B. TECH. PROJECT REPORT

On

Planning Water Sustainability through Identification of Potential Rainwater Harvesting Sites for Five Districts of India, Using SCS-CN method

BY

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DISCIPLINE OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY INDORE

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Planning Water Sustainability through Identification of Potential Rainwater Harvesting Sites for Five Districts of India, Using SCS-CN method

A PROJECT REPORT

Submitted in partial fulfillment of the requirements for the award of the degree

of
BACHELOR OF TECHNOLOGY
in

CIVIL ENGINEERING

Submitted by:
Shashank Bhargava
(160004034)

Guided by:
Dr. Manish Kumar Goyal

INDIAN INSTITUTE OF TECHNOLOGY INDORE
December 2019

CANDIDATE'S DECLARATION

I, Shashank Bhargava, hereby affirm that the project titled **"Planning Water Sustainability through Identification of Potential Rainwater Harvesting Sites for Five Districts of India, Using SCS-CN method"** submitted in partial fulfilment for the award of the degree of Bachelor of Technology in 'Civil Engineering' completed under the supervision of **Dr. Manish Kumar Goyal, Associate Professor, Department of Civil Engineering,** IIT Indore is my own work. I confirm that where I have consulted the published work of others, this is always clearly attributed.

Further, I declare that I have not submitted this work for the award of any other degree elsewhere.

Signature and name of the student with date

CERTIFICATE by BTP Guide

It is certified that the above statement made by the student is correct to the best of my knowledge.

Signature of BTP Guide with dates

Preface

This report on "Planning Water Sustainability through Identification of Potential Rainwater Harvesting Sites for Five Districts of India, Using SCS-CN method" is prepared under the guidance of Dr. Manish Kumar Goyal.

Through this report, I have tried to find potential rainwater harvesting sites for the construction of appropriate structures to harvest rain water in five districts of India using the SCS-CN method with highly developed tools such as remote sensing and GIS.

I have tried to explain the contents of this thesis to the reader in a comprehensive and lucid manner to my best abilities. I have also added maps and tables to put everything together in a more descriptive and illustrative manner.

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I wish to thank Dr. Manish Kumar Goyal for his constant support and guidance in structuring this project and his valuable feedback throughout the course of this project. His overseeing the project meant there was a lot that I learnt while working on it. I thank them for their time and efforts.

It is his help and support, due to which I became able to complete the design and technical report.

Without his support, this report would not have been possible.

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Abstract

An investigation was carried out in 5 of the total 731 districts of India to discover possible sites for the building of structures to harvest rainwater. These districts include Indore district, Bikaner district, Latur district, Mandsaur district, and Rajnandgaon district. Indore district from the southern edge of the Malwa plateau was chosen for an expansive and focussed study to find precise results. For the same, highly developed tools like GIS (geographical information system) and remote sensing were used for the derivation of the best results with precision. The concept revolved around the studying and understanding of the terrain covered in basalt in a spatial framework to discover information about RWH structures. Some RWH structures like farm ponds, percolation tanks, check dams, and gully plugs were considered for the same. Many thematic layers like soil distribution, land use/land cover, slope profile, drainage, and runoff values were used. In the later stages, the thematic layers, hence achieved, were processed with the aid of the Arc-CN runoff tool to find runoff through the SCS-CN method (Soil Conservation Service-Curve Number method). SCS-CN method indicates that water-bodies and agriculture lands (including harvested land) have high runoff potential, followed by open scrubs, dense scrubs, and settlements. Whereas open forest and dense forest areas have low runoff potential. These thematic layers were over-laid using the boundaries of our study areas and were intersected on the basis of parameters such as hydro-geomorphology and geology of the area. Ground truth field verification was carried out by investigating these sites, hence found, in the IIT Indore campus for the structures' suitability and implementation. Finally, it can be said that the SCS-CN method paired with advanced tools can help find better and more precise results for larger catchment areas, as well.

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CHAPTER 1

Introduction

India encompasses a diverse range of climatic conditions, amid which prevails a disaster called the climate change. As said by Leonardo DiCaprio, “Climate change is real and it is happening as we talk about it.” Changing climatic conditions have various repercussions which include changes in rainfall patterns. Annual average precipitation has encountered a decline in magnitude and frequency. This, in turn, alters the hydrological cycle and affects the whole nation. According to some studies, 45% of the ever-increasing Indian population suffers from high to severe water stress (Chakrabarty and Bhardwaj, 2019).

Groundwater levels are depleting due to the over-utilization of freshwater resources. This ‘over-use’ is a direct by-product of the increasing population and the rapid industrialization, and agricultural activities that follow the urbanization process. Groundwater recharge potential has been decreasing ever since rapid urbanization has taken control, due to less infiltration of rainwater. Rainwater harvesting, as stated and confirmed by many, has the potential to counter these effects and improve water yield (Handia et al. 2003; Concepcion et al. 2006; Sazakli et al. 2007; Abdulla and Al-Shareef 2009; Vohland and Barry 2009; Moon et al. 2012). Rainwater harvesting as a method can be understood as the process of collection, storage and distribution of runoff water for various uses ranging from domestic to agricultural fields (Rockstrom, 2000; Sutherland and Fenn, 2000). Hence, to have a proper water supply, rainwater harvesting is very crucial. To face this problem and come through, the creation of these structures for harvesting rainwater is proposed for relieving water storages above and under the surface. Some of the secondary benefits of the construction of such structures include decreasing soil erosion, recharging of the aquifer and reduction of run-off water wastage (D. Ramakrishnan et al. 2009; Aladenola and Adeboye 2010). On top of all this, the conventional geographical survey processes are time-consuming; and remote sensing and GIS have been in use to set up potential RWH structures with efficiency (Winnaar et al. 2007; Jasrotia et al. 2009). Although, over a period of so many years after the discovery of this (remote sensing and GIS) process, very few studies have been done over the semi-arid zone in the basaltic region of western India. In this study, Indore district, in western India, is selected as it lies in a semi-arid and basaltic region to understand and use the RWH potential.

Water budget can be defined as the understanding of the balance among input factors such as rainfall and output factors such as water loss by runoff, evapotranspiration and groundwater recharge in a watershed (Jasrotia et al. 2009). Run-off, the vital factor when it comes to the detection of sites for the installation of structures to harvest rain water, is heavily dependent on the type and distribution of soil, LULC and AMC (antecedent moisture conditions) in any single area (Winnaar et al. 2007). These parameters can be used to further understand the slope and elevation, rainfall, and lithology of the land under the survey.

Over time, many methods have been articulated and executed to understand the rainfall-runoff of a watershed. Water balance approach (Jasrotia et al. 2009); Thiessen polygon and SCS-CN are some of the examples. SCS-CN method, particularly, has many advantages over other mentioned methods. Using it alongside other sophisticated tools such as GIS and remote sensing can help in the accurate estimation of the run-off parameter and provide us with the much required precision and accuracy in the identification of potential RWH sites. It is also cost-effective. Factors such as the soil distribution, LULC, AMC (moisture conditions at the initial stages in the watershed before the run-off event that is being examined) and surface conditions are taken into consideration during the application of this method, resulting into a sole CN (curve number) value (Winnaar et al. 2007). In spite of the fact that SCS-CN method was initially made to be used on watersheds of area lesser than 15 km^2 originally, this method has been altered over time to apply for larger areas with the use of weighing curve numbers considering the LULC of the study area (D. Ramakrishnan et al. 2008).

RWH structures are a crucial need in basaltic regions, especially in western India because of the irregularities in monsoonal rainfall in this semi-arid region. The rainwater hence collected from the run-off can be used at the time of scarcity for multiple purposes which can be domestic, industrial or agricultural. Studies of a similar kind are needed and in the future can provide us with an opportunity to help identify potential structures for harvesting rainwater with the help the tools mentioned before. This will help develop a nation-wide database that may help with similar problems in the future.

Keeping this in mind, Indore district from Deccan volcanic province has been selected to study and understand, alongside the objectives to: (1) Use SCS-CN method on the watershed to estimate runoff potential; (2) identify potential RWH sites to recharge groundwater and use the harvested rainwater; and (3) check the accuracy with which this technique works.

1.1 Study Area

Indore district (Figure 1) covers an area of 3989 km^2 and is bordered by Chambal river of Ganga basin watershed and Kanar river in Narmada basin watershed in Madhya Pradesh state of India entangling between North 22° 31’ and 23° 05’ and East 75° 25’ and 76° 15’. Indore district is mainly covered by regions of plateaus (350-550m above mean sea level) with comparatively lower levels. However, the locations of higher elevations can be found in the southern part (587m) and the locations for lower elevation (497m) can be observed in the north-western part of Indore district. Indore district has high runoff potential and evapotranspiration and is present in a region of semi-arid climate. The average annual temperature of the Indore district remains around 24.6°C and ranges from about 18.2°C during January to 32.5°C during May. It receives an annual average rainfall of 983mm. The study area comprises of plains of extrusive origin and colluvial fans and dominated by black soil, characterized by basaltic origin on the Deccan trap. The hydraulic conductivity, i.e. the quantification of water that flows between the gaps between the particles of the soil ranges from low (5m/day) to moderate (15m/day). To understand the storage capacity and the stability of the structure to be constructed, the hydro-geology of the area plays an important role.

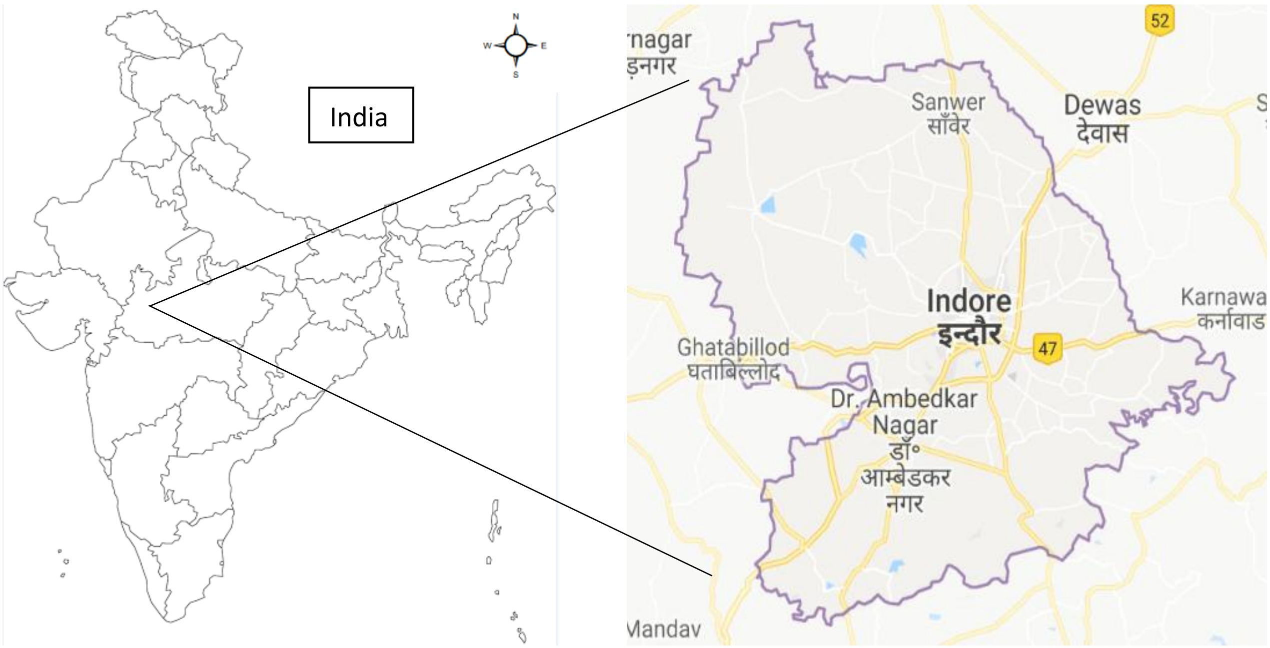

Figure 1. Location map of Indore District, India

CHAPTER 2

Data and Methods

LULC map with a spatial resolution of 90m scale and other similar spatial data are taken from (https://glovis.usgs.gov) and used. Soil classification map is used and it is reclassified according to the system of USDA soil classification (1972). Base map, contour layer, and drainage map were also used. Using the DEM and satellite data in ArcGIS, the drainage map was generated. Stream ordering in the drainage map was defined using the Horton (1945) method.

Gridded daily precipitation data and climate data were obtained and extracted from a spatial resolution, i.e. 0.25° x 0.25°, India Meteorological Department 4 (IMD4) data set (Pai et al. 2014) for Indore district from 3 different stations distributed across Indore district for the period from 1901 to 2015. The precipitation data from three nearby stations in the Indore district have been collected. Variations in AMC (determined by the total amount of rainfall in the 5 day spell preceding the run-off) have been accounted for (Table 1). SCS-CN method on different combinations of LULC classes, soil distribution and AMC values, helps with the estimation of the run-off values.

Table 1. AMC classification

AMC Class	Antecedent rainfall (mm) for a spell of 5 days	Condition
I	<12.5	Dry
II	12.5 to 27.5	Normal
III	>27.5	Wet

The accuracy of the calculated curve number value influences the usefulness of the SCS-CN method. This parameter is closely and sensitively connected to the method. Curve number(CN) is reliant on the soil group, LULC, and AMC. During an event of a storm, initially, the soil absorbs the rainwater to its capacity during the early spell and hence the soil moisture increases. Later, run-off starts. Curve number is calculated according to different AMC classes for the study area. Hence, run-off can be calculated using curve numbers and equations 1 and 2.

Figure 2. Geology map of Indore District

Runoff equations for AMC-II are as follows:

Since, CN ϵ [0,100] (USDA 1972)

S = potential maximum soil retention

Runoff = $\frac{(Rainfall - 0.2S)^2}{Rainfall + 0.8S}$ where Rainfall > 0.2S

Runoff = 0 where Rainfall $\leq$ 0.2S

For Indian condition,

$$S = \frac{1000}{CN} - 10 \qquad \text{(inch)} \qquad \text{(Equation 1)}$$

$$S = \frac{25400}{CN} - 254 \qquad \text{(mm), SI units(D. Ramakrishnan et al. 2009)} \qquad \text{(Equation 2)}$$

Calculation of Weighed CN is done next with Eq. 3, since the Indore district area is >15 km^2.

$$CN_w = \frac{\sum(CNi \times Ai)}{A} \qquad \text{(Equation 3)}$$

Where

CN_w = weighted CN

CN_i = CN from 1 to any number ’n’

A_i = area with $CN=CN_i$; and

A = total watershed area.

Using a weighted curve number leads to spatial data loss and hence causes inaccuracy. To counter this problem and work with different shapes of polygon area, while calculating run-off, the ArcCN-Runoff extension in ArcMap is used. The reference table (Zhan and Huang 2004) regarding soil distribution and LULC information helps in using CN values.

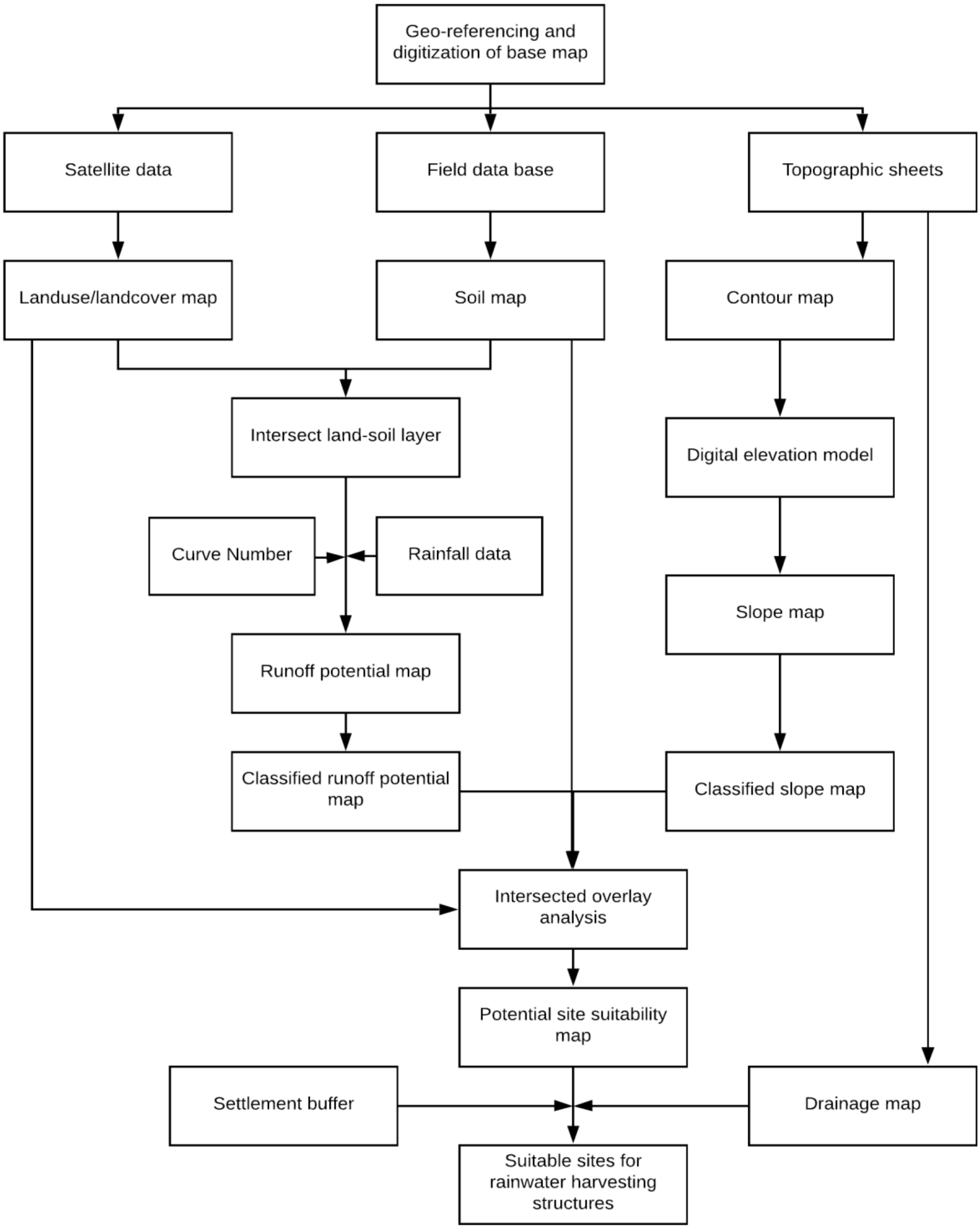

Figure 3. Methodology Flowchart

Run-off potential map was found out following these steps: (1) Clipping of soil distribution data and LULC data with the boundary layer of Indore district. (2) Reclassifying of soil data onto 4 HSG classes as stated in the system of USDA soil classification. New and smaller polygons were generated to increase accuracy and perform better than that in case of a raster grid format. This was done by intersecting soil and LULC data. (3) Finding and assigning of curve number for the land-soil layer drawn (Zende, A. and Atal, K. R., 2015) using the ArcCN runoff calculation tool.

Potential RWH sites were identified by the help of the intersection of various thematic layers (namely soil, LULC, slope and runoff potential) that were derived. Drainage map is also overlaid to check the favourability of all the potential RWH sites. Ground truth investigation is used for checking the availability of water for these structures to be constructed. Figure 3 shows the methodology. Accuracy was checked by ground truth investigation on the IIT Indore campus.

CHAPTER 3

Discussion and Results

3.1 LULC and HSG

The study area is a semi-arid zone. Indore district lies in basaltic region which comprises of mainly nine types of LULC (Figure 4). Built-up land is also shown. For an area, the run-off and evapotranspiration are greatly influenced by its land-use pattern (Harbor 1994), as it is a vital parameter for suitable site selection for rainwater harvesting. It can be seen that most of the area is covered with cropland (mostly sugarcane, cotton, jute, and millets), fallow land, woody vegetation and built-up land (Table 2).

Mixed forests, as well as scrubland, are in smaller patches and meagre areas in the catchment of the study area. This indicates how majorly and negatively human activities (anthropogenic disruptions) such as some agricultural activities have affected the pre-existing rainwater harvesting structures and will get in the way of the construction of the new proposed structures. Because of less public interference and more open area in open lands and scrublands, they provide us with a higher potential for possible RWH structures. Other factors such as soil infiltration and soil texture determine the type of structure at a potential location (Jasrotia et al. 2009). To reclassify the soil according to the system of USDA soil classification, reference maps are utilized.

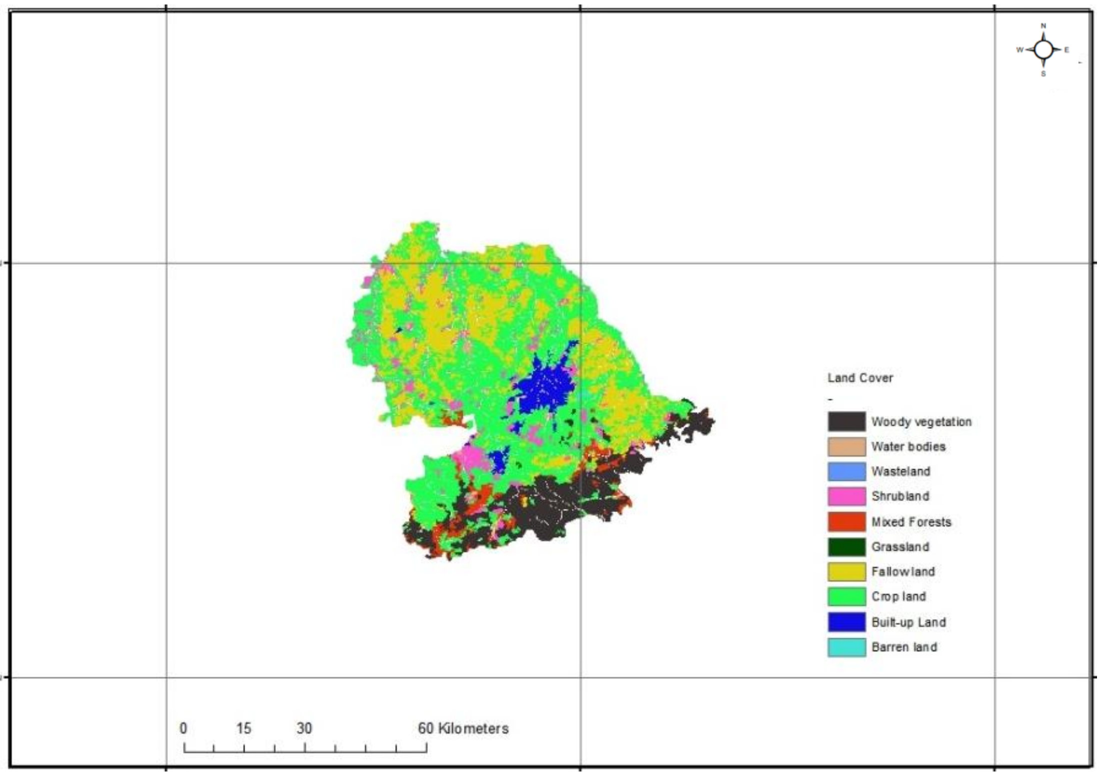

Figure 4. Indore District LULC

Table 2. Recommendations for structures considering LULC (IMSD 1995)

S.No.	LULC	Significance	Recommendation for structures
1	Cropland	Unsuitable	-
2	Fallow land	Suitable	Farm pond
3	Mixed forest	Suitable	Check dam, Gully plug
4	Scrubland	Suitable	Percolation tank, Farm pond, Check dam
5	Woody vegetation	Suitable	Percolation tank, Farm pond, Check dam
6	Water bodies	Unsuitable	-
7	Built-up land	Unsuitable	-
8	Barren land	Suitable	Check dam, Percolation tank
9	Grassland	Suitable	Check dam, Percolation tank, Gully plug
10	Wasteland	Unsuitable	-

Due to the presence of rich amounts of iron and ferric oxide in higher regions, the basaltic soil is reddish-brown in colour. They are silty in nature and have high permeability. The black soil present in the study area has high water holding capacity having rich amounts of humus and organic contents.

Basalt, as we know, is fine-grained and contains minerals that, generally, weather rather rapidly and produce clay. Hence, predominantly, clay is present all over this study area (Kale and Gupta 2001). Since clay is helpful in reducing downstream water losses; this fine-grained soil is beneficial for the construction of RWH structures such as check dam and percolation tanks by acting as a good soil barrier. To sum it up, A, B, and C hydrological soil groups are absent in the Indore district. It, predominantly, comprises of hydrological soil group D (Figure 5), which consists of clay loam, sandy clay, silty clay loam, silty clay or clay (Table 3).

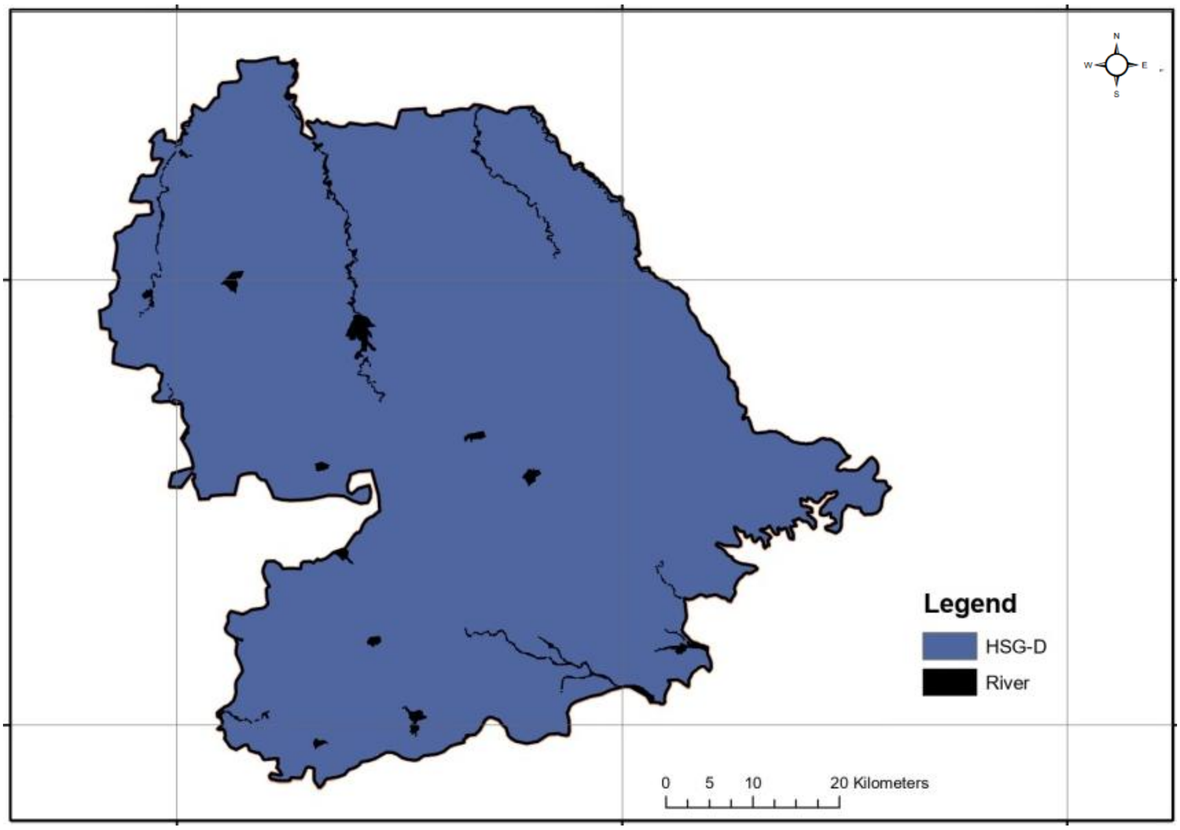

Figure 5. Indore District reclassified soil map

Table 3. Soil classification according to USDA-SCS (USDA 1972)

Hydrological soil group	Infiltration rate	Runoff potential	Soil Texture
HSG A	High	Low	Sand, Sandy loam, Loamy sand
HSG B	Moderate	Moderate	Loam, Silty loam
HSG C	Moderate	Moderate	Sandy Clay Loam
HSG D	Low	High	Clay loam,Silty clay loam,Sandy clay,Silty clay or clay

3.2 Slope

An imperative parameter while identifying potential spots for harvesting rain water for the implementation of said systems can be contemplated as the slope distribution (Ziadat et al. 2006; Winnaar et al. 2007). Groundwater levels are highly influenced by the slope of the area since the slope is inversely proportional to the rate of infiltration, i.e. steeper the slope, less is the infiltration rate (Figure 6) (Table 4) (Mondal et al. 2009). To find slope profile of the Indore district, the DEM (digital elevation model) of the Indore district was first used.

Table 4. Indore District slope classification (IMSD 1995)

S. No.	% slope	Type	% area	Significance (surface run-off)
1	0-1	Nearly level	6.7	Low
2	1-3	Very gentle	5.8	Low
3	3-5	Gentle	27.2	Low
4	5-10	Moderate	29.9	Medium
5	10-15	Strong	18.7	Medium
6	15-35	Moderately steep	9.2	High
9	>35	Very steep	2.5	High

IMSD refers to the slope in an area in various classes, as in Table 4 given below (Figure 6). Most of this district lies in a very gentle to medium slope region.

This shows that the infiltration rates are high to medium and the surface runoff is low to medium. This makes for a good opportunity for recharging the groundwater and construction of other RWH structures. And hence it confirms if the so found potential sites are suitable for the construction of farm ponds and check dams along the drainage.

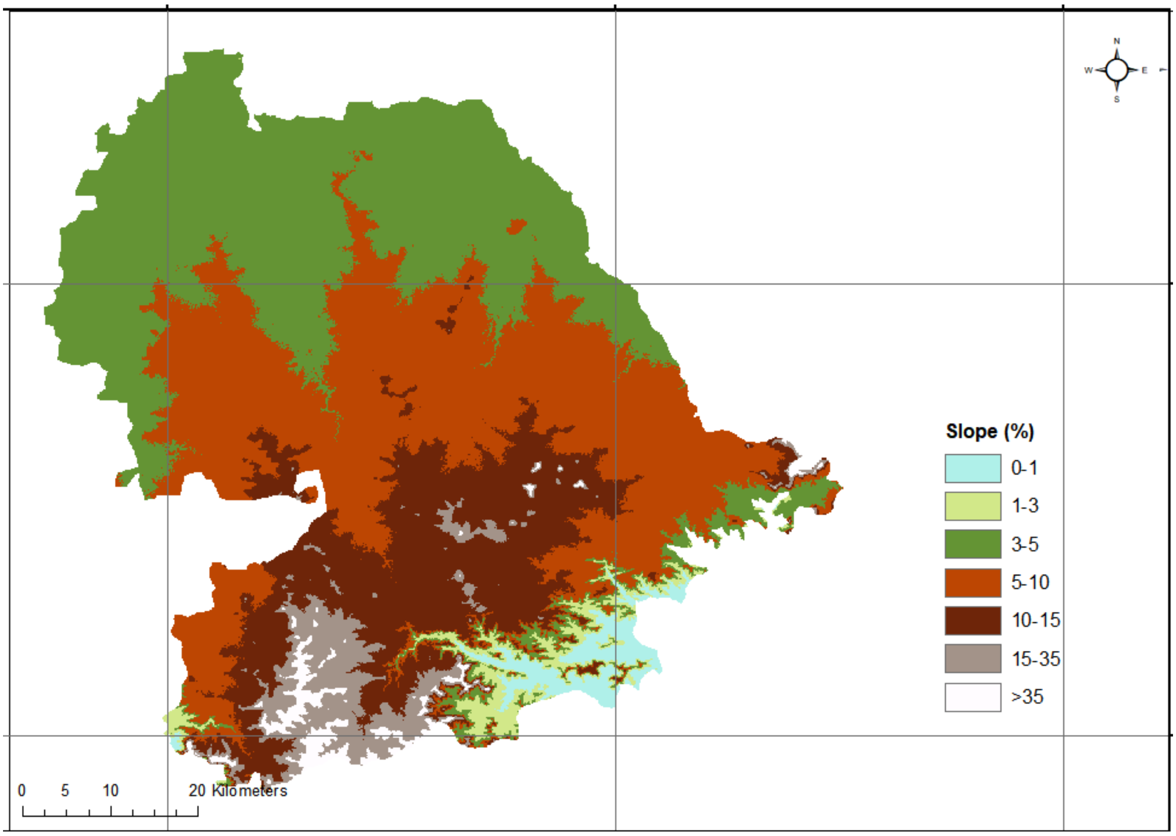

Figure 6. Indore District slope distribution map

3.3 Runoff Potential

HSG soil group layer, found after reclassification, and the LULC layer are intersected and using ArcMap software a modified Soil-LULC layer is generated. The runoff values are thus computed and are shown in Table 5. Generally, the highest runoff potentiality is found in the plain areas where the land cover includes some water bodies. The runoff potential map, hence derived, was classified into 3 major classes considering histogram distribution (Figure 7). However, 53.6 % of the area is covered with zones of medium runoff potential, whereas 16.7 % of the total area was covered with zones of high runoff potential (Figure 7). Zones with high to moderate runoff potential are the most suitable for the construction of RWH structures. Regions of high runoff potential are observed in the northern part of the study area. This can be attributed to the presence of more water bodies in that area. Irrigation practiced in such areas is highly conditional on the mechanical lifting of water from other basins. This affects the runoff potential as such irrigation practices, on one hand, result in the filling of existing watershed, but on the other hand may increase the clay concentration of the upper layers of the soil under seasonal tillage due to the upward movement of soluble salts. This in turn leads to the compaction of the surface layers of the soil.

Table 5. Runoff calculation for Indore District

S. No.	**HSG soil type**	**LULC**	**CN**	**Runoff (mm)**
1	D	Woody vegetation	80	138
2	D	Water bodies	100	983
3	D	Wasteland	68	-
4	D	Scrubland	91	378
5	D	Mixed forest	76	345
6	D	Grassland	84	135
7	D	Fallow land	87	787
8	D	Cropland	84	174
9	D	Barren land	88	638

3.4 Site Specifications

Rainwater harvesting has been around for quite some time and has been iteratively improved to fit the increasing need for water harvesting techniques. It has multiple benefits ranging from (1) Recycling water to raise crops and other agricultural activities; to (2) Prevention and decreasing of soil erosion in the area of practice. In addition to these benefits, rainwater also directly helps in relieving temporal discontinuity between crop moisture demands and the availability of water or rainfall.

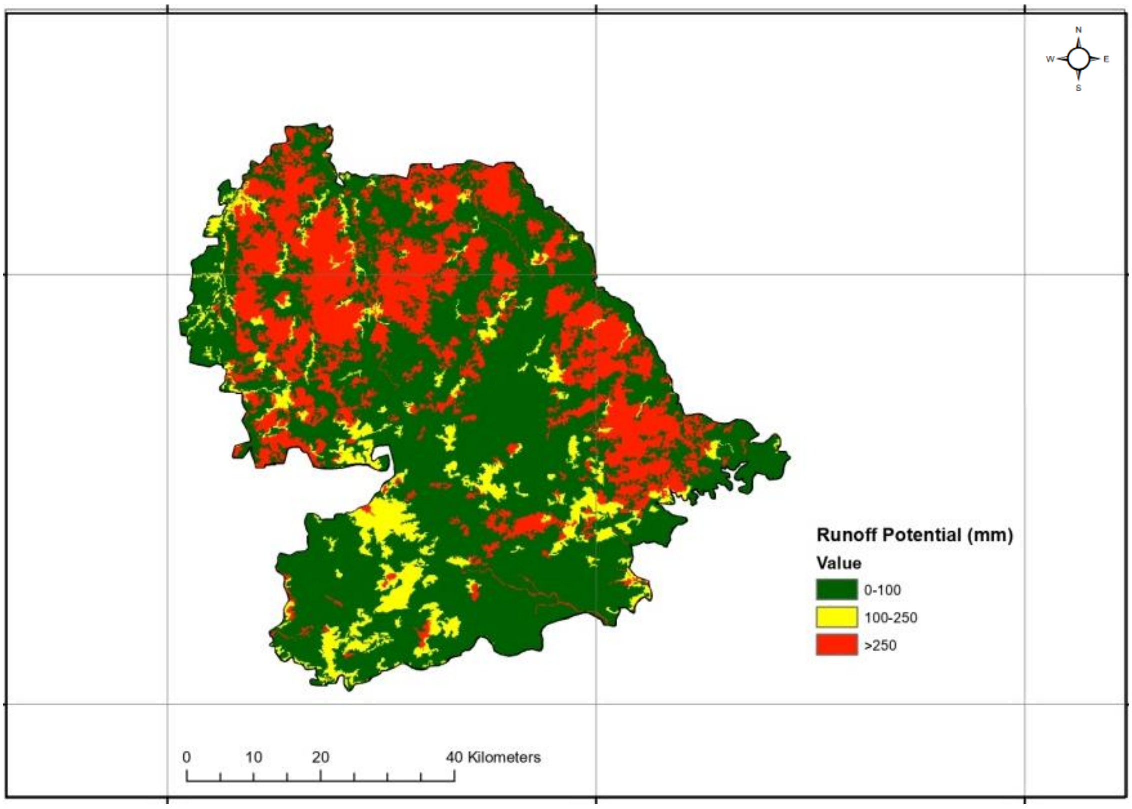

Figure 7. Indore District runoff potential map

Indore district is filled with runoff regions of moderate to high potential, which is an appropriate condition for the construction of structures. Various thematic layer maps, based on their priority, were integrated with the use of intersection tools. Finally, the identification of suitable structures was done considering the specifications in Table 6. To check for the non-availability of land due to settlement area within 500 m range, precautions were taken. Under normal conditions, a water loss of 20-35 % is observed from over the surface structures that are used for storing water. This water deficiency is mainly by reason of evaporation and infiltration (Dahiwalker and Singh 2006). This study to understand and find sites for the construction of suitable RWH structures highlights that approximately 70.3% of the area in the Indore district is suitable (Figure 8).

Table 6. Suitable structures' selection (IMSD 1995)

Structure	**% Slope**	**Runoff potential**	**LU/LC**	**Soil type**
Farm Pond	0-5	Moderate to High	Scrubland	Sandy clay loam
Check dams	<15	Moderate to High	Scrubland or River bed	Sandy clay loam
Percolation tank	<10	Low	Scrubland	Clay
Gully plug	15-20	High	Scrubland	Sandy clay loam, clay

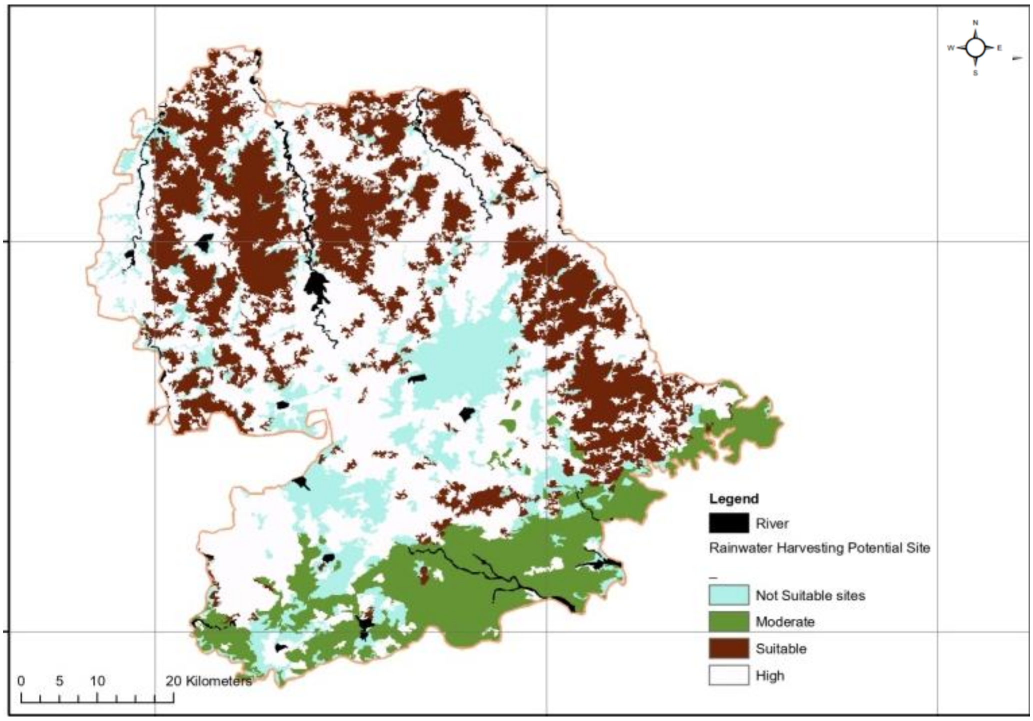

Figure 8. Indore District potential RWH site map

3.5 IIT Indore Campus Ground Truth Verification

For the process of ground truth verification of the selected potential rainwater harvesting sites, a smaller area was selected. IIT Indore campus with an area of 2.06 km^2 was selected for field investigation. The results of the site investigated are given in Table 7. The main objective of performing ground truth survey was to check the accuracy with which potential rainwater harvesting sites were found and to authenticate the SCS-CN method. Four existing lakes were recognized in the campus. A total of 10 potential sites were identified. Prerequisites such as fourth-order streams and HSG-D soil proved beneficial.

Table 7. Derived RWH structure accuracy check for IIT Indore campus

Structure	Existing site	Potential site	% accuracy
Lakes	4	10	100

*Accuracy = % matching of existing sites with derived sites

Six new sites are proposed. Hence, the ground truth survey authenticates that the SCS-CN method, when integrated with advanced tools, gives results with high accuracy of 100% and is beneficial to use.

3.6 Accuracy of the Results

Finally, a total of 74 suitable structures at various potential sites have been proposed for rainwater harvesting. These structures include 38 percolation tanks, 26 farm ponds, 4 check dams and 6 gully plugs (Figure 9). To complete the accuracy assessment process, overlaying of the potential rainwater harvesting map with pre-existing structures' locations at the IIT Indore campus was done (Table 7). Accuracies in the range of 75% to 100% are a good sign to follow up with field implementation.

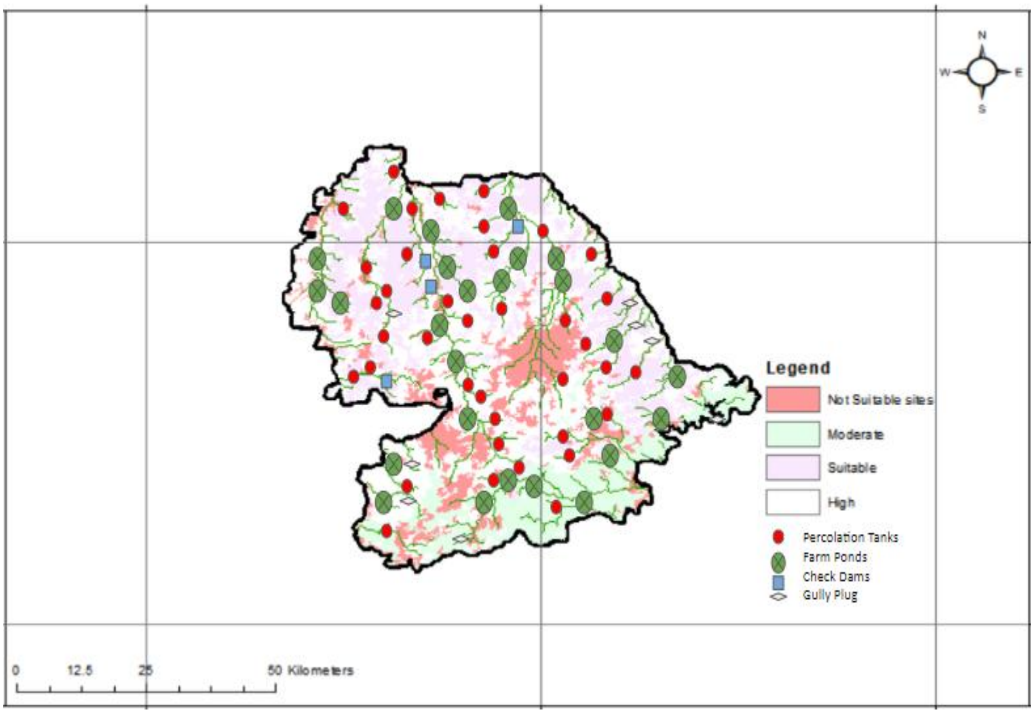

Figure 9. Indore District map indicating sites for proposed structures

3.7 Future Management of Harvested Rainwater

Rainwater harvesting is a strong approach towards elimination of water scarcity throughout the planet. The main focus for the present study on the Indore district was on the integration of highly developed tools for developing resources of water. In a country like ours, a large percentage of the population practice agriculture for their livelihood. Ample amount of water is needed for the same but water scarcity is dominant, especially during summer months and drought years. Semi-arid regions in India face the same problem with equal intensity if not more. Harvesting rain water is necessary because it helps with the fulfilment of requirements of water over the extended periods of water scarcity in the summers and during times of drought. Rainwater can be used as drinking water at times of drought due to declined groundwater levels. To meet these ever-increasing water requirements for domestic, industrial and agricultural uses, crucial and solid steps need to be taken towards the identification and construction of suitable rainwater harvesting structures. This study can help planners working on the establishment of different water resource management agendas. This study can help such planners in finding the best possible location for rainwater harvesting to be considered and also where it is not a viable option.

Further, the harvested water can be supplied to areas of higher demands at times of water scarcity, especially during the late summer months. The crop yield of nearby agricultural lands can be improved by connecting them with surface channels. Households can be supported for meeting their daily water requirements. Harvested water can be used for recharging groundwater with the help of percolation tanks.

On a financial note, construction of the proposed rain water harvesting structures is fairly expensive and requires the appropriate backing from both government and private sector organization. Support from individuals as well as NGOs (Non-Governmental Organizations) for raising funds can provide us with the huge amounts required for the construction of structures.

Government agencies working in collaboration with agencies like UNICEF, WHO, and the World Bank can bring in much-needed funding. The use of harvested water needs to be regulated according to the priorities. Areas like the Indore district need special attention to ensure healthy agricultural practices and to minimize submergence of water quality for public use. Government agencies like the Agricultural and Irrigation Department undertake the final construction project. Individuals can help through participation programs as well as by fundraising.

The structures constructed at these potential rainwater harvesting sites help in recharging the groundwater table by increasing percolation through dug wells and percolation tanks. They help minimize soil erosion by reducing the runoff velocity with the help of barriers. Spillways are a great example of structures used in check dams to regulate the amount of runoff water passing during the time of excess rainfall, especially during monsoon season.

CHAPTER 4

Other Study Areas

The same methodology can be applied to study other areas of our interest also with some minor changes in our approach. Other study areas are shown in Figure 10.

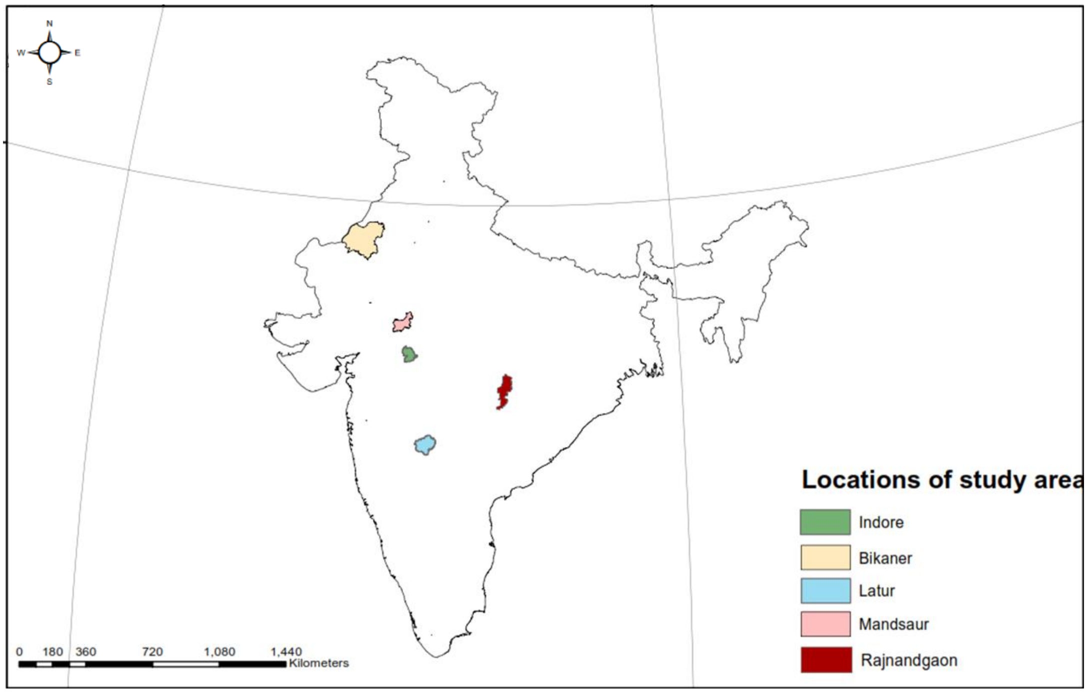

Figure 10. Map of India with highlighted study areas

4.1 Bikaner District

Bikaner district lies in the Thar Desert region of Rajasthan. The main source of irrigation water in this area is the Indira Gandhi Canal running from north-east to south-west. Its coordinates are 28°1′ N, 73°18′ E. The temperature varies from 5.6°C to 41.7°C over the year. It has a total area of 30247.90 km^2. The annual average rainfall in this district is 325 mm with a monsoon peaking during the month of July.

Land cover of Bikaner district mainly comprises of barren land which provides shows scope for building of suitable structures for harvesting rainwater. The north-western region is predominantly covered in cropland and the northern part of the district has scrubland. Small patches of forest land, grassland and water bodies are also observed throughout the district (Figure 11).

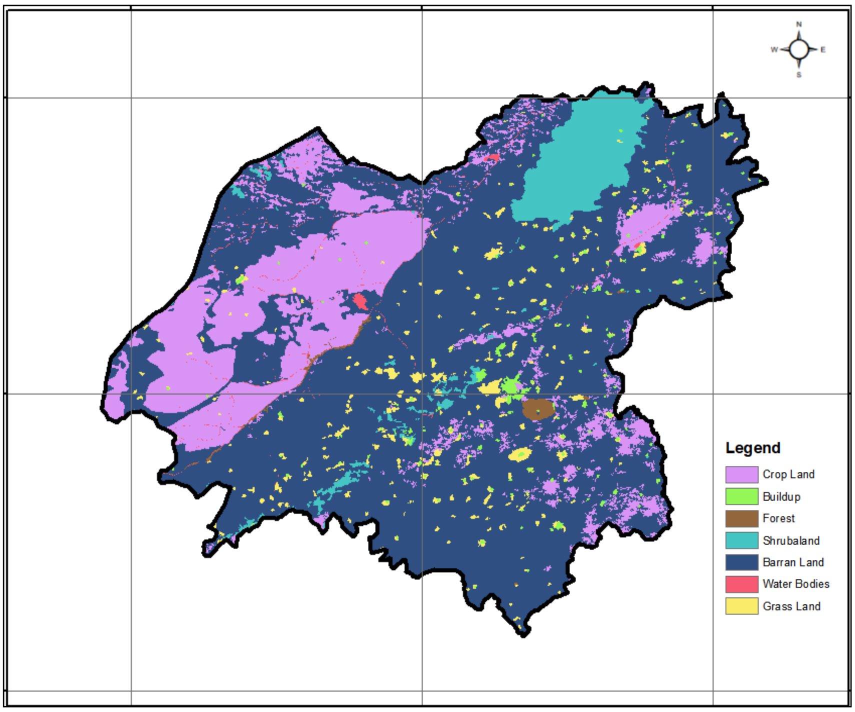

Figure 11. Bikaner District LULC map

Soil distribution of the Bikaner district comprises of clay loam, loam, and loamy sand out of which loamy sand dominates (Figure 12). HSG C and D are found in this region. D type HSG is found in smaller proportions (Figure 13).

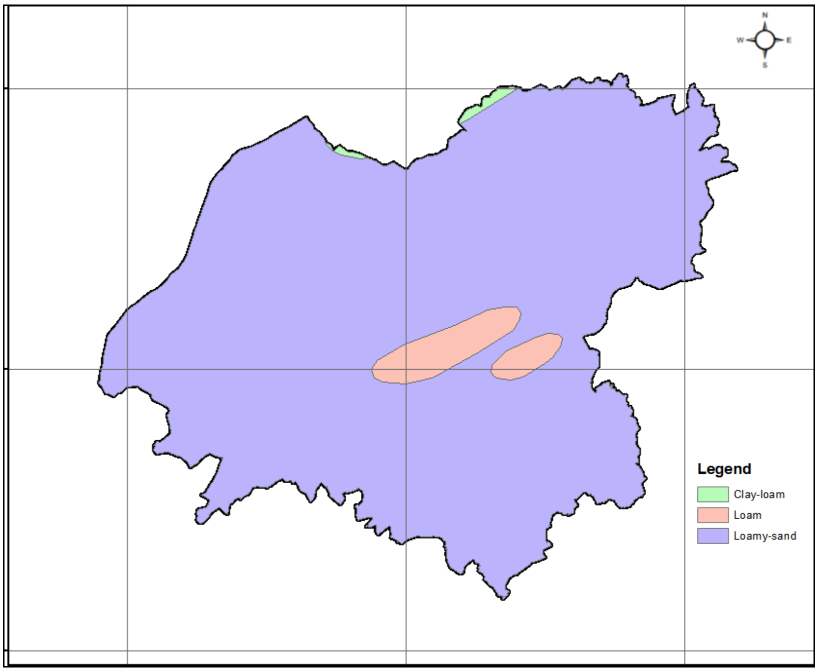

Figure 12. Bikaner District soil map

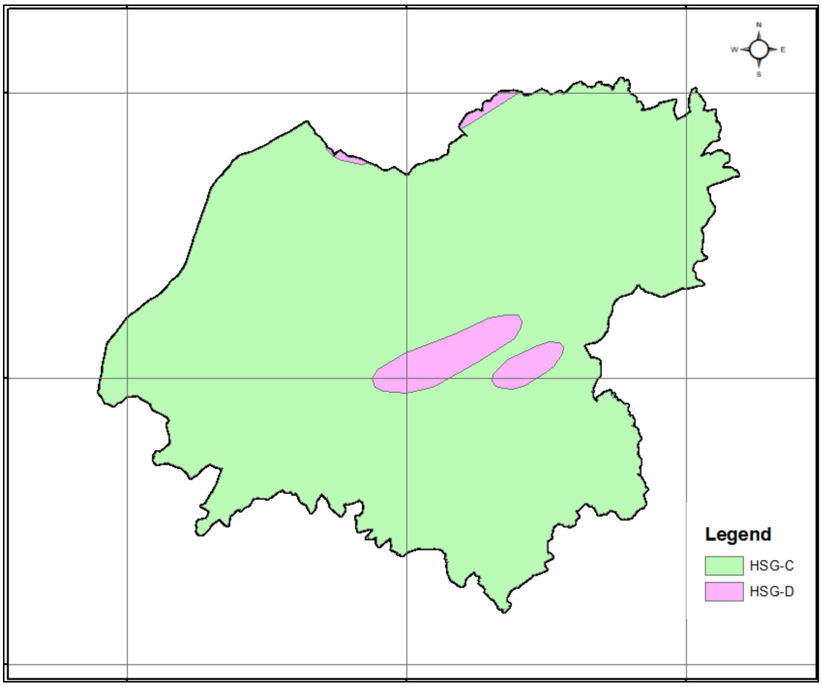

Figure 13. Bikaner District reclassified soil map

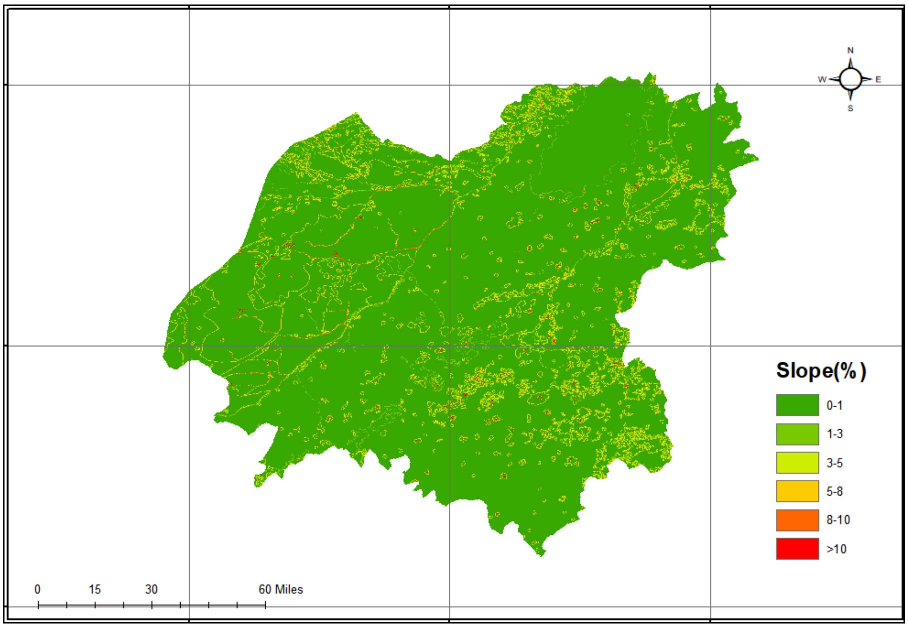

Figure 14. Bikaner District slope map

Bikaner district, overall, has a nearly levelled land cover with 0% to 3% slope in most of the region. Smaller fractions with steep slope are scattered in this area (Figure 14).

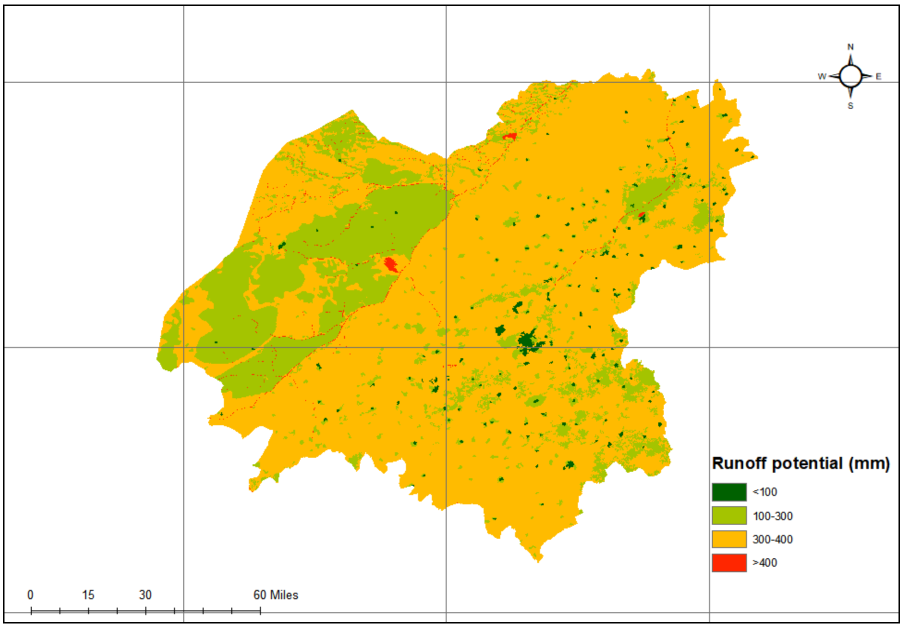

Figure 15. Bikaner District runoff potential map

Bikaner district shows a runoff potential of 100 mm to 400 mm in a year. This is a moderate amount of runoff over a huge area that provides us with the scope of rainwater harvesting (Figure 15).

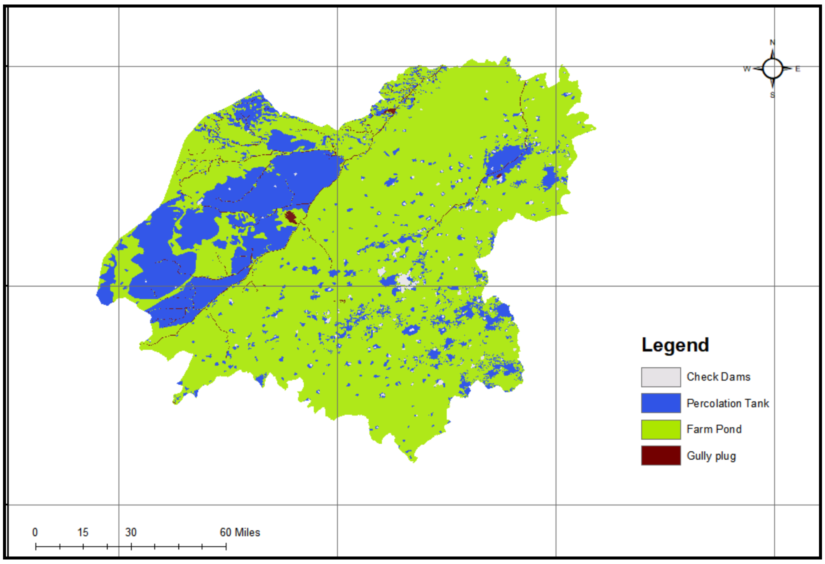

Figure 16. Bikaner District Potential RWH structures map

It can be inferred from the above parameters that the Bikaner district is suitable for the creation of structures for harvesting rain water. In particular, structures like farm ponds and percolation tanks can be considered for construction over most of the area (Figure 16). This increases the scope of the rainwater harvesting management system in the Bikaner district.

4.2 Latur District

Latur district lies in the Marathwada region in the Balaghat-Deccan plateau of Maharashtra, located between 17°52' North to 18°50' North and 76°18' East to 79°12' East. The average elevation of the area is 631m above mean sea level. The main source of irrigation water in this area is the Manjara River. The temperature varies from 13°C to 41°C over the year. The total area of this district is 7157 km^2. And the annual mean rainfall in this district is 725 mm with most of it falling between the months of June and September.

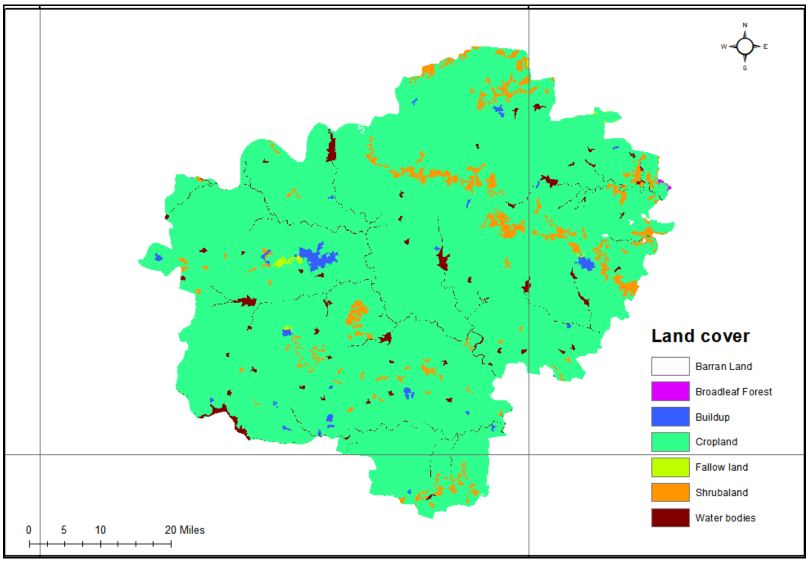

Figure 17. Latur District LULC map

Latur district has a very diverse land cover dominated by cropland and followed by scrubland. It also has water bodies and built-up land distributed across the district in smaller sections (Figure 17).

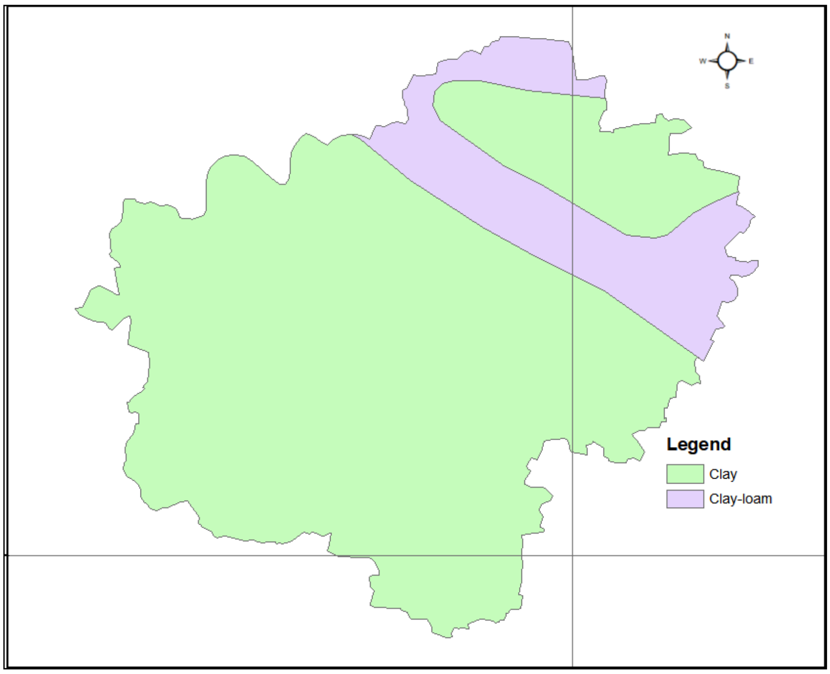

Figure 18. Latur District soil map

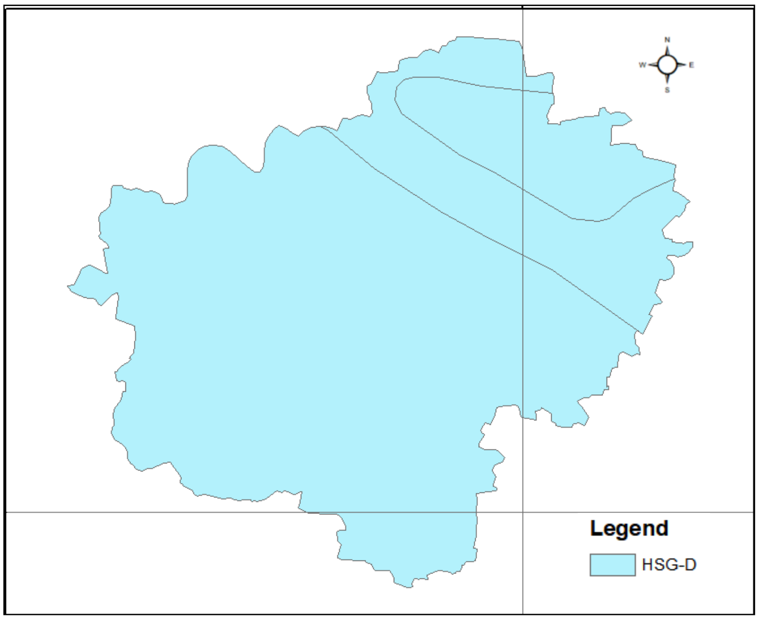

Figure 19. Latur District reclassified soil map

Soil distribution in this district shows HSG D type soil all over the area (Figure 19) which is mainly clay and clay loam soil (Figure 18).

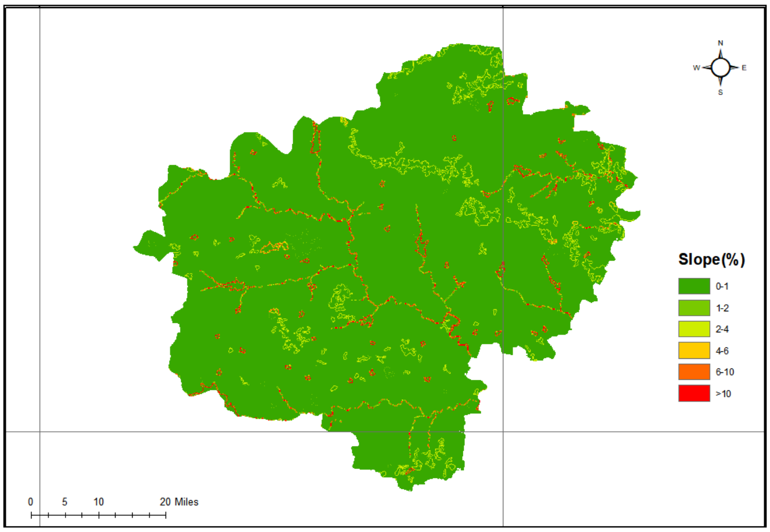

Figure 20. Latur District soil map

The slope map of Latur district clearly shows that the area is dominantly covered with a nearly levelled ground (Figure 20). Hence, it provides scope for low runoff velocity and high infiltration rates. It also has very small sections of moderate to high slopes spread across the district.

Runoff potential of the area varies mostly from 100 mm to 300 mm per year with the presence of 400 mm to 510 mm of annual runoff at some sites. This provides us with a decent scope of rainwater harvesting in Latur district (Figure 21).

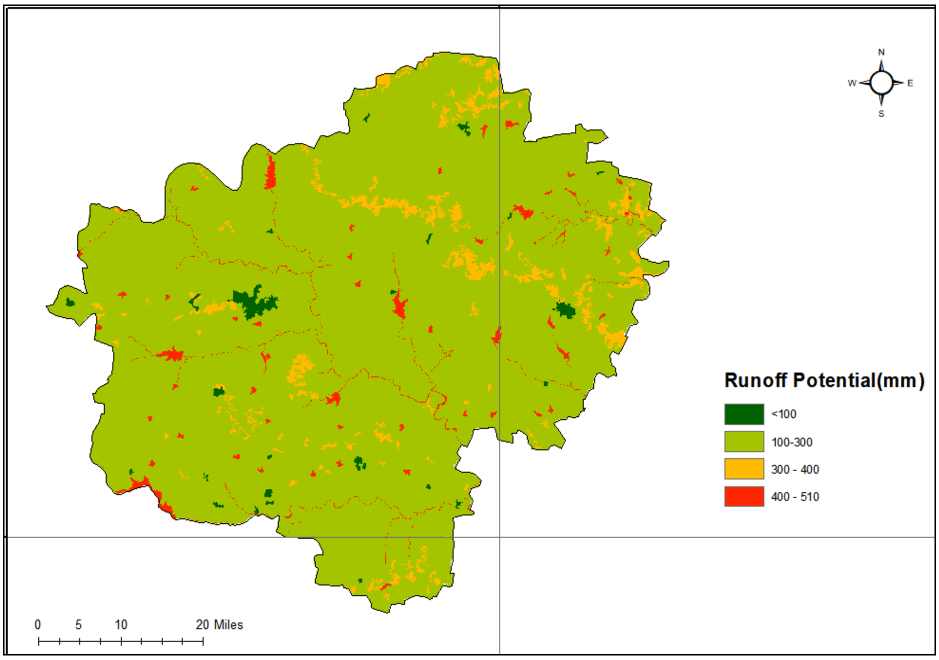

Figure 21. Latur District runoff potential map

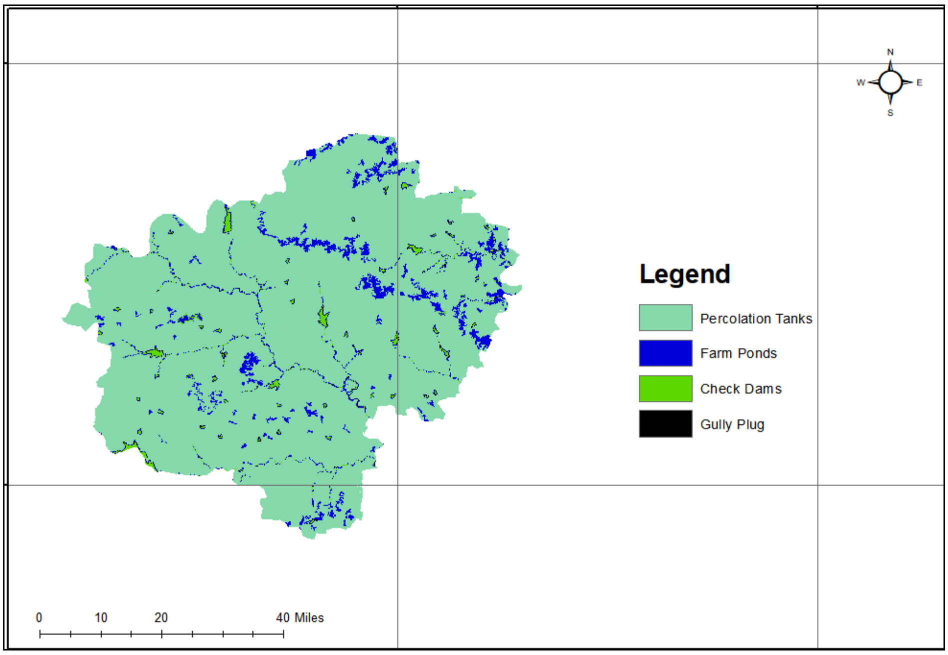

Figure 22. Latur District potential RWH map

The above parameters can be used to understand that Latur district has a scope of rainwater harvesting and rainwater harvesting structures, especially percolation tanks are suitable and can be constructed to help relieve the problem of water scarcity (Figure 22).

4.3 Mandsaur District

Mandsaur district covers a total area of 9791 km^2 and lies in the Malwa region of Madhya Pradesh. It lies between 23°45' North and 25°2' North, and 74°42' East and 75°50' East and falls under the Ujjain division. The temperature varies from 9.3°C to 39.8°C over the year. The annual average rainfall in this district is 786.6 mm with a monsoon peaking during the month of June.

Land use and land cover area of Mandsaur district mainly show the presence of croplands. The northern region of the district is predominantly covered in deciduous broadleaf forest and mixed forest followed by water bodies (Figure 23).

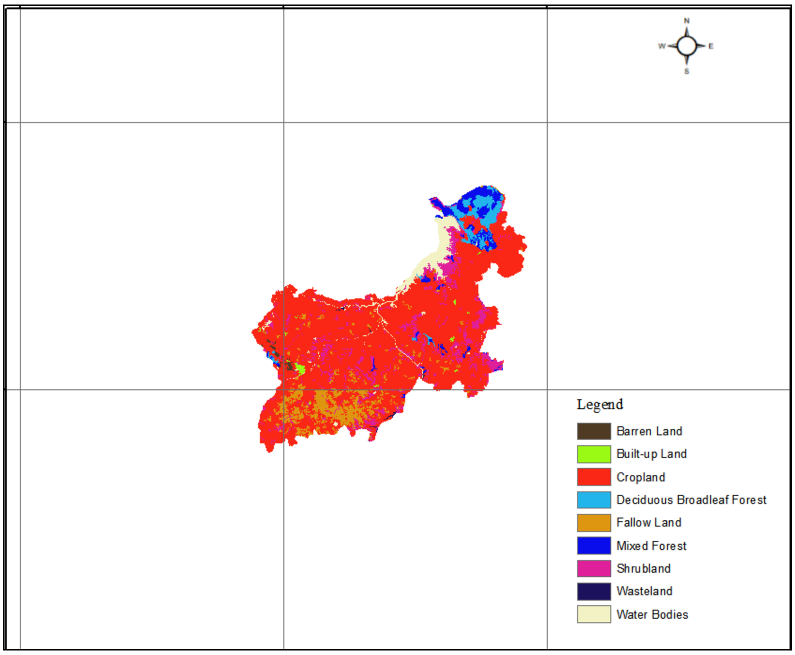

Figure 23. Mandsaur District LULC map

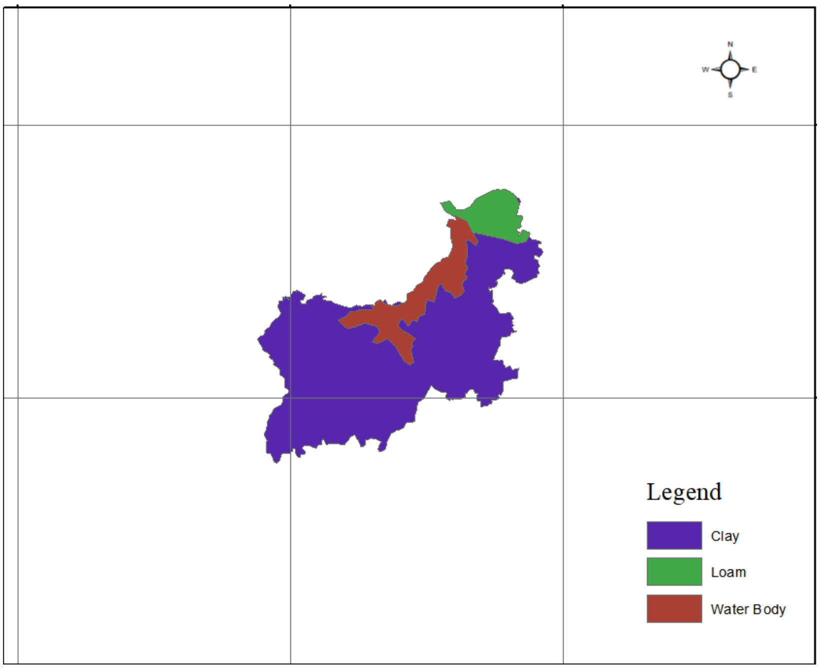

Figure 24. Mandsaur District soil map

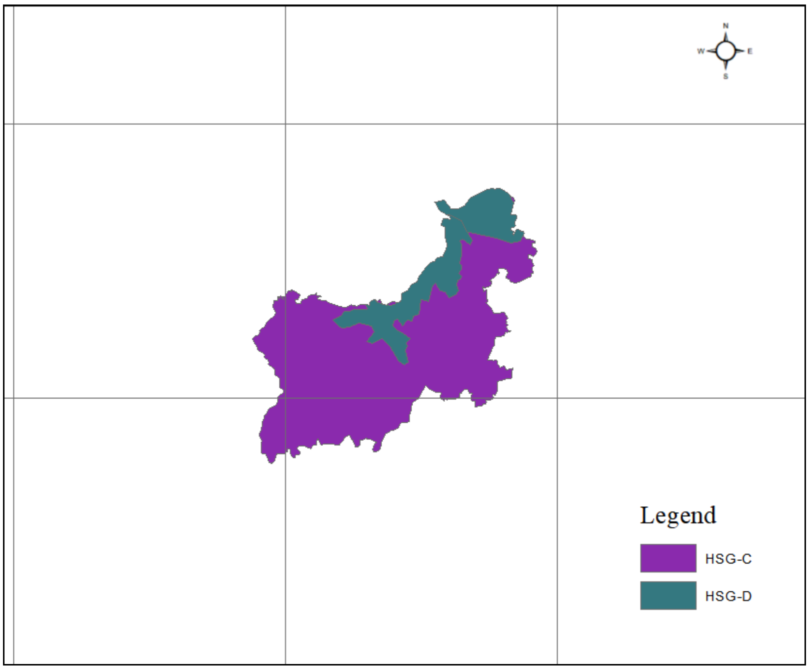

Figure 25. Mandsaur District reclassified soil map

Mandsaur district is mostly covered in HSG C type with HSG D in the northern region of the district (Figure 25). The region is mainly covered in clay and loam (Figure 24). The water body in the north falls under HSG D type, as well.

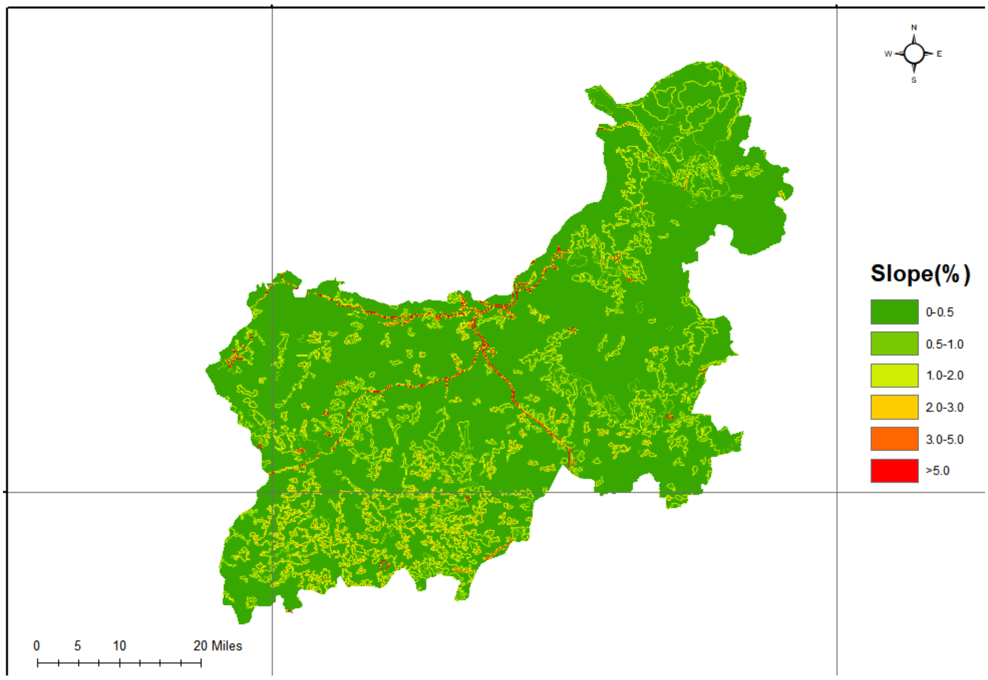

Figure 26. Mandsaur District slope map

Mandsaur district is nearly levelled and has a slope percentage of 0% to 3%. It has a slope greater than 5% along a few geographic lines (Figure 26).

Mandsaur district shows great runoff potential along the northern boundaries where water bodies are present. Most of the district shows a runoff potential between 100 mm to 600 mm over a year (Figure 27).

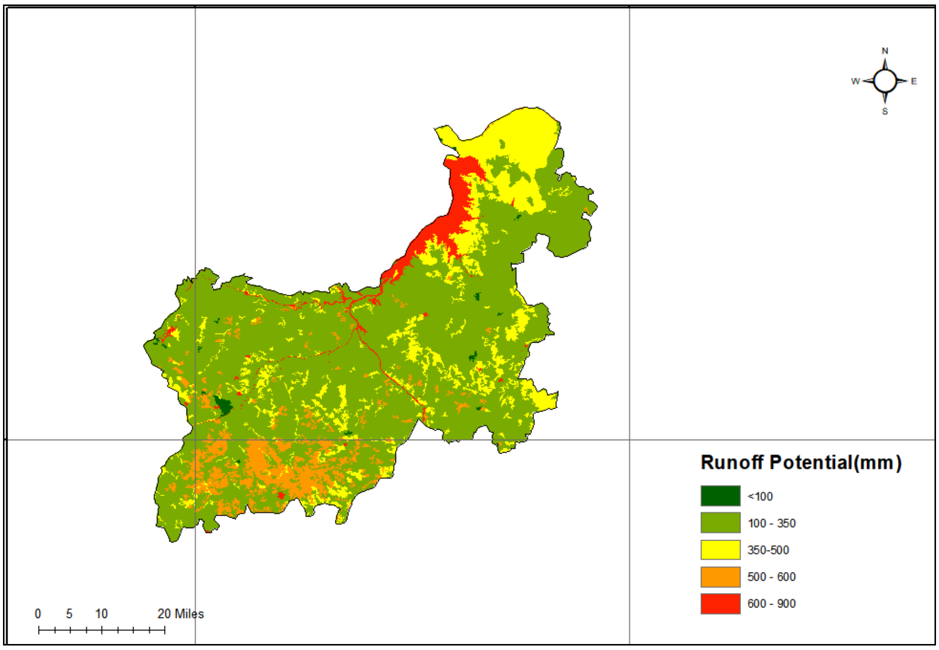

Figure 27. Mandsaur District runoff potential map

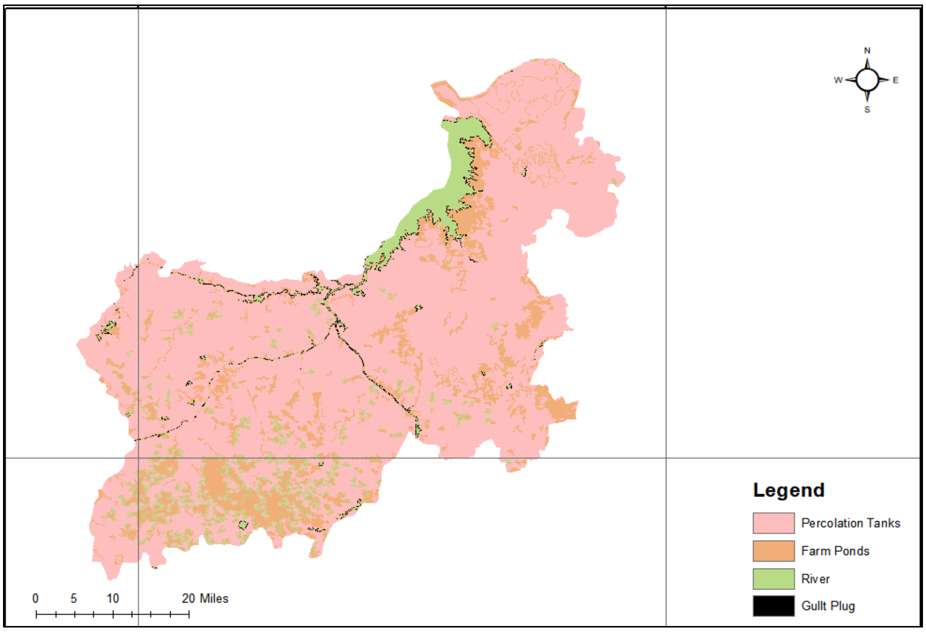

Figure 28. Mandsaur District potential RWH site map

The parameters discussed above can be used to come to the conclusion that the Mandsaur district has the potential for rainwater harvesting along some particular geographic lines with the use of gully plugs. Percolation tanks are suitable in most of the areas and can be constructed to help solve the water crisis problem. Farm ponds can also be used (Figure 28).

4.4 Rajnandgaon District

Rajnandgaon district covers a total area of 8070 km^2. It lies in the state of Chhattisgarh. Its coordinates are 28°1′ N, 73°18′ E. The temperature varies from 11°C to 47°C over the year. And the annual average rainfall in this district is 511 mm.

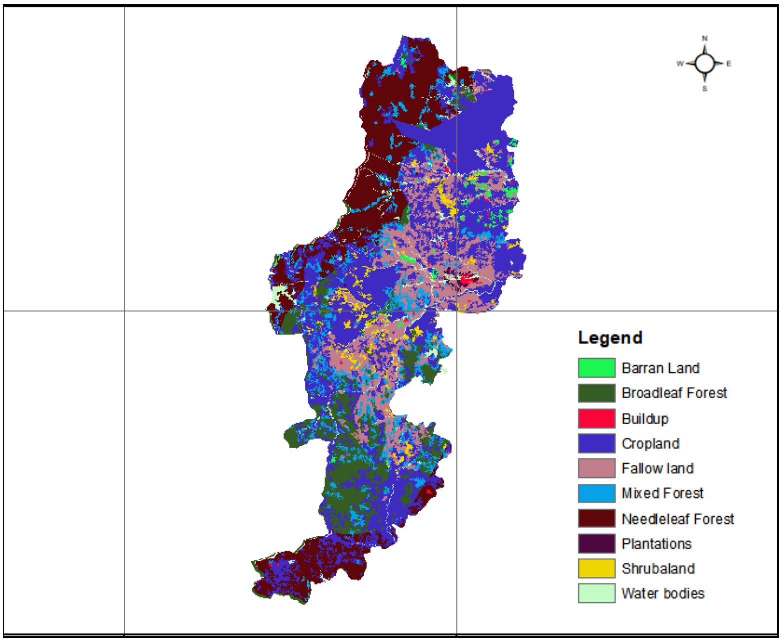

Figure 29. Rajnandgaon District LULC map

Rajnandgaon district mainly comprises of mixed forest and needle-leaf forests. The central and eastern region is covered in fallow land. Small patches of scrubland and broadleaf forest are also observed throughout the district (Figure 29).

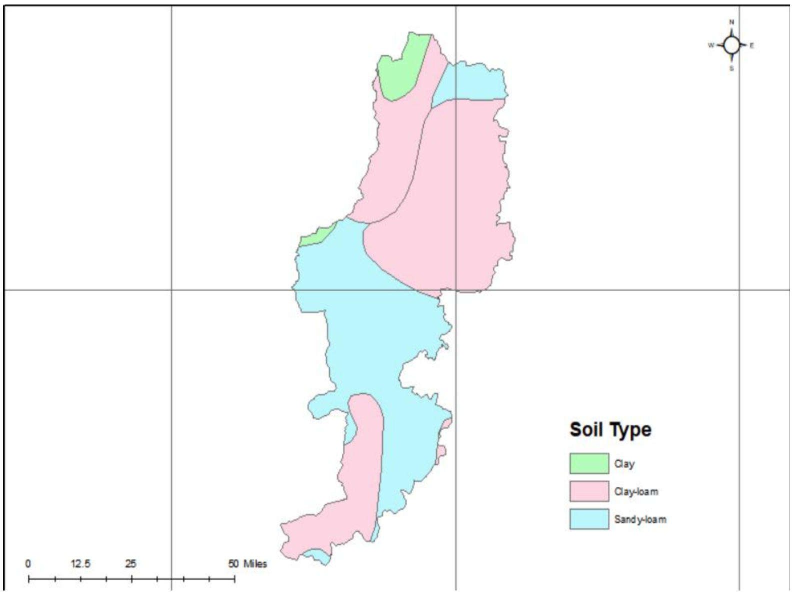

Figure 30. Rajnandgaon District soil map

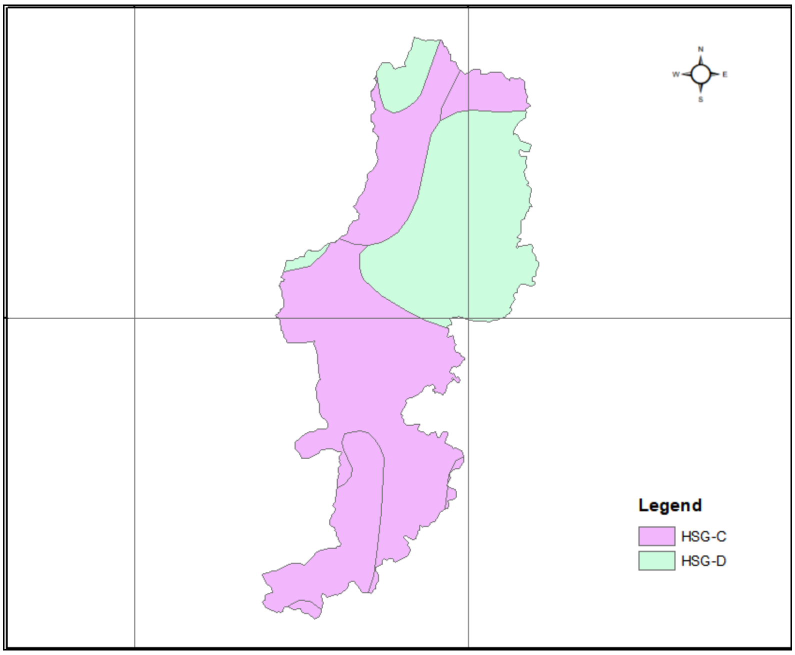

Figure 31. Rajnandgaon District reclassified soil map

Soil distribution of Rajnandgaon district comprises of sandy loam and clay loam. It also has clay in minor areas (Figure 30). HSG C and D are found in this region. C type HSG dominates in this district (Figure 31).

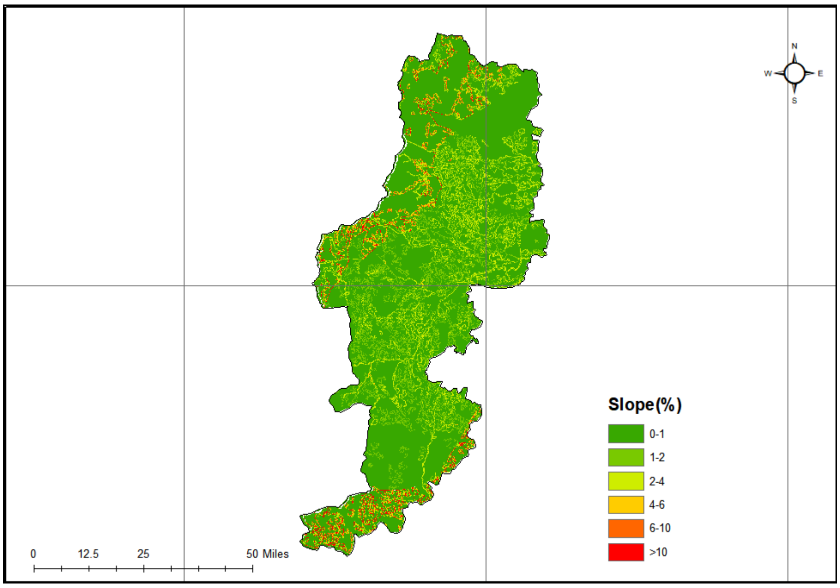

Figure 32. Rajnandgaon District slope map

Rajnandgaon district is a nearly levelled area with small patches of slope percentage greater than 6% (Figure 32). This helps with the infiltration rate maximization and slows down the runoff.

Runoff potential in most of the regions of Rajnandgaon district ranges between 250 mm to 450 mm per year. The higher annual runoff regions are found in the western patches of the district. This makes the district of Rajnandgaon, a potential district to implement rain water harvesting (Figure 33).

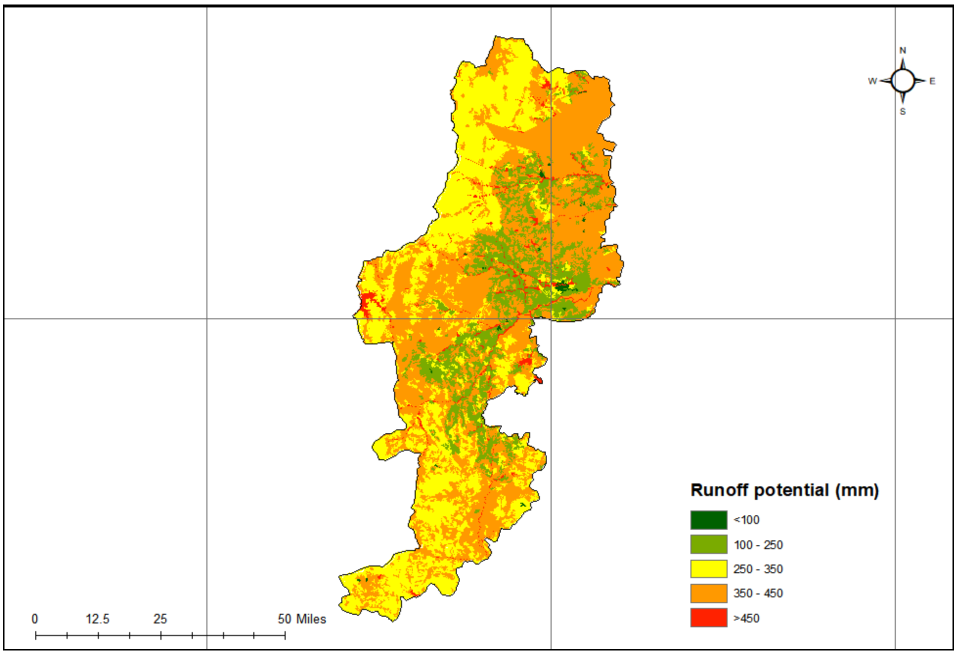

Figure 33. Rajnandgaon District runoff potential map

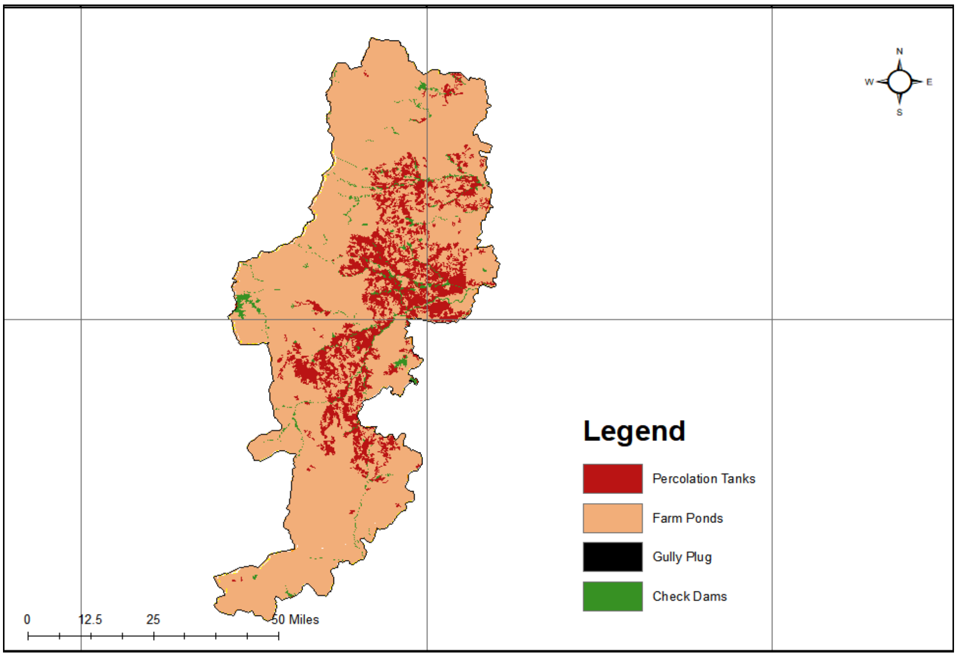

Figure 34. Rajnandgaon District potential RWH map

The study done over this area helps understand that farm ponds are suitable for most of the regions in the Rajnandgaon district. Construction of percolation tanks is also a good option and check dams can also be used (Figure 34).

CHAPTER 5

Conclusions

The SCN-CN method has demonstrated considerable value in the identification of potential RWH sites. This method can also be combined with highly developed tools such as GIS and remote sensing, to further increase the usability of results. It provides us with the efficiency and accuracy that other methods lack. This method can also be extended for use in remote areas without the availability of sufficient data. Due to the uncertain nature of the south-west monsoon in the past few years and other anthropogenic activities, the surface resources, as well as sub-surface water resources, have been depleting. Indore district, in the semi-arid zone, has been facing water scarcity with more frequency than ever before. This area shows the possible sites for harvesting rain water due to the moderate to high runoff in the regions. The 5 selected districts face major water scarcity problems and rainwater can prove beneficial in the elimination of water crisis.

The results show that this method provides us with a precision between 75% and 100% in determining prospective RWH sites. Nearly 70.3% of the area under the Indore district is appropriate for the establishment of possible RWH structures. SCS-CN method, here, gives an accuracy percentage of 100% for lakes in the IIT Indore campus. To authenticate the study and give surety about the stability and storage capacity of the proposed potential RWH structures, field investigation of the geology of the study area ought to be carried out. In conclusion, this method is less time consuming and can be used for remote areas with lesser data to create a database for future references and projects. It is a better technique that provides us with higher accuracy and efficiency. It can be used on larger areas to find potential rainwater harvesting sites with small modifications.

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