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Assessing the Climate Resilience of Community-Managed Water Supplies in Ethiopia and Nepal

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Abstract: Understanding the resilience of water supplies to climate change is becoming an urgent priority to ensure health targets are met. Addressing systemic issues and building the resilience of community-managed supplies, which serve millions of people in rural LMIC settings, will be critical to improve access to safe drinking water. The How Tough is WASH (HTIW) framework to assess resilience was applied to community-managed water supplies in Ethiopia and Nepal to assess the effectiveness of this framework in field conditions. The resilience of these water supplies was measured along six domains—the environment, infrastructure, management, institutional support, community governance and supply chains—that can affect how they respond to climate change effects. We found that the HTIW framework provided an objective measure of resilience and could be used to rank water supplies in order of priority for action. We also found that systemic issues could be identified. The tools and methods used in the framework were easy to deploy by field research teams. The water supplies studied in Ethiopia and Nepal had low to moderate resilience to climate change. Service management and institutional support were weak in both countries. The data from Ethiopia and Nepal suggests that many water supplies in rural and small-town communities are unlikely to be resilient to future climate change without increased investment and support. The use of simple frameworks such as HTIW will be important in supporting decisions around such investments by identifying priority communities and actions.

Keywords: climate change; community adaptation; indicators; rural supply; WASH

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1. Introduction

The effects of climate change are already being felt by communities worldwide. The years 2016 to 2020 have been the 5 hottest years on record, and wildfires, windstorms and flooding are becoming more frequent and severe [1]. Inter-annual climate variability, long-term changes in climate patterns and extreme events have the potential to disrupt lives through their impact on water availability [2]. Changing atmospheric and oceanic conditions mean that several parts of the world will be faced with either too little or too much water, both of which can be catastrophic for human life.

Communities in resource-limited settings, largely in low- and middle-income countries, are projected to face the brunt of climate change. The vulnerability of these communities can be ecological or economic and socio-political [3]. There is increasing recognition of the role of water, sanitation and hygiene (WASH) in building the resilience of communities to climate change [4,5]. Improved water supplies offer a buffer against water scarcity and both improved water and improved sanitation can minimize exposure to diseases [6]. However, to do this, water and sanitation services themselves must be made resilient to the effects of climate change. Heavy rainfall, long dry spells and sea level rise pose key threats to these services by causing contamination of water sources, damage to infrastructure and decreased water availability [7,8].

Building resilience in water and sanitation is not solely achieved through modifications to design or the construction of more complex systems, although both make important contributions to resilience in some settings. Services will require more efficient management and government support with the capacity for learning, monitoring changes in system performance and repairing damage to infrastructure as quickly as possible [9–11]. There also needs to be greater knowledge regarding climate threats among managers and strong governance.

Several studies have examined the potential vulnerability and adaptation of water and sanitation technologies and management [12–14]. Furthermore, qualitative assessments of resilience of water and/or sanitation have been undertaken in communities in Bangladesh, Kenya, Ghana, Madagascar, Zambia and the Solomon Islands [15–18]. The GWP and UNICEF framework [19] provides a risk assessment tool with a comprehensive list of potential indicators and has been used to determine the risk of WASH-related exposure and vulnerability of a community in Limpopo province, South Africa [20].

None of these studies above offer a simple framework for assessments of resilience which can be operationalized and used to monitor adaptation efforts over time in settings with limited resources. Experience from water supply surveillance has shown that simple systems of monitoring can be effective in identifying and supporting action to improve service quality [21,22]. To address this gap, Howard et al. [23] proposed a new framework —How Tough is WASH (HTIW)—which considers the climate resilience of water supplies and sanitation along six domains that can affect how services respond to climate effects (Table 1). The framework consists of one indicator for each domain, which can be scored from 1 to 5 based on a set of indicators, with a score of 1 being the lowest resilience, and a score of 5 being the highest [23]. The selected domains and their indicators were identified as providing measures of resilience to climatic events, as described by Howard et al. [23]. Indicator scores, based on data collected through community discussions and a technical analysis of infrastructure and environmental conditions, reflect the likely resilience of services to climate effects. Howard et al. [23] suggested that such an assessment framework can be embedded into monitoring systems and used to determine the success of adaptation programs.

The aim of this work was to apply the HTIW framework to rural and small-town community-managed water supplies to assess its usefulness in understanding resilience, with field studies undertaken in Ethiopia and Nepal. Both countries face significant threats from climate change, with projections for more rainfall variability and warming temperatures [1]. The communities chosen for the study rely on simple technologies that have been shown to be vulnerable to climate threats [12,24] and are typically managed by communities or local governments with limited technical skills and knowledge. Such supplies often fail from a lack of skilled management, financial sustainability and support from the government [25]. The limited capacity and capability of service managers in these settings mean that developing resilience assessments and plans for each individual supply is unrealistic and standardized assessment tools that allow rapid assessment are essential. Furthermore, as millions of people in sub-Saharan Africa and Asia rely on such systems, it is important to be able to compare different systems to support prioritization for investment and technical assistance to improve resilience.

Table 1. The domains of resilience in the How Tough is WASH framework [23].

Domain	Definition	Relevance of This Domain
Environment	The wider environment and catchment around water supply	Degraded catchments can encourage rapid surface runoff, contain significant sources of pollution and increase the risk of falling groundwater levels during dry season
Infrastructure	The headworks and distribution network (where it exists) and sanitary protection measures	Sanitary protection measures at the infrastructure can protect water supplies from contamination and damage from flooding or landslides
Management	The system of formal management of the water supply	Adaptive management of the water supply will be critical to cope with climate variability and future changes, and ensure adequate supply of safe water, especially after extreme weather events
Community governance and engagement	Wider decision-making and formal and informal governance in the community	Community engagement with water supply issues must be considered as part of a wider assessment of community dynamics, which is critical to how communities cope with environmental stresses
Institutional support	Local support offered to managers by the government	Timely support by local government to water supply managers can ensure the effective management of services with minimal disruption
Supply chains	The businesses that sell spare parts and services needed for operation and maintenance of water supplies, and the roads and communication networks that support them	Robust supply chains respond to extreme weather events with minimal or no disruption of water supply services

This study presents an example of how the HTIW framework can be applied in rural and small-town water supplies and shows how the findings can be used to prioritize water supplies and identify specific actions to improve resilience.

2. Materials and Methods

2.1. Study Area

Longitudinal, observational field studies were carried out in Nepal and Ethiopia between November 2019 and August 2021 to assess the climate resilience of a sample of rural and small-town drinking water supplies using the HTIW framework. Both countries face significant threats from climate change. Ethiopia is projected to become warmer, which is likely to increase the risk of diarrhoeal disease. There is uncertainty regarding future precipitation trends, but Ethiopia is likely to become wetter overall, albeit with significant temporal and spatial variation [1].

Nepal is expected to become overall slightly wetter, but this will be accompanied by intensification of precipitation leading to increased flood risks and threats to water and sanitation services [1]. Increasing temperatures are leading to glacier recession, which may particularly affect communities that rely on springs recharged from localised glacial melting.

Only 13 and 18% of the population in Ethiopia and Nepal, respectively, have access to safely managed drinking water, according to nationally representative data sources collated by the Joint Monitoring Programme (JMP) [26], making both countries extremely vulnerable to the threats that climate change poses to water supplies [7,8].

2.2. Field Study Sites

Sites were purposively selected to cover different agro-meteorological zones—lowlands, midlands and highlands in Ethiopia and the mountains (2000–5000 masl), mid-hills (300–2000 masl) and low-lands or Terai plains (<300 masl) in Nepal—and different types of water supply technologies, as listed in Table 2. Twenty rural communities in Kersa and Haramaya districts in Ethiopia, and fifteen rural and small-town communities in Chitwan and Kaski districts in Nepal were included in the study (Figure 1), each with access to an improved water source using the definitions used in the JMP [26], which included piped water, boreholes or tubewells, protected dug wells, or protected springs. Each water supply in Ethiopia served 80–500 households through public taps or handpumps. The protected springs and boreholes with handpumps in Nepal served 10–200 households, while the larger piped-water supplies served up to 8500 households.

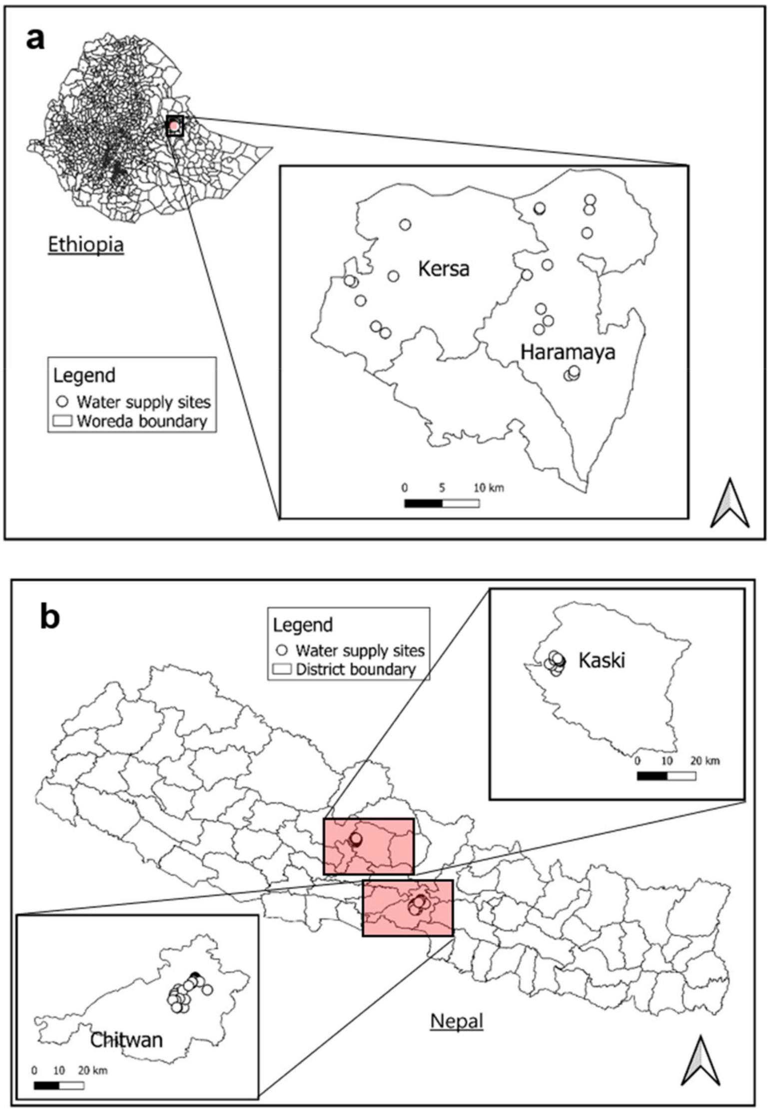

Figure 1. Locations of water supply sites in (**a**) Ethiopia and (**b**) Nepal.

Table 2. Types of water supply technology at study sites.

Country	Water Supply Technology
Ethiopia	8 protected dug wells 6 boreholes (tubewells) with handpumps 1 mechanized borehole 2 springs with distribution 3 springs on spot
Nepal	2 boreholes with distribution 6 springs with distribution 7 boreholes with handpumps

2.3. Data Collection

Sanitary inspections were undertaken to identify risks at the source and collection points using WHO sanitary inspection forms [27]. For piped-water systems, the sanitary inspections were performed at the source, at reservoirs, and at a sample of taps within the system. GPS coordinates were retrieved from the handheld GARMIN (Model: OREGON 650).

The GPS coordinates were uploaded to Google Earth™ for geospatial analysis of satellite and aerial imagery. Images were used to identify risks in the wider environment, including slope, presence of landslide scars, major roads, settlements, and forest cover in the catchment of the water supply. Data was also collected on the population density around the source, the presence of latrines uphill of the source and their risk of flooding through user surveys and visual inspection.

Topic guides were developed for semi-structured key informant interviews (KII) and focus group discussions (FGD) (Tables S1 and S2). Members of water management committees (WASH committees in Ethiopia and Water Users' and Sanitation Committees (WUSC) in Nepal) were asked about their experience with the water supply, seasonal changes in water quality and quantity, access to water testing equipment or results, ability to carry out minor and major repairs, the natural hazards that occur in the area, and their perception of climate change. Water managers were also interviewed regarding the support, advice and training provided by local authorities, and what challenges they faced in procuring parts and carrying out repairs.

Since women were generally responsible for collecting water at the study sites, representatives of women groups were interviewed where possible to capture their experience with the water supply and participation in water-related decisions. Community elders and members of prominent local groups (a local self-help group, AFOSHA, which is influential in communities in Ethiopia and plays an active role in community decision-making, and health extension workers) were also interviewed for their experience with water supply management, their perception of changing climate patterns in the region, and to assess the dynamics of community decision-making.

Local government officials with responsibility of overseeing water supply services were interviewed about the support they provided to managers, the support they received from higher levels of government, what challenges they faced in supporting service delivery, and whether they were considering climate effects as part of government support. Information was also collected from 10 users of boreholes in Chitwan, Nepal who informally manage the water supply, including 6 users from a marginalized community (members of the Musahar community in Chitwan, Nepal).

The interviews were conducted in Amharic in Ethiopia and Nepali in Nepal and recorded after obtaining the informed consent of the participants. A translator was hired for the discussion with residents of a marginalized communities in Chitwan. The audio recordings were then transcribed and translated to English. No information that could be used to identify participants was stored. The number of participants who participated in interviews and community discussions is listed in Table S3.

2.4. Indicator Scoring

The data collected for each water supply were used to score each indicator—environment, infrastructure, service management, institutional support, community governance, and supply chains—following the framework set out in [23]. Scores were assigned on a 5-point Likert scale based on the indicator criteria that met the conditions around the water supply most closely. The risks identified in the catchment of water supplies were used to score the environment indicator. The infrastructure indicator was scored based on median scores from 6 rounds of sanitary inspections, which were undertaken to assess seasonal variation in risks over the 22 months of the study, and qualitative evidence of trends in yield collected from discussions with operators. The management, institutional support, supply chain and community governance indicators were assigned scores based on qualitative analysis of the key informant interviews and community discussions. This analysis was completed using deductive coding, using a pre-defined list of codes developed from an initial review of the data [28], allowing us to identify themes in the interview transcripts that were relevant to the framework. Codes were developed based on indicator criteria, to ensure that the information extracted from the interviews could be used to compare water supplies against the indicator criteria and assign an appropriate score.

Scores assigned to each indicator were added up for overall system resilience scores for each water supply, which were used to prioritize water supplies for action to improve resilience, using the system of prioritization shown in Table 3.

Table 3. Prioritization of water supplies by resilience scores [23] (licensed under CC BY 4.0).

Total Score	Resilience	Priority	Qualifier	Action
25–30	Very high	Low	If the score reduces because of failure on one domain, action required in that domain	Maintain performance
19–24	High	Low	Action focused on specific indicator failures	Limited improvements
13–18	Medium	Medium	Likely to be across multiple indicators	Substantial improvements
7–12	Low	High	Action required across all indicators	Large-scale improvements
6	Very low	Very high	Action required across all indicators	Systemic improvements

3. Results

3.1. Indicator Scores

Scores for each indicator and the overall system are shown in Tables 4 and 5 in increasing order of resilience. Examples of the detailed scoring of indicators is provided in Tables S4–S9.

3.1.1. Environment

The risks identified in the wider environment around a source, or its catchment, included risk of damage from flooding and landslides, and faecal contamination from open defecation or pit latrines that are at risk of flooding. The scores for this indicator varied from 1 to 4 in Ethiopia and from 2 to 4 in Nepal (Tables 4 and 5). Sources in less densely populated areas with pit latrines not at risk of flooding do not face a serious risk of heavy faecal contamination and received scores of 3 or 4. Sources located on relatively flat (the criteria used to assess steepness of slope are presented in Supplementary Information Table S10) ground or downhill of forested land also received high scores because they are at low risk of damage from rapid surface runoff, falling debris or landslides.

Table 4. Indicator scores for water supplies in Ethiopia.

Site	Supply Type	Environment	Infrastructure	Management	Institutional Support	Community Governance	Supply Chains	Total
Adele manabernota	Borehole with handpump	3	2	1	1	1	2	10
Genda Sole	Protected dug well	3	3	1	1	1	4	13
Genda Gode	Spring with distribution	1	2	2	2	3	3	13
Genda Ilamo	Spring on spot	1	3	2	1	4	2	13
Genda Wele01	Protected dug well	2	2	2	2	3	3	14
Genda Giricho	Protected dug well	3	3	2	1	3	2	14
Genda Able	Borehole with handpump	3	3	2	2	2	2	14
Genda Aleka	Borehole with handpump	3	2	2	2	3	2	14
Genda Kusharo	Protected dug well	2	2	2	2	3	3	14
Genda Gelelcha	Spring on spot	4	2	1	2	3	2	14
Genda Aroji	Borehole with handpump	3	2	3	2	3	2	15
Genda Tabu	Protected dug well	3	2	2	2	3	3	15
Genda Arga	Borehole with handpump	2	2	2	2	3	4	15
Genda Usman	Spring with distribution	3	3	2	2	3	2	15
Genda Oter	Mechanized borehole	3	3	2	2	3	2	15
Genda Gobeya	Protected dug well	4	3	2	2	4	1	16
Genda Didimtu	Protected dug well	3	3	2	2	3	3	16
Genda Kalu	Protected dug well	4	3	2	2	4	2	17
Genda Musa	Spring on spot	2	3	3	2	4	3	17
Genda Gelmo	Borehole with handpump	4	3	3	2	4	3	19

Decreasing priority for action ↓

Table 5. Indicator scores for water supplies in Nepal.

Site	Supply Type	Environment	Infrastructure	Management	Institutional Support	Community Governance	Supply Chains	Total
Musahar cluster bird chowk1	Borehole with handpump	2	2	1	1	2	2	10
Musahar cluster bird chowk2	Borehole with handpump	2	2	1	1	2	2	10
Musahar cluster bus park1	Borehole with handpump	2	3	1	1	2	2	11
Musahar cluster bus park2	Borehole with handpump	2	3	1	1	2	2	11
Tarbu scheme Matque	Spring with distribution	2	2	1	1	4	2	12
Dhailung Khola	Spring with distribution	3	3	1	1	3	1	12
Potyala scheme	Spring with distribution	3	3	2	1	3	1	13
Guisolo scheme	Spring with distribution	2	4	1	1	4	1	13
Tirim and Umlaga scheme	Spring with distribution	2	4	2	1	3	2	14
24 gharey tubewell	Borehole with handpump	4	2	2	1	4	2	15
Korean tap	Borehole with handpump	4	3	2	1	4	2	16
Kalika bus park tubewell	Borehole with handpump	4	3	2	1	4	2	16
Jutepani scheme	Borehole with distribution	4	3	2	2	3	4	18
Dharapani scheme	Spring with distribution	4	3	3	1	4	4	19
Ratnanagar scheme	Borehole with distribution	4	3	4	3	2	4	20

Decreasing priority for action ↓

On the other hand, water sources located downhill of steep slopes with managed forests, cultivated land or bare soil may be at risk of damage during heavy rainfall and therefore, received low scores, depending on the slope angle and evidence of landslide scars uphill of the source. In total, four boreholes in the Terai plains in Nepal were reported to be located near pit latrines at risk of flooding and therefore received a score of 2. Piped schemes where taps were at risk of damage from runoff or erosion or were located downhill of toilets, also received low scores.

3.1.2. Infrastructure

Infrastructure indicator scores for water supplies in Ethiopia were either 2 or 3, indicating low to medium resilience in this domain (Table 4). The piped schemes in Nepal had scores from 2 to 4, while the boreholes with handpumps received scores of 2 or 3 (Table 5). Water supplies with high sanitary inspection risks received low resilience scores to account for the risk of contamination and damage from surface runoff. The risks most reported for each water supply type are listed in Table 6.

Table 6. Most frequently reported sanitary risks in Ethiopia and Nepal, by type of water supply technology.

Water Supply Technology	Most Frequent Sanitary Risks
Ethiopia	
Protected dug well and borehole with handpump	Animal excreta or rubbish within 10 m of the handpump, inadequate wall or fencing around the source
Spring with distribution	Area around the spring unfenced, water accumulated around the tap stand, leaks in the distribution system
Spring on spot	Lack of surface diversion ditch around the source, source accessible to animals
Mechanized borehole	Faulty drainage around pumphouse, uncapped well within 100 m
Nepal	
Borehole with distribution	Latrine or sewer within 100 m of the pump house, unsanitary air vents or inspection covers, exposed mains, signs of leaks near taps
Spring with distribution	Signs of leaks in the distribution network and at tap stands
Borehole with handpump	Sources of pollution within 10 m of the borehole

None of the water supply managers had records of source yield, which is indicative of a lack of monitoring and can be a source of low resilience. Users in all but 6 of the 35 study sites reported experiencing water shortages in the dry season, which was used as qualitative evidence of a seasonal reduction in yield and factored into the infrastructure score.

3.1.3. Management

All water supplies in the study were community-managed, either through volunteer user committees or informally by residents. Based on the KIIs, it was found that community members in Ethiopia had limited awareness of climate change. Community managers in Nepal overall had better awareness of changing climate patterns, especially in relation to timing and amount of snowfall and frequency of flooding and precipitation patterns. However, most of this awareness was from the media, and managers had not received any climate-related training or attended any relevant workshops.

The skill level of committees to effectively maintain the water supplies varied from low to moderate in both countries. Managers were not trained to test water quality or had any training in climate risk assessments. However, they were skilled in minor repairs, constructing source protection measures, such as fencing and digging diversion ditches, and cleaning the area around the source. These skills were developed through training from local authorities (the woreda (district) water and energy office in Ethiopia and the municipal government in Nepal who were responsible for overseeing the water supply in the study sites) or charities and some informal guidance provided by technicians over the years who came to repair bigger issues. Committee members were aware that open defecation and damaged toilets can cause contamination of the water supply, especially in the rainy season. Overall, management was relatively weak in both countries and indicator scores were generally between 1 and 3 (Tables 4 and 5).

Only one water supply in Nepal was assigned a score of 4 because it had a competent, elected management committee, with strong financial support from the government, savings for emergency use on service improvement and staff with a basic understanding of climate change. This committee was also planning to construct recharge ponds to address depleting groundwater. However, due to the lack of participation in climate risk assessments, the committee did not receive a score of 5.

Several remote, mountainous communities in Nepal did not have registered WUSCs and residents maintained the water supply on an ad hoc basis i.e., if an issue arose, residents volunteered to visit the source and perform the repairs. The boreholes used by communities in the Terai plains in Nepal had similar informal management. Some WASH committees in Ethiopia had disbanded over prolonged unresolved conflicts over the water source. These communities all received a score of 1.

In total, 4 of the 20 communities in Ethiopia and 5 of the 15 communities in Nepal collected a fee from residents on a monthly or annual basis. There was some representation of women on management committees in most of the water supplies studied, but none in leadership roles. The constitution of Nepal mandates 33% representation of females on WUSCs. This was reported in all the registered committees in the study areas.

3.1.4. Institutional Support

The WASH committees in Ethiopia received some support from the woreda water and energy office in the form of training to conduct basic repairs, support for procuring spare parts and technical assistance for major repairs. However, this support was rarely perceived to be adequate by communities. The resulting delays in repairs led to several water supplies being non-functional for months at a time, and inadequate water supply to support the increased demand put on the remaining sources.

Neither of the two woredas currently have a formal climate risk management program in place nor do they discuss the challenges associated with climate change with WASH committees. The lack of a formal risk management program and support to WASH committees for climate adaptation, combined with limited coordination with other sectors at the woreda-level resulted in low institutional resilience scores. The perception of institutional support differed marginally between communities and therefore the indicator scores were either 1 or 2 (Table 4).

The requirement for communities in Nepal to request support for developing the water supply means that several remote mountainous communities and the marginalized community in the Terai did not have registered WUSCs and received no support from the government beyond some initial financial inputs at the time of construction of the water supply. Some of the registered WUSCs received funds from the government to construct the water supply and for repairs but receive no other form of support. None of the user groups managing boreholes with handpumps reported any form of government support. This resulted in 13 of the 15 study sites in Nepal being assigned a score of 1, indicating very low resilience. Two water user committees receive ongoing financial and some technical support from the government but have not received training in climate risk assessments. Therefore, they received scores of 2 and 3. One of these committees reported facing some confusion over how to access government support and received a score of 2.

3.1.5. Community Governance and Engagement

The community governance scores in Ethiopia and Nepal ranged from 1 to 4, and 2 to 4, respectively (Tables 4 and 5). Management committees in most of the study sites were elected by residents. Communities where residents were actively engaging with management committees through regular meetings about water-related issues, cooperating over access to water, or participating in digging diversion ditches and keeping the area around the source clean, received scores of 3 or 4.

One member of the WASH committee, generally the female member, was in charge of resolving conflict among residents over water collection when it arose with support from village elders and a local self-help group. However, there was less participation of women in water-related decisions and community decision-making generally, compared to men in all the study communities and therefore, none of the systems were assigned a score of 5.

The community played an active role in maintaining the water supply where a registered committee did not exist such as in the remote, mountainous communities in Nepal. Residents contributed funds and several hours of labour during the construction of the water supply and informally volunteer to clean tanks and undertake repairs when needed. Funds for these repairs were collected with the help of local community groups and in some cases local charities. These communities received scores of 4 in this indicator.

3.1.6. Supply Chains

The scores of the supply chain indicator for systems in Ethiopia ranged from 1 to 4 (Table 4). Management committees with access to multiple markets for spare parts and consumables or those who stored spare parts locally were assigned higher scores. Some of the WASH committees in Ethiopia sourced spare parts from their woreda office for free. If not, they had access to markets in multiple towns and reported that they could carry out minor repairs within 2 days. For some communities, this time did not change even during the rainy season. However, others faced challenges in travelling to markets or the woreda office in the rainy season, causing delays in repairs of up to several weeks. These water supplies were assigned scores of 1 or 2.

In a few cases, indicator scores were lowered based on the lack of locally stored spare parts, despite communities having easy access to markets and good transportation. Even if the lack of local storage does not currently cause delays, this may become a source of low resilience in the future if travel to towns becomes less convenient because of heavier or more frequent rainfall.

Communities in Nepal also had access to multiple markets mostly in the Terai. Residents in remote areas reported challenges in travelling to towns far away to buy consumables, which can take 1 or 2 days. The road conditions also deteriorate during the rainy season, and flood or landslide damage to roads was commonly reported. These communities were assigned scores of 1 or 2. Communities that were well connected to other towns with easy access to markets, or locally stored spare parts received scores of 4.

3.2. System Scores and High Priority Supplies

System scores for Ethiopia and Nepal ranged from 10 to 19 and 12 to 20, respectively (Tables 4 and 5). Based on these scores and the framework shown in Table 3 (adapted from [23]), the water supplies were ranked in order of priority for action to improve resilience. One water supply in Ethiopia has low resilience and therefore, is a high priority for support and improvements across multiple domains (Table 4). Its lowest scores were in management, institutional support and community governance. This water source is located inside a school and the local school board elected the WASH committee after discussions with the kebele (the smallest administrative unit in Ethiopia) administration. Local residents were not included in this process and have no way to engage with the committee. There is no income for the WASH committee as the school takes the tariff collected from users. This has resulted in a delay in repairs after a flood damaged the infrastructure. Additionally, none of the committee members have received training or support from the woreda. The rest of the water supplies in Ethiopia are a medium or low priority for investments in resilience and will require action in specific domains only.

The boreholes in the marginalized areas in Chitwan and the mountainous spring-fed supplies received the lowest scores in Nepal and are a high priority for action (Table 5). None of these systems were managed by a formally registered user committee and received no government support. The boreholes were in flood-prone communities within 10 m of pit latrines at risk of flooding. Community discussions revealed wider issues around affordability of services which extend to the water supply. The municipal piped-water supply was recently expanded to this community but the user tariff and cost of setting up a new connection are not affordable for several residents who continue to rely on the boreholes. While there were no reports of sources drying up, the overuse of handpumps causes frequent mechanical issues, and an increased demand on the other boreholes in the community. Several residents cannot afford to contribute financially, and the volunteer managers cannot buy spare parts for repair even though they are available locally.

In addition to the lack of WUSC, the spring-fed supplies also had high sanitary risks in the form of exposed, leaking pipes and erosion near tap stands. Since these communities are remote, residents described challenges in traveling to the nearest town and paying for lodging to attend trainings. Seasonal disruptions to road networks also cause delays in buying parts for repair.

The systems categorized as medium priority will need action in one or two domains. Among these, institutional support was often the weakest followed by service management (Tables 4 and 5). The two water supplies that received the highest resilience scores only require limited improvements and are a low priority for action.

3.3. Systemic Issues of Low Resilience

Service management, institutional support and supply chain indicators had the lowest median scores (either 1 or 2) in both countries (Figure 2), indicating systemic issues of low resilience.

While simpler repairs can be carried out without significant delays by committees in Ethiopia, the technical skills and government support for monitoring seasonal changes and carrying out major repairs are currently lacking in all the supplies. The borehole-fed piped systems in Nepal had strong management and received adequate government support including funds and training in water quality testing, but this did not extend to smaller systems, where management is weak, and no external support is available.

Institutional support was also weak across most water supplies. In Ethiopia, woreda offices lacked the budget to train technicians and WASH committees which has hindered their ability to support major repairs. This was especially the case for boreholes with mechanized pumps. Both the woredas claimed not to have the necessary technical expertise to support WASH committees in maintaining these systems. The woreda offices rely on the zonal office to repair pumps and power generators, and it can take several months to receive this support.

As several committee members and government officials in Nepal noted, federalization has led to confusion about guidelines and the role of officials at different levels of government. The responsibility of overseeing water supply has shifted from the federal to the local and provincial governments which has created gaps in support for WUSCs. There are budgetary gaps which limit the number of risk assessment trainings that the government can provide, especially when there are many small water supplies. The relatively short tenure of WUSC members (3–5 years) presents an additional challenge for the government to provide trainings and support climate adaptation.

As described by a key informant, since the federal drinking water policy in Nepal requires user groups to contribute financially toward the cost of construction of the water supply (generally, 20–30% of the project cost), including climate adaptations in projects can be cost prohibitive for communities. Budget constraints are also preventing private water suppliers from extending piped supplies in rapidly expanding small towns, where communities often must rely on contaminated boreholes.

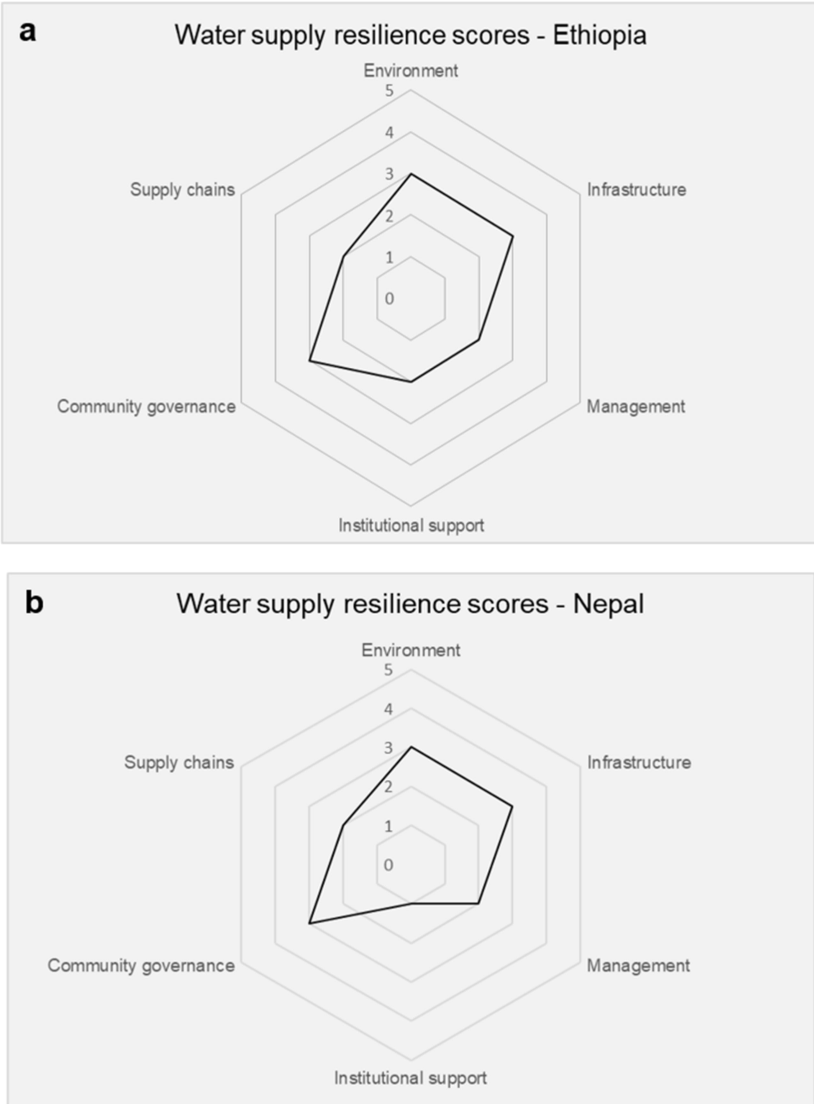

Figure 2. Median resilience scores for water supplies in (**a**) Ethiopia and (**b**) Nepal.

Low resilience of supply chains was evident where managers could not always afford to procure spare parts and access external support on time. Committee members in Ethiopia reported that some transport service providers increase their prices during rainy seasons, making multiple trips unaffordable. Residents in the remote, mountainous communities of Nepal reported being cut off from the nearest town where they generally buy spare parts, because of flood or landslide damage to the main road. Combined with the absence of locally stored spare parts and consumables, this creates substantial challenges for quick repairs and efficient service delivery.

Technicians working at the woreda offices in Ethiopia also face transport hurdles. Staff from one woreda support more than 300 water sources and find it challenging to travel long distances. The water and energy office does not have a reliable vehicle and is sometimes forced to borrow motorbikes for technicians from other offices in the woreda.

4. Discussion

This study showed that the HTIW framework can be applied to rural and small-town water supplies in LMIC settings to determine their response to current climate variability, and their likely resilience to future climate change. Field assessment of the individual indicators used simple tools that required only limited training. The aggregate scores provided a basis for ranking water supplies in order of priority for action and are consistent with approaches to water quality surveillance [21,22,27].

Geospatial analysis of aerial images proved to be a useful tool to identify physical features in the catchment of water supplies that would result in hazardous events such as flash floods related to extreme weather. It was also useful in identifying potential sources of faecal contamination such as densely populated communities. Availability of free satellite and aerial images on a free-to-use platform such as Google Earth^{TM} means that such analysis can be completed without the use of proprietary GIS software, which requires specialist skills. Repeated site visits and sanitary inspections of the infrastructure over 22 months provided information about delays in repairs and changes in performance of the water supplies over time (e.g., mechanical breakdowns or dried-up wells), which are indicative of how systems might respond to threats in the future.

Community discussions with water supply managers, local government, users and community leaders shed light on the challenges faced by residents and the government. The data collected were critical in developing recommendations for service improvements. The field study showed that in applying the HTIW framework, it is important to ensure that the range of respondents selected should cover all relevant stakeholders to capture different perspectives on the performance of the water supply and causes of poor service delivery. The importance of developing topic guides that allow interviewers to guide discussions to focus on the issues related to the indicator was confirmed from the field studies. Topic guides were developed for these field studies based on preliminary visits to communities and informal discussions in order to identify key issues that would need to be explored. It is important that sufficient time is dedicated to developing topic guides if relevant and reliable data are to be obtained. The field studies also showed the importance of data collectors having the requisite skills to undertake qualitative data collection and analysis. The team in Ethiopia included a qualitative social scientist and thus development of appropriate guides and analysis was relatively straightforward. The team in Nepal did not have a qualitative research specialist and therefore more training and support was required to ensure the field team had the skills and tools required. In both countries, quality assurance on the qualitative research was provided through field visits from experts and joint development of tools across the different country teams to ensure comparability. Undertaking joint analysis of the data was also found to be important as this provided opportunities for discussion on emerging themes and consensus on the findings.

Future work will focus on applying this framework to a wider range of settings, including professionalized, piped-water supplies and to identify patterns in resilience scores based on region, water supply technology, and management model. Engagement with implementing agencies and governments will be needed to further test this framework, collect evidence of the response of water supplies to changes in rainfall and temperature, and strengthen the link between resilience metrics and policy.

Use of the Framework to Recommend Improvements

By aggregating the indicator scores we were able to rank water supplies in both countries in order of priority for action and also to identify systemic failures. System resilience scores allowed us to identify water supplies that are in urgent need of support (resilience scores <12). Assessment of each system along multiple domains gave us a nuanced picture of its strengths and critical weaknesses, based on which we were able to suggest specific actions that may lead to improved resilience.

The data from the 35 water supplies in Ethiopia and Nepal revealed that these systems are only moderately resilient to the threat of climate change, with consistently low scores in service management, institutional support and robustness of the supply chain. The systemic issues of low resilience identified in this study reflect the strengths and weaknesses of community-managed water supplies, and highlight the role of community participation, financial contribution and external support in effective service delivery, which are well-documented [10,25,29–32]. As evidenced by user reports of seasonal scarcity and delays in repairs, these services are struggling to provide adequate services year-round and will need substantial improvements in multiple domains to improve services and adapt to a changing climate.

From the community discussions, we found that urgent support is needed for the lowest scoring water supply in Ethiopia to strengthen the role of the WASH committee, with more control over funds and better technical support from the woreda office. Previous studies have shown that better community engagement and a sense of ownership over the water supply can lead to improved service delivery [33].

In Nepal, community interviews and geospatial analysis showed that the four lowest scoring systems were boreholes located in flood-prone communities with pit latrines that flood with rainwater. Assessments of the risk of faecal contamination of groundwater are recommended, which can be used to identify improvements to source resilience. Detailed guidance for such field assessments is available [34,35]. Such interventions could include siting latrines at a safe distance from the boreholes or modifying their design to reduce the risk of flooding and damage to the containment [35]. Source protection measures to address other risks at the borehole can further reduce the risk of contamination from sanitation and surface runoff [36].

The mountainous springs with distribution systems in Nepal require similar interventions to register their water user group and improve their access to technical and financial support. Previous studies have shown that active engagement by water user groups or similar bodies are an important aspect of effective and resilient water services [33,37–40].

5. Conclusions

There is growing agreement around the need for building resilience of water supplies to protect public health from the effects of climate change. The aim of this study was to apply the HTIW framework to community-managed water supplies in Ethiopia and Nepal to determine how effectively this could be applied to assess likely climate resilience.

The HTIW framework was found to be effective. Data were obtained that provided an objective assessment of resilience using relatively simple and robust data collection tools. The framework utilises widely available tools and data collection methods and could be applied across different types of water supplies and settings. The aggregated indicator scores provided a basis for ranking water supplies on order of priority for action and allowed the identification of systemic issues affecting the resilience of water supplies in rural and small-town settings.

The application of the framework in 35 water supplies revealed critical weaknesses in service delivery and low to moderate resilience of most systems. The factors that contributed to the low resilience of these systems were a lack of financial and technical support for water supply managers and inadequate source protection measures.

These weaknesses are widely seen in rural community-managed water supplies, which millions of people in LMICs rely on. Services that already struggle to provide a robust, uninterrupted water supply in the face of existing seasonal variability are unlikely to withstand the increased uncertainty posed by climate change. Improving their resilience will require more investment in water safety management and local government support. The use of simple metrics such as the HTIW framework can support this investment by identifying the priorities for action both in terms of comparisons between communities and in identifying which issues require concerted action.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w14081293/s1, Table S1: Interview guide for KIIs completed in

Ethiopia; Table S2: Interview guide for KIIs completed in Nepal; Table S3: Number of participants in KIIs and FGDs; Table S4: Rationale for assigning environmental indicator scores; Table S5: Rationale for assigning infrastructure indicator scores; Table S6: Rationale for assigning management indicator scores; Table S7: Rationale for assigning institutional support indicator scores; Table S8: Rationale for assigning community governance and engagement indicator scores; Table S9: Rationale for assigning supply chain indicator scores; Table S10: Slope classification used to score water supplies on the environment indicator.

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