Sustainable Water Resources Management (2020) 6:34
https://doi.org/10.1007/s40899-020-00391-x

ORIGINAL ARTICLE

Vulnerability assessment of water resources in Hilly Region of Nepal

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Received: 17 July 2019 / Accepted: 4 May 2020

Abstract
Water security is a key in achieving sustainable development goals (SDGs); however, it is gradually becoming a scarce resource due to pressure from both climatic and non-climatic factors. Understanding sources and extend of vulnerability of the water resources is the very first step to design appropriate strategies aimed at securing water for various uses. This study therefore assessed vulnerability of water resources and its spatial distribution across the Palikas (new local governments) with Gulmi district in Province-5 as the case study. Vulnerability was assessed using an indicator-based framework comprising of two components and six sub-indices. Results showed that Musikot is the highly vulnerable Palika among the 12 Palikas, and Resunga is the least vulnerable. The results are useful for prioritizing the Palikas for allocating resources aimed at targeting new programs for reducing poverty and conserving natural resources.

Keywords Indicators · Nepal · Palikas · Vulnerability assessment · Water vulnerability · Water scarcity

Introduction

Water is a dedicated sustainable development goal (SDG 6), alongside zero hunger (SDG 2) and climate action (SDG 13) in the 2030 Agenda for sustainable development (Giordano et al. 2019). The aims of water goal are to ensure the availability and sustainable management of water and sanitation for all the sectors, including agriculture and the environment (United Nations 2015). This indicates that water is an integral part of the ecosystem, and highly interconnected to key sectors such as energy and food. It's unlikely to secure energy and food and achieve SDGs without securing water.

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It is also called as the most manageable natural resource as it is capable of diversion, transport, storage and recycling (Kumar et al. 2005). However, most of the countries are suffering from water stress and are vulnerable to the adverse impacts of climate change; particularly increase in temperatures, less and more erratic precipitation, drought and desertification (Al-Kalbani et al. 2014). The frequency and magnitude in developing countries are projected to increase in the future resulting in more vulnerable to climate change (Mirza 2003). Therefore, investments are needed in water sector to cope with water scarcity (both physical and economic) for achieving SDGs related to food security, livelihood benefits and poverty reduction.

Water is the primary medium through which climate change influences the Earth's ecosystems, people's livelihoods and wellbeing (Gain et al. 2012). The world is increasingly facing the risk of climate change and all the regions of the world are expected to experience a net negative impact of climate change on water resources and freshwater ecosystems (Parry et al. 2007). Both natural variability and direct/indirect human interventions are blamed for that (Flörke et al. 2018; Koutroulis et al. 2019; Rodell et al. 2018). Still, more than 40% of the total global population does not have access to sufficient clean water and the majority of these populations live in developing countries (Gurung et al. 2019). In Asia, more than a billion people could be

Published online: 14 May 2020

affected by a decline in the availability of freshwater by 2050 (Sharma and Ambili 2009).

Climate change has added an additional stress on poor communities in the least developed countries like Nepal, where the poor communities in hills have to struggle for basic needs like water. It is ranked in the world's top five countries with a poorly developed drinking water system (McPhillips 2017; Gurung et al. 2019) and the 4th most vulnerable countries to climate change in the world (Maplecroft 2011). Drying and depletion of water sources is increasing in the different parts of country (Chhetri et al. 2018; Chhetri and Kumar 2018; Chhetri and Saroj 2018). Reducing in the water availability may be the one of the limiting constraints for crop production, hydropower, human health and food security across the world (Magadza 2000). About 39% of mountain populations (both urban and rural) in developing countries were considered vulnerable to food insecurity in 2012, an increase of 30% compared to 2000 (Sharma et al. 2019). Due to lack of resources, existing social conditions and structures that hinder the ability of people to cope with stresses (Kelly and Adger 2000; Shrestha et al. 2019).

Understanding the sources and extend of vulnerability of the water resources is the very first step to design appropriate strategies aimed at securing water for various uses, including human and environment. The vulnerability assessment is an essential tool which links biophysical aspects of water to the socioeconomic issues such as poverty reduction and diversification of livelihoods (O'Brien et al. 2004). Though there are many studies focusing on various aspects of societal vulnerabilities, studies related to vulnerability of water resources are limited. Vulnerability assessment is a way to understand the series of causal linkages where changes in the biophysical environment interact with socioeconomic factors to cause vulnerability (Huq et al. 2015; Kuchimanchi et al. 2019; Ramprasad 2018). Vulnerability assessment is also needed for understanding the exerting pressure on water resource systems (Anandhi and Kannan 2018) and design and implements strategies to deal with those pressures. Lucidly, vulnerability is defined as "the degree to which the system is susceptible and is unable to cope with adverse effects of climate change" (Adger et al. 2005). It is the process of identifying, quantifying and prioritizing (or ranking) the vulnerabilities in a system. According to Pandey et al. (2016), vulnerability analysis is a useful tool for understanding the ongoing changes and impacts of the both climatic and non-climatic issues on water resources. Thus, vulnerability assessment of water resources generates important evidence for the decision and policy makers for identifying and planning of water resources management interventions and developing adaptation strategies for dealing with climate change impacts. In addition, most previous vulnerability studies on the Nepal have been based river basin (Babel et al. 2011; Pandey et al. 2011; Manandhar et al. 2012 etc.); however, this study is intended to fill this gap and focused on micro-level. Therefore, the objectives of this study, are—(i) to assess spatial distribution of vulnerability of water resources; and (ii) to prioritize the sub-units (i.e., Palikas in this case) as per the vulnerability status.

Materials and methods

Study area

Gulmi is one of the 12 districts in Province-5 (Fig. 1), which includes ten rural and two urban Palikas (Table 1). The district covers about 1149 sq km, which is 0.78% of total area of Nepal. It is extending from 27° 55′ to 28° 27′ N latitudes and 83° 10′ to 83° 35′ E longitudes. Based on the altitude, three types of climate zone exist, which are tropical (less than 1000 m), subtropical (1000-2000 m) and temperate (greater than 2000 m) (Lillesø et al. 2005). The population of the districts is 280,160 which is 1.2% of the country's total population (CBS 2011). The land use pattern of Gulmi district shows that agricultural land is the dominant land covering 657.23 sq km, i.e., 57.2% of total land which is followed by forest area covering 38.1% (437.77 sq km). It is followed by forest area covering 38.1% of total land area. Long-term (1981–2018) average annual rainfall all the Palikas range from 1398 to 1,845 mm (http://chg.geog.ucsb.edu/data/chirps/). Remittance, coffee plantation, livestock, tourism and agriculture are the main sources economic activities. It includes the major river such as are Kaligandaki, Wadiguard, Nisti, Ridi, Chaldi and Panah. The major sources of drinking water in the Palikas were wells, piped tab, tube well, pond, stream and spring. In the district water supply, situation shows that 66.54% of household (HH) have access of drinking water supply and 33.67% of HH are lacking access of water services (DSWASH 2016). The key threats for the reduction in the water resources in the districts were the reduction in rainfall, landslide, flood, water resource below the human settlement and forest fire (DSWASH 2016).

Methodology

An indicator-based framework for vulnerability assessment was applied with appropriate customization for the study area. The vulnerability index (VI) was calculated as the ratio of the water stress index (WSI) and adaptive capacity index (ACI) as used in Babel et al. (2011). The WSI and ACI were further calculated by aggregating three sub-indices to each as shown in Table 2.

The indicators within each parameter were selected in such a way that they are easy to understand, minimum in number but sufficient to represent the concept, are dependent on the availability of data, and their applicability to other

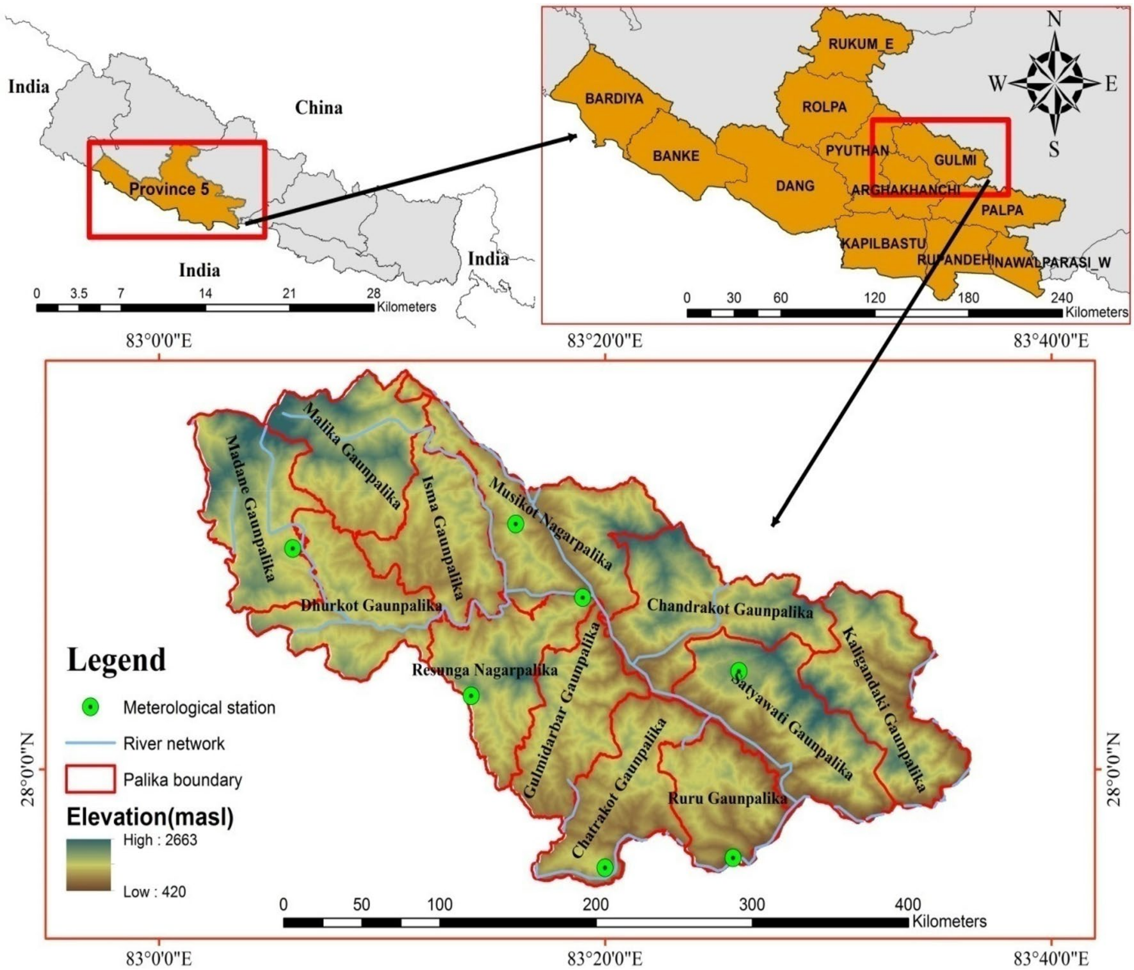

Fig. 1 Location and associated administrative boundaries of the Gulmi district in Nepal

Table 1 Main characteristic of 12 Palikas within Gulmi district, Nepal

S N.	Name of Palika	Location (Latitude N, Longitude, E)	Population density (person/km^2)	Average rainfall (mm)	Elevation range (masl)
1	Chandrakot Gaupalika	28.121°N, 83.403°E	206	1625	568–2528
2	Chatrakot Gaupaliaka	27.979°N, 83.341°E	247	1559	523–1686
3	Dhurkot Gaupalika	28.109°N, 83.142°E	260	1721	845–2007
4	Gulmidarbar Gaupalika	28..027°N, 83.308°E	275	1628	568–2131
5	Isma Gaupalika	28.153°N, 83.212°E	187	1845	741–1964
6	Kaligandaki Gaupalika	28.059°N, 83.541°E	187	1636	479–2537
7	Madane Gaupalika	28.173°N, 83.077°E	231	1398	1014–2559
8	Malika Gaupalika	28.144°N, 83.144°E	235	1473	870–2663
9	Musikot Nagarpalika	28.158°N, 83.292°E	400	1738	602–2523
10	Resunga Nargarpalika	28.063°N, 83.256°E	254	1816	625–2344
11	Ruru Gaupalika	27.979°N, 83.424°E	275	1473	420–1652
12	Satwati Gaupalika	28.037°N, 83.464°E	206	1594	454–2563

SN serial number, *mm* millimeter, *km* kilometer, *masl* is meters above mean sea level, *N* Northing, *E* Easting, *Lat* Latitude, *Long* Longitude

Table 2 Vulnerability sub-indices, parameters and indicators for district-level assessment

Category	Sub-Index	Equation	Indicator(s)
Water stress index (WSI)	Water variability (WV)	WV = CV/0.30	Coefficient of variation (CV), which reflects variation of available water resource over the year
	Water scarcity(WS)	$WS = \frac{1700}{\text{Water per capita}}$	Total renewable water resources: Total amount of water resources available (m^3/yr) in the Palika Population: total population in the Palika
	Water resource exploitation(WE)	WE = (Total water use × 0.4)/(Available water)	Total renewable water resources (m^3/yr) Total water use in the Palikas (m^3/yr)
Adaptive capacity index (ACI)	Human capacity (HC)	Literacy rate	Percentage of population above five years who can read and write
	Natural capacity (NC)	Area under vegetation = area with NDVI > 0.1	Area under vegetation (km^2) Total area of the study unit (km^2)
	Access capacity(AC):	$AC = \frac{SDWA+ISA}{2}$ where; $ISA = P_\beta/P$; and $SDWA = 1- P_\alpha/P$	P_β is a total number of households (HHs) with access to improved sanitation facilities P_α is a total number of HHs without access to improved water sources or water supply

SDWA is safe drinking water accessibility; ISA is improved sanitation accessibility; NIR is near-infrared band; R is red band; NDVI is normalized difference vegetation index

areas (Pandey et al. 2011). They are selected based on following criteria: (i) theoretically well founded within the vulnerability framework; (ii) relatively stable and independent; (iii) measurable and comparable, easy to quantify; (iv) data are available and accessible (Zhou 2016). Careful consideration was given for avoiding the overlaps of indicators as this may result in overestimation of its contribution; for instance, coefficient of variation in rainfall was chosen as this is more representative rather than variation in surface water flow that was used by (Hamouda et al. 2009) in their study on the Nile river basin (Simha et al. 2017). Following section elaborates the indicators and parameters in detail.

Water stress index (WSI)

Water stress index (WSI) was calculated by aggregating following three sub-indices.

Water variability (WV): Variation of water resources over the years determines reliability of annual available water resources. To reflect the long-term variation of water resources, coefficient of variation (CV) of rainfall over the last 38 years was calculated. The reason for using rainfall rather than runoff is because it feeds to runoff, soil moisture as well as groundwater and is more representative of water availability in an area. Other researches (e.g., Pandey et al. 2010; Babel et al. 2011) have also used rainfall as representative of water availability. Furthermore, it is a key parameter that is affected by climate change. A critical level of 0.3 was determined as did in researches (Huang and Cai 2009; Babel et al. 2011) to calculate WV.

$$WV = \frac{\sigma}{0.30 \times x} \times 100 \tag{1}$$

Water scarcity (WS) An increasing trend in water resources scarcity and exploitation reflects higher vulnerability of freshwater resources. The resource variation parameter is an average of temporal as well spatial scale (Babel et al. 2011). With regard to the value of 1700, it is a threshold value proposed by (Falkenmark 1989). According to this framework, water resources relates with population as the ratio of Falkenmark's threshold (1700 m^3/person/year).

$$WS = \frac{1700}{\text{Water/person/year}}. \tag{2}$$

Water resources exploitation (WE) Water resource development rate, i.e., ratio of water use to the total exploitable water resources is used to demonstrate the bin's inability for a healthy renewable process. It reflects the sites to satisfy their water needs from the limited resources. The threshold of 40% is set as critical threshold (Babel et al. 2011). Available water was calculated as the product of rainfall and area (m^3/year).

Therefore,

$$\mathrm{WE} = \frac{\text{Total water use} \times 0.4}{\text{Available water}}. \tag{3}$$

Adaptive capacity index (ACI)

The adaptive capacity index (ACI) was calculated by aggregating following three sub-indices.

Natural capacity (NC) It reflects the ecological capacity to cope with stresses which is the ratio of vegetation cover and total area of Palika. The area of vegetation cover data was measured using remote sensing technique. The L2 product image of LANDSAT-8 dated October 2018 was downloaded from EARTH Explorer (NASA) website. Further, Red and NIR (Near infrared band) was used to calculate the NDVI as follows

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - R}{\mathrm{NIR} + R} \tag{4}$$

where NDVI is normalized difference vegetation index, NIR is near-infrared band, R is red band image.

Vegetation cover of the study area was calculated as, vegetation cover = NDVI > 0.1

Human capacity (HC) It is reflected through literacy rate, which is the ratio of the population above 5 years who can read and write to the total population. A higher value may reflect a relatively better ability on water management (Pandey et al. 2011).

Access capacity (AC) Access capacity was calculated by using average of the two indicator, i.e., safe drinking water accessibility (SDWA) and improved sanitation accessibility (ISA), as follows

$$\mathrm{AC} = \frac{\mathrm{SDWA} + \mathrm{ISA}}{2} \tag{5}$$

The safe drinking water accessibility (SDWA) indicator was developed to illustrate the ability of local people to get fresh drinking, and the availability of technologies can impact water withdrawal (Huang and Cai 2009; Cai et al. 2017). Therefore, the degree of SDWA was quantified by analyzing the proportion of the household number with access to improved water sources or water supply, including piped water, public taps, boreholes or pumps, as well as protected wells, springs, or rainwater (Cai et al. 2017; Huang and Cai 2009; United Nation 2003). It was calculated as follows

$$\mathrm{SDWA} = 1 - \frac{P_\alpha}{P}. \tag{6}$$

where P is the total number of households within a Palika and P_α is a total number of households without access to improved water sources or water supply.

Similarly, improved sanitation accessibility (ISA) indicator was designed to analyze the proportion of households with access to improved sanitation facilities (Huang and Cai 2009; United Nation 2003; Cai et al. 2017). It was calculated as follows

$$\mathrm{ISA} = \frac{P_\beta}{P}. \tag{7}$$

where P_β is a total number of households with access to improved sanitation facilities and P is the total number of households within a Palika.

Assigning weights

The variables of indicators were selected after the review of researches that are well found within vulnerability framework (Al-Kalbani et al. 2014; Al-Sibai et al. 2012; Cai et al. 2017; Manandhar et al. 2012; Pandey et al. 2009, 2010, 2011). Five indicators for water stress as well as adaptive capacity (Table 2) were selected to compute vulnerability index and its sub-indices. The parameters were defined in such that they were normalized in a scale of 0–1, with 1 reflecting the high vulnerability and zero reflecting low vulnerability (Pandey et al. 2011). All the parameters and sub-indices were provided equal weights to avoid any biases, to make the index more transparent to decision-makers and stakeholders with the comparable results among different Palikas (Manandhar et al. 2012; Pandey et al. 2011). Differential weighting has been criticized at different grounds as an arbitrary process and equal weighting structure can rationally justify the distribution of weight to a given indicator (Manandhar et al. 2012; Pandey et al. 2012, 2011).

Data and sources

The analyses were based on secondary data collected from various sources as mentioned in Table 3. The secondary data were collected from municipality profiles, village development committee (VDC) profiles, district water supply and sanitation office, Office of District Coordination Committee, (International) Non-Governmental Organizations, and civil society groups based in district during the field survey (Table 3). Long-term annual total rainfall data for the period of 1981–2018 were taken from CHIRPS global gridded precipitation data (http://chg.geog.ucsb.edu/data/chirps/). This was used to calculate the coefficient of variance of annual rainfall and further CV for each Palika is calculated as gridded average value. Vegetation coverage was estimated using LADSAT-8 L2 product image and then processed to extract NDVI data. Access to safe drinking water and sanitation data were collected from national census database collected

Table 3 Summary of data and corresponding sources

Data(for 12 municipalities)	Data source
Rainfall data (1981–2018)	Climate Hazards Group Infrared Precipitation with Station data (CHIRPS) (0.05 degree resolutions)
Households, population, age group, literacy rate,	Central Bureau of Statistics (CBS) (2011),VDC profile (2011) and municipalities' profiles published in 2019
Vegetation Cover (October-2018)	LANDSAT-8 L2 satellite image, Downloaded from EARTH Explorer (NASA) website
Water resources availability	Estimated by using average rainfall (as suggested by Babel et al. 2011)
Safe drinking water accessibility	Estimated by total number of HH within a Palika to a total number of household without access to improved water sources or water supply
Improved sanitation accessibility	Estimated by total number of HH within a Palika to a total household without access to improved sanitation facilities (CBS 2011)

in 2011. Details on data type and sources are tabulated in Table 3.

Data Analysis

Based on these indicators vulnerability was expressed as the ratio of water stress index (WSI) and adaptive capacity index (ACI) as shown in Eq. 7 (Babel et al. 2011). The water vulnerability of was classified into four classes as suggested by Huang and Cai (2009), i.e., Low [<0.2], moderate [$0.2 \le VI < 0.4$], high [$0.4 \le VI < 0.7$] and severe [≥ 0.7]. The results were represented in both tabular form and GIS maps. Further, the ranking was assigned to Palika on the basis of its vulnerability index.

$$\text{Vulnerability} = \frac{\text{WSI}(\text{WV} + \text{WS} + \text{WE})}{\text{ACI}\left(\text{HC} + \text{NC} + \frac{\text{SWDA+ISA}}{2}\right)}. \tag{8}$$

where WSI is water stress index, WV is water variability, WS is water scarcity, WE is water exploitation, ACI is adaptive capacity index, HC is Human capacity, NC is natural capacity, SWDA is safe drinking water accessibility and ISA is improved sanitation accessibility.

Results

Water Stress Index (WSI)

Water stress is assessed based on three sub-indices, namely, WV (water variation), WS (water scarcity) and WE (water exploitation), were quantified in all the Palikas. The result is discussed hereunder.

Water variability

The water variation index was calculated based on the rainfall data from the CHIRPS (0.05-degree resolution gridded precipitation) showed uneven distribution of water variability across the Palikas from 0.50 to 0.54 (Fig. 2). The CV of annual rainfall time series in the study area below the thresholds level of 0.30 reflects low variability while if it is equals or exceeds the threshold value reflects higher vulnerability of water resources to variation. Among the 12 Palikas, the highest water variation ($WV = 0.54$) was found in the Madane and the lowest ($WV = 0.50$) in the Chandrakot.

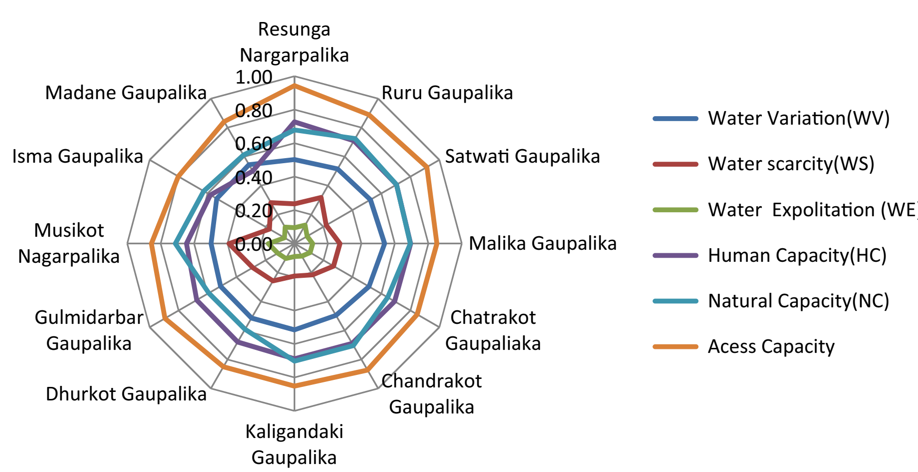

Fig. 2 Pattern of water variation (WV), water scarcity (WS), water exploitation (WE), human capacity (HC), natural capacity (NC) and access capacity (AC) indices of the Palikas in Gulmi district, Nepal

Water scarcity

The water scarcity of the Palikas ranges from 0.17 to 0.39 (Fig. 2). In municipalities and rural municipalities, the highest water scarcity was observed in Musikot Nagarpalika and lowest in the Isma Gaupalika. It also shows that decrease in the rainfall pattern in the study area increases the water scarcity.

Water exploitation

Water exploitation was determined based on the total water use and available water resources. Water use was obtained from the product of the Falkenmark's threshold and total population. Their value across the Palikas ranges from 0.06 to 0.15 (Fig. 2). Water exploitation was observed highest in the Musikot Nagarpalika and lowest in the Isma Gaupalika. Water consumption increased with the total population and socioeconomic development. Higher the water demands certainly mean higher over-exploitation of resources. Furthermore, increase in the population and rapid socioeconomic development in the district results more pressures in the water resources leading to water crisis.

Adaptive capacity index (ACI)

Adaptation of water stress deals with the water user living with limited resources (Babel et al. 2011). Four indicators of adaptive capacity have been selected for this study. They are human capacity, natural capacity, access capacity (safe drinking water accessibility and improved sanitation accessibility).

Human capacity

The literacy rate was used as a proxy for the human capacity. The literacy rate calculated by using the census data shows that its value across the Palikas ranges from 51 to 72% (Fig. 2). The highest literacy rate was found at Resunga Nargarpalika and lowest at the Madane Gaupalika.

Natural capacity

Vegetation coverage was used as variable for natural capacity. Area of the vegetation cover as percentage of total area of Palika ranges from 59 to 72% (Fig. 3) whereas the indicator value varied between 0.59 and 0.72 (Fig. 2). Among the 12 Palikas, the highest vegetation cover was observed in Ruru Gaupalika whereas the lowest in Dhurkot Gaupalika.

Access capacity

Access capacity was based on improved sanitation accessibility and safe drinking water accessibility parameters. The highest household number without access of both improved sanitation accessibility and safe drinking water accessibility was found at Isma Gaupalika and lowest was found in Resunga Nagarpalika. The indicator value was varied between 0.80 and 0.94 (Fig. 2). The improved sanitation and drinking water accessibility supports for the livelihood

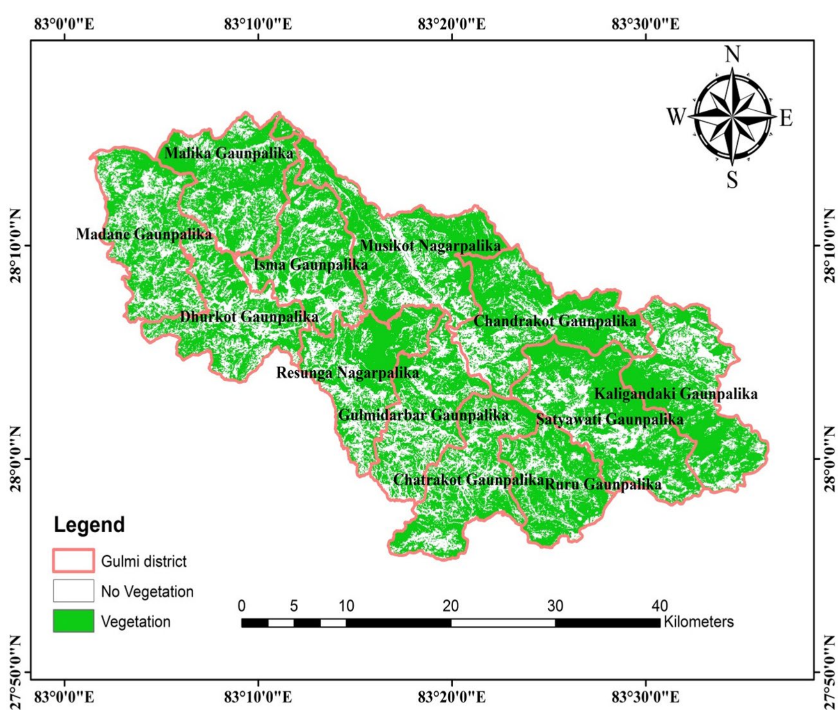

Fig. 3 Distribution of vegetation areas in the Gulmi district extracted from LANDSAT-8 satellite image

improvements which ultimately help in reduce the waterborne diseases and the pollution level.

Vulnerability index

The vulnerability index computed as a ratio of the water stress index (WSI) and adaptive capacity index (ACI). The study addressed the water situation in the districts of 12 Palikas and vulnerability scores across the Palikas range from 0.253 to 0.341 (Table 4 and Fig. 4). This variation in altitude along uneven distributions of physical infrastructure results variations in vulnerability among the Palikas. Based on the classification Huang and Cai (2009), all the Palikas in the Gulmi district falls under moderate vulnerability. The analysis clearly depicts that vulnerability index of the district is 0.28. Among the 12 Palikas, the highest vulnerability (VI = 0.341) was found at the Musikot and the lowest (VI = 0.253) in the Resunga. This high vulnerability is because of lower socioeconomic status, high agriculture dependency and lower human development indicators in terms of education, health, roads and other physical infrastructures. Besides this the limited water resources are in increasing stressful condition due to relentless increases in human population, development activities and land use/cover changes which are responsible for decreased on water resources availability.

Table 4 Results of water resources vulnerability index, its three components and vulnerability rank of the Palikas in Gulmi district

S. N.	Name of Palika	WSI	ACI	VI	Rank
1	Chandrakot Gaupalika	0.80	3.14	0.254	11
2	Chatrakot Gaupaliaka	0.89	3.03	0.295	6
3	Dhurkot Gaupalika	0.87	2.97	0.294	7
4	Gulmidarbar Gaupalika	0.91	3.06	0.299	4
5	Isma Gaupalika	0.78	2.81	0.277	8
6	Kaligandaki Gaupalika	0.79	3.09	0.255	10
7	Madane Gaupalika	0.94	2.79	0.336	2
8	Malika Gaupalika	0.92	3.09	0.297	5
9	Musikot Nagarpalika	1.05	3.07	0.341	1
10	Resunga Nargarpalika	0.83	3.29	0.253	12
11	Ruru Gaupalika	0.96	3.21	0.299	3
12	Satwati Gaupalika	0.83	3.24	0.257	9

SN serial number, *WSI* water scarcity index, *ACI* adaptive capacity index, *VI* is vulnerability index

Discussion

This study assessed spatial distribution in water resources vulnerability within a district based on water stress and adaptive capacity indices. Water variability, scarcity and exploitation were considered for the water stress index, whereas adaptive capacitive parameters include the natural capacity, human capacity and access (to water and sanitation) capacity. Water variability was determined by coefficient variation of rainfall and its value varied from 0.50 to 0.54 among the Palikas. The amount of rainfall received over an area is an important parameter to determine the availability of water

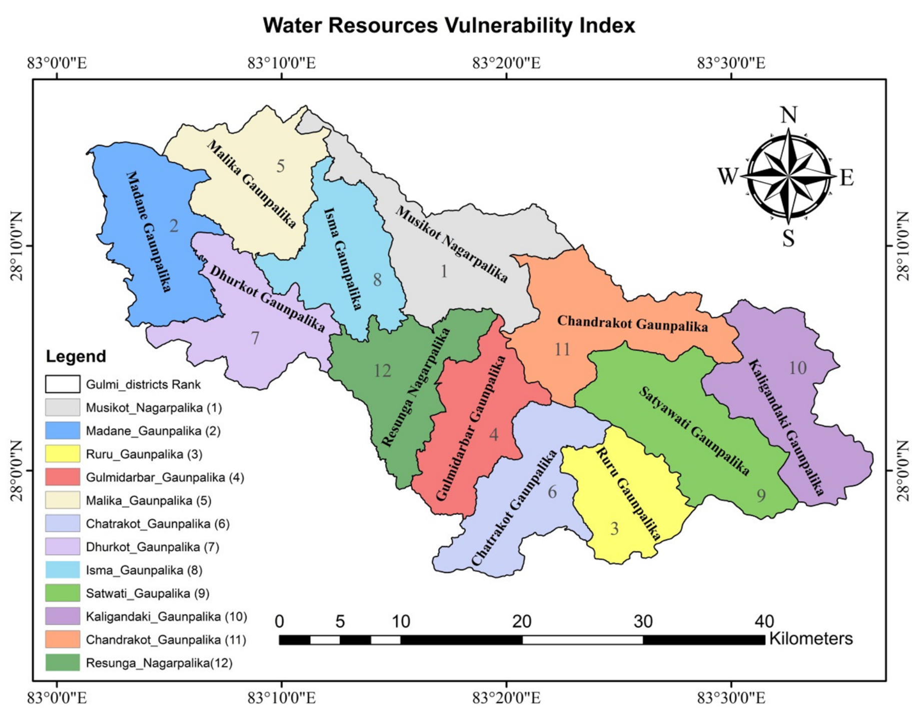

Fig. 4 Water resources vulnerability rank of the Palikas in the Gulmi district, Nepal

where the most of the people is depended on rainfall for agriculture, irrigation and other human activities (Chhetri and Kumar 2018). The major hydrological problems such as floods, drought and landslides in the hilly region are caused due to the variation of rainfall and change in the intensity of rainfall (Rosenberg et al. 2010). It also shows that decrease in the rainfall pattern in the study area increases the water scarcity, which has further impacted in the rural livelihoods. Water resources availability varies seasonally and annually, thus, enhancing vulnerability of rural communities to face climate changes (Portilla et al. 2020). Gurung et al. (2019) and MOF (2017) have also mentioned that the water scarcity has severe effects on the rural economy as more than 80% of populations rely on agriculture for their livelihood. Further Gawith et al. (2017) summarized that the expected changes in water availability under climate change pose a greater threat to agriculture. It was found that water exploitation was increased with the increase in the population and rapid socioeconomic development. Stathatou et al. (2016) also suggested that the pressures of non-climatic factors, such as population increase, rapid economic development and land use changes, on water resources systems will further aggravate the impacts of climate change on freshwater resources. In addition, Kinouchi et al. (2019) mentioned that water scarcity will progress globally, particularly in regions where large populations occur and/or there is a shift to drier climatic conditions with decreased precipitation. Meanwhile, Lamastra et al. (2017) pointed that the amount of available water resources in a region is limited, and the water resource stress increases with water use and consumption. Similarly, for the purpose of ensuring sustainability of economy, social development and water resources development in region, there is a need to address the issue of water resources vulnerability (Pan et al. 2017). Notably, Xinchun et al. (2017) also reported that the efficient and sustainable utilization of water resources is the basis for maintaining social and economic development and the demand for environmental management.

The indicator and index values at the district show increasingly stressful water situation and inadequate adaptive capacity to cope with increasing stress. This result is in line with that of Pandey et al. (2009) for the Bagmati river basin in Nepal. For mitigating the pressure of overconsumption water, inefficient use and climate change which are responsible for causing more vulnerable water resources availability there is always need of good polices and technical solutions. Outcome of the study also supports for the policy and decision-makers for new options to assess the recent situation, modify existing policies and implement adaptation and mitigation measures for sustainable water resources management. Al-Kalbani et al. (2014) were coinciding the similar outcomes. Further the Pandey et al. (2010) suggested that the knowledge on water resource vulnerability explores useful information related to the type of stresses, their extent and actions needed to improve water. Moreover, the Chen et al. (2019) conclude that the assessing water resources vulnerability is the foundation of water resources management. Hence, management of water resources is an important issue for the future of water resources (Kale and Sonmez 2020). There is therefore a need to assess and address the vulnerability of water resources systems for enhanced management strategies, also including robust adaptation measures for sustainable use of water resources in a long-run (Mohammed and Al-Amin 2018).

This study also suggests using the water efficiently by putting additional efforts such as rainwater harvesting, conservation of spring sources; storage during deficient months, multiple uses of water resource, etc. However, as noted earlier by Pandey et al. (2011) documented that the judicious management of water resources is linked not only to assessing availability of water resources. Another view by Hamouda et al. (2009) suggests that the assessment framework presents a good approach for tracking improvement in the vulnerability situation of water resources systems by repeating the study on a basis of 5-year period. In addition, understanding the root causes of vulnerability is a valuable contribution in the design of policies and strategies of adaptation to climate change within the context of local development stressors (Rodríguez et al. 2018)

Vulnerability assessment of water resources index values ranges from 0.253 to 0.341 and also shows the moderate vulnerability on all sites. Based on the ranking of Palikas with highest vulnerability in terms of water availability was found at Musikot Nagarpalika and lowest vulnerability was observed at Resunga Nargarpalika. In future, increasing trend of environmental changes such as rapid population growth, land use/cover changes, economic development and mismanagement of water resources will exert more pressure on water resources. This may also worsen the vulnerability from moderate to high. Therefore, the framework used in this study may serve as a tool for identification of better solutions to water management–decision problems and/or provide important insights during decision making in similar environments as indicated in Simha et al. (2017). Thus this study provides decision-makers with options to evaluate the current situation, modify existing policies and implement adaptation and mitigation measures for sustainable water resources management in this study area. As Nepal has changed the governance system to federal model, with sharing of power and resources among three tier governments, and many local governments (called as Palikas) are very much interested in taking development and conservation hand-in-hand, it's right time to generate evidence on extent of vulnerability of water resources, factors contributing to the vulnerability and potential strategies to address them.

Stathatou et al. (2016) also refer to used vulnerability index for comparing and ranking the areas, as well as to benchmark areas as to their vulnerability threshold. Various researchers (Alcamo et al. 2007; Komba and Muchapondwa 2012; Tesfaye and Seifu 2016) shows that climate change adaptation is the only option available and unavoidable way to reduce the current observed and projected impacts of climate change. Even in countries that are rich in water resources, regional shortages may occur due to differences in the spatial and temporal distribution of water (Moncada et al. 2020). Pandey et al. (2010) refer the adaptation and appropriate management actions are necessarily required to be taken at local level, it is important to understand vulnerability issues at smaller spatial scale. Unfortunately, in some cases, not much is documented that government is lacking to add the effective and adaptation measures about the nature and scope of the challenges as well as coping strategies in the water resources availability. In other words, the study suggests that the investments are needed for supporting water communities to cope with water scarcity (both physical and economic) for achieving food security, livelihood benefits and poverty reduction goals. The outcome of this study could be concluded on the small scales which cannot represent the water problems of the whole country. Therefore, to ensure sustainable water security in the country, the government needs to design vulnerability study mechanisms at larger scales as climate risks vary even within the cluster of villages as observed in the study sites.

Conclusion

The study was focused to assess spatial heterogeneity in vulnerability of water resources in hilly region of Nepal. The outcome indicates that the major contributing factors were population, access of freshwater and rainfall. These factors have significant impact on making water resources relatively vulnerable. The vulnerability profile of the twelve study sites was formulated by comparing the value obtained from two major indices, namely water stress index and adaptive capacity index. The two indices were calculated based on three parameters/indicators for each of them. The values range from 0.253 to 0.341. The study areas show the moderate vulnerability situation in the district and its all Palikas. Based on the vulnerability rank, the Palika with the highest vulnerability in terms of water resources vulnerability was found at Musikot and the lowest as Resunga. These indicators could be used as a practical tool for the governments and policy makers for identifying the vulnerable communities and understand the factors contributing to vulnerability. These results can further guide to develop appropriate adaptation strategies to mitigate the impacts. It also supports in the decision making and planning processes and to prioritize or targeting the areas for interventions for supporting the communities to cope with water scarcity (both physical and economic) for achieving food security, livelihood benefits and poverty reduction goals. Finally, these tools help guiding policy maker with evidences for framing measures at addressing the vulnerability of communities through options such as diversification of livelihoods, and conservation and management of water resources, among others.

Acknowledgements The author would acknowledge the Forest research Institute (deemed to be) University for supporting this study. The author would also like thankful to Gobinda Paudel, Megha Shrestha, Keshav Tyagi, Rahul Yadav, Sumit Sharma, Saroj adhikari and Rajesh Raut for their concern support and kind cooperation during study period.

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