B. TECH. PROJECT REPORT

On

Identifying Artificial Recharge zones in The Cites of Indian Subcontinent using Geospatial Techniques and Multicriteria Decision Analysis

BY

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DISCIPLINE OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY INDORE

November 2019

Identifying Artificial Recharge zones in The Cites of Indian Subcontinent using Geospatial Techniques and Multicriteria Decision Analysis

A PROJECT REPORT

Submitted in partial fulfilment of the requirements for the award of the degrees

of

BACHELOR OF TECHNOLOGY

in

CIVIL ENGINEERING

Submitted by:

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Guided by:

Dr. Manish Kumar Goyal

INDIAN INSTITUTE OF TECHNOLOGY INDORE

November 2019

CANDIDATE'S DECLARATION

I hereby declare that the project entitled "**Identifying Artificial Recharge zones in The Cites of Indian Subcontinent using Geospatial Techniques and Multicriteria Decision Analysis**" 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 an authentic work.

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 students is correct to the best of my knowledge.

Signature of BTP Guide with dates

Preface

This report on “**Identifying Artificial Recharge zones in The Cites of Indian Subcontinent using Geospatial Techniques and Multicriteria Decision Analysis**” is prepared under the guidance of Dr. Manish Kumar Goyal.

Through this report I have to find rainwater harvesting sites and artificial recharge zones for the construction of suitable structures to harvest rainwater using multicriteria decision analysis.

I have tried to the best of my abilities and knowledge to explain the content in a simple way.

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Acknowledgements

I wish to thank Dr. Manish Kumar Goyal for his kind support and valuable guidance.

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

Water scarcity and climate change are some of the most urgent problems we as a society are facing in today’s era. Rainwater harvesting is one of the best and most efficient methods that can be used to counter these problems and provide an alternative source of water. To practice rainwater harvesting we need to assess RWH potential and then select sites those are suitable for RWH the constructing of RWH structures. Water management becomes a harder task as we increase the area undertaken to implement rainwater harvesting. The application of geospatial and MCDA (multi criteria decision analysis) techniques provide the much-needed help to counter such challenges. This study mainly focuses on the use of such methods to help promote rainwater harvesting in selected study areas. ArcGIS has been used to derive desired thematic layers with the use of remote sensing and local data of the field. These thematic layers include drainage density maps, runoff coefficient maps, and slope maps. Further, these selected raster layers were integrated into the ArcMap software with respect to their assigned weight to prepare a rainwater harvesting potential map for the study area. Runoff coefficient maps and annual runoff potential maps were also generated in the software following the distributed curve number method. In the rainwater potential map identification of zones for suitable structures was done, considering the runoff coefficient, drainage density and slope percent of the zones. Based on the study all the study area was divided into three RWH potential zones on the basis of their harvesting potential: (i) good (Suitable), (ii) moderate (Suitable)(iii) poor (not-suitable). Through this study, it can be established that integrated geospatial techniques along with MCDA techniques can prove to be beneficial in Rainwater harvesting planning of an area.

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1. Introduction

India, as we know, is a developing country with a sufficient average annual rainfall of 1100 mm. Freshwater, apart from being useful for domestic purposes, is also important for agricultural as well as industrial purposes. And hence, water also affects the growth of our country. Factors such as increasing population and rapid industrialization lead to water scarcity in many parts of our developing country (Biswas et al., 2009). Hence, measures need to be taken to conserve water and find alternate sources as well. To fight against environmental and socio-economic problems such as poverty, HIV/AIDS and water scarcity, the United Nations came up with plans such as the Millennium Development Goals (MDGs). India was one of many countries who adopted this eight-goal program called MDGs. According to this, India needs to work around its water resources with efficiency and must come up with water conservation plans. One of the problems, regardless of the sufficient amount of rainfall, is the uneven rainfall distribution around the year because of the monsoon season variations. Because of this restricted rainy period, the country faces floods, droughts and many other problems. To be specific, summer seasons being water shortage with them and this affects most parts of the country (Hussian, 2007). The use of rainwater to counter problems such as pollution through non-point as well as point sources is one of the most feasible and simple approaches. Rainwater harvesting, if done right, ensures safe and affordable water for different domestic and agricultural purposes. Livestock and small-scale industries are also benefitted along with the recharging of groundwater (Samara et al., 2002). Some of the secondary benefits of rainwater harvesting include flood control and conservation of soil (Singh et al., 2007). RWH systems are usually dependent on six major factors while selecting sites for RWH (food and agriculture organization, 2007), that include: hydrology, topography, agronomy, soil, climate and socio-economic condition. The climate depends on rainfall. Hydrology of an area depends on the relation of precipitation and runoff. The slope profile of an area majorly affects the topography of the area under study. Crop classification influences the land agronomy. Soil texture and depth are some major parameters to understand the soil present. And finally, socio-economic conditions such as population density, land-tenure, laws, water availability, and expenses play an important role. For proper identification of zones for RWH and the selection of RWH site with great efficiency, advanced tools like geographic information system (GIS) have been used. Recently, the importations of spatial techniques in identifying RWH potential zones has been Discovered by many Planners (Rana et al., 2007; Di Winaar et al., 2009). Selection of factors and conditions like thematic layers in order to identify zones for RWH structures. Right integration of various thematic layers is very important thing to considering during planning and here in the present study it is done by the Weighted Linear Combination technique in ArcMap software by assigning weights to the layers as well as to the features of the layers. Assigned weights are assigned on the scale of 1-9 on ArcMap Weighted overlay tool as shown by Saaty (1980). Also, furthermore, many Rainwater harvesting planners reported the Boolean logic analysis having a perticular suitability criteria for the harvesting structures for the environments can be implemented easily on the land and similar conditions having perticular modifications (Saran and Choudhwry, 1996). In recent past, a combination of WLC technique and Boolean logic technique have been used by a many planners and researchers for the identifying suitable sites for artificial recharge zones (Jarotia et al., 2006; Choudhury et al., 2000). From the previous studies applied before, it can be concluded that in applying geospatial techniques and MCDA using remote sensing and GIS techniques, appropriate finalization of suitable raster layers, assigned weights and application of MCDA techniques and use of propriate suitability criteria are very important. By taking care of these factors, we can identify potential RWH sites for suitable water harvesting structures. This is the main aim of this study. Using GIS, and MCDA techniques, a robust methodology is developed. The methodology is shown in our case study. Instead of directly using thematic layers like in earlier studies, derived thematic layers are used in combination with a distributed curve number approach.

2. **Study area overview**

2.1 Overview of Bilaspur, India

Bilaspur is a district in the Chhattisgarh state of India. Bilaspur is situated between 21.5646°,23.5678° N latitudes and 81.5678°,83.6787° E longitudes and it has an average elevation of 264 meters across the district. The total area of the district is 7342km^2 and the average annual rainfall in the district is 1234mm(http://www.weatherbase.com). The

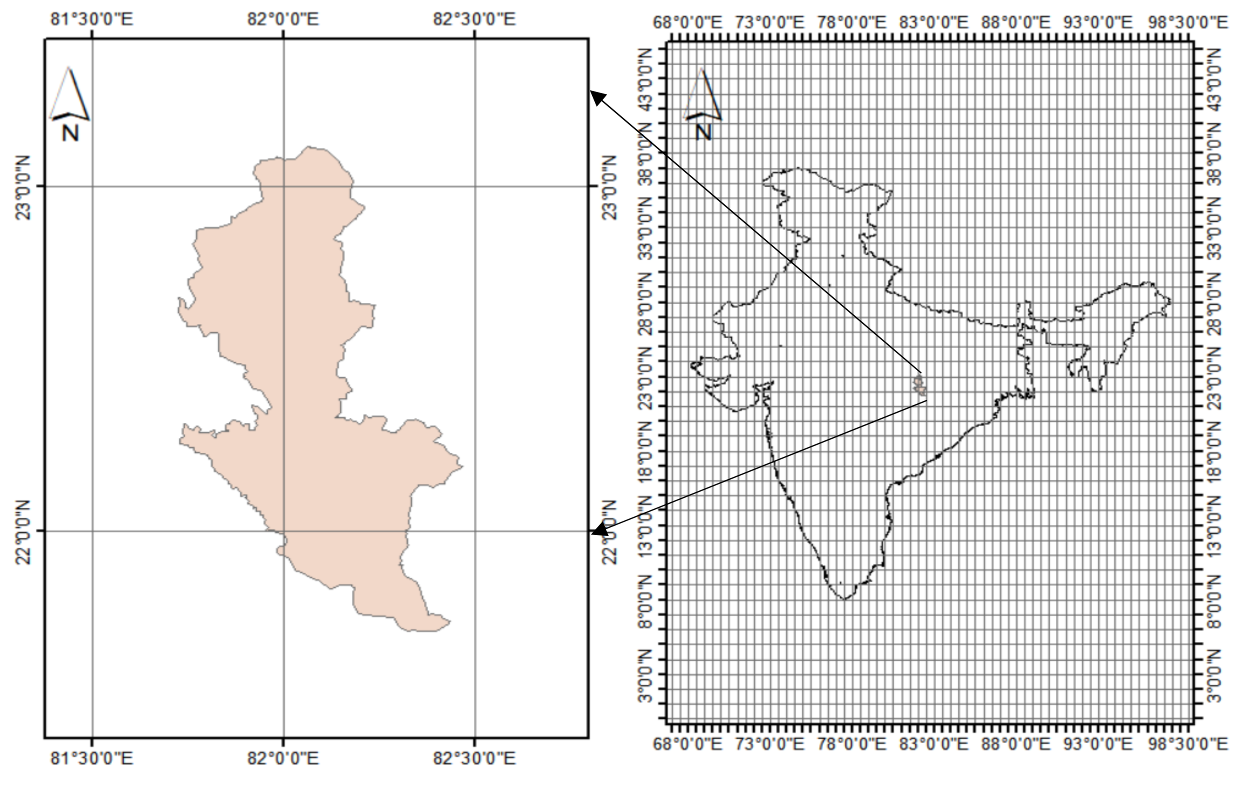


Figure 1 Location map of Bilaspur district, India

population of the district is 2,663,265 according to the 2011 census. There are four divisions in Bilaspur district those are pendra, kota, bilaspur, takhatpur.

2.2 Overview of Dang, Nepal

Dang is a district located in province no. 5 of Nepal. Dang is situated between 27.99078°,28.24566° North latitudes and 82.20145°,82.78656° East longitudes, average elevation across the district is 646 meters across the district area of Total Dang is 2955km^2 with population of 54678 according to 2011 census. Annual precipitation in the Dang is 1234mm. There are 32 divisions in the district's major divisions in the district are Rajpur, Bela, Hansipur.

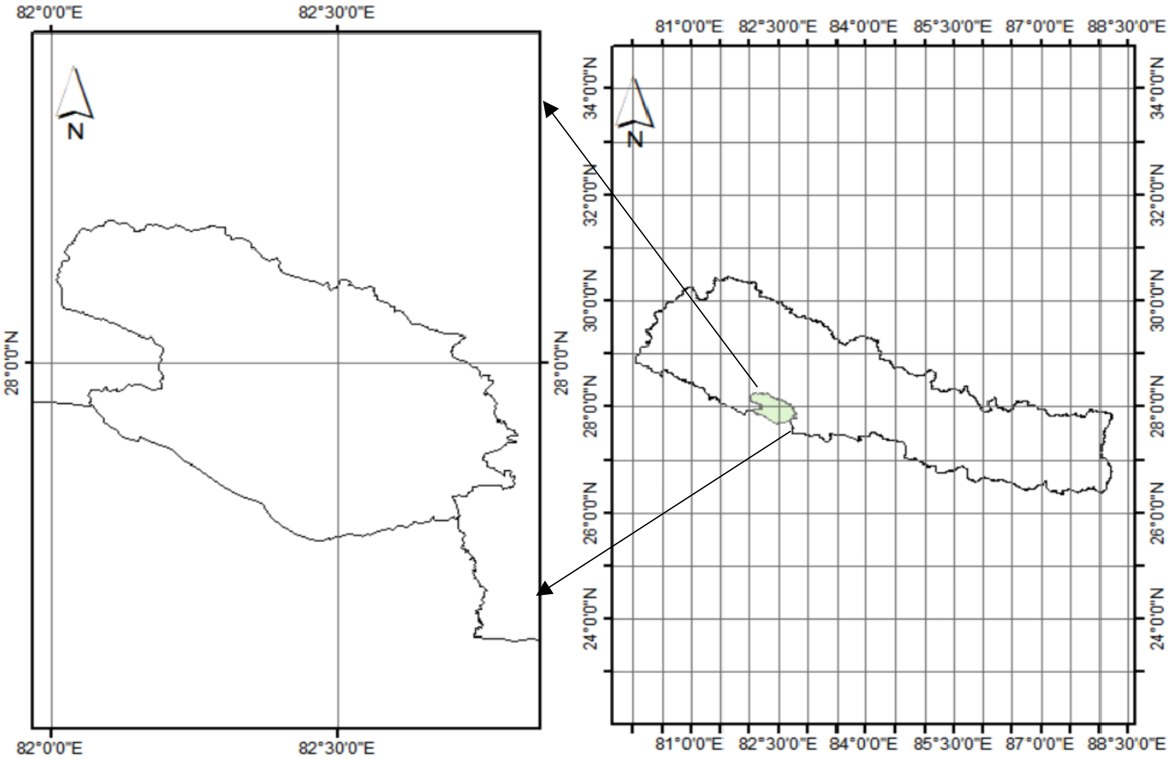


Figure 2 Location map of Dang Block, Nepal

2.3 Overview of Jamshedpur metropolis city, India

Jamshedpur Block is a division in the Indian state of Jharkhand. It is famous as India's first metropolitan city. Jamshedpur is situated between 22.2343°,22.9786° N latitudes and 85.9675°,86.4657° E longitudes and average elevation across the district is 943 meters and area of the block is 2,238,686 according to 2011 census. Annual precipitation in the area is recorded 988mm. Almost half of the block is surrounded by forests and there are 654 villages in the block.

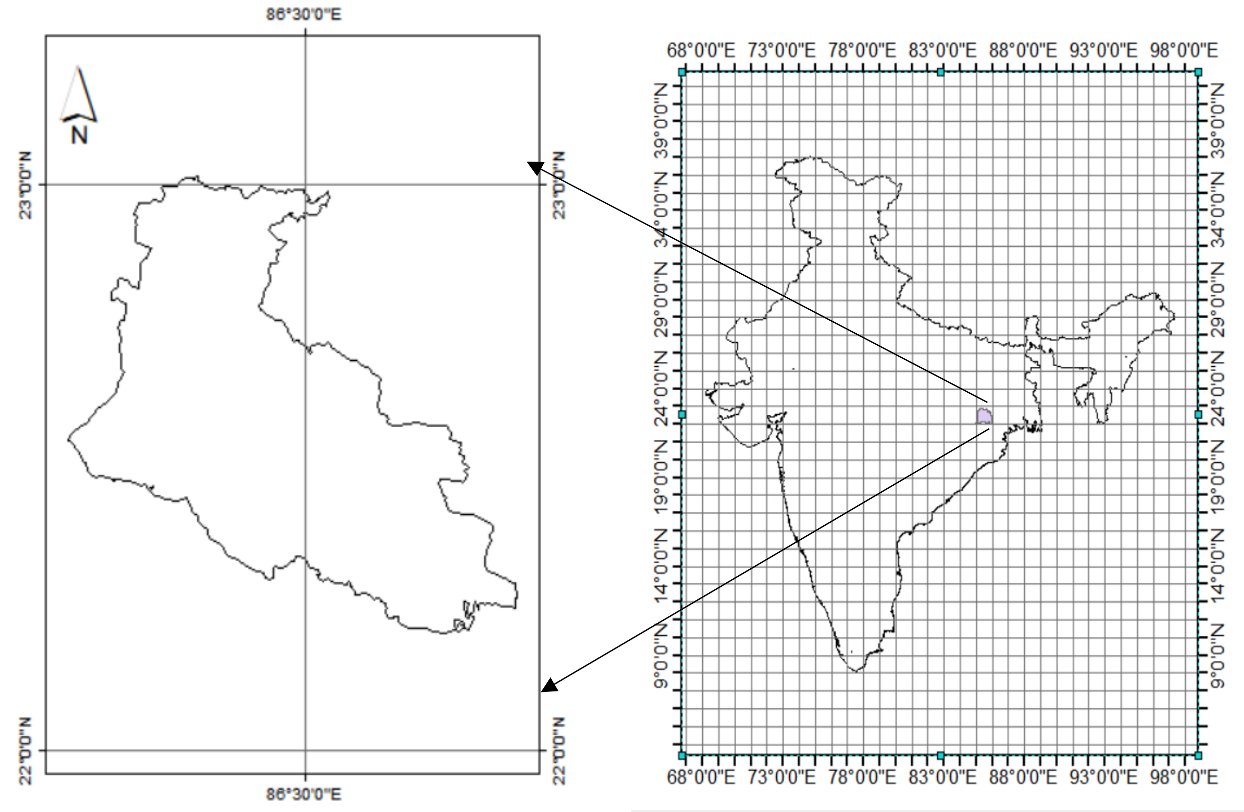


Figure 3 Location map of Jamshedpur metropolis city, India

2.4 Overview of Nasirabad, Bangladesh

Nasirabad is a district in South-eastern Bangladesh. It is situated between 26.0343°,26.8786° N latitudes and 74.5675°,75.1242° E longitude. It is part of the Chittagong province of Bangladesh. It is a port city to the Bay of Bengal; it has an area of 5283 km^2 and a population of 7,213,657 and very high population density. Annual precipitation in the district is 2232mm. The district is divided into several administrative boundaries there are about 1235 villages in the district.

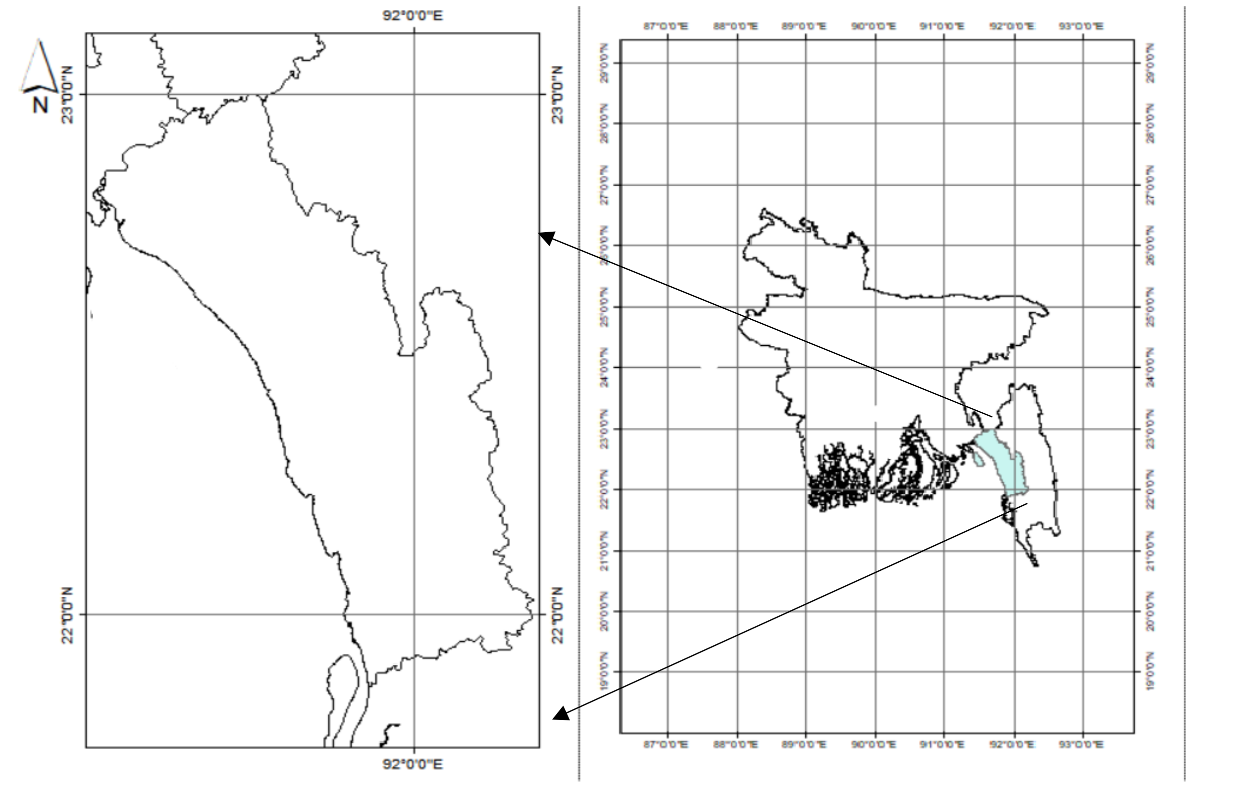


Figure 4 Location map of Nasirabad, Bangladesh

2.5 Overview of Thimphu, Bhutan

Thimphu district is a District city of Bhutan. Nasirabad is situated between 27.4343°,27.9786° N latitudes and 89.6334°,90.0656° E longitude. Thimphu has an average elevation of 7640 meters and a total area of 1792 km^2 and a population of 138,736 according to census 2011. There are eight major divisions in the Thimphu district shown in figure 5.

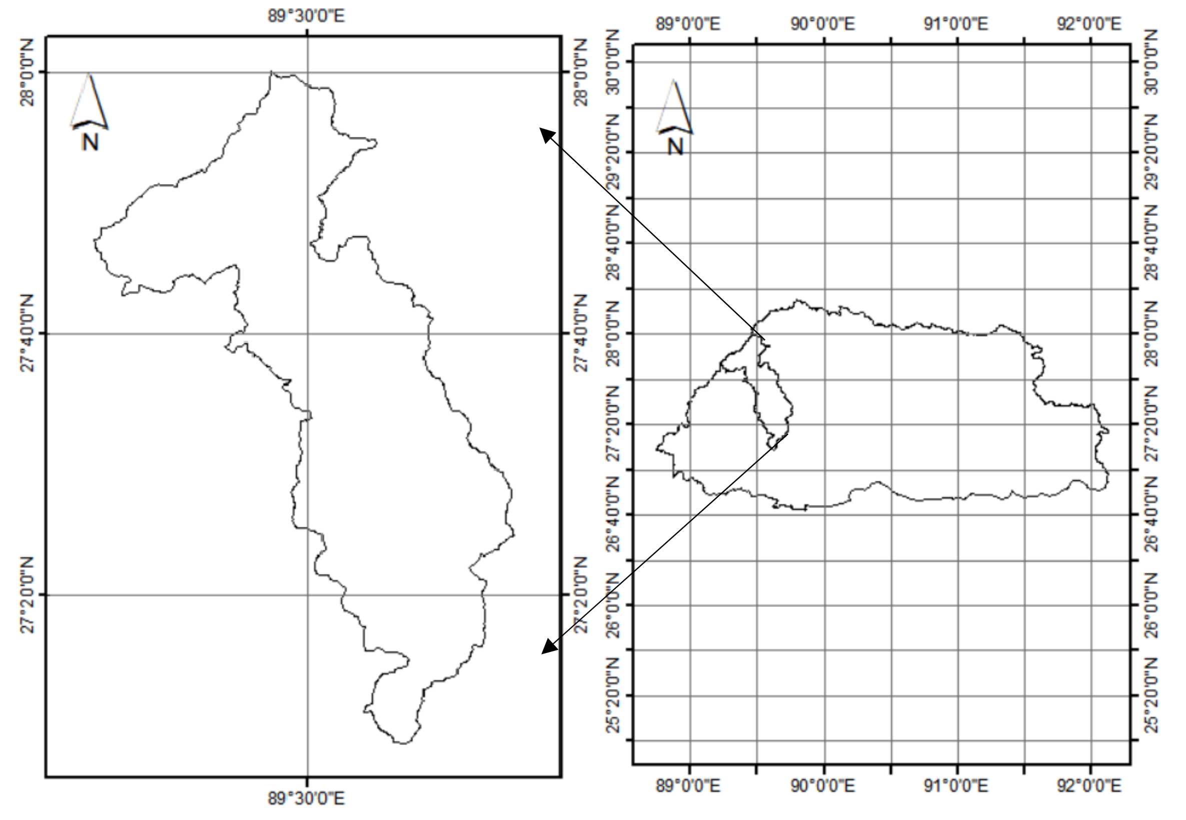


Figure 5 Location map of Thimphu, Bhutan

3. Methodology

3.1. Collection of the data

In the current study, remote sensing field data for the study area is collected from different government Satellite websites and agencies. Shuttle Radar images with resolution of 30 m of the study area are taken from 2nd November 2013 to 23rd November 2013 were downloaded from the National Geospatial-Intelligence Agency (NGA) website opentopo.edu. Shapefiles of administrative areas for the study were collected from ESRI official website. Soil GeoPackage maps of the study area at a 1:500,000 scale is collected from the official website of the Food and Agriculture Organization (FAO). Landsat 4-5 TM C1 Level-1 images with 90 m × 90 m resolution were downloaded from global visualization of the official website of United States Geological Survey (USGS) and gridded daily precipitation data for 01-15 was downloaded with spatial resolution 0.25° x 0.25° of IMD4 (India Meteorological Department 4) data set (Pai et al., 2014) which has been prepared using daily rainfall from a big network of 6955 rain gauges in the country for Jamshedpur and Bilaspur. And daily rainfall data of resolution of 0.25° x 0.25° with that is gridded over 1950-2010 for Nasirabad, Thimphu and Dang.

3.2. Selecting the thematic layers

In comparison to previous research on Rainwater harvesting zone identification using Gis techniques where mostly the ArcMap raster layers were selected on the basis of available data, in this study, ArcMap raster layers such as soil layer, land cover layer, slope percent raster layer and drainage Network layer, Drainage density layers were generated using ArcMap© and the field data, as well as runoff coefficient and runoff potential thematic layers, were Prepared. The main factor that generates Runoff is rainfall. The threshold Precipitation that generates runoff is a necessary component in RWH. The main criteria for the generation of runoff are Land-use/land-cover. Classes of land-covers such as forest, conifer forest, shrubland, fallow land, cropland, water bodies, wetlands, build-up, and settlements have a significant effect on the rainfall to conversion in the runoff. Toposheet layer features such as the slope percent are area of one of the important considerations in the performing RWH Procedures because it has a important part in generating the runoff (Atsumi et al., 2007) From the view of RWH point, slope of the land increases and Significance of that area for RWH decreases and vice versa. For example, runoff is high at steep slope. One more of the necessary factors for the RWH is soil as the texture of soil governs infiltration. On rainy days clay soil generates the highest runoff potential value, while the sand has less runoff value in compare. And the value of drainage density in the region, that governs the time of concentration for the runoff, Low value of drainage density is considered good here for the RWH. With the increase in drainage network's density, RWH suitability in the region for the RWH decreases. On the basis of consideration of the above facts, On the basis of daily rainfall data and location of rain gage stations are used for creating annual rainfall maps using ArcMap© software. Thiessen polygon method of calculating areal rainfall (Mackay et al., 2012) was used for the areal rainfall maps for the study area. LULC map is prepared using digital image processing and reclassify tools of ArcMap© software. All of five slope maps were generated by integration of DEM images and Extracting it by mask on ArcMap© and then using arc toolbox tool called Surface Slope 3D analyst in ArcMap software and the soil type maps of the study area were clipped using clip tool from downloaded global soil map from FAO and was vectorized using ArcMap© software. Soil map of the study area must be classified on the basis of texture and infiltrating rate of the soil.

Hence, the soils in this study were divided into classification of National resources conservation service those are hydrologic soil groups (HSGs): HSG-A, HSG-B, HSG-C, and HSG-D (Saddam, 1990), and so HSG soil map was prepared. Furthermore, Drainage network layer and spatial drainage density maps were too Generated using spatial analyst tools and hydrology tools within GIS environment. With the use of aerial rainfall distribution map and runoff potential map, the Raster layer of the runoff coefficient was prepared using ArcMap© software. Moreover, a Raster layers such as drainage network map, build-up map layers were overlaid to check rainwater harvesting sites and these thematic layers were used for identifying and selecting sites for ponds, recharge zones, and settlement tanks, check dams and percolation tanks.

3.3. SCS-CN method and runoff calculation

The Soil Conservation Service Curve Number method (Lyon & Walter, 2004) is modest and conceptual method for the direct runoff estimation. In the previous studies, this method is a very simple approach in GIS Environment to calculate the runoff value. This method follows a water balance equation of Precipitation in time (t). Runoff calculated from a catchment can be given as (Ponce & Hawkins, 1996):

$$Q = \frac{(P-\lambda S)^2}{P+(1-\lambda S)} \qquad (1)$$

where, O= Runoff from the catchment, P = precipitation on the catchment, λ= abstraction, and S = maximum retention.

λ value in the Eq. (1) was considered 0.2 it is a typical value. After putting $\lambda = 0.2$ in Eq. (1), Equation of the runoff:

$$Q = \frac{(P-0.2S)^2}{P+(1-0.2S)} \qquad (2)$$

λ value is in range 0.1 to 0.4 (S. Singh & Mishra, 2012). For the Asian conditions, 0.1 and 0.3 are recommended values of abstraction ratio and antecedent moisture condition Types are AMC-I, AMC-II, and AMC-III. The modified equation for Asian standards is shown below (Subramaniya, 2007):

$$Q = \frac{(P-0.1S)^2}{P+0.9S}; \forall\ P \geq 0.1S \qquad (3)$$

Eq. (3) for the soils under conditions AMC II and AMC III.

$$Q = \frac{(P-0.3S)^2}{P+0.7S}; \forall P \geq 0.3S \tag{4}$$

Eq. (4) can be used for the soil under AMC I as well as to all other soils having AMC I, AMC

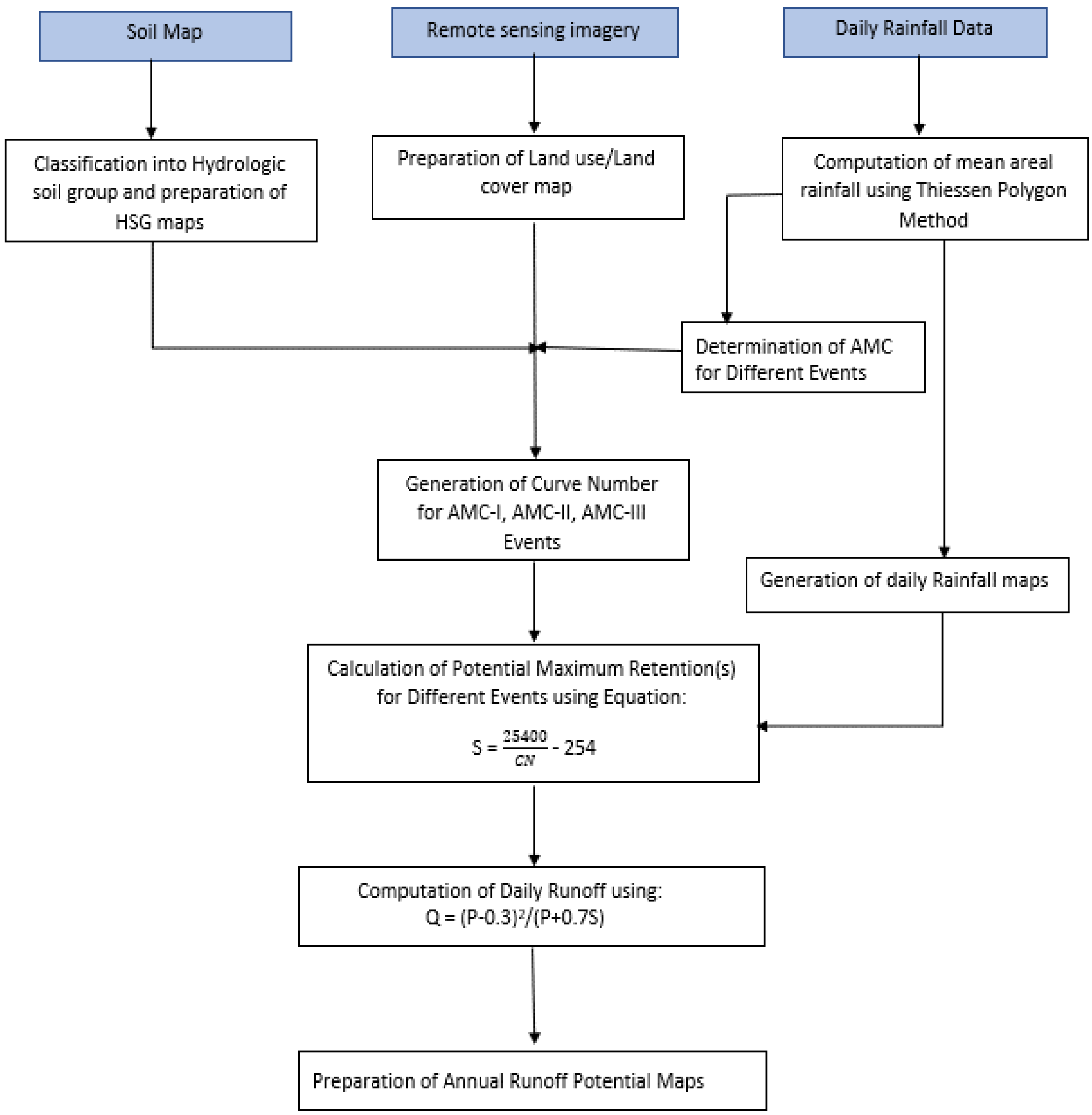


Figure 6 Flowchart for Preparation of runoff potential maps using SCS-CN method

II and AMC III. Eq. (4) was used to calculate direct runoff in this study. Potential maximum retention is calculated by using Eq. (5):

$$S = \frac{25400}{CN} - 254 \quad (5)$$

3.4. Runoff potential map preparation

LULC layer and HSG layer were overlaid, intersected and a modified soil-land cover map was prepared using ArcMap©. Every land type has unique CN value base on the Hydrologic soil group they are assigned to and the CN value details for the computation were taken from the standard table of the SCS (Subramanya, 2003). After finding the AMC-I, II and III conditions for possible various precipitation events, and value of retention (S) for each condition computed from Eq. (5). And spatial distribution of curve numbers is calculated, the runoff potential every curve number map was calculated from Eq. (4). Hence, the yearly runoff maps were prepared for 2007-2010 using ArcMap©. furthermore, adding daily surface runoffs, annual runoff potential was computed for the 2007-2010.

3.5. Runoff coefficient map preparation

Runoff coefficient is basically fraction of precipitation that generates runoff. Value of Runoff coefficient for sandy soils varies from 0.05 to 0.9 for the concrete catchments (Singh, 1992). In the present study, Coefficient of runoff is a ratio of runoff potential to the corresponding annual rainfall. In GIS Environment maps for runoff coefficient were prepared and classified. in present study, the runoff coefficient map of the year 2007 was applied to classify the RWH sites in the area. runoff coefficient is accountable for precipitation, soil, and land type which affect the process of runoff.

3.6. Rainwater harvesting potential map Preparation

In the present study, Analytic Hierarchy Process of MCDA methods (Saatyji, 1980) and earlier ArcMap methods were applied to generating RWHP map of any study area. In past researches in this field, they directly used all the required raster layers (Soil layer, Land cover layer and

Slope layer) for computation of RWH potential map layers of runoff coefficient Map

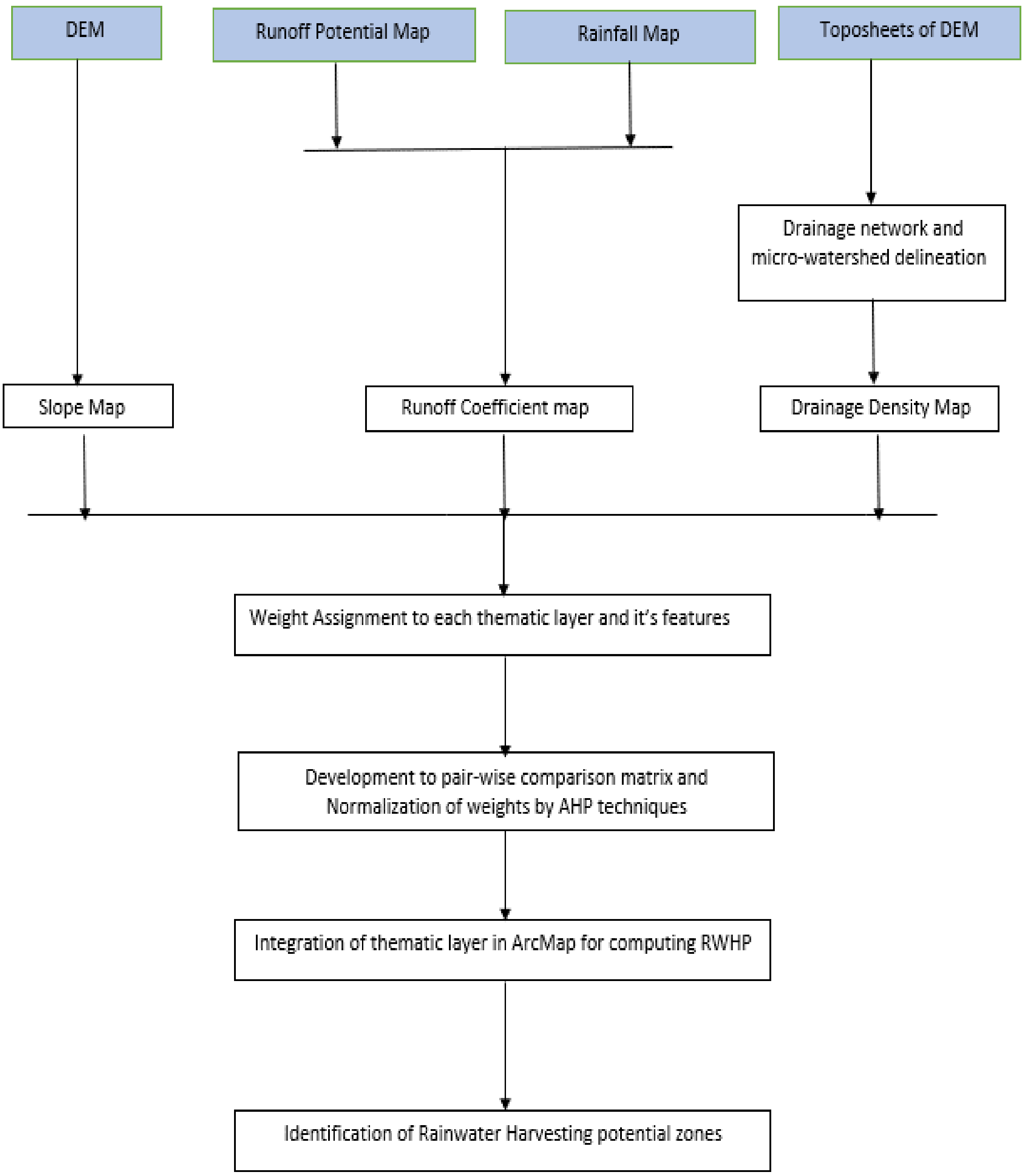


Figure 7 Flowchart for preparation of rainwater harvesting potential zones

(Integrated map of annual rainfall layer, land use/land cover layer, and soil), slope map, and drainage density map are taken in consideration for classification of runoff potential zones in the study area. All selected thematic layers and their features were assigned weights on the scale on the saaty's journal (Saaty 1980) for assigning saaty's weightage, the impact of all thematic layer was taken into consideration. Once the assigned weight of themes and their features were finalized, Tables of these assigned weights and features were prepared from Saaty's Analytic Hierarchy Process. So, normalized weights themes and features were computed. Hence, each of the three thematic layers with their normalized weights were integrated and performed weighted overlay operation using ArcMap© software. Net weights of various parts in the overlaid layer were calculated by using ArcMap tools within GIS environment by using the Weighted overlay technique below:

$$RWHPI = RC_{w.t}RC_{w.f} + SL_{w.t}SL_{w.f} + DD_{w.t}DD_{w.f} \tag{7}$$

where, RWHPI = Index of Rainwater Harvesting Potential, $RC_{w.t}$ = normalized weight for runoff coefficient, $RC_{w.f}$ = normalized weight for feature of the runoff coefficient, $SL_{w.t}$ = Slope theme normalized weight, $SL_{w.f}$ = normalized weight for feature for the slope theme, $DD_{w.t}$ = normalized weight of the drainage density theme, and $DD_{w.f}$ = drainage density features's normalized weight. RWHPI is very important parameter in finding RWH potential zones in an area. Furthermore, the RWH potential map and the runoff potential map were Overlaid in ArcMap© software in order to find runoff in individual RWH potential zones.

Table 1

Criteria used for identification of zones for RWH structures.

Percolation Tank (on the ground)	Percolation Tank (along the stream)	Check dams	Farm pond
• Land slope:<3% • Land cover: Degraded forest • Soil: light texture soil	• Slope percent:<5% • Soil: light texture soil • Stream order:2nd and 3rd	• Land slope:<15% • Soil: fine texture soil • Drainage order 2nd and 3rd	• Land slope<3% • Land cover: agriculture • Soil: fine texture soil

Table 2

Land use/land cover and their suitability for RWH

S.No.	Land use/land cover	Suitability
1	Agricultural land	Unsuitable
2	harvested land	Suitable
3	Open forest	Suitable
4	Conifer forest	Unsuitable
5	Shrubland (Scrubs)	Suitable
6	Grassland	Suitable
7	Buildup	Unsuitable
8	water bodies	Unsuitable
9	Barren lands	Suitable
10	Wastelands	Unsuitable

Table 3

Hydrological soil groups and corresponding soil textures.

HSG Group	Runoff Description	Soil Texture
HSG-A	Low runoff potential and Infiltration rate high	Sand, loamy-sand Sandy-loam
HSG-B	Moderate infiltration rate And moderate runoff potential	Silty-loam, loam
HSG-C	High Runoff potential and low infiltration rate	Sand-clay-loam
HSG-D	High runoff potential and very low infiltration rate	Clay-loam, Silty-clay, clay

3.7. Identification of suitable zones for rainwater harvesting structures

This study not only identify RWH potential zones, this research also took the selection of the suitable zones in solemn consideration for constructing RWH sites and recharge sites such as dams, percolation tanks both on the stream and on the ground. achieving above goal For,

Table 4

Land cover types, their hydrological conditions and corresponding Curve numbers to HSG soil type.

Land property		**Hydrological Soil Group**			
Land cover Type	**Hydrological condition**	**HSG-A**	**HSG-B**	**HSG-C**	**HSG-D**
Build-up	Poor	54	74	82	92
Grassland	Moderate	30	58	70	78
Fallow land	Good	77	86	91	94
Shrubland	Good	43	65	76	82
Broadleaf forest	Good	40	55	74	80
Mixed forest	Good	35	54	70	76
Cropland	Moderate	67	78	82	89
Conifer forest	Moderate	46	68	72	84
Barren land	Good	42	70	76	88
Wasteland	Poor	30	45	56	68

individual RWH structures were confirmed on the criteria of suitability and review from past researches in RWH and the inhabitant's information are in Table 1. For the site identification, 2nd and 3rd stream order drainage network was clipped from the stream network after that stream map main buffer tool was performed on the both sides of the drainage network with the buffer distance of 90 m. The thematic layers LULC, slope percent, soil type, and drainage network (buffer of second and third order drainage) were integrated in order to find the good sites for RWH structures such as ponds and recharge sites. Conditions for particular land type and suitability is given in Table 2. Hence, zones those are suitable for RWH structures were found out based on the various geological and hydrological information.

4. Results and discussion

4.1. Land use/land cover map

The LULC maps are shown Five figures below, that there are fifteen categories of land cover manly Shrubland, conifer forest, broadleaf forest, dense forest, open forest, degraded forest, crop land, fallow land, plantation, snow and ice, build-up, grassland, wasteland, water bodies, mixed forest, permanent wetlands, evergreen forest, salt pan, aquaculture and river.

- Land cover of Bilaspur district have about 30% of broadleaf forest as major land cover and besides them settlement/Build-up is 5%, water bodies 2%, Cropland is 52% and shrubland barren land is less than 10%.
- There are seven types of cover in Dang block, where forest cover 54% of dense forest, 0.79% woody vegetation (shrubland), grassland over 2%, agricultural land is 34%, barren land 1.9%, water body less than 1% build-up is less than 5%.
- Land cover area of Jamshedpur includes ten types of the land covers where 27% land is deciduous broadleaf forest, settlement is 6%, Cropland is 19%, shrubland and barren land is about 14%, fallow land is 14%, water bodies 2% and plantation is 7%.

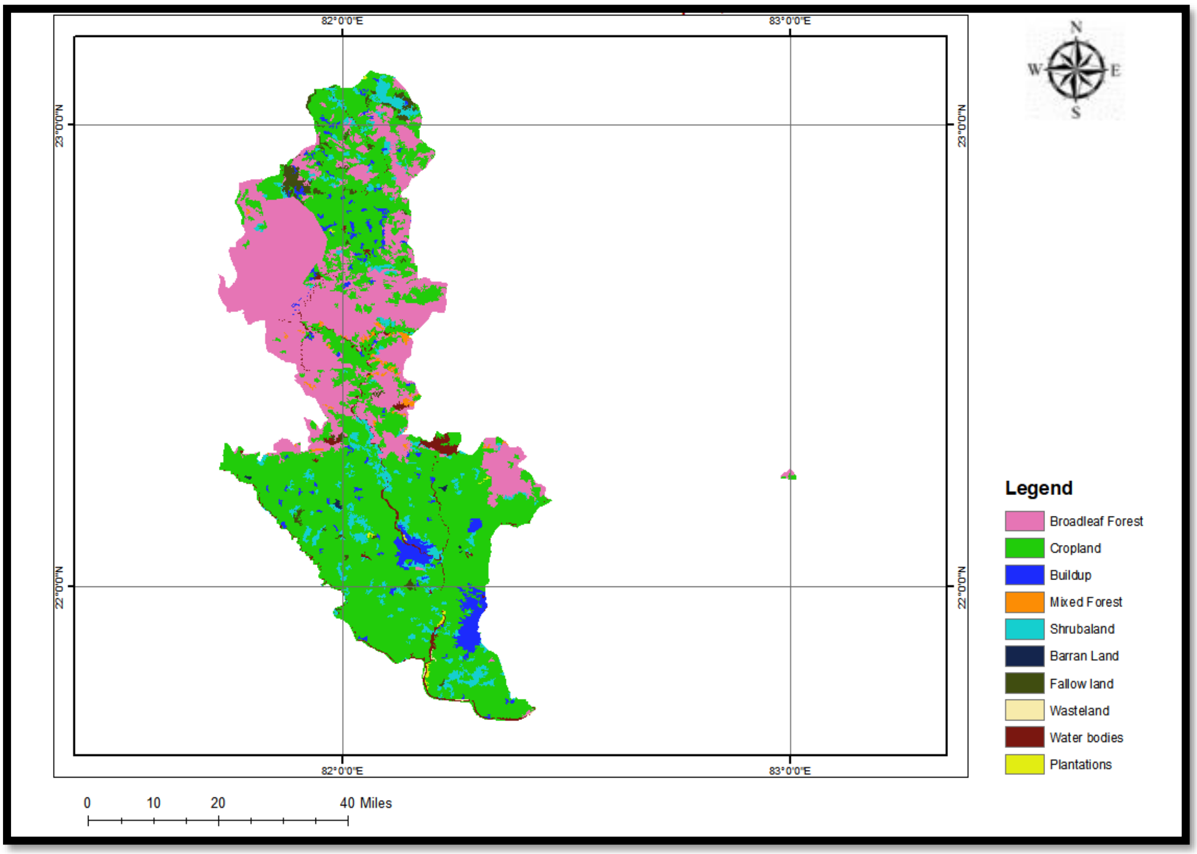


Figure 8 Land use/land cover of Bilaspur, India

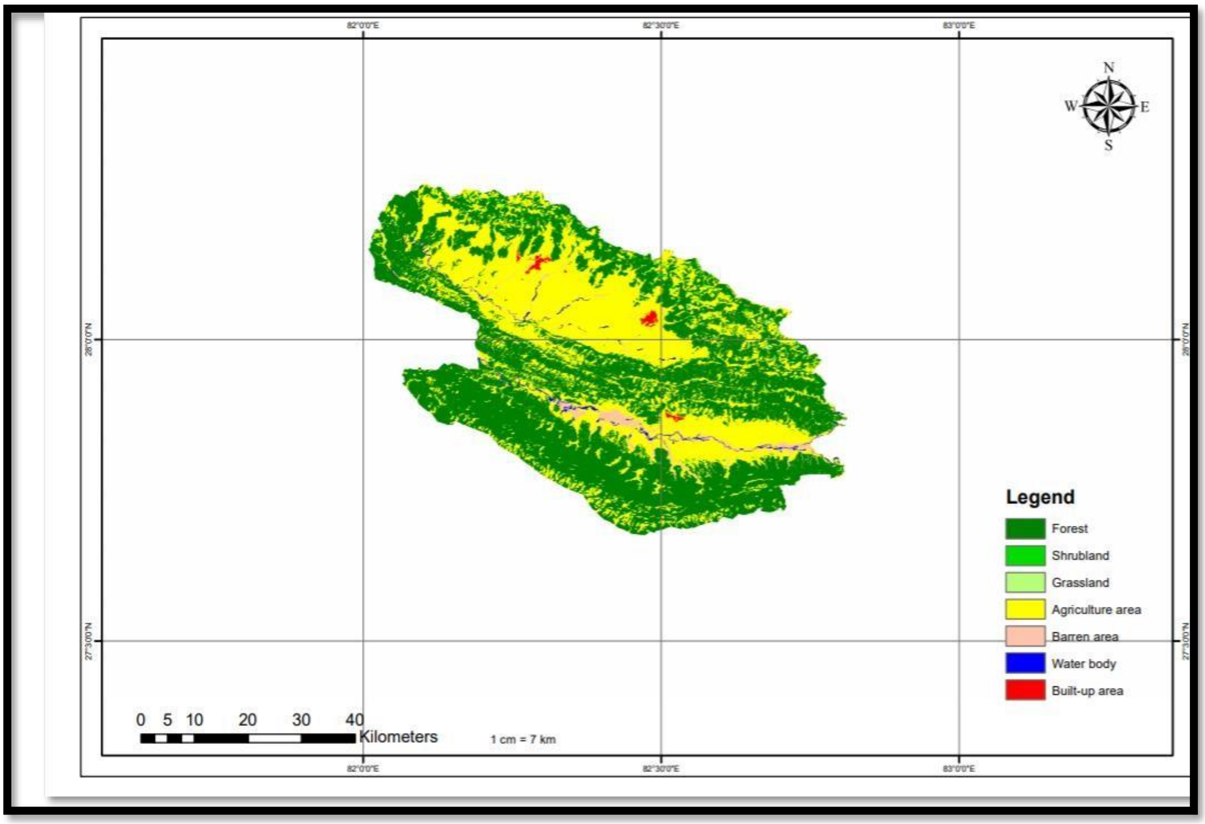


Figure 9 Land use/land cover map of Dang Block, Nepal

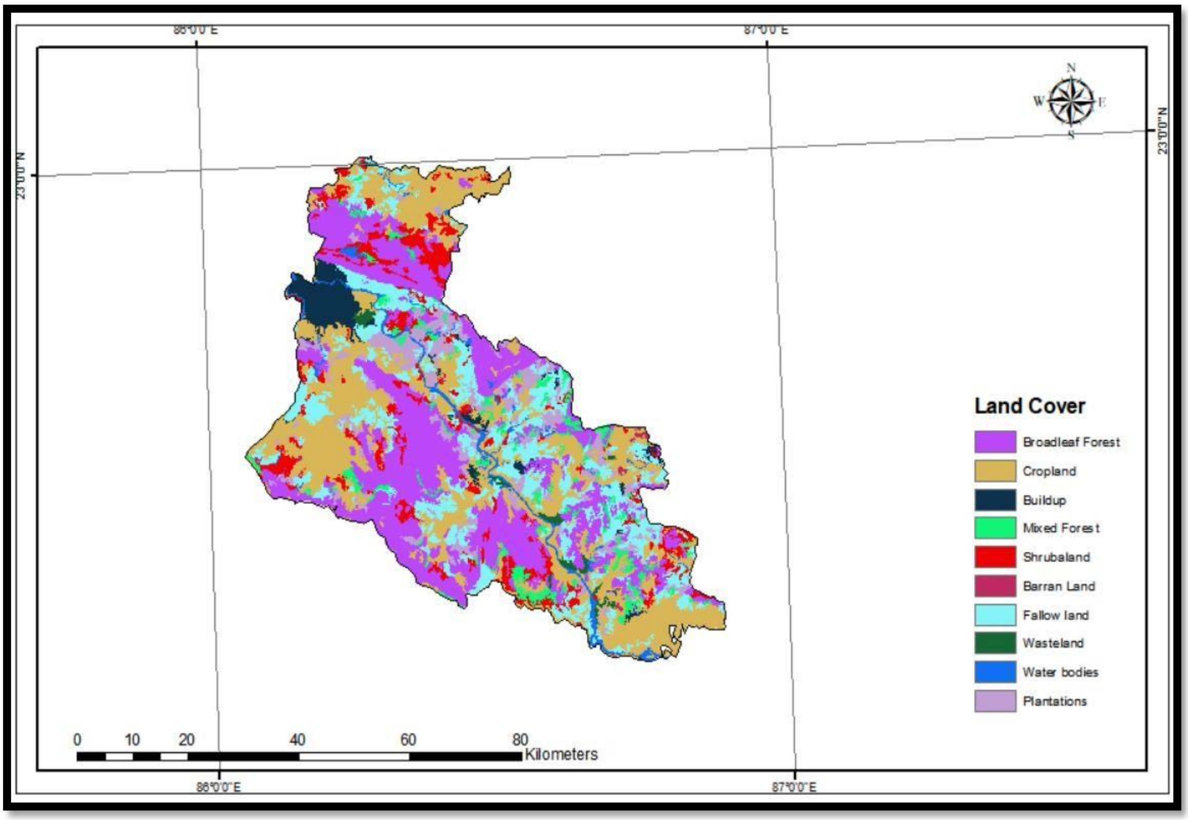


Figure 10 Land use/land cover map of Jamshedpur metropolis city, India

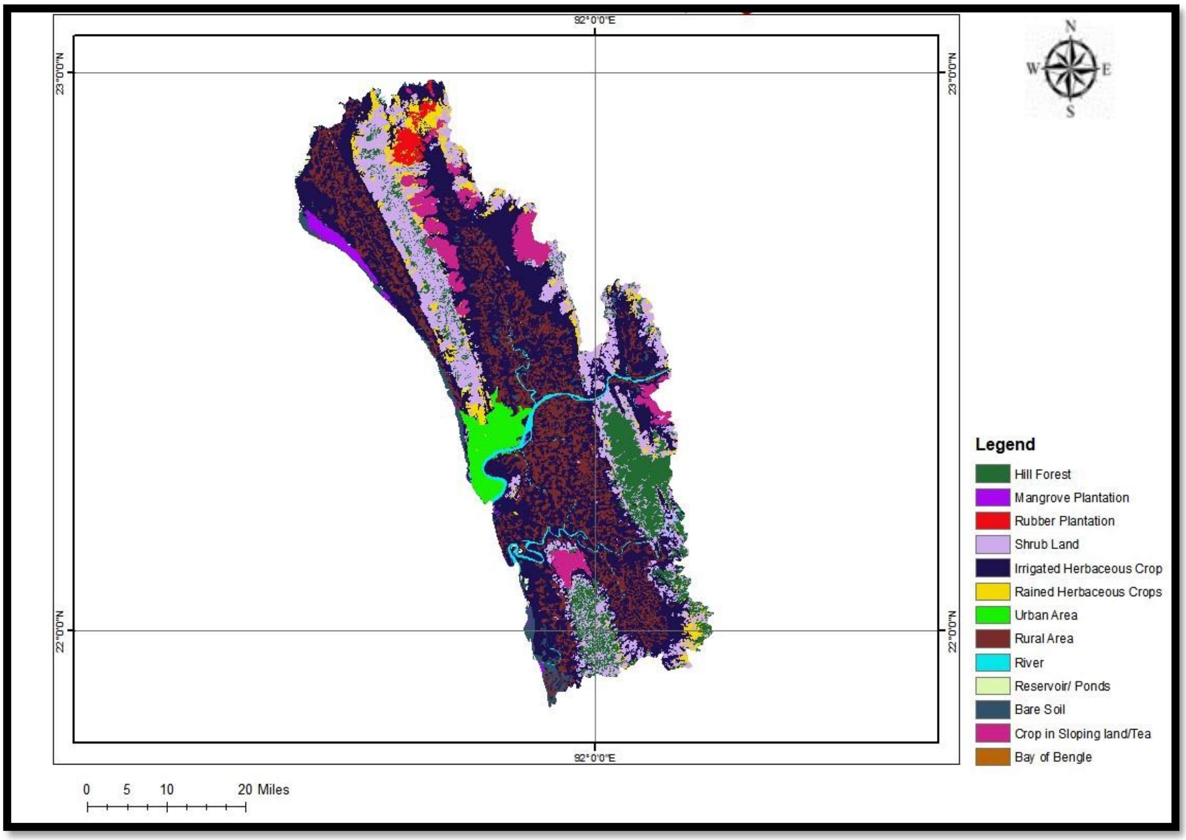


Figure 11 Land use/land cover map of Nasirabad, Bangladesh

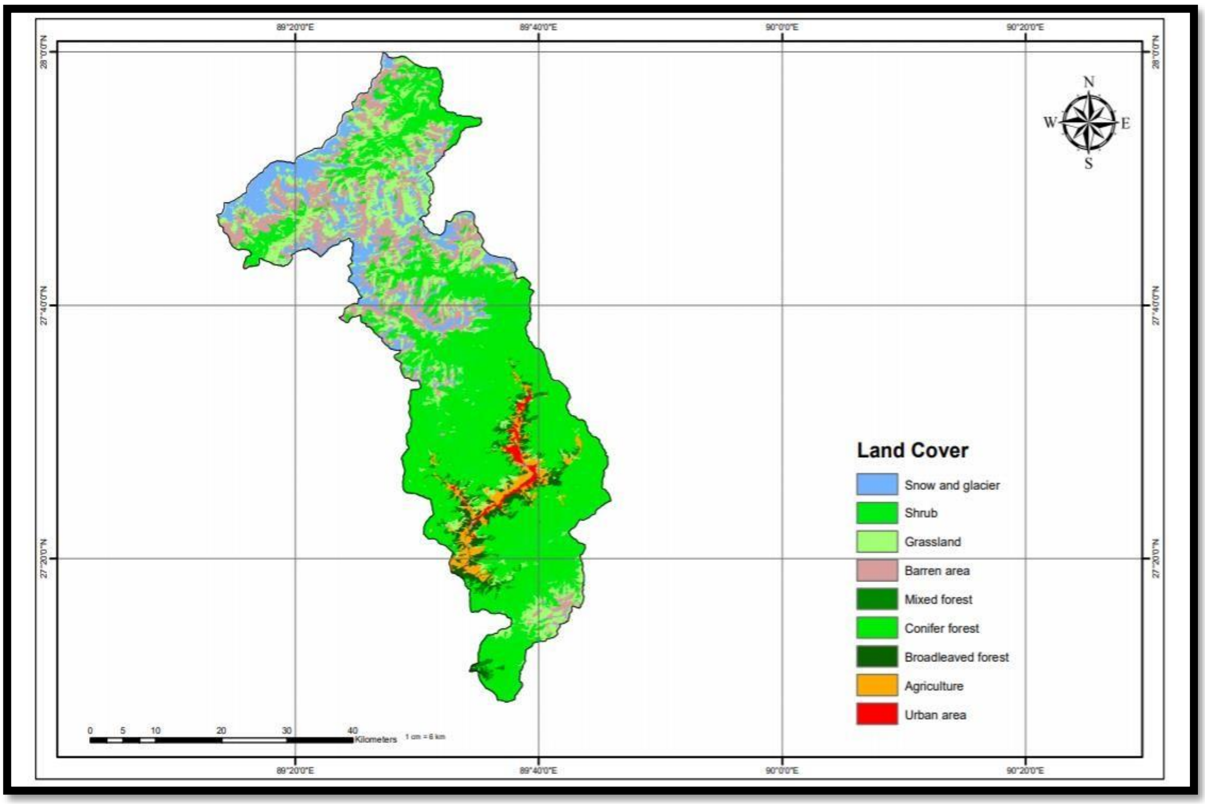


Figure 12 Land use/land cover map of Thimphu District, Bhutan

4.2. Soil map

The soil maps of all the five-study area shows that there are six soil types in this study: sandy-clay-loam, sandy-loam, loam, silty-loam, clay-loam and clay, silty-clay, WUB soil these all the soil classification is based on food and agriculture institute's report of 2006. From figure 14 to figure 18 are the soil map of all five study areas.

- There are 3 types of soils which Bilaspur district is covered with which includes loam soil of 18%, sandy-clay-loam soil of 8% and rest of the soil is sandy loam which is very good for the agriculture activities.
- Dang block of Nepal geographically a border district to India. There are four layers of soil in the region they have two types of soil clay-loam and loam upper region is loam

soil region below region of that is clay-loam region. Clay loam soil is in about 46% of the area while loam soil region is about 54% of the area.

- Jamshedpur City comes under district east singhbhum which is known for water scarcity and wasteland soils. From the classification of soils from the global soil data and fao soil ArcMap© files it is found that there is 3 types of major soil in the area clay, loam, sandy-loam where clay is about 8% and loam is 31% and rest of remaining the soil is of type sandy-loam.
- Nasirabad district is a port district of Bangladesh it has mainly three types of soil based on universal soil classification loam, Sandy-loam. 8% area of the District have Sandy-loam soil which is in north eastern part of district while loam soil is in 92% of the total area.
- Thimphu is covered with two types of soil groups those are loam and unweathered bedrock.

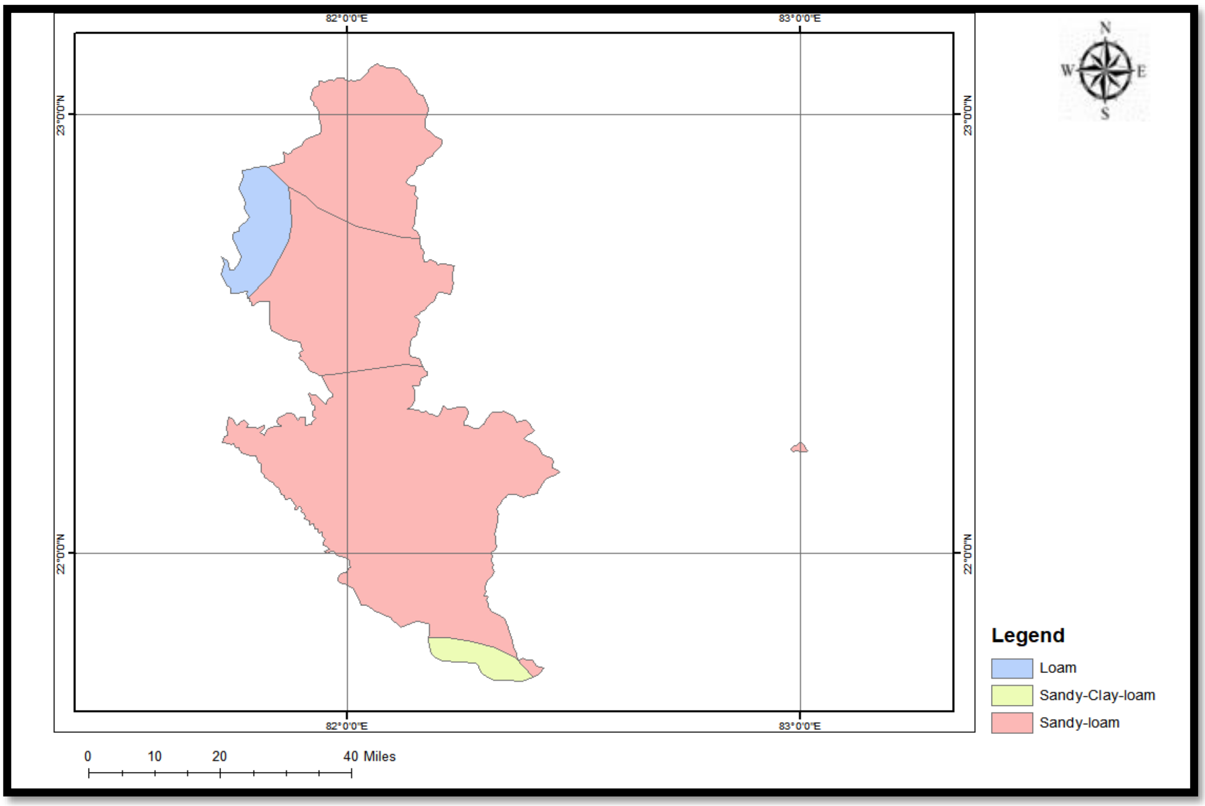


Figure 13 Soil map of Bilaspur district, India

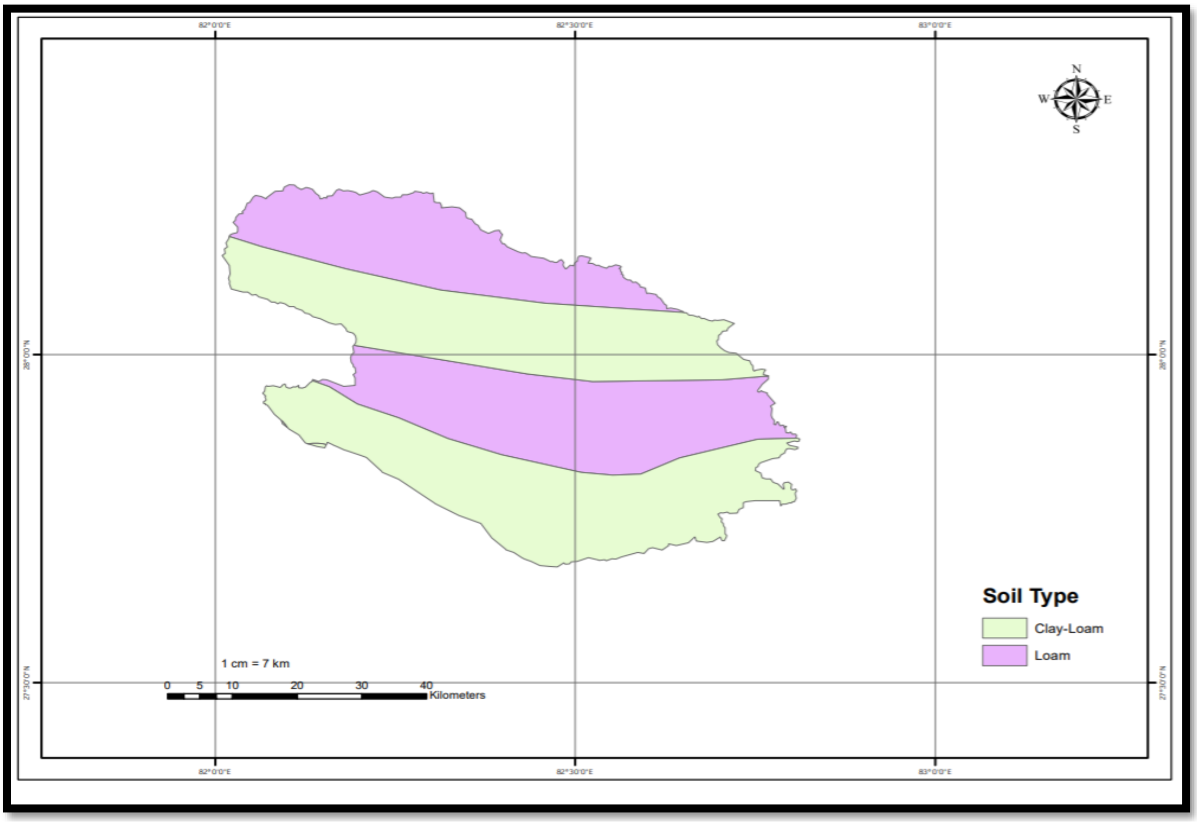


Figure 14 Soil map of Dang Block, Nepal

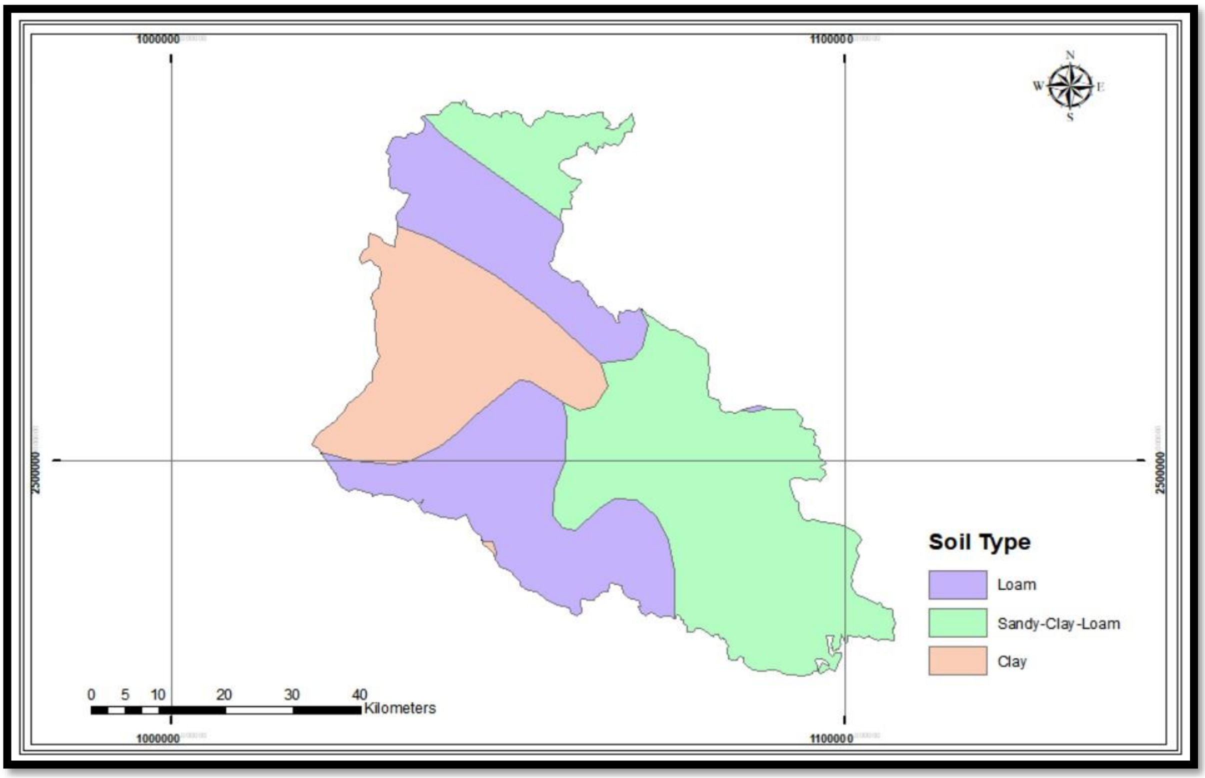


Figure 15 Soil map of Jamshedpur metropolis city, India

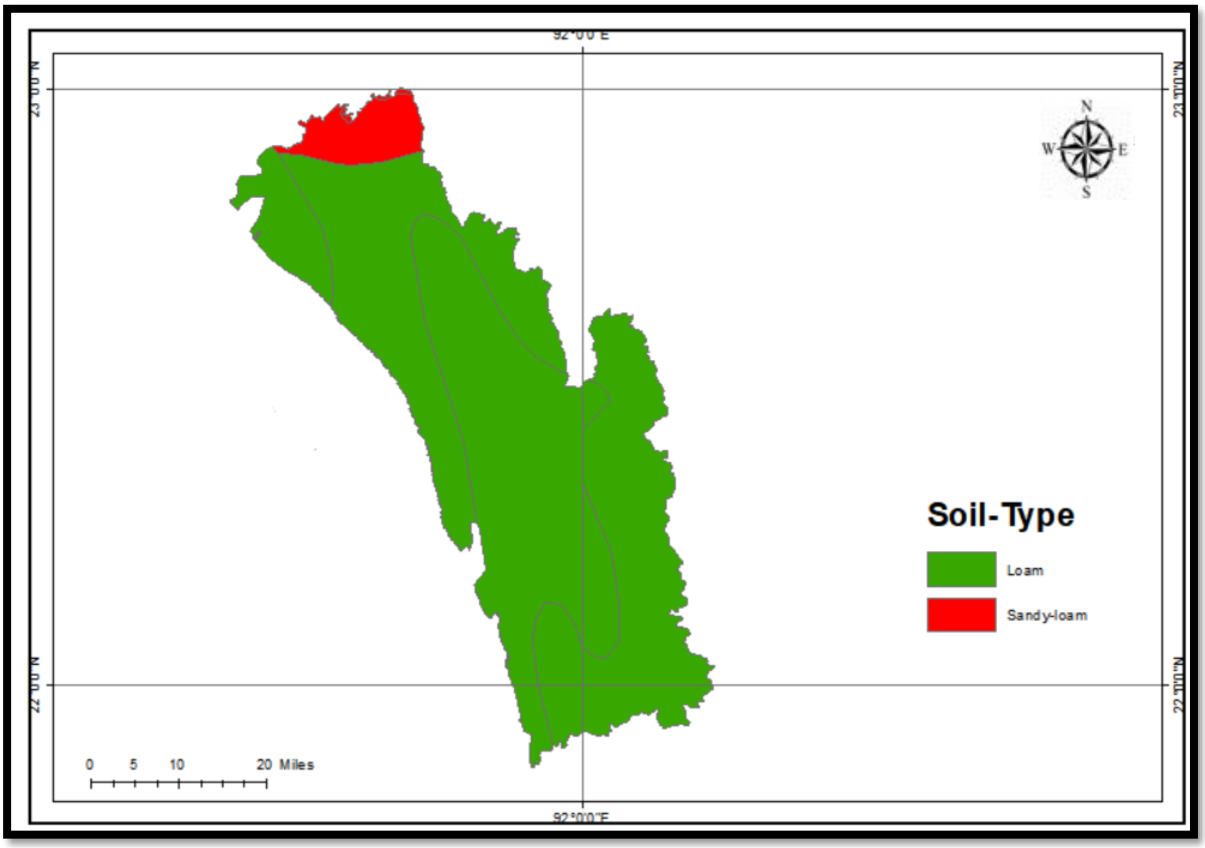


Figure 16 Soil map of Nasirabad, Bangladesh

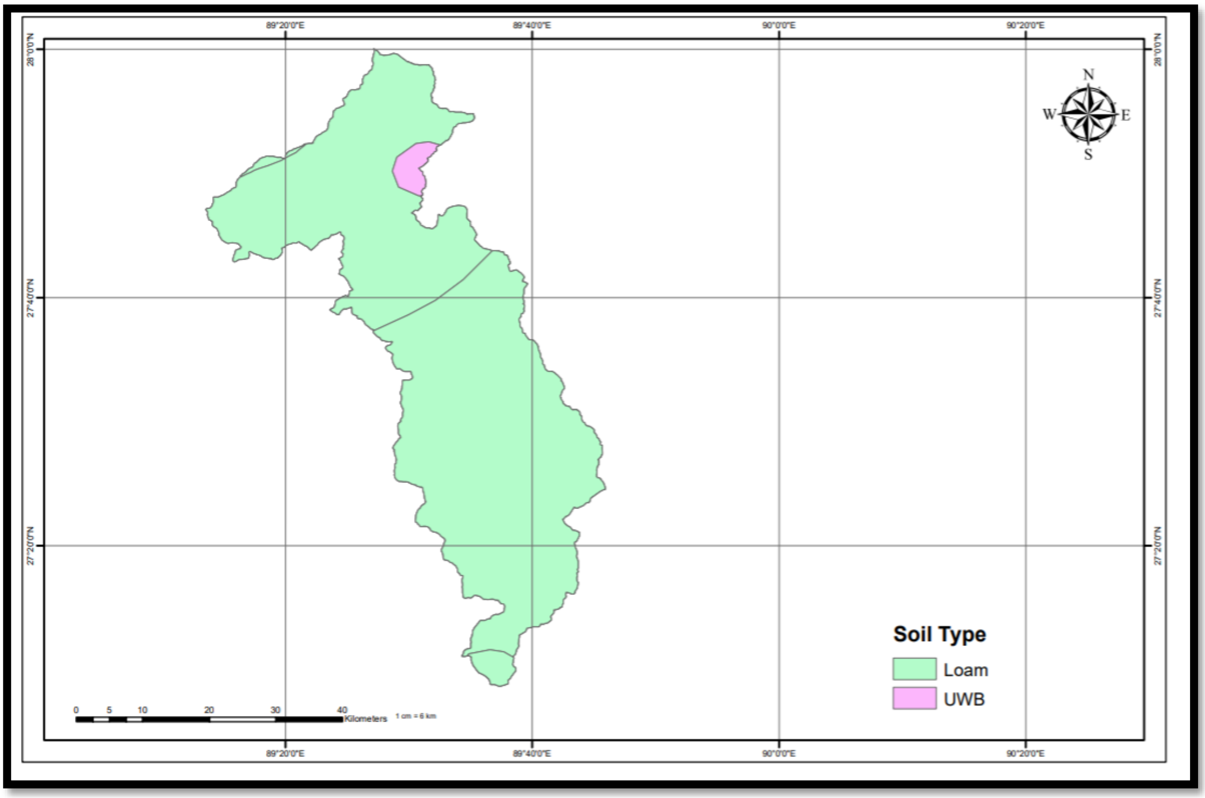


Figure 17 Soil map of Thimphu, Bhutan

4.3. Hydrologic soil group map

The Cover of hydrologic soil groups (HSGs) for all five-study area is shown below from figure 19 to figure 23.

- Bilaspur district is covered with two hydrologic soil groups: HSGs B and C. The HSG B exists in the western part of the study area having an area of about 378 km^2 (39%), while the HSG C is found in the eastern region of Bilaspur.
- There is four hydrologic soil group layers in the study area Dang those are HSG-C, HSG-D. In southern region and central north region there is soil HSG-C encompassing area of 53% while HSG-D is in central southern region and in north region encompassing area of 47% of total area.
- There is 2 soil hydrologic soil group layers in the study are of Jamshedpur those are HSG-C, HSG-D. HSG-C is in everywhere in the Jamshedpur except north west region encompassing area of 74.87% while HSG-D exists in North west region encompassing area of 25.13%.
- Harbor city of Bangladesh Nasirabad consists two types of Hydrologic soil groups those are HSG-B, HSG-C, HSG-D. HSG_C is major contributor encompassing area of 98% while both HSG-B, HSG-D exists in only 2% of the area.
- Capital city of Bhutan, Thimphu consist two type of hydrologic soil groups those are HSG-C, HSG-D. HSG-D exists in small eastern part of Thimphu encompassing are of 4% while HSG-C exists in rest of the area of Thimphu encompassing area of 96%.

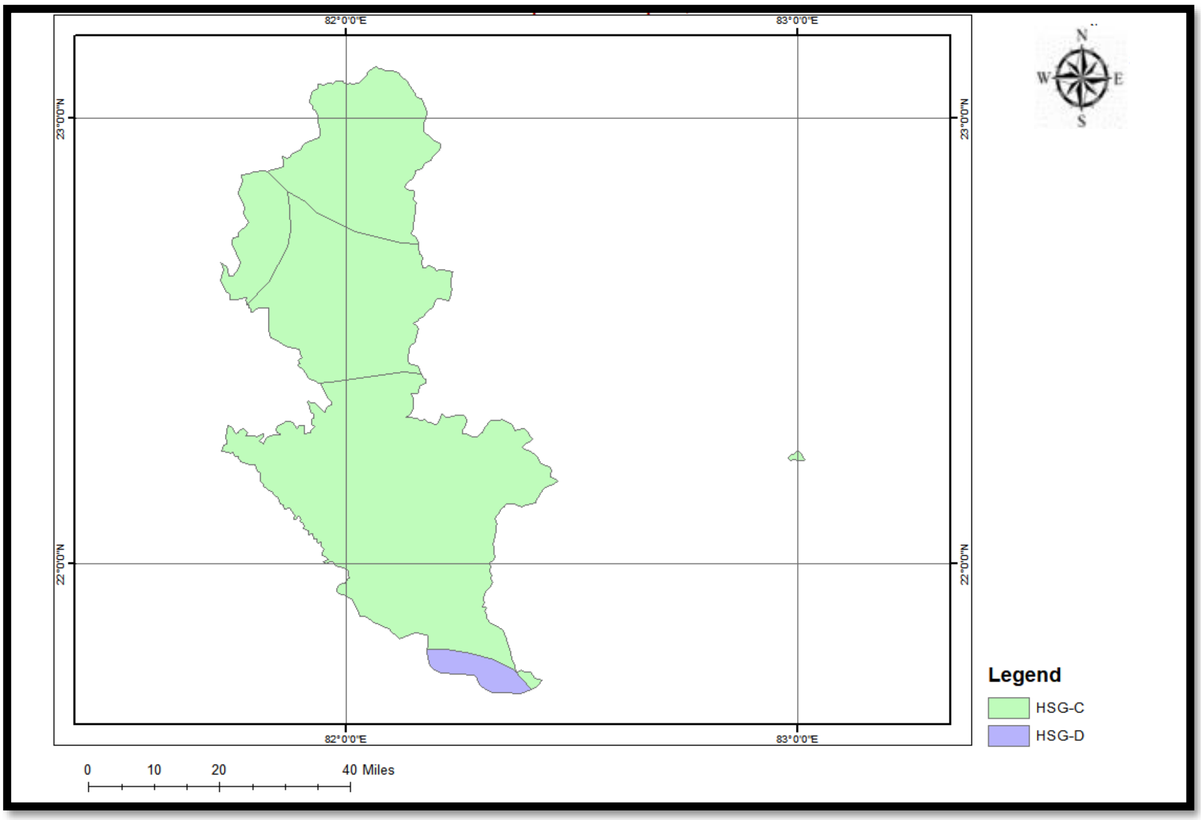


Figure 18 HSG map of Bilaspur, India

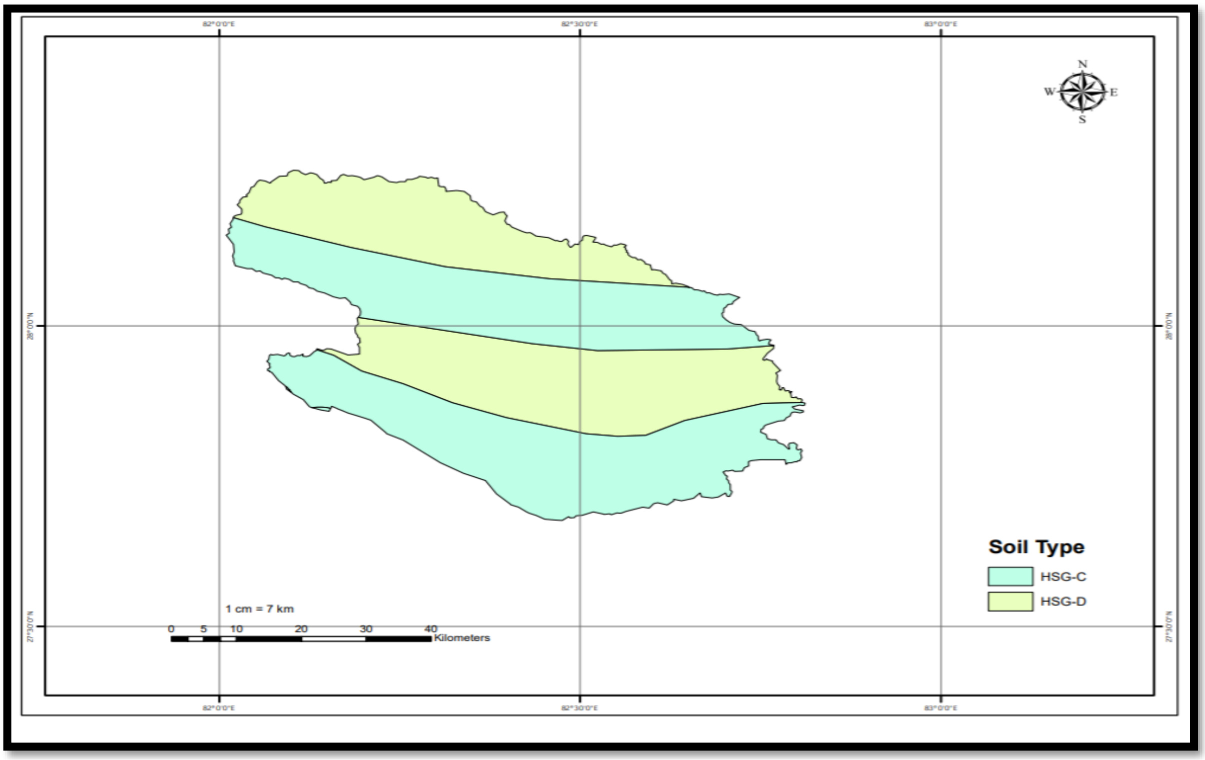


Figure 19 HSG map of Dang, Nepal

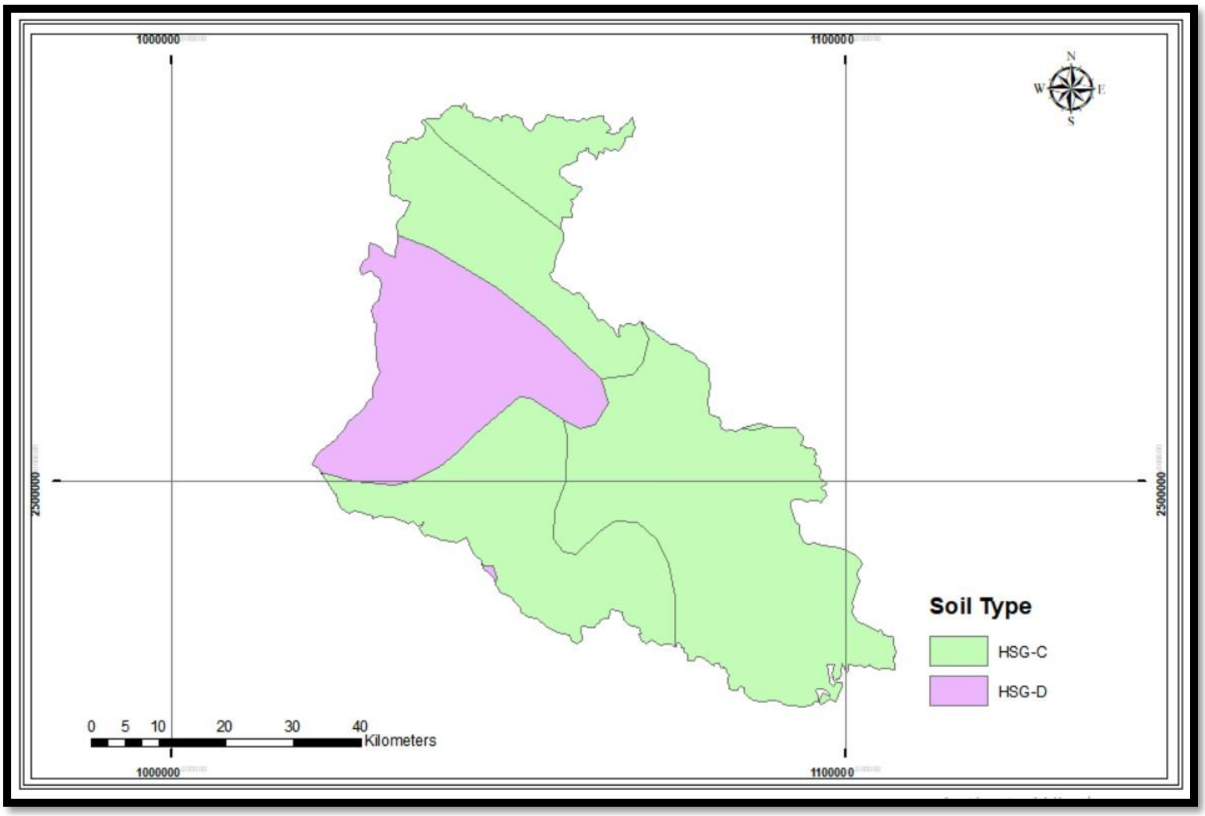
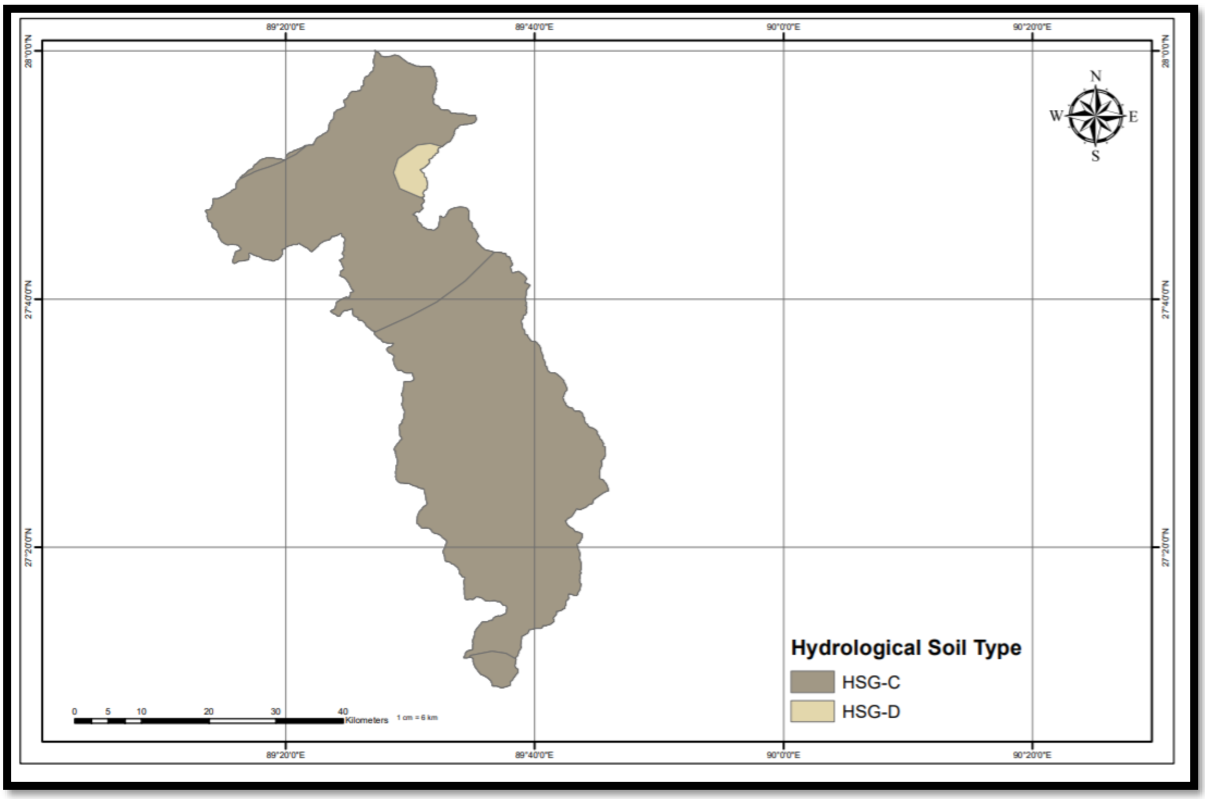


Figure 20 HSG map of Jamshedpur metropolis city, India

Figure 21 HSG map of Nasirabad, Bangladesh



. Figure 22 HSG map of Thimphu, Bhutan

4.4 Slope map

The thematic slope layer is classified in the area varies from 0% to 20% as given in Table. 5, The slope percent of here were divided into six types: The slope classes level and gentle were taken suitable for RWH. Slope percent in the Bilaspur district are classified into 6 slope classes from 0 to 40 percent and class 0-3% and 3-10% are suitable for constructing rainwater harvesting sites.

- Slope percent in the Dang Block are classified into 6 slope classes from 0 to 35 percent and only 0-5% class is suitable for constructing rainwater harvesting sites. Because only this class falls under level to gentle category of slope.
- Slope percent in the Jamshedpur are classified into 6 slope classes from 0 to 20 percent and 0-3% and 3-5% classes are suitable for constructing rainwater harvesting sites. Only these two classes are under gentle, moderately gentle, level category of slope.

- Slope percent in the Nasirabad are classified into 6 slope classes from 0 to 20 percent and 0-3% and 3-5% classes are suitable for constructing rainwater harvesting sites. Only these two classes are under gentle, moderately gentle and level category of slope.
- Slope percent in the Thimphu are classified into 4 slope classes from 0 to 40 percent and 0-10% class is suitable for constructing rainwater harvesting sites. Only this class comes under gentle, moderately gentle and level category of slope.

Table 5

Slope percent and their classes

Slope (%)	**Slope class**
0-1	Level
1-3	Gentle
3-5	Moderate gentle
5-10	Steep
10-20	Moderate steep
>20	Very steep

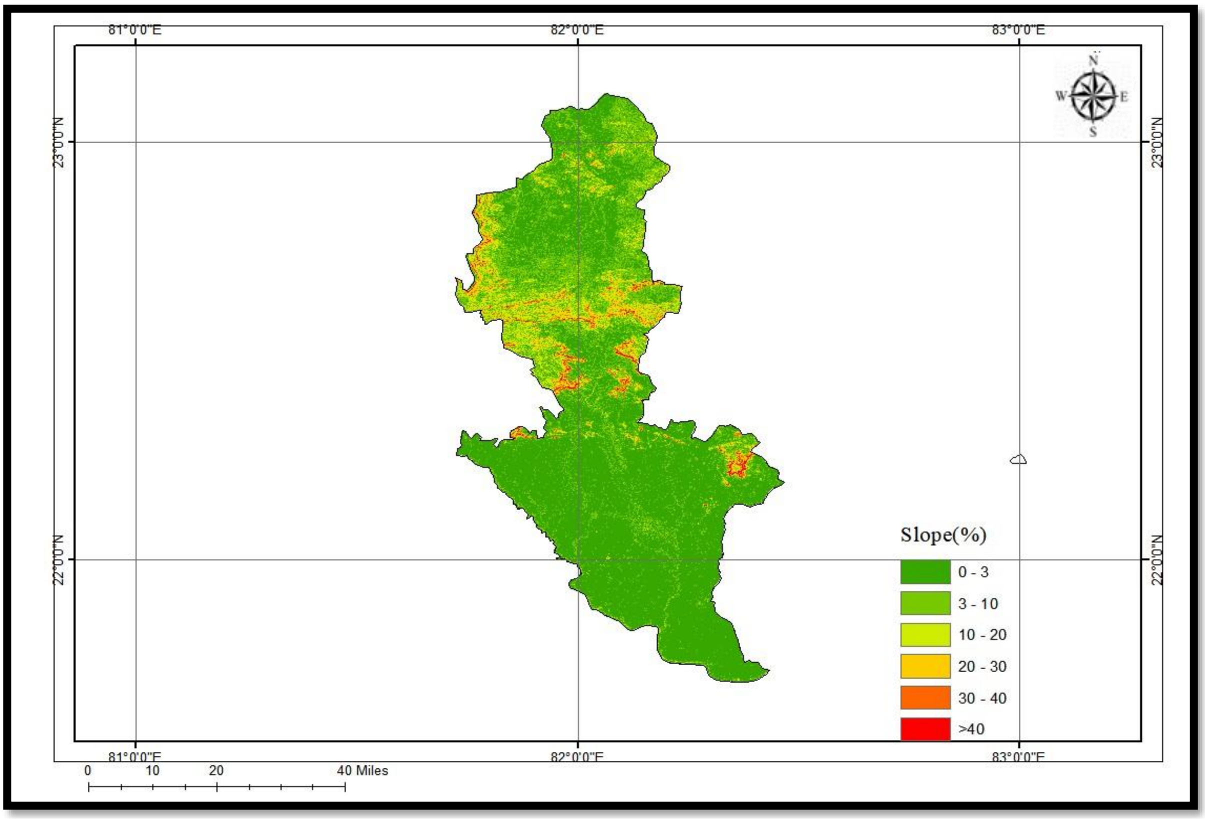


Figure 23 Slope percent map for bilaspur, India

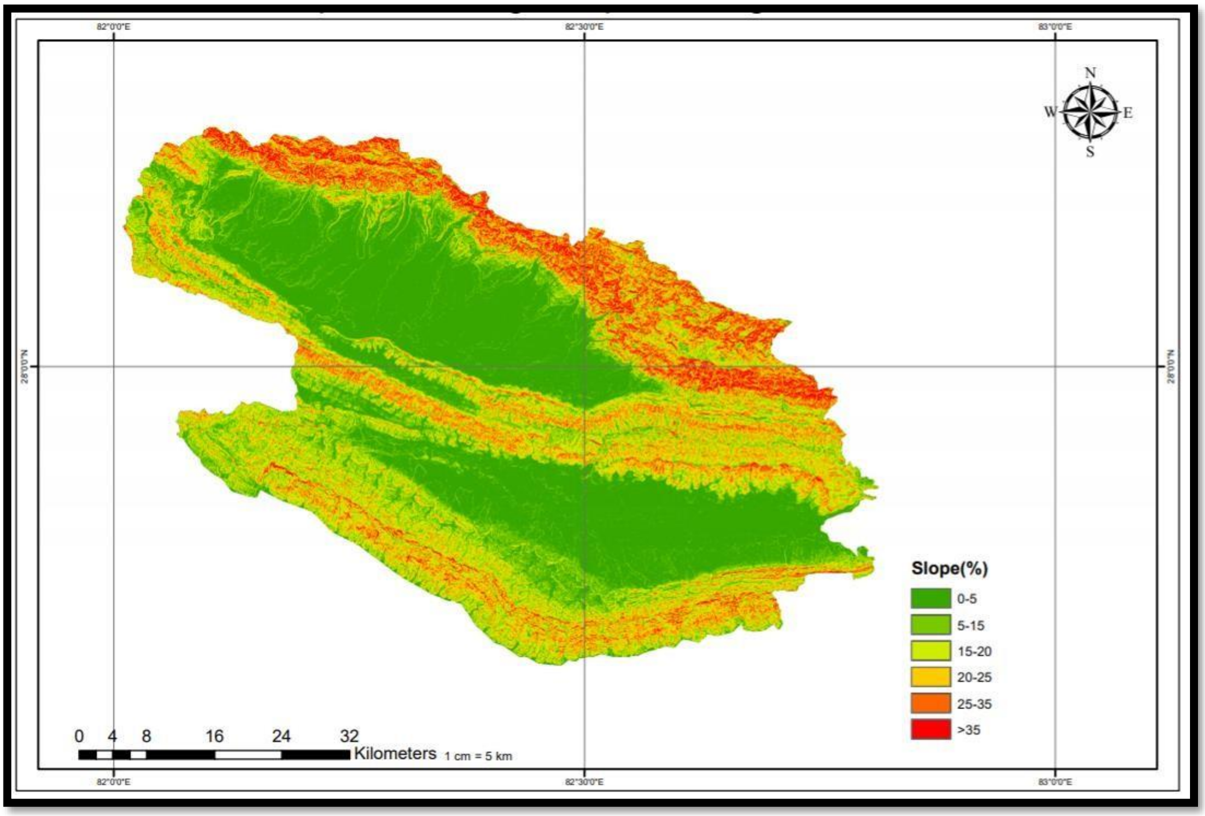


Figure 24 Slope percent map for Dang, Nepal

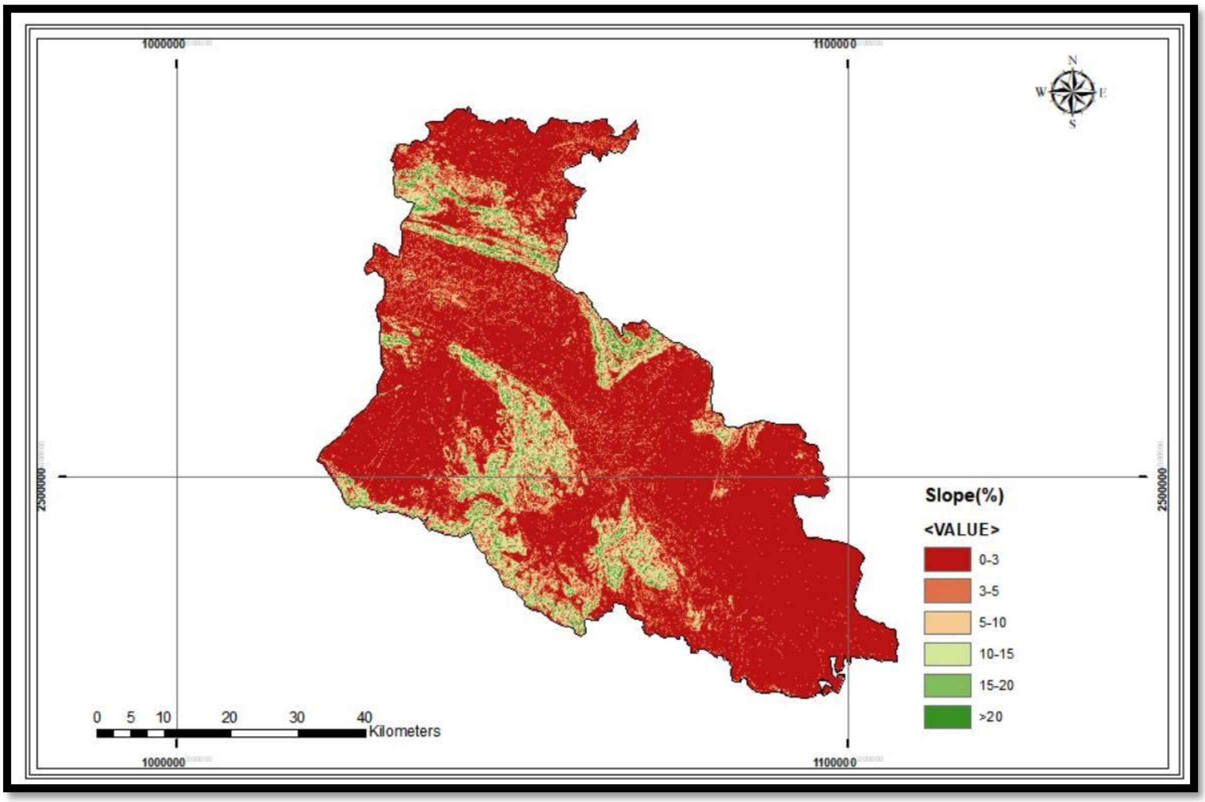


Figure 25 Slope percent map for Jamshedpur metropolis city

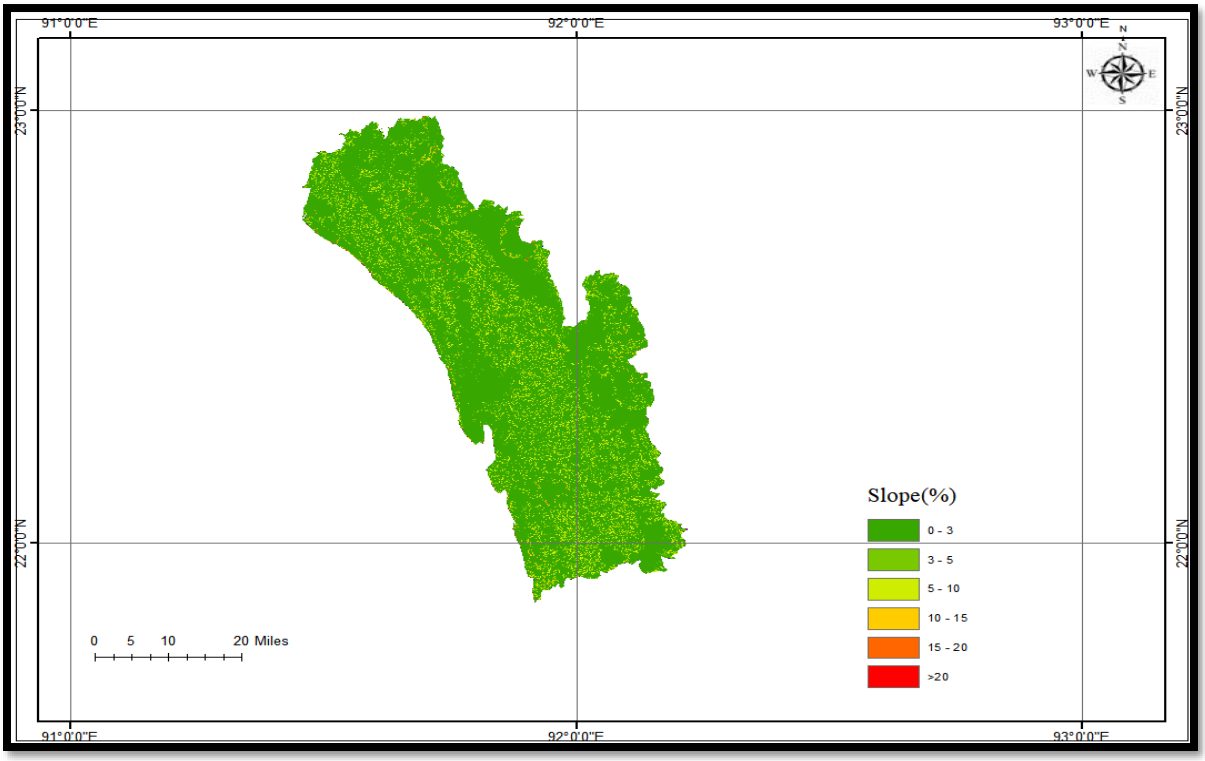


Figure 26 Slope percent map for Nasirabad, Bangladesh

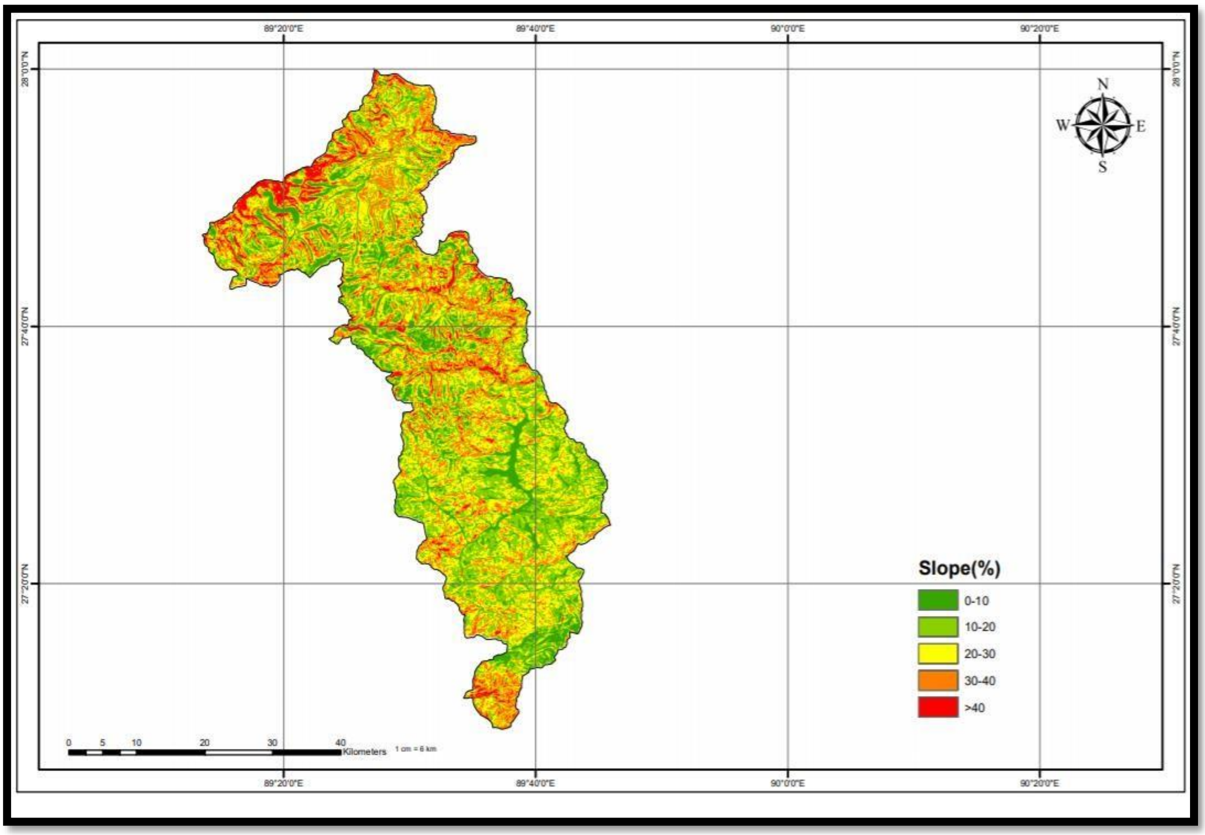


Figure 27 Slope percent map for Thimphu, Bhutan

4.5 Drainage network map

Drainage networks can be seen from the drainage network map (Figure 27 to figure 31) Jamshedpur have Fifth order of stream line, fourth order for Bilaspur, second order for Nasirabad, with a ideal stream network in the west region. Total length of the first order streams in Jamshedpur is very high while in Nasirabad there are so many small second and first order stream.

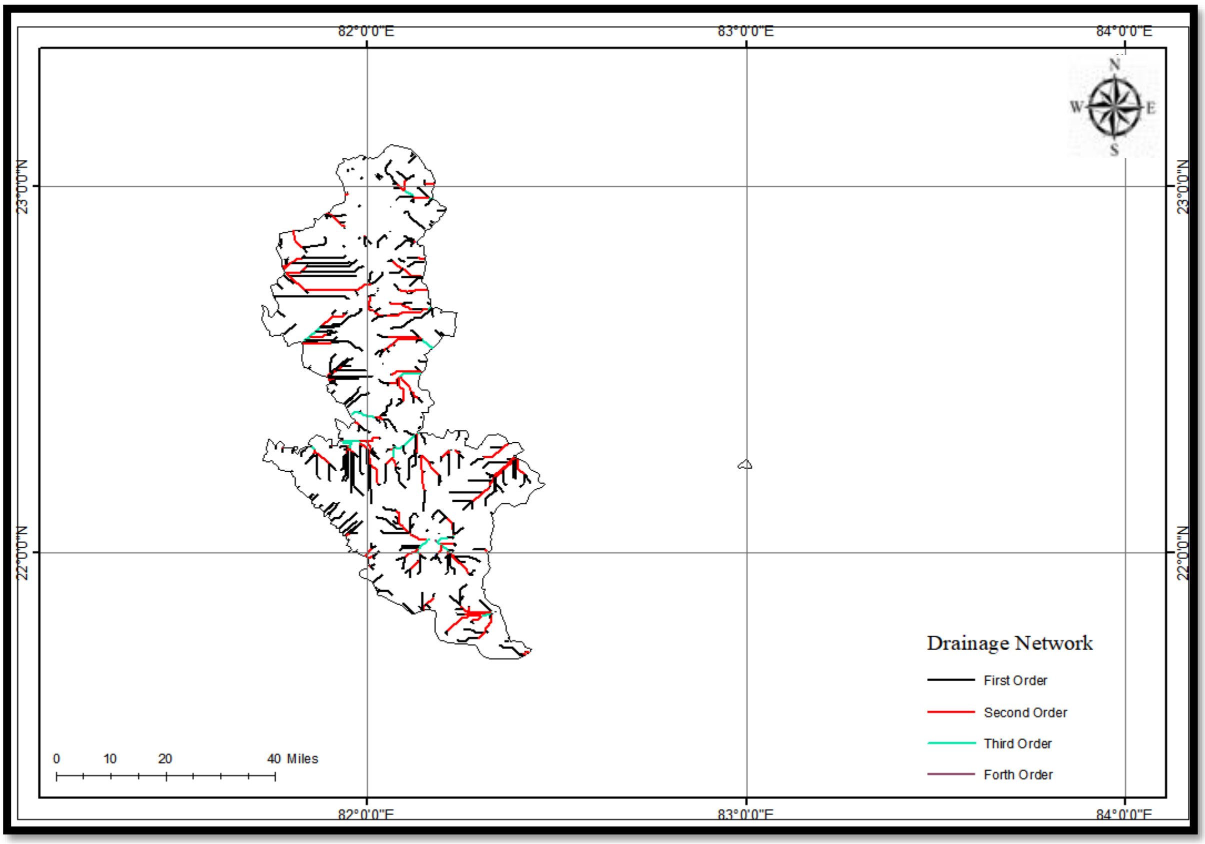


Figure 28 Drainage Network in Bilaspur, India

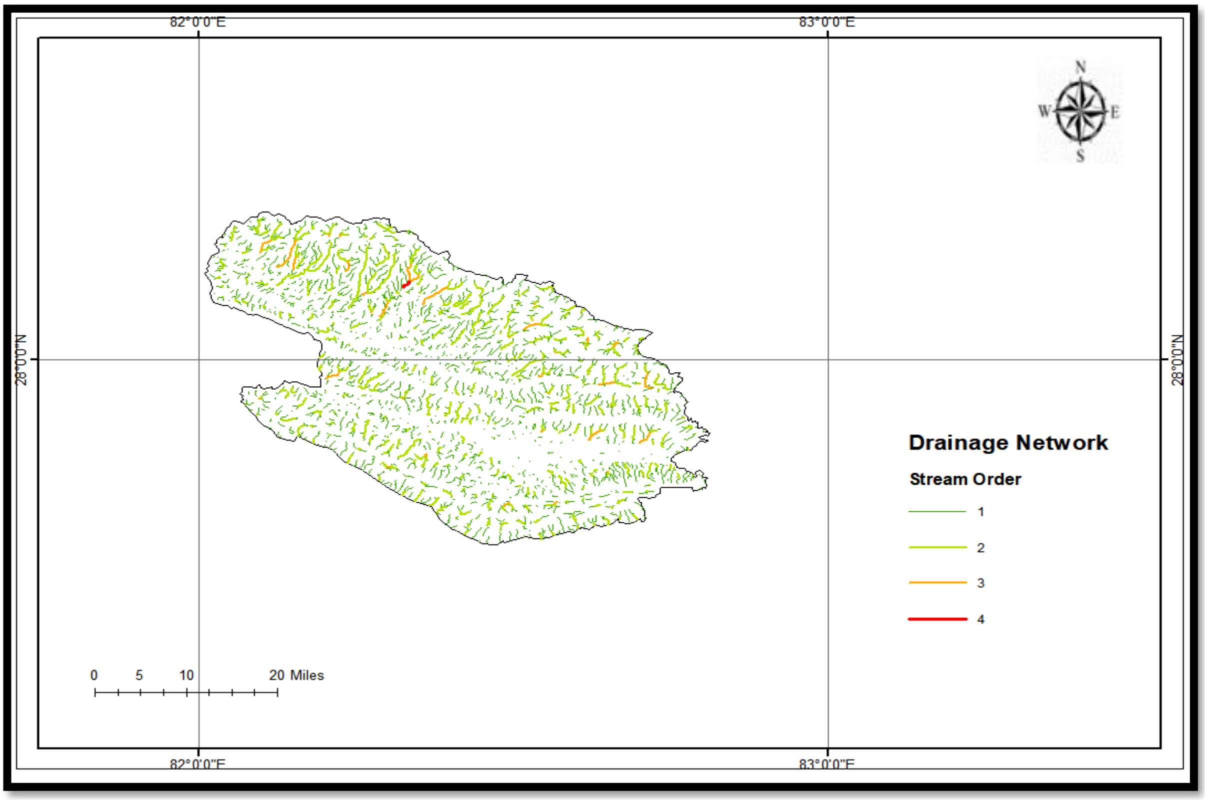


Figure 29 Drainage Network in Dang, Nepal

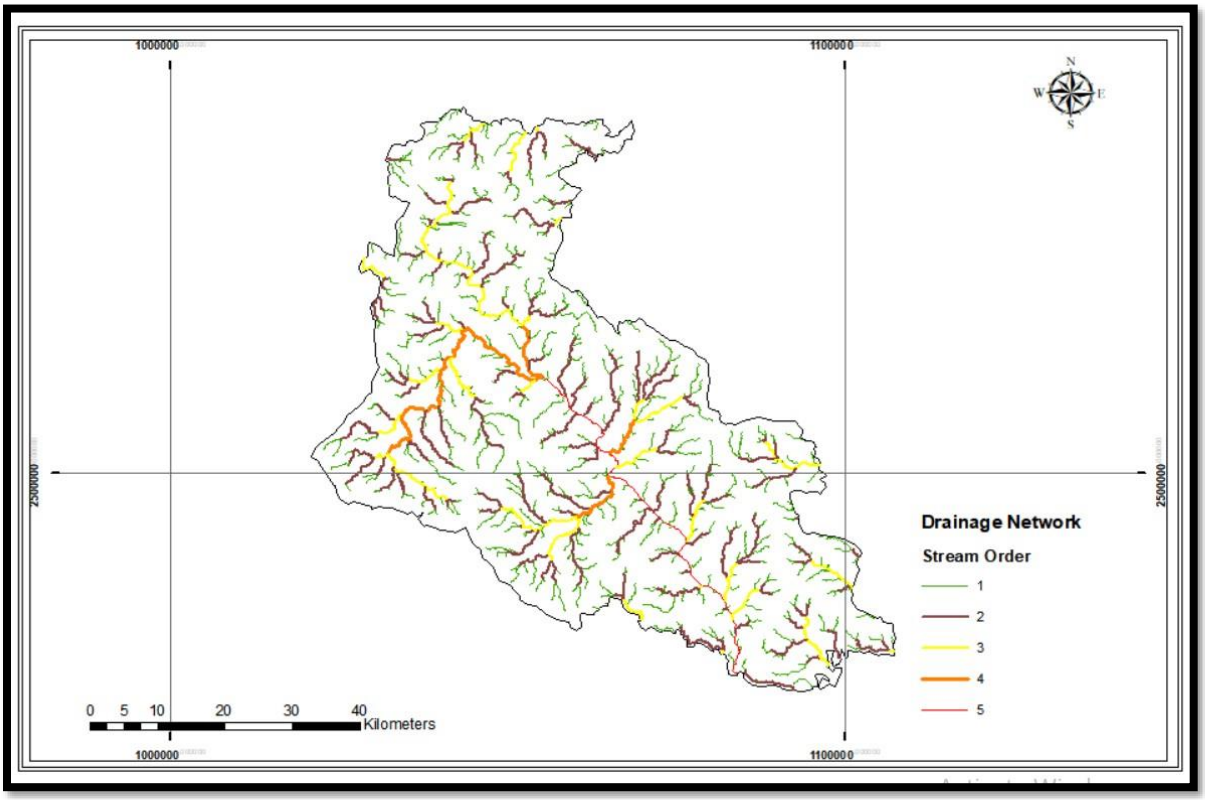


Figure 30 Drainage Network in Jamshedpur metropolis city

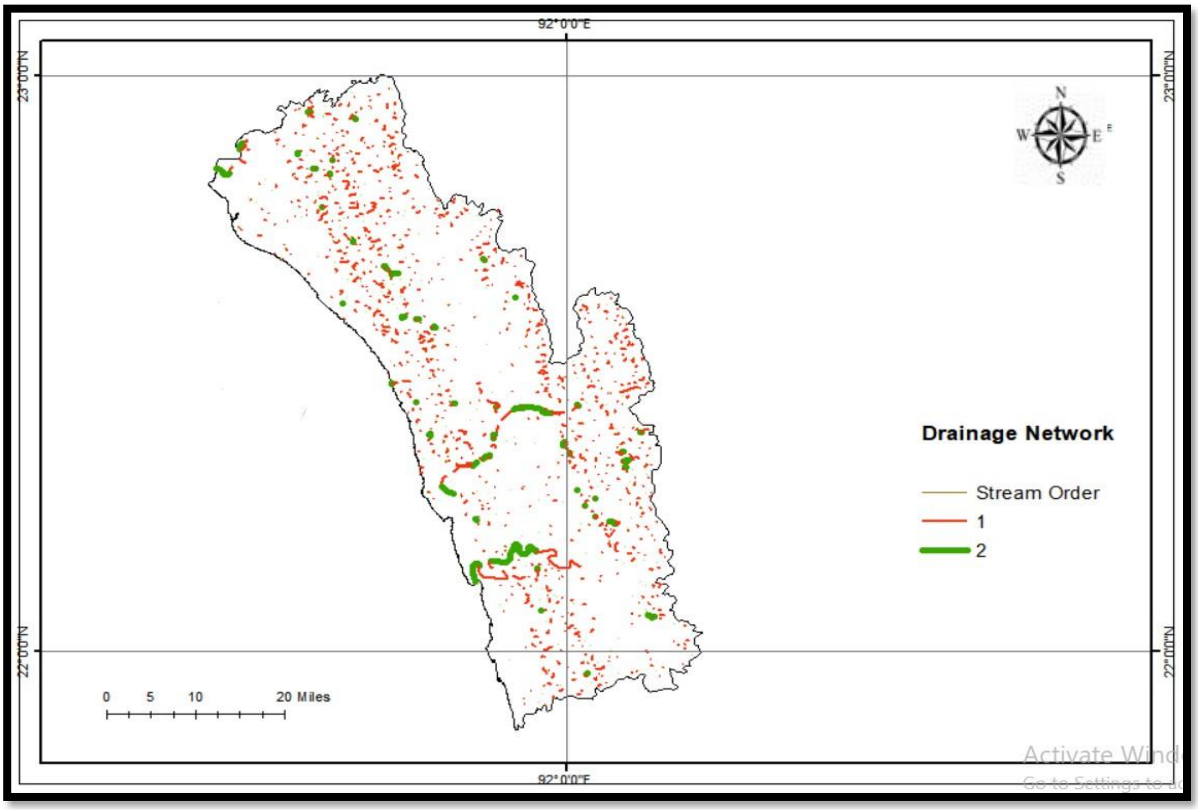


Figure 31 Drainage Network in Nasirabad, Bangladesh

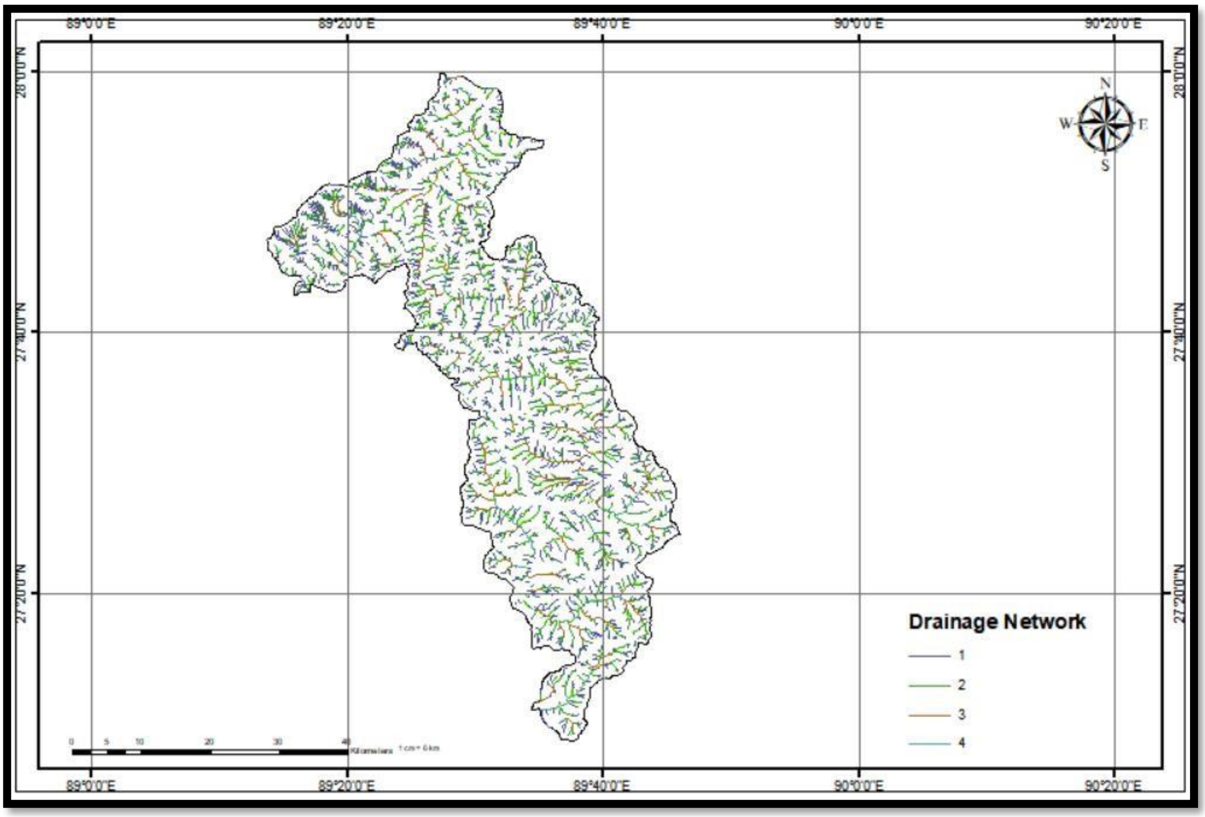


Figure 32 Drainage Network in Thimphu, Bhutan

4.6 Drainage density map

Drainage density is basically kernel line density of the drainage network layer the drainage density in all of the five study area was classified into six ranges as shown in the below maps: (i) Very-poor(0–0.8), (ii) Poor (0.8–1.), (iii) Moderate good (1.5–2.25), and (iv) Good(>2.25). Assumption for constructing rainwater harvesting zone was considered was that region have high drainage density value is not suitable for harvesting the rainwater even that zone have high RWH potential value, and that's why the area with small drainage density value was considered according the rainwater harvesting point.

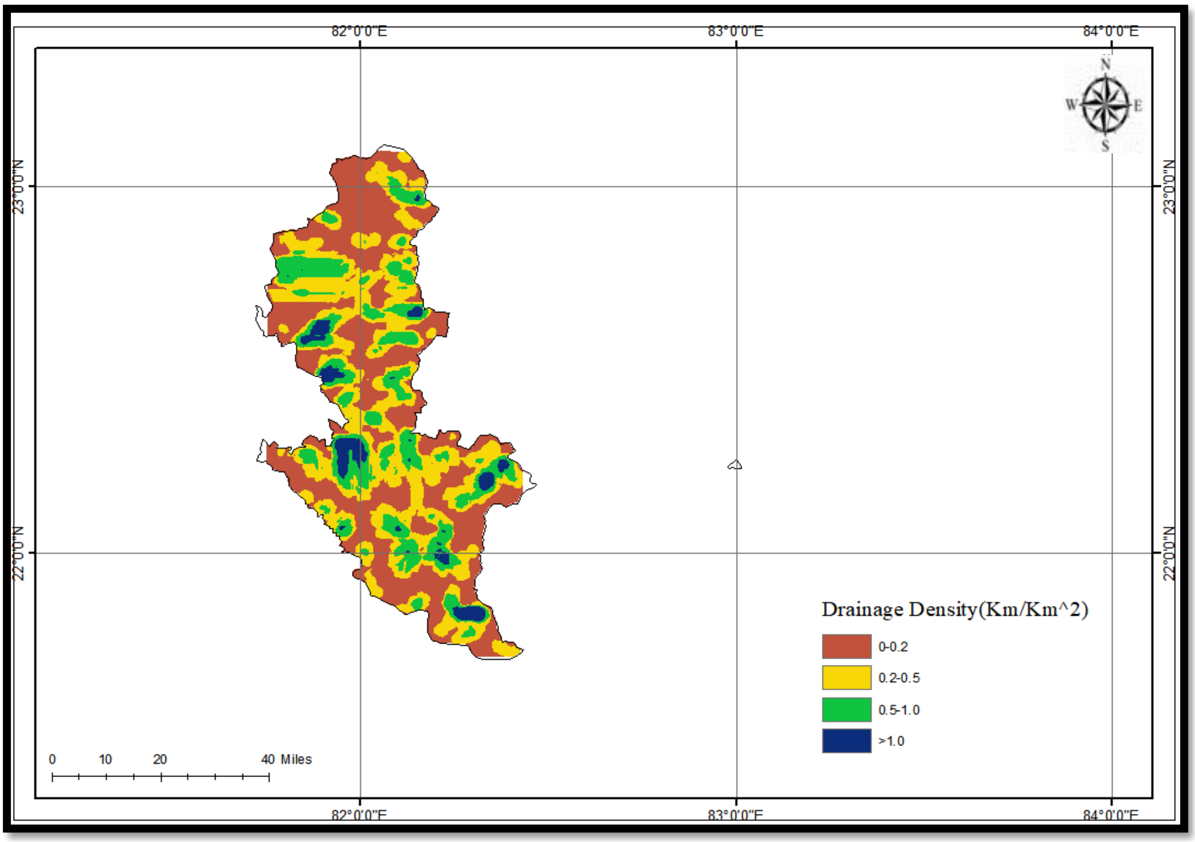


Figure 33 Drainage Density in Bilaspur, India

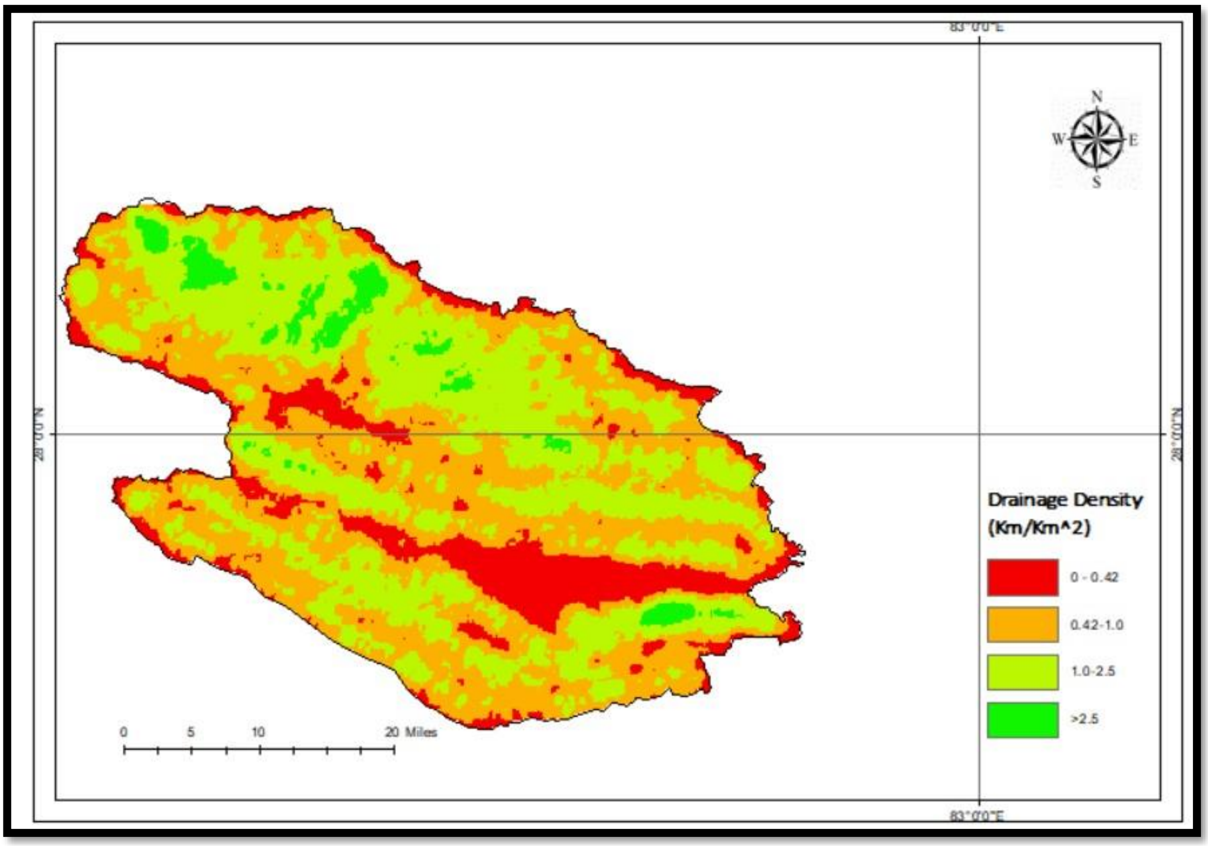


Figure 34 Drainage Density in Dang, Nepal

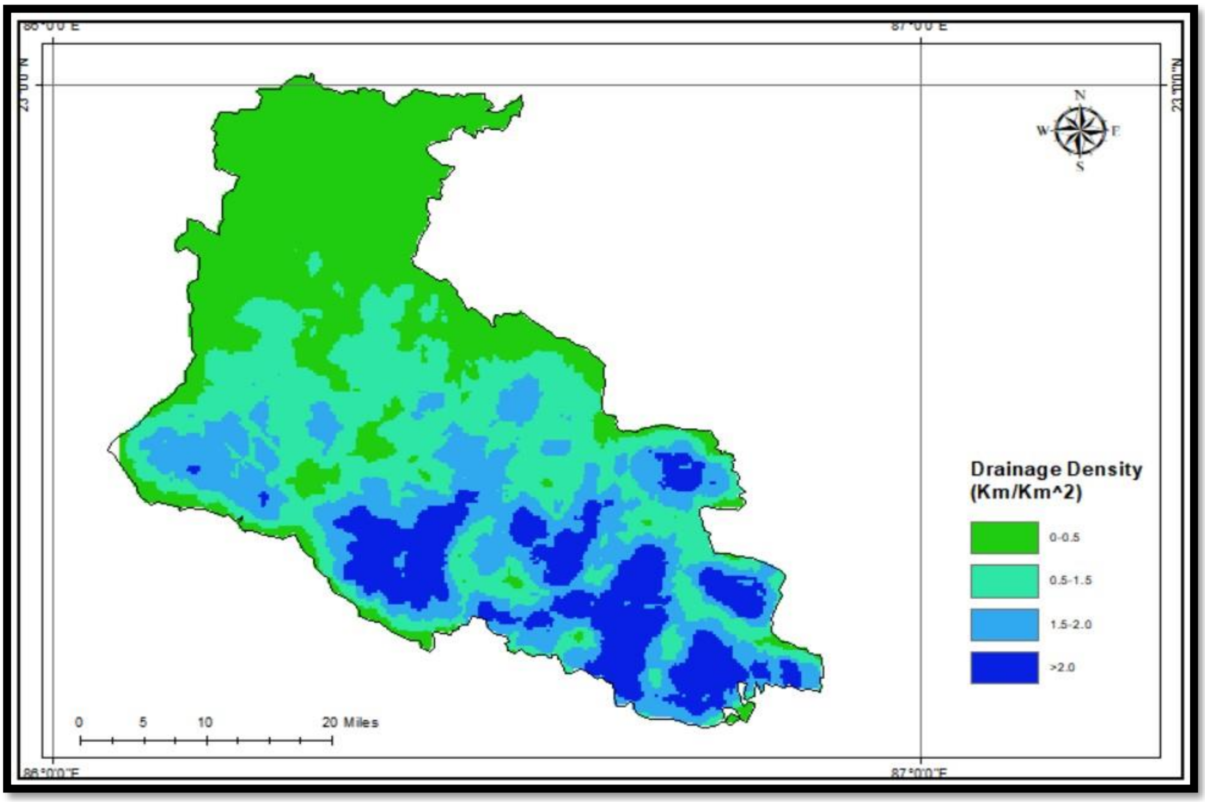


Figure 35 Drainage Density in Jamshedpur, India

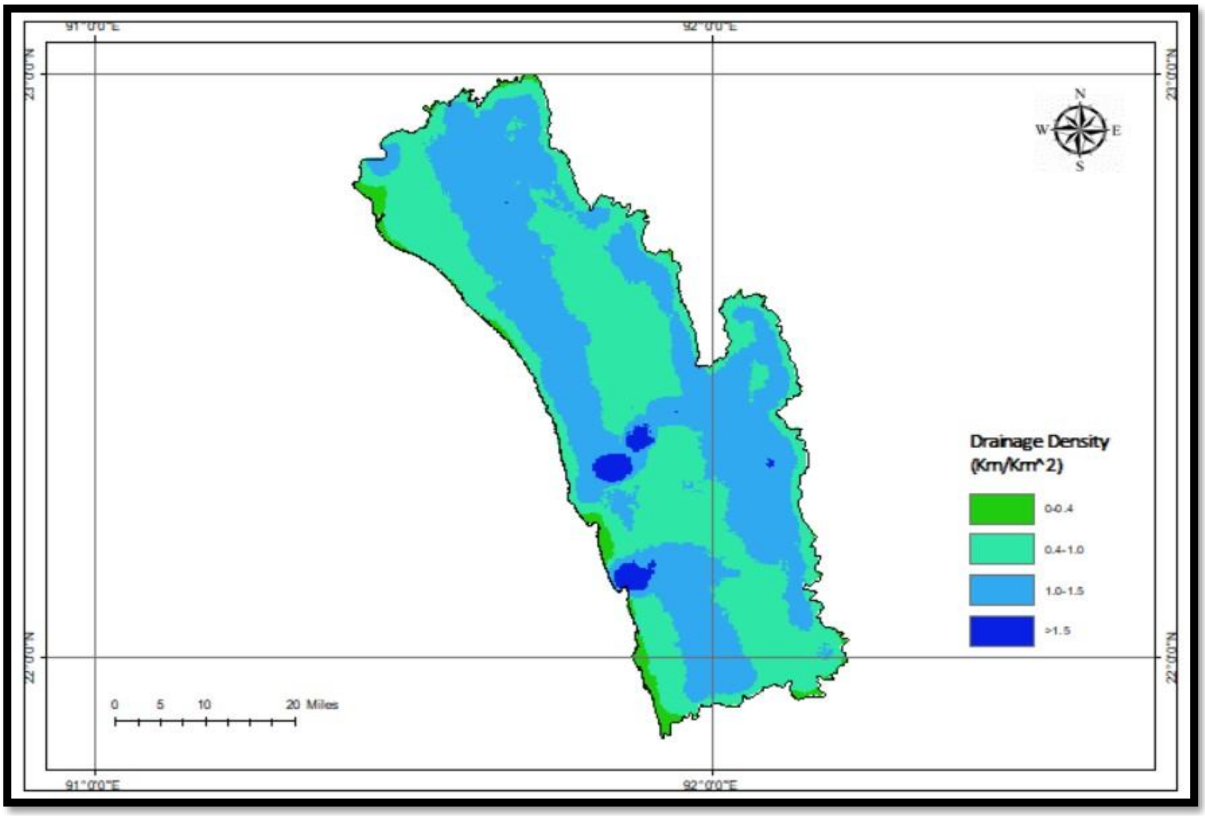


Figure 36 Drainage Density in Nasirabad, Bangladesh

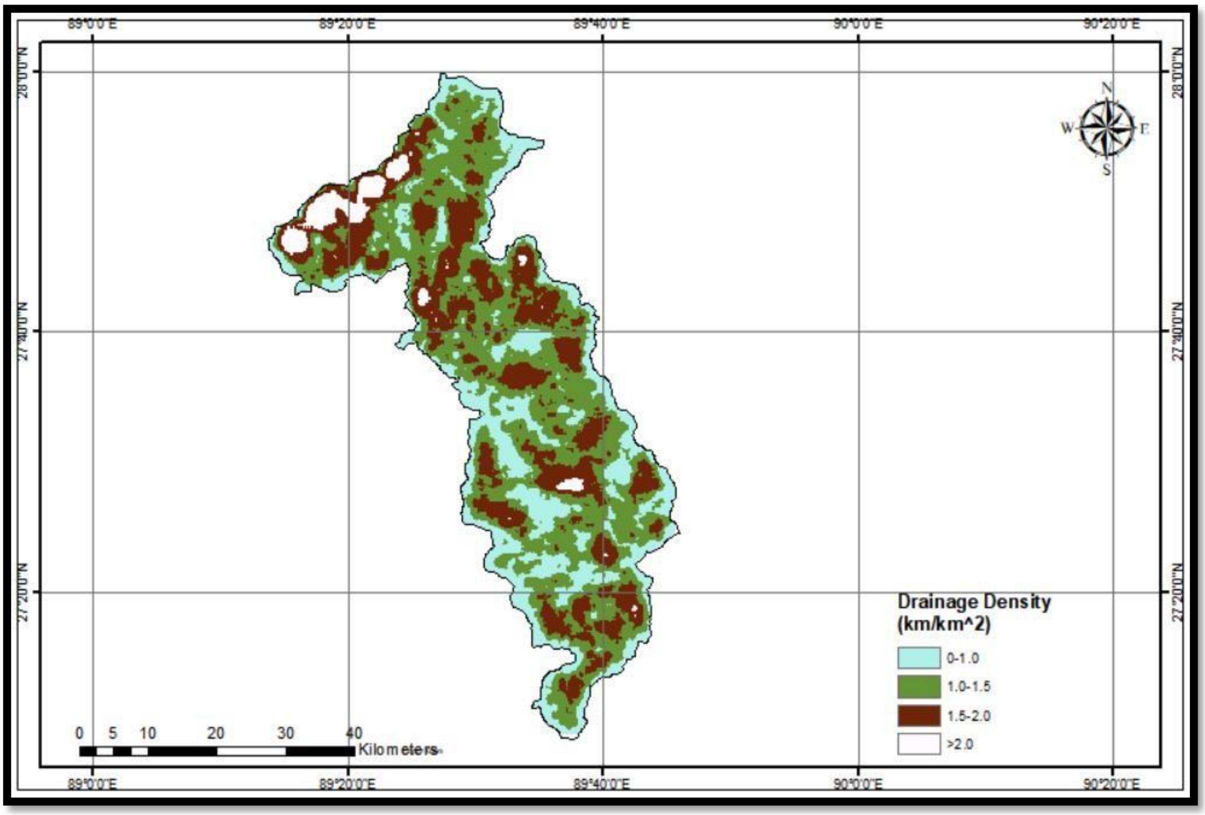


Figure 37 Drainage Density in Thimphu, Bhutan

4.7 Runoff potential map

The runoff potential here for normal rainfall (2007-2010) years were classified into six types as shown in table. 6. Runoff potential moderately Good(300-400mm), Good (400- 600mm), Very Good(>600mm) are suitable for identifying zones for RWH. From figure 37 to figure 41 are runoff potential maps for the study areas.

Table 6

Runoff potential and suitability classes

Runoff Potential (mm)	**Classes**
<100	Very Poor
100-200	Poor
200-300	Moderate
300-400	Moderately Good
400-600	Good
>600	Very Good

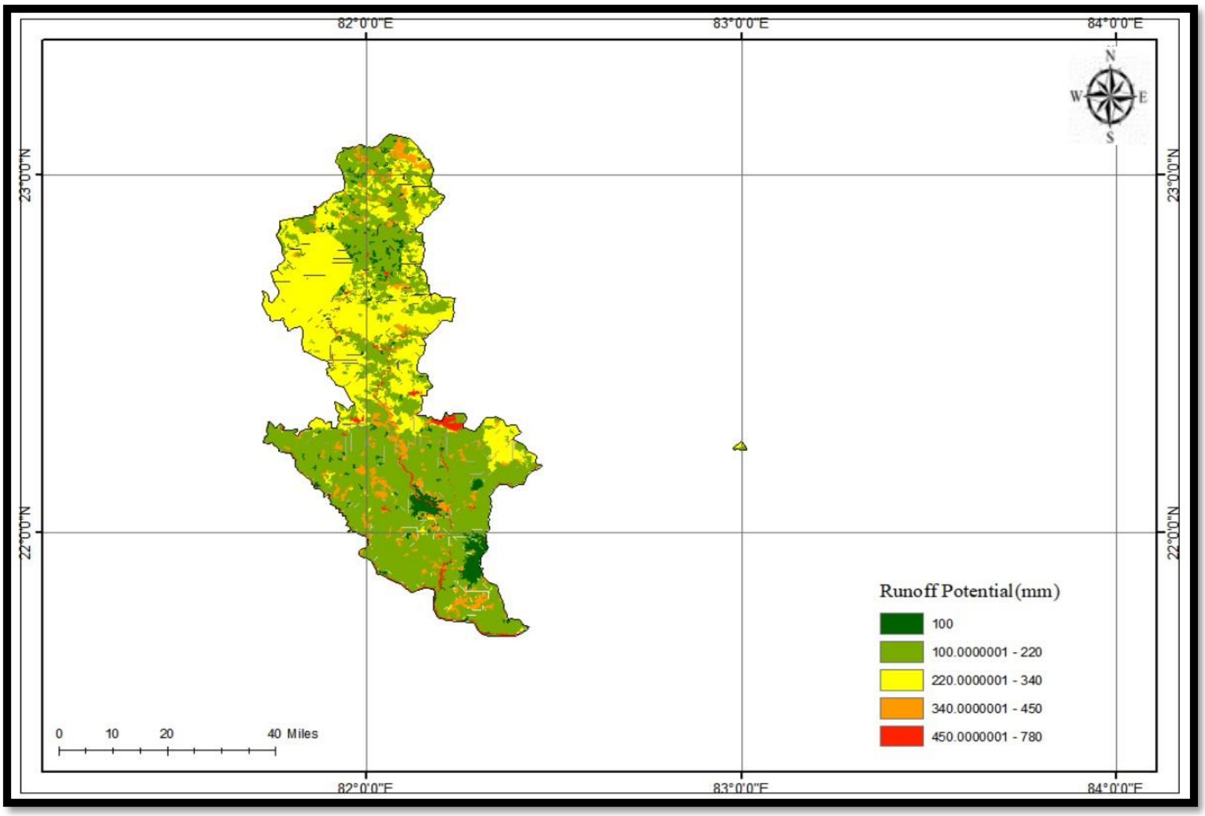


Figure 38 Runoff potential map for Bilaspur, India

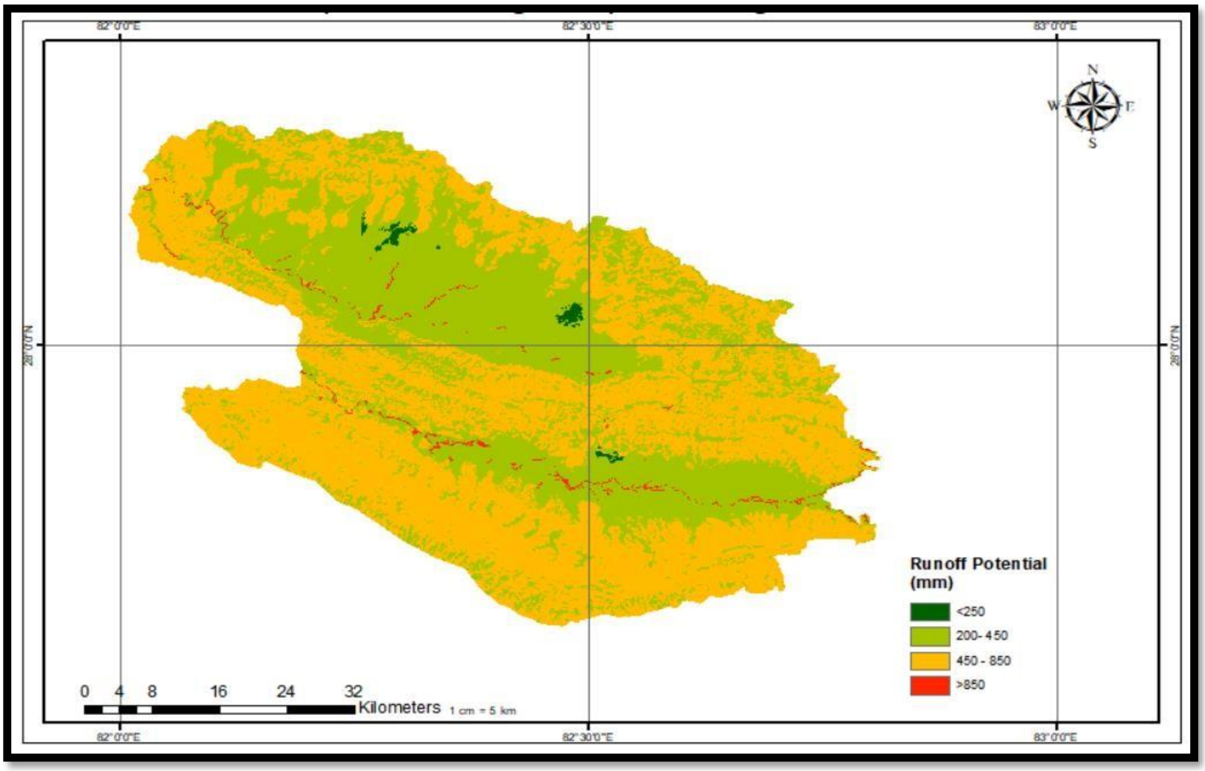


Figure 39 Runoff potential map for Dang, Nepal

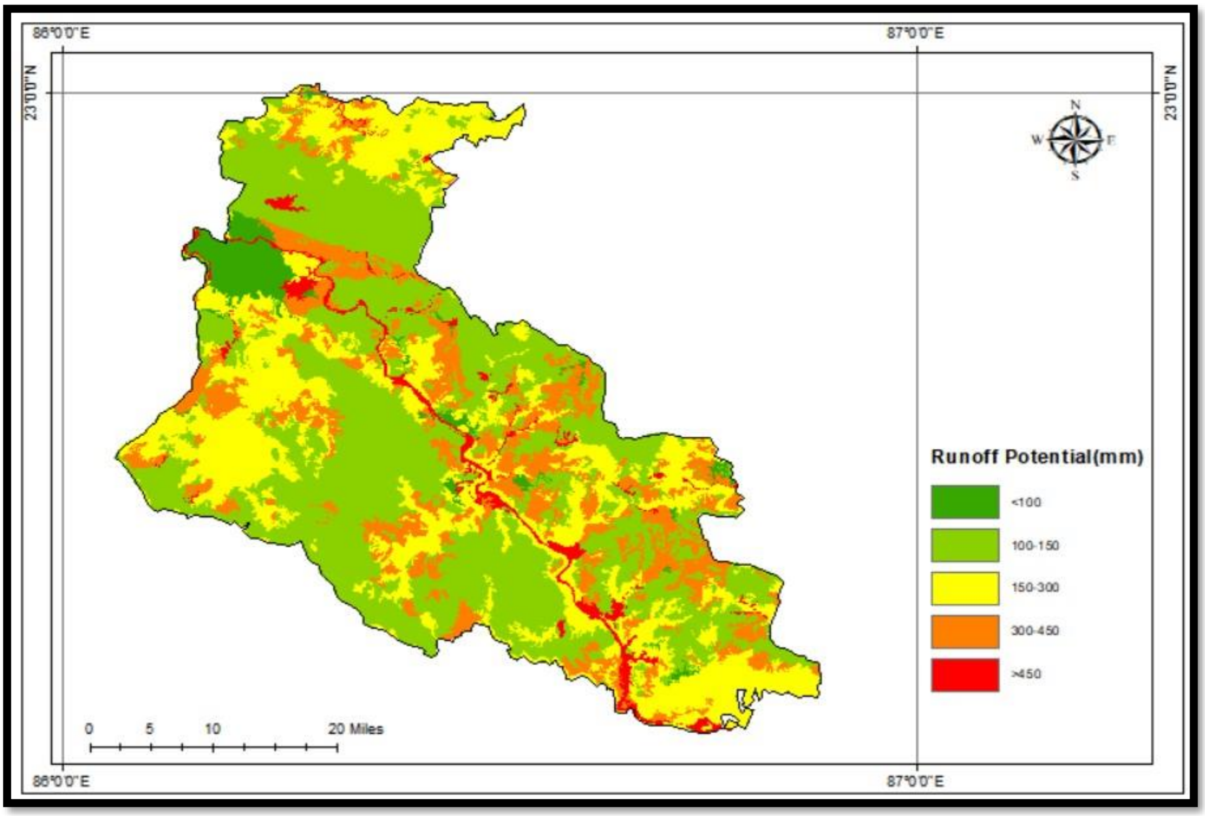


Figure 40 Runoff potential map for Jamshedpur metropolis city

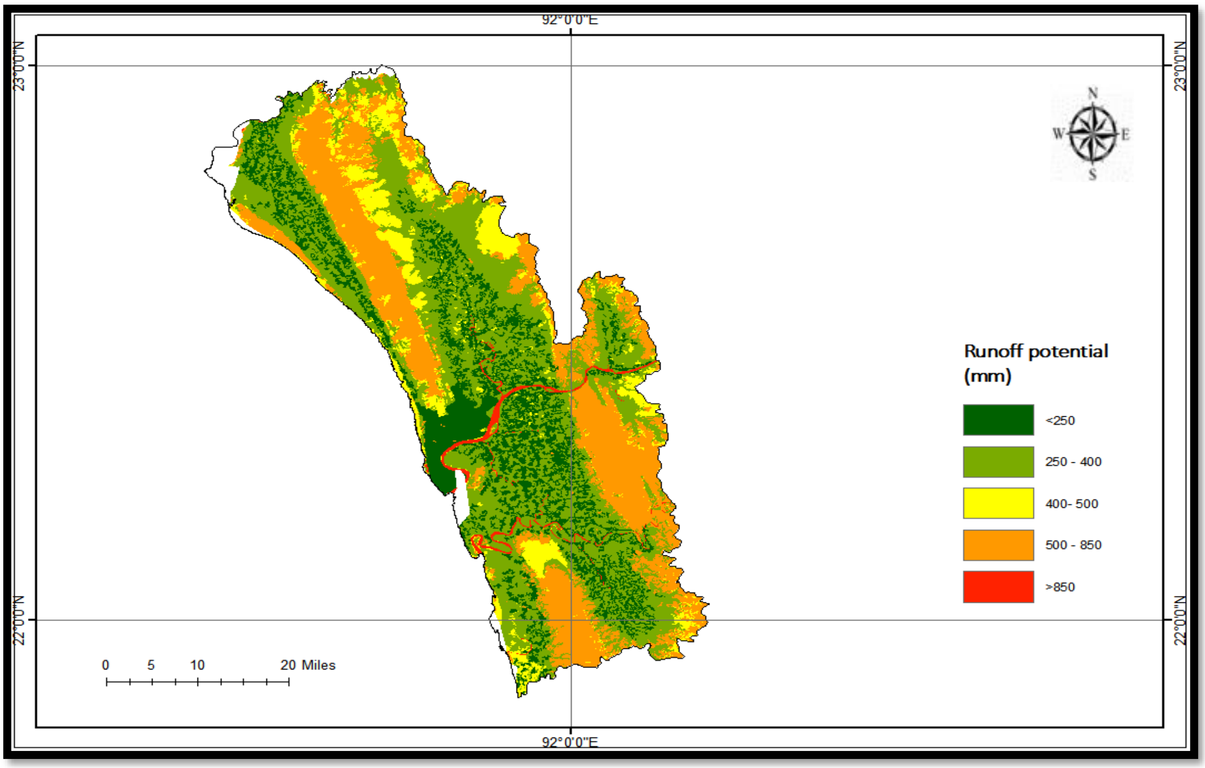


Figure 41 Runoff potential map for Bilaspur, India

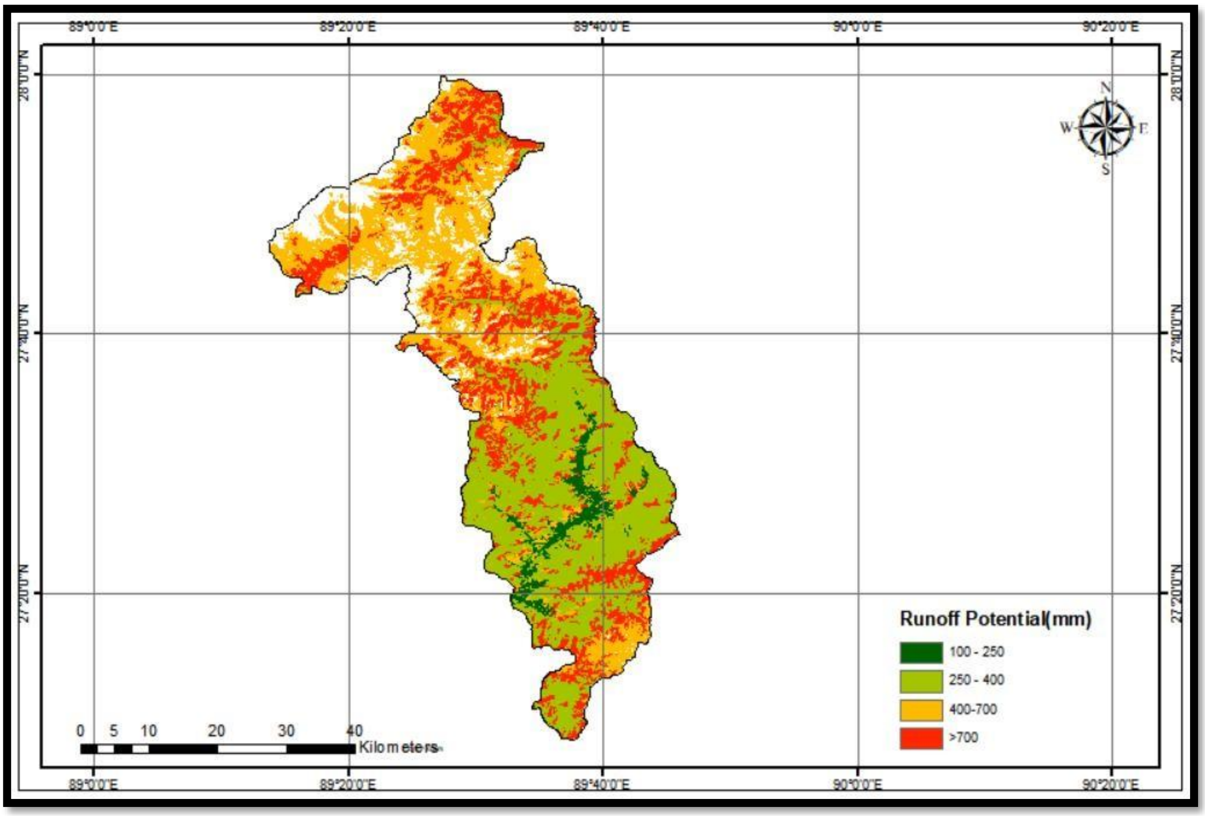


Figure 42 Runoff potential map for Thimphu, Bhutan

4.8 Runoff coefficient map

In the current study based on properties of runoff potential the runoff coefficient values in all the study area were divided in four spatial classes: High, Moderate, Low, Very Low and their ranges are shown in the maps given below. Runoff coefficient maps for all five-study area are given below from figure 42 to figure 46.

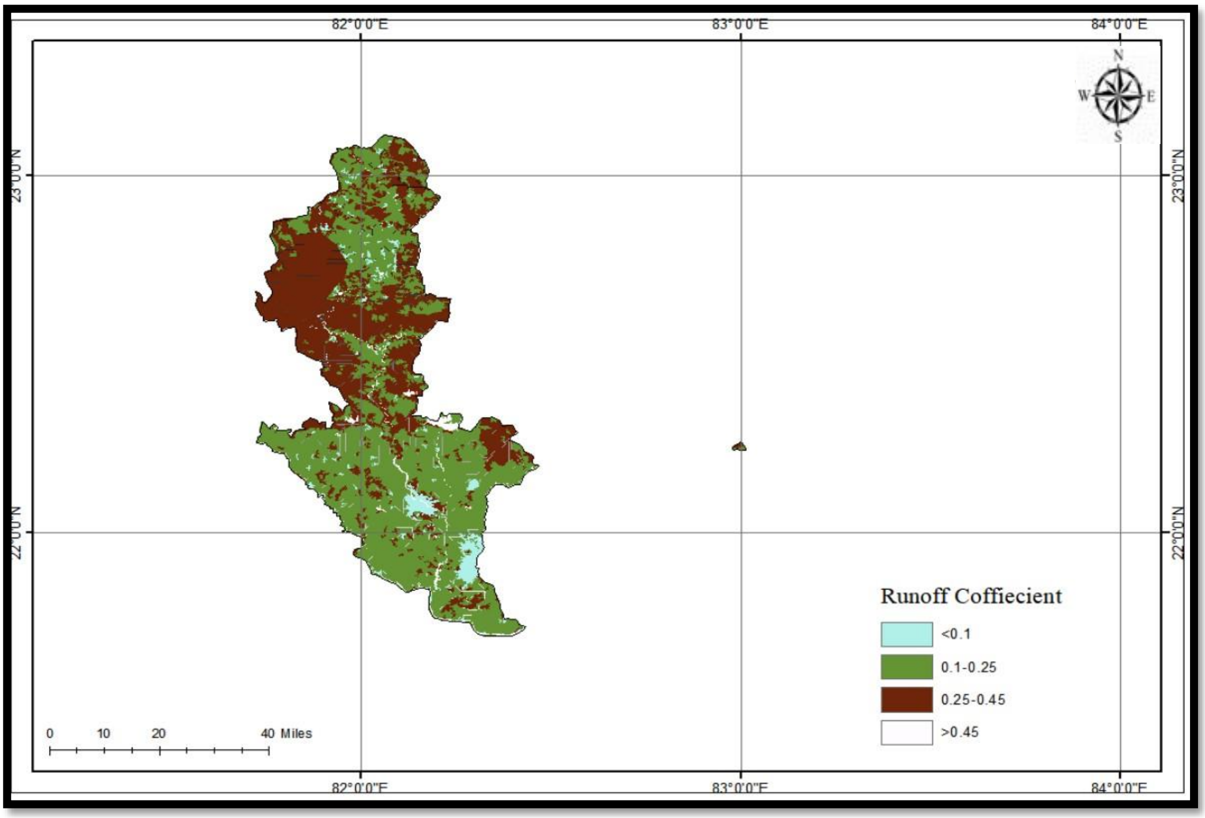


Figure 43 Runoff Coefficient map for Bilaspur, India

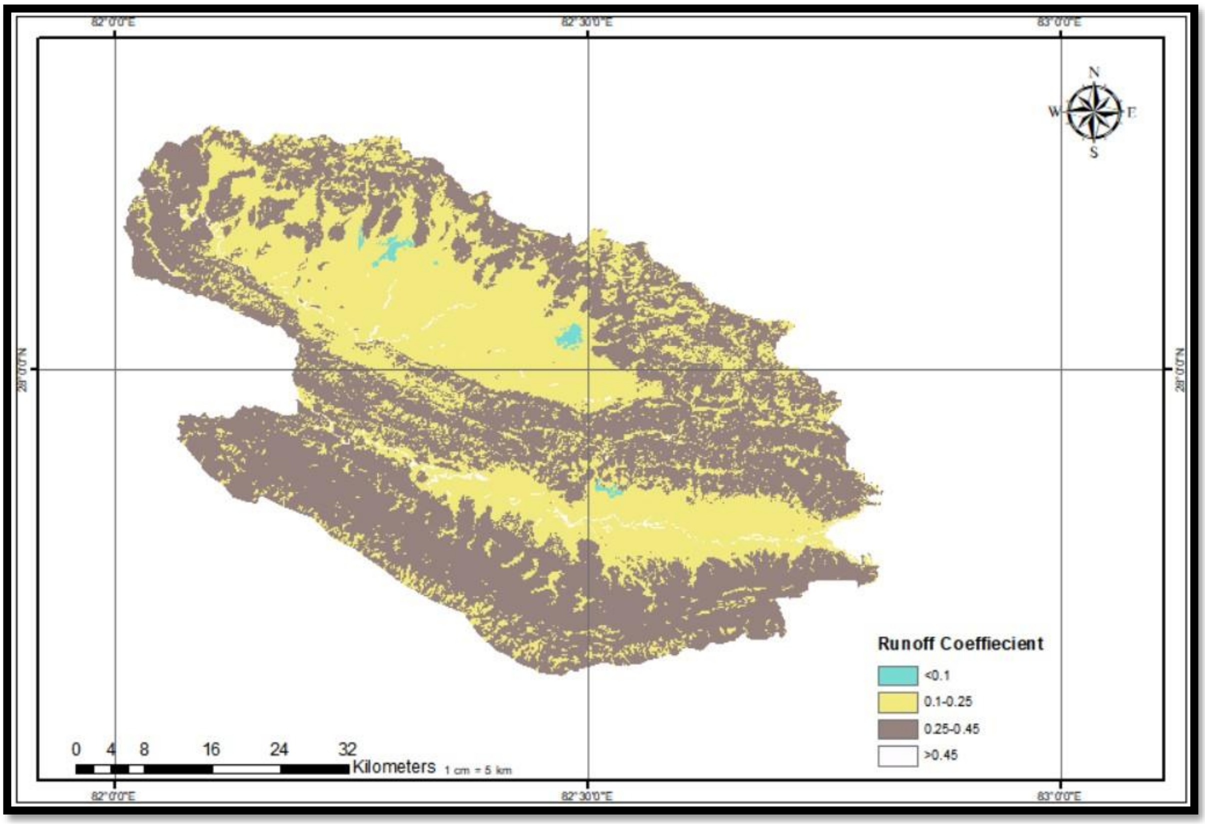


Figure 44 Runoff Coefficient map for Dang, Nepal

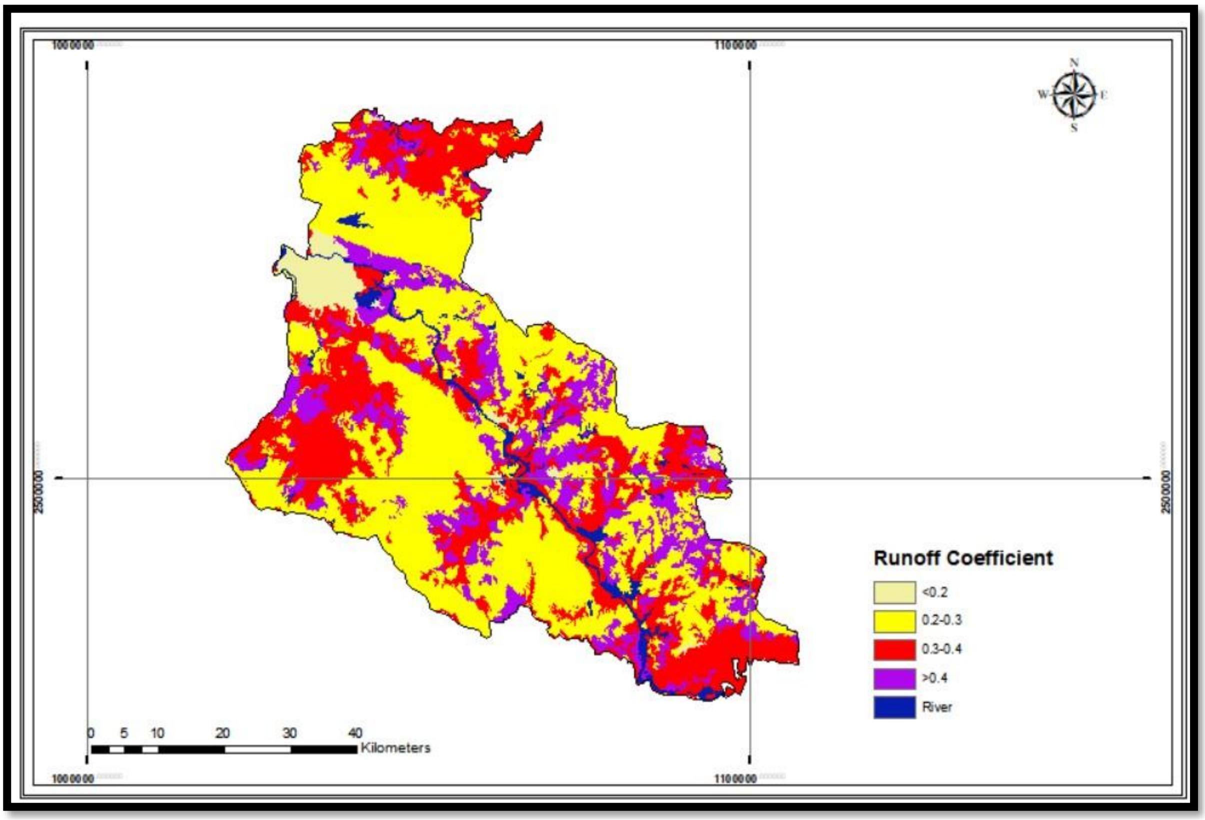


Figure 45 Runoff Coefficient map for Jamshedpur metropolis city

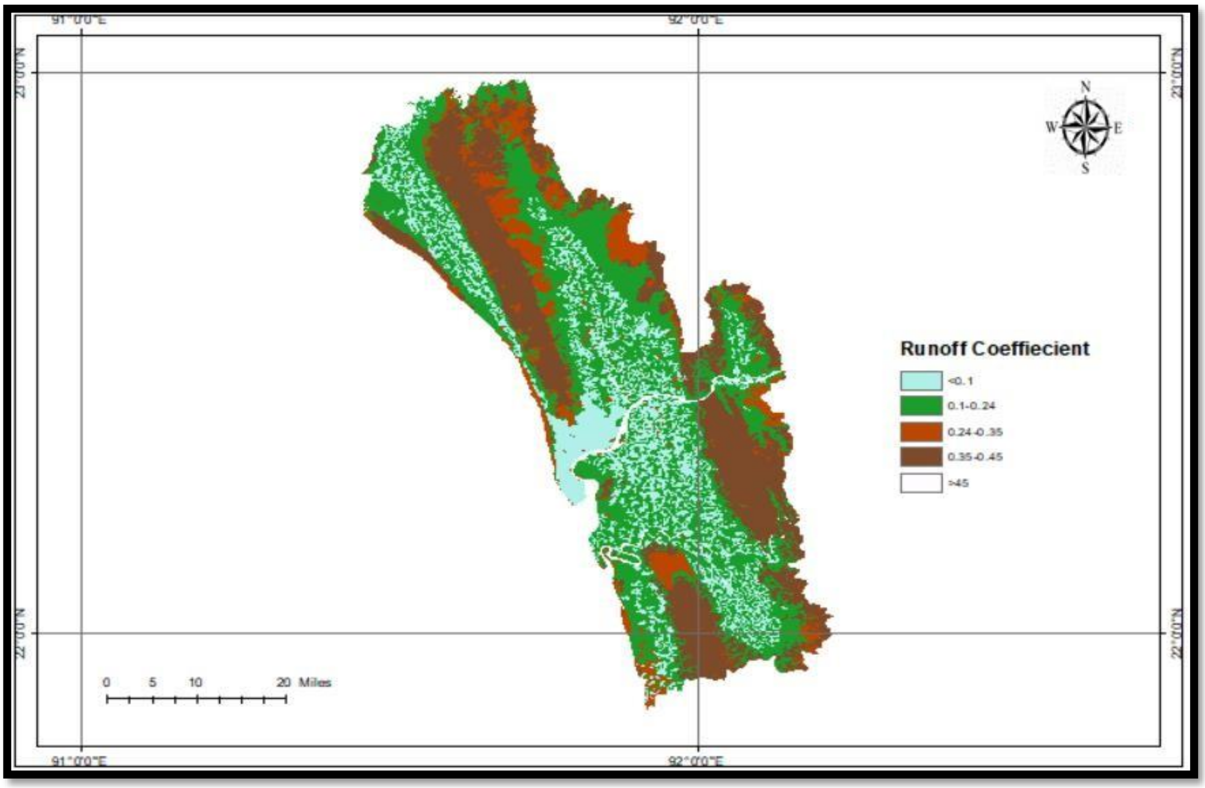


Figure 46 Runoff Coefficient map for Nasirabad, Bangladesh

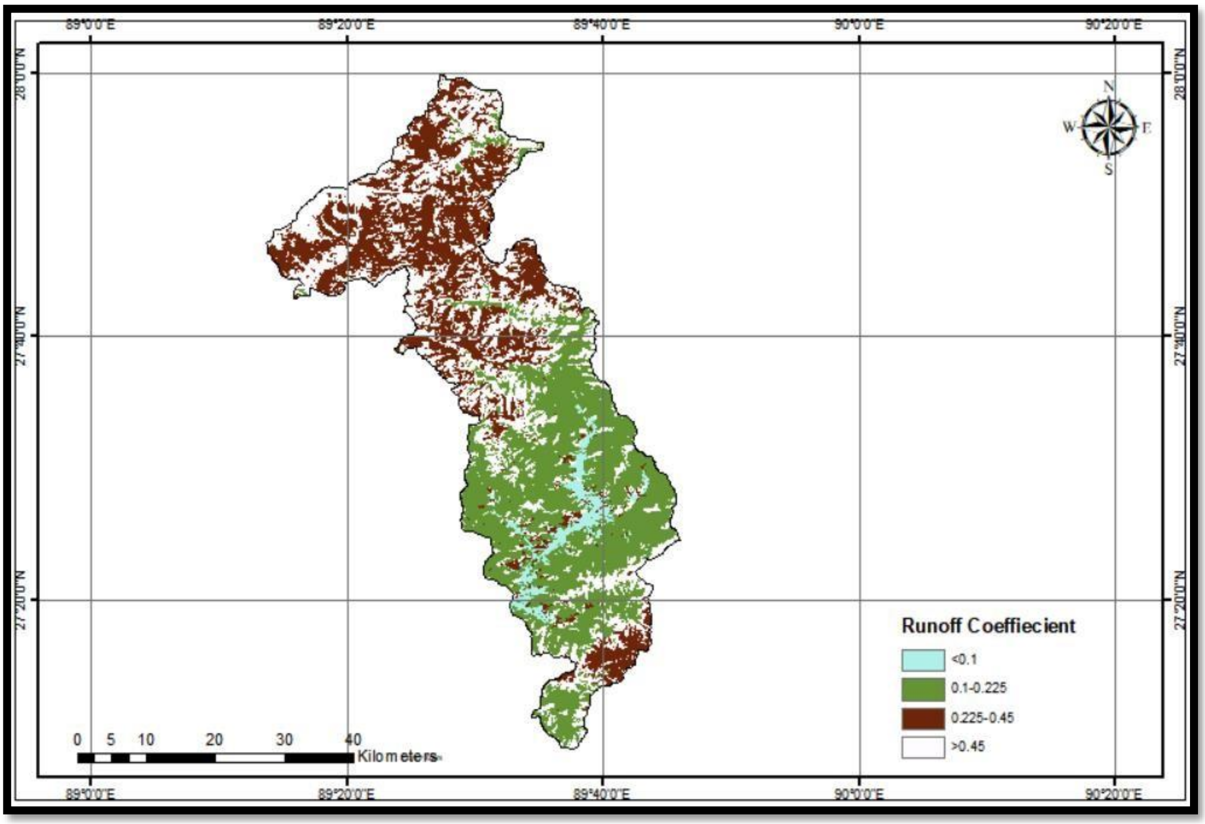


Figure 47 Runoff Coefficient map for Thimphu, Bhutan

4.9 Rainwater Harvesting Potential maps

RWHP maps of were prepared by ArcMap integration of runoff coefficient layer, slope percent layer and layer of drainage density, after that calculating RWH potential index using given above Eq. 7 and Table 7 mentioned below. From the values of RWHPI, Regions were divided into respective zones on the basis of their rainwater potential index as: (i) Good, (ii) moderate, and (iii) poor RWH potential. Figure 47 to figure 51 shows RWHP zones for all of five study area.

Table 7

Weights of thematic layers and their features.

Thematic Layer	Feature Class	Assigned Weight	Normalized weight
Runoff Coefficient	>0.4(High)	9	0.36
	0.3-0.4(Moderate)	8	0.39
	0.3-0.1(Low)	6	0.27
	<0.1(Very low)	5	0.23
Slope	0-1% (Nearly Level)	8	0.35
	1-3% (Gentle)	7	0.31
	3-5% (Moderately Gentle)	5	0.27
	5-15% (Steep)	3	0.19
	15-25% (Moderately Steep)	2	0.12
	>25% (Very Steep)	1	0.08
Drainage Density (km/km^2)	<0.75	8	0.26
	0.75-1.5	8	0.35
	1.5-2.5	7	0.30
	2.5-3.0	5	0.22
	>3.0	3	0.13

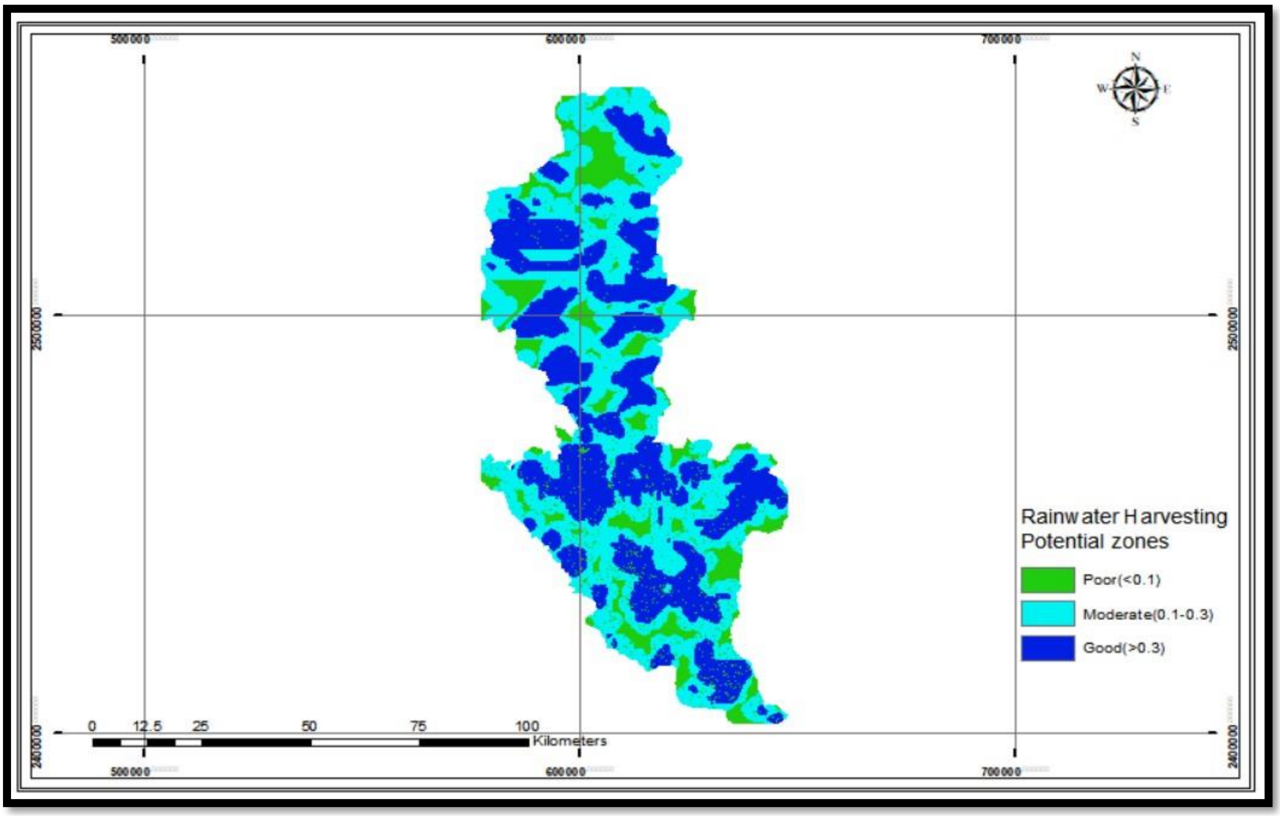


Figure 48 Rainwater harvesting potential zones for Bilaspur, India

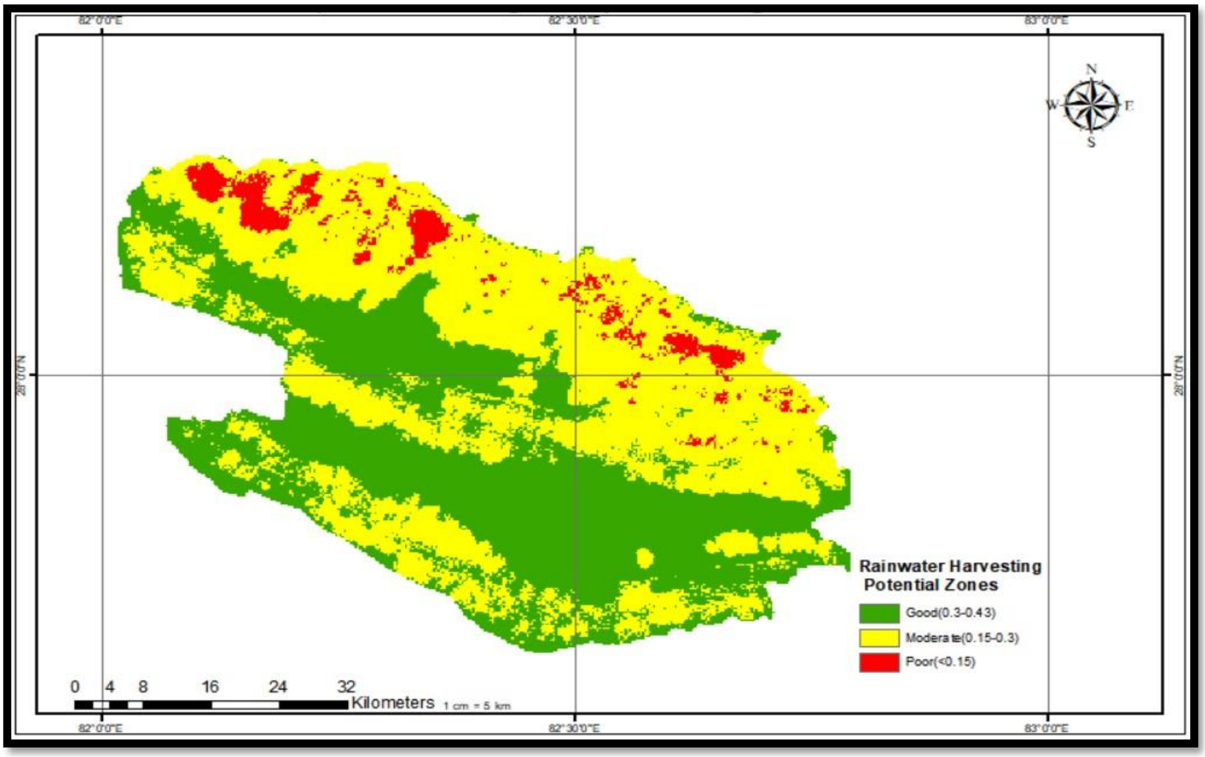


Figure 49 Rainwater harvesting potential zones for Dang, Nepal

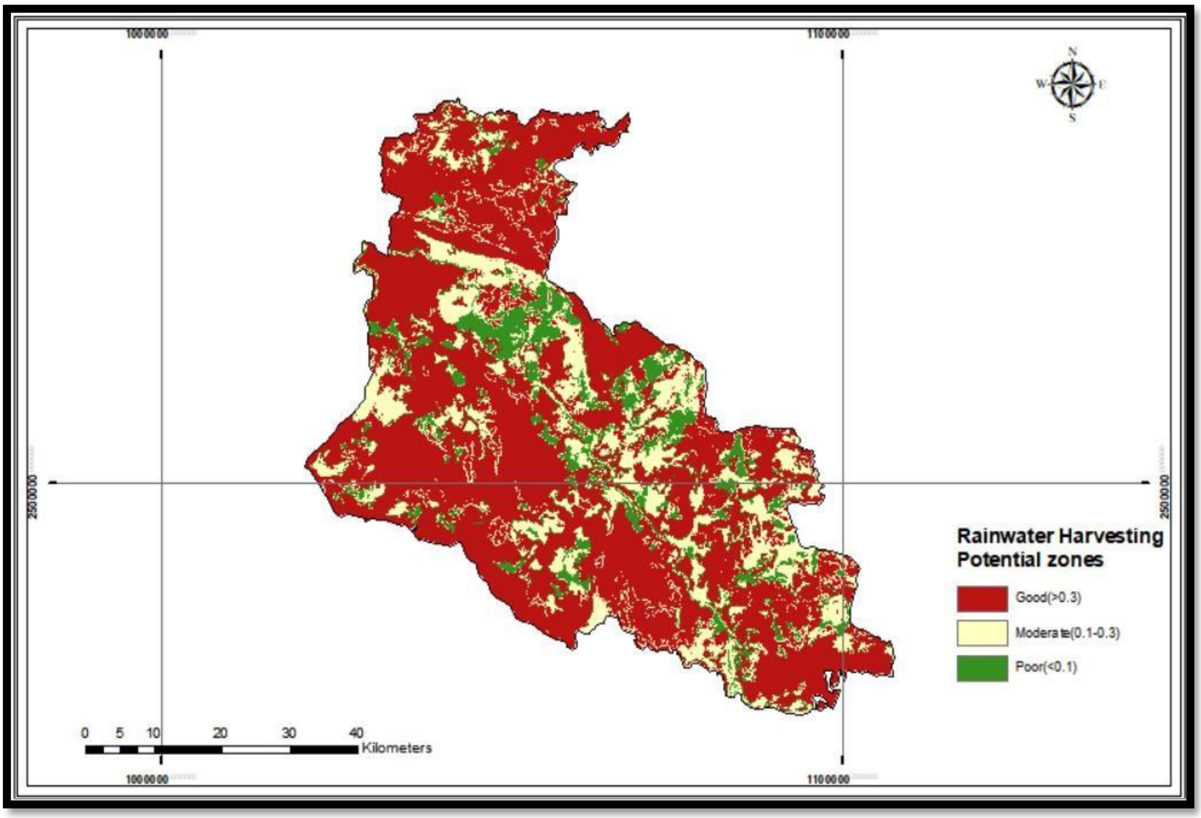


Figure 50 Rainwater harvesting potential zones for Jamshedpur metropolis city

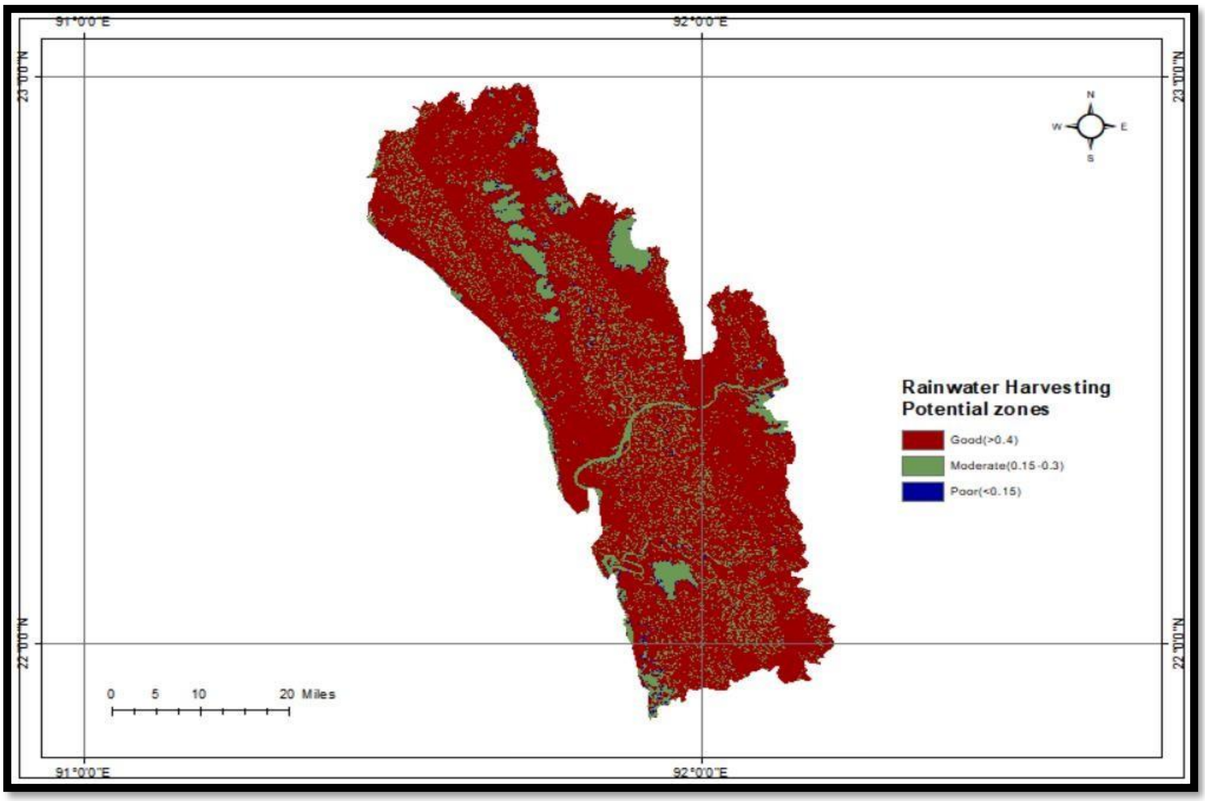


Figure 51 Rainwater harvesting potential zones for Nasirabad, Bangladesh

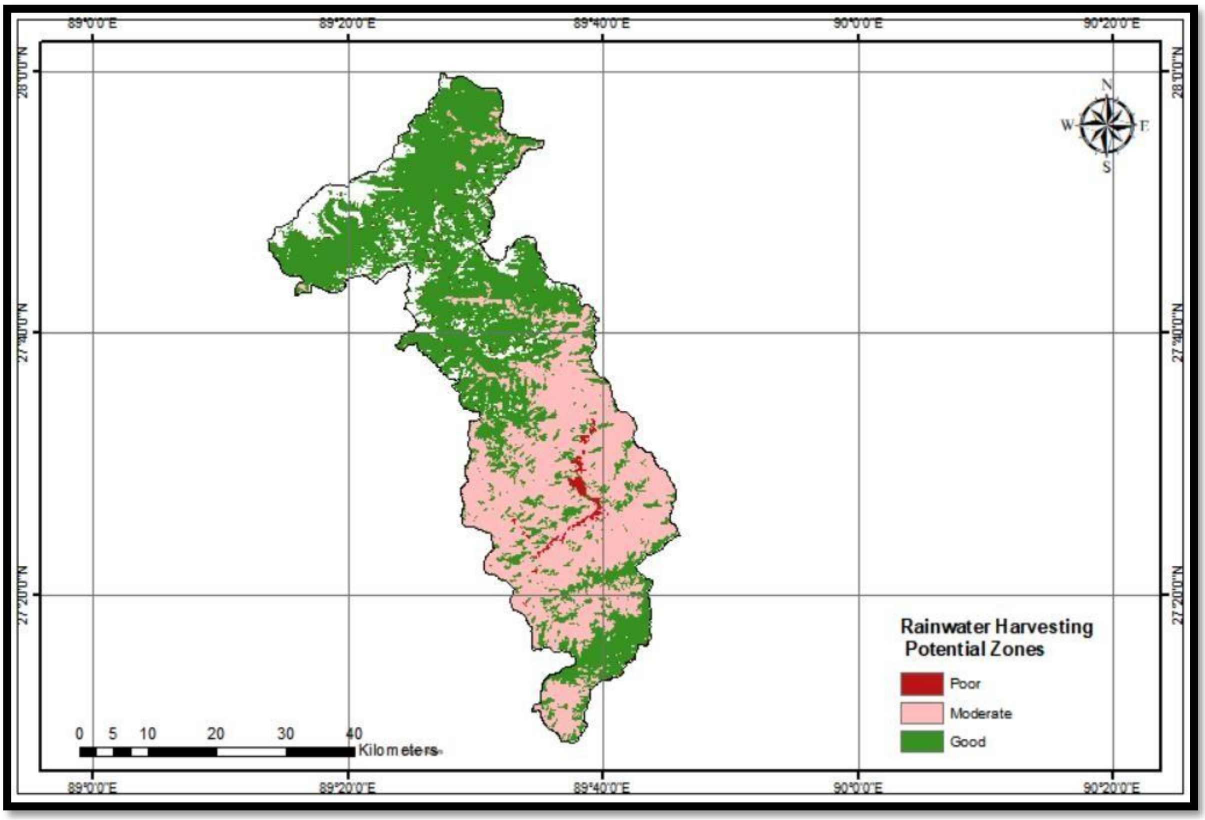


Figure 52 Rainwater harvesting potential zones for Thimphu, Bhutan

4.10 Zones/sites suitable for RWH structures

RWHP sites for recharge structures like check dams and farm ponds for Jamshedpur were generated as given in Fig. 52 Main criteria for identifying suitable zones for agricultural ponds was that farm LULC should be used (Table 1) as agricultural ponds supplies water for irrigation.

Finally, total suitable region agricultural ponds were found 118 km^2 (3% of the area of Jamshedpur) and area found for the percolation tanks were 106 km^2 (about 2.7% area of Jamshedpur). Precisely, drainage stream map, road map, were intercepted to identify the RWH site map hence 87 recharge sites were found which includes check dams and percolation tanks both inside and outside the settlement buffer.

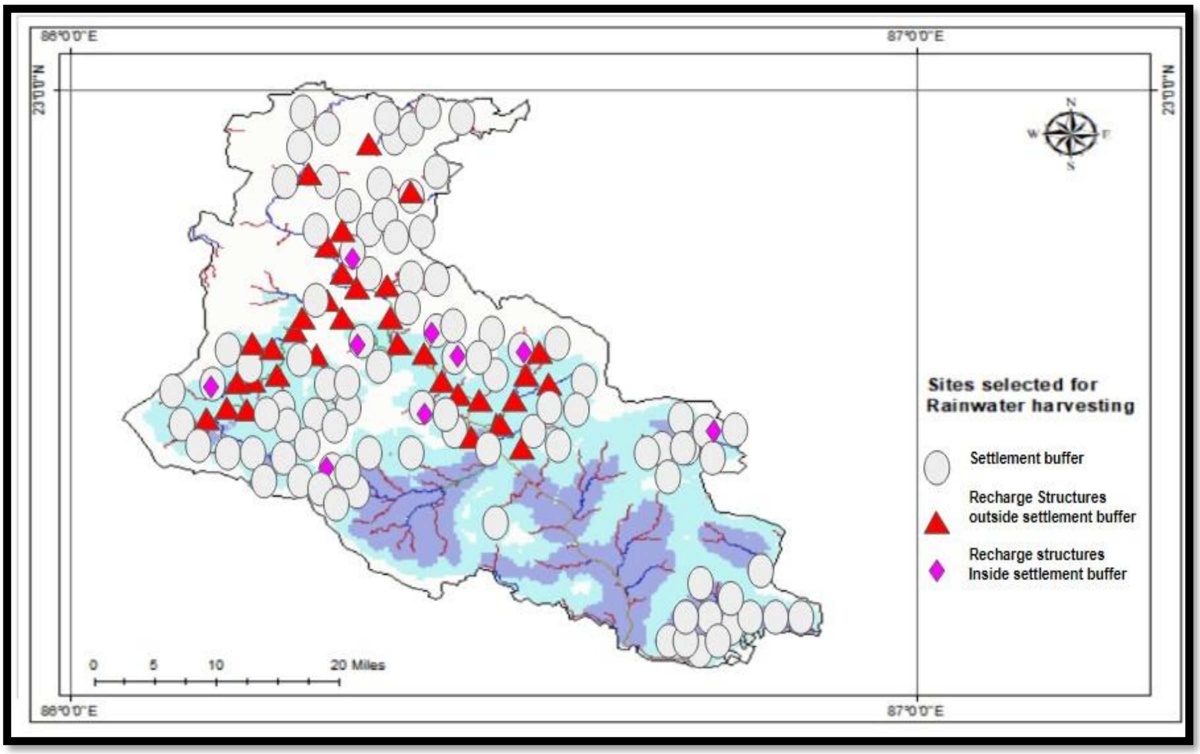


Figure 53 Suitable zones for recharge structures (percolation tanks and check dams)

It was found out by intercepting the buildup with 2000-m buffer and a and 34 recharge zones were identified considering it would be convenient for the people to use recharge and Rainwater harvesting structures.

5. Conclusions

RWH is very capable and pragmatic methods solve water scarcity with improving water levels on a long-term basis. RWH is considered as one of the very significant adaptation for measuring for climate change across the world. Still, the assessment of potential of RWH and the selection of the appropriate zones for various RWH and recharge structures very stimulating

For RWH water Resources engineers, on bigger scales. To get this challenge done, it proves a fairly strong procedure for assessment of the Rainwater harvesting potential zones and identification of Rainwater harvesting potential sites from implication of geospatial technique and MCDA from the results in this study, drawn conclusions are given as:

• Runoff potential for Jamshedpur was for normal rainfall years (2007-2010) was found and it was classified into categories for instance moderate for runoff depth of 25 to 30 cm, poor for depth of 10 to 25 cm and poorer for depth lesser than 10 cm.

• On the basis of results Jamshedpur was divided in three RWHP zones for normal rainfall year conditions: (i) good (Having 27% area), (ii) moderate (having 46% area), and (iii) poor (having 27% area).

Hence, the present study concludes that Analytical hierarchy process in the ArcGIS environment with the help of water resources engineering experiences offers a cost-efficient and supportive tool in assessment of Rainwater harvesting potential and for the selecting the zones suitable for artificial recharge structures. It helped to generate required maps for RWH potential zones, runoff potential sites, and zones suitable for construction of RWH structures are very useful to planning engineers for the effective planning and management water resources in their study and to guarantee supportable supply of good water and improved cleanliness in the area. This particular rainwater harvesting planning can be implemented in near future to combat water scarcity.

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