

Where to Sense, Who Decides: A Spatial Siting and Data-Governance Framework for Community Water-Monitoring Networks in Climate-Stressed Mountains

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Abstract:

Low-cost sensors and citizen science have made community water monitoring technically feasible across the mountain regions of the Global South, yet the networks built on them repeatedly underdeliver. The reasons are rarely about hardware. They concern where sensors are placed, who owns and governs the resulting data, and how volunteer participation is sustained beyond an initial project cycle. This paper argues that these are, at their core, spatial and institutional problems, and therefore squarely within the domain of geography. It develops an integrated framework with three coupled components. The first is a spatial multi-criteria siting protocol that ranks candidate monitoring locations by catchment representativeness, hydrological value, climate-hazard exposure, accessibility, and existing community and institutional presence, using an analytic hierarchy process to combine these criteria and to derive maximum information from a minimal set of instruments. The second is a tiered data-governance architecture that defines data ownership, quality assurance, and the explicit routes by which observations enter local decision-making, closing the persistent gap between data generation and action. The third is a community-anchored sustainability model that embeds monitoring in village institutions through feedback, recognition, and shared benefit in order to curb the volunteer attrition that dissolves most networks. The framework is illustrated for the Nainital and Ranikhet belt of the Kumaon Himalaya, where drying springs, a declining Naini Lake, and intensifying forest fires expose communities that remain largely unmonitored. The contribution is a transferable, low-cost blueprint that operationalises the data layer of the water security nexus and links scientific evidence, community practice, and equitable decision-making.

Keywords: citizen science; water monitoring; data governance; sensor siting; mountain water security

1. Introduction

Mountains are the water towers of the world. They generate a disproportionate share of the runoff on which downstream populations depend, and they do so from a small fraction of the global land surface, which makes them at once indispensable and acutely sensitive to change (Immerzeel et al., 2020). In the Himalaya, this general truth acquires a sharper social edge. Ridge-top settlements sit above the rivers that flow through the valleys below them, so the water that sustains daily life is not the river but the spring, the small lake, and the seasonal recharge held in the slopes. Securing that water, in the sense articulated by Grey and Sadoff (2007) as an acceptable quantity and quality of water together with an acceptable level of water-related risk, is among the defining development challenges of the region.

Climate change is reshaping this balance. Warming, more erratic precipitation, declining winter and post-monsoon rainfall, and more frequent hydrological extremes interact with land-use change and demographic pressure to stress water, energy, food, and ecosystem systems at once. Managing those interactions is the ambition of the water, energy, and food nexus, which has become a dominant framework for reasoning about interconnected resource systems (Hoff, 2011). Yet a nexus approach is only as good as the evidence that feeds it. Understanding trade-offs and synergies between sectors, and governing them fairly, requires observations of the resource base at a spatial and temporal resolution that mountain regions rarely possess. The nexus, in other words, rests on a data layer, and in the mountains of the Global South that layer is thin.

The reasons are structural. Conventional hydrometric monitoring is expensive, logistically demanding, and institutionally concentrated. Steep terrain, dispersed populations, and constrained public budgets mean that official gauging networks are sparse, and the fine-grained resources on which communities actually depend, the individual spring or the village tank, fall almost entirely outside them. Into this gap has come a technological opening. The maturation of robust, inexpensive sensing equipment and the parallel rise of citizen science have made it feasible, in principle, for communities themselves to generate hydrological data at densities that agencies cannot match (Buytaert et al., 2014; Njue et al., 2019). Volunteered geographic information, in Goodchild's (2007) framing of citizens as sensors, promised to convert dispersed local presence into a distributed observing system.

The promise has proved difficult to keep. A now substantial literature documents that community water-monitoring initiatives frequently underperform or lapse, and that the causes lie less in the instruments than in how programmes are designed and embedded (Kosmala et al., 2016; Chase & Levine, 2016; Carlson & Cohen, 2018). Three problems recur. Sensors are sited by convenience or enthusiasm rather than by hydrological logic, so the resulting data are not representative of the systems that matter. The data that are collected have uncertain ownership, uneven quality assurance, and no reliable pathway into decisions, so they accumulate without informing action. And volunteers, initially motivated, disengage once novelty fades and feedback is absent, so networks decay. These are not hardware failures. They are failures of spatial design and of institutional design.

This paper takes that observation as its starting point and argues that the unresolved obstacles to community water monitoring are precisely the questions a geographer is equipped to answer: where to observe, how to route knowledge into governance, and how to sustain a socio-technical network in place. It develops an integrated framework that addresses the three failure modes together rather than in isolation. The framework couples a spatial multi-criteria siting protocol, a tiered data-governance architecture, and a community-anchored sustainability model, and it is designed to extract maximum decision-relevant information from a minimal and affordable set of instruments. The contribution is conceptual and methodological rather than empirical: the framework itself, its internal logic, and a worked illustration are the object of the paper. The Nainital and Ranikhet belt of the Kumaon Himalaya serves as the illustrative setting, chosen because it concentrates the drying-spring, declining-lake, and forest-fire dynamics that define the wider regional crisis.

Three questions organise the argument. First, why do the well-documented failures of community water monitoring constitute a spatial and institutional problem rather than a technological one? Second, what design would place a sparse sensor network so that it is hydrologically representative, governable, and durable? Third, how would such a framework operationalise the data layer of the nexus in a specific mountain context, and what would that imply for practice and policy? The remainder of the paper addresses these in turn.

2. The mountain water-data problem

2.1 Water security, climate change, and the nexus in the mountains

The nexus perspective insists that water, energy, food, and ecosystems cannot be governed in isolation because an intervention in one propagates into the others across scales (Hoff, 2011). In mountain systems this interdependence is especially tight. The same forested slope that regulates infiltration and spring discharge also supplies fuelwood, stabilises soil for terrace agriculture, and buffers downstream flow. A change in land cover, a shift in the timing of rainfall, or a decision to abstract more water for a growing town therefore reverberates through the whole system. Governing such interactions in the integrated, equitable manner the nexus calls for depends on the ability to observe the resource base, to quantify how its components move together, and to detect change early enough to act. Where observation is absent, nexus thinking remains an abstraction, unable to guide the concrete allocation and protection decisions that water security requires (Grey & Sadoff, 2007).

2.2 The Himalayan case: springs, lakes, and the intensifying hazard climate

The Hindu Kush Himalaya is both a critical and a vulnerable water tower, and its mountain water systems are under compounded stress from climatic and socio-economic change (Immerzeel et al., 2020; Scott et al., 2019). For the majority of hill communities, springs rather than rivers are the primary source of water. The scale of dependence, and of the emerging crisis, is now well established at the policy level: an assessment by NITI Aayog (2018) concluded that a large share of the millions of springs across the Indian Himalayan Region have already dried or become seasonal, with direct consequences for domestic supply, agriculture, and out-migration. Field evidence has accumulated over decades. Tambe et al. (2012), reporting the Sikkim experience that later informed national

policy, documented substantial lean-season declines in spring discharge and demonstrated that hydrogeologically informed recharge interventions could reverse them, establishing spring-shed management as a replicable adaptation.

Lakes tell a parallel story. In the Kumaon Himalaya, Naini Lake supplies the bulk of the drinking water for the town of Nainital and depends on rainfall, spring inflow, and subsurface recharge rather than on any large river. Studies of its hydrology and hydrochemistry have linked its condition to catchment land-use change and to climatic variability, and recent years have seen the lake fall to unusually low levels as recharge zones are degraded and abstraction rises. Alongside these slow-onset changes, the region has experienced an intensifying fire climate, with dry pre-monsoon spells and reduced soil moisture producing more frequent and extensive forest fires that further compromise the vegetated slopes on which recharge depends. Springs, lakes, and forests are not separate problems here but coupled expressions of a single water-forest-livelihood system under stress.

2.3 The monitoring deficit

What is striking, given the severity and the documentation of this crisis, is how little of it is measured at the resolution at which it is lived. Regional climatologies and national inventories establish the aggregate trend, but the individual spring that a hamlet drinks from, the small tank that irrigates its terraces, and the recharge slope above it are typically ungauged. The consequence is a governance system that must act on a resource it cannot see. Interventions are designed without discharge baselines, their effects are inferred rather than measured, and communities have no evidence with which to advocate for the protection of the specific sources on which they depend. This is the deficit that community monitoring is meant to fill, and the reasons it has not yet done so are the subject of the next section.

3. Community sensing: promise and persistent failure

3.1 The technological opening

Citizen science, understood as the participation of non-professionals in the generation of scientific knowledge, has expanded rapidly across environmental fields and has been the subject of a growing scientometric and methodological literature (Kullenberg & Kasperowski, 2016). In hydrology its appeal is straightforward. Many hydrological variables of interest, such as water level, presence or absence of flow, and simple water-quality indicators, can be observed with modest training and inexpensive equipment, and the observers can be the very people who depend on the resource (Buytaert et al., 2014). The hardware constraint that once justified centralised monitoring has largely dissolved. Robust low-cost instruments now exist for a range of parameters, and a broad review of the field concludes that citizen science has moved from novelty to a recognised component of hydrological monitoring, particularly valuable in data-scarce regions (Njue et al., 2019). The observing capacity, in principle, is available.

3.2 Three recurrent failure modes

Yet the translation of that capacity into durable, decision-relevant monitoring has been uneven, and the literature is candid about why. The difficulties cluster into three areas, and it is important to see that all three are addressable by design rather than by better instruments.

The first is siting and representativeness. Community networks tend to grow where volunteers happen to be, near homes, schools, or accessible roads, rather than where measurement would be most informative about the resource system. The result is spatial bias: clusters of redundant observations in convenient places and blind spots over the springs, recharge zones, and hazard-exposed reaches that matter most. Because the scientific value of a monitoring network is a function of where its nodes sit relative to the processes being observed, poor siting caps the usefulness of the data no matter how accurate each individual reading is.

The second is data quality and data governance. Skepticism about volunteer-generated data is common, but the evidence shows that well-designed projects, using training, validation, replication, and appropriate treatment of error, can produce data of professional quality (Kosmala et al., 2016). Quality is therefore a design property, not an inherent limitation. The deeper and less-discussed problem is governance: who owns the data, who assures its quality, who may access it, and by what route it reaches a decision. Where these questions are unresolved, citizen-generated data is under-used by the very agencies and communities it could serve, and its potential to inform policy goes unrealised (Carlson & Cohen, 2018; Hadj-Hammou et al., 2017). Data without a governed pathway to action is inert.

The third is participation and sustainability. Programme success depends heavily on design factors that shape and retain volunteer engagement, including feedback, recognition, and a sense of tangible benefit (Chase & Levine, 2016; Cappa et al., 2018). Intrinsic motivation carries a project through its early enthusiasm, but without institutional anchoring and visible returns, participation decays and the network with it. Sustainability is thus not a matter of exhortation but of embedding monitoring in local structures that give it durability.

3.3 A spatial and institutional reframing

Set side by side, the three failure modes share a character. None is a problem of sensing technology. Each is a problem of arranging a socio-technical system in geographic and institutional space: positioning nodes with respect to hydrological processes, constructing the institutional channels through which their outputs acquire authority and consequence, and binding the whole into the social fabric of a place so that it persists. This is the reframing on which the framework rests. Volunteered geographic information has always been as much about the social relations and institutions of data as about the data itself (Goodchild, 2007; Haklay, 2013). Treating community monitoring as a design problem in spatial and institutional terms is what allows the recurrent failures to be addressed at their source.

4. Conceptual approach and framework development

The framework was developed through structured synthesis rather than primary data collection. Its logic proceeds in three steps. First, the failure modes identified in the literature were mapped to their underlying determinants, which located each within either the spatial or the institutional domain, or both. Second, established methods from spatial decision science and from the governance of common-pool and volunteered data were selected to address each determinant. Third, the components were integrated into a single workflow so that the output of one informs the next, rather than operating as a set of disconnected recommendations.

The spatial component draws on multi-criteria decision analysis, the family of methods developed to structure choices among alternatives evaluated against several, often conflicting, criteria, and widely applied to geographic problems through the integration of criteria in a geographic information system (Malczewski, 2006). Within that family, the analytic hierarchy process provides a transparent and well-tested procedure for eliciting the relative importance of criteria through pairwise comparison and for combining them into a composite score, with an explicit consistency check on the judgements involved (Saaty, 1980, 2008). The analytic hierarchy process is especially suited to data-scarce, expert-guided settings, and it has become a standard tool for the closely related task of mapping groundwater and recharge potential, where heterogeneous thematic layers must be weighted and combined (Arulbalaji et al., 2019). Its use here is deliberate: siting a monitoring network and mapping recharge potential are formally similar spatial problems, and the same rigorous, auditable weighting logic applies.

The framework is guided by four principles. Parsimony: the design must extract the greatest decision-relevant information from the fewest and cheapest instruments, because affordability is a precondition of adoption. Representativeness: node placement must be driven by the structure of the resource system, not by the convenience of observers. Governability: every observation must have a defined owner, a quality standard, and a route to a decision. Durability: the network must be embedded in local institutions so that it survives the end of any external project. These principles recur through the three components described next.

5. The framework

5.1 Component one: a spatial multi-criteria siting protocol

The first component determines where a limited number of sensors should be placed. It treats the monitoring area as a field of candidate locations, scores each against a set of siting criteria, and then selects nodes to maximise coverage of the highest-priority locations while avoiding redundancy. Six criteria are proposed, chosen to capture the hydrological, exposure, and social dimensions that together define a good monitoring site.

Catchment representativeness asks whether a location samples a distinct and significant part of the resource system, so that the network as a whole spans its important sub-units rather than over-sampling one. Hydrological value ranks locations by their importance to supply, giving weight to perennial springs, active recharge zones, and the feeder channels and tanks on which settlements

depend. Climate-hazard exposure prioritises reaches subject to the stresses that monitoring is meant to detect, such as sources with steep dry-season recession, slopes exposed to fire, or catchments with pronounced rainfall decline. Accessibility accounts for the practical reality that a volunteer must be able to reach a site safely and repeatedly, since an ideal location that cannot be visited yields no data. Community and institutional presence favours locations near settlements with an active water-user group or comparable body, because a node embedded in a functioning institution is far more likely to be maintained. Network complementarity, applied last, penalises candidate sites that would duplicate information already captured by selected nodes, which is what turns a set of individually good sites into an efficient network.

These criteria are combined using the analytic hierarchy process. Experts and, importantly, community representatives perform pairwise comparisons to establish the relative weight of each criterion, the consistency of those judgements is checked, and the resulting weights are applied to the normalised criterion scores of every candidate location to yield a composite siting priority (Saaty, 1980, 2008; Malczewski, 2006). The output is a ranked map of candidate sites from which a network of the affordable size is selected from the top down, subject to the complementarity rule. The procedure is transparent and auditable: the weights are explicit, the judgements are recorded, and the rationale for every placement can be reconstructed and contested. This is precisely the property that convenience-based siting lacks, and it is what makes the resulting network defensible to the agencies and communities that must trust its data.

5.2 Component two: a tiered data-governance architecture

The second component addresses what happens to an observation once it is made. Its purpose is to guarantee that data is owned, assured, and routed to a decision, thereby closing the gap between generation and use that leaves so much citizen-generated data inert (Carlson & Cohen, 2018). The architecture is organised as three tiers, each with defined roles, standards, and flows.

At the local tier, the community that hosts a node is the primary custodian of its data. Ownership resting with the community is not only an equity commitment but a practical safeguard of the durability of participation, since people sustain what they own. Observations are recorded against a simple, standard protocol, and a first level of quality assurance is applied through basic plausibility checks and periodic duplicate readings, following the established finding that structured protocols and replication raise volunteer data to reliable standards (Kosmala et al., 2016). At the intermediate tier, an intermediary such as a college, a non-governmental organisation, or a district cell aggregates data across nodes, applies a second level of validation, maintains the shared repository, and, critically, provides feedback to the communities in an intelligible form. This feedback loop is where governance meets sustainability. At the decision tier, the assured data enters defined governance processes, informing catchment protection, the prioritisation of recharge interventions, the regulation of abstraction, and local development planning. The essential design feature is that these routes are specified in advance. A datum's path from a spring to a decision is part of the architecture,

not an afterthought, which is what gives the observation consequence and, therefore, the exercise its point.

The architecture also names access and interoperability rules, so that data is neither locked away from those who could use it nor stripped from the communities that generate it. Handled well, this positions community monitoring within a wider spatial data infrastructure while preserving local authority over it, consistent with long-standing arguments about the governance of volunteered geographic information (Goodchild, 2007; Haklay, 2013).

5.3 Component three: a community-anchored sustainability model

The third component is directed at the failure mode that dissolves the most networks, namely the decay of participation. Its premise, well supported in the literature, is that sustained engagement is produced by design features rather than assumed from goodwill (Chase & Levine, 2016; Cappa et al., 2018). Three mechanisms are built in. Feedback returns processed information to observers in a usable form, so that a volunteer sees their readings become a picture of their own water source rather than disappearing into a distant database. Recognition confers visible standing on participation, through the acknowledgement of contributors and the social status of the monitoring role within the community. Shared benefit ties monitoring to tangible returns, most directly by using the data to secure and target interventions that improve the community's own water security, so that participation pays.

Underpinning all three is institutional anchoring. Rather than recruiting individuals in isolation, the model locates monitoring within an existing local institution, typically a water-user association or village committee, which absorbs the role into a durable structure with its own continuity, accountability, and capacity to induct new members. This is what allows a network to outlast the external project that establishes it, and it is the difference between a monitoring campaign and a monitoring system.

5.4 Integration

The three components form a sequence that is also a cycle. The siting protocol determines where nodes are placed. The governance architecture determines how their data is owned, assured, and routed to decisions. The sustainability model determines how participation, and therefore the flow of data, is maintained, and its feedback mechanism draws on the governance architecture, while the value it demonstrates reinforces the case for the sites the protocol selected. Over time, the data generated can refine the siting weights and reveal where additional nodes would add most, so the network adapts. The framework is thus not a one-time design but a self-reinforcing socio-technical system, parsimonious by construction, representative by siting, governable by architecture, and durable by anchoring.

6. Illustrative application: the Nainital and Ranikhet belt, Kumaon Himalaya

The framework can be made concrete by considering how it would be applied in the Nainital and Ranikhet belt of the Kumaon Himalaya, a setting that concentrates the regional water-security crisis. The belt depends on springs for dispersed rural supply and on Naini Lake for the concentrated

demand of Nainital town, and it is subject to the drying springs, declining lake levels, and intensifying forest fires described earlier (NITI Aayog, 2018; Tambe et al., 2012; Scott et al., 2019). It is also, in the sense that matters here, largely unmonitored at the resolution of the individual source. The illustration is presented as an application of the framework to a documented context, not as a report of field measurement, and its purpose is to show how the framework's logic would operate.

Applying the siting protocol, candidate locations across the belt would be scored against the six criteria. Perennial springs serving hamlets and the active recharge slopes above them would score highly on hydrological value; sources with steep dry-season recession and slopes with a history of fire would score highly on hazard exposure; the principal feeder drains of Naini Lake and its recharge zone would score highly on both representativeness and hydrological value; and villages with functioning water-user groups would raise the community-presence score of nearby sites. Weighting these criteria through the analytic hierarchy process, with local representatives participating in the pairwise comparisons, would yield a ranked map from which a small, affordable network could be drawn. The complementarity rule would ensure that the selected nodes spanned the belt's distinct hydrological sub-units, a cluster on the lake's critical feeder and recharge zones together with a spread across representative and hazard-exposed springs, rather than concentrating where access is easiest.

The governance architecture would then determine how the readings from these nodes acquire consequence. Host communities would own and first-check their data; an intermediary, for which a local institution such as a degree college is well suited, would aggregate, validate, curate, and feed results back; and the assured data would enter defined decision routes, informing the protection of the lake's recharge zone, the prioritisation of spring-shed interventions of the kind demonstrated in the region, and the regulation of abstraction under stress. The sustainability model would embed the monitoring in the belt's water-user institutions, return each community a legible picture of its own springs, and tie the effort to the tangible benefit of better-targeted protection and recharge. The result, on paper, is a parsimonious network whose every node is justified, whose data reaches decisions, and whose operation is owned locally. That is the state the framework is designed to reach, and the illustration indicates the path to it without asserting results that only implementation could provide.

7. Discussion

The framework's central claim is that the binding constraints on community water monitoring are spatial and institutional, and that addressing them together operationalises the data layer on which nexus management depends. Three implications follow. First, the approach converts the nexus from an analytical aspiration into an observable system at the scale where water is actually used and governed. By siting a sparse network to represent the coupled water-forest-supply system and routing its data into decisions, the framework supplies exactly the resource-base observation that integrated management requires but mountain regions lack (Hoff, 2011; Grey & Sadoff, 2007).

Second, the framework is built to link science, practice, and decision-making rather than to stop at data. The governance architecture makes the pathway from observation to action a designed feature, and the sustainability model ties the scientific activity of monitoring to the practical returns that keep communities engaged. This directly answers the well-documented problem that citizen-generated data too often fails to inform policy (Carlson & Cohen, 2018; Hadj-Hammou et al., 2017), and it places authority over data with the communities that generate it, an equity property consistent with the ethics of volunteered geographic information (Goodchild, 2007; Haklay, 2013).

Third, the design is transferable. Although illustrated for the Kumaon Himalaya, the framework encodes no site-specific assumptions. Its criteria, its weighting procedure, and its governance tiers can be re-parameterised for other mountain contexts across the Hindu Kush Himalaya and the wider Global South, where the same combination of data scarcity, dependence on dispersed sources, and climate stress prevails (Immerzeel et al., 2020; Scott et al., 2019). Parsimony and reliance on open, low-cost methods are what make such transfer realistic.

Several limitations should be stated plainly. The framework is a conceptual and methodological contribution, and it has not been implemented or validated in the field; the illustrative application demonstrates its logic but does not test its performance. The analytic hierarchy process, for all its transparency, rests on subjective judgements whose quality depends on the expertise and representativeness of those who make the comparisons, and the involvement of communities in that weighting is a design commitment that requires care to realise. The sustainability of participation, though addressed by design, ultimately turns on social dynamics that no framework can guarantee. These limitations define the agenda for the next stage of work: a pilot implementation in the Nainital and Ranikhet belt through which the siting weights could be calibrated with local participation, the governance routes established with the relevant institutions, and the durability of participation observed over time. Such a pilot would convert the framework from a proposal into a tested instrument and would generate the empirical evidence that this paper deliberately does not claim.

8. Conclusion

Community water monitoring in the climate-stressed mountains of the Global South has been held back not by the cost or capability of sensors, which have largely ceased to be the constraint, but by unresolved questions of where to observe, who governs the resulting data, and how to sustain the people who collect it. These are geographic and institutional questions, and this paper has argued that they are answerable by design. The framework it proposes couples a transparent spatial siting protocol, a tiered data-governance architecture, and a community-anchored sustainability model into a single, self-reinforcing system that extracts decision-relevant information from a minimal and affordable network, routes that information to the decisions that matter, and embeds the whole in local institutions so that it endures. Illustrated for the Nainital and Ranikhet belt of the Kumaon Himalaya, the framework offers planners and communities a defensible answer to a deceptively simple question, where to act first, and it does so in a form transferable across the mountain regions

where water security is most fragile. Its promise now rests on implementation, and the pilot that would test it is the natural next step.

References

- Arulbalaji, P., Padmalal, D., & Sreelash, K. (2019). GIS and AHP techniques based delineation of groundwater potential zones: A case study from Southern Western Ghats, India. *Scientific Reports*, 9, 2082. <https://doi.org/10.1038/s41598-019-38567-x>
- Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Alemie, T. C., Bastiaensen, J., De Bievre, B., Bhusal, J., Clark, J., Dewulf, A., Foggin, M., Hannah, D. M., Hergarten, C., Isaeva, A., Karpouzoglou, T., Pandeya, B., Paudel, D., Sharma, K., Steenhuis, T., ... Zhumanova, M. (2014). Citizen science in hydrology and water resources: Opportunities for knowledge generation, ecosystem service management, and sustainable development. *Frontiers in Earth Science*, 2, 26. <https://doi.org/10.3389/feart.2014.00026>
- Cappa, F., Laut, J., Porfiri, M., & Giustiniano, L. (2018). Bring them aboard: Rewarding participation in technology-mediated citizen science projects. *Computers in Human Behavior*, 89, 246-257. <https://doi.org/10.1016/j.chb.2018.08.017>
- Carlson, T., & Cohen, A. (2018). Linking community-based monitoring to water policy: Perceptions of citizen scientists. *Journal of Environmental Management*, 219, 168-177. <https://doi.org/10.1016/j.jenvman.2018.04.077>
- Chase, S. K., & Levine, A. (2016). A framework for evaluating and designing citizen science programs for natural resources monitoring. *Conservation Biology*, 30(3), 456-466. <https://doi.org/10.1111/cobi.12697>
- Goodchild, M. F. (2007). Citizens as sensors: The world of volunteered geography. *GeoJournal*, 69(4), 211-221. <https://doi.org/10.1007/s10708-007-9111-y>
- Grey, D., & Sadoff, C. W. (2007). Sink or swim? Water security for growth and development. *Water Policy*, 9(6), 545-571. <https://doi.org/10.2166/wp.2007.021>
- Hadj-Hammou, J., Loisel, S., Ophof, D., & Thornhill, I. (2017). Getting the full picture: Assessing the complementarity of citizen science and agency monitoring data. *PLOS ONE*, 12(12), e0188507. <https://doi.org/10.1371/journal.pone.0188507>
- Haklay, M. (2013). Citizen science and volunteered geographic information: Overview and typology of participation. In D. Sui, S. Elwood, & M. Goodchild (Eds.), *Crowdsourcing geographic knowledge: Volunteered geographic information (VGI) in theory and practice* (pp. 105-122). Springer. https://doi.org/10.1007/978-94-007-4587-2_7
- Hoff, H. (2011). Understanding the nexus. Background paper for the Bonn 2011 Conference: The Water, Energy and Food Security Nexus. Stockholm Environment Institute.
- Immerzeel, W. W., Lutz, A. F., Andrade, M., Bahl, A., Biemans, H., Bolch, T., Hyde, S., Brumby, S., Davies, B. J., Elmore, A. C., Emmer, A., Feng, M., Fernandez, A., Haritashya, U., Kargel, J. S., Koppes, M., Kraaijenbrink, P. D. A., Kulkarni, A. V., Mayewski, P. A., ...

- Baillie, J. E. M. (2020). Importance and vulnerability of the world's water towers. *Nature*, 577(7790), 364-369. <https://doi.org/10.1038/s41586-019-1822-y>
- Kosmala, M., Wiggins, A., Swanson, A., & Simmons, B. (2016). Assessing data quality in citizen science. *Frontiers in Ecology and the Environment*, 14(10), 551-560. <https://doi.org/10.1002/fee.1436>
 - Kullenberg, C., & Kasperowski, D. (2016). What is citizen science? A scientometric meta-analysis. *PLOS ONE*, 11(1), e0147152. <https://doi.org/10.1371/journal.pone.0147152>
 - Malczewski, J. (2006). GIS-based multicriteria decision analysis: A survey of the literature. *International Journal of Geographical Information Science*, 20(7), 703-726. <https://doi.org/10.1080/13658810600661508>
 - Njue, N., Kroese, J. S., Graf, J., Jacobs, S. R., Weeser, B., Breuer, L., & Rufino, M. C. (2019). Citizen science in hydrological monitoring and ecosystem services management: State of the art and future prospects. *Science of the Total Environment*, 693, 133531. <https://doi.org/10.1016/j.scitotenv.2019.07.337>
 - NITI Aayog. (2018). Report of Working Group I: Inventory and revival of springs in the Himalayas for water security. Government of India.
 - Saaty, T. L. (1980). *The analytic hierarchy process: Planning, priority setting, resource allocation*. McGraw-Hill.
 - Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, 1(1), 83-98. <https://doi.org/10.1504/IJSSCI.2008.017590>
 - Scott, C. A., Zhang, F., Mukherji, A., Immerzeel, W., Mustafa, D., & Bharati, L. (2019). Water in the Hindu Kush Himalaya. In P. Wester, A. Mishra, A. Mukherji, & A. B. Shrestha (Eds.), *The Hindu Kush Himalaya assessment: Mountains, climate change, sustainability and people* (pp. 257-299). Springer. https://doi.org/10.1007/978-3-319-92288-1_8
 - Tambe, S., Kharel, G., Arrawatia, M. L., Kulkarni, H., Mahamuni, K., & Ganeriwala, A. K. (2012). Reviving dying springs: Climate change adaptation experiments from the Sikkim Himalaya. *Mountain Research and Development*, 32(1), 62-72. <https://doi.org/10.1659/MRD-JOURNAL-D-11-00079.1>

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