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Climate vulnerability and adaptation of water provisioning in developing countries: approaches to disciplinary and research-practice integration

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Developing countries are faced with the dual challenge of adapting to climate change even as current water needs remain unmet. We review the literature specifically on water provisioning in this context to see what insights can be derived for achieving better integration across disciplinary and research-practice divides. We identify several disconnects in the climate-vulnerability literature: scale mismatches, missing linkages, multiple stressors and concerns, concepts emerging from different intellectual traditions, and inattention to stakeholder priorities. Recent work attempts to overcome some of these challenges. At the conceptual level, the coupled human–environment systems (CHES) framework forces analysts to address scale mismatches and multiple stressors, although given its breadth, applications of CHES still tend to follow disciplinary divides. At the methodological level, participatory/mediated modelling forces attention to stakeholder priorities while historical/comparative methods provide an empirical assessment of long-term adaptation not just short-term reactive strategies. In conclusion, we suggest ways of further integrating the strengths of these approaches in the context of water provisioning in developing countries.

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Introduction

The recent Special Report of the Intergovernmental Panel on Climate Change (IPCC) documents the range of possible climate change impacts on freshwater resources and possible vulnerabilities and adaptation approaches [1]. Empirical studies on climate change adaptation in the developing world have proliferated in recent years [2] and there are several comprehensive reviews on climate vulnerability and adaptation [3,4*].

But although climate vulnerability assessment is by definition an interdisciplinary exercise linking biophysical and social processes to outcomes, in practice integration has been challenging.

In this review we specifically focus on climate vulnerability and adaptation of *water provision and use in developing countries*. Such a focus is important because the problem has some special characteristics. The links between user-scale vulnerability and climate in the water provisioning context are indirect. Unlike other areas of study, such as rain-fed agriculture, flooding or fishing, irrigated farm, domestic consumers and industry often do not depend directly on the natural environment for their water needs. Instead, water is delivered through a piped or canal infrastructure. In the case of developing countries, the water delivery infrastructure is often unreliable and not well understood. Moreover, developing countries must adapt to climate change even as current water needs are poorly met. The synergies and trade-offs between alleviating existing scarcity and inequity versus future unsustainability and vulnerability in water supply are only beginning to be explored [3,4*]. However, the literature epitomises the multiple types of disconnects common to research on the environment in general and climate change vulnerability in particular [5,6]. With the above in mind, we review the major disconnects that limit or delay understanding of climate vulnerability and adaptation. We then critically summarize current theoretical frameworks and methodologies that attempt to overcome these. Finally, we suggest ways of improving integration.

Disconnects in integrated climate vulnerability assessments of water provision

By integrated assessments, we mean the generation of linked knowledge, both between disciplines as well as between academic research and practice, necessary to understanding climate-change induced vulnerability in water provisioning and use. The generic barriers to such integrated assessments are well documented — differences in values or concerns, epistemologies and methods, idiosyncratic use of language, institutionalisation of differences and hierarchy between disciplines [7–9]. These barriers play out in specific ways in the context of climate vulnerability in water provisioning in developing countries resulting in both conceptual and methodological disconnects.

Diverse conceptualizations of vulnerability

The term vulnerability has multiple conceptualizations. Natural scientists tend to define vulnerability in a top-down manner, as a consequence or outcome of natural phenomena. By this view, water *systems* are vulnerable to droughts; people are vulnerable as a consequence of their dependence on the water system. In contrast, social scientists tend to conceptualize vulnerability in a bottom-up manner as a pre-existing state. By this view, *people* are vulnerable and climatic variability is one of many different stressors that may affect them. These differing conceptualizations result in different types of research and policy action [4,10].

Diverse conceptualizations of adaptation versus coping

There are similarly divergent views of the notions of coping and adaptation. Part of the problem is terminological, originating from different intellectual traditions both between and within social and physical sciences [11], corresponding to different aims, time frames, response types and learning [12*]. However, the root cause of the confusion goes beyond semantics to the nature of the climate problem itself. Climate change is a gradual, long-term change; its impact on water provisioning manifests both through secular shifts such as reduced average rainfall, as well as increased frequency of extreme events like floods or droughts. Social scientists have historically focused on *coping strategies*, taking environmental variability as exogenous. The attention to adaptation as longer term, planned adjustments is relatively recent. In contrast, many natural scientists have a long history of examining secular shifts in conditions and *adaptation* to such shifts through co-evolution (biological, hydrologic, technological or socio-cultural).

However, the confusion defies simple disciplinary categorization and cuts to the core of what adaptation entails. For instance, water resources engineers implicitly use adaptation to refer to centralized civil engineering works and coping when referring to private actions, even if they entail long-term investments [13,14], while many scholar-practitioners include reactive, temporary measures in adaptation strategies [10]. This makes it difficult to categorize if private wells or water rationing arrangements represent successful adaptations or simply burdensome coping responses to variable supply. Adapting to climate change requires a clear definition of the term and this requires researchers to go beyond their traditional conceptualizations.

Mismatch in scale and missing linkages

Historically, the water literature has suffered from a scale mismatch: while water resources researchers study the links between weather, runoff and reservoir inflows, engineers focus on the infrastructure, economists estimate water demand and other social scientists focus on the institutional arrangements and politics of water delivery and

access. This traditional fragmentation is exacerbated in the context of climate adaptation, hydrologists analyse hydro-climate changes at a coarser scale (basin/regional scale) [15–17] while the impacts are experienced at finer scales (community/village/household scale).

Although a range of methods exists to bridge the scale mismatch in purely hydrologic terms [18], whether down-scaled climate models are as yet reliable enough for hydrologic applications is debatable [19]. But the challenge is not just a matter of physical downscaling. The real problem is that climate adaptation assessments — even bottom-up ones — by hydrologists and water engineers focus on the climate-risk and reliability of infrastructure decisions [20] and do not scale down to household water vulnerability. The unstated assumption is that if bulk infrastructure is managed well, households will enjoy water security. But this assumption breaks down in developing world situations, where there is no universal coverage and public supply remains unreliable. The political economy of infrastructure [21], entitlements [22], techno-economic [23] and governance institutions [24*,25] are mediating factors that determine how much water actually reaches users; making it challenging to link basin-level hydrologic variability to vulnerability of individual households. How hydro-climatic changes ‘ripple’ through water infrastructure and institutions to affect end-users, remains a crucial missing link in integrated analyses.

Similarly, assessments originating in the (non-economic) social sciences emphasize participatory decision-making and community-based adaptation [26,27]. However, these are rarely linked up to climate projections through models of supply at the basin scale. The lack of attention to the resource availability and infrastructure limits community-based adaptation approaches.

Multiple stressors

Natural and social scientists also differ on the extent to which they consider the climate problem separable or independent from other stressors and concerns. The tendency amongst natural scientists has been to focus on a single stressor — urbanization, land use change, economic development, globalization or climate change — ignoring the interactions and potential for double exposure [28]. But, as a recent study of four basins shows, although climate change will have major hydrological impacts, anthropogenic water extractions remain the principal driver of reduced flows [29]. For instance, as water sources become physically scarce in urbanizing regions of the developing world, cities resort to water appropriation from distant places and users [30], often competing with agriculture [31,32] and compounding pre-existing rural–urban water disparities in access to water [33]. How these conflicts are resolved will have profound implications on water availability to different users,

greatly complicating the nature of climate-related vulnerability [34], but this aspect is poorly addressed in climate vulnerability studies.

Multiple normative concerns

Pre-existing problems in water provisioning in developing countries are not adequately captured by the framing of climate change as the primary driver and vulnerability as the primary concern. In many developing regions, groundwater resources are depleting rapidly [35], water quality is declining, and infrastructure is unreliable and deteriorating [36] resulting in inequity, and raising concerns about future generations. This poses a problem when it comes to bridging the gap between academic research and policy practice — climate adaptation research cannot be separated from general water and sanitation sector debates. Yet, few studies have linked adaptation to broader sustainable development goals [6] and there have been few cross-regional, empirical analyses which would provide the evidence base for better design and implementation of adaptation policy [37] in the water sector. To be useful, adaptation knowledge must be co-produced through sustained stakeholder–scientist interactions to develop tools in formats that decision makers can use [38].

Current integrated approaches

Over the past few years, several attempts have been made at linking the natural to the social and at crossing the academic-policy divide in climate vulnerability research, from both the theoretical and the methodological angles.

Theoretical integration: coupled human–environment systems (CHES) linking multiple scales and stressors

The most comprehensive, integrated framework currently available is the coupled human–environment systems framework [3,39,40^{**}]. The basic architecture of CHES consists of: (i) linkages to the broader (exogenous) human and biophysical conditions and processes; (ii) perturbations and stressors that emerge from these conditions and processes; and (iii) the coupled human–environment system including exposure and responses (i.e. coping, impacts, adjustments, and adaptation).

One example of the application of this framework to water provisioning in developing countries is the assessment of vulnerability to drought and urbanization in Chennai, India [41^{**}]. This was carried out by linking basin-scale water flows via a simplified model of the piped infrastructure to water availability at the household. An agent model of short-term and long-term actions by households is scaled up to the basin-scale by incorporating the bi-directional feedbacks. The inclusion of such feedbacks, a direct consequence of the CHES framework, shows that that some private adaptation mechanisms (e.g. groundwater pumping) could cumulatively make the system more vulnerable.

This integrated nature of the CHES framework, highlighting linkages and feedbacks, addresses at least the multi-scale disconnect described in the previous section. Nevertheless, it has some limitations. First, the all-encompassing nature provides little guidance on *which* variables, scales and linkages to focus on. So many studies remain at the conceptual level [42]. In operationalizing CHES, researchers have tended to frame the problem along disciplinary lines emphasizing different scales and aspects — political ecologists focus on structure and the role of infrastructure and agencies, economists focus on consumer coping behaviour and adaptation and so on. Second, although it potentially enables one to go beyond coping and study adaptation because it allows for multiple temporal scales, it provides no explicit theoretical attention to this issue. Third, the CHES framework is not explicitly anchored in the priorities of stakeholders and could result in ‘ivory-tower’ research that does not contribute to context-specific solutions.

Methodological integration

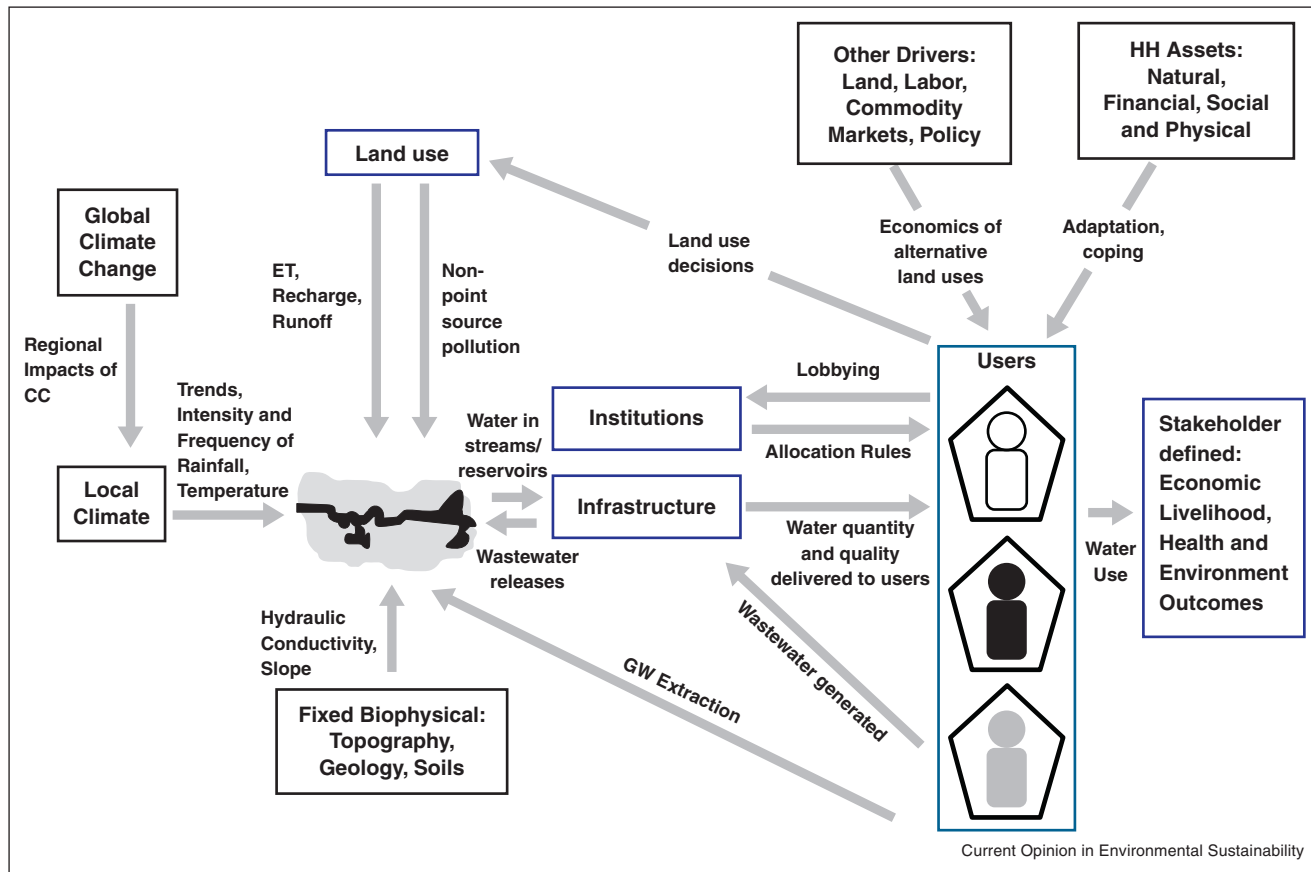
Several integrated methodologies have been developed and applied in the context of water related climate vulnerability. We have broadly categorized these methodological approaches into two.

Stakeholder elicitation of adaptation priorities and responses

One methodological approach has been to involve stakeholders explicitly. Stakeholders are presented with scenarios and asked to come up with adaptation strategies. In one variant, the climate models are developed by experts, and then culturally appropriate tools are used to explain model insights to communities and elicit how they would respond to the predicted changes [35,43,44,45^{**}]. In another variant, which we call ‘mediated modelling’, models and scenarios are developed collaboratively and iteratively between experts and stakeholders [36,46,47]. A third variant that has emerged recently is the integration of citizen generated data and/or scenarios into web-based simulation models [48,49]. Allowing local practitioners to upload sensor data relevant to their watersheds and adjust model parameters and interpret model results bridges some of the distance between researchers, stakeholders and decision-makers.

Participatory approaches have the advantage of explicitly acknowledging stakeholder input, thereby overcoming the research-practice gap to an extent. However, the link between climate variability and the institutional/social response is often weak. In the first variant, the link is skipped, as stakeholders are asked to simply respond to predicted changes in climate variables without considering institutions or infrastructure. The mediated modelling and citizen data variants can potentially include detailed linkages and attention to infrastructure and agency policies, although so far the models have tended

Figure 1



An integrated assessment accounting for stakeholder priorities and multiple stressors and scales.

to be primarily biophysical ones. Moreover, these approaches do no better on long-term adaptation and multiple stressors because respondents have difficulty in thinking beyond immediate responses and individual drivers of change.

Empirical observation of adaptation responses

An alternative approach pioneered in some studies uses past history or analogous regions [50] to learn about the climate adaptation. These studies rely on empirical observations of adaptation strategies. They use ethnographic methods, key-informant interviews, participatory rural appraisal (PRA), instrument records, other types of biophysical evidence and government documents [51,52] in a longitudinal [53] and sometimes comparative approach [24,50] to obtain generalizable relationships. Such historical/comparative analyses have the advantage of being empirically rooted, and if they cover a sufficiently long duration or distinctive regions, may provide some insight into adaptation, not just coping. The problem with such 'natural experiments' is that the climate–water infrastructure–water user link is a black box; many factors may vary simultaneously across regions, making it difficult to

unpack the influence of individual factors. For instance, Engle and Lemos attempt to unpack the relationship between governance and adaptive capacity for 18 river basins in Brazil. The study [24] demonstrates the challenges in standardizing responses and isolating cause-and-effect relying solely on interviews or observed historical responses to extreme events.

Moving forward

Climate and water vulnerability research has forced a certain degree of convergence between disciplines. While frameworks such as CHES provide a broad direction for conceptual integration, operationalizing the 'coupling' while incorporating stakeholder concerns remains a challenge in practice. Useful contributions have come from both participatory approaches and empirical analysis.

To take this process of integration in climate–water vulnerability assessments in the developing world forward, we offer some specific recommendations. First, we recommend conceptualizing outcomes not just in terms of vulnerability but also chronic scarcity, pollution, inequity and unsustainability, with explicit inclusion of multiple

stakeholders, both governmental and non-governmental as well as local communities. The fleshing out of these outcome variables should be carried out iteratively with stakeholder interactions (including experts and user groups). Second, the biophysical model must be built at the basin scale, but with inclusion of surface storage structures, water imports, self-supply through wells and water tanker markets, and institutions and policies that determine inclusion and exclusion. Third, it is imperative to recognize and choose an appropriate theoretical framework recognizing that both political and economic considerations play a role in water delivery and land use dynamics. Fourth, the major non-climatic drivers of increased water demand and hydrological change must be factored in (increasing population through immigration, agricultural shifts that respond to urban demand and labour scarcity, industrial policies and zoning). And finally, the links between different variables must be established through both historical analyses and stakeholder inputs. Explicitly distinguishing between short-term and long-term strategies would address the conceptual confusion between coping and adaptation. The framework that we have outlined in Figure 1 is indicative. We believe that such an approach implements CHES effectively, and incorporates the methodological strengths of stakeholder priorities and evidence-based research approaches.

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6 Open issue 2013

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