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# Towards characterizing the adaptive capacity of farmer-managed irrigation systems: learnings from Nepal

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Small-scale irrigation systems managed by farmers are facing multiple challenges including competing water demand, climatic variability and change, and socioeconomic transformation. Though the relevant institutions for irrigation management have developed coping and adaptation mechanisms, the intensity and frequency of the changes have weakened their institutional adaptive capacity. Using case examples mostly from Nepal, this paper studies the interconnections between seven key dimensions of adaptive capacity: the five capitals (human, financial, natural, social, and physical), governance, and learning. Long-term adaptation requires harnessing the synergies and tradeoffs between generic adaptive capacity that fosters broader development goals and specific adaptive capacity that strengthens climate-risk management. Measuring and addressing the interrelations among the seven adaptive-capacity dimensions aids in strengthening the long term sustainability of farmer-managed irrigation systems.

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## Introduction

Local institutions across the globe to varying degrees are coping with and adapting to changing climate and rapidly evolving socioeconomic conditions like migration, urbanization, and income diversification [1••,2]. Farmer-managed irrigation systems (FMIS) in Nepal and other Asian countries (e.g., Philippines, Thailand, and Cambodia), are among the prevalent local resource-governance institutions that have survived decades and even centuries of social, ecological, and cultural changes [1••,3,4]. FMIS are autonomous institutions whose community members are responsible for overall irrigation management including water appropriation, distribution, canal maintenance, and conflict management through collective action [3,5]. In Nepal, they are characterized by use of low-cost technology appropriate for heterogeneous local conditions such as diverse geographic terrain, autonomous decision making suited to local sociopolitical contexts, and collective action for maintenance and operation of infrastructure [6–8]. FMIS are adaptive to changing hydroclimatic and socioeconomic conditions partly attributed to the high autonomy in farmers' decisionmaking; flexible rules that suit users' needs; and high social capital in the form of trust, mutual cooperation, and collective action [9].

While many FMIS remain functional, dramatically changing hydroclimatic conditions, accelerated biophysical risk, and rapidly evolving socioeconomic change — together understood as global change [10] — have weakened their capacity to cope with and adapt to these changes. Climatic change and variability have contributed to delays in the onset of monsoon and winter rainfall, which means more intense and unpredictable precipitation causing flash floods and drought [11]. Higher evapotranspiration and temperature causes shifts in irrigation-water demand and crop choice [12]. The situation is further compounded by socioeconomic changes including a palpable rise in responsibility of women in FMIS governance due to male out-migration; and erosion of interest in collective action due to decreased productivity and profitability of irrigated agriculture [1••,13,14]. Understanding and strengthening the key elements of adaptive capacity is crucial for the long-term sustainability of FMIS. This paper reviews the main components of adaptive capacity of FMIS, with case examples mostly from Nepal, and identifies potential indicators to measure them.

Since very few articles are published on adaptive capacity and FMIS, we first reviewed the literature on adaptive capacity in general. The seven dimensions and indicators of adaptive capacity were short-listed (see Table 1) based on their relevance to FMIS (see the additional notes for a description of the methodology).

## Characteristics of adaptive capacity

Institutional adaptive capacity has been defined focusing on various aspects like climate risk management [15], multi-level learning process [16], and diversity of

**Table 1**

**Generic and specific adaptive capacities**

| Generic adaptive capacity | Dimensions of generic adaptive capacity | Indicators of generic adaptive capacity | Dimensions of specific adaptive capacity | Indicators of specific adaptive capacity | References |
|---|---|---|---|---|---|
| Human capital | Labor force | - Economically active labor population | | | [50,51] |
| | Education attainment | - Literacy rate | | | |
| | Knowledge and skills | - Years of agriculture and irrigation experience | Knowledge related to climate risk management | - Local knowledge on drought<br>- Crop diversification knowledge<br>- Water conservation knowledge | |
| Social capital | Formal and informal rules[a] | - Water distribution, resource sharing & other rules<br>- Resource & labor contribution by head/tail end users | Contingency plans for risk management | - Water allocation rules during water shortages | [20,40, 52,53•] |
| | Trust | - Perception of trust | Information sharing | - Information sharing about vulnerability and adaptation strategy | |
| | Membership | - Membership in FMIS | | | |
| | Access to institutions & resources | - Rules on access to irrigation water & WUA | | | |
| Physical capital | Basic services infrastructure — health, transportation, Market access | - Distance to road, hospital, and market | Irrigation infrastructure | - Concrete lining<br>- Reservoir | [21,51] |
| | Irrigation & agriculture technology | - Adoption rate of technology | Climate risk management technology | - Adoption rate of water saving/augmenting technology | |
| Natural capital | Water source | - Cropping intensity | Water quality and quantity | - Alternate water source | [36,54] |
| | Forest condition | - Forest cover rate | | | |
| Financial capital | Income | - Annual income per household | | | [33] |
| | Income distribution/ inequality | - Farm size<br>- Gini Coefficient | | | |
| | Access to finance | - Account at financial institution | Internal and external financial support | - Support from external agencies | |
| Governance | Transparency & accountability | - Financial audits<br>- Meetings and disclosure<br>- Graduated sanctions<br>- Monitoring & evaluation | | | [28,45, 46,52] |
| | Equity, inclusive and participatory process | - Cropping intensity at head and tail-end<br>- Labor contribution at head and tail-end<br>- Participation in decision making | | | |
| | Leadership | - Leadership performance rating | | | |
| | Multi-functional Institutions | - Organizational activities | Multiple functions | - Services provided by FMIS | |
| Learning | Flexibility | - Room for rule change | Intra- and inter institutional interactions | - Meeting with other agencies | [39] |
| | Collective learning | - Interactions with diverse stakeholders | | | |

[a] Since most of the rules are informally made by farmers, formal and informal has been categorized in social capital.

functions [17]. This paper uses the definition proposed by Bettini *et al.*, 'the ability to mobilize and combine different capacities within a system, to anticipate or respond to economic, environmental, and social stressors, in order to initiate structural or functional change to a system and thereby achieve resilient or transformative adaptation [18•].' This definition is particularly useful in our case because it incorporates multiple stressors and emphasizes the role of human agency in responding to stresses through governance. Here, human agency refers to individual or collective ability to mobilize, respond, anticipate, initiate, and achieve adaptive changes within a sociocultural context [18•].

The literature that assesses adaptive capacity has grown in the last decade [18•,19]. These assessments generally take one of two approaches. An asset-based approach emphasises on the five livelihood capitals (human, financial, natural, social, physical), usually applied at household and individual levels [20,21,22••], while a process-based approach emphasizes decisionmaking including multi-stakeholder collaboration, flexibility in decision making, and learning through refinement in rules, procedures and routines of organizational activities [23–26]. Nonetheless, the multi-dimensionality and latency of adaptive capacity, which makes it invisible until external (climate or other) event occurs, complicate the measurement of adaptive capacity [27].

While there has been some progress in characterizing adaptive capacity, very few studies have explored that for FMIS. Most of the literature on assessment of FMIS has concentrated on self-governance and institutional performance [26,28,29]. Some studies have explored the robustness of institutional arrangements to external drivers of change — including climate change — but none has elaborated the adaptive-capacity dimensions [3,30]. This paper contributes to the literature by applying and extending institutional adaptation analyses to FMIS facing global change. Capturing the dynamic nature of adaptive capacity, the paper addresses both the assets and process dimensions.

## Generic and specific adaptive capacities

In order to understand the interlinkages, adaptive capacity is classified into two broad categories — generic and specific. Generic adaptive capacity (GAC) addresses the structural deficits that must be addressed for sustainability of a system or an institution [22••,31]. These capacities are clustered into the seven dimensions that consist of five capital assets, plus governance and learning. GAC comprises the endowments that enable flexible responses to a spectrum of climatic and non-climatic stressors [32]. Specific Adaptive Capacity (SAC), by contrast, refers to strategies to manage risk of climate hazards (or other global-change drivers; for the sake of brevity, we refer here primarily to climate-induced water shortages and hazards). SAC helps users by furnishing tools and knowledge required to anticipate and effectively respond to specific climate threats [32]. Examples of SAC include climate-related knowledge and skills, access to external finance, alternate water sources to buffer shortages, and formal and informal rules to address climate risks. SAC can be considered part of a broader continuum of GAC because, while SAC focuses solely on climate risks, GAC incorporates all types of risks (see Figure 1).

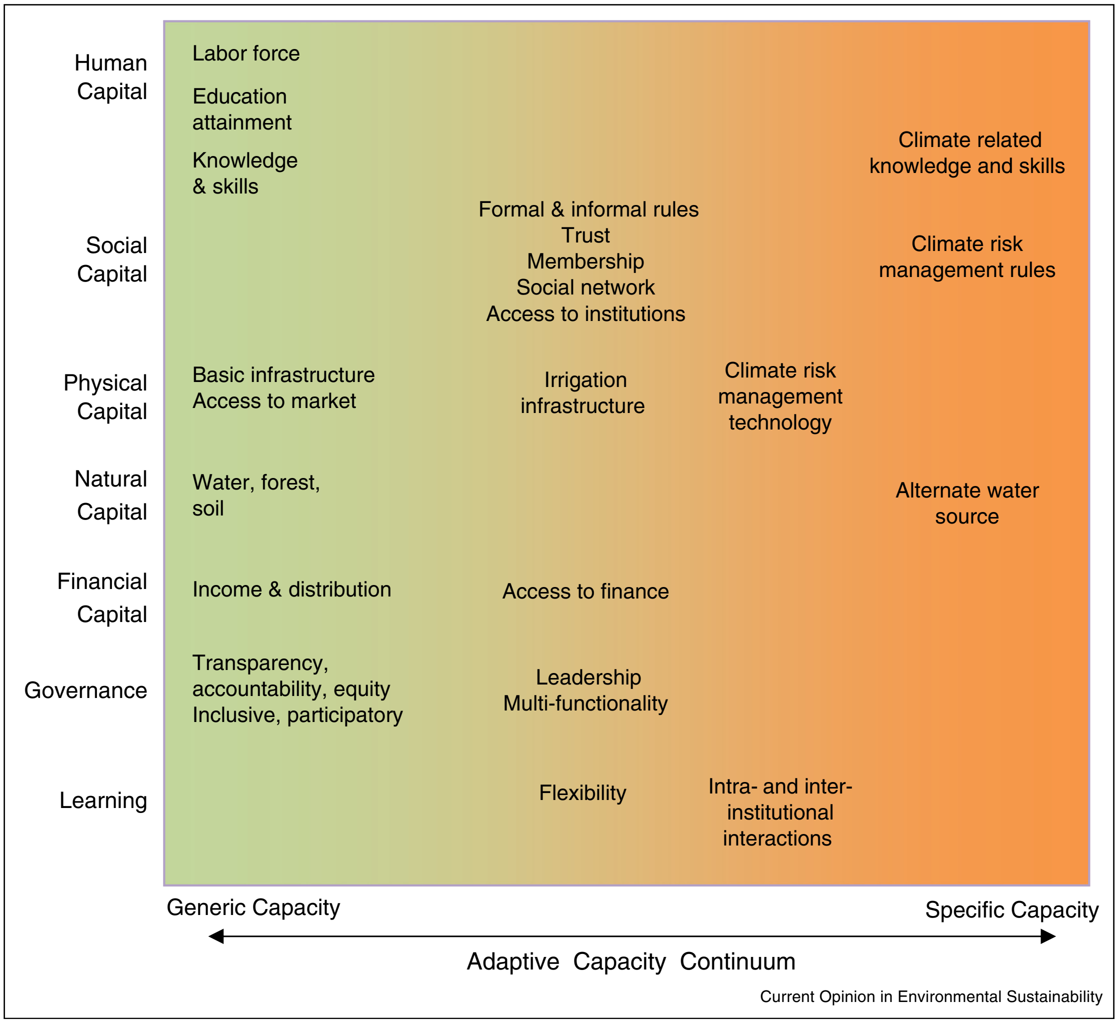
Based on the literature review, the key components of adaptive capacity are as follows:

**The five capitals:** The five capitals — human, physical, natural, social, and financial — are critical assets for long-term sustainability of an effective institution. We further classify a type of capital as generic or specific in terms of the adaptive capacity it confers to FMIS facing global change and climate-induced water scarcity, in particular. Human capital in SAC terms refers to farmers' local knowledge of climate risk (e.g., drought severity and duration), as well as skills to respond effectively (e.g., crop diversification and use of alternative water sources); while labor force and educational attainment are human capital that enhance GAC [33]. Social capital that strengthens GAC includes formal and informal rules, trust, and FMIS membership necessary for effective operation of the institution [34•]. In specific terms, trust promotes reciprocity among farmers — for example, altering irrigation rotations during period of stress — and facilitates the flow of information and resources about crop vulnerability to water stress, pests, and other stressors, as well as place-based interventions. Social capital can sometimes increase vulnerability [35]: for instance, a highly cohesive group of farmers reliant on local knowledge specific to certain conditions can be hesitant to incorporate information as conditions evolve, disregarding scientific information on new risks and potential adaptation.

The physical capital of FMIS to enhance climate-related SAC includes infrastructure such as concrete lining and diversion weirs that reduces inefficiencies, while generic physical capital (e.g., roads, hospitals, and schools) aid not just the FMIS but broader rural communities [36]. Specific natural capital includes alternate water sources from the stream or the local aquifer, or mountain groundwater system that may compensate for water shortages. Broader natural capital may include forest cover that meets a range of livelihood needs. Technologies such as groundwater pumping and gabion walls for erosion control are types of physical capital that can reduce climate hazard risks and strengthen SAC.

In GAC terms, financial capital comprises income, access to finance, and income distribution. In Nepal, the ability of FMIS to receive financial support from government

**Figure 1**




Adaptive capacity continuum.

agencies, especially after the natural disasters, is a SAC that is crucial for system sustenance. Due to limited funds, complex government bureaucracy [37], and weak FMIS leadership [7], very few FMIS receive government funding for infrastructure rehabilitation. Such support is crucial when FMIS face natural disasters like flooding, landslides, or earthquakes.

**Water governance:** Effective governance is fundamental for the sustenance of any resource management regime, including irrigation [27]. Among many principles of effective governance, this paper addresses four broad categories: Firstly, transparency and accountability; secondly, equity, inclusiveness, and participatory process; thirdly, leadership; and finally, multi-functionality. Since FMIS are made functional through collective action based on trust and reciprocity, they are highly sensitive to transparent and accountable governance. A national-level study of FMIS in Nepal revealed that the perception of fairness is the determining factor for sustained cooperation of FMIS [38]. Effective governance, facilitated by good leaders, is crucial for climate-change adaptation because it addresses underlying factors that produce vulnerability in the absence of equity, inclusiveness, and deliberation. Leaders build trust with farmers and are capable of performing vital organizational functions [25], including facilitating collective action for canal cleaning, conflict resolution over water deliveries, and resource securitization in the face of risks such as upstream water diversions or from natural factors such as landslides [3]. During natural disasters, leaders play important role by maintaining cohesiveness, seeking external and internal funding, and mediating multiple risks. Leaders can also balance power dynamics by ensuring inclusiveness of all members in the decisions making processes [25].

**Learning:** One of the characteristics of a highly adaptive system is its ability to learn from uncertain and changing global-change phenomena. In the context of FMIS, learning occurs at individual and institutional levels [39]. Institutional level learning can be defined as 'the process by which the group's learning outcomes are stored in and brought forth from organizational memory, such as rules, procedures, routines, and organizational cultures [39].' Learning occurs effectively when institutions are flexible and permit rule change [41]. In SAC terms, farmers need to integrate both traditional and scientific knowledge on irrigation and promote experimentation through 'learning by doing' [10], especially for cropping practices and water appropriation. As examples of GAC, institutional learning is also influenced by social learning where changes in understanding go beyond the individual level to wider social units or social groups through interactions of actors within the social network [42]. Social learning promotes adaptive capacity by improving collective learning and strengthening trust and relationships [43]. Though learning does not necessarily lead to action and change in behavior it can serve as a platform for sharing information about climate risk and adaptation [44].

Another component of learning that is very relevant to climate adaptation is interaction and interlinkages with formal and informal institutions including local, regional, national, and international organizations. Informal groups are important because they can help in the exchange of information related to vulnerability and adaptation, and secure resources to build the adaptive capacity [45]. For example, interaction of FMIS with agricultural extension and irrigation department can provide avenues for learning about climate adaptation strategies and secure funding opportunities.

## Discussion

### Linkages between generic and specific adaptive capacities

The SAC and GAC interlink in two noticeable ways. First, SAC in many cases are considered a subset of GAC because they concentrate on only one (here, climate risk), among the multiple risks that GAC addresses. GAC can be conceptualized as the underlying, foundational capacity that must be strengthened in order to develop SAC. For example, targeting on climate services for irrigation or building irrigation infrastructure without enhancing managerial capacity and strengthening ties to government or other external sources of information and funding is unlikely to assure long-term adaptation. This implies the need for FMIS-wide prioritization in selecting interventions [46].

Second, there are synergies and tradeoffs between GAC and SAC. When focusing on building infrastructure or a climate-services-knowledge platform, local knowledge systems and unique ingenuities should not be eroded [31]. In terms of synergy, strong leadership can be crucial in formulating rules for climate risk management and procuring infrastructure funds.

### Inter-linkages among the five capitals

In the case of FMIS, the five capital assets also supplement and complement each other. Despite poor physical canal infrastructure, many FMIS in Nepal are functioning well due to the strong social capital in the form of collective action, labor contribution, and cooperation [47]. For example, the Raj Kulo of Arghali, Palpa district has one of the complex water governance mechanisms that strengthened the system's performance despite the inefficient infrastructure conditions [48]. On the other hand, an irrigation system with good infrastructure can fail to function effectively when the social capital is lacking. The erosion of social capital can occur due to inappropriate government policies like state centric government policies; technology adoption like individual groundwater pumps that discourages the community irrigation; and lack of interest in collective actions and irrigated agriculture [3,49]. Siran Baguwa of Sindhupalchowk district suffered from poor performance after the farmers at the head end stopped participating in collective maintenance due to lack of trust [28].

Despite promising developments in SAC for climate-risk response and GAC for foundational capacity building, there are conceptual and operational limits to adaptive capacity for FMIS. Increases in individual or even institutional flexibility (under the learning dimension) do not necessarily lead to increases in adaptive capacity. Higher flexibility may be good in the short term, but flexibility that leads to uncoordinated action can hinder adaptation in the long run [45]. For example, individual-level groundwater extraction without coordinating at the FMIS-level or watershed-level to maintain groundwater balance can degrade long-term sustainability. Hence, there is a need to move from individual or institutional level flexibility to collaborative flexibility through supra-local coordination mechanisms [45].

Another cautionary note is the fact that adaptive capacity is inherent or latent within a system or institution and its effectiveness or failure is not fully apparent until after an influential climatic event [27,45]. Also, identification of adaptive capacity does not necessarily lead to adaptation actions [39], a process that is influenced by individuals' perception of risks, access to resources and entitlements, and socio-cultural factors [22••].

## Conclusion and the way forward

Adaptive capacity is characterized across seven dimensions — the five capital assets, governance, and learning. To understand cross-scale and multi-dimensional linkages, adaptive capacity is further classified into two broad categories: generic and specific. While generic adaptive capacity (GAC) concentrates on capacities to address the multiple global-change drivers, specific adaptive capacity (SAC), as we have taken it here, addresses only climate-induced water risks.

The key SACs necessary for strengthening the response of FMIS to changing climate include knowledge and skills on climate risk management, formal and informal rules, irrigation infrastructure and technologies, and inter-agency and intra-agency interactions and collaboration. These SACs can only be effective as part of broader GACs, such as governance, trust, and leadership.

From the perspective of policy and practice, it is important not only to identify these capacities but to understand their interconnections including the synergies and trade-offs among multiple capacity dimensions. As climate change impacts become more acute and programs to address impacts and enhance capacity grow more prominent in policy and practice, understanding and operationalizing adaptive capacity will receive greater attention. In order to move from conceptual understanding to support for adaptive actions in practice, generic and specific adaptive capacities must be understood from a holistic perspective and addressed in an integrated way for long-term adaptation of local FMIS institutions.

## Methodology

Keyword for search included — adaptive capacity, adapt*, farmer managed irrigation, resilience, local institutions, generic adapt*, specific adapt*, determinant adapt*, agricultural water. The peer reviewed literature was searched for the period 2010–2016 on Web of Science, Google Scholar, and Science Direct. More than 123 articles were downloaded for the given search, of which 78 articles were reviewed in detail because they explained about the characteristics/dimensions of adaptive capacity. Since few articles are published in international journals on FMIS, the literature search for FMIS indicators was extended to national workshop proceedings on FMIS in Nepal and national journals. The seven dimensions of adaptive capacity were short-listed based on their relevance. The criteria are considered relevant when the dimension of adaptive capacity is applicable to FMIS context. For example, the dimension of trust and social is applicable in both the literature on FMIS and adaptive capacity. Learning dimension is not prominent in FMIS literature, but it is incorporated because it is applicable in local institutional context.

## Disclaimer

The views expressed in this work are those of the creators and do not necessarily represent those of the UK Government's Department for International Development, the International Development Research Centre, Canada or its Board of Governors, and are not necessarily attributable to their organizations.

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