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RESEARCH ARTICLE

VULNERABILITY ASSESSMENT OF ENVIRONMENTAL AND CLIMATE CHANGE IMPACTS ON FRESHWATER RESOURCES IN THE DROUGHT – PRONE TAHSILS IN JALGAON DISTRICT (MAHARASHTRA STATE), INDIA

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ABSTRACT

Climate change and its consequences present one of the most important threats to water resource systems which are vulnerable to such changes due to their limited adaptive capacity. Water resources in semi- arid drought – prone study region is vulnerable to the potential adverse impacts of environmental and climate change. Besides climatic change, current demographic trends, economic development are exerting pressures and have direct impacts on increasing demands for water resources and their vulnerability. In this study, vulnerability assessment was carried out using guidelines prepared by United Nations Environment Programmed (UNEP) and Peking University to evaluate four components of the water resource system: water resources stress, water development pressure, ecological health, and management capacity. The calculated vulnerability index (VI) was high, indicating that the water resources are experiencing levels of stress. Ecosystem deterioration was the dominant parameter and management capacity was the dominant category driving the vulnerability on water resources. The vulnerability assessment help in developing long-term strategic plans for climate change mitigation and implement effective policies for sustainable water resources management. The region itself is considered one of the world's most water-stressed. In the last three decades, most tahsils in the study region have undergone dramatic demographic and socio-economic transformation, resulting in a substantial increase in water demand. These demands have been driven mainly by the implementation of agricultural policies aimed at achieving national food security and escalating urbanization, leading to immense pressures on the limited water resources in the region.

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INTRODUCTION

Freshwater resources are key ecosystem services which sustain life and all social and economic processes. Their disruption threatens the health of ecological systems, people's livelihoods and general human wellbeing. However, water resources are being degraded as a result of multiple interacting pressures particularly environmental and climate changes (MEA, 2005). The Fourth and Fifth Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC) played a major role in framing understanding of likely impacts of climate change on human society and natural systems, making it clear that "water is in the eye of the climate management storm" (IPCC), 2007; (Gosling *et al.,* 2011).

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The Earth's surface temperature has increased by about 0.5 °C during the last two decades, and a rise with similar amplitude is expected up to 2025, with direct effects on the global hydrological cycle, impacting water availability and Demand (IPCC), 2007; (Gosling *et al.,* 2011). Negative impacts on water availability and on the health of freshwater ecosystems will have negative consequences for social and ecological systems and their processes (Kundzewicz *et al*., 2007). For example, with an approximately 2 °C global-mean temperature rise, around 59% of the world's population would be exposed to irrigation water shortage (Rockstrom *et al.,* 2009). Besides climate change impacts, other drivers of environmental changes such as demographic trends, economic development, urbanization and related land-use changes are exerting pressures and increase demand for water resources (UNEP), 2012. Together, these drivers are stressing water resources far beyond the changes caused by natural global climatic changes in the recent evolutionary past. As a result of rapid population growth and economic development, and mismanagement of water resources, these drivers exert pressures on water resources, changing them both spatially and temporally and causing imbalances between supply and demand in hydrological systems (UNEP), 2012. The IPCC has defined vulnerability to climate change as the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes (Schneider *et al.,* 2007); (Adger *et al.,* 2007).

Vulnerability is also a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (McCarthy *et al.,* 2001; Lavell *et al.,* 2012). Vulnerability to climate change is generally understood to be a function of a range of biophysical and socioeconomic factors. It is considered a function of wealth, technology, education, information, skills, infrastructure, access to resources, and stability and management capabilities (O'Brien *et al.,* 2004); (O'Brien, *et al*., 2007). Most water-stressed arid countries are vulnerable to the potential adverse impacts of climate change; particularly increases in temperatures, less and more erratic precipitation, drought and desertification. This is especially true in arid plateau region particularly nine drought prone tahsils in the study region where a unique set of water management practices has enabled the development and survival, over centuries, of an agro-pastoral oasis social-ecological system. This study was conducted to assess the environmental and climate change impacts on water resources of the study region since no vulnerability assessments have been previously conducted in plateau region ecosystem. These are essential components for computing vulnerability index and assessing water resources in the region. The results should provide decision-makers with options to evaluate the current situation, modify existing policies, and implement adaptation and mitigation measures for sustainable water resources management in the study area.

The Study Area

The region selected for the study is the drought-prone tahsils. They are located in the Jalgaon district of Maharashtra State. There are 09 drought-prone tahsils identified by V. Subramaniam, (Review Committee, 1987). These tahsils are Amalner, Dharangaon, Parola, Erandol, Chalisgaon, Bhadgaon, Pachora, Jamner and Muktainagar. Looking into its delicate ecology and poor socio- economy, the study region is one of the most vulnerable regions of Maharashtra State. The topography of the region is hilly, plateau, undulating and rolling. The degraded soils with exposed rocks resulted from severe erosion is the common landscape. It covers an area of about 6994.54 km^2. It lies between $20^0 11^0$ to $21^0 13^0$ North latitudes and $74^0 46^0$ to $76^0 24^0$ East longitudes (Fig.1). Average rainfall is 682.8 mm in the said area. Also, temperature and relative humidity varies 18^0C to 35^0C and 45% to 72% over the years respectively.

Objectives

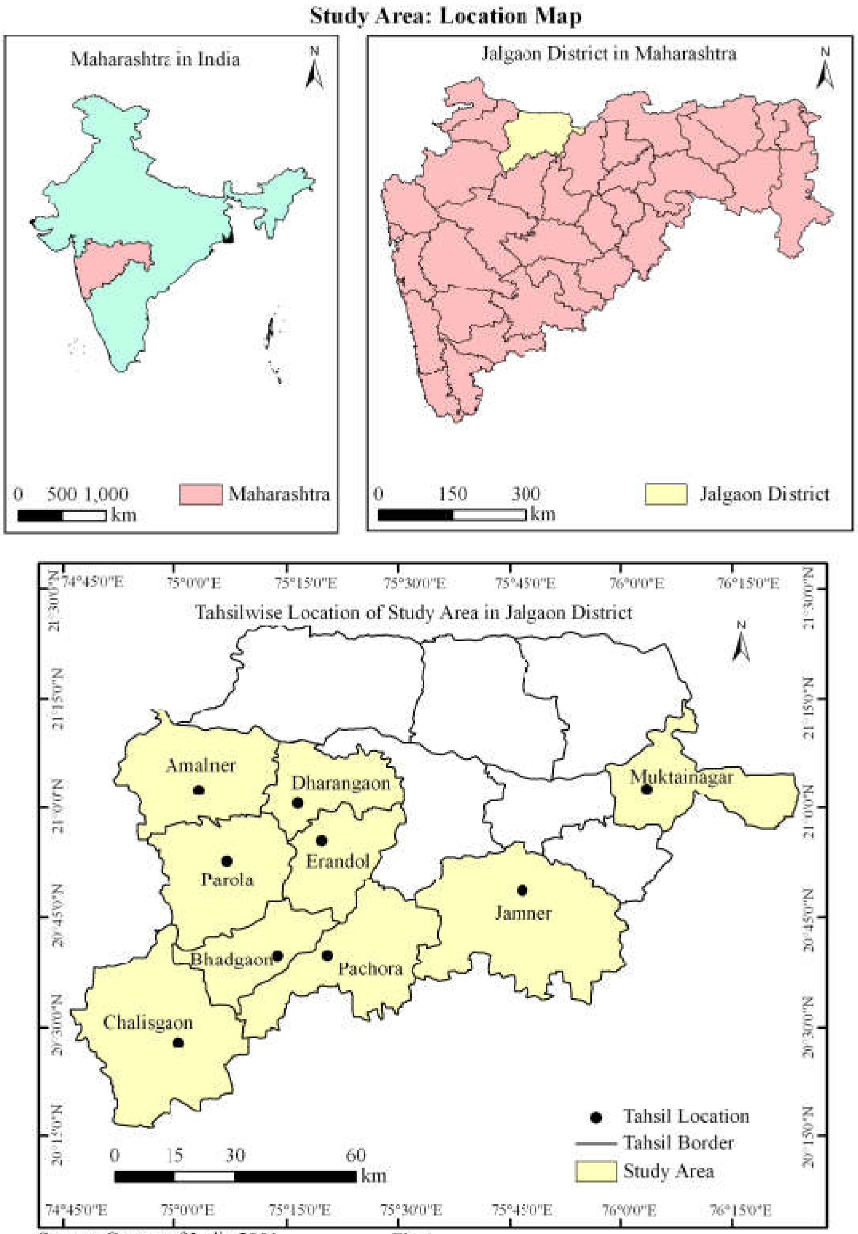
- To carry out a regional vulnerability assessment of freshwater resources to better understand the existing status of water under the prevailing conditions and to ascertain the most dominant factors that influence vulnerability in the study region.
- The availability of such an assessment will provide decision-makers with options to evaluate and to implement measures to improve water resource management

METERIALS AND METHODS

The methodological guidelines for "Vulnerability Assessment of Freshwater Resources to Environmental Change", developed by United Nations Environment Programmed (UNEP) and Peking University (UNEP, 2009) were used to assess the vulnerability of water resources of the study region to environmental change and climate impacts. According to the guidelines, the vulnerability of water resources can be accessed from two perspectives: the main threats to water resources and their development and utilization dynamics. The threats can be assessed in terms of resource stresses (RS), development pressure (DP), ecological health (EH) and management capacity (MC). Thus, the vulnerability index (VI) of the water resources can be expressed as: VI = f (RS, DP, EH, MC) Huang and Cai, 2009. Each component of VI has several parameters: RS = f [water stress (RSs) and water variation (RSv)]; DP = f [water exploitation (DPs) and safe drinking water inaccessibility (DPd)]; EH = f [water pollution (EHp) and ecosystem deterioration (EHe)]; MC = f [water use inefficiency (MCe), improved sanitation inaccessibility (MCs), and conflict management capacity (MCg)]. In accordance with the vulnerability assessment guidelines, a number of governing equations were applied to estimate these parameters and VI (Table 1).

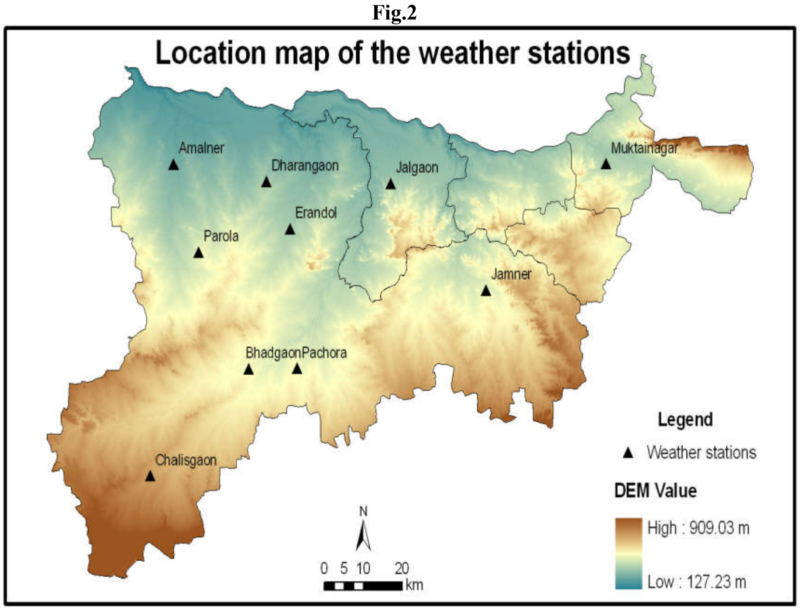
RS determines the water resources availability to meet the pressure of water demands for the growing population taking into consideration the rainfall variability. Therefore, it is influenced by the renewable water resources stress (RSs) and water variation parameter resulting from long-term rainfall variability (RSv). RSs is expressed as per capita water resources and usually compared to internationally agreed water poverty index of per capita water resources (1700 m3/person/year) (Huang and Cai, 2009). As the nine droughts - prone tahsils is part of study region characterized by scarce water resources, the more appropriate and realistic value of 1000 m^3/person/year (UNEP, 2012) was used. RSv was estimated by the coefficient of variation (CV) of the rainfall record from 1980 to 2011, obtained from IMD, Pune. The population data collected from Census Handbook of Jalgaon Distinct.

The CV was calculated for ten year period at intervals starting 1991, 2001 and 2011 by the ratio of the standard deviation of the rainfall record to the average rainfall (Table 1). DP was estimated in terms of the overexploitation of water resources (DPs) and the provision and accessibility of safe drinking water supply (DPd). DPs were estimated by the ratio of the total water demands (domestic, commercial, agriculture) to the total renewable water resources (Table 1). DPd is defined here as the provision of adequate drinking water supplies to meet the basic needs for the society, in regard to how the water development facilities address the population needs (UNEP, 2012). The lack of safe water accessibility was estimated by the ratio of the percentage of population lacking accessibility to the size of the population (Table 1). EH was measured in terms of the water quality/water pollution parameter (EHp) and the ecosystem deterioration parameter (EHe).



Source: Census of India 2001 Fig.1

Fig.2



EHp was estimated by the ratio of the total untreated wastewater discharge in water receiving systems to the total available renewable water resources (Table 1). EHe is defined in this study as the ratio of land area without vegetation coverage (*i.e.*, total land area except that covered with pastures and cultivated areas) to the total land area of the study region (6994.54 km^2) (Table 1). MC assesses the vulnerability of water resources by evaluating the current management capacity to cope with three critical issues: efficiency of water resources use; human health in relation to accessibility to adequate and safe sanitation services; and overall conflict management capacity. Thus, MC was measured with Water use inefficiency parameter (MCe), Improved Sanitation inaccessibility parameter (MCs), and Conflict Management Capacity Parameter (MCg). MCe was estimated in terms of the financial contribution to gross domestic product (GDP) of one cubic meter of water in any of the water consuming sectors compared to the world average for a selection of India. Since the agriculture sector is the major consumer of water in the study area, it was used to indicate the financial return from the water use. Therefore, MCe was calculated using the mean GDP value produced from 1 m^3 of water for the Maharashtra state (Table 1) MCs were used as a typical value to measure the capacity of the management system to deal with livelihood improvement in reducing pollution levels. Improved sanitation was defined here as facilities that hygienically separate human excreta from human, animal and insect contact, including sewers, septic tanks, flush toilets, latrines and simple pits (Huang and Cai, 2009). MCs were estimated as the ratio of proportion of the population without accessibility to improved sanitation facilities to the total population of the area (Table 1). MCg demonstrates the capacity of a water resources management system to deal with conflicts. A good management system can be assessed by its effectiveness in institutional arrangements, policy formulation, communication mechanisms, and implementation efficiency (Huang and Cai, 2009). The parameter was defined here as the capacity of the area to manage competition over water utilization among different consuming sectors. MCg was determined based on water assessment survey and expert consultation (Abahussain, 2014) using conflict management capacity scoring criteria ranging from 0.0 to 0.25, taking into consideration the interrelation of all variables in this table.

These aspects were assigned scoring criteria ranging from 0 to 1 giving weights to each parameter. Because the process of determining relative weights can be biased, making it difficult to compare the final results, equal weights were assigned among the parameters in the same category, and also among different categories. According to the guidelines (Huang and Cai, M. 2009), the weight of 0.25 was assigned across all categories (RS, DP, EH, and MC). For parameters RSs, RSv, DPs, DPd, EHp and EHe, the weight of 0.5 was applied, and for parameters MCe, MCs, and MCg, the weight of 0.33 was assigned. The total weights given to all parameters in each category should be equal to 1, and the total weights given to all categories should be also equal to 1 (Huang and Cai, M. 2009). The vulnerability index (VI) was finally estimated based on the four categories using the equation in Table 1. VI provides an estimated value ranging from zero (non-vulnerable) to one (most vulnerable) to determine the severity of the stress being experienced by the water resources of the study area. A high VI value shows high resource stresses, development pressures and ecological health, and low management capacities.

RESULTS AND DISCUSSION

Resource stresses

Water Stress Parameter

The calculation of water stress for the study area, shows a medium water stress (RSs = 0.30) (Table 3) based on the estimated total renewable water resources per capita of 821 m3/person/year (FAO, 2014). The increase in population and rapid socioeconomic development in the study region exert pressures on water resources: domestic water consumption increased from 97.46 m^3 in 1991 to 187 m^3 in 2011; an increase of 11.36 % per decade year. Much of this increase may be due to the urbanization and industrialization. For 1991, 2001, and 2011, the calculated RSs for the study region was 0.16, 0.24, and 0.30 based on the estimated per capita renewable water resources of 1013, 908 and 821 m3/person/year, respectively (UNEP, 2012).

Water Variation Parameter

Rainfall amount and availability are the dominant factors in the supply of water resources in the study area. Analysis of rainfall data records from 1980 to 2010 resulted in a water variation parameter (RSv) of 1.00, based on the estimated CV of 0.486, indicating high rainfall variability. The methodology guidelines (UNEP, 2012) designate a set of rainfall variation values for the coefficient of variation as CV = 0.3 or as a CV > 0.3. When CV is > 0.3, RSv is assigned a highest value of 1, indicating large rainfall variation in time and space; a CV less than 0.3 reflects low variability. However, the study area experienced increasing temperatures over the same period (Figure 2). Minimum, mean and maximum temperatures increased at rates of 0.30, 0.20 and 0.12 °C per decade, respectively. Analysis of rainfall data showed a reduction in water availability, with a general decrease in total rainfall from 1980 to 2010 (Figure 2). Over this period, the average rainfall was 682.8 mm; the highest total was in 1981 (980 mm) and annual rainfall decreased subsequently to 330.4 mm in 2000, with an overall decrease in total rainfall at a rate of −9.7 mm per decade; indicating that the area is vulnerable to climate change as it is an semi - arid hilly region. Projection of future climate in the study region using the IPCC A1B scenario shows an increase in temperature and a decrease in rainfall over the coming decades (Al-Charaabi and Al-Yahyai, 2013).

Water Development Pressures

Water Exploitation Parameter

The assessment of water development pressures indicated that the study area suffers from critical conditions in the development of water resources as determined by the water exploitation parameter (DPs = 0.86) based on total water demands of 1381.9 million m3/year and the available total water resources of 1598 million m3/year (Table 2), resulting in water shortages for domestic and agricultural purposes. There have been increases in the total population and socioeconomic development as well as increases in construction and commercial activities including hotels, and therefore water consumption by different sectors, causing an imbalance between supply and demand in the absence of the implementation of any conservation and management practices.

Table 1. Equations used for calculation of all categories and parameters of vulnerability index of water resources in the study area

Category	Parameter	Equation	Description
Resource Stress (RS)	RSs	RSs = (1000 − R)/1000	R: Total renewable water resources per capita (m3/person/year)
	RSv	RSv = CV/0.3 CV = S/μ	CV: Coefficient of variation μ: Mean rainfall (mm) S: Standard deviation
Development Pressures (DP)	DPs	DPs = WRs/WR	WRs: Total water demands WR: Total renewable water resources
	DPd	DPd = Pd/P	Pd: Population without access to improved drinking water sources P: Total population of the area
Ecological Health (EH)	EHp	EHp = (WW/WR)/0.1	WW: Total untreated wastewater WR: Total renewable water resources
	EHe	EHe = Ad/A	Ad: Land area without vegetation coverage A: Total area of the country
Management Capacity(MC)	MCe	MCe = (WEwm − WE)/ WEwm	WE: GDP value produced from 1 m3 of water WEwm: Mean WE of West Asia countries
	MCs	MCs =Pd/P	Pd: Population without access to improved sanitation P: Total population of the area
	MCg	MCg = parameter matrix	Matrix scoring criteria (Table 2)
$VI = \sum_{i=1}^{n}\left[\left(\sum_{j=1}^{m_i} x_{ij} * w_{ij}\right) * w_i\right]$			n: number of parameter category mi: number of parameters in ith category Xij: value of jth parameter in ith category Wij: Weight given to jth parameter in ith category Wi : Weight given to ith category

Table 2. Study Area: Calculation of the four parameters used for estimating the Vulnerability Index for the region (2011)

Category	Resource stress (RS)		Development Pressure (DP)		Ecological Health (EH)		Management Capacity (MC)		
Parameter	RSs	RSv	DPs	DPd	Ehp	EHe	MCe	MCs	MCg
Calculated	0.30	1.00	0.86	0.25	0.11	0.12	0.34	0.40	0.48
Weight in category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.15	0.50	0.43	0.13	0.06	0.06	0.11	0.13	0.16
Component Total	0.65		0.55		0.11		0.40		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	0.16		0.14		0.03		0.10		
Overall Score				0.430	High				

Source: Computed by the researcher, 2017 Notes: Water Stress (RSs); Water Variation (RSv); Water Exploitation (DPs); Safe Drinking Water Inaccessibility (DPd); Water Pollution (EHp); Ecosystem Deterioration (EHe); Water Use Inefficiency (MCe); Improved Sanitation Inaccessibility (MCs); Conflict Management Capacity (MCg).G

Safe Drinking Water Inaccessibility Parameter

The calculated safe drinking water inaccessibility parameter (DPd) was 0.25. The key factors making the latter four tahsils highly vulnerable is the high population growth rate, limited financial resources and finally, limited availability of water resources. Water needs of the different segments of society. Drinking water supply inaccessibility varies from 0.20 to .28 for the decade year 2011. The government supplies drinking water to all households via groundwater wells and a piped desalinated water project is in progress, to increase the availability of drinking water in the area.

Ecological Health

Water Pollution Parameter

The estimated water pollution parameter value was (EHp = 0.11) (Table 2) based on the total untreated wastewater of 181.250 m3/year and the total available water resources of 1569 million m3/year, given that the urban water usage is 11.5 million m3/year. The analysis indicates low water pollution risks, which may be attributed to investments in wastewater treatment facilities: the government has established three wastewater treatment plants in the area with tertiary treatment levels and some sewerage systems, and all modern houses and other establishments have septic tanks. However, more investments are needed to increase the proportion of sewer networks. Figure 3 Trends in mean air temperature (T_{mean}) and annual rainfall in the study region tahsil Meteorological Stations (World Meteorological Organization (WMO) Index: 41254, Universal Transverse Mercator (UTM) coordinates Latitude: 20° 11' to 21^0 13’ N, Longitude: 74° 46' to 76^0 24’ E, Elevation: 586 m) from 1980 to 2010 (IMD, Pune) connected with the treatment plants. Moreover, some septic tanks in old houses have unlined foundations and need to be reconstructed to avoid pollution to groundwater aquifers.

Ecosystem Deterioration Parameter

Ecosystem deterioration due to the absence of adequate vegetation cover and modified natural landscape is a critical parameter in the study area, causing severe problems in supporting the functioning of ecosystems. EHe was calculated as 0.12, in this calculation of the annual degradation rate compared to the total area of each tahsils was calculated to estimate the ecosystem deterioration parameter. A decrease in vegetation coverage due to natural and anthropogenic activities has been observed in most tahsils, particularly after 1991, as shown in Table - 2, a high degree of deterioration is due to unsustainable land use practices, decrease in vegetation cover due to a decrease in rainfall, overgrazing and urban expansion into farm areas. Jammer tahsil has relatively reasonable vegetation cover that can be attributed to higher rainfall. There are some indications of ecosystem deterioration in the study area due to decreased rainfall over the last three decades and therefore a decline of groundwater levels and the drying up of most wells.

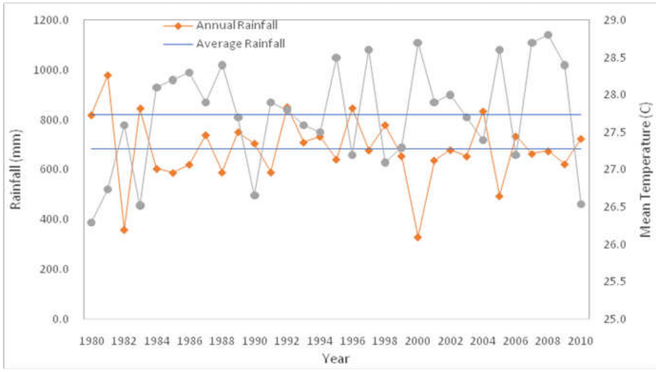
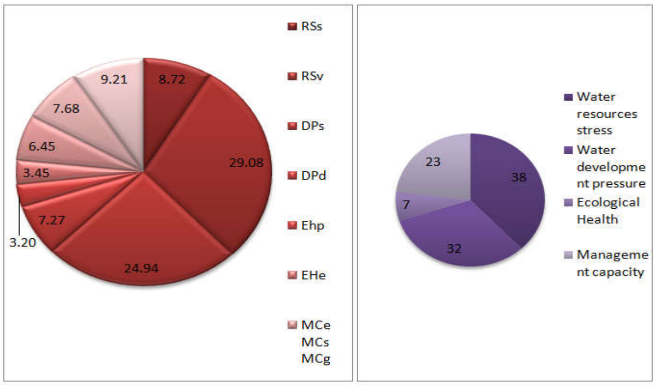


Fig 3

Management Capacity

Water Use Inefficiency Parameter



Notes: Water Stress (RSs); Water Variation (RSv); Water Exploitation (DPs); Safe Drinking Water Inaccessibility (DPd); Water Pollution (EHp); Ecosystem Deterioration (EHe); Water Use Inefficiency (MCe); Improved Sanitation Inaccessibility (MCs); Conflict Management Capacity (MCg).

Fig 4 (a) Percentage of the weighted parameters for Vulnerability Index (b) Share of the percentage of the weighted categories to the final Vulnerability Index for the study area

This parameter was not calculated for the study area since it is based on the country scale and cannot be estimated at a regional scale. In the study region, farmers still use a traditional method of irrigation by flooding, with no application of modern irrigation technology or investments in improving irrigation infrastructure systems. Based on water assessment survey and personal communication with the author of the UNEP report on this situation, MCe for the study area was estimated 0.34, representing medium water use inefficiency. This indicates sustainable water resources management practices in the presence of a comprehensive water sector plan and strategy, leading to reduced medium water availability and increased vulnerability.

Improved Sanitation Inaccessibility Parameter

Availability of sanitation infrastructures reduces pollution levels and preserves water resources. Accessibility to improved sanitation is used as a typical value to measure the capacity of a management system to deal with likelihood improvement in reducing pollution levels. This parameter is calculated as the proportion of population without access to improved sanitation facilities. The country value was used since no data was available at the regional scale. Jamner has better sanitation accessibility than Chalisgaon and Pachora tahsils, in the study region as shown in Table - 2. The sanitation inaccessibility values reported in Table – 2, ranging between 0.29 and 0 .48 in 2011 indicate higher sanitation inaccessibility values entire population of the study area has low access to sanitation facilities. In the study region most of its area is considered rural which have lower coverage

Conflict Management Capacity Parameter

The study area has competition over water utilization with the neighboring regions. However, there is competition over water utilization between different sectors (agriculture and domestic). Agriculture is the dominant water consumer, with no application of conservation mechanisms and proper management capacity. There is also an increase in the domestic water consumption from groundwater wells, due to an increase in population and number of hotels and commercial activities, and there is no clear strategy for the development of the area. Therefore, the assessment of MCg showed a high vulnerability situation in regard to conflict management capacity (MCg = 0.48) since this parameter takes into consideration the interrelation of different categories including institutional, agreement, communication and implementation capacity.

Vulnerability Index

Based on the available data, the calculated VI is 0.430, in the range of 0.4–0.7 which is classified as high based on the reference sheet for the interpretation of VI (Huang, Y., Cai, M., 2009) indicating that the water resources of the study region are highly vulnerable and experiencing high stresses. Water Resources variation is the dominant parameter, contributing 29.08 % (Figure 3a). The area has also been experiencing a high degree of water resource exploitation, and conflict management capacity representing 24.94%, 9.21% and 8.72%, respectively (Figure 4a), influencing the overall vulnerability on water resources. Comparison of the share of the different category groups to the final VI showed that the water resources stress contributes most to the water resources vulnerability and is the dominant category (37.81%), followed by water development pressure with 32.21 % and management capacity with 23.34 % (Figure 4b).

Conclusions and Recommendations

This is the first comprehensive vulnerability assessment of water resources in the study region. The results have served to highlight which aspects of water management (resources stress, development pressure, ecological health, and management capacity) contribute most to the vulnerability of water resources and to understand the various risks and thus to suggest potential areas to best focus management efforts. The vulnerability assessment indicated high VI (0.457). Water variation is the dominant parameter contributing 27.32% to the vulnerability index. The water resources of the area have also been experiencing a high degree of water use inefficiency, water stress, conflict management capacity and, influencing the overall vulnerability index by 23.44%, 14.4% and 12%, respectively. Water resources stress is the dominant category, representing 41% of the category groups, driving the vulnerability of the water resources, which are also highly influenced by the water development pressure (27%) and management capacity (25%). These could be used as indicators for the vulnerability of water resources to environmental and climate changes in the study area. Nevertheless, it must be recognized that due to the lack of availability of local data, some of the inputs to the assessment are at national scale. There is a clear need for policies and technical solutions to mitigate the pressures which make the water resources more vulnerable. A longer term strategic development plan should be made, with a focus on management capacity to deal with the main threats of conflicts between water consuming sectors, as well as implementation of effective management practices in line with the integrated water resources management approach. Additional effort is needed to improve irrigation water use efficiency, conservation technologies, rainwater harvesting, and grey water to relieve some of the agricultural pressures on water resources. There is also an urgent need for mitigation and adaptation to climate change impacts since the region is expected to face further increases in temperatures and decreases in rainfall over the coming decades. The major contribution of ecosystem deterioration to the overall index suggests that, in order to sustain the ecological health of the area, more efforts are needed to conserve and rehabilitate vegetation cover and implement best practices for land use management and strategic development.

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