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Research Article

USE OF GEOSPATIAL TECHNOLOGIES FOR VILLAGE LEVEL VULNERABILITY ASSESSMENT OF WATER SCARCITY IN HIMACHAL PRADESH

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A B S T R A C T

Nearly 70 percent of the population of India lives in rural areas. The requirement of basic natural resources like drinking water, sanitation, technology, agriculture, education etc. in these areas poses a challenge to the policy makers to plan, implement and monitor various developmental schemes. There is a constant change in the landuse of topography of Himachal Pradesh. The constant development and growth combined with variable climatic conditions over the years cause more stress on natural resources specially water resources. This paper examines vulnerability assessment of water scarcity between domestic, livestock and agriculture water use with geospatial parameters at the household level in rural villages of Himachal Pradesh. Rainfall data for five years was analyzed for the study area along with household interviews, self-reporting by households and statistical mapping. The village wise available water requirement for two cropping seasons Kharif and Rabi was estimated for different crops and livestock water use requirement using the GIS and Remote sensing. Runoff available for each village based on average annual rainfall was calculated. Results show that spatial variation of water use for domestic, livestock, and agriculture use remained high for the year 2012 as there was evidently less amount of rainfall. The vulnerability maps were generated for the years 2012 and 2016 which depicted the areas which were vulnerable to the water scarcity compared to the other regions in the cluster. The villages having dominant landuse as tea gardens depicted less variation over the period, due to the minimal landuse change. This study confirms the appropriateness of the geospatial technologies alongwith direct observation, survey, and micro-geographical methods for quantitative water use studies at village level.

INTRODUCTION

There is a constant change in the land use and topography of Himachal Pradesh. The infrastructure development and growing population combined with the dominant variability in the rainfall trends over past few years is causing more stress on the already depleting water resources. This water shortage for some activities, group or environmental sector, is causing economic losses and significant damage to human lives. The most important use of water includes growing the food necessary for humans and rearing livestock. The water requirement for increasing human population with the constant increase in the demand of agriculture has increased significantly in developing countries threatening the outcome of major environmental, social and economic problems. The world's cultivated area has grown by 12% over the last 50 years. During this period, the global irrigated area has doubled, accounting for most of the net increase in cultivated land (FAO 2011). Agriculture makes use of 70% of all water withdrawn from aquifers, streams and lakes. Globally, groundwater provides around 50% of all drinking water and 43% of all agricultural irrigation. Irrigated agriculture accounts for 20% of the total cultivated land but contributes 40% of the total food produced worldwide (FAO 2011). Recent trends of rainfall over Himachal Pradesh shows a decreasing trend of about 13% in precipitation from its mean from 1977 to 2007 (Kumar *et al*. 2015). Village systems are the most complex units as the livelihoods are purely dependent on availability of natural resources. Rapid land use changes witnessed in the state result in scarcity of land and consequently a dearth of agricultural by-products such as fuel and fodder, making them less available to the rural sections. The rural population receives more impacts caused by urbanization, changes in agricultural production and marketing or in the quality and availability of common natural resources. Understanding the basic water uses at village level will is of great use in judicious

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water allocation and management. The gradually increasing population and economic development in rural sectors along thus emphasize the need for water management by taking into consideration the available water resources. Different sectors of society use water for different purposes like drinking, growing food, hygiene, livestock rearing (Gleick 1996) which put together exploit the local natural resources. Combined with the constantly varying rainfall and increasing temperature, the ground recharge mechanism is failing and quantifying to drought conditions. Drought is a regional phenomenon whose characteristics will vary significantly among regions. Drought is a critical phenomenon of climatic change whose occurrence, duration, intensity and spatial extent is difficult to quantify (Ray 2000; Wilhite 2000). Some of the major indicators for identifying the drought hazard is to analyze rainfall, temperature, and soil moisture measurements from meteorological stations (Beguería and Vicente-Serrano 2006). Natural resources like land and water is exploited due to degradation of land resources, climate variability, water scarcity and drought leading to many changes in the villages. The major indicator in identifying drought conditions in rural areas can be identified with decreased productivity due to non-cultivation of cultivable area due to lack of availability of irrigation water. For village level planning and development it is essential to study the agro-economic variables like rainfall, cultivated area, crops grown as well as rising population demands (Rao, Babu, and Bantilan 2009). Village agro-ecological systems are the most complex systems as the livelihoods depend on availability of natural resources to meet various demands. Hence, estimation of basic water uses at village level will be of great use in water allocation and management. Therefore, the study of variation and trend in rainfall and village water use and availability are paramount to conserve village systems. The spatial extent and variation of drought is not only dependent on rainfall occurrences but also on surface and groundwater movement and availability (Deshpande *et al*. 2016). The immediate signs of water scarcity and drought conditions are villages that other regions. In any development plan for water resources, priority shall be to meet the basic needs of a village as well as safeguarding of ecosystems. A study by (Mokgope and Butterworth 2001) on water resources and water supply for rural communities in the Sand river catchment, South Africa identified the productive uses of water at the household level and irrigation. The water requirements for the crops grown, domestic use and livestock demand were estimated for a watershed in Yunnan Province, China (Ma, Xu, and Qian 2008). (Vedula 1985) estimated the crop water requirements for different cropping patterns as per existing package and practice and irrigation water requirements of the different crops based on the guidelines of the Water management division of the Ministry of Agriculture for a river basin, India. The analysis of rainfall trends and water use requirements at village level is crucial for better agricultural and water resources management, which would lead to the village development. Many technologies are available for identifying the early signs for available water and management of it. The different Government departments are working on assessing the water demand at different scales via watershed development and management programs. The objective of this project was to examine the spatial relationship between domestic water use and agriculture water use at the household level in rural villages of Himachal Pradesh with the help geospatial technologies and support as tool for the village level information and development framework.

Study area

The study area is grouped into one cluster comprising of six villages lying between 32º 6′ 48.94′′ N to 32º 8′ 10.16′′ N latitude and 76º 31′ 17.65′′ E to 76º 33′ 3.26′′ E longitudes. The cluster lies in Zone 2.2 agro ecological zone (AEZ). The elevation profile ranges from 1000 m to 1500 m. The area is located in the close proximity of the Dhauladhar mountain range and is located on the northwestern region of Himachal Pradesh. The region is surrounded with pine forest and tea gardens. Livelihood options are mainly agriculture and livestock rearing besides other related options in various sectors. Cropping seasons are divided in two seasons namely Kharif (June to October) and Rabi (November to March). The rainfall period is noted for the months from mid-July to August. Agriculture is practiced mainly in five out of six villages in the cluster and in one village; the tea garden dominates the land cover. Both cropping season are purely rain-fed and dependent entirely on the irrigation channels constructed for irrigation scheduling during the season from nearby rivulets. Tube wells are main source for drinking water purpose as the depth of aquifers is deep and water table lies at varying depths, which tends to run dry soon after dry monsoon periods. Village level population data was obtained from census data(Registrar General and Census Commissioner 2011). Mainly cows and goats are reared for livestock in the region besides very less poultry farming. Wheat is the main crop that is cultivated in the Rabi season along with some millet and other forage crops whereas in Kharif season Maize and Paddy are the main crops that are cultivated. Some vegetables like tomato, peas, chilies, cucumber are also grown at marginal scale in the region.

MATERIALS AND METHOD

Village wise Water Requirement Calculation

Population statistics is the crucial player in the estimation procedure of domestic water demand. The water requirement for each village in the cluster depends directly on the socioeconomic activities of population residing in the villages. The most dominating occupations are agriculture, tea gardening and livestock rearing besides the working population of the cluster. A lot of population of the nearby municipal area is residing in the cluster areas and have contributed to the significant built up area of the cluster, thereby increasing the number of households. The total amount of the water required per day is dependent on the water use of a village for domestic, livestock and agriculture purposes.

Domestic Water Requirement - Water requirements for domestic purpose is defined for maintaining human survival. This includes the basic water requirements for sanitation defined for providing sanitation services, bathing alongwith water requirement for cooking (Butterworth and Soussan, 2001). (Mokgope and Butterworth, 2001) estimated domestic water needs based on population. For estimation a focus group based field survey was conducted to calculate the average water usage to meet daily household activities by each individual. Observations recorded during the survey varied from 30 liters to 56 liters per day for bathing, cooking and sanitation purposes. This was in consensus to (Asokan and Dutta 2008) who recommended water requirement per person in urban areas to 135 liters per day and in rural areas to 40 liters per day. The water requirement for the domestic purposes were estimated using the equations given by (Ganapuram *et al*. 2013) as follows:

Quantity of water required per day (WD) = Total population of the village * 40 liters /day
Quantity of water required per year (WD_a) = 365 * WD

Livestock Water Requirement - The livestock in the cluster includes cattle. It is essential to have an estimation of water required for livestock rearing. Water requirement for livestock refers to the quantity of water required for drinking and water in feed to support livestock production. The water required for livestock was estimated by counting the number of cattle heads in each village which were considered as consumptive head. (Fowe *et al*. 2015; Frasier and Myers 1983) have estimated water requirement for different cattle from 35 liters per day to 85 liters per day. We have aggregated the consumption per day to 50 liters per day for the local breed of the cow found in our cluster. The water requirement for the domestic purposes were estimated using the equations given by (Ganapuram *et al*. 2013) as follows:

Quantity of water required for livestock consumption per day (WL) = No of cattle * 50

Agricultural Water Requirement – Water use for agriculture cultivation of each village was estimated based on irrigation requirement for cultivation of different crops during the cropping seasons. The major crops cultivated during Kharif (June to Oct) and Rabi (November to March) and their irrigation water requirements were used in the estimation of village agricultural water requirements. The major crops cultivated in the cluster were wheat, maize, sugarcane, paddy, sorghum, bajra, potato and vegetable like tomato, onion, chilies, cauliflower, citrus during the two cropping seasons. The irrigation water requirements as reported by (Bhagat *et al*. 2006; Michael 1978) for these crops are shown in Table 1.

Table 1 Irrigation requirement for various crops

Crops	Irrigation requirement (mm)
Wheat	450 mm
Maize	625 mm
Sugarcane	2200 mm
Paddy	1000 mm
Sorghum	500 mm
Bajra	500 mm
Potato	300-500 mm
Other Crops / Vegetables Tomato, Onion, Chillies, Cauliflower, Citrus	500 mm

The water requirement for the agriculture purposes were estimated using the equations given by (Ganapuram *et al*. 2013) as follows:

Quantity of water required for agriculture for Kharif season (WK) = Cultivated area (in acres) * Water requirement for $Kharifcrop_1$* 4046.9 + Cultivated area (in acres) * Water requirement for $Kharifcrop_2$* 4046.9

For Rabi season agriculture water use (WR) = Cultivated area (in acres) * Water requirement for $Rabicrop_1$* 4046.9 + Cultivated area (in acres) * Water requirement for $Rabicrop_2$* 4046.9

Mapping Village wise Water Requirement

The total water usage for each season and for the whole year is estimated as the sum of all type of activities that consume water for various purposes as mentioned in the above sections i.e. domestic purpose, livestock consumption and agriculture cultivation. This data was tabulated and normalized for each village in the cluster and termed as attribute data for the each village alongwith the other non-spatial data prepared for the cluster. The spatial data included the georeferenced and digitized cadastral maps for each village prepared using ESRI ArcGIS Desktop 10.3 version. A recent cloud free 50-cm resolution, colour, orthorectified imagery Pléiades Satellite Imagery was procured for the study area through National Remote Sensing Centre, Hyderabad. Multi- resolution segmentation was used for classifying satellite imagery (Liu, Wang, and Liu 2005). Training sets were created for building roof tops based on which the classification was carried out. Object oriented classification was used to create a vector file which was stored in a Geodatabase created for the cluster wherein the feature class namely khasra boundary, buildings were stored. The cadastral maps were procured from the Local revenue office was georeferenced and was digitized on the scale of 1:1000 using ESRI ArcGIS Desktop 10.3.1 software. The cadastral map was categorized into different feature classes as agriculture area, tea garden, grasslands, settlements and non-cultivable area. The water requirement estimated for domestic usage, livestock rearing and crops cultivation of each village mentioned in the above sections was joined to the spatial data as attribute data for the village mapping. Thematic maps showing the spatial variability of water demand for domestic, livestock and cultivation were prepared. Thematic map depicting the total water use of a village was also generated. Estimation of water available for usage was estimated by adopting a simple method proposed by (Ganapuram *et al*. 2013). The rainfall data for five consecutive years was collected from the local weather station from 2012 to 2016. The estimated value for available water can be calculated by accounting for the amount of water that gets evaporated through the open surface, surface run off and deep seepage. These parameters are dependent on the vegetation cover and soil type. The total amount of water received in a year by the village in million cubic meters can be estimated by multiplying the area of the feature classes categorized as household, agriculture area and grasslands with rainfall as:

Total water available (TWA) = Satellite imagery based Area of the village * Annual Rainfall in mm * 0.001 m/mm

RESULTS AND DISCUSSIONS

The water requirement of each village in the cluster was estimated. The total geographical area of the cluster is 304 ha. which requires approximately about 4.05 million cu.m annually for domestic, livestock and agriculture usage to cope with any water stress vulnerability. Based on the methodology discussed above, water requirement for domestic usage, livestock rearing and agriculture usage was estimated to around 0.104 million cu.m, 0.009 million cu.m and 3.9367 million cu.m respectively per annum. Around 162 ha. is under cultivation which is used for various crops during the two cropping seasons. Village Har with population of around 475 persons and 35 ha. of cultivable area was estimated to require 1.02 million cu.m/year water. Similarly Village Aima having highest population of around 2775 persons and 32 ha. of cultivable area required 0.040 million cu.m in the cluster. Similarly for livestock rearing consumption Lohna having highest livestock around 239 cattle heads estimated 4361 cu.m/year of water requirement as compared to 730 cu.m/year of water requirement for Bandla Khas village with merely 40 cattle heads and 793 persons and 14 ha. area as cultivable area as shown in Fig 1. Rainfall data for the period 2012 to 2016 was collected from the local weather stations. After classification using Arc GIS desktop spatial analyst and image classification tools, it was observed that around 48.26% of the cluster is under agriculture cultivation and other farming activities throughout the year. The estimated data was stored in the Geodatabase with the corresponding village fields. Using the geospatial tools the mapping of the usage requirement for domestic and agriculture use was done. Water requirement for Kharif season is comparatively remains high as compared to Rabi season (Fig. 2).

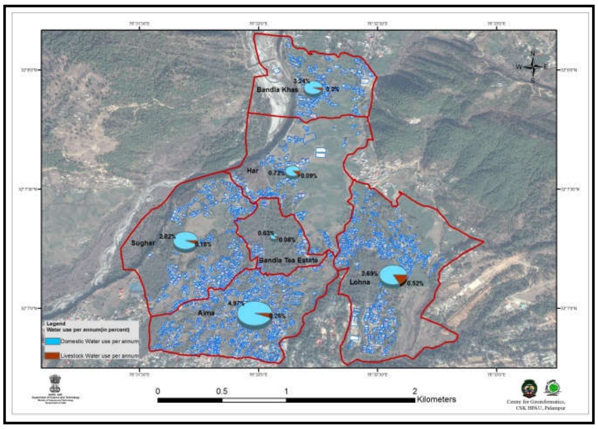

Fig 1 Villagewise requirement of Domestic and Livestock water consumption

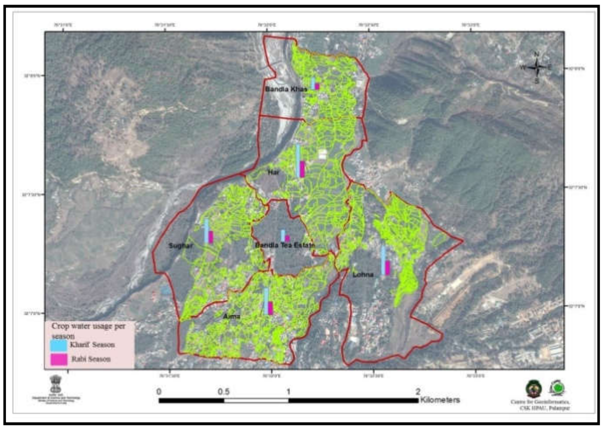

Fig 2 Season wise requirement for agriculture water consumption

With annual rainfall data, available water was estimated using the methods mentioned in the above sections. It was observed that 2012 received around 70% deficit from the normal rainfall trend in the region (Fig. 3). The following years 2013-2016 were observed for nearly normal rainfall. Despite being the variability in the rainfall, farmer still cultivate the traditional crops like Maize, paddy and wheat during the season. The cultivated area remains almost the same with a very less variability caused due to varying available water in the cluster. Approximately 15 % of the area during the Rabi season remains uncultivable of the total cultivable agriculture area. The erratic rainfall and lack of water storage facilities in the cluster enforce the farmers to shift toward the small scale farming leaving certain areas as fodder and barren which often is nonproductive and the produce is marginal. This is another reason that a dominant change is evident in the land use as the landuse is being changed from agriculture to settlements. Village Aima being densely populated and village Har having the largest cultivable area in the cluster remain at close margins with the available water over the period of five years except year 2012 as shown in Fig. 3. The water requirement for various activities in the village is very useful in planning the critical scenarios at micro shed level within the villages itself.

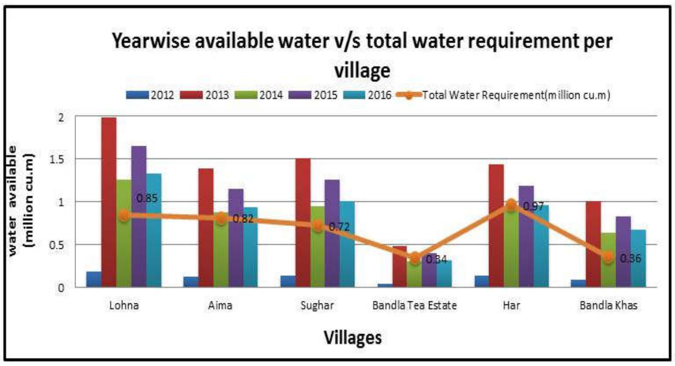

Fig 3 Total water requirement versus available water for five years

Assessment of water scarcity was determined using the budget equations for the cluster.

The water budget for two years i.e. 2012 and 2016 for each village were estimated by subtracting the total water usage annually from available water available for the corresponding years. Water scarce vulnerable areas for the cultivable areas in the cluster were classified using the equations and mapped thematically into five classes as very high, high, moderate, low and normal for the two years (Fig. 4 and Fig. 5). The Tea garden areas in the whole cluster was not considered during the budget estimation as these gardens were more than 25 years old and the production is only done on the existing plants and no new plants or gardens have been planted in over recent past.

In the year 2012 as depicted in the map at shown at Fig. 4, it is observed that the water availability was below the normal requirement in each village. This made around 74 ha. of the cultivable area very highly to highly vulnerable for water scarcity depicted by Red and Orange colors in the Fig. 4, which is approximately 45 % of the total cultivable area in the cluster.

Similarly the vulnerability map using the same budget equation was estimated for the year 2016 and is depicted by the map shown in Fig. 5. For the year 2016, it is observed that the available water was almost in normal range of the water required (Fig. 3) for each village. The vulnerability classification for the year 2016 was over and above around normal range. It was estimated that around 22 ha. of the cultivable area was under moderate vulnerability of water scarcity which is around 13 % of the rest of the cultivable area having sufficient water availability to meet the requirements Fig. 5. These maps were tested with trial rain gauges in selected villages of the cluster by measuring the rainfall. Interpretations of the data through the rain gauge are in agreement with vulnerability maps developed.

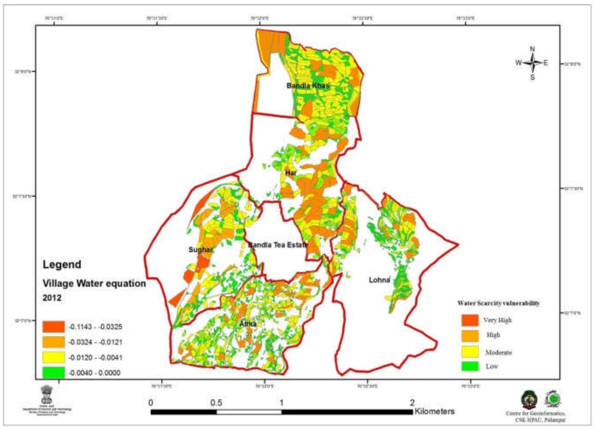

Fig 4 Water scarcity vulnerability map for the year 2012

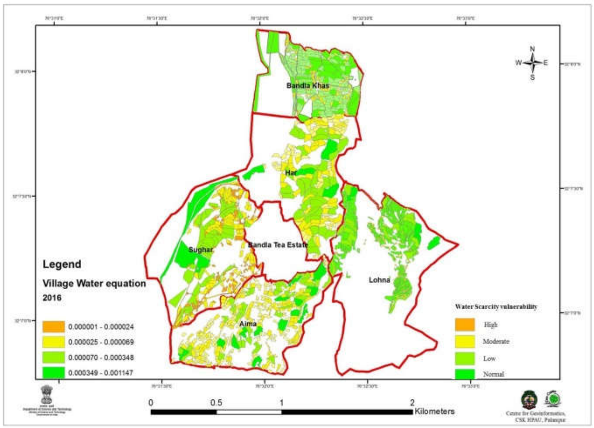

Fig 5 Water scarcity vulnerability map for the year 2016

CONCLUSION

It is observed that water consumption in these villages was lower than the norms laid down by the Bureau of Indian Standards. The lower consumption is mainly because of the erratic rainfall trends and water supply mechanism, not meeting the population growth and increasing needs of various activities. It was also observed that though a majority of households consume water below the specified norms, they were satisfied with available water and met the minimum daily requirements. Rain water harvesting methods, which have a large potential to solve emerging water crises in the regions where agriculture is practiced closely to the households are not known to a majority of people, more so those belonging to the poorer classes, which results greater amount of water loss as surface run off. However, it is found that a large number of households often reuse water, to cater the daily needs. The vulnerability thematic maps for the two scenarios thus were prepared keeping in mind the rural awareness programs, where the farmers and local community could be explained about the maps. Therefore, these kind of maps prepared at local level with some inputs from the community can be integrated in a water development framework to help the planners and administrative officials to thwart disaster and implement development programs.

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