International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-3, Issue- 4, April 2017
ISSN: 2395-3470
www.ijseas.com

Identification of Potential Water Collection Spots in Tribal Region of Himachal Pradesh, India Using Remote Sensing & GIS

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Abstract

Harvesting of rain water involves collection and storage of rain water for future use. The tribal region of Himachal Pradesh receives a very less rainfall in monsoon period because mountain ranges act as barrier for monsoon winds. This area gets most of rainfall in winter by western disturbances, mostly in the form of snowfall. In this study we seeks to identify potential sites for water collection spots in the tribal region of Himachal Pradesh. Weighted Vector Overlay Analysis have been used to identify water collection spots in the study area. The criteria factors taken into consideration for the Weighted Vector Overlay Analysis include; Geology, slope map, soil depth, soil taxonomy, drainage density, geomorphology and land use/cover map from the LANDSAT satellite imagery respectively. The image processing software ERDAS IMAGINE 10 and GIS software ArcGIS 10.3.1 were used to process the images and to establish a geo-information system comprising digital data sets.

Keywords: *Rain Water Harvesting, collection spots, tribal region, Weighted Vector Overlay Analysis.*

1. Introduction

Water is the most precious natural resource for sustaining life and is used in many ways. It is a part of the larger ecosystem in which the reproduction of the bio-diversity depends (Sivanappan, 2006). Water plays a vital role not only in fulfilling basic need for life and health but also in socio-economic development (Chand *et al.,* 2015). Rainfall and soil water are fundamental parts of all terrestrial and aquatic ecosystems, which supplies goods and services for human well-being. The available water resources are under pressure due to increasing demands. Conservation and preservation of water resources is therefore urgently required. Water management has always been practiced in our communities since ancient times, but today this has to be done on priority basis.

Rain water harvesting involves collection and storage of rain water for future use and is required to be taken up on a priority basis. As the world is facing an alarming situation of water scarcity its conservation requires immediate action (Kiran *et al*., 2014). The sustenance of life in future largely depends on how we protect these resources. Increasing population has resulted in over-exploitation of resources and the situation has become worse with increasing droughts in many areas. Therefore, it becomes necessary for us to harvest water efficiently and minimize wastage of rain water (Prasad et al., 2014).

According to United Nation Environment Program "*Rainwater harvesting locally collects and stores rainfall through different technologies, for future uses to meet the demands of human consumption or human activities*". Rainwater harvesting is described as the process of concentrating, diverting, collecting and storing surface runoff for different productive purposes e.g. domestic water supply, livestock, agriculture and environmental management. Rainwater harvesting consists of a wide range of techniques used to collect, store and provide water with the particular aim of meeting demand for water by humans and/ or human activities. Increased water provisioning capacity at a specific location enables management and use of water for multiple purposes in order to bridge dry spells and droughts (Barron *et al.* 2009).

The art of rainwater harvesting has been probably developed around 4500 BC (Li *et al.,* 2000) and practiced since the first human settlements. (Agarwal *et al*., 2005). Rainwater harvesting structures using cisterns was as early as 3000 BC in the Middle East (Barron *et al.,* 2009). Earlier rainwater harvesting systems were designed primarily to meet domestic needs for water. In recent decades many countries like India have made efforts to develop a wide variety of techniques to collect, store and use precipitation for agricultural purposes (Li et al., 2000).There is a need to develop tools for identifying suitable sites for these RWH technologies for their enhanced sustainability thereby increasing water availability for domestic and agriculture.

2. Objectives of the study

The study has been aimed to achieve the following objective.

- To identify the suitable spots for water collection in the study area through geo-spatial technology.

3. Data source, Tools and Methodology

Data for this study have been derived from different sources that include Landsat-8 OLI image, Geological map of Himachal Pradesh, Soil map of Himachal Pradesh and Topographic sheet of Survey of India. Data on population have been collected from Census of India, 2011.

a) Primary data (Satellite data): Landsat 8 sensor image (Operational Land Imager OLI 3rd August 2014) has been downloaded from USGS web portal. Image data in multispectral bands 2nd, 3rd, 4th and 5th {(blue (0.42-0.52 µm), green (0.52 – 0.59 µm), red (0.62-0.68 µm), near infrared (0.77 – 0.86 µm)} have been stacked together to create a multispectral image of spatial resolution of 30 m and this image was merged with Landsat 8 panchromatic data of having 15 m spatial resolution for better visualization in multispectral image. Aster DEM, and Carto. DEM was downloaded from USGS and Bhuvan Geo-platform respectively. Then, all these images were re-projected in UTM projection and WGS 1984 datum for extracting Slope maps and drainage map.

b) Secondary data: A number of published maps and reports have been used for the purpose of thematic layer generation as input. These are topographical maps at 1:50,000 scale from Survey of India (SOI), geological maps at 1: 5, 00,000 scale from Geological Survey of India (GSI) and soil maps at 1:5, 00,000 scale from National Bureau of soil survey (NBSS).

3.1 Weighted Vector Overlay

Weighted vector overlay analysis (Multi criteria equalization process) has been incorporated in order to find out the site suitability for water collection spots in the study area. A numerical weighting factor is assigned to each thematic layer according to its relative importance compared to all other layers. After that, the weighted layers are overlaid. All the attributes of the features taking part in the overlay are carried through, to create a new polygon layer. The feature of one layer are split where they are crossed by feature of other layer. The suitability maps have been ranked and grouped in order to identify the zones that are most suitable for the water collection. While determining suitable water collection zone, the goal is to minimize negative environmental effects in the final suitability areas.

The methodological flowchart of the study is given in the Figure 1.

Methodological Flow Chart Model

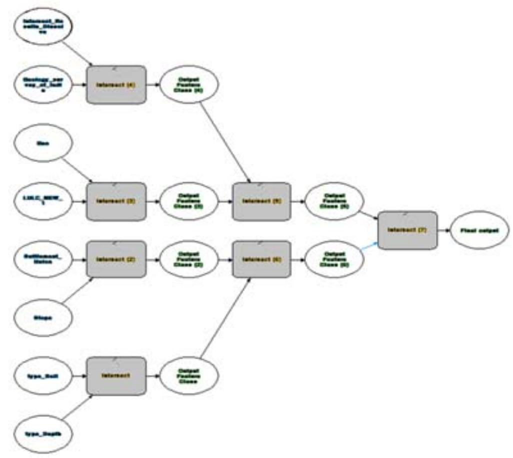

Fig.1 Methodological flow chart model built in Model builder (ArcGIS 10.3.1.)

Multi criteria equalization (MCE) requires that the values contained in the map are converted into comparable units. Therefore, the criteria maps has been re-classed into five comparable units. Table 1 shows the reclassified scale for suitability analysis. The suitability classes then has been used as base to generate the criteria maps (one for each criterion).

Table 1 Suitability class scale

1	3	5	7	9
Very low	Low	Moderate	High	Very high

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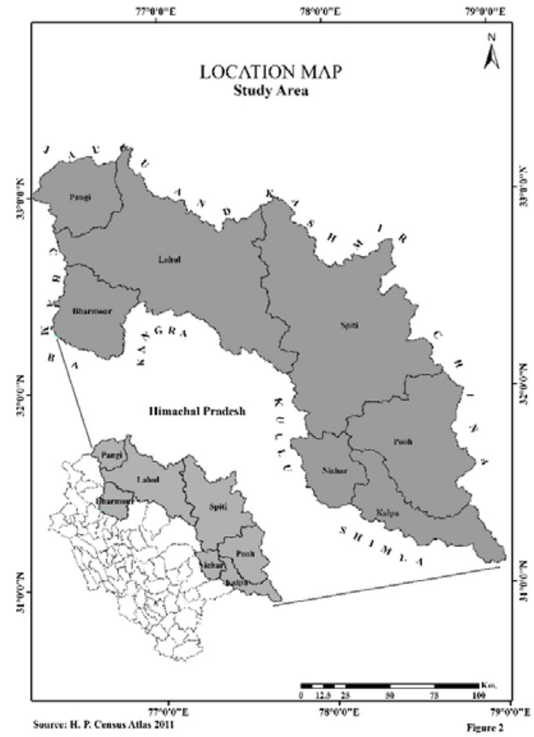
All required layer have been digitized using Arc GIS 10.3.1 software version. Slope layer have been derived from DEM of the study are using slope tool under surface tool in Arc GIS 10.3.1. All required layers have been given weight according to methodology used. All layers are weighted from 1 to 9 (Least suitable to most suitable) according to their suitability for the water collection.

4. Study Area

The scheduled tribe area in the state constitutes the entire districts of Kinnaur and Lahaul-Spiti and the C.D. blocks of Pangi and Bharmaur of Chamba district (Fig. 2). The tribal regions situated in the north and north-eastern part of the state forming a continuous belt along the border of the state of J&K and Tibet border behind high mountain passes and are amongst the remotest and relatively inaccessible areas in the state.



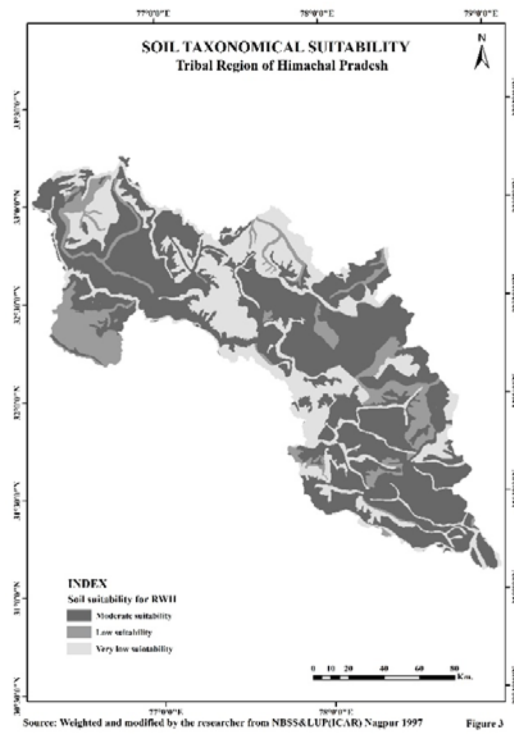
The study area lies between 31º6′55″ and 33º15′55″ N and 75º13′47″ and 79º1′25″ E. The eastern part of the state share the international boundary with Tibet (China), the western boundary is formed by Chamba and Churah tehsil of district Chamba. In the south of the tribal region lies Kangra and Kullu district of the state. Spreading over the area of approximately 23,655 sq. km, the tribal region has 681 inhabited villages. The study area constitutes about 42.5% of the geographical area of the state and is a home of 2.74% of the total population of the state.

5. Results and Discussion

5.1 Soil Texture

Soil texture indicates the relative content of clay in the soil. Soil texture is an important soil characteristic that comprises particles of various size, such as sand, silt and should be considered for suggesting water harvesting structures (Chand *et al*. 2014). Water-holding capacity is controlled primarily by soil texture and organic matter. Soils with smaller particles (silt and clay) have a larger surface area than those with larger sand particles, and a large surface area allows a soil to hold more water. The study area have five type of soil texture class's i.e. Coarse loamy, Fine loamy, Loamy-skeletal, Sandy and Sandy skeletal.

Clay soils have low permeability (high hydraulic resistance) and can hold the harvested water, and therefore they are the best soils for water storage. Soils with high water holding capacity are suitable for water collection whereas sandy soils are not suitable (Mbilinyi et al., 2005). Therefore loamy soils are most suitable for water collection whereas clay soils are less suitable because of their low infiltration capacity and risk of water logging.



The spatial distribution of soil texture suitability in the study region has been depicted by figure 3. Soils with moderately suitability have been witnessed in 13,846.95 sq. km. (58.73%) of the study area. It is distributed in western, eastern central and southern part of study area. Soil with low suitability spread over an area of 2,986.58 sq. km. (12.67 %) of the study area and has a spread over entire western and a few patches in eastern part. Soils with very low suitability have been witnessed in 28.60% of the study area (Fig 3).

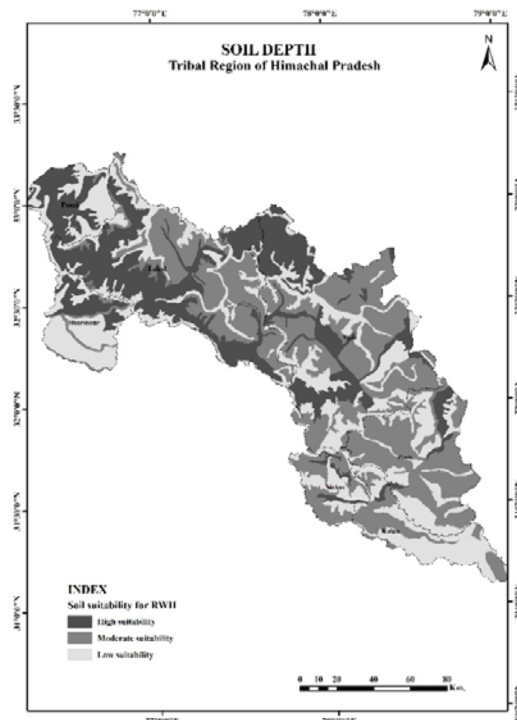
Table 2 : Suitability rank for soil taxonomy

No.	Type	Suitability	Area in Sq. Km.	Area in %	Rank
1	Fine loamy and Loamy Skeletal	Moderately suitable	13846.95	58.73	5
2	Coarse Loamy	Less suitable	2986.58	12.67	3
3	Sandy and Sandy Skeletal	Very less suitable	6742.39	28.60	1

Source: Compiled and compute from figure 3

5.2 Soil depth

From the standpoint of water holding capacity, one of the most important feature of soil is variation in porosity with depth. Porosity is measure of the open space within some soil or rock and it is function of the sizes of the particles and the way they are arranged (Chand et al. 2014). Critchley *et al.* (1991) consider soil depth as one criteria and suggest deeper soil as suitable for various micro RWH methods. This dataset has only three depth classes namely deep (100-150 cm), moderately deep (75-100 cm) and shallow (50-75 cm).



Source: NBSS & LUP (ICAR) Nagpur.1997 Figure 4

Table 3 : Suitability rank for soil depth

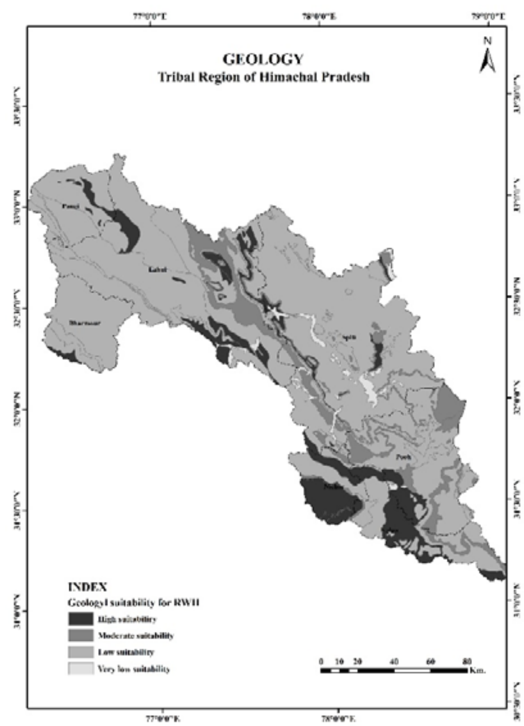
No.	Type	Depth	Suitability	Area in sq. km.	Rank
1	Very deep	> 150 cm	Most suitable	-----	9
2	Deep	100 – 150 cm	Suitable	6429.76	7
3	Medium deep	50 – 100 cm	Moderately suitable	9413.49	5
4	Shallow	25 – 50 cm	Less suitable	7755.85	3
5	Very shallow	<25 cm	Very less suitable	-----	1

Source: Compiled and computed from figure 4

The spatial distribution of soil depth suitability in the study area has been displayed in figure 4. Soil with suitable depth covers only 27.27% of the study area. Soil with moderately suitable depth covers more than one third area 9,413.49 sq. km. (39.93%) of the study area. Soil with less suitable depth (shallow soil) covers 7,755.85sq. km. (32.90 %) of the study area and have been found in the very high mountainous region of the study area (Fig. 4).

5.3 Geological Setup

Geological setup of an area plays a vital role in the distribution and occurrence of ground water (Krishnamurthy et al., 1995). The geological setup and stratigraphy of the tribal region of the state is very complex dominated by igneous and sedimentary rocks. Metamorphic rocks are also found at some places of the study area. This geological dataset has four classes according to the Mohs scale of hardness.



Source: After Geological survey of India Hyderabad 2011 Figure 5

Figure 5 show the geographical distribution of the geological suitability for water collecting spots in the study area. Geological structure with suitable hardness comprises a very small proportion (11.87 %) in the study area. Hard geological structure like Quartz, Quartzite, Granite, Sandstone and siltstone etc. have been found in the small patches in the central and eastern part of Pangi and southern part of Bharmaur block of Chamba district. It has also been witnessed in the central part of Lahul- Spiti district and in the western and northwestern part of Nichar block. Geological structure with moderately suitable hardness also comprises a small proportion (0.87 %) the study area. Moderately hard rock comprises geological structure like Gneiss, Dolomite, Biotitic, Black shale, Schist and Limestone etc. Geological structure with less suitable hardness covers almost three forth area of the study area. It covers almost 18,041.30 sq. km. (76.91 %) of the total area of the study area. This type of rocks comprises structures like Shale, Slate, Phyllite, Conglomerate and Grey Quartzite.

Table 4: Suitability rank for geological structure

No.	Type	Mohs Hardness	Suitability	Area in sq. km.	Rank
1	Very hard	> 8.0	Most suitable	-----	9
2	Hard	6.0 – 8.0	Suitable	2799.99	7
3	Medium hard	4.0 – 6.0	Moderately suitable	2345.23	5
4	Soft	2.0 – 4.0	Less suitable	18041.30	3
5	Very soft	< 2.0	Very less Suitable	406.99	1

Source: Compiled and computed from figure 5

Geological structure with very less suitable (Very soft geological structure) comprises Moraines and Hill wash scree. These type of rocks covers a very small part of the study area this type of rocks comprises only 1.72% of the total study area. This type of rocks have been found in small patches in the southwestern part of Lahul block and central, western and southern part of Spiti block of Lahul-Spiti district (Fig. 5).

5.4 Geomorphology

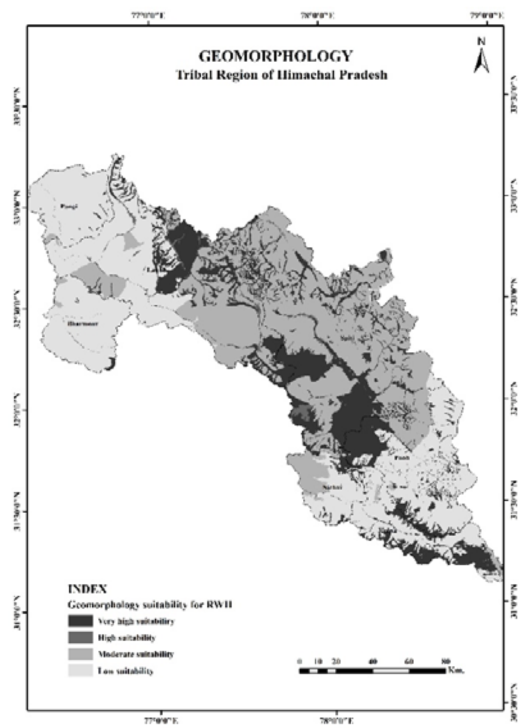
Geomorphology of an area is one of the most important feature in evaluating the ground water potential and prospect. The geomorphology as such control the subsurface movement of the ground water (Kumar et al., 2008).

Table 5 Suitability ranks for geomorphological structure

No.	Hydro-geomorphological units	Suitability	Area in sq. km.	Rank
1	Alluvial plain, Plain, Flood plain, Valley fill	Most suitable	5028.81	9
2	Moderately weathered Pediment	Suitable	226.23	7
3	Structural hills	Moderately suitable	8722.75	5
4	Denudated Hills	Less suitable	9558.87	3

Source: Compiled and compute from figure 6

Geographical distribution of suitability of geomorphological structure in the study area has been depicted by figure 6. Areas with most suitability geomorphology (alluvial plain, flood plain and water body) cover almost 5,028.81 sq. km out of the total area of the state. These areas has been distributed along the upper river beds of Spiti River, Satluj River, upper portion of Chandra and Bhaga river and northern and southwestern part of Lahul-Spiti district of the study area. Areas with suitable geomorphology cover a very small portion i.e. 226.23 sq. km. of the total geographical area of the tribal region. These areas have been witnessed in the areas where lower order streams merge with upper order streams.



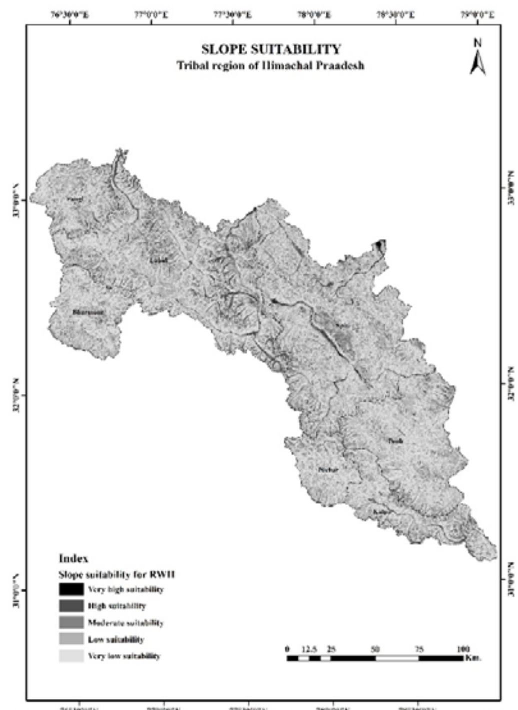
Source: After LANSAT 8 (Operational Land Imager) image 2014 Figure 6

Area with moderate suitable geomorphology have been witnessed 8722.75 sq. km. area and have been distributed in the whole part of Kinnaur district except small patches on southern part and central parts and in Pangi and Bharmaur block and eastern part of Lahul block of Lahul-Spiti district of the study area (Fig. 6). Area with less suitable geomorphology structure covers 9558.87 sq. km. and has been witnessed in the western, northern, eastern and southwestern Lahul-Spiti district. Pediments and structural valley represent a very small part of the study area mostly near to the river bed of the study area (Fig. 6).

5.5 Slope

The slope of land is important in site selection for water collection spot. The slope length can be used to determine the suitability for macro or micro- or mixed water harvesting systems decision making (Prinz et al 1998). RWH structure is not recommended for areas where slopes are greater than 5%, due to uneven distribution of run-off and large quantities of earthwork required which is often costly **(**Critchley et al., 1991).

Figure 7 shows the spatial distribution of the slope suitability in the study area. Areas with very less suitable slope have been witnessed in almost 42.57 % of the total (slope above 30º) entitled as mountainous region. These slope categories have been distributed all over the place in the very high altitude region especially in the mountainous region. This region is of very less importance while selecting the suitable site for RWH so least rank given to this category.



Source: Weighted and modified by researcher form ASTER GDEM 30 mtr resolution Figure 7

Table 6 : Suitability rank for slope

No.	Slope class	Slope in degree	Suitability	Area in sq. km.	ranks
1	Flat	<2	Most suitable	166.01	9
2	Undulating	2-8	Suitable	1272.33	7
3	Rolling	8-15	Moderately suitable	2533.58	5
4	Hilly	15-30	Less suitable	9603.83	3
5	Mountainous	>30	Very less suitable	10036.74	1

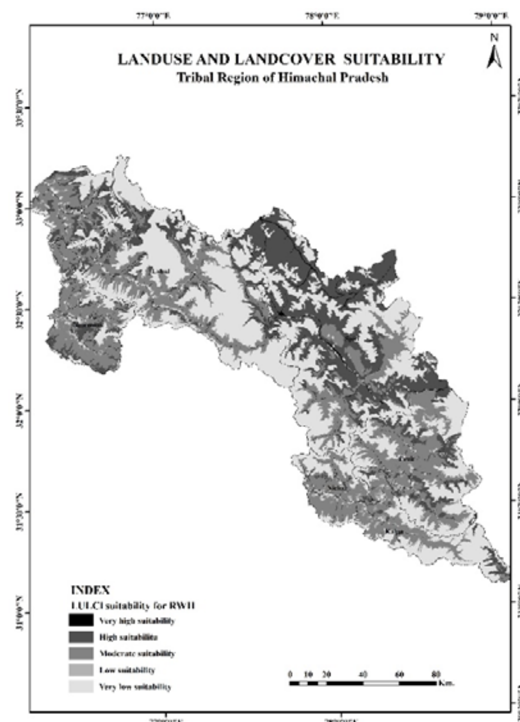
Source: Compiled and compute from figure 7

Areas with less suitable slope (slope between 15 º to 30 º) have been witnessed in almost 9,603.83 sq. km. (40.73 %) of the total geographical area of the study area. Areas with moderately suitable slope (rolling category) have been witnessed in 10.75 % of the study area. Undulating category covers almost 6.5 % of the study area. This area is considered as good for site suitability so weighted second highest for site suitability for rainwater structure (Fig. 7).

Areas with most suitable slope type (flat areas) have been distributed along the river covers only 2% of the total geographical area of tribal region of the state. Flat region is considered as the best place for site suitability of rainwater harvesting structure construction so this category is weighted as highly suitable site (Fig. 7).

5.6 Land use and Land cover

Vegetation is another important parameter that affects the surface runoff. An increase in the vegetation density results in a corresponding increase in interception losses, retention and infiltration rates which consequently decrease the volume of runoff.



Source: Weighted and modified by researcher from LULC Generated from LANDSAT 8 image. Figure 8

The geographical distribution of the suitability of land use and land cover in the study area for water collection spots has been displayed in figure 8.

Table 7 : Suitability rank for LULC

No.	Land use Land cover class	Suitability	Area in sq. km.	ranks
1	Settlement,	Very less	9850.36	1

	Snow covered areas and glacier	suitable		
2	Forest land and Grass land	Less suitable	7424.87	3
3	Agricultural land	Moderately suitable	551.94	5
4	Wasteland	Suitable	5457.26	7
5	Water body	Most suitable	302.01	9

Source: Compiled and compute from figure 8

Areas with very suitable, suitable and moderately land use and land cover have been witnessed in 13183.14 (55.92 %) of the total area of the tribal region of the state. These area have been witnessed in the lower plain belt along the river bed and drainage areas and wasteland. Area with less suitability has been witnessed in 7424.87 sq. km. of the study area. Area with very less suitable land use and land cover has been witnessed in 9850.36 sq. km. of the total geographical area of the study area (Fig. 8).

5.7 Drainage Density

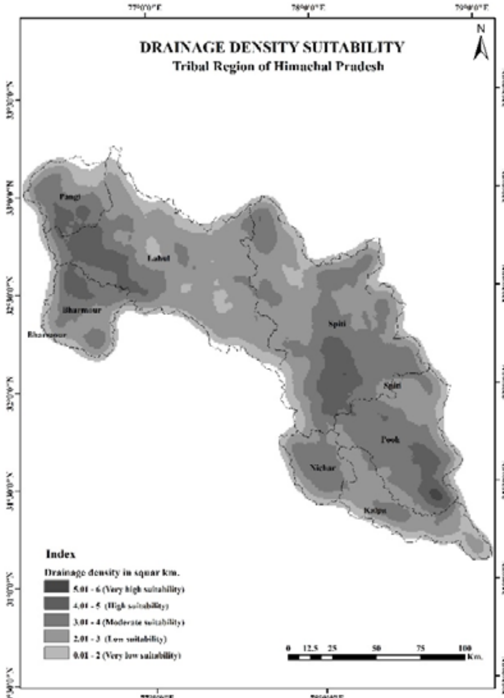
Drainage density is the length of a river per unit area in drainage basin. It is derived by dividing the total length of all the streams and rivers by the total area of the drainage basin.

$$D_d = \frac{L_T}{A_{\text{basin}}}$$

Table 8: Suitability rank for drainage density

No.	Drainage density	Per square kilometer	Area in sq. k.	Ranks
1	Very high	>4	35.01	9
2	High	3 – 4	2302.02	7
3	Moderate	2 – 3	7930.66	5
4	Low	1 – 2	10287.62	3
5	Very low	<1	4247.40	1

Source: Compiled and compute from figure 9



Source: Weighted and modified by researcher from Drainage map (SOI Toposheet 1:50000 and ASTER GDEM 30 mtr resolution

Figure 9

Drainage network helps in delineation of watershed and for suggesting various water harvesting structure and soil conservation measures.

High drainage density is the resultant of weak or impermeable sub surface material, thin vegetation and mountainous relief. The low drainage density of the watershed reveals that they are composed of permeable subsurface material, good vegetation cover, and low relief which results in more infiltration capacity in the watershed (Singh *et al.* 2014).

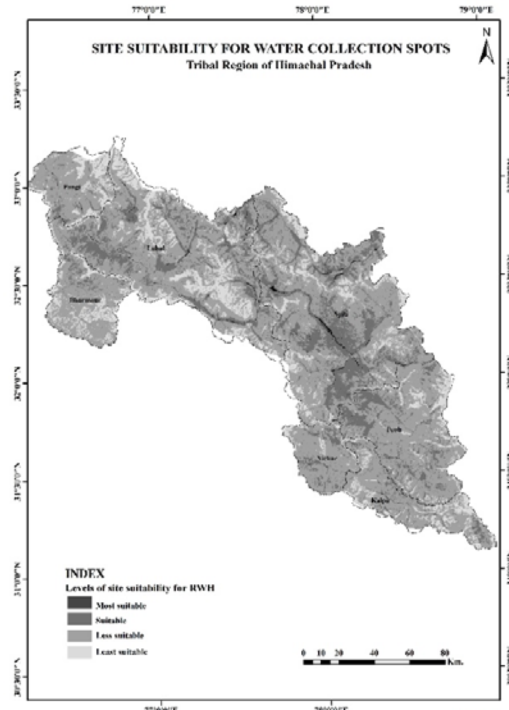
Figure 9 shows the spatial distribution of the drainage density in the study area. Drainage density from 1 to 6 has been witnessed in the study area. Very high drainage density has been witnessed in 17% of the study area. It is located in the Southern part of Pangi block along Chenab river basin and northern part of Bharmaur block along the Ravi river basin. It also covers western part of Lahul along the Chenab River and southern part of Spiti block along the Satluj and their tributaries in Lahul-Spiti district of the study area.

High drainage density has been witnessed around 16 % of the area, covering the northern part of Pangi and central and north-western part of Bharmaur block of Chamba district. It is also witnessed in western part of Lahul, northern central and eastern part of Spiti and western part of pooh, central part of Nichar and central part of Kalpa block of Kinnaur district. Moderate drainage density has been witnessed in 34% of the study area. Very low drainage density have been witnessed in 17 % or the study area covering very high altitude areas and the glacial regions of the study areas in central and northern part of Lahul-Spiti (Fig.9).

5.8 Weighted Overlay Analysis and Suitable Sites for Water Collection

Figure 10 and figure 11 shows the geographical distribution of the suitable sites for water collection in the study area. Areas with very high suitable water collection spots have been witnessed only in 73.33 sq. km. (0.3%) of the total geographical area of the study area. Figure 3.9 shows that the upper region of Spiti river bed, Lingti river bed and Pin river bed of Spiti region have very high suitability. River beds of Chandra and Bhaga have also shown very high suitability. While in Kinnaur district flat river bed of Satluj and their tributaries also have shown some very suitable sites. The majority of the areas with very high to high suitability have slopes between 2 to 8% and with an intensively cultivated land cover at some places. The major soil type in the very high suitable area is loamy and coarse loamy with fine and medium texture, have deep soil and very high drainage density.

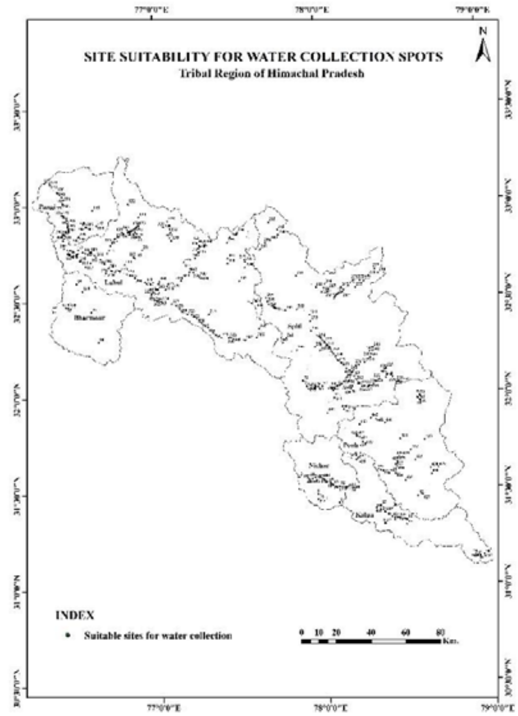
About 18.2% of the study area has shown high suitability for water collection. The spatial distribution of the suitability map shows that southern and southwestern part of Pangi and low lying area along the river bed of Ravi River in Bharmaur block have witnessed high suitability sites. The western, northwestern, northern central region, eastern and southeastern region of Lahul block and northeastern, central and southeastern region of the Spiti block have also shown suitable site.



Figer 10

In Kinnaur district western, northeastern central and southeastern part of Pooh block, eastern and southwestern part of Nichar block and low lying area along Baspa river in Kalpa block have shown suitable sites for water collection. The majority of the areas with high suitability have slopes between 2º and 15º and with mostly wasteland and sparse forest. The major soil type in the very high suitable area is loamy skeletal and coarse loamy with fine and medium texture, have medium deep and deep soil and very high drainage density.

A very high proportion (about 66%) of the study area has been witnessed under low suitability for water collection. The spatial distribution map shows that the northwestern part of Pangi block and central, eastern part of Bharmaur block of Chamba district have shown low suitability for water collection structure. In Lahul-Spiti district higher altitude region of Lahul and Spiti blocks have witnessed low site suitability. In Kinnaur district the eastern, central and south western part of Pooh block, western, eastern southern part of Nichar block and higher altitude of Kalpa block have shown low site suitability.



Figer 11

Approximately 16% of the total geographical area of tribal region area have witnessed very low/poor suitability for the water collection in the study area. This area covers the eastern and northeastern part of Pangi block and southern and southeastern part of Bharmaur Block of Chamba district. In Lahul-Spiti the northwestern and central part of Lahul and northern, western and eastern part of Spiti have shown very low/poor suitability for the water collection. In Kinnaur district eastern part of Pooh block, central part of Nichar and eastern and western part of Kalpa have shown very low suitability.

6 Conclusion

The study has demonstrated the capabilities of using MCE supported in GIS for identifying potential sites for water collection technologies that may be used for development and management of water harvesting intervention. MCE-GIS have proved to be a flexible, time-saving and cost-effective tool to screen large areas for their suitability water collection intervention. The suitability maps provide an easy path to identify areas that are more promising than other areas intervention. Such an information is helpful for decision-makers and planners.

7 Acknowledgements

The Authors acknowledge the help received from Aryabhatta Geo-informatics & Space Application Centre (*AGiSAC*), *Shimla*, Himachal Pradesh. for providing the lab facility and an opportunity to accomplish the study in more scientific manner.

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