

Climate Change Water Vulnerability and Adaptation Mechanism in Constrained Touristic Himalayan City, Nainital

Disha Chauhan

Indian Council of Forestry Research and Education

Muthuprasad Thiyaharajan

Indian Council of Forestry Research and Education

Anvita Pandey

Center for Ecology Development and Research Council

Nidhi Singh

Center for Ecology Development and Research

Vishal Singh

Center for Ecology Development and Research

Sumit Sen

Indian Institute of Technology Roorkee

Rajiv Pandey (✉ rajivfri@yahoo.com)

Indian Council of Forestry Research and Education <https://orcid.org/0000-0003-4849-775X>

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Abstract

Urban water management is a growing concern in India's rapidly urbanizing cities. Population growth and climatic variability are further exuberating the impact on surface and underground water supply. Understanding the causes and the extent of water vulnerability is required for developing effective strategies for water insecurities. This study attempts to assess the water vulnerability across different wards of a touristic city of Himalaya - Nainital using IPCC approach considering the three dimensions exposure, sensitivity and adaptive capacity. Seven indicators, mostly spatial i.e. edaphic (aspect, elevation), climatic (land surface temperature) besides some water infrastructural (distance to water distribution) and population were considered for development of vulnerability index using Analytical Hierarchy Process for assigning weights. These indicators were simple to extract and easy to obtain and mostly available from secondary sources and were capable to account the variability at micro level. Moreover, the current adaptation mechanisms for water security were also derived through conducting surveys by randomly selecting households across the wards. Staff House and Harinagar wards were the most vulnerable. The survey results that the adaptation mechanism should be managed at individual and organisation level. Policy measures such as optimum use of water; grey water recycling, spring rejuvenation, rain water harvesting, leakage proof infrastructure with intervention of new technologies may be adopted and implemented for reducing the water vulnerability in the city along with the public participation.

Introduction

About two third of the world's population live under serious water shortage for at least one month of the year, and half a billion face severe water scarcity every year (Mekonnen and Hoekstra, 2016). Escalating water insecurity under rapid urbanization, climate change under current water scarcity with water governance is a global concern (Flörke et al., 2018). Moreover, the current population growth in expanding cities will increase the water demand, resulting in over-exploitation of surface water and ground water resources (Hoekstra et al., 2018) and therefore ensuring the cities have an ample source of water becomes exceedingly necessary (Padowski and Jawitz, 2012). This problem is critical as by the end of 2050, around 66 % of the world population will be residing in urban areas with high proportion to the Asia and Africa (UNDESA, 2014). With a population of 1.3 billion and an anticipated growth of 1.7 billion by 2050, providing clean and safe water to vast majority of populace in India is difficult (Kumar, 2019). The problem is severe as climate change has already impacted the water accessibility and is most likely to exacerbate water availability and accessibility in the future (IPCC, 2012). Water crisis is already recognized as one of the global high-risk issues (WEF, 2017) and the urban areas of the remote and fragile Himalayan mountains are facing acute problem for water supply through municipalities (Singh et al., 2020). The increased water demand due to increasing ecotourism (Cook and Bakker, 2011) coupled with climate change (Singh et al., 2020) would further broadened the water crisis in cities of the Himalayan region.

In the Himalayan region of India, urban growth is instrumental towards the improvement of infrastructure in the remote areas (Tiwari and Joshi, 2016) however, the haphazard urban growth in the fragile mountains is instrumental for disturbing the ecosystem thereby disrupting the hydrological regimes causing depletion of natural resources, drying of springs and reduction in ground water recharge (Tiwari et al., 2018). Moreover, majority of the population in Himalaya for water depend on groundwater either from nearby spring or through digging wells and bore wells and majority of urban areas are lacking the infrastructure for satisfying water demand of the population from municipal sources (Singh et al., 2020). Change in the water demand and supply due to urban sprawl; land-use changes due to population expansion and impact of climate change are projected to further threaten the water sustainability (Schnoor, 2015).

Excessive reliance on ground water in the Himalayan region will have deleterious consequence keeping in view the inherent fragility of aquifers in mountainous regions and thus, mountain-specific urban planning and accountability of the stakeholders is required to address the grim future of water resources (Singh et al., 2020). Because of vast socioeconomic, geographic, and meteorological differences existing among cities, a generalised national level water policy may not be appropriate to streamline the water infrastructure for distribution and supply of water to the urban population. Therefore, a systematic assessment of criticality of water under the current pace of urbanisation and climate change at the city level is required with consideration of stakeholders' perception at spatio-temporal scale matching with municipal water infrastructure schemes (Dong et al., 2020). Vulnerability analysis tends to be a reasonable approach for assessing the crisis as the information provided may be useful for the policy makers in decision making for addressing the water crisis (Pandey et al., 2015).

Vulnerability is defined as the extent to which a system is susceptible to, unable to cope with the adverse effects (Thornes, 2002) and encompasses three dimensions namely exposure, sensitivity and adaptive capacity (Sharma and Ravidranath, 2019). Though various vulnerability assessment frameworks exist for assessing climate change and water vulnerability, there is no specific methodology with adequate indicators for assessment of water vulnerability at micro-level for the hilly region. Those prevailing methodologies applied at macro level will not be suitable for micro-level household analysis since factors and characteristics differs at the micro level framework (Pandey et al., 2014). Vulnerability may be accessed through a composite index, which is a unit less relative construct for measuring the susceptibility of the system, using various relevant system specific indicators of the three dimensions of vulnerability (Abson et al., 2012; Giri et al., 2021). However, conceptualizing vulnerability and choosing appropriate indicators are key challenges for vulnerability assessment (Fussel, 2007). Therefore, site specific micro level operative model framework for water crisis management is required to formulate in order to create awareness among the policy makers and authorities to plan their responses in implementation of water management policies (Nguyen et al., 2020). Moreover, results of such evaluation at the city level would add value to local level water planning, which is essential to strengthen the local governance ability for facilitating the informed decision making by the policy makers (Ojha et al., 2020).

Hill town and cities are degrading in variety of aspects such as micro climate, vegetation, recharging of aquifers, water table and leading to affect the environment of the town and city and also the surrounding regions (Kumar and Pushplata, 2013). Therefore, an evaluation for water vulnerability under current stresses was attempted in Nainital city which surrounds the Nainital lake in the lower Himalayas, to supplement information about the water management. Nainital lake is the major source of water supply for drinking and other domestic purposes in the town of 40,000 local inhabitants and tourists including recreational activities (Purushothaman et al., 2012). Moreover, various anthropogenic activities such as illegal construction, litter, domestic discharge, and recreational usage of lake is detrimental for the lake's quality and quantity (Purushothaman et al., 2012). The current scenario of water issues in the city and differential distribution of water in the different wards was evident from the interview and the field survey conducted during the year 2020–2021. The study hypothesised that the municipal wards have differential vulnerability and are governed by physical and infrastructural resources besides population density. The study objectives were to estimate ward-level vulnerability and identify adaptation mechanism at stakeholder levels. The study was primarily based on remote sensing data for majority of the key indicators and the results are also represented using GIS maps for better visualization and understanding besides primary information were also collected from the local population to understand the coping mechanism. The key indicators for evaluation were less in number and easily assessable and primarily based on secondary sources and therefore facilitating to the dynamic nature of vulnerability. The results will support the decision makers to re-orient policies with inclusion of more pronounced role of public and therefore implying appropriate measures in various wards to reduce the water vulnerability. The proposed theoretical framework in this study can be used in future studies focussing on micro-level water vulnerability assessment through customised modification.

Theoretical Framework

Present study considered “vulnerability - as the susceptibility to be harmed” and is measured using IPCC framework based on the three dimensions of vulnerability exposure, sensitivity and adaptive capacity (Pandey et al., 2014; IPCC, 2014; Omerkhil et al., 2019; Giri et al., 2021). Vulnerability in the present context was derived from a mixture of physical units by considering the physical characteristics of the system i.e. urban region by considering edaphic factors along with using political ecology connect by considering population, land use and land cover besides governance in terms of water supply distribution. The water vulnerability of the city can be broadly socio-economic and bio-physical in nature. From a socio-economic perspective, looking specifically at a city's population, the vulnerability encompasses with various factors such as awareness of climate change, relative mobility, socio-economic status, length of residence time (Lindley et al., 2011) and in a mountainous city with low population, the awareness, constrained mobility along with residence time, population density was considered as prime factors for the study. The physical fabric of a city encompasses through edaphic factors including the quality and location of physical infrastructure which also an indicator of governance mechanism (Carter et al., 2015).

The humans, possessions, livelihoods, habitats are exposed to climate through creating potentially harmful environment for water distribution and infrastructure, and keeping in view of local level of variability, land surface temperature (LST) as a proxy of element of climate i.e. temperature was considered. Despite the fact that the two temperatures differ in their physical meanings and responses to atmospheric circumstances, there is a strong link between near surface air temperature and LST (Mutiibwa et al., 2015). Rise in urban temperature due to variety of reasons such as urbanization, population, climate change poses urban heat and water availability, as a use to cool and various other purposes for human system, is important for reliable water supply as a measure to adapt the increasing urban heat. Land surface temperature (LST), the skin temperature of the land is an important parameter for determining hydrology between the ground and the atmosphere in urban system (Adanu et al., 2020). Sensitivity is defined as the factor that cause a system or population to be harmed or deprived of water, and thus population density, a measure of water requirement (Lee and Choi, 2018) and edaphic factors such as slope and elevation (Gupta et al., 2020; Sekhri et al., 2020), were considered as indicators for sensitivity besides land use and land cover (LULC) as proxy to modify water availability (Adanu et al., 2020) i.e. less urbanization at gentle slope at low altitude lead to improvise the condition for improved water availability by reducing the evapotranspiration. LULC change has direct impacts on water yield (Li et al., 2018) by modifying the underlying mechanisms of transferring rainfall to the surface water balance and the partitioning of precipitation into evapotranspiration, runoff, and groundwater flow (Foley et al., 2005). Slope has indirect impacts on water availability (Tse-ring et al., 2010). Steep slope can increase the flow rate of a waterbody which could lead to increase in soil erosion, moreover slope has a significant effect on the infiltration rate of groundwater, the amount of infiltration decreases with increase in the slope (Fox et al., 1997).

The capacity of water availability and facility for household use was considered as adaptive capacity in the present context and therefore keeping in view of mountainous city, distance to water body i.e. lake (Das et al., 2020) and distance to road (Pandey and Jha, 2012) was considered as indicators for adaptive capacity (Table 1). It was presumed that shorter the distance between infrastructure and the water supply and distribution system, lower the infrastructure requirements besides reducing the chances of leakage. Moreover, the road infrastructure also reflects better maintenance of water distribution systems under the vulnerable state such as leakage, pipe bursting during winter.

Overall, seven indicators for defining different dimensions of vulnerability were included where exposure, sensitivity and adaptive capacity included one, three and four indicators respectively, keeping in view of policy perspective based on less number of parameters (Table 1). As the study area was small, climatic factor could not be obtained through remote sensing for exposure and hence Land Surface Temperature (LST) was considered as a proxy of temperature. Sensitivity included four indicators such as land use land cover, slope, population density and elevation which had positive effect on the water vulnerability of the city. The adaptive capacity included two indicators namely distance to lake and distance to road since these two indicators can aid people to cope with the water stress in the wards. The relationship of each indicator with vulnerability is illustrated in Table 1, where positive sign shows the direct relationship and negative sign indicates the inverse relation of indicator with

vulnerability. Adaptation mechanism for bio-physical and governance units may be visualized directly through the perception of locals.

Table 1
Indicators and their functional relationship with Vulnerability

Dimension	Indicator	Description	Functional Relationship	References
Exposure	Land Surface Temperature	Surface temperature is a proxy for temperature and high value reflects higher exposure. Warming is detrimental for society and water.	Positive	(Pandey et al., 2014; Omerkhil et al., 2019)
Sensitivity	Population Density	Sensitivity due to the population pressure. Population density is proxy to resource availability.	Positive	(Lee and Choi, 2018; Sekhri et al., 2020)
	Land Use Land Cover	Sensitivity due to urban, forest and open area	Positive	(Koech et al., 2020)
	Slope	Sensitivity due to steeper slopes	Positive	(Lee and Choi, 2018; Gupta et al., 2020; Sekhri et al., 2020)
	Elevation	Sensitivity due to topography. Higher elevation requires better infrastructure and high pressure for water distribution.	Positive	(Gupta et al., 2020; Sekhri et al., 2020)
Adaptive Capacity	Distance to Lake	Distance to lake is proxy for infrastructural availability of water and more the distance, high the vulnerability.	Negative	(Das et al., 2020)
	Distance to Road	Distance to lake is proxy for availability of water and more the distance, high the vulnerability.	Negative	(Jha and Gundimeda, 2019; Pandey and Jha, 2012).

Materials And Methods

Profile of Study area

The study area Nainital town is situated in Kumaon Lesser Himalaya in Uttarakhand state of India. The town with varied topography spreads in a total area of 11.73 km² and lies at 29°22' 49" N Latitude and 79°27' 48" E Longitude with the average elevation at 2084 m above mean sea level. This area is bounded by various hills such as Naina peak, Sher-ka-Danda, Deopata, Lariyakata, Alma, and Ayarpatha. The

kidney shaped Nainital lake is the major source of water supply to the town, other sources encompass of various springs such as Pardadhara, Sipahidhara, etc. The chief drainage of the area is Balia nala which is fed by the Nainital lake (Khanduri, 2019). The major geomorphic features of the region are characterized by mountain peaks, hill slopes, topographic depressions and debris cones. The slope mainly varies between 20° and 40°, occasionally over 50° at some places and covered with slope of wash materials, with the lacustrine deposits at topographic depressions (Sah et al., 2018). The town has a tropical climate with a mean temperature of ~25°C in summer and near to 0° in winter with snowfall (Gupta et al., 2016). Pine, Oak, Walnut, Chinar, Hisalu, Kaphal, Buruns and other temperate forests species are main vegetation in the town (Fig. 1).

Nainital is a popular tourist destination in Uttarakhand with a population of 41,377 as per the Census of India 2011 and distributed in fifteen wards. Although, tourism boost the economy of the locals but excessive tourism has become a critical issue in the city affecting the quality of the lake water besides reduced water supply to the residents due to provisions for hotels (Barbhuiya, 2020). The Nainital lake forms the city's primary source of water, as all the infiltration wells and shallow tube wells are directly recharged by lake water and has been utilized for varied purposes starting from tourism, irrigation, potable water, and to fisheries at times. The dependence of the individuals of the town on the lake for their livelihood and for water supply is increased during peak tourist season thereby exhibiting high stress on the water bodies.

Dataset collection

The different datasets utilized in the study for vulnerability analysis is from secondary sources and specified in Table 2. The indicators as per theoretical framing was ward wise population, Land Surface Temperature (LST), Land Use Land Cover (LULC), slope, elevation, distance to road and distance to lake. Except ward wise population all other variables have been retrieved from remote sensing whereas ward wise population data was obtained from Nagar Palika Parishad, Nainital. The tools Google Earth Engine and ArcGIS 10.1 software were used in this study for data collection and analysis.

Data processing in GIS

The exposure component was determined by LST, due to the coarser resolution of the climatic data causing insignificant variation in the climatic data in different closely connected wards and the absence of the metrological station in the nearby area. LST was considered and was obtained from Landsat data (with 30m resolution) derived through google earth engine. The thermal bands of Landsat TM, ETM + and Landsat 8 are commonly used for temperature analysis (Cristobal et al., 2018). Code was run in google earth engine to obtain annual mean of LST for the period 1990 to 2020. Layers having no data value or gap value were filled with the help of focal statistics tool and by using raster calculator, mean was obtained in ArcGIS 10.1 software.

The sensitivity dimension consisted of land use land cover classification (LULC), which was obtained from Landsat data and processed in ArcGIS 10.1 software. Google earth engine was used for the supervised classification

as well as for Reprojection and Clipping. SVM (support vector machine) classifier, a supervised non-parametric method present in google earth engine was used to extract the Land cover features. The merit of the approach was its ability to generalize well in cases where training dataset is limited and achieve higher accuracy than other conventional methods, such as (ML) Maximum Likelihood (Mantero et al., 2005; Mountrakis et al., 2011). A total accuracy of 0.83 was obtained with the assessment being determined by comparing the classified image with higher resolution data using a confusion matrix.

Other indicators of sensitivity included slope and elevation that were derived through SRTM DEM with 30m resolution, whereas for population density, the dataset of population was obtained from the Nagar Palika in excel format. The data was converted to a shapefile by joining the excel sheet with the ward level boundary of Nainital. The shapefile was then projected and resampled to 5 m resolution. Population density (PD) was then obtained by dividing the population of each ward with the respective ward area in the attribute table of the ward boundary and converted to a raster, using polygon to raster tool in ArcGIS 10.1. software (Table 3).

Table 2
Dataset required for mapping Vulnerability

Dimension	Data Layer	Data Sources
Exposure	Land Surface Temperature	Derived from Landsat (30m) by running a code on google earth engine https://earthengine.google.com
Sensitivity	Land Use Land Cover	LISS – 4 (5.8 m), from NRSC (National Remote Sensing Centre), Hyderabad. https://www.nrsc.gov.in
	Slope	Derived from Shuttle Radar Topography Mission Digital Elevation Model of NASA (SRTM DEM) (30m) https://www.usgs.gov
	Elevation	Derived from Shuttle Radar Topography Mission Digital Elevation Model of NASA (SRTM DEM) (30m) https://www.usgs.gov
	Population Density	Obtained from Nagar Palika Parishad, Nainital
Adaptive Capacity	Distance to Road	Major roads were downloaded from Open Street Map. https://www.openstreetmap.org
	Distance to Lake	Digitization of the lake was done in ArcGIS 10.1 software.

The two indicators for adaptive capacity dimension comprised of distance to road (DR) and distance to lake (DL). The lake was digitized and the road network shapefile was downloaded from Open Street Map (OSM) and clipped to the ward boundary of Nainital using the ArcGIS 10.1. software. Euclidean distance tool, was used for estimation of distance to lake and distance to road from the ward boundary. It was made sure that all the raster layers were resampled to 5 m, and based on field observation and expert knowledge, weights were assigned to each indicator in this study using the methods of AHP and pairwise comparison matrix.

Survey and data collection

Based on the theoretical framework for adaptation a questionnaire was designed for household interview and a survey was conducted during January to March 2020- 21. Household interview was conducted keeping in view of obtaining a comprehensive view on various water issues at household level following the guidelines of the government under the COVID crisis. The questionnaire contained four sections for accounting various issues of water including perception for climatic trends and adaptation protocol for addressing water vulnerability within the limited resource mix. The first section includes general information about the respondents' group. A section was devoted for the challenges of water with focus on quality for uses; groundwater recharge and water scarcity and crisis. The third section mainly included questions on changes in climatic parameters and impacts of climate change in the last decade. The fourth section primarily dealt with the adaptation mechanism by managing the stakeholder role i.e. public and water institution. Before administering the questionnaire, pre-testing was done and redundant questions were deleted. We adopted a random sampling approach to select nine to ten households from each fifteen wards of the city. After briefing on the study and receiving consent, the interview was conducted with the head of households. Based on respondents' preference, the interview was conducted in the local language for at most 30 minutes with 148 randomly selected groups.

Table 3
Demographic features of the fifteen wards of the city

Ward Name	Population	Distance to Lake (m)			Ward Area (km ²)	Population Density (km ²)
		Minimum	Maximum	Mean		
Sree Krishnapur	2317	607.85	1821.58	1300.92	0.89	2590
Harinagar	2409	135.65	712.99	512.57	0.05	48584
Tallital Bazar	2310	16.96	561.37	203.06	0.13	17187
Rajbhawan	3172	75.83	1138.13	566.21	0.98	3236
Sher ka Danda	3481	220.44	713.20	474.79	0.46	7496
Narayan Nagar	2524	1174.44	2299.95	1752.23	0.56	4509
Upper Mall Road	3364	16.96	568.75	227.37	0.59	5726
Shukhatal	3384	541.03	1587.53	975.41	0.46	7403
Nainital Club	2623	465.62	917.08	690.59	0.16	16406
Snow View	3072	372.28	856.11	592.63	0.26	11679
Sainik School	2241	767.38	1710.04	1276.88	0.48	4663
Mallital Bazar	2479	180.25	570.01	369.24	0.06	40232
Awagarh	2391	84.78	508.99	317.99	0.09	27374
Ayarpata	2482	0.00	736.21	279.30	0.67	3704
Staff House	3128	288.27	700.38	496.64	0.07	47881

Source: Nagar Palika for population related parameters; Area is estimated through remote sensing

Vulnerability assessment

The overall methodology to assess water vulnerability is categorized into four broader steps (1) Identification of appropriate indicators associated with all the three dimensions of vulnerability, (2) Assigning weight to each indicator after rational and scientific evaluation, (3) Integration of all the indicators at its dimension level and (4) Estimation of water vulnerability index for spatial representation of vulnerability in each ward. The methodological steps adopted for the present study is reported in Fig. 2.

The indicators were selected as per the theoretical settings. Assigning weight to the indicators is one of the crucial points in vulnerability assessment (Papathoma et al., 2019), as each indicator contributes differentially to vulnerability and has its own positive and negative impact on water vulnerability (Pandey et al., 2014). Several methods are available in literature to allocate weights to the indicators, however Analytical Hierarchy Process (AHP) is a widely used method for assigning weight in water resource management (Zhou et al., 2018). AHP is a multi-criteria decision-making method and used to provide a systemic methodology for assessing and combining the effects of various variables, including qualitative and quantitative data (Saaty, 1980). AHP basically involves four steps, in the first step a pairwise comparison matrix is constructed for each criterion, in the second step the resulting matrix is transformed into a normalized matrix, third step involves the calculation of the average of the values in each row to get the corresponding weight and the last step includes the determination and verification of the consistency ratio.

The relative significance of two indicators is estimated on a scale of 1 to 9, where 1 indicates that the two indicators have equal importance and 9 specifies that one indicator is significantly much more important than the other (Saaty, 2008). The relative significance of factor was adjudged based on the experts of the theme including the authors. All the weights were compiled into a pairwise comparison matrix with a diagonal value 1 and reciprocal weights on the lower left triangle. Each comparison matrix yielded an eigen vector, which was used to assign weight to each of the factors (Filho et al., 2020). For example, in Table 3 the first row has LULC value equal to LULC thus it was marked as 1, then LULC compared to Slope, PD, DL, Elevation, DR, LST is marked on a scale from 2 to 9 as given in Table 1. The consistency ratio (CR) was used to assess the precision of the measured weights and the variations between pairwise measurements. The accepted consistency ratio is less than 0.1, otherwise, it is necessary to re-check subjective arbitrary assumptions and recalculate the weights (Saaty and Vargas, 2001). The consistency ratio (CR) is calculated by using equation

$$CR = \frac{CI}{RI}$$

Where, CI is the consistency index and determined by the equation

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

where, n represents the size of the matrix and λ_{\max} is the average of the values. RI represents the random matrix to check the consistency of pairwise comparison matrix. The value of RI was computed by (Saaty, 1980).

The average values for comparison matrix were estimated in two steps, first by multiplying each column of the pairwise comparison matrix by the corresponding weight and in second step sum of the rows was divided by its corresponding weight for estimating the final average values denoted by (λ_{\max}) (Table 4).

The weight for each indicator was estimated and reported in Table 5. After AHP analysis, each indicator layer was reclassified into three classes, value of 1 was assigned to the sub criteria contributing minimum to vulnerability and a value of 3 to the sub- criteria contributing maximum to vulnerability (Table 5). In the case of indicators of adaptive capacity, the distance to road and distance to lake, were classified into three classes and value 3 was assigned to the distance nearest to lake, as it would contribute to a higher adaptive capacity due to low requirement of infrastructure and better support for maintenance leading to lower vulnerability. Precisely, the values for adaptive capacity indicators were inversed.

Further, the indicator layers were multiplied with its respective weights and aggregated to derive component and overall vulnerability. IPCC framework was applied for the vulnerability analysis with consideration of the three dimensions. The bottom-up approach provides improved stakeholder perspective for adaptation mechanism (Pandey et al., 2018). This approach also provides an advantage of visualizing separate maps for each dimension of vulnerability and therefore facilitates better understanding about the leading factors responsible for the vulnerability (Gupta et al., 2020; Sekhri et al., 2020). The formula for estimating water vulnerability was as follow (Pandey et al., 2017) with low the value, the low is the vulnerability.

$$\text{Vulnerability} = f(\text{Exposure, Sensitivity, Adaptive capacity})$$

$$= \text{Exposure} + |\text{Sensitivity} - \text{Adaptive capacity}|$$

Table 4: A pairwise comparison matrix for assessing the relative importance of each layer of factor

Component	LULC	Slope	PD	DL	Elevation	DR	LST
LULC	1.00	2.00	3.00	4.00	6.00	7.00	9.00
Slope	0.50	1.00	2.00	3.00	5.00	6.00	7.00
PD	0.33	0.50	1.00	2.00	3.00	5.00	6.00
DL	0.25	0.33	0.50	1.00	2.00	3.00	5.00
Elevation	0.17	0.20	0.33	0.50	1.00	2.00	3.00
DR	0.14	0.17	0.20	0.33	0.50	1.00	2.00
LST	0.11	0.14	0.17	0.20	0.33	0.50	1.00

CI=0.03, RI=1.24, CR=0.02; (LULC – Land Use Land Cover; PD - Population density; DL – Distance to lack; DR – Distance to road; LST-Land surface temperature)

The above calculation was performed using raster calculator in ArcGIS 10.1. software. The aggregated components were divided into grids with the help of fishnet tool in ArcGIS for estimating the differential vulnerability across the ward

Table 5: Relative weights of the indicators and sub-criteria

Indicator	Weight	Sub-criteria	Rating
LULC	0.36	Forest	1
		Open Vegetation	2
		Urban	3
Slope	0.25	0 - 15	1
		15 - 25	2
		25 - 65	3
Population Density	0.16	2,590 - 5,726	1
		5,727 - 17,187	2
		17,188 - 48,584	3
Elevation	0.06	1,457 - 1,834	1
		1,835 - 2,085	2
		2,086 - 2,353	3
Distance to Lake	0.10	0 - 599	3
		600 – 1,216	2
		1,217 – 2,314	1
Distance to Road	0.04	0 - 112	3
		113 - 283	2
		284 - 681	1
LST	0.03	14 - 18	1
		19 - 22	2
		23 - 29	3

Result And Discussion

Apart from the secondary sources, preliminary field survey was conducted through structured questionnaire to retrieve the general information regarding the water status and challenges in the city. The result of the data analysis revealed that the households of the city receive intermittent water supply from Municipality, and all households were equipped with metered connection. The water charge varies from minimum 200 to maximum 3000 depending upon the requirements of the households. More than 86% households reported that water supply was not sufficient for the uses of households. Most of the

household's store water in tanks with varying capacity from 500 to 3000 liter in either one or up to four tanks. During crisis, almost 37% households collect water from nearby springs or water tank. In the wards, public water source was also available at a place which is at most 100 m vicinity to 50% households, survey revealed. Twenty three percent household reported that water quality was good however 76.4 percent reported normal water quality. Water taste was more or less normal however the water quality was ensured through filtering by 90% household and remaining 10% boil water for drinking purposes. Interestingly, all the respondents agreed that water quality of lake has been improved with the efforts of the responsible organizations and civil body, however, ground water recharge was perceived to reduced by 97.3% households. The water quality was attributed to the leakage in the pipelines, lack of effective regulation for sustainable water use and discharge and lack of modern technology. Majority of households were in favor of modern technology for water supply and filtration i.e., water distribution infrastructure; and law and regulation for sustainable water use and discharge (Table 6).

Almost all households reported that they face water scarcity during summer and they were also not practicing water harvesting in their houses. However, the households identified over-exploitation of ground water resources through either water withdrawal or concrete house construction as major problems for reduction in ground water recharge, along with urbanization and climatic parameters such as rainfall and impact of climate change particularly changes in temperature (Table 6). Water crisis and scarcity were also investigated during the survey to understand the possible causes. The households reported that tourism and urbanization were the major causes, in spite of the fact that tourism is a major economic activity in the city, reported the households. Climate change and unsustainable use of water resources were also one of the causes, however, the intensity of these causes was not as severe as tourism and urbanization, reported the respondents. Households were having a normal perception about the working and management of the water institution (Table 6).

Table 6
Perception for the possible reasons for water issues

Reason	Severe	Moderate	Normal
Water quality for water uses			
Leakage	20.9	20.9	58.1
Lack of law and regulation for sustainable water use and discharge	32.4	37.2	30.4
Lack of modern technology	46.6	41.9	11.5
Reduction in groundwater recharge			
Impacts of long-term Climatic variations/change	37.8	30.4	31.8
Change in rainfall pattern	24.4	31.8	43.8
Decrease in percolation and infiltration due to urbanization	53.3	28.4	18.3
Over-exploitation of groundwater resource	84.4	9.5	6.1
Water scarcity and crisis			
Unorganized urbanization (construction and development)	47.9	18.9	33.2
Increase in tourism and related activities	77.7	11.5	10.8
Impact of climate change/ variation	20.9	22.4	56.7
Unsustainable use and over-exploitation of water resources	19.0	24.9	56.1
Ineffective management by Local water management authority	35.8	23.0	41.2
Unorganized urbanization (construction and development)	47.9	18.9	33.2

Exposure Component Analysis

Major water challenges faced by the households were supply for limited time (38.5%); leakage (25%); long distance from water pump (16.2%), besides water cost (15.5%) and insufficient storage (4.7%), as reported by the respondents. Changes in the climatic conditions were also having an adverse impact on water issues, reported the households, moreover, respondents perceived changes in climatic parameters (Table 7). All households reported that the amount of snowfall, and rainfall has been decreased during the last ten years with changes in frequency of rainfall (94.6%). However, the frequency of hailstorm and frequency of drought could not be adjudged conclusively and about 50% households were reported inconclusive for both the parameters (Table 7). Conclusively, climate was attributed for changes in water availability.

Table 7
Perception about changes in climatic parameters during last a decade

Parameter	Decrease	No change	Increase	Can't say
Number of cold days	93.9	5.4	0.7	-
Number of hot days	18.2	79.1	1.4	1.4
Amount of snowfall	100.0	-	-	-
Amount of rainfall	100.0	-	-	-
Frequency of rainfall	94.6	3.4	-	2.0
Frequency of drought	-	10.8	-	89.2
Frequency of hailstorm	39.9	12.8		47.3

In the hilly areas due to the typical scarcity of meteorological stations, LST may be the most useful variable (Voogt and Oke, 2003) in characterizing spatial- temporal patterns of near surface air temperature (Mutiibwa et al., 2015). Therefore, LST was considered as a proxy to temperature and a key indicator for exposure dimension. Higher temperature was given a value of 3, while lower temperature was assigned a value of 1. The wards with high LST values were Awagarh, Mallital bazar, Sree Krishnapur and Harinagar. The high value of LST were found in these wards as they covered high urban area and barren land, since both have a direct relationship with Land Surface temperature (Tan et al., 2020). Moreover, area with open vegetation also showed high value of LST, as urban vegetation and LST are negatively correlated (Weng et al., 2004; Chen et al., 2006; Buyantuyev and Wu 2010). Further, replacement of rural land cover type with concrete urban elements has substantial environmental consequences, such as reduce evapotranspiration, increased surface runoff and lower air and water quality (Yue et al., 2007). Therefore, higher value of LST may have a positive influence on vulnerability and may affect people since it indicates the inadequate surface water availability (Traore et al., 2021). Thus, wards with higher LST in low vegetation and high urban area, due to the presence of impervious surface results in increased surface runoff and decline in ground water recharge (Srinivasan et al., 2012) (Fig. 3).

Sensitivity Component Analysis

The sensitivity dimension was estimated based on four indicators (LULC, slope, elevation and population density) revolving around bio-physical and demographic factors, each of which is addressed under separate heading in the following paragraphs.

Land Use Land Cover

LULC has been divided into three classes namely forest, urban and open vegetation, where urban was given value of 3 since it has a higher impact on water resources and forest was given the lowest rating 1.

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In the study area forest cover was around 31km² whereas areas under urban and open vegetation were 1.78 km² and 0.99 km², respectively. Maximum settlement (urban area) was observed near the lake (Fig. 4a). The land use land cover may have a great impact on water resources for domestic and non-domestic purposes, as urban expansion will increase the demand of water supply for infrastructure development and for other domestic use, which would eventually put pressure on lake. Moreover, LULC affects water yield through altering infiltration, evapotranspiration and groundwater recharge capacity that is mainly determined by the biophysical characteristics of LULC composition (DeFries and Eshleman, 2004; Li et al., 2018). Apart from this LULC have effect on the surface water quality due to various point and non-point source pollution under different land uses (Mallin et al., 2009). Moreover, vegetated land has relatively lower water yield due to higher evapo-transpiration and water infiltration than built-up areas and bare land due to their impermeable surface (Li et al., 2018). Therefore, the area has high possibility of lower water yield due to high vegetation cover.

Slope

The slope varies from 0 to 65° and based on literature, slope was classified in three classes ranging from 3 (steep slope) to 1 (gentle slope) with the view that steep slope can increase the surface runoff and reduce the groundwater infiltration (Fox et al., 1997). Slope with 0–15 degree were considered as low, (15–25) as moderate and (25–65) as high slope. Moreover, the steep slopes lead to rapid changes in climatic zones over small distances, posing a significant impact on water availability (Tse-ring et al., 2010). Our result shows area with steeper slope in Sree Krishnapur, Ayarpata, Upper Mall and Sher ka Danda wards (Fig. 4b).

Elevation

Topography such as elevation also plays a critical role in sensitive analysis as people residing in higher elevation are more distant from the primary source of water that is Nainital lake and also during the water crisis, alternative sources of water like water tank were generally not available in wards with higher elevation. Another impact of the elevation was requirement of high pressure for water supply. This was evident from the field questionnaires where most of the respondents agreed that during water shortage there was no alternate supply of the water tank due to the topography of the area. The elevation was classified into three categories and higher elevation was given a value of 3. The study shows higher elevation for wards Sher ka Danda, Snow View and in the upper region of Sainik school, Rajbhawan and Aryarpata wards (Fig. 4c).

Population density

The analysis of population data shows that maximum population density was obtained for Harinagar Ward and the least population density was obtained for Sree Krishnapur Ward. Increase in population has a direct impact on the water resources, as high population require more water for domestic purposes and would lead to put more pressure on the water resources (Fig. 4d).

Adaptive Capacity Analysis

The adaptive capacity dimension comprised of two indicators, distance to lake and distance to road. In the city, lake is the primary source of water, therefore people residing near to the lake have more access to water and are better equipped with water sources, thus have high adaptive capacity as compared to people residing far away from the lake. The layer was categorized into three with the distance closest to the lake receiving a high value of 3, indicating that it has a high adaptive capacity (Fig. 5a). Distance to major road is considered as proxy for infrastructure (Byrne, 2014; Egyir et al., 2015), as people residing near the road had more easy access to water as compared to people living far from the road (Fig. 5b). Therefore, in the study, a value of 3 and 1 was assigned to the wards near and far from the road respectively. The result shows that wards Mallital, Rajbhawan, Aryarpata, Upper Mall, Tallital Bazar and Sher ka Danda, were nearer to lake and major roads and possess high adaptive capacity.

Estimation Of Water Vulnerability Index

Water vulnerability index was developed by aggregating all the components of exposure, sensitivity and adaptive capacity (Fig. 6). The map for the three dimensions was developed as per the methodology, by aggregating the respective indicators and reported in Fig. 6. The respective values for each dimension for each of the wards have been stated in Table 8. The result shows that Sree Krishnapur, Harinagar, Mallital Bazar and Awagarh were the most exposed wards though the level of exposure was very low due to the low value of LST. The sensitivity was high for Staff House, Harinagar, Awagarh and Mallital Bazar and was least for Narayan Nagar and Rajbhawan (Table 8). The adaptive capacity was maximum in Mallital Bazar, Tallital Bazar, Uppar Mall Road and Awagarh, however the poorest adaptive capacity was for Narayan Nagar (Table 8).

Vulnerability was estimated and reported in Table 8 with Staffhouse and Harinagar being the most vulnerable wards, due to their high population density and high built-up area in these wards. The high population density increases water consumption thus putting pressure on the infrastructure.. Moreover, the LST was also high leading to more exposure of urban heat, besides less infiltration and excessive surface runoff due to the existence of impervious surface. The least vulnerable was the Rajbhawan and Ayarpata wards. The vulnerability map was divided into three categories low, moderate and high. Low category was assigned to wards having value between 0-0.17, moderate between 0.18–0.25 and higher vulnerability to wards falling between value 0.26–0.4. The most vulnerable wards were Mallital, Awagarh, Nainital club, Staff House, Tallital and Haringar. as there overall sensitivity and exposure were high. . Wards that fall under moderate category were Sher ka Danda, Upper Mall, Sree Krishanpur, Sukhatal and Sainik School (Table 8; Fig. 7).

Table 8
Dimensions of Vulnerability in various wards

Ward name	Exposure	Sensitivity	Adaptive Capacity	Vulnerability	Rank
Sree Krishnapur	0.014	0.359	0.234	0.257	11
Harinagar	0.015	0.473	0.388	0.298	14
Tallital Bazar	0.011	0.424	0.414	0.225	7
Rajbhawan	0.009	0.316	0.340	0.153	1
Sher ka Danda	0.006	0.400	0.367	0.221	6
Narayan Nagar	0.008	0.314	0.209	0.215	5
Uppar Mall Road	0.008	0.378	0.406	0.182	3
Shukhatal	0.009	0.345	0.302	0.204	4
Nainital Club	0.011	0.421	0.312	0.275	13
Snow View	0.007	0.415	0.356	0.246	9
Sainik School	0.010	0.352	0.251	0.237	8
Mallital Bazar	0.014	0.444	0.418	0.249	10
Awagarh	0.014	0.461	0.404	0.273	12
Ayarpata	0.008	0.350	0.399	0.160	2
Staff House	0.009	0.483	0.352	0.316	15

In order to enhance the resilience of a community, respondents were suggested adaptation mechanism. The adaptation mechanism revolved around the improvement in provision of water through rain water harvesting, proper storage and sustainable use of water at individual and household level. Moreover, at the water supply institution, the respondents were very critical for reduction of leakages i.e. minimum loss of water while distribution through effective mechanism including proper upkeep and use of advance and modern technology. Respondents were also in favor of recycling of water besides educating the people for better and sustainable use of the water. Most of the households reported proper storage and sustainable use of water as the best possible practice for water management one can do at the initial level. At institutional level, among the various suggestions grey water recycling mechanism, revival of spring and awareness among the stakeholders were given priorities, as reported by the households (Table 9).

Table 9
Perception for the possible measures by public and institutions

Possible measure	Normal	Good	Excellent
Water scarcity management by the public			
Proper storage	40.6	19.6	39.9
Rainwater harvesting	46.0	33.8	20.3
Sustainable use of water – Optimum use of water	41.2	25.7	33.1
Creating awareness among local	72.4	20.9	6.7
Water scarcity management at the water institution level			
Sustainable supply of water – Minimization of water loss	92.6	5.4	2.1
Sustainable use of water – Optimum use of water	58.7	19.6	21.6
Formulation and adoption of Grey-water recycling mechanism	8.8	25.0	66.2
Revival of spring	39.2	11.5	49.3
Creating awareness among stakeholders	12.2	23.6	64.2
Installation of modern technology for underground water extraction	76.4	14.2	9.5
Rainwater harvesting	20.3	33.1	46.6

Conclusion

In the given study area, Nainital lake is the primary source of water for people residing in the town. Increasing human pressure, unsustainable land use practices, declining lake depth and drying of springs are some of the existing challenges within the city. Consequently, this study focused on understanding the water vulnerability of Nainital city at ward level using GIS modelling approach.

To assess the water vulnerability of the different wards in the area, it was essential to select appropriate indicators that were substitutions of the component's exposure, sensitivity and adaptive capacity. The proposed method included seven main indicators (land use land over, slope, population density, elevation, land surface temperature, distance to road and distance to lake) to evaluate the vulnerability of 15 wards within Nainital town. Weights were provided to the indicators using AHP analysis and maps were produced that showed vulnerability categories within the wards using GIS spatial analysis tools. The analysis results into overall moderate vulnerability in most of the wards of the town, however high value of vulnerability was observed in Mallital, Awagarh, Nainital club, Staff House, Tallital, and Harinagar wards, primarily due to high sensitivity in these wards Hence, the focus of this study was to determine the water vulnerability at ward level, with it aims to guide the policy makers and the government to reorient the policies and develop appropriate adaptation strategies according to the vulnerability level in each ward.

Declarations

Ethical Approval

Not applicable

Consent to Participate

All participants were provided their consent for participating into the interview.

Consent to Publish

Not applicable

Author Contribution

RP, VS, AP and SS conceptualize and designed the study; DC collected and analyzed the data and written the first draft with the support of RP and MT; RP and MT interpreted the analysis. VS, AP, SS and NS read and modified the paper. All the authors have contributed extensively for data interpretation and discussions and consented for the publication.

Competing Interests

The authors declare that they have no competing interests.

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Author Contribution

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Figures

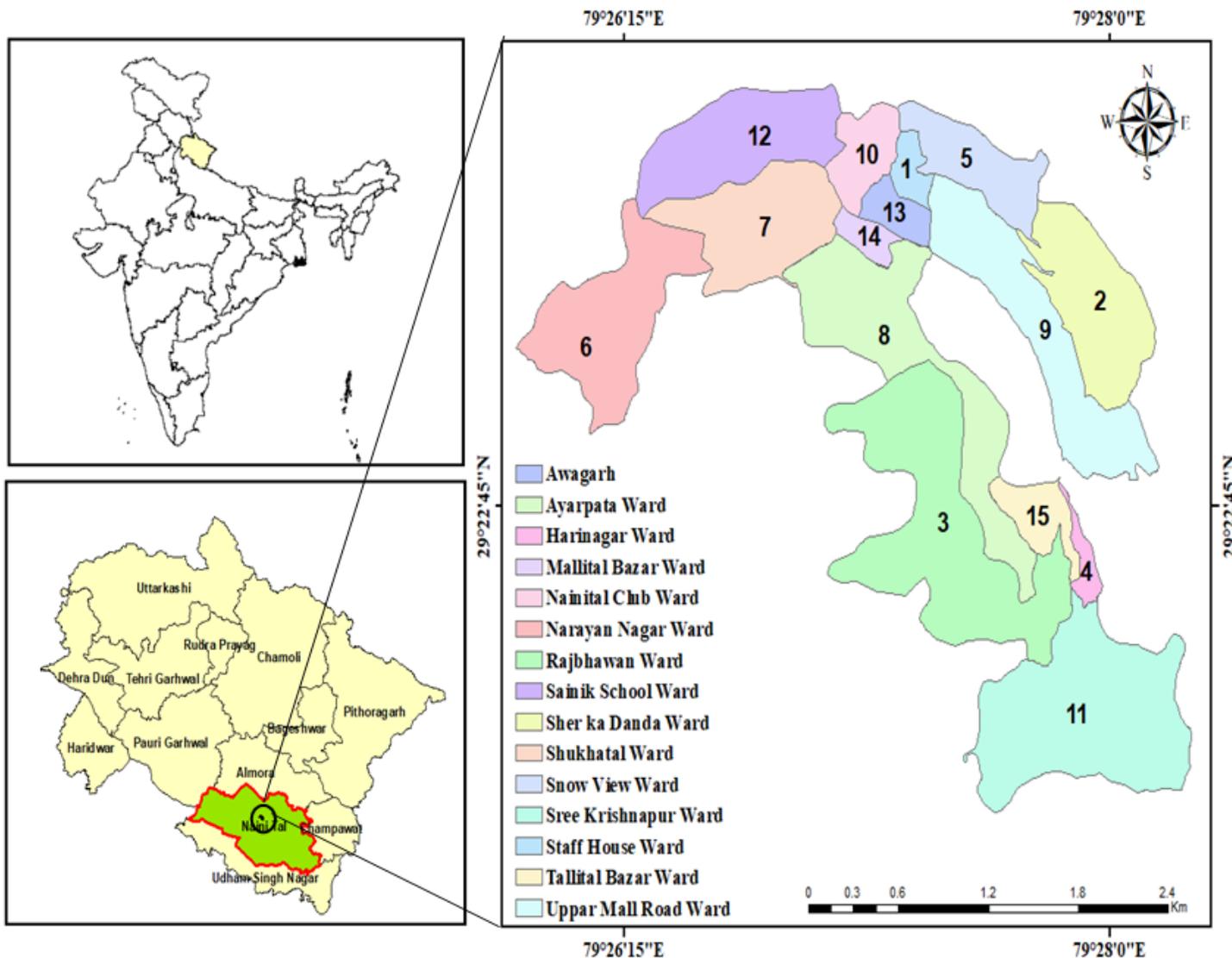


Figure 1

Location map of the study area comprising of different wards of Nainital city Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

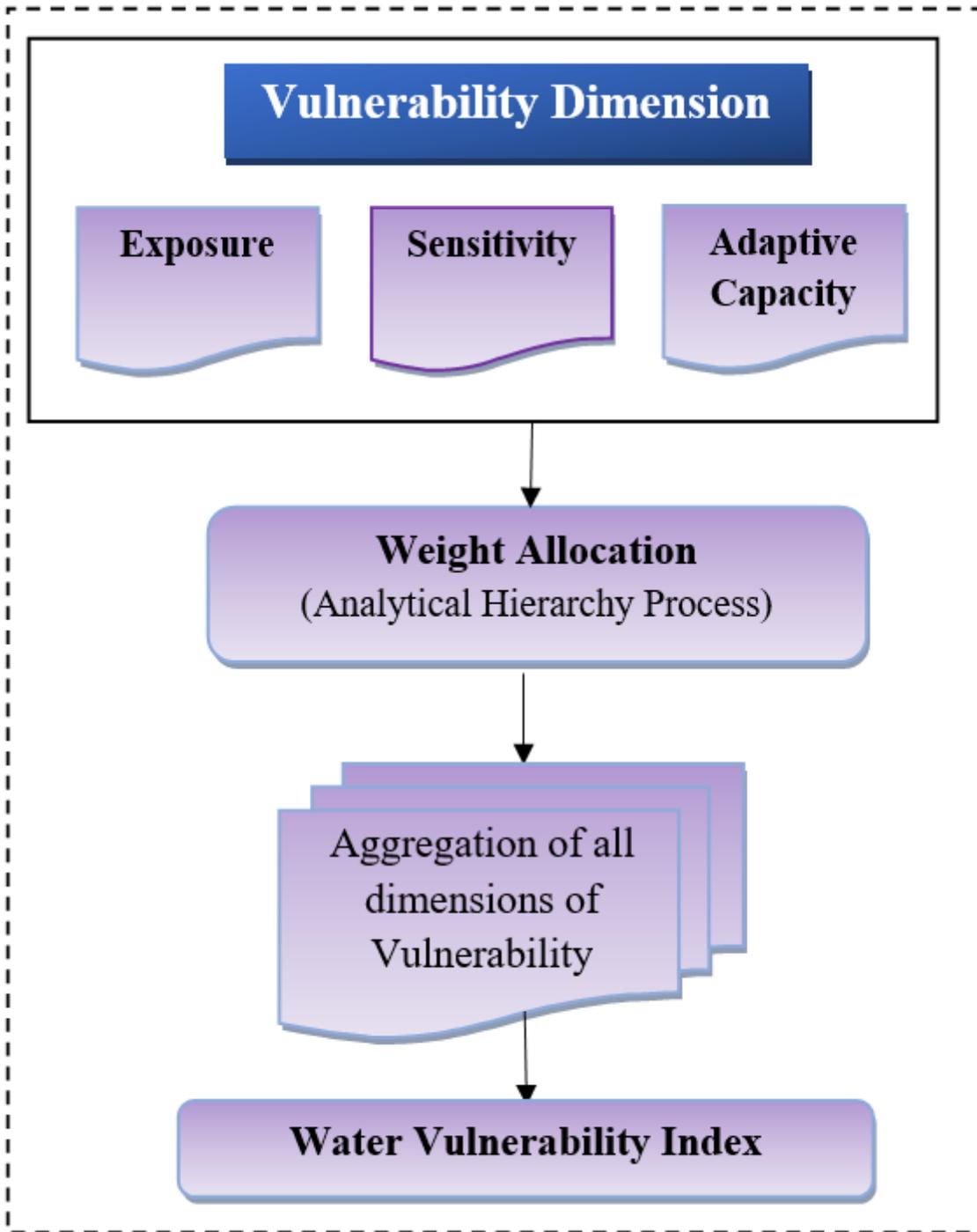


Figure 2

Methodological flowchart for mapping water vulnerabili

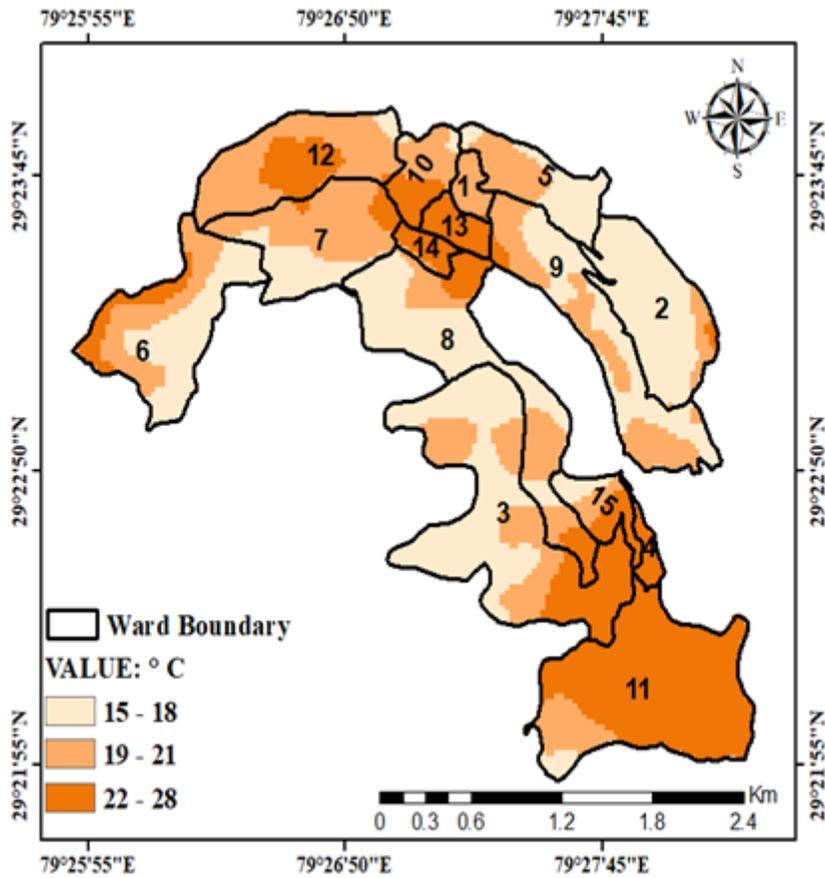


Figure 3

Indicator of Exposure - Land Surface Temperature Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

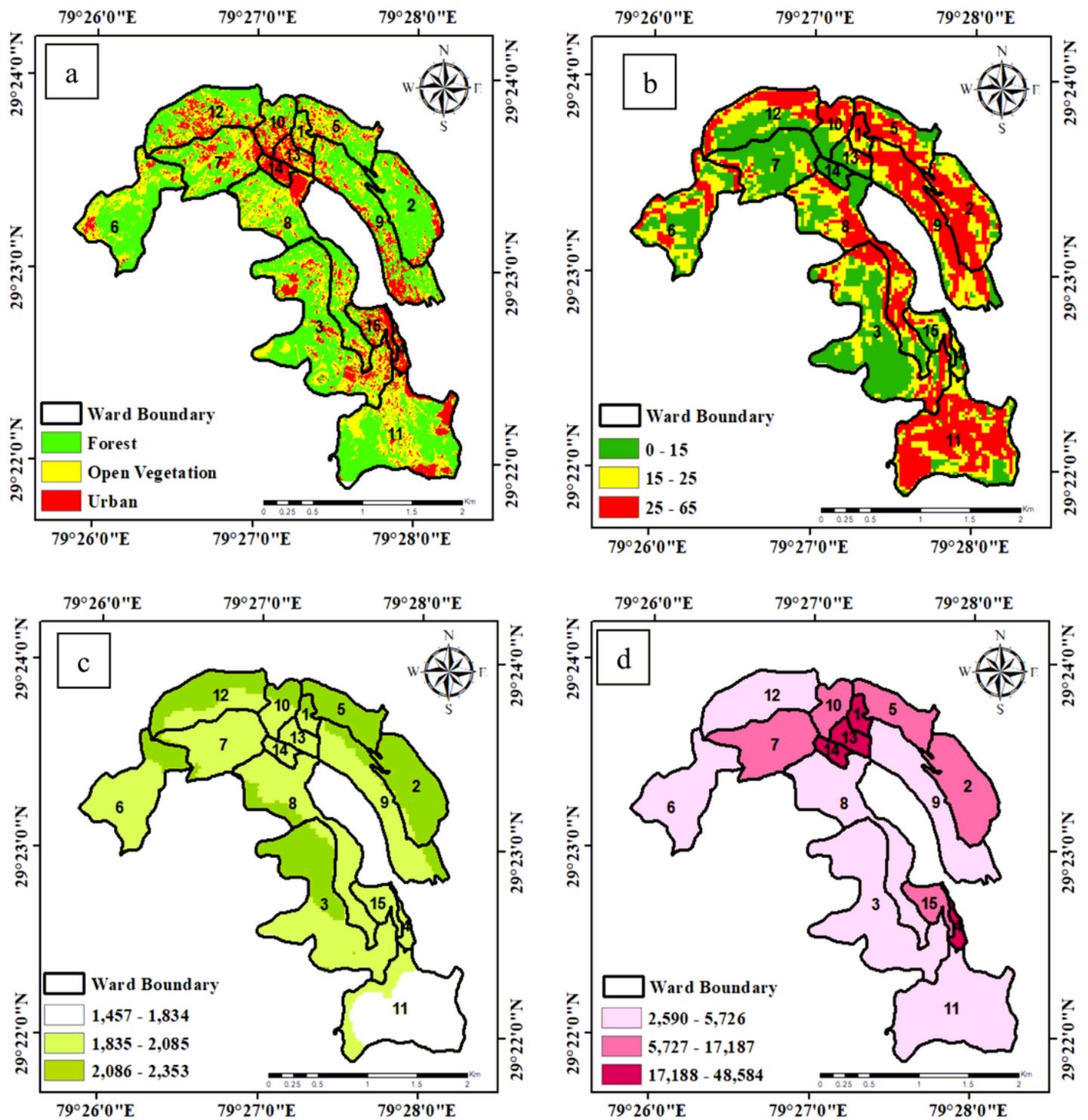


Figure 4

Indicators of Sensitivity a) LULC b) Slope c) Elevation d) Population Density Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been

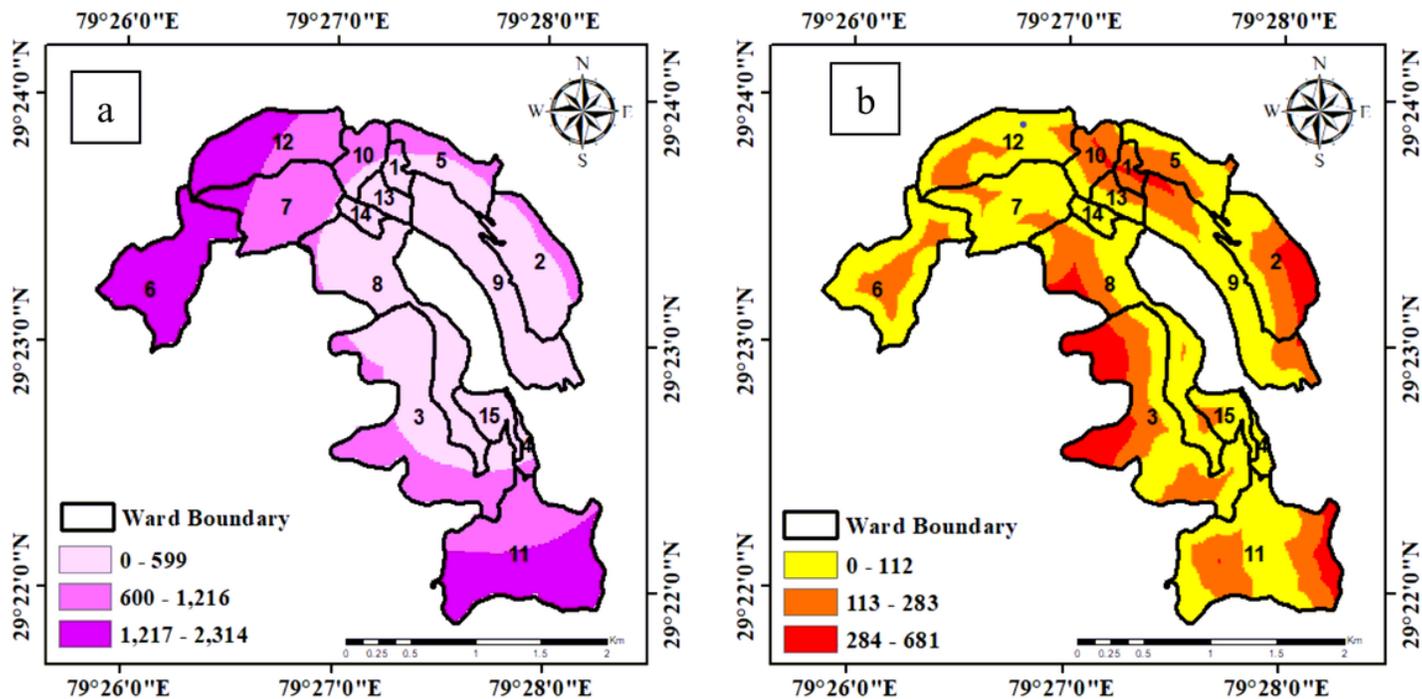


Figure 5

Indicator of Adaptive Capacity a) Distance to Lake b) Distance to Road Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

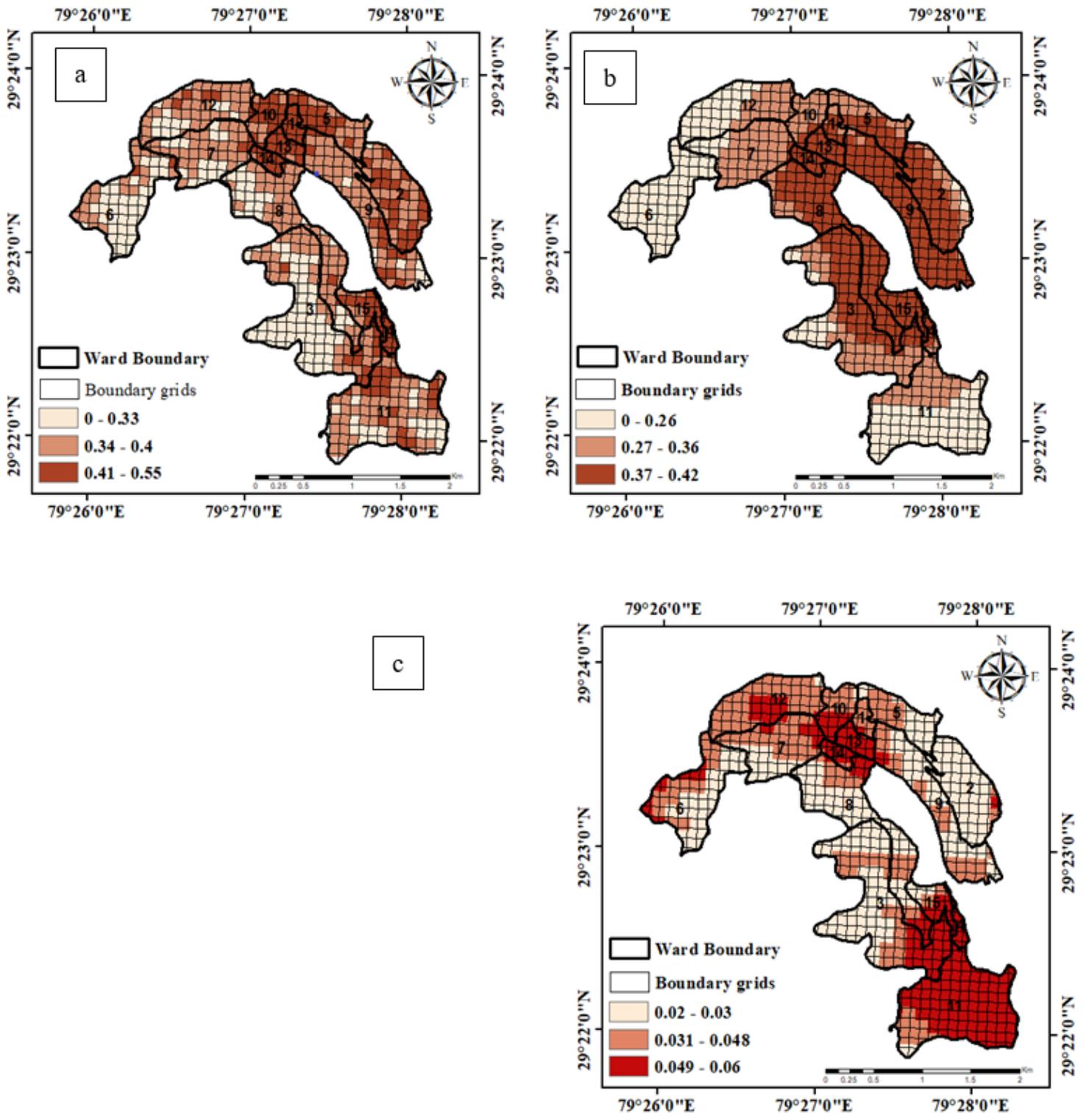


Figure 6

Dimension of Vulnerability a) Sensitivity b) Adaptive capacity c) Exposure Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

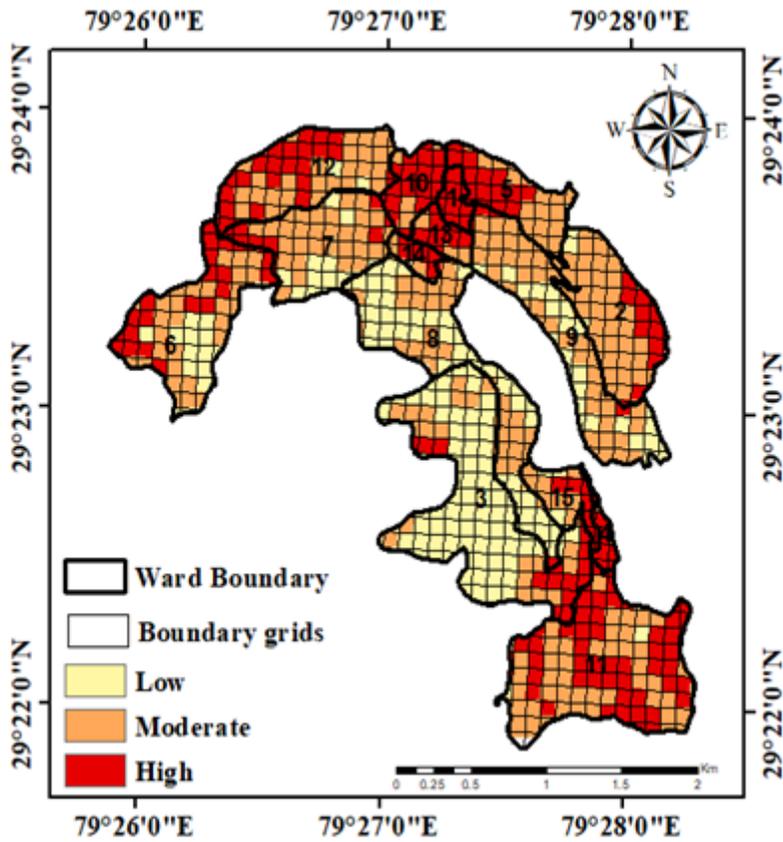


Figure 7

Vulnerability Map Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.