Robustness, vulnerability and adaptive capacity in social ecological systems: the case of spate irrigation systems in Pakistan

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Abstract

Socio-ecological systems (SESs), the spate irrigation system in our case, operate under the environment of stress from several external and contextual factors. The literature on collective action in Common Pool Resources (CPRs) considers non-storage and non-stationary characteristics of a resource as major obstacle to its sustainability. However, the case study systems have endured, despite acute scarcity and uncertainty of irrigation, for centuries in arid and semi-arid environments of the Middle East, Africa, South Asia, parts of South America and Central Asia, where rainfall is too low to support rainfed farming. These rainfall dependent irrigation systems are more complex and can exhibit unexpected changes as a result of climatic disturbances. Thus, actions directed at enhancing robustness to a particular set of disturbances can trigger changes in ecological dynamics that may, in turn, alter the set of disturbances faced by communities. The four case study systems for this research were selected from the Punjab (Pakistan) by purposive sampling, comprising two perennial and non-perennial farmer managed spate irrigation systems (FMIS) and two perennial and non-perennial agency managed irrigation systems (AMIS), providing 2X2 typology for analysis. The sustainability framework by Anderies et al. (*A framework to analyse the robustness of social-ecological systems from an institutional perspective*. Ecology and Society, 2004) has been used for analysis of this study.

Keywords: vulnerability, sustainability, adaptive capacity, irrigation management, arid and semi-arid environments, spate irrigation, Punjab Pakistan.

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1 Introduction

Indigenous irrigation systems are facing new threats because of openness to the new world, the commercial interests of farmers, the rising cost of maintenance, increased competition for water and weakened social cohesion due to reasons that include state interventions [1]. Socio-ecological systems (SESs), irrigation systems in our case, are 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 [2]. The nature of resources (mobile or stationary) responds differently to predictable and unpredictable disturbances [3]. The CPR theorists consider lack of storage and the non-stationary character of a resource, spate irrigation in this study, as a major obstacle for collective action [4]. The strong connections of SESs with larger scale phenomena pose challenges and opportunities for stakeholders. Literature based on past performance of resource systems shows that many long endured SESs have successfully adapted their institutions to these disturbance regimes [5], while others collapsed [6].

Spate irrigation is a type of water management system, which is unique to semi-arid environments, where flood water is generated by heavy rainfall in upper catchments and these systems use the occasional flow of floods to operate intermittently throughout the year [7]. The uncertainty about the occurrence of flood water, as well as the timing and size of the flood, are major factors leading to variation in cropped areas across cropping years [8]. Water rights in such systems are found to be complicated and conflicting, as different users have different rights depending upon the type of flow [9].

The spate irrigation systems have endured the known shocks of regular climate variability and floods with varying degrees of success in different management regimes and resource uncertainties [10], and are now exposed to climate related novel shocks and disturbances at a pace never experienced in human history [11]. Already, there is a 10–15% decrease in precipitation in arid areas of Pakistan and the predicted rainfall, particularly during the summer monsoon, is expected to increase [12]. Similarly larger drought periods, and the frequency as well as unfamiliar size and nature of floods, can have catastrophic impacts [13].

This paper looks into the adaptive capacity of spate irrigation systems, coping with 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 estimating the chances of success of coping with novel shocks in the face of climate change. We have discussed our case study related issues, major threats and possible panaceas across the core components of a SES *viz* the resource system; governance system; resource units; resource users individually and in relationships that affect each other and the related ecosystems [14].

2 Methodology

In order to analyze the core entities of the SES and understand interactions between them, we adopted the framework proposed by Anderies et al. [15]. The

framework focuses on four entities, which are mostly involved in CPRs harvested by people (Figure 1). The two entities in the framework namely, 'resource users' and 'public infrastructure providers' involve humans. The other two entities namely 'resource' and 'public infrastructure' involve physical and institutional aspects. The public infrastructure consists of human-made physical and institutional capital [16]. The 'resource' entity represents the biophysical system used by the 'resource users' through joint provision effort of the two human based entities in the framework *viz.* '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. Similarly, external threats can also affect components and interactions in the framework.

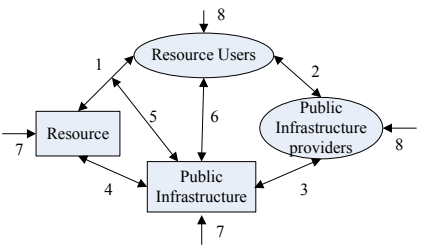

Figure 1: Anderies et al.'s [15] framework for SES sustainability.

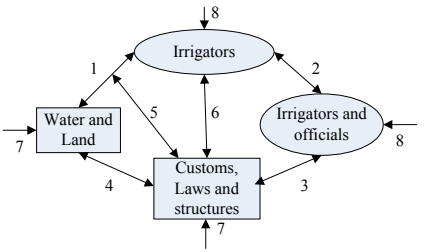

Figure 2: Modified framework for spate irrigation systems.

In FMIS, the resource users and public infrastructure providers are the same, and the factors that impact one entity also in return impact the other (if provision of public infrastructure is impacted by some factor, the users are also affected by it). In AMIS in our study, the human entities of the framework involve different actors i.e. public infrastructure is influenced by state departments and officials, with less influence of local communities compared to community managed systems.

3 Analysis and discussion

3.1 Institutional change in spate community irrigation systems

The deterioration of local resource management institutions by neglect of colonial powers is well documented in forestry, irrigation and fisheries resources [14]. Pakistan's water management policies are largely continuation of British colonial legacy [17]. These policies were made for consolidation of colonial control rather than concerns for public well-being and equity [18]. The irrigation control provided strong link between local communities and colonial state in such an arid environment [17]. The inability of the state to change colonial laws resulted in continued policing role of the state rather than that of a service

provider [18]. The comparative analysis of "Riwajat-e-Abpashi (1864)" and "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.

Now after the analysis of process and nature of institutional change, we move forward to understand how such changes lead toward management of these systems.

3.2 Cropping patterns in a changing context

The choice of crop(s) is highly influenced by availability of water and the cropping pattern varies with type of spate irrigation system and supplemental water availability. Usually, sorghum, millets and Chickpea are major summer crops and the next wheat crop cannot be cultivated in the fields with summer crops as there is not enough residual moisture to support it. Similarly if fields get subsequent spate water later in summer season (August-September) then the moisture will be stored and land will be allocated for wheat instead of summer crops (in this case the land is ploughed even if any other crop was sown in that field). In lowland perennial systems have adapted to wheat and cotton or rice cropping systems (with sorghum and vegetables as mixed crops). The rain-fed farming is practiced for growing fodder on non-haqooq or lands out of spate command. Due to growing scarcities with bringing more areas at head ends, clear distinction can be observed between head end and tail ends crops, crop

Table 1: Impact of institutional change on agricultural production systems.

Impacts on agricultural production systems	AMIS				FMIS			
	Perennial		Non-perennial		Perennial		Non-perennial	
	Head	Tail	Head	Tail	Head	Tail	Head	Tail
Customary Land use followed	12.9	21.4	32.9	40.0	82.9	90.0	81.4	88.6
Increase in number of crops	87.1	18.6	31.4	14.3	14.3	8.6	11.4	21.4
Decrease in number of crops	0.0	60.0	35.7	45.7	2.9	1.4	4.3	0.0
Inclusion of commercial crops	67.1	24.3	17.1	25.7	32.9	25.7	0.0	0.0

Note: Figures show % of yes response.

yields and cultivated area. Also the declining kamara system has weakened communities' ability to stop and or divert big floods; only small and medium floods can be used for irrigation most of which is taken by head end lands.

3.3 Eroding social capital and declining collective action

The water users in indigenous irrigation systems can have conflicts in various water management aspects. However, only few members talk about conflicts in such homogenous societies in order to maintain communal harmony [2]. Therefore, the respondents in this study were asked to name and prioritize problems associated with collective action for water management and related risks to their traditional irrigation. The institutional risk values were calculated by calculating and Incidence (I) and severity index (S) [19]. The severity index shows the severity of risk of a problem on a scale of 1 and 2 (where 1 shows 'most severe' and to 2 represents 'least severe') and the incidence index shows how many respondents reported that problem (with '1' representing incidence and '0' representing non-occurrence of problem in a response). The major benefit of this method was that the respondents were neither fixed with the number of problem to report nor they were fixed with the choices to select among. The severity index for a problem shows the order in which a respondent mentioned the problem in total responses. The mean value of the responses was then calculated for the respondents who reported a particular problem in survey.

Table 2: Perceived institutional risks.

Risks to institutional sustainability	Overall Index	AMIS		FMIS	
		Perennial	Non-perennial	Perennial	Non-perennial
Violation of rules	0.47	0.60	0.57	0.33	0.36
Officials intervention in customary laws	0.30	0.59	0.37	0	0
Declining relative value of farming	0.52	0.51	0.60	0.42	0.54
O&M cots	0.47	0.43	0.32	0.52	0.56
Outmigration	0.43	0.54	0.54	0.36	0.18
Decreasing land holdings	0.55	0.45	0.54	0.63	0.58
Support from government in losses due to very heavy floods	0.56	0.33	0.46	0.62	0.75
Extension and research services	0.41	0.07	0.31	0.51	0.56

The information was then used to construct a composite risk index to compare these issues across systems and across different management regimes.

The index values show that higher violation, interventions in customary laws and conflicts in operation and maintenance and management of the systems were viewed as high risk factors in AMIS compared with FMIS. However the decreasing land holding due to distribution (among all children according to Islamic law) and lack of government support even in very large floods which destroy crops and demolish structures was viewed as a major constraint by farmers in hilly FMIS. The high indexes for extension and research support in hilly area and non-perennial spate respondents shows that they consider lack of specific research and extension services for crop and livestock as major risk to sustainability of spate farming. The outmigration in AMIS was created problems in terms of abandoning farming in those lands and increased labour costs for remaining farmers (non-perennial systems mainly) and handing over lands for rental farming and new entrants prefer to grow non-traditional cash crops and high yielding varieties with the use of pesticides and fertilizers which create hazards for downstream drinking water for humans and animals (the case study FMIS perennial systems has traditional drinking water rights equal to two fingers width in the main lateral).

3.4 Performance of the systems and outcomes

The performance of irrigation systems can be measured by variety of methods including sophisticated technical ways using marginal productivity, irrigation efficiency, conveyance efficiency etc. Our objective is to compare the performance of systems which are different in their absolute performance

Table 3: Comparison of performance indicators in selected systems.

Performance measures	AMIS				FMIS			
	Perennial		Non-perennial		Perennial		Non-perennial	
	Head	Tail	Head	Tail	Head	Tail	Head	Tail
Participation in maintenance work	24.3	15.7	60.0	47.1	67.1	75.7	84.3	88.6
Conformance with water distribution rules	44.3	84.3	80.0	68.6	81.4	91.4	90.0	98.6
Water adequacy considering system characteristics in average years	78.6	38.6	67.1	50.0	87.1	95.7	77.1	70.0

Note: Figures show % of 'yes' response.

characteristics (like perennial and non-perennial can be measured using same scale). Therefore instead of going into absolute measurement methods, we analyzed systems performance using outcome criteria [20], like participation in maintenance; rules conformance and adequacy of water under different scenarios at head end and tail ends of the system (higher participation, better conformance to rules and adequacy compared with systems actual capacity show better performance of system and vice versa).

The external interventions in the form of institutional change impaired system performance in the form of participation in collective work and water adequacy and violence of rules. The external interventions in the form of institutional change impaired system performance in the form of participation in collective work and water adequacy and violence of rules. The results show that FMIS performed better than their corresponding AMIS. The major differences can be found in overall responses about system performance in general and difference in head end and tail end responses in case of AMIS. The situation is even worse in case of perennial AMIS where the higher productivity; potential to grow commercial crops, lower labour requirements coupled with officials ability to manipulate promoted opportunistic behaviour by head-end farmers.

3.5 Robustness, vulnerability and adaptive capacity of the systems

Our study is based on the hypothesis that the institutional change without giving due consideration to possible effects to other entities in SESs leads to counterproductive output. The analysis of 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 interactions among the entities of the core subsystems of SESs (Table 4) shows 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 has been analyzed in detail.

The interventions by public infrastructure providers' in the in the form of changed rules at constitutional choice level impacted operational level rules through changed role of actors at collective choice arenas in AMIS. This further impacted the public infrastructure by construction work which resulted in decreased willingness of users in the maintenance work despite of high failure rates and lack of functioning of these structures after few huge floods. This change bring with it poor monitoring responsibility with government officials in the form of scanty staff of low pay scales and more authority, leading to corruption and rent seeking. This resulted in overriding further promoted by prolonged and expensive court cases.

On the other hand the FMIS continued to remain under same institutional structures with centuries old water use traditions and formulated appropriate rules to cope the external shocks. The rules in the form of reactive water rights,

Table 4: Linkages involved in SESs to cope with climate change and other challenges.

Linkages among core entities	Major Threats to spate systems	AMIS	FMIS
Between resource and resource users	Changing rainfall patterns resulting in variation in time, duration, and size of floods	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.
Between users and public infrastructure	Declining deliberation process and weak monitoring.	i. Conflicting state and community laws and officials dominates decisions ii. Officially appointed lower staff involve in corruption.	i. Irrigator's agreed customary laws which are reactive in nature ii. Locally selected monitors paid proportionate to total production makes irrigation fair.
Between public infrastructure providers and public infrastructure	i. Fixed maintenance plans ii. The increasing high floods events in frequency and intensity.	i. Meeting is called by official decree without consulting local farmers ii. High floods damage permanent state structures and sometime demolish them.	i. Farmers' gathers before rainy season and select maimar and or irrigators for the season/year ii. The low cost structures are rebuild using local material; once destructed by floods.
Between public infrastructure and resource	Concrete build engineering works fail to address flood challenges and customary laws.	Reliance on permanent structures made by short term projects affected community participation by realization that state should maintain infrastructure.	Only locally constructed earthen structures exist which are maintained and build every flood season by community and has kept collective action intact.
Between public infrastructure and resource dynamics	Saline ground water unfit for irrigation. Pumping of saline water to fulfil cash crops water requirements.	The farmers growing commercial crops and new varieties supplement with saline water which leads to salinity problem.	People following customary laws are following traditional land use and are not confronting any salinity issues.
Between resource users and public infrastructure	Conflicts, court cases, head-tail and 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.
External forces on resource	Changing flood paths with erosion of flood plain due to heavy floods.	The fixed rules and fixed points for water diversion creates problem in emerging external challenges.	The reactive water rights help farmers to adjust diversion points to changing flood paths.
External forces on resource users	Preference for non-farm jobs due to economic integration and decreasing returns due to climatic shocks	The outmigration has resulted in higher costs per unit of irrigated land for maintenance and operation.	The flexible water laws provided equitable distribution of water to all members and resulted in continued farming in these areas.

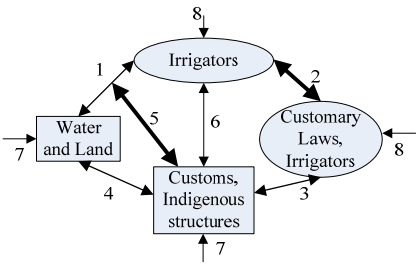

Figure 3: Modified framework for FMIS (bold lines represent strong linkages).

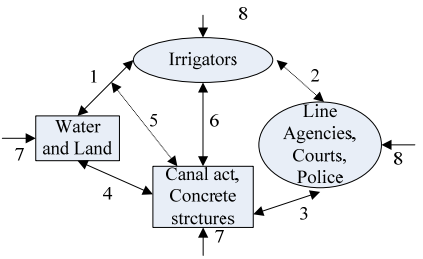

Figure 4: Modified framework for AMIS (dotted lines represent weaker linkages).

with more flexibility and fair community monitoring mechanism, kept the functioning intact and resulted in superior outcomes in the form of participation in the maintenance work and maintaining equity across the systems.

The major difference in the two management regimes was found in stronger relationship among resource users and public infrastructure providers in FMIS which resulted in robust public infrastructure and resource dynamics (Figure 3). On the other hand, in AMIS, the weakened relationship between resource users and public infrastructure providers resulted in weak public infrastructure and its fragile relationship with resource dynamics (Figure 4).

4 Conclusion

We have looked into dynamics of four spate irrigation systems in the southern Punjab part of Pakistan in the context of variation in governance and resource availability. In the plain areas systems, the state interference to get better hold on key resources in colonial times, transferred management roles to local landlords (in the form of *'Patti Daar' or 'zamindar')* and government officials, who continued with the customary laws until the enactment of the minor canal act of 1905. The state sponsored machinery and construction of permanent diversion and protection structures, reduced needs for labour and bullocks and provided chance to local influential farmers to use rules in their favour where officials were granted final authority to make any changes in irrigation rights and change in watercourses and canals. The results shows that collective action and local institutions are fragile and more vulnerable to external shocks in perennial systems where lower cost of maintenance compared with returns and higher interest of officials to manipulate rules to favour head-end influential landlords provided incentive to use rules against customary laws. This resulted in fixed rules, violation of customary laws, more conflicts, weakened authority of traditional water masters and growing conflicts and court cases.

A complete analysis of entities involved in the system was done to understand institutional issues in the systems [14]. It was given equal importance to

understand how rules were designed and established and how far the users adapted to these rules and desire any change for better resource management. The institutional diversity provides better opportunity and greater social capital for institutional design [21]. The results shows that the FMIS proved to be more robust by adapting to shocks of changing economic, socio-political and ecological conditions through better appropriate institutional design which can also endure future shocks [15]. This study has also identified stronger and weaker linkages in the linkages among the core entities involved in SESs in the two management regimes. It is important to understand relationships among all entities involved in SESs, before making any policy to make systems more robust and sustainable institutions.

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