APPENDIX

I. Methods: Coding manual

A) *Coding of cases into cultural types*

There is an extensive literature on the application of grid-group Cultural Theory (CT) to various social, political and environmental issues (see Mamadouh, 1999 for a survey). Two methods have generally been used to identify cultural types in these studies: design of special survey measures to directly identify cultural types or reinterpretation of results from previous surveys or cases studies. We relied on the latter approach using case studies in our selected sample and developed the coding manual below based on our review of the literature on CT applications.

i) **Egalitarian:** Low grid-high group. Author(s) provides description of RU as characterized by closely knit and bounded group with low socio-economic differentiation and few formal regulations. The group is maintained through multiplex relations between group members, which are mostly reciprocal and driven by peer pressure and mutualism rather than transactional. Examples of descriptive words used by author(s): group solidarity, reciprocal relations, fairness, moral/religious principles, ritualistic practices and peer pressure.

ii) **Individualist:** Low grid-low group. Author(s) provides description of RU as characterized by individuals with limited group identity and weak regulations or role prescriptions. Here relationships between irrigation users are transactional in nature, as in a market. Examples of descriptive words used by author(s): unregulated environment, entrepreneurialism, voluntary contracts, private transactions.

iii) **Hierarchical:** High grid-high group. Author(s) provides description of RU (farmers' group or water users' association) and PIP (e.g. irrigation association or agency) as distinct entities but with strong links, and differentiated roles based on rank/position within the system with binding prescriptions/rules. These prescriptions are justified by the importance of the collective over the individual. Examples of descriptive words used by author(s): strong regulations, prescriptions, stability and strong structure

iv) **Fatalist:** high grid-low group**.** Author(s) provides description of RU (may or may not be organized as farmers' group or water users' association) and PIP (e.g. irrigation association or agency) as distinct entities with very weak links. This archetype is characterized by weak group identity, and highly differentiated roles based on caste/landholding size/location in the system (upstream/downstream). Given the high level of socio-economic differentiation, the RU do not constitute a cohesive unit and are mostly driven by individual rather than collective logic. Examples of descriptive words used by author(s): apathy, powerlessness, sense of chaos and futility, social exclusion.

We followed a deductive coding procedure, with the description of attributes as identified above serving as the basis of the codes. Then as we delved in the actual process of coding, we had to revise the description of a few codes to narrow the gap between the theoretical concept and the data as it appears in the case studies.

B. Coding of attributes of different sub-systems in Robustness framework

Case study research designs enable in-depth understanding of underlying factors, interactions and causal relationships at a high level of contextual detail. However, this restricts its validity beyond the specific study sites (Poteete et al. 2010) and raises questions regarding which results are generalizable, and how contextual factors modify general insights (Oberlack et al. 2019). In our coding for cases, we coded for the system attributes (related to RU, NI, PI and PIP), as identified in the conceptual framework section and shown in the table below. The coding of these attributes was used for mapping of the co-occurrence of attributes (Figure 2).

Table A1: Coding of Robustness framework attributes

(Descriptions and rationale are provided in Conceptual foundations section)

Attribute	Categories for coding	Additional comments
RESOURCE USERS (RU)		
Group size: # of households	1. Small: < 200 households. 2. Medium: 200 -500 households 3. Large: > 500 households	In case studies where the size of households was not provided by the author(s), it was estimated based on population estimates provided by the author(s)
Market access	1. Limited 2. Improved	Based on author(s) description of walkability to nearest market or access to public transportation
*Nature related beliefs	1.Nature fragile 2. Nature robust 3. Nature tolerant 4. Nature capricious	See description in Conceptual foundations section. 1. Ball on top of single peak (nature fragile) 2. Ball at bottom of single peak (nature robust) 3. Ball at bottom of rugged landscape with multiple peaks (nature tolerant), 4. Ball on flat surface (nature capricious).
Natural infrastructure (NI)		
Agro-climate	1. Arid 2. Semi-arid 3. Humid and sub-humid	Based on CRU (Climate Research Unit) Time Series dataset v. 4.03, as reported Wang and Zhang (2020)
Location-gradient	1. Plains (<300m) 2. Low altitude: (300-1,000m) 3. High altitude > 1,000m	Based on classification used in Agrawal and Chhatre (2006)
Public infrastructure (PI)		
**Size of command area	1. Small: < 200 ha 2. Medium: 200-3,000 ha 3. Large: >3,000 ha	Based on classification generally used in irrigation studies.
Canal layout	1. Bifurcated 2.Hierarchical	See description in Conceptual foundations section.
Public Infrastructure providers (PIP)		
Organizational structure & type of relation with RU	1. PIP same as RU (with cooperative relations) 2. PIP same as RU (with non-cooperative relations) 3. PIP are state agencies, with strong links to RU (embedded) 4. PIP are state agencies, with weak links to RU (isolated)	See description in Conceptual foundations section.

*Attribute not included in co-occurrence of attributes map because sufficient information to code was not available in more than 25% of selected case studies.

** Attribute not included in co-occurrence of attributes map because it was found to be highly correlated with another included attribute (e.g. Size of command area was highly correlated with group size).

II. Results of coding

The first author and another researcher conducted the coding and met to discuss any discrepancies. A couple of discrepancies were noticed in multi-level irrigation cases where two cultural types seemed to co-exist: one at the village/community level and another at the systems level. For example, in Meinzen-Dick's (1984) case, the irrigation system consists of a river that feeds into a system of tanks. At the overall system level (including the river and tanks), the criteria for hierarchical archetype fitted best, but at the level of individual tanks, the criteria for egalitarian type fitted best. Since our focus here is on SES, we chose the representation at the system level.

Our coding of the 60 selected cases according to the attributes of cultural types led to the following distribution (see table below): Egalitarian-31; Individualist-5; Hierarchical -14; and Fatalist -10. Most of the cases in the SES library collection are part of the original Common-Pool Resource (CPR) database at Indiana University, which was developed under the direction of Elinor Ostrom in the 1970s and 1980s. Given Ostrom's interest in self-governance of the commons in traditional small-scale settings, there is an over-representation of cases under the Egalitarian archetype. The individualist archetype, associated with informal water markets, has become more prevalent after the 1980s and so there were no cases falling under this archetype in the SES collection. For this archetype, we selected cases known through our previous research.

Table A2: Cases coded under each archetype

Archetype	**Cases from SES library: Author (location)**	**Other notable cases**	**Total # of cases**
Egalitarian	Bacdayan (Philippines), Beardsley (Japan), Cifdaloz et al. (Nepal), Coward (Phillipines),), Cruz (Philippines**)**, de los Reyes (9 cases in Philippines), Fernea (Iraq), Geertz (Indonesia), Gupta (India), Lando (Indonesia), Martin and Yoder (Nepal), Nirola & Pandey (2 cases in Nepal), Potter (Thailand), Pradhan (Nepal), Sarker & Ito (Japan), Sharma et al (Nepal), Spooner (2 cases in Iran), Water and Energy Commission (2 cases in Nepal)	Baker (India), Lansing (Indonesia)	31
Individualist	None	Aggarwal (India), Dubash (India), Janakarajan (India), Meinzen-Dick and Sullins (Pakistan), Shah (India)	5
Hierarchical	Bottrall (Taiwan); Bottrall (Indonesia); Coward (Laos), Coward and Ahmed (Bangladesh), Duncan (Thailand), Gillispie (Thailand), Meinzen Dick(India), Ongkinco (2 cases in Phillipines), Tan Kim Yong (Phillipines), Wang et al. (2 cases in China	Lam (Taiwan), Wade (South Korea)	14
Fatalist	Bottrall(India); Bottrall (Pakistan); Lowdermilk (Pakistan), Merrey and Wolf (Pakistan), Mirza and Merrey (Pakistan), Reidinger (India), Vander Velde (India), Wade (India)	Ramamurthy (India), Mollinga (India)	10
TOTAL			60

III. Context specific details that are associated with special emergent features observed under each archetype

A. Egalitarian archetype

Pumpa irrigation system, Nepal (Cifdaloz et al. 2010): emergence of highly adaptive fairness based distribution rules

This is one of the 125 farmer managed irrigation systems in Chitwan district of Nepal (Cifdaloz et al. 2010). Various kinds of water distribution rules—based on fairness norms—have emerged to address the high variability of water flows, without any storage capacity in this case. When water flow is close to average, the optimal strategy is open flow (minimum labor requirements), but when water scarcity increases beyond a certain threshold, the irrigators switch to a sequential water distribution strategy. Under specific conditions of water scarcity, associated with a wash out of the main headgate infrastructure, the optimal strategy for irrigators is to use a 12-hour or 24 hour rotation depending on the time needed to repair the infrastructure. Cifdaloz et al. (2010) show that this system is very robust in the sense that yields can be maintained, in the face of environmental variation and shocks to the infrastructure, though only up to a certain point. Their modeling shows that with climate change, as this threshold is crossed, the system is likely to become highly vulnerable. This is a case where given the harsh bio-physical setting and the primitive technology, the institutions have become highly optimized to manage the tight coupling between the environment (timing of rain, river flows, and the agroecology of rice) and physical infrastructure (constraints on flow rates and distribution of water). This also shows why external attempts at changing institutions—such as through recent efforts towards decentralization—are likely to fail.

Kuhl irrigation system, India (Baker 2005): emergence of networks to share risks

While the majority of cases that fall under the egalitarian archetype operate at relatively small scales (<200 ha.) and are highly vulnerable to large scale drivers (e.g. political economy, globalization, climate change), the case of Kuhls in the western Himalayan state of Himachal Pradesh in India, has managed to survive for centuries despite the recurring destructive environmental disturbances and the shocks imposed by colonialism and globalization (Baker 2005). The uniqueness of this case derives in large part from its unusual, bifurcated topography: broad alluvial plains and river terraces, dissected by numerous perennial snow fed streams. Because of this bifurcated topography, most villages engage with multiple Kuhls: being simultaneously positioned upstream in some Kuhls and downstream in others. Baker describes how at the watershed level, the pattern of multi-kuhl villages and multi village Kuhls creates a network of interconnected regimes, which plays a major role in sharing risks (*ibid*, p.67).

Subaks, Indonesia (Lansing (1991): network of temples to address pest and water scarcity problems

Lansing's research examines the social dilemma here which consists of balancing between two inter-related problems: first, is the need to control pests, which is most effectively done when all rice fields have the same schedule for planting rice; second, is to allocate the limited supply of water, which is best handled by staggering the planting dates for rice. Recent ethnographic and computer work by Lansing and colleagues suggests that the need to coordinate water allocations and pest control led to the self-organization of a yield-enhancing autonomous complex adaptive system of an intricate network of water temples and shrines, which were able to withstand ecological shocks (such as pest outbreaks and droughts) much better than otherwise identical models that lacked temple networks.

Zanjeras, Philippines (Coward 1979; revisited by Yabes and Goldstein 2015): emergence of innovative system of land sub-division for equitable water sharing
In this case, large variability in water flows and high uncertainty (due to frequent typhoons) makes equitable water allocation very challenging. An interesting institutional innovation that emerged within the indigenous communities living here is the subdivision of the main blocks of farming land into smaller units, such that each member had an upstream, midstream, and downstream parcel. As a result, water scarcity was shared by all members and this emergent institution driven by egalitarian logic, served to further reinforce it.

Qanat system, Iran (Spooner 1974): **shows limits of local level collective action**
This is a case that shows limits of local level collective action in management of irrigation. Irrigation here is based on qanats, which are network of underground canals that transport water from aquifers in highlands to surface at lower levels by gravity. The qanats need maintenance that requires highly specialized skills and resources not available in local community. In the past, local tribal patrons (khans) financed the maintenance, but they have out-migrated recently. Although strong community bonds and reciprocal labor exchanges are common for regular canal maintenance, villagers are too poor to pay for qanat specialist. Farmers have turned to private investments in tubewells and tourism, leading to further deterioration of the qanat system.

B. Individualist archetype

Informal groundwater markets, India (Aggarwal, 2006)
Although generally characterized as "informal water markets", several scholars have pointed out that it is more accurate to call these rental markets in well equipment because water rights are not well defined (Saleth 1994). The market structure here is highly fragmented because each well-owner can only sell water to neighbors that are connected via his/her own private investment in pipes and canals. Diverse types of contracts—such as, fixed price and various combinations of output/input sharing—have emerged to address the tradeoffs between sharing risks and reducing transaction costs of monitoring, bargaining, and negotiating (Aggarwal, 2006). Very often these different types of contracts co-exist within the same village and are found to be finely tuned to the specific water requirements of the crops grown, availability of energy for pumping, and the characteristics of the parties involved (Dubash 2002, Shah et al. 2006).

C. Hierarchical archetype

Irrigation Associations (IAs), Taiwan (Lam 1996: 1041)

IAs in Taiwan are legally owned and formed by farmers and supervised by governments at higher levels. Their legal status as juristic entities entitles them to a high degree of de jure autonomy and also certain public authorities to levy water fees. This is a special feature of the Taiwanese system that enabled a highly decentralized model of irrigation management. On the other end of the spectrum are highly centralized irrigation systems in South Asia, largely established by the British for protection against widespread famines, where the central authority has complete control not only at the project level but up to the farm level. Other cases of bureaucratic large scale irrigation systems from Asia fall somewhere in between and highlight different configurations of state, intermediary agencies, and user relationships.

South-Korea (Wade,1982) – parastatals called Farmland Improvement Associations (FLIAs). Objectives of the FLIA are to improve land under paddy cultivation, give advice, cover costs, and collect charges from beneficiaries. No formal mechanisms for co-production with farmers, but FLIA staff are recruited from the same area as beneficiaries and are generally from the same social class. Important instruments for motivating the irrigation staff and holding them accountable include: pay based partly on agricultural indicators (such as agricultural yields) and government orchestrated competitions.

Water Users Association: in most other cases under this archetype we find Water Users' Associations (WUAs) formed by farmers, where farmers have varying degrees of decision making and control relative to the state controlled irrigation agency under different forms of decentralization. Examples from SES library include: Bottrall (1981)for Indonesia; Coward (1979) for Laos, Gillispie (1975) for Thailand, and Ongkinco (1973) for Phillipines.

D -Fatalist archetype

Emergence of village level collective institutions and bribes, India (Wade1988)
Wade reports on the emergence of four main types of village level collective institutions: village council, fund, common irrigators and field guards. Of the 31 villages studied by Wade, 8 had all four of these, 11 had at least some but not all, and 12 had none of them. Villages at the tail-end were more likely to have all four institutions, and used the village funds to raise funds and use their influence to bribe irrigation officials to ensure that water reaches the tail-end. A revisit to Wade's study site by Reddy and Reddy (R&R) (2002) two decades later found the collective institutions to be in order and effective, despite the spread of green revolution technologies, greater penetration of markets, and spread of groundwater irrigation. Interestingly, they found that these emergent (informal) collective institutions continued to operate even after the legislation to formally set up Water User Associations (WUAs) was passed in 1997. R&R compared villages where only the WUAs were operational with villages where informal collective institutions continued to operate and support the newly formed WUAs. They found that the latter set had better water availability, greater equity in distribution, and were better funded. They attributed the greater success of informal institutions to their social embeddedness and their commitment and cohesiveness, as these have "evolved from within the system" (p. 532), and have greater flexibility in adapting to changing conditions, as compared to formal institutions that they found to be "rigid and rule bound" (*op cit.*).

The emergence of bribes in tail-end villages has been reported in other highly centralized bureaucratic irrigation systems across South Asia, where alternative accountability mechanisms between farmers and irrigation officials are lacking. Examples include Ramamurthy (1995) and Mollinga (1996) for South India; and Lowdermilk et al. (1975) and Bottrall (1981) for Pakistan.

Emergence of political lobbying, India (Mollinga 1996)
Mollinga (1996) in his study of a large-scale canal irrigation system, the Tungabhadra Left Bank Canal system in South India, reports on the emergence of another accountability mechanism:

political lobbying. Farmers in this region are closely networked with local Members of the Legislative Assembly (MLAs), and so instead of paying bribes, the farmers find it more cost effective to lobby the local MLA to influence the Irrigation Department officials to implement rotation schedules in their favor. The MLAs have control over the transfer of Irrigation Department officials, and they use this power to influence the official to implement rotation schedules in favor of their constituents. As Mollinga (1996: 168) explains, “there is an accountability feedback loop in political lobby in which the initiative lies on the farmers' side: the threat not to re-elect the MLA.” In contrast to the egalitarian archetype, where rotation schedules are based on norms of fairness, in this case of the fatalist archetype, “the rotation schedules and the way they are implemented can be interpreted as the institutionalisation of the balance of power between head end and tail end farmers, as well as that between water users and the Irrigation Department” (Mollinga 1996: 152).

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