Water Practice & Technology

© 2023 The Authors Water Practice & Technology Vol 18 No 9, 2168 doi: 10.2166/wpt.2023.130

Water poverty in Western Nepal: assessment of Alital Rural Municipality in Rangun watershed

Sushma Tiwari [a,*], Sanot Adhikari[b], Udhab Raj Khadka[c], Motilal Ghimire[d] and Rocky Talchabhadel[e]

[a] Department of Environmental Science, Saptagandaki Multiple Campus, Bharatpur, Chitwan, Nepal
[b] Youth Alliance for Environment (YAE), Gairidhara, Baluwatar, Kathmandu, Nepal
[c] Central Department of Environmental Science, Tribhuvan University, Kirtipur, Kathmandu, Nepal
[d] Central Department of Geography, Tribhuvan University, Kirtipur, Kathmandu, Nepal
[e] Department of Civil and Environmental Engineering, Jackson State University, Jackson, MS, USA
*Corresponding author. E-mail: sushmatchhetri@gmail.com

ST, 0000-0002-3330-4460

ABSTRACT

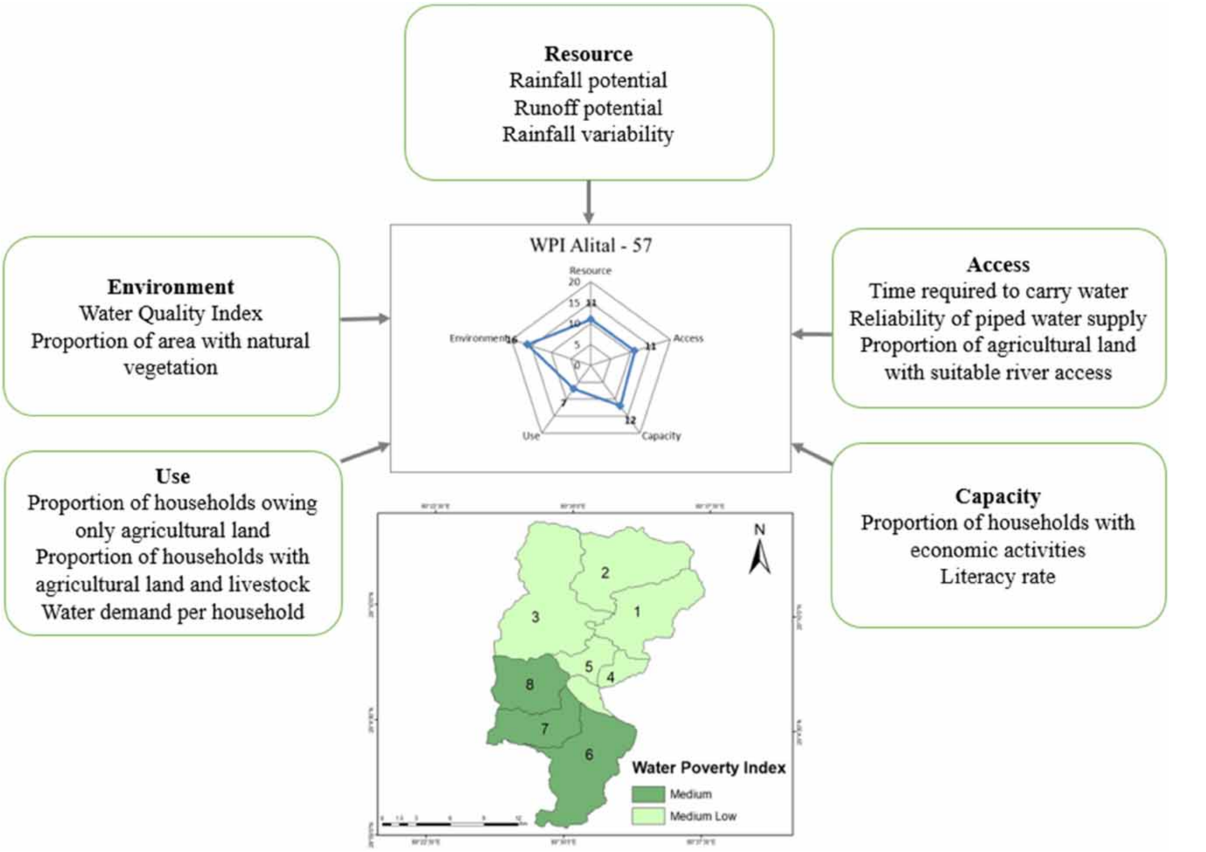
Water poverty is an emerging issue in Nepal. Several factors, including population growth, climate change, land-use transitions, and poorly planned road construction, significantly impact water quality and quantity. Water poverty in Alital Rural Municipality, Dadeldhura, in Rangun Watershed is examined in this study. Elements of the water poverty index (WPI) were used – (i) access, (ii) resource, (iii) use, (iv) capacity, and (v) environment. The WPI was determined as 57, indicating a medium-low level of water poverty. The WPI for the various wards, the smallest administrative units, ranged from 54 to 64. The environment component yielded the highest score, the use component the lowest. Water use for household and agricultural purposes was negligible compared to other uses. Effective water management plans are essential for increasing household water use and consumption in the watershed. The WPI can be used as an integrated tool for water resource management at various scales, from local to national, by linking all environmental factors to identify and prioritize the areas that require immediate management interventions for integrated, multi-disciplinary, and sustainable water resource management.

Key words: access, capacity, environment, integrated tool, water resource management

HIGHLIGHTS

- Nepal, despite being water-rich, is experiencing increasing water poverty and scarcity.
- The water poverty indicators and issues differ with location, so it is important to select appropriate indicators.
- In certain areas, accessibility to water resources is particularly low, forcing people to travel long distances to meet their water needs.
- Alital Rural Municipality has a medium-low WPI, with ward 7 having the worst water poverty.
- The WPI takes access to resources, the environment, and human capacity for using them into account, making it an effective integrated tool for water resource management.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Water is fundamental to life, and both human survival and economic growth depend on a sufficient supply of water of potable quality (Barbier 2004). Human activity is known to impact the ecosystem and water resources directly (Dodds *et al.* 2013), making it necessary to change people's behavior to conserve water resources and sustain future generations (WCED 1987), given that global water resources are limited. Water scarcity is an emerging issue in the rural watersheds of Nepal (Merz *et al.* 2003; Gyawali *et al.* 2019). Rapid population growth and interest in sophisticated lifestyles and agriculture-dependent livelihoods have put significant pressure on Nepal's water resources (Kattel & Nepal 2022). Consequently, it is of utmost importance to develop new management strategies that combine traditional practices and scientific research to meet water demands and preserve water quality in Nepal's rural watersheds (Merz *et al.* 2003).

Water-related problems are often specific to location and influenced by human behavior and its interconnection with other factors, e.g., environmental, social, technological, etc. (Alexander *et al.* 2010). Addressing the multi-dimensional aspects of water-related problems is challenging but necessary, and indices that incorporate social, environmental, economic, and management factors are best suited for water poverty assessment (Manandhar *et al.* 2012). Various indices have been developed to address water availability and quality issues, providing a clear framework for addressing water-related challenges at different levels of governance, from municipal to federal (Sullivan 2011). Indicators and indices have been widely used in the water sector, such as the WPI by Sullivan *et al.* (2003), the water sustainability index by Chaves & Alipaz (2007), the climate vulnerability index by Sullivan & Meigh (2005), and others.

A composite instrument, the WPI integrates human well-being and water availability indices to assess the effects of water scarcity on human populations (Pandey *et al.* 2012). The emphasis lies on underprivileged and marginalized communities, and the approach incorporates data and information concerning water availability, scarcity, accessibility, and people's capacity to use water for various purposes (Sullivan *et al.* 2003). Its primary objective is to evaluate available water resources and identify community requirements and demands. However, depending on needs, it can be adapted to various scales and intensities (Sullivan *et al.* 2006).

Water poverty is becoming increasingly severe in Nepal due to factors including declining water quality, an inadequate and unreliable water supply system, rising water demand for irrigation and domestic use, financial insecurity, population growth, and a shortage of human resources to manage water resources (Panthi *et al.* 2018). Other factors contributing to Nepal's water scarcity are rugged topography, inadequate facilities for healthcare, education, hygiene, and clean water, and the reliance of mountain communities on agriculture despite significant issues such as a lack of irrigation systems, poor road infrastructure, and challenging geology (WWF 2012).

There have been limited water poverty assessments in larger watersheds across Nepal, including the Indrawati Basin (WWF 2012), West Rapti and Kankai River basins (Pandey *et al.* 2012), Kali Gandaki River Basin (Manandhar *et al.* 2012), Upper Bagmati River Basin (Thakur *et al.* 2017), Karnali River Basin (Panthi *et al.* 2018), and Koshi Basin (Koirala *et al.* 2020). However, there is a significant demand for small, watershed-specific studies, particularly in western Nepal. This study was done to determine the extent of water poverty and scarcity in Alital Rural Municipality, Dadeldhura District, in the Rangun Watershed.

2. STUDY AREA

Alital Rural Municipality (Figure 1) has eight wards and was formed by combining two Dadeldhura's village development committees (VDCs) – i.e., Alital VDC and Gankhet VDC (Alital Rural Municipality 2018). The study area extends from 29° 60′ 51″ to 29° 08′ 51″ N latitude and 80° 03′ 04″ to 81° 40′ 78″ E longitude and covers about 293 km^2 (i.e., 19% of the Dadeldhura district and 0.19% of Nepal). The municipality's elevation range is from 480 to 2,570 masl, and it lies 70 km south of Dadeldhura District headquarters. The climate

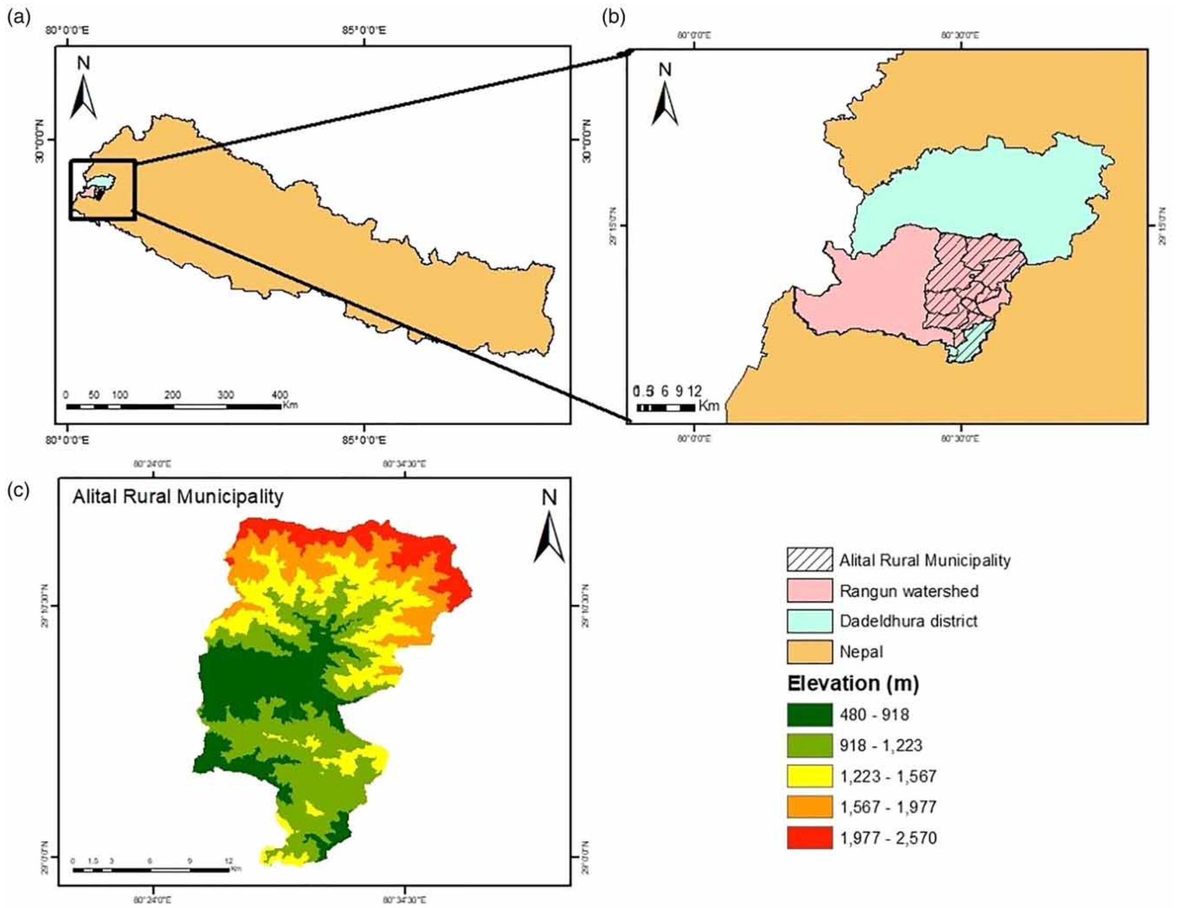


Figure 1 | Alital Rural Municipality, Dadeldhura District, Nepal (Rangun Watershed): (a) Map of Nepal. (b) Alital and Rangun Watershed. (c) Elevation map of Alital Rural Municipality.

varies from tropical at mid/lower elevations to cold temperate at higher elevations, and the annual precipitation ranges from 1,500 to 2,000mm (Karki *et al.* 2016), with most rainfall from June to September. The temperature range is from 8.6 to 35.7 °C, and the major economic activity is agriculture (Alital Rural Municipality 2018).

3. MATERIALS AND METHODS

3.1. Data and data sources

Five components, as proposed by Sullivan *et al.* (2003), were used to calculate WPI: resource, access, use, capacity, and environment. As water poverty issues and indicators differ between locations, each indicator must be carefully analyzed and selected while calculating the WPI. Thirteen sub-components were chosen for this study, taking data accessibility and experts' viewpoints into account. The WPI components and sub-components and their relationships are listed in Table 1.

Table 1 | Components and sources, and their relationship with the WPI

Major components	Sub-components	Information sources	Relationship with WPI
Resource (*R*)	Rainfall potential	DHM	Decrease
	Runoff potential	DHM	Decrease
	Rainfall variability	Data analysis	Increase
Access (*A*)	Time required to carry water	Field Survey (2019)	Increase
	Reliability of piped water supply	Field Survey (2019)	Decrease
	Proportion of agricultural land with suitable river access	Field Survey (2019)	Decrease
Capacity (*C*)	Proportion of households with economic activities	Alital Rural Municipality WASH survey report (2018)	Decrease
	Literacy rate	Alital ward profile (2019)	Decrease
Use (*U*)	Proportion of households owning only agricultural land	Field Survey (2019)	Increase
	Proportion of households with agricultural land and livestock	Field Survey (2019)	Increase
	Water demand per household (domestic and cattle use)	Field Survey (2019)	Increase
Environment (*E*)	Quality index of water sources	Data Analysis	Decrease
	Proportion of area with natural vegetation.	GIS and RS	Decrease

Source: WWF (2012); Thakur *et al.* (2017).
Note: DHM, Department of Hydrology and Meteorology; WASH, water, sanitation & hygiene; GIS, geographic information system; RS, remote sensing.

The relationship of sub-components with the overall WPI could be either decreasing (inversely proportional) or increasing (directly proportional). For example, an increase in the rainfall variability would increase the WPI because rainfall fluctuation would bring more water-related problems, whereas an increase in the literacy rate would eventually decrease the WPI, because people would have a greater ability to cope with issues when they are more literate.

3.2. Data collection

A wide range of data was collected from both primary and secondary sources. Primary data include a questionnaire survey and focus group discussion (FGD), where purposive sampling was done. Secondary data were collected from the Department of Hydrology and Meteorology (DHM) Nepal and several scientific journals and articles.

3.3. Data analysis

3.3.1. Calculation of WPI

WPI was computed at ward level, on the basis of the values of five components, using the following equation:

$$\text{WPI} = \frac{W_1 \times R + W_2 \times A + W_3 \times C + W_4 \times U + W_5 \times E}{W_1 + W_2 + W_3 + W_4 + W_5} \quad (1)$$

where W_i is the weight assigned to each of the five components; R is the resource; A is the access; C is the capacity; U is the use; E is the environment.

The WPI intensity scale developed by WWF (2012) was used to determine the water poverty in the study area (Table 2).

Table 2 | Water poverty intensity scale (WWF 2012)

WPI scale	Water poverty intensity
75–85	Very low
65–75	Low
55–65	Medium low
45–55	Medium
35–45	Medium high
25–35	High
15–25	Very high

3.3.2. WPI components

Following is a description of how the five components are calculated (Coppin & Richards 1990):

*3.3.2.1. Resource (*R*).* The physical accessibility of both surface – and ground-water is included; water quantity, quality, and variability are also considered, using the following equation:

$$R = \frac{(I_r + I_k)}{2} \times 20 \quad (2)$$

where I_r denotes the rain index, and I_k denotes the corrected runoff index

When annual precipitation is sufficient for the area's agricultural production, rain index $(I_r) = 1$. If precipitation is 'p' percent lower than the amount of water the crop needs in a year, $I_r = 1 - p/100$. Similarly, current runoff should be distinguished from adequate perennial runoff when calculating I_k, and its maximum value should not exceed 1.

Corrected runoff index (I_k) is calculated using the following equation:

$$I_k = R \times (1 - B) + B \quad (3)$$

where R denotes runoff index; B denotes perennial river benefit factor.

Runoff index (R) is calculated using the following equation:

$$R = \frac{Q}{P} \quad (4)$$

where P is the precipitation; Q is the runoff.

The settlements living nearby the major rivers get benefit from such rivers and the perennial river benefit factor 'B' represents settlements that depend on and get benefit from such rivers (where 'B' is 1 when all settlements benefit) (WWF 2012).

*3.3.2.2. Access (*A*).* Access refers to accessibility for human use, including the distance to a safe source and time needed for collection per household, etc., and is calculated using the following equation:

$$A = \frac{(I_d + I_i)}{2} \times 20 \quad (5)$$

where I_d denotes the household water carrying time index, and I_i denotes irrigation access index.

I_d is calculated using the following equation:

$$I_d = 1 - \frac{T}{\text{maximum time taken to carry water (in minutes)}} \tag{6}$$

where T denotes the time to collect and store water (minutes).

At VDC scale, I_d can be calculated via the following equation:

$$I_d = \frac{(w_1 * Id_1 + w_2 * Id_2)}{(w_1 + w_2)} \tag{7}$$

where w_1 denotes the number of households reliant on distant water supply; w_2 denotes the number of households reliant on piped water; Id_1 –I_d for distant water supply; Id_2 –I_d for piped water.

I_i was calculated using the following equation:

$$I_i = \frac{T_i}{T_a} \tag{8}$$

where T_i represents the total area accessible to irrigation supply (km^2); T_a represents the total cultivable land (km^2).

In this study, the number of household's dependent on piped water sources is defined as the number of houses with a piped water supply in their backyard, whereas household's dependent on distant water sources were defined as the number of households that depend on community taps, springs, spouts, wells, rivers, and streams.

3.3.2.3. Capacity (C). C takes into account people's ability to manage the available water wand is calculated using the following equation:

$$C = \frac{(I_c + I_{ic})}{2} \times 20 \tag{9}$$

where I_c represents the education capacity index, and I_{ic} represents the income capacity index.

I_c is calculated via the following equation:

$$I_c = \frac{L}{100} \tag{10}$$

where L is the literacy rate (%) and I_{ic} via the following equation:

$$I_{ic} = \frac{T_e}{T_h} \tag{11}$$

where T_e denotes the households involved in economic activity, and T_h represents the all households.

Economic activities in this study were defined as those resulting in direct financial gain, such as business operations, wage labor, receiving remittances, government service, etc.

3.3.2.4. Use (U). Water is used for many activities and this component indicates the volume required in liters/capita/day for a household. It can be determined using the following equation:

$$U = \frac{(S - S_{min})}{(S_R - S_{min})} \times 20 \tag{12}$$

where S denotes the total household water demand (liters/capita/day); S_{min} represents the minimum household water requirement (liters/capita/day); S_R represents the optimum household water requirement household (liters/capita/day).

S is determined using the following equation:

$$S = \frac{T_w}{T_p} \tag{13}$$

where T_w is the total water demand (L/day), and T_p is the total population.

WHO states that a person requires 20 L of water per day to be healthy (WHO/UNICEF 2000). In this study, the minimum water required for domestic purposes (S_{min}) is taken as 1 liters/capita/day (Thakur *et al.* 2017), while the maximum (S_R) is taken as 100 liters/capita/day (Howard & Bartram 2003).

3.3.2.5. Environment (E). The environment factor is used to assess the ecosystem benefits and services, provided by aquatic habitats and environmental integrity related to water (Equation (14)):

$$E = \frac{(I_w + I_v)}{2} \times 20 \qquad (14)$$

where I_w is the water quality index (WQI), and I_v is the vegetation coverage index.

The National Sanitation Foundation (NSF) provided procedures for calculating WQI in 1970 (Brown *et al.* 1970). According to NSF, the sub-indices linear weighted sum was used to determine WQI (I). Table 3 displays the weights of the variables used to calculate WQI.

Table 3 | Significance weights for the WQI calculation (WWF 2012)

Parameters	Unit	Importance Weight (W_i)
Dissolve oxygen (DO)	% saturation	0.17
Fecal coliforms (FC)	count in 100 mL	0.15
pH	no unit	0.12
Biochemical oxygen demand (BOD_5)	mg/L	0.1
Nitrate (NO_3)	mg/L	0.1
Phosphate (PO_4)	mg/L	0.1
Temperature variation	°C	0.1
Turbidity	NTU	0.08
Total dissolved solids (TDS)	mg/L	0.08

$$\mathrm{WQI} = \sum_{i=1}^{n} W_i{*}I_i \qquad (15)$$

where W_i is the weight of the *i*th water quality parameter; I_i is the sub-index value of the *i*th water quality parameter; *n* is the number of water quality parameters.

I_v was calculated using the following equation:

$$I_v = \frac{V}{A} \qquad (16)$$

where I_V is the vegetation index; *A* is the total area (km^2), and *V* is the area covered in vegetation (km^2).

4. RESULTS AND DISCUSSION

4.1. Results

4.1.1. Resource

To calculate the rainfall and runoff potential and the rainfall variability sub-components of the resource component, data from 12 meteorological stations around the Rangun Watershed were used. The rain index was calculated on the basis of rainfall sufficiency for crop cultivation. Alital's rain index ranged, on a ward by ward basis, from 0.33 to 0.52 (Table 4).

The runoff index was calculated by differentiating present from perennial runoff and ranges from 0.23 to 0.26 (Table 4). Many villages in Alital benefit from the river in one way or another, so the perennial river benefit factor ranged from 0.27 to 0.99 (Table 4).

The resource component – ward by ward range 9 to 15 – was calculated by integrating all of these indices. Ward 2 was shown to have the highest resource availability and ward 6 the lowest (Table 4).

Table 4 | Resource component in Alital, ward by ward basis

Ward	Rain index	Perennial river benefit factor	Runoff index	Corrected runoff index (I_k)	Resource
1	0.44	0.45	0.24	0.58	10
2	0.52	0.99	0.23	1.00	15
3	0.43	0.77	0.23	0.83	13
4	0.38	0.59	0.25	0.69	11
5	0.45	0.91	0.25	0.94	14
6	0.45	0.27	0.26	0.46	9
7	0.33	0.44	0.25	0.58	9
8	0.38	0.67	0.25	0.75	11

4.1.2. Access

The household survey found that 50% of those surveyed have access to piped drinking water (Table 5), but only for between 1 and 12 h per day. Water drying during summer and pipe blockages during the monsoon also forced people to carry water from distant sources. Most households share a common drinking water tap, and consume water from nearby streams, springs, and stone spouts. Some 22% of the areas also have irrigation facilities. Access components in Alital on a ward by ward basis varied from 9 to 15 (Table 5).

Table 5 | Access component in Alital, ward by ward basis

Ward	Households depending on distant water sources	Households using piped sources	I_d for distant sources	I_d for piped sources	I_d	I_i	Access Index
1	29	50	0.72	1	0.9	0.16	11
2	59	18	0.92	1	0.94	0.61	15
3	25	73	0.57	1	0.89	0.15	10
4	9	76	0.5	1	0.95	0.3	12
5	21	50	0.71	1	0.91	0.17	11
6	36	41	0.73	1	0.87	0.03	9
7	26	46	0.75	1	0.91	0.01	9
8	39	42	0.83	1	0.92	0.22	11

4.1.3. Capacity

Capacity is calculated based on the people's literacy rate and economic condition. According to the ward profile (2019), the literacy rate in Alital is 78.9%, comprising 71.93% of females and 85.33% of males. The ward by ward capacity component of Alital ranged from 10 to 14 (Table 6).

Table 6 | Capacity component in Alital, ward by ward basis

Ward	L (%)	Education index	Households involved in economic activities (T_e)	Total households (T_h)	Income activity index	Capacity
1	86.0	0.86	113	389′	0.29	12
2	82.1	0.821	130	348	0.37	12
3	77.7	0.777	148	538	0.28	11
4	81.5	0.815	211	386	0.55	14
5	69.0	0.69	157	368	0.43	11
6	79.3	0.793	190	408	0.47	13
7	78.0	0.78	166	331	0.5	13
8	77.7	0.777	115	512	0.22	10

4.1.4. Use

Higher use values indicate lower water poverty levels. The use component in Alital ranged from 5 to 11 (Table 7).

Table 7 | Use component in Alital, ward by ward basis

Ward	No. of households	Total daily water demand (T_w) (L/day)	Total population (T_p)	Water use (L/c/day)	Use component
1	79	26,875	495	54.29	11
2	77	11,695	471	24.83	5
3	98	22,130	616	35.93	7
4	85	16,780	580	28.93	6
5	71	17,780	592	30.03	6
6	77	22,143	473	46.81	9
7	72	12,893	406	31.76	6
8	81	15,789	540	29.24	6

4.1.5. Environment

The WQI was analyzed using seven parameters (i.e., DO, PO_4, NO_3, pH, temperature variation, TDS, and Turbidity). The overall WQI in Alital Rural Municipality is 73 and varies from 71 to 79 in different wards (Gurung *et al.* 2019a, 2019b).

The natural vegetation coverage was calculated using ArcGIS version 10.2.1 and Landsat image from 2018. Alital's environment component, determined ward by ward, ranged from 15 to 17 (Table 8).

Table 8 | Environment component in Alital, ward by ward basis

Ward	Vegetation coverage (I_v)	Water quality index (I_w)	Environment
1	0.85	0.71	16
2	0.91	0.79	17
3	0.90	0.77	17
4	0.87	0.76	16
5	0.85	0.73	16
6	0.78	0.72	15
7	0.90	0.73	16
8	0.89	0.76	17

4.1.6. Water poverty index

All WPI components were given equal weight by multiplying by 20, so that the cumulative score would be 100 (WWF 2012; Thakur *et al.* 2017). The ward by ward values showed that wards 6, 7, and 8 have medium water poverty, while wards 1, 2, 3, 4, and 5 have medium-low poverty (Figure 2). In particular, water poverty is highest in ward 7 (54) and lowest in ward 2 (64). Alital's average WPI is 57, indicating a medium level of water poverty (Table 9). The use component scored the lowest values in every ward in Alital, while the environment component always scored the highest (Figure 3).

4.1.7. Correlation among WPI components

The results of the correlation analysis are shown in Table 10.

5. DISCUSSION

The Alital water poverty indicates a medium-low level of poverty, with a WPI score of 57. However, the severity of water poverty varied among the wards, ranging from medium-low to medium. The WPI component values showed the primary factors contributing to water poverty in each ward. For example, wards 2, 3, 4, 5, 7, and 8

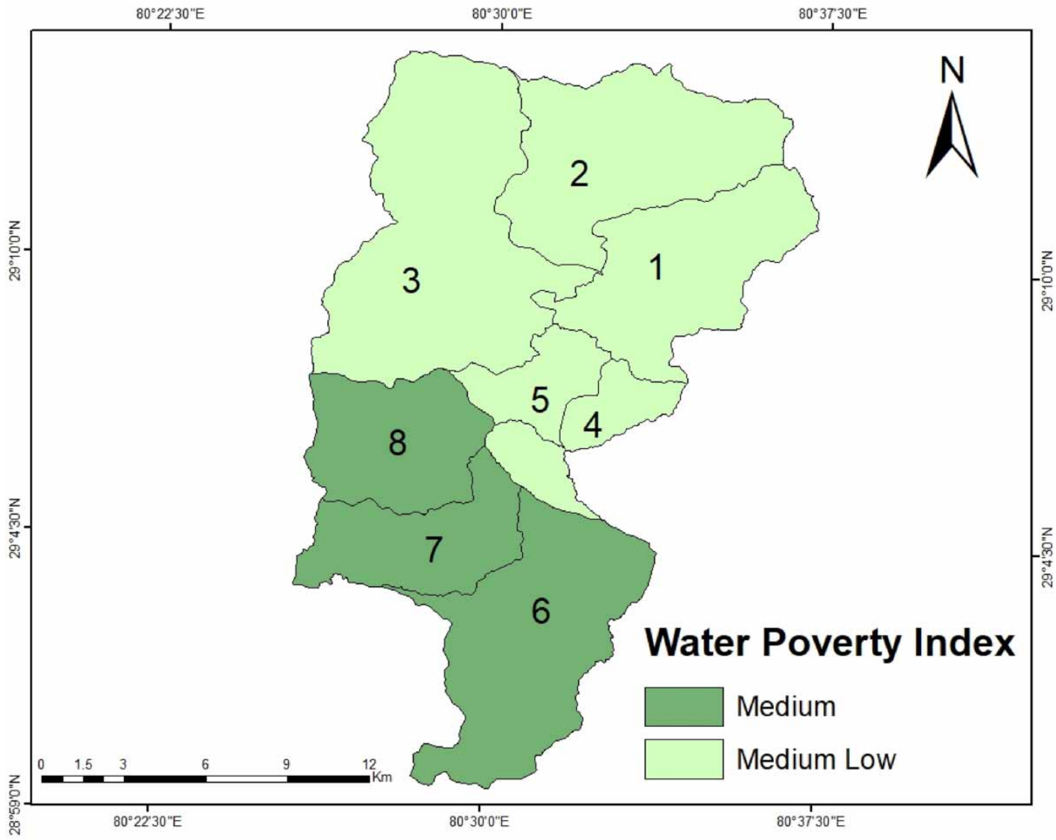


Figure 2 | Water poverty map of Alital Rural Municipality.

Table 9 | Ward by ward WPI for Alital

Ward	Resource	Access	Capacity	Use	Environment	WPI	Water poverty intensity
1	10	11	12	11	16	59	Medium Low
2	15	15	12	5	17	64	Medium Low
3	13	10	11	7	17	57	Medium Low
4	11	12	14	6	16	59	Medium Low
5	14	11	11	6	16	57	Medium Low
6	9	9	13	9	15	55	Medium
7	9	9	13	6	16	54	Medium
8	11	11	10	6	17	55	Medium
Average	11	11	12	7	16	57	Medium Low
	WPI					57	Medium Low

exhibit poor water use, while wards 1 and 6 face challenges in terms of resource and access, respectively (Figure 4).

A similar study of eleven districts in the Kaligandaki river basin by Manandhar *et al.* (2012) also showed water use as low with a better environment component. Pandey *et al.* (2012) observed low water consumption and emphasized the need to create irrigation plans and arrangements for domestic level water use in Nepal's medium-sized river basins. Most studies in Nepal show low water consumption patterns, indicating that the government needs to focus mainly on increasing domestic and agricultural water use (Manandhar *et al.* 2012; Panthi *et al.* 2018). Agriculture is considered as the primary source of income and a significant contributor to Nepal's livelihoods. In a developing country such as Nepal, home gardening utilizing excess water from household

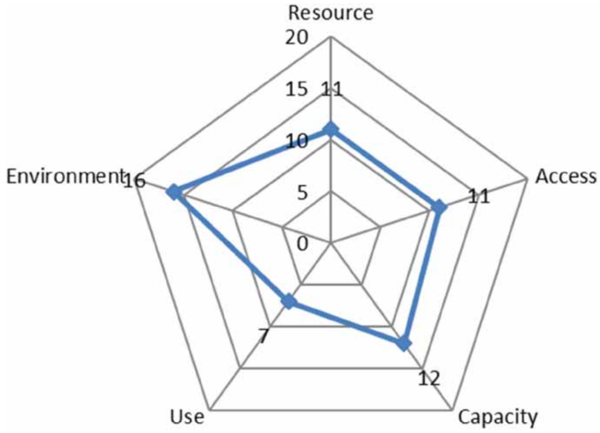


Figure 3 | Spider diagram showing WPI component values for Alital Rural Municipality.

Table 10 | Correlation analysis among WPI components

Component	Resource	Use	Environment	Access	Capacity
Resource	×				
Use	−0.56	×			
Environment	0.56	−0.72**	×		
Access	0.74**	−0.56	0.63	×	
Capacity	−0.38	−0.002	−0.25	0.01	×

**Correlation is significant at the 0.05 level.

water use would significantly contribute to increased food security and financial independence (Galhena *et al.* 2013; RVWRMP 2020). Thus, the country should invest in the water sector and focus on improving domestic and agricultural water use (Pandey *et al.* 2012).

Water use among wards of Alital ranged between 5 and 11, which indicates that domestic water use is very low across Alital. Poor water use, which leads to water poverty, may be due to limited water supply (i.e., 1–12 h a day), a decrease in water availability during summer (mainly March to May), and an unreliable piped water source in the area. Such problems can be overcome by focusing on rainwater harvesting, controlling runoff and developing water use.

The Nepali government has made significant strides in the education sector under Sustainable Development Goal 4 (SDG4), which aims to provide education for all by 2030 (UNESCO 2017). These efforts have resulted in substantial improvements in the country's literacy rate. In Alital, the literacy rate increased 13% between 2014 and 2019, rising from 66% (52.32% female and 77.32% male), to 78.9% (71.93% female and 85.33% male). Enhanced literacy plays a crucial role in empowering individuals to manage available water resources effectively, ultimately contributing to poverty reduction, as demonstrated worldwide. In Alital, where 39% of households have a source of income (refer to Table 7), the municipality exhibits both a high literacy rate and a substantial income source. This indicates that the local population possesses the capacity to afford and manage water resources effectively.

The access component is determined by the availability of drinking water and irrigation facilities. The survey revealed that 50% of households in Alital have access to drinking water, which aligns with the overall ward profile of 56%. However, nearly half of households lack access to piped drinking water, and those who do have access experience limited supply (typically ranging from 1 to 12 h per day). As a result, households are compelled to travel long distances to fetch water, relying on springs, stone spouts, and streams to meet their needs. During the dry season, the piped water supply becomes inadequate due to decreased water availability. Furthermore, the irrigation coverage in Alital Rural Municipality is alarmingly low, at only 22%. Therefore, there is a pressing need to enhance both drinking water and irrigation water supply in order to improve access throughout the area.

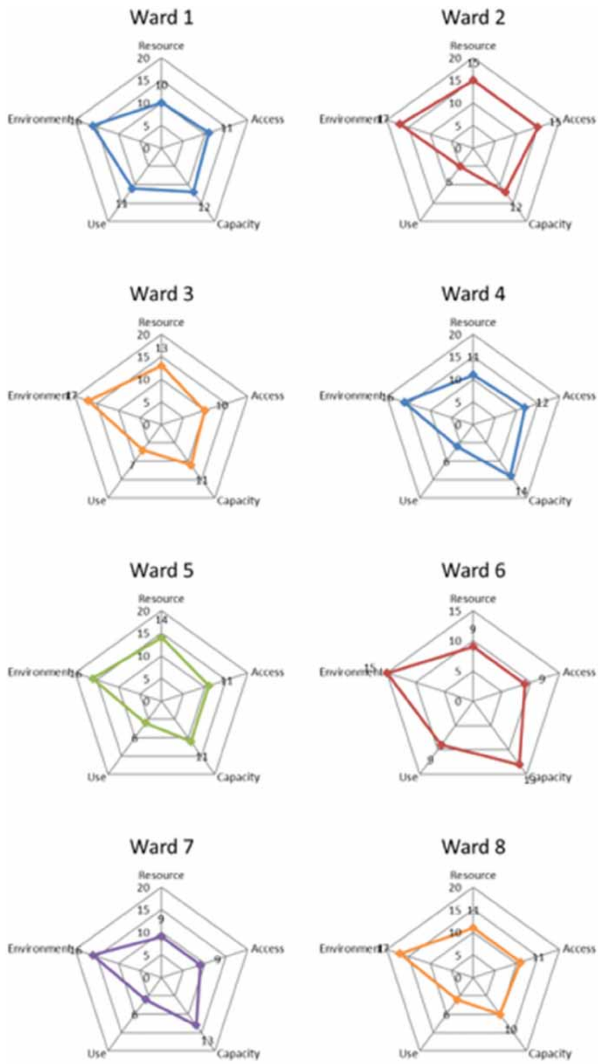


Figure 4 | Spider diagram showing WPI component values for the eight wards in Alital Rural Municipality.

There is a robust positive correlation between resources and access, implying that enhancing resource accessibility would reduce the time and effort required to collect water, consequently alleviating water poverty. However, the positive relationship between resources and the environment is not statistically significant, suggesting that an increase in resource availability may not directly result in an expansion of environmental resources. Similarly, the positive relationship between access and the environment is also not statistically significant, indicating that an increase in environmental resources may not necessarily lead to improved access. On the other hand, a notable negative correlation is observed between use and the environment, signifying that a higher utilization of environmental resources will diminish water availability. For example, increased use of forest products can lead to a reduction in forest cover, exacerbating water poverty. These findings are summarized in Table 10.

A WPI is an index-based approach that facilitates the integration of water resource management across different scales, ranging from local to national (Tu 2011). It serves as a valuable tool for promoting an integrated and sustainable approach to water resource management, including the development of a water use master plan (WUMP) (Neupane *et al.* 2015, as cited in Thakur *et al.* 2017). The combination of WPI and WUMP helps in identifying areas that require management interventions, thereby minimizing risk and uncertainties at lower levels (Thakur *et al.* 2017). Furthermore, the WPI is beneficial for policymakers and water resource managers, as it aids in identifying water-scarce regions and enables the development of comprehensive approaches that address poverty, health, environment, capacity, and water resource availability (Sullivan 2002; Manandhar *et al.* 2012; Koirala *et al.* 2020). However, it is crucial to select appropriate indicators carefully for each component to ensure they reflect the actual ground scenario accurately during assessments.

6. CONCLUSIONS

The assessment of water poverty in Alital Rural Municipality unveiled an average WPI score of approximately 57, indicating a medium-low level of water poverty. The WPI scores varied across the different wards, ranging from 54 to 64. Consistently, the use component obtained the lowest score, highlighting the need for improvement in this component. Conversely, the environment component consistently scored the highest, indicating favorable availability of resources. The assessment revealed a significant positive correlation between resources and access, suggesting that an increase in resources would significantly improve their accessibility. However, a significant negative correlation between use and the environment was found, indicating that increasing resource use would result in a decrease in water availability.

The pressure on water sources in the area has increased due to population growth, changes in precipitation patterns, concreting of water sources (to reduce infiltration there), and haphazard road construction (Adhikari *et al.* 2021). Key factors contributing to water poverty in the area include unreliable piped water sources, limited water supply, reduced water availability in summer (mainly March to May), and inadequate irrigation facilities. To address these challenges, appropriate measures should be implemented to optimize the use of available water resources in the area. It is crucial to prioritize water development and utilization, with a focus on improving both irrigation and domestic water use. Strategies such as rainwater harvesting, runoff control, and other water harvesting techniques should be adopted to meet domestic water consumption. Considering the variations in scores for resources, environment, use, access, and capacity among different wards, prioritization should be tailored based on individual scores to effectively address the water poverty situation. A water poverty assessment is a prerequisite to sustainable water management, and the method used in this study can be applied broadly.

ACKNOWLEDGEMENTS

This study was done as a part of M.Sc. thesis work at the Central Department of Environmental Science (CDES), Tribhuvan University, Kirtipur, Kathmandu, Nepal. The study was funded by Youth Alliance for Environment (YAE) under the Paani Program, Baluwatar, Kathmandu, Nepal. The authors are grateful to CDES for this research opportunity, and YAE for technical and financial support and all team members YAE for their guidance and support.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Adhikari, S., Gurung, A., Chauhan, R., Dongol, B. S., Rijal, D., Aryal, D. & Talchabhadel, R. 2021 Status of springs in the mountains watershed of Western Nepal. *Journal of International Water Policy* **23**(1), 142–156.

Alexander, K. S., Moglia, M. & Miller, C. 2010 Water needs assessment: learning to deal with scale, subjectivity and high stakes. *Journal of Hydrology* **388**, 251–257.

Alital Rural Municipality. 2018 *Alital Rural Municipality Level Water, Sanitation and Hygiene Survey Report 2075*. Report Alital Rural Municipality, Dadeldhura, Nepal.

Alital Rural Municipality. 2019 *Digital Profile System*. Available from: http://13.126.80.192:8081/login/auth (accessed 20 August 2019).

Barbier, E. B. 2004 Water and economic growth. *The Economic Record* **80**(248), 1–16.

Brown, R. M., McClelland, N. I., Deininger, R. A. & Tozer, R. G. 1970 A water quality index – do we care? *Water Sewage Works* **117**(10), 339–343.

Chaves, H. & Alipaz, S. 2007 An integrated indicator based on basin hydrology, environment, life, and policy: the watershed sustainability index. *Water Resource Management* **21**, 883–895.

Coppin, N. J. & Richards, I. G. 1990 *Use of Vegetation in Civil Engineering*. Construction Industry Research and Information Association, London.

Dodds, W. K., Perkin, J. S. & Gerken, J. E. 2013 Human impact on freshwater ecosystem services: a global perspective. *Environmental Science & Technology* **47**, 9061–9068.

Galhena, D. H., Freed, R. & Maredia, K. M. 2013 Home gardens: a promising approach to enhance household food security and wellbeing. *Agriculture & Food Security* **2**(8), 1–13.

Gurung, A., Adhikari, S., Chauhan, R., Thakuri, S., Nakarmi, S., Rijal, D. & Dongol, B. 2019a Assessment of spring water quality in the rural watersheds of Western Nepal. *Journal of Geoscience and Environment Protection* **7**, 39–53.

Gurung, A., Adhikari, S., Chauhan, R., Thakuri, S., Nakarmi, S., Ghale, S., Dongol, B. & Rijal, D. 2019b Water crises in a water-rich country: case studies from rural watersheds of Nepal's mid-hills. *Water Policy* **21**(4), 826–847.

Gyawali, D., Sharma, B. & Pokharel, G. S. 2019 *Water Scarcity: Nepal Country Snapshot. Report Prepared for the International Water Association and the Food and Agriculture Organization of the United Nations During August-December 2018.* Nepal Water Conservation Foundation. NWCF Working Paper 1/2019, Kathmandu.

Howard, G. & Bartram, J. 2003 *Domestic Water Quantity, Service, Level and Health*. World Health Organization, Geneva.

Karki, R., Talchabhadel, R., Aalto, J. & Baidya, S. K. 2016 New climatic classification of Nepal. *Theoretical and Applied Climatology* **125**, 799–808.

Kattel, R. R., Nepal, M., 2022 Rainwater harvesting and rural livelihoods in Nepal. In: *Climate Change and Community Resilience* (Haque, A. K. E., Mukhopadhyay, P., Nepal, M. & Shammin, M. R., eds). Springer, Singapore.

Koirala, S., Fang, Y., Dahal, N. M., Zhang, C., Pandey, B. & Shrestha, S. 2020 Application of Water Poverty Index (WPI) in spatial analysis of water stress in Koshi River Basin, Nepal. *Sustainability* **12**, 727.

Manandhar, S., Pandey, V. P. & Kazama, F. 2012 Application of Water Poverty Index (WPI) in Nepalese context: a case study of Kali Gandaki River Basin (KGRB). *Water Resource Management* **26**, 89–107.

Merz, J., Nakarmi, G. & Weingartner, R. 2003 Potential solutions to water scarcity in the rural watersheds of Nepal's middle mountains. *Mountain Research and Development* **23**(1), 14–18.

Neupane, M., Bhatta, M. R., Shrestha, R., Thakur, J. K., Rajbhandari, R. M., Tharu, B. R., 2015 *GIS-supported water use master plan: a planning tool for integrated water resources management in Nepal*. In: *Geospatial Technology for Water Resource Development* (Srivastava, P. K., Pandey, P. C., Kumar, P., Raghubanshi, A. S. & Han, D., eds.). Taylor and Francis, Boca Raton, Florida.

Pandey, V. P., Manandhar, S. & Kazama, F. 2012 Water poverty situation of medium-sized river basins in Nepal. *Water Resource Management* **26**, 2475–2489.

Panthi, J., Khatiwada, K., Shrestha, M. L. & Dahal, P. 2018 Water poverty in the context of climate change: a case study from Karnali river basin in Nepal Himalaya. *International Journal of River Basin Management*. doi:10.1080/15715124.2018.1531421.

RVWRMP 2020 *Increasing Women's Independence Through Commercial Vegetable Farming*. Available from: https://www.rvwrmp.org.np/single-post/2017/03/05/increasing-womens-independence-through-commercial-vegetable-farming (accessed 9 July 2023).

Sullivan, C. A. 2002 Calculating a water poverty index. *World Development* **30**(7), 1195–1210.

Sullivan, C. A. 2011 Quantifying water vulnerability: a multi-dimensional approach. *Stochastic Environmental Research and Risk Assessment* **25**(4), 627–640.

Sullivan, C. A. & Meigh, J. R. 2005 Targeting attention on local vulnerabilities using an integrated indicator approach: the example of the climate vulnerability index. *Water Science & Technology (Special Issue Climate Change)* **51**(5), 69–78.

Sullivan, C. A., Meigh, J. R., Giacomello, A. M., Fediw, T., Lawrence, P., Samad, M., Mlote, S., Hutton, C., Allan, J. A., Schulze, R. E., Dlamini, D. J. M., Cosgrove, W., Priscoli, J. D., Gleick, P., Smout, I., Cobbing, J., Calow, R., Hunt, C., Hussain, A., Acreman, M. C., King, J., Malomo, S., Tate, E. L., O'Regan, D., Milner, S. & Steyl, I. 2003 The water poverty index: development and application at the community. *Natural Resources Forum* **27**, 189–199.

Sullivan, C., Meigh, J. & Lawrence, P. 2006 Application of the water poverty index at different scales: a cautionary tale. *Water International* **3**, 412–426.

Thakur, J. K., Neupane, M. & Mohanan, A. A. 2017 Water poverty in upper Bagmati River Basin in Nepal. *Water Science* **31**, 93–108.

Tu, J. 2011 Spatially varying relationships between land use and water quality across an urbanization gradient explored by geographically weighted regression. *Applied Geography* **31**(1), 376–392.

UNESCO. 2017 *Literacy and Lifelong Learning*. Available from: http://www.unesco.org/new/en/kathmandu/education/literacy-and-lifelong-learning/ (accessed 1 September 2019).

WCED. 1987 *Our Common Future*. World Commission on Environment and Development (WCED), Oxford University Press, Oxford, United Kingdom.

WHO/UNICEF. 2000 *Joint Monitoring Program for Water Supply and Sanitation, Global Water Supply and Sanitation Assessment 2000 Report*. Report World Health Organization/United Nations Children's Fund (WHO/UNICEF), Geneva/New York.

WWF. 2012 *Water Poverty of Indrawati Basin, Analysis and Mapping*. Report World Wildlife Fund For Nature (WWF), Nepal.

First received 11 June 2023; accepted in revised form 10 August 2023. Available online 23 August 2023