation systems were built in plain Terai and valley areas. The spate irrigation systems are found in all provinces of Pakistan and are the largest indigenous irrigation systems. The low average annual rainfall (less than 200 mm per year) forced the settled tribes to dig these systems in order to make living possible in such arid environments with too poor quality aquifers and too deep water tables to extract ground water.
There is a great variation in actual cultivated area due to dependency on flows and rainfall. The cropping intensity also vary from year to year and the average of last 5 years is presented in Table 2, which was lower for non-perennial systems than perennial systems.

The prominent features of the selected systems from Pakistan are presented in Table 3.

Table 2 Main features of the spate irrigation systems in Pakistan

Features	Minimum	Maximum	Mean
Age (year)			>1000
*Command area (hectare)	2000	15000	5000
Number of users (households)	500	5000	2000
**Cropping intensity at head-end (%)	75	250	150
**Cropping intensity at tail-end (%)	66	150	100
Type of system	Run-off-the-river type		
Canal lining	Mostly not lined		
Governance system	FMIS and AMIS		

* There is huge year-to-year fluctuation in actual cultivated area
** The mean value of 5 years

In Nepal, there was large variation in the age of the selected irrigation systems ranging from newly constructed irrigation systems (~ 10 years of age) to the very old systems existing since more than 200 years. Whereas the spate irrigation systems of Pakistan are believed to be among one of the world's oldest irrigation systems (Steenbergen, 1997) and farming by these systems in Pakistan is as old as 3000 BC (Meadow, 1991).

The command area of the sampled irrigation systems also varied significantly (Table 2). Some FMIS in the mid-hills of Nepal were as small as of just around 15 hectare where as the sampled system in the Terai region of Nepal had the command area of more than 6 thousands hectares. Reflecting the variation in the command area of the selected systems, the total number of users also varied greatly. The large size of the group (number of users) means more heterogeneity among the users.

3. External disturbances to the irrigation systems

The external disturbances can include biophysical distraction (Arrow 7 Figure 1), such as floods, droughts, rainfall, that impact the resource and the public infrastructure, or policy and socio-economic changes (Arrow 8 Figure 1), such as population increases, migration, market forces, that have an impact on the resource users and the public infrastructure providers.
Irrigation systems face several kinds of external disturbances, such as, natural events like floods and droughts, policy changes and market pressures. The external disturbances affect the entities, both resource and human part, of the social ecological systems in various ways. The major effects would be: affecting the infrastructure of irrigation systems and thereby water availability, expansion/contraction of irrigated command areas, increased competition for water use and resulting conflict, labor shortages and collective action, and shift in management regimes.

In this section we discuss the major natural and human induced external disturbances and how those disturbances affected the irrigation systems operation and performance. Then we relate how these external disturbances affect to the entities of the framework.

3.1. Natural events as external disturbances

Irrigation systems are adversely affected by climatic variability such as the recurring occurrence of droughts and floods. In the recent decades the delayed onset of monsoon, both in Nepal and Pakistan, has become common that affects the capacity of irrigation system to supply the water when there is need. The changing rainfall patterns due to the climate change have heavy influence on completely rainfall dependent spate irrigation systems of Pakistan.

The commonly observed situation is such that farmers cannot get sufficient water in their irrigation canals at the time when they need to start the cultivation practices for the priority crop. The priority crops are rice (Nepal) and wheat (Pakistan).

In case of Nepal, Rice requires some amount of water as early as in the month of May for seedbed preparation. During transplantation time June-July it requires large amount of water and thereafter the requirements varies depending on the stages of the plant. But in the recent few decades, as an impact of climate change, the start dates of rainy seasons have shifted to the late days. As most of the systems in Nepal are completely dependent on the rainfall it results into unavailability of the water at the time of transplanting and critical growth stages of the crop. In case of prolonged delay farmers cannot at all cultivate the rice as reported in some of the sampled systems.

In contrary, in some years, and some areas, the excessive rainfall, mostly in August-September, results into flash floods in the stream and often damaging the headwork of the irrigation systems. The flood also causes damages to the irrigation canals. It is common almost every year especially in the irrigation systems of foothill areas of Nepal. Besides enormous loss due to the damage of the irrigation infrastructure, it also makes water conveyance difficult in the later part of rice cultivation season. It also affects the water distribution for winter crops, mainly wheat, if it used to be available in normal years.

In case of Pakistan, Wheat is the staple food and priority winter crop for most spate farmers in Pakistan. The crop sowing is done with the help of conserved moisture in the fields. However the decisive role in crop success is on winter rains which have become less likely in the time of germination (shift in start of winter rainfall) when sole dependence of the crop is on rainfall. As the Spate irrigation farming of Pakistan is completely dependent on the rainfall it results into unavailability of the water at the critical growth stages of the crops. In absence of timely winter rain, the spate farmers face crop failure and are forced to use wheat as fodder before it reach harvesting maturity or shift to some low value crop like sorghum or barley. In case of spate irrigation, while the medium-sized floods are best suited for spate farming, the occurrence of heavy floods makes it difficult to divert the water to the fields. And in some cases, it also damages the temporary diversion structures of the spate irrigation systems. The changed frequency and intensity of rains has heavily disturbed the floods flow pattern.

The climate change and the variability have adversely affected the capacity of the irrigation systems to maintain the steady supply of irrigation water. Such external disturbances have increased the vulnerability of the irrigation systems. Irrigation systems are sensitive to the changes in the infrastructure and the degree of sensitiveness significantly affects their capacity to maintain robustness.

3.2. Policy changes

Another major external disturbance that the irrigation systems face is the changes in related policies at different level. Such changes affect the entities of the SES in different ways especially on the public infrastructure and public infrastructure providers. The policy changes may result in the area expansion, system rehabilitation, management change and others.

In Nepal until the beginning of 20th century there was very little involvement of state in irrigation development and management. Few *raj kulos* were reported; otherwise the majority of the systems were constructed and managed by users themselves. Some public sector irrigation schemes were initiated around 1920s (Shukla and Sharma 1997; Shah and Singh 2000). Nepal focused on expanding irrigation areas after the initiation of planned development efforts during 1950s (Shah and Singh 2000). During 1970-1985 the focus shifted from the infrastructure development to production enhancement activities. It included completion of water distribution structures of already constructed irrigation systems, rehabilitation support to FMIS and other activities related to improved agricultural technology. Further, Nepal focused on improving the performance of the existing irrigation systems that included renovation and expansion of FMIS command areas, and participation of users in development and management of irrigation infrastructures, among others.

Major policy shift was observed after the formulation of new irrigation policy 1992, giving the main emphasis on users' participation. The government adopted the participatory irrigation management policy with two action plans: turn-over, or more commonly known as Irrigation Management Transfer [IMT], of AMIS to the user groups, and joint management of large irrigation systems where users and government agencies share the responsibilities.

The changes in government policies have, over the period, affected the various entities. The major effect was on the irrigation infrastructure, the public infrastructure, mostly the increase in overall capacity to supply the irrigation water. The changes were on improvement in the capacity of the existing irrigation infrastructure, such as rehabilitation of FMIS, and the expansion of irrigated areas with construction of new irrigation infrastructure. Similarly, the policy changes have affected the composition of public infrastructure providers and thereby the service delivery mechanism (water allocation). Many agency-initiated systems, where the irrigation officials used to play the role of public infrastructure providers, are now handed over to the user groups. In the changed situation the resource users and the public infrastructure providers have become more or less the same. The new policy has improved the water delivery, the resources condition, and resulted into better outcome, the increase in agricultural production. The adoption of IMT resulted into strengthened the capacity of the Water Users' Association (WUA), the public infrastructure providers. The empowered WUAs became more capable in dealing with the external or internal disturbances to their system.

Overall, the policy changes seemed to have positive effects on the various entities of irrigation system and interactions among them. But in some cases it also resulted into conflict and lack of coordination between public infrastructure providers, the WUA and irrigation agencies. Similarly, the changes in policy meant that the resources users needed to cover the direct costs related to operation and management of their irrigation systems.

The first regular settlement of the study area in Pakistan was done in 1869-74 and fluctuating revenue based on cropped area in a year was promulgated. It was in this settlement that the irrigation customs (Riwajat-e-Abpashi) for all canals and spate systems were codified for better management of the systems. The codified customs were different across different spate systems due to variation in practices of the local communities about managing their water resources. However the colonial approach to get legal control over these community systems and generate revenue, the Punjab Minor Canal Act (1905) was promulgated. The management guidelines in the act are markedly different from what was codified in the customs documents partly because of efforts to bring all indigenous systems of the province under uniform management plan and partly because of the British intention to transfer powers from communities to the state. The riwajat documents were compiled at the district level and written in Urdu language in presence of local stakeholders and bearing signatures of command area farmers; whereas for minor canal act (1905) no such consultation was done. After the transfer of management to state governed "Rod Kohi" department; and approval of 'the Act' parallel to 'Riwajat', the authority of government officials to give a special allowance to non-haqooq lands in the state managed systems resulted in massive violation of customary irrigation rights. Some big land owners made alliance with the low-cadre staff for illegal irrigation to non-haqooq lands. Whereas in the community managed systems the water allocation continued to be fixed to actual share holders with flexibility to shift to other lands of same shareholders with changing flood paths. The comparative analysis of "Riwajat-e-Abpashi" and "Punjab Minor Canal Act (1905)" shows that the colonial act transferred powers to state from communities in respect of Operation, Maintenance and management of spate irrigation systems and found that the act provides greater authority and decisions making powers to the state which is quite conflicting with the customary rights.

The supply side policies can have disastrous outcomes in the form of poor resource condition and fragile management institutions. For indigenous irrigation systems of Pakistan, the British policy to take control of the system was different from stated policy objective of better water management following community norms as guidelines. The policy resulted in negative outcomes in terms of overall performance of the systems kept under colonial control as compared to similar spate systems which were exempted from this policy due to political reasons. The policy shift changed the role of providers by altering power relationships in the existing structure. This in turn, directly affected the relationship between providers and users and from users the affect is transmitted to infrastructure and the resource itself. So policies intended to improve existing power relationships between providers and between providers and users can further strengthen infrastructure and sustainable use of the resource and vice versa.

3.3. Market pressure

Market diversification and integration affect irrigation water management (FAO 2007). Market related factors influence the operation and performance of the irrigation system. Various aspects such as, commercialization of the farming activities, seasonal migration, changing pattern of water use, contract farming, have direct effect to the water use dynamics and the characteristics of the water users.

Crop intensification, multiple cropping and increased vegetable cultivation were noted in case of many sampled irrigation systems in Nepal. Especially the vegetable cultivation requires more water in dry season when there is water shortage in general. High comparative advantage, better market and price, however, has tempted farmers to grow the commercial crops but the water shortage means possible conflict among the users. The interdependencies between market trends, demand and price, and the farming decision also play important role in water use and thereby robustness of the irrigation system.

In the recent decades, the seasonal migration of the economically active population to the regional urban centers or the capital is on rise. This demographic transition in the farming areas has created labor shortage. Many irrigation systems we studied reported this situation. It has two implications. First it directly affects the labor availability of the household farming activities thereby forcing people to bring the hired labor. Second, farmers cannot allocate necessary time to contribute in repair and maintenance of the irrigation system. Such changes in the characteristics of the resource users due to the market associated factors ultimately result into less collective action to manage the resource and the public infrastructure. Many others have also reported the effect in resource management due to increasing market integration (Agrawal and Yadama 1997) that often result in decreasing collective action (Araral 2009).

In Pakistan, the cultivation of high delta crops (high water demanding crops like rice, sugarcane) and high yielding crop varieties resulted in increased competition for water and thereby disturbance of water balance in the systems. Where the irrigated area to available water ratio was already under pressure or in equilibrium, the increased water demand resulted in overall water shortage status of the system at water sensitive growth stages. The irrigators at the head-end of the systems or powerful farmers with ability to manipulate state apparatus in their favor benefitted from the situation at the cost of the rest of the community. The situation where effort needed to bring water was far less than the returns; favored powerful and head-end farmers to exploit the benefits. The market forces, by disruption of collective action and equity among the farmers in resource use, resulted in conflicts and further deviation from the customary rights. In the AMIS, the powers rested in hands of state departments for mediation and authority to change rules promoted weakening of the local institutions.

4. Internal disturbances to the irrigation systems

Internal disturbances refer to rapid reorganization of the ecological or social system induced by the subsystems of the ecological or social system (Marty et al, 2005). We discuss here commonly observed disturbances in the irrigation systems included in this study: change in internal management, change in users' characteristics and change in water appropriation.

4.1. Internal management change on the entities

Infrastructure providers and resource users make up human part of the framework (Figure 1). The resource users and the service providers can be the same (in FMIS case study systems) and separate entities (AMIS in our analysis). The effects of management change depend on the underlying change process. The FMIS, with long history of democratic decision-making and close ties, have lesser chances to go into elite capture. The AMIS, with more involvement of outsiders, is more exposed to threat of bureaucratic trap and elites capture. However, even in case of FMIS sometimes the internal dynamics may influence the resource use pattern.

In case of Nepal, the leadership of Water Users' Association [the Executive Committee] is normally changed at the interval of 2 years. In the past, farmers used to select the committee mostly on the basis of consensus, in case of FMIS, often bringing the more experienced and committed people in the leadership. Slowly, they have adopted the voting system for selection of the leadership, mostly after political change of 1990. In general, voting system is the better system. But due to the vested interests of local politicians or local elites in some cases it has resulted into selection of not-so-competent leadership. In such cases due to the lack of proper experiences or interest to contribute in the real cause such leadership are not able to bindtogether the resource users and manage the operation and maintenance of the irrigation infrastructure.

4.2. Change in users' characteristics

The other humanly devised component of the analytical framework is resource users. The users are affected by and influence other three entities in the framework (Figure 1). The users have multiple roles as service providers or responsible for their selection (in FMIS) and directly affected by the decisions. On the other hand users face challenge to make decisions from available choices. With declining relative value of farming compared with other non-farm jobs and decreased per capita land availability, the users face choice of whether to remain in farming or quit it. At the same time seasonal outmigration has affected demographic composition in rural areas. It also put pressure on the time availability to contribute on collective activities. The ultimate effect could be on the state of the irrigation infrastructure.

In Pakistan, the underlying objective of British policy to bring indigenous systems under state control to introduce and new class of elites and control natives weakened the relationship between users and providers on one hand; and providers and infrastructure on the other hand due to poor understanding of infrastructure to providers. The continued control of FMIS by natives maintained dynamic role of infrastructure providers in changing biophysical and resource context.

4.2.1 Change in infrastructure and water appropriation

Water distribution rules have evolved over time in indigenous irrigation systems. These rules help reduce unpredictability of irrigation and ensure collective action in operation and maintenance of the systems. The situation where rules have been created by power play and intention to hold local resources resulted in legal injunctions and weakened system wide equity and efficiency.

The construction of permanent concrete structures and strong headwork without consulting customary rights and indigenous wisdom result in larger upstream control (imbalance in power among resource users), fixation of location along the system and water turns (the tail enders will always be getting left over from the flood as in earlier pattern the indivertible flood water by local structures was used by tail enders without waiting for their turn from main canal) and changed maintenance burden (the upstream users have less need for downstream labor).

Spate irrigation systems in Pakistan have several examples of infrastructural intervention affecting irrigation rights and local institutions. One such example is Rehanzai Bund where the technically successful permanent diversion in area with considerable power differential between upland and lowland communities accompanied by absence of effective enforcement authority lead to inequity and migration of downstream farmers abandoning the settlement and farming (FAO 2010).

The cases show that the physical infrastructural interventions initiated from producers immediately affect the rules and customs part of infrastructure, which in turn affect the users by creating inequalities and putting one group at advantageous position at the cost of others. The resulted loss in collective action leads to reversal to the initial infrastructure or higher work burden and cost which may lead to abandoning farming in a systems providing sustainable livelihoods previously and irrigating lands for centuries.

4.2.2. Responses to the disturbances

It is important to understand how irrigation systems [and farmers in particular] deal with disturbances to their system; and cope with scarcity, competition and conflict situations as a result of such disturbances. The role of governance structures and institutions in mediating such disturbances and maintain the robustness of the irrigation system is the major concern. Thus in this section we discuss how irrigation systems respond to the particular disturbances.

4.3. Institutional responses

In this sub-section we assess 'How the autonomy of SES affect on robustness; are the highly autonomous systems able to respond firmly to the shocks and disturbances; if so why?' We also try to discuss 'How forces of change (external and internal disturbances as discussed in section 3.2 and 3.3) interact with existing patterns or forces of continuity, and how far irrigation systems are successful to respond to such forces by filtering out undesirable traits (Axinn and Axinn, 1997).

Earlier we noted that majority of the sampled irrigation systems in Nepal were managed by farmers through water users' associations (WUAs). The FMIS were initiated and are being managed by farmers themselves for long periods through WUAs. WUAs in FMIS have high degree of autonomy than the AMIS. Higher the degree of autonomy of the irrigation systems, the more will be the recognition of the users' rights to organize without external interference. The result showed that highly autonomous WUAs in FMIS also satisfy the conditions as mentioned in the design principles (Ostrom 1990) that characterize robust self-governing CPR institutions. Thus the highly autonomous FMIS those satisfy the conditions as discussed in the design principles are more robust compared to AMIS. Here, the robustness was defined on the basis of satisfying the institutional conditions and the autonomy of the WUAs. The robustness is reflected in their capacity to respond firmly to the disturbances. For example, in case of many FMIS they are capable of generating quick response from the users to fix the infrastructure in case of damage due to flash floods. It was mostly due to well-defined rules, roles and responsibilities, and most importantly well enforced monitoring mechanisms.

In many cases social capital and networks play important part. The role of local leadership is crucial in dealing with external shocks. In most of the FMIS of Nepal, the head of WUA is generally the experienced farmers, who based on his/her experience in farming and water management play important role in dealing with the problems at system level. Moreover, the WUAs of FMIS are federated at different level in Nepal. It provides them the opportunity for mutual learning and, thus, to deal with uncertainties.

In spate irrigation systems under community control, the tribal elder is usually most respected person in the community and mediate all sorts of disputes with consultation of other tribal elders.

The key post in the committee is that of a mason (locally known as *maimar*) as he is the most experienced and considered as expert in spate diversion structures. His assignments include estimation of work needed in a flood season, guiding labor for construction, monitoring water distribution according to customs. The appointment contract is renewed on yearly basis and remuneration is in the form of fixed proportion of produce from land of each member. His impartiality is ensured through yearly extension of his appointment and his interest with overall higher productivity across the system as his remuneration is attached with overall production rather than giving benefit to selected few. The AMIS, have replaced *maimar* with a state appointed lower cadre official. Due to permanent nature of job, any complaint can lead to a maximum of transfer which is sometimes a desired objective of the officials due to transfer from remotely located spate systems to high revenue generating canal irrigation systems.

5. Rules and allocation practices

The focus of this subsection is on to discuss 'What sorts of rules and allocation practices are in place to deal with the complexity created by the nature of public infrastructure?' In this sub-section we discuss about various kinds of rules and the enforcement mechanisms.

Operational level rules establish the operational level action and specify rights and responsibilities to the users. The operational level actions, in turn, interact with the physical attributes of the resource to produce outcomes array from sustainable use of the resource to its complete destruction. Operational rules to manage the common pool resources are grouped into seven categories (Ostrom, 2005): position, boundary, choice, aggregation, information, payoff and scope rules. We also followed the same categories for analysis. Description of each type of rule is presented in Table 3.

Table 3 Seven types of operational level rules in irrigation management

Rules	**Description**
Position	The position rules define the set of possible positions for participants.
Boundary	The boundary rules define; eligibility to enter a position, the process determining which eligible participants may (or must) enter the position, and the process of exit (may or must) from any position
Choice (allocation)	Choice rules guide which action is required or forbidden. It specifies that any participant occupying particular position must, must not, or may do certain action
Aggregation	The aggregation rules are related to decision process which determines whether a single participant or a group of participant can decide about any action
Information	The information rules directly affect the level of information available to the participants involved in action situation
Payoff	Payoff rules provide provisions for rewards, burdens or sanctions being involved in particular action situation
Scope	This rule is directly related to the outcome which must, must not, or may be affected by the result of actions taken by participants within specific situation

Source: Ostrom, 2005

The comparison shows that the rules evolve in different ways in resources of different nature and with variation in management. If certain type of rule is present in our case study systems we denote bye ‘Y’ (Yes), and if absence we denote by ‘N’ (No) for comparison (Table 4). The list of the rules presented in the table is not the exhaustive list of all operational rules. We present only the most commonly used and known rules to the farmers.

Table 4 Comparison of operational rules in two management regimes

Rules type and rules	Pakistan		Nepal	
	FMIS	AMIS	FMIS	AMIS
Position Rules				
Does position of water Monitor exist?	Y	N	N	Y
Boundary Rules				
Is it possible to get irrigation rights from outside community authorities?	N	Y	N	-
Are water rights fixed with land and transfer together in land documents?	N	Y	Y	Y
Choice (Allocation) Rules				
Is the allocation procedure fixed (fixed time slots etc)?	N	Y	Y	Y
Is the sequence of irrigation fixed?	N	Y	Y	Y
Aggregation Rules				
Is monitoring community’s own responsibility?	Y	N	Y	N
Monitors selected solely by community	Y	N	Y	N
Users strictly follow mutually agreed and understood rules	Y	N	Y	N
Information Rules				
Community elected members inform about input contribution	Y	N	Y	N
Is record maintained for labor contribution?	Y	Y	Y	N
Pay off Rules				
Does the punishment always start with monetary penalties?	N	Y	N	N
Are the decisions for infraction and conflicts decided outside community?	N	Y	N	Y
Is the proposed punishment implemented by outside community agencies?	N	Y	N	Y
Scope rules				

Rules type and rules	Pakistan		Nepal	
	FMIS	AMIS	FMIS	AMIS
Are the crops cultivated as mentioned in irrigation rights documents?	Y	N	Y	N

In case of Nepal, WUAs in FMIS have greater autonomy to make and enforce the rules. In FMIS users can devise rules based on their interest and necessity, and manage rules themselves. The experienced committee members in FMIS formulate rules based on interest and necessity of the users. But in AMIS agency involvement in drafting rules is high. Similarly, FMIS are far better than AMIS in monitoring and sanctioning arrangements as well. The rule enforcement mechanisms are well institutionalized in case of FMIS. In addition, in FMIS a majority of the users follow the rules whereas in AMIS substantial levels of violations were found in more than half of the irrigation systems. The higher the proportion of rule violators and higher level of violations, the greater is the chance of less collective action. Ultimately it affects the smooth operation and management of irrigation systems and their capacity to deal with disturbances.

6. Coping strategies

In this sub-section we focus on 'How the irrigation systems cope with general shocks or whether they fail to do so?' In sections 3.2 and 3.3 we looked on how the irrigation systems face with external as well as internal disturbances. Some of such disturbances may even be helpful to improve the system performance as well. But most of the external or internal disturbances often increase the vulnerability of the systems to maintain its characteristics and services. The capacity to cope with such disturbances depends on the sensitiveness of the irrigation systems to small changes in infrastructure and biophysical context.

The external disturbances mainly affected the availability of the irrigation water in time often resulting into less water or no water situation due to low rainfall or damage in irrigation infrastructure. In such situation, irrigation systems tend to develop different coping strategies to deal with the disturbances. In Nepal, in majority of the irrigation systems we studied, farmers have alternative management strategies to cope with water scarcity resulted due to external factors such as delayed rainfall or damage in intake structures or canal. It helps to reduce potential for conflict. This was particularly apparent in the old, but flexible farmer-managed systems. They try to adjust allocation based on resource condition and demand situations. Farmers agree to allocate water only to those areas [mainly near to the water source, that is head-end areas] that is possible to cover by the available water. Farmers who get the water contribute more resources to fix the problem earlier possible if it was due to damage in the system infrastructure. Farmers in other areas [normally the tail-end users] plant other alternate crops. But in AMIS we did not find any such examples.

It shows the crucial role of local institutions that, in some cases, also help to adjust the farmers with the new context. For example, in Pakistan normally medium-sized flow is the ideal condition for spate farming but the changed rainfall pattern [frequency and intensity] has heavily disturbed the floods flow pattern. Heavier and smaller flows have become common. In the changed context, the reliance of spate farming is now shifted to small flows and institutions are adjusted to new flow patterns. FMIS has adopted new rules: irrigation turns determined through draw system for each season and custom of irrigating one field in a sequence in non-perennial flows, and fixed time for given land along with rotating irrigation turn in case of perennial irrigation systems. But the fixation of rules, in AMIS has failed to adjust to changed flow patterns and head to tail irrigation system or fixed sequence and quantity of irrigation has put the tail-end farmer at disadvantage.

In the irrigation systems, which mainly rely upon rainfall; the rainfall variability can be easily detected in the form of production variability as well as in the form of risk-averse livelihoods and coping strategies evolved over time among the local communities. The coping strategies can be grouped into three categories: *ex-ante* such as risk-tolerant varieties, diversification of farming and other livelihood enterprises; *during season* adjustments in response to specific climatic shocks; and *ex-post* risk management options to minimize impacts of adverse shocks on livelihoods (Cooper et al, 2008). The way people cope these uncertainties and whether the uncertainties become a risk to their production and livelihood systems depend upon many factors including the social capital and capacity to organize collectively.

In the sampled irrigation systems of Pakistan and Nepal the uncertainties arise both from inherent physical features, external disturbances as well from policy changes. However, the communities have been using various coping strategies to combat such uncertainties (Table 5).

Table 5 Uncertainties with production and livelihood systems and coping mechanisms at community level

Uncertainties inherent to irrigation systems	Impacts on production and livelihood systems	Coping strategy at community/system level
Droughts	Years without crops, Shift to minor crops, Food shortfalls	Drought resistant local varieties and technologies, Cereals exchange, provision of loans and help among communities
Normal weather (not the same as "ideal" weather rather include anticipated cyclical fluctuations)	Low productivity, Low returns, fluctuating cultivated area	Selection crops and variety depending on weather, Ability to promote collective action to best utilize scarce water for maximum benefits by efficient application techniques and low delta crops/varieties inclusion in cropping systems
Changes in policy	Impact local institutions and collective action	Collective actions and linkages for favorable policy
Reduced competitiveness due to non-farm opportunities	Outmigration and impact on local institutions leading to less labor supply and loss of system functioning and productivity	Livelihood diversification and employment generation, collective action to exploit the emerging market potential i.e. Organic farming, medicinal crops etc.

The coping strategies in response to these uncertainties vary both in terms of scale as well as timing. Such uncertainties need separate coping strategies for plant level to community level as well as with the stage of incidence of such events (Table 6). The coping strategies at farm/household level to the system level may vary. The local communities have been showing resilience to such well-known uncertainties since centuries; but the emerging threats to these systems are from rapid economic changes and have posed a threat to the existence of these indigenous systems.

Table 6 Scale and timing of interventions

Scale	Ex-ante	During the season	Ex-post
Plant	Stress/drought tolerant varieties	Replanting with early maturing varieties	-
Plot	Planting density, mixed cropping, moisture conservation	Reduced crop density, Decision about cultivation	Failed plots grazing by animals, fodder without reaching harvesting stage
Farm	Crops diversification, cropping pattern	Shifting crops across the plots	Late planting for fodder and forages
System level	Livelihood diversification, cereal stocks, social and off-farm employment networks, livestock assets	Collective action and reciprocity to minimize losses, internal borrowing of money and cereals from better of households and villages	Assets sales for cereals purchase and outmigration

7. Discussion: Robustness of the irrigation systems

The analysis of external and internal disturbances, and the responses in the changes circumstances provided the interesting facts on changes in the characteristics of resource and public structure, changes in different aspects of resource users and the role of public infrastructure providers. In this section we analyze the linkages and interactions among various entities of the irrigation system, as a social ecological system. The changed role of resource users and public infrastructure providers (human components of the Anderies et al, 2004 framework) resulted in the form of variation in operational-level rules and variation in interventions in the form of structural improvements of systems. The interaction among the entities of the core subsystems of SES (Table 7) provides the hints on difference in robustness due to variation in capacity to cope challenges associated with these systems. The inherent uncertainty in these systems has been a major threat and will be further aggravated due to climate change and preparedness of systems under two different management regimes with variation in resource uncertainty.

Table 7 Entities of irrigated social ecological system and linkages among entities

Entities/linkages	Major Threats to the irrigation systems	Issues related to selected systems from Pakistan		Issues related to selected systems from Nepal	
		AMIS	FMIS	AMIS	FMIS
Resource	Rainfall patterns; floods intensity and frequency	Uncertainty on availability of the water	Uncertainly in water availability, but flexible rules to allocate water	Low reliability and uncertainty in availability of the water	Less reliable water availability in some situation but flexible rules to allocate
Resource users	Outside interference in rules	Since British times; the scope for outside agencies and courts has increased	Attached to customary practices followed by flexible and reactive water rights	Users have limited role in rule formation	High autonomy in forming rule based on the need
Public Infrastructure	High failure rates of engineering structures due to design challenges and unanticipated flood intensities; irrigation customs and laws	Engineering designs don't fit for flood irrigation systems	Structures build with local material have flexibility to build due to low cost	Infrastructure do not match with traditional systems that were prevalent in the same area; costly and difficult to replace when damage	Simple and flexible structure using locally available materials, easy to re-build in case of damage
Public Infrastructure Providers	Insufficient capacity to operate the infrastructure in the changes situation	Engineers lack training in managing flood irrigation and fail by using available structural designs for perennial canals	Local people have long experience on spate farming and are more able to adjust with changing flow condition	Agency officials lack clear understanding of local situation and local need	Same people as resource users and so have better knowledge to operate the canal infrastructure

Between resource and resource users	Changing rainfall patterns, variation in available water and changing use pattern	Fixed rules implemented by state have exacerbated the situation of coping unusual climate events	Reactive water rights have potential to cope climatic change induced rainfall patterns	Not enough attention and capacity to deal with the shocks and changing demand	Fast and collective response capacity, alternate to deal with demand
Between resource users and public infrastructure	Declining deliberation process and weak monitoring	Conflicting state and community laws; corruption by officials	Pressure from external climatic and market forces; new skills needed for new challenges	Low resource contribution for O&M, poor condition, free-riding, poor monitoring and enforcing	Climatic variability, competition due to market pressure, reduced collective action
Between public infrastructure providers and public infrastructure	Fixation of rules, social capital and new infrastructural challenges	Top down approach from making laws to making infrastructure; violation of customary rights	Pressure for state involvement; NGOs and development agencies intervening with infrastructure projects	Infrastructure and allocation mechanism decided on top-down approach	Change in management, and transfer the responsibility of O&M of the systems
Between public infrastructure and resource	High failure rates of structures and unpredictable resource availability	Reliance on permanent structures affected community participation by realization that state should maintain infrastructure	Lack of dynamic leadership and less youth available due to new non-farm jobs opportunities	Infrastructure not fit to biophysical context, Ineffective due to lack of maintenance	Labor shortages for contributing in O&M, competition for water
Between public infrastructure and resource dynamics	Ground water pumping, use of saline water, head-tail end issues	Farmers growing commercial crops and new varieties supplement with saline	People following customary laws are following traditional land use and	Use of groundwater and in some cases overexploitation	Sometimes tension between head-end tail-end users, but does not

		water which leads to salinity problem.	are not confronting any salinity issues.		become severe
Between resource users and public infrastructure	Conflicts, court cases, free riding issues	Tension among members and high costs as cases go to police and even at high court level in some instances.	Decisions are made at local level and most conflicts are mediated by tribal elders at community level.	No-incentive to maintain the infrastructure, free-riding	Good conflict resolution arena, local institutions manage the conflict, if any
External forces on resource and infrastructure	Flash floods, changing flood paths with erosion of flood plain due to heavy flows	Fixed rules and fixed points for water diversion creates problem in emerging external challenges	Reactive water rights help farmers to adjust diversion points to changing flood paths.	Increasing frequency of floods with uncertain strength damage infrastructure	Flash floods, but the users provide quick response to fix it
External forces on resource users	Preference for non-farm jobs due to economic integration and risk aversion.	Outmigration has resulted in higher costs per unit of irrigated land for maintenance and operation.	Risk of losing irrigation rights if not cultivated for several years provides incentive for some members to continue cultivation	Outmigration, labor scarcity	Trend of seasonal outmigration, but still maintaining the systems mainly for subsistence oriented farming

External disturbances most often affected the public infrastructure and resource characteristics directly affecting the water availability. At the same time the interventions by public infrastructure providers' in the form of changed rules at constitutional choice level have impacted operational level rules through changed role of actors at collective choice arenas mostly in AMIS. In such situation resource users in case of AMIS, in both countries, were not willing to contribute in maintaining the resource systems mainly due to the inflexible rules. The lack of maintenance further aggravated the capacity of infrastructure to cope the damage by floods. The FMIS, on the other hand, also faced the external disturbances but the flexible rules and better monitoring mechanism help keep the functioning intact by providing fast collective response.

Similarly, as a result of market forces there was competing resource use and increased demand for the water resulting into conflict in many cases. It resulted into reduced collective action in case of FMIS also. But the FMIS has shown the robustness to adjust with the effects of external factors. The flexible rules, autonomous WUAs and local institutions provided the capacity to self-govern and maintain the robustness of their irrigation systems.

8. Conclusion and implications

Natural events as a result of climatic variability and change, policy changes and market pressure are the major external disturbances affecting core entities of the framework at varying degree. Among these disturbances, the natural events seem to have universally negative affects due to its uncertain nature. The vulnerability of the irrigation systems to those disturbances also depends on the sensitiveness to small changes in infrastructure and biophysical context. The FMIS with flexible rules and better collective action seems to have better adaptive capacity to adapt with the disturbances caused by natural events. It shows the robustness of FMIS compared to AMIS.

The policy changes, on the other hand, have both positive and negative effects. The policy change brought realizing the experiences at community level and devised considering customary rights and local institutions have positive outcomes in the form of strengthened public infrastructure and the providers (cases from Nepal). The imposed policy from outside and created to shift authority from farmers to outside agency weakened the relationship between providers and public infrastructure as noticed in Pakistan. The negative effects are felt from rules violation, worsening resource condition including inefficient use (case study from Pakistan) and conflicts among users.

The market pressure have multidimensional effects in the form of tendency to use more water by some at the cost of others and also in the inter-sectoral competition causing shift in manpower from agriculture to other employment and investment opportunities. The internal disturbances in the form of management changes of WUAs affected the irrigation systems in different ways. External interference was always dominant in AMIS and thereby affecting the public infrastructure providers. In some cases FMIS also fell into the trap of local selfish politicians and local elites who often wanted to use the CPR in their personal or group benefits. Seasonal outmigration of the people also affected the collective action.

Irrigation systems dealt with external disturbances in various ways. Governance structure and local institutions were found crucial in deal with the disturbances. Mostly, highly autonomous FMIS were able to adjust with the changing situation. High autonomy provided them the opportunity to adjust their institutional conditions according as the changed context. It in turn enhanced their adaptive capacity making them capable of generating rapid response to the external shocks and maintains the robustness of their system. Existence of various forms of rule and better compliance by the users was another important aspect in FMIS. But in AMIS rule formation was mainly done by the agencies being it ineffective in implementation. But in many FMIS the centuries old local rules prevailed and new rules were also formed based on the community needs. The irrigation systems showed their robustness in the form of diversity of rules to different situations, stronger institution of local leaders, and adoption of coping strategies to match with uncertainty in irrigation.

Analysis of institutional diversity and responses in diverse settings was the main focus of this paper. We analyzed robustness and dynamics of irrigation systems considering the variation in governance and nature of irrigation resource. We realize that a complete analysis of entities involved in a system is necessary before making any policy solution and institutional restructuring to improve system performance (Ostrom 2009; Ostrom et al 2007). The detail analysis of rule formation process and application to deal with external shocks would provide further insight for irrigation water management.

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