“PRIORITIZATION OF SUB-WATERSHEDS FOR CONSERVATION PLANNING USING GIS TECHNIQUES”

**A Case Study of Khandala Drainage Basin,
Tahsil Khandala, District Satara**

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Submitted By

Amog Ambadas Kadage

Under the Guidance of

Dr. Sunil W. Gaikwad

February 2016

C E R T I F I C A T E

This is to certify that the dissertation entitled **“Prioritization of Sub-Watersheds for Conservation Planning Using GIS Techniques”**. which is being submitted herewith for the award of the Master of Philosophy (M.Phil) in Geography of Tilak Maharashtra Vidyapeeth, Pune is the result of original research work completed by **Mr. Amog Ambadas Kadage** under my supervision and guidance. To the best of my knowledge and belief the work incorporated in this dissertation has not formed the basis for the award of any Degree or similar title of this or any other University or examining body.

Dr. Sunil W. Gaikwad
Research Guide,
Associate Professor,
P.G. Teaching & Research Centre
Department of Geography,
S. P. College, Pune 30

Place : Pune

Date :

DECLARATION

I hereby declare that the dissertation entitled "**Prioritization of Sub-Watersheds for Conservation Planning Using GIS Techniques"** is the original research work carried by me under the guidance of **Dr. Sunil Gaikwad** Associate Professor, P.G. Teaching and Research Center, Department of Geography, S.P. College, Pune for the award of **M.Phil** degree in Geography to the Tilak Maharashtra Vidyapeeth, Pune. This thesis is completed and written by me has not previously formed the basis for the award of any Degree or other similar title upon me of this or any other Vidyapeeth or examining body.

Mr. Amog A. Kadage
Research Student

Place : Pune

Date :

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Place: Pune **Mr. Amog A. Kadage**

Date:

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ABSTRACT

In the present study, an attempt has been made to ascertain the priority levels of sub-watersheds for conservation planning based on Morphometric Analysis and Soil Loss Estimation in each sub-watershed. The present study demonstrates the usefulness of GIS for Morphometric Analysis, Soil Loss Estimation and Prioritization of the sub-watersheds of Khandala watershed.

Aims and Objectives:

- To quantify the geomorphological characteristics of the watershed.
- To ascertain the priority levels of sub basins for conservation planning based on Morphometric Analysis.
- To ascertain the priority levels of sub basins for conservation planning based on estimated soil loss in each sub-basin.

Study Area :

The study area is the comprises of an upland watershed of Veer dam, a tributary of Nira River in the upper Krishna Valley. The study area is located from latitude 18°00′ 33.9144″ N to latitude 18° 07′ 56.9148″ and longitude 73° 58′ 8.8163″ E to longitude 74° 04′ 34.8166″ E. The river has its source in the Western Ghats on the leeward side of the mountains in Khandala taluka of Satara district, Maharashtra. Morphometric analysis is a significant tool for prioritization of sub-watersheds.

Methodology :

The study of Pedogeomorphic Approach for prioritization of sub-watersheds form conservation planning for Khandala basin has been taken into consideration in the present study. Morphometric analysis and the Stehlik’s method has been used for predicting the

annual rate of soil loss. Prioritization rating based on soil loss estimation of all the eleven sub-watersheds of Khandala watershed was carried out by giving higher ranks to the sub-watersheds with greater values of soil loss.

Morphometric parameters like drainage density, drainage frequency, etc. are calculated. Prioritization rating of all the eleven sub-watersheds of Khandala watershed is carried out by calculating the compound parameter values. The every sub-watershed is given the ranking with respect to value which are calculated.

Arrangement of Text :

Present study is divided into 6 chapters.

Chapter 1 : Introduction

Chapter 2 : Geographical Set Up of the Study Area

Chapter 3 : Database and Methodology

Chapter 4 : Basin Morphometry and Soil Characteristics

Chapter 5 : Prioritization of Sub-Watersheds for Conservation Planning

Chapter 6 : Findings, Conclusion and Suggestions

Findings and Suggestions :

It is observed that in the study area four distinct geomorphic units i.e. Hill summit (1%), hill fringe (7%), pediment summit (71%) and valley floor (21%) can be identified. This units however are subject to various geomorphic processes leading to soil loss, runoff etc. It is also observed that, being a semi arid zone, soil environment is very conducive for such kind of processes (soil loss and runoff) as it can be inferred from textural analysis, that entire area is predominantly characterized by sandy soil environment, indicative of high runoff and soil erosion.

Infiltration rates and hydraulic conductivity observations made in the field also confirm that, soil environment is very prone to erosion. According to land use/ land cover analysis, it is observed that most of land surfaces are of wasteland type and subjected to degradation. It is also inferred that there is a strong relationship exist between geomorphic processes and soil environment.

As far as slope morphology is concerned, slope is from 0 to 40% and mainly comprises the pediment (55.84 sq. km) 73% surface. According to basin morphometric analysis it is observed that 2 watersheds comprising about 6 % area is subject to severe land degradation in terms of soil loss and runoff. The maximum soil loss in Khandala watershed noticed to 32.80 kg/m2/y. The average annual soil loss in Khandala watershed was 12.80 kg/m2/y. The soil loss increases due to increase in slope and rainfall.

Composite map prepared from morphometric analysis and soil loss estimation clearly gives the idea of entire watershed, these watersheds needed urgent conservation planning measures in the study area.

As conservation and land rehabilitation measures are highly expensive, the area for reclamation should be prioritized based on the severity of the land degradation, the nature of the extent of the problem and the proposed land use. The maps and the data given in this publication can be effectively used for such initiatives.

The database and GIS-based maps generated in the study can be used most effectively by the National and State Planning Commissions/ departments to assign high priority to areas identified as degraded and wastelands. Soil conservation approach is to minimize the silt content which goes to the reservoir. Conserve maximum amounts of water in the soil profile, to promote growth of crops, vegetables, trees etc.

This approach, elementary as it would appear initially, is suitable in micro level planning and also in development planning for villages in the watershed.

1 Introduction

1.1 Introduction

A watershed or drainage basin is a natural geo-hydrological unit for planning regional development. Watershed management means scientific management of the land, water and biotic resources in the watershed. Watershed management helps in decision making and is the key to success which brings sustainable development. Drainage basins are the fundamental units for conserving natural resources. The watershed management studies interrelationships between relief, slope, land use and soil. Soil and water conservation are the major concerns in watershed management.

Environmental degradation problem in the watershed can be effectively controlled by watershed management techniques. Watersheds are managed on "ridge to valley" approach. Management of land in a scattered manner will not lead to watershed development. A land lying in a valley cannot be improved if the land at upper reaches is not managed properly. Therefore, the entire watershed community is to be involved for the integrated development of watershed. For watershed conservation work, it is not possible to take the whole area all together. Thus the entire catchment is divided into several smaller units such as basins sub-basins, sub-watersheds or micro-watersheds, by considering drainage system.

1.1.1 Watershed Development

Watershed development is the conservation and judicious use of the natural resources like land, water, vegetation etc. within the watershed area. Watershed development is the development of watershed area based on soil properties, vegetative cover, rain water etc. Watershed development includes dimensions like equity, sustainability, gender and peoples' participation. It has become a tool for the overall development of the village and people living within the watershed. Watershed development programmes can be planned for village/micro watershed levels. The holistic approach of watershed development will bring balance between environmental concerns and developmental aspirations.

1.1.2 Advantages of Watershed Development and Management

1. Watershed which experience high soil erosion can be effectively managed so as to reduce the soil loss.
2. Vast areas of land covered by wastelands or barren hill slopes can be covered by vegetation through afforestation programmes in the watershed.
3. Agro-horticultural and Agro-forestry programmes can be implemented in the watershed for better source of livelihood for the local people.
4. Water resources in the catchment can be effectively harvested through bunds, gully embankments etc.

1.2 Significance of the study

The whole state of Maharashtra is divided into six revenue divisions; Pune, Konkan, Nashik, Aurangabad, Amravati and Nagpur. Satara district is part of the Pune division along with the districts of Pune, Sangli, Kolhapur and Solapur. Satara district covers an area of 10480 sq. km with an east west expanse of 135 km and a north south expanse of 112 km. The district is divided into eleven administrative sub units (tahsils) Satara, Wai, Khandala, Koregaon, Phaltan, Khatav, Man, Karad, Patan, Jawali and Mahabaleshwar.

The Satara district has three natural sub-divisions based on the topographical situations- Hilly area in the west, plains of the Krishna River in the central part and the plateau area in the east. In Khandala tahsil, the soil has low fertility, coarser and is rocky except for the area along the Nira River and its tributaries. The soil loss is also considerable in Khandala tahsil. In Satara district the area under wasteland is 783 sq. km out of 10480 sq. km i.e. **7.5%** and the drought prone area is approximately 2300 sq. km i.e. **22%**. The agriculture area is 69% and forest area is 15%, so there is need for soil and water conservation in Khandala tahsil.

The present study attempts to mainly identify geomorphic units and the contemporary geomorphic processes associated with detailed examination of soil properties and also ascertains the variation in its spatial distribution and hence highlights the dominant physical determinant.

The present study lies in the satara district, which consists of geomorphological parameters such as hills, plateaus and plains. Khandala watershed is a part of veer dam.

1.2.1 Review of Literature

The morphmetric analysis work is carried out by methods / techniques which are applied in the actual work. The analysis of different watershed or sub-basins is carried out in India on a large scale. The review of some scholars, gives the clear understand and usefulness of GIS in present conditions.

In the study of sukana lake catchment area, the author has applied the GIS techniques in delineation and prioritization of soil erosion in that study area. A GIS technique is also used in morphmetric analysis of sub-watershed of pawagada area which gives clear idea about the use of GIS in watershed management. The use of modern Remote sensing data and satellite image which is used in watershed prioritization work of Guhiya basin.

The use of modern technique in GIS application has been applied to findout the sediment yield index model and prioritization of micro watersheds. The integrated study of geographic information system and remote sensing approach to prioritize the Murli sub watershed in the Subarnarekha basin is also carried out. The murli sub watersheds was further divided into 44 micro watersheds, which were prioritization which is based on the morphometric parameters. Suitable soil conservation measures were suggested. They concluded that prioritization of micro watersheds using GIS is handy as well as effective in recommending proper treatment.

Remote sensing and GIS both the techniques were used to updated drainage and surface water bodies and to evaluate linear, relief and aerial morphmetric parameters for different studies in india. The integrated use of GIS and Remote sensing plays the significance role in area recurring drought coupled with increase in ground water exploitation which results in decline in the groundwater level.

Waikar and Chavadekar have carried out investigations on spatial and temporal land use/land cover (LULC) changes at regional scales.

Ravikumar has carried out quantitative morphometric analysis by estimating their various aerial, linear, relief aspects which gives the importance of morphometric properties.

In the present study, the major aim to prioritize the sub-watershed on the basies of Morphometric analysis and soil properties, integrated prioritization of sub-watersheds are carried out for Khandala Drainage Basin, Tahsil Khandala, District Satara, which determines the priority level as per the integrated analysis of sub-watershed of study area.

1.2.2 Aims and Objectives of Study Area:

- To quantify the geomorphological characteristics of the watershed.
  To ascertain the priority levels of sub basins for conservation planning based on Morphometric Analysis. To ascertain the priority levels of sub basins for conservation planning based on estimated soil loss in each sub-basin.

❑❑❑

2 Geographical Set Up of Study Area

2.1 Study Area

2.1.1 Satara District

Satara district is one of the oldest districts and located in western part of Maharashtra state. In 1960, northern Satara district was named as Satara and Southern Satara district was named as Sangli district. It is bounded by Pune district in the north, Solapur district in the east, Sangli district in the south and Ratnagiri district in the west. Raigad district lies to its north-west. Satara district is located in the western part of Deccan plateau and lies between 17°05' and 18°11' north latitudes and 73°33' and 74°54' east longitudes. The entire area of the district falls in parts of Survey of India degree sheet No's 47-G, 47-K, 47-J and 47-F.The district has an area of 10480 sq.km, which constitutes about 3% of the total area of Maharashtra. Prior to 1971, district had 9 talukas but presently there are 11 talukas. These talukas consist of 1721 villages and 10 towns.

Satara district is broadly divided into four physiographical divisions. They are as follows

i) <u>Sahyadri hilly region :</u> Sahyadri ranges runs in west side of the district mainly in Wai, Patan, Jawali and Mahabaleshwar taluka.

ii) <u>Eastern hilly region :</u> Khatav and Man taluka are included in this division.

iii) <u>The region of Krishna river basin :</u> Krishna River is flowing through the central part of the district. Krishna and its tributaries expanded in Karad, Wai, Satara and Koregaon tahsil.

iv) <u>Region of Nira river basin :</u> The Nira river flows to the northern boundary of Satara dilstrict, Khandala and Phaltan tahsils are included in this division.

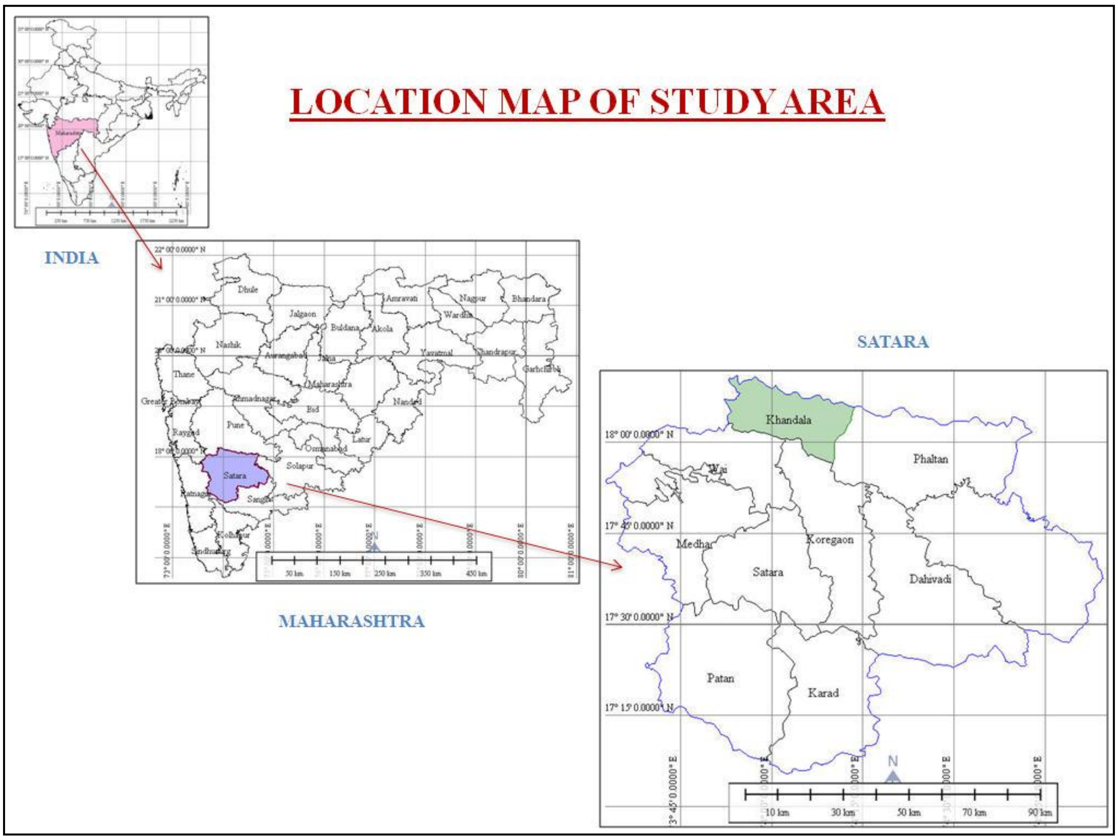

FIG. 2.1(a) : LOCATION MAP

2.1.2 Khandala Taluka

Khandala is a taluka in the Satara district in Maharashtra, India. The Nira River passes through the region. Khandala Taluka is situated on the northern side of Satara district. Khandala, Shirwal and Lonand are large towns in the taluka. Khandala got separated from Wai Taluka along with Mahabaleshwar for easier administration. The Nira River flows from the northern border of the taluka. "VEER" is the largest dam on the Nira River in Khandala. The southern border is covered with "MAHADEVACHE DONGAR", meaning Mahadev Hills.

Khandala is located at (18.03°N, 74.01°E), approximately 55 km south of the city of Pune. It has an average elevation of 700 metres (2300 feet). It is surrounded by the mountainous region of the Sahyadris; the boundaries of Khandala taluka are as follows, to the east of Khandala are the talukas of Phaltan and Baramati, to the west lies the talukas of Wai and Bhor, the northern border abuts the Purandar Taluka in Pune district and the southern border is shared with Wai and Koregaon. The headquarters of the taluka of Khandala is the city by the same name, populated by about 7000 people. Khandala is 50 km from Mahabaleshwar, 25 km from Wai, 45 km. from Satara, 55 km. from Pune, 230 km. from Mumbai. Khandala is situated on the Pune-Satara highway part of National Highway No. 4. Khandala is a major city on the way to hill stations such as Mahabaleshwar and Panchgani from Pune.

Khandala is an area having the first order streams flowing from three directions. There is a steep slope present which ranges from 30% to 40% in Khandala area. The upper part of area is covered with reserved forest. All the streams meet to Nira river of Krishna valley. The origin of river Nira is in Hirdose, taluka Bhor, district Pune, which flows from Pune, Satara and Solapur, which meets to the Bhima river. The Veer dam is built on Nira River in the year 1961-62 which was under Government of Maharashtra, Water Resources Department for Hydro power (Existing Veer Dam Hydroelectric Project and Proposed NLBC Hydroelectric Project). Veer reservoir consists of catchment area of 1756 sq. km, total storage capacity of water is 9835 TLCM. Submerged area is 31.69 Sq. Km/12.21 Sq. Miles, Total Capacity is 278.493 Mcum/9835 Mcft, Useful Storage 266.40 Mcum/9408 Mcft, High Flood Level is 579.85 Mtr/1900.40 Ft. Veer dams watershed area is spread from Katraj ghat to Khambatki ghat i.e. 1756 Sq Km. The Khandala sub-watershed area lies at right side of Nira river which covers an area 76.018 Sq Km.

The study area comprises of an upland watershed of Veer dam, a tributary of Nira River in the upper Krishna Valley. The river has its source in the Western Ghats on the leeward side of the mountains in Khandala taluka of Satara district, Maharashtra. The study area is located between latitude 18°00′ 33.91″ N to latitude 18° 07′ 56.91″ and longitude 73° 58′ 8.81″ E to longitude 74° 04′ 34.81″ E. The region experiences the tropical type of climate and is characterized by monsoon rain. The average annual rainfall in catchment area is 1066.80 mm and near Veer dam is 408 mm and the average maximum temperature is 32°C. and minimum temperature is 18°C.

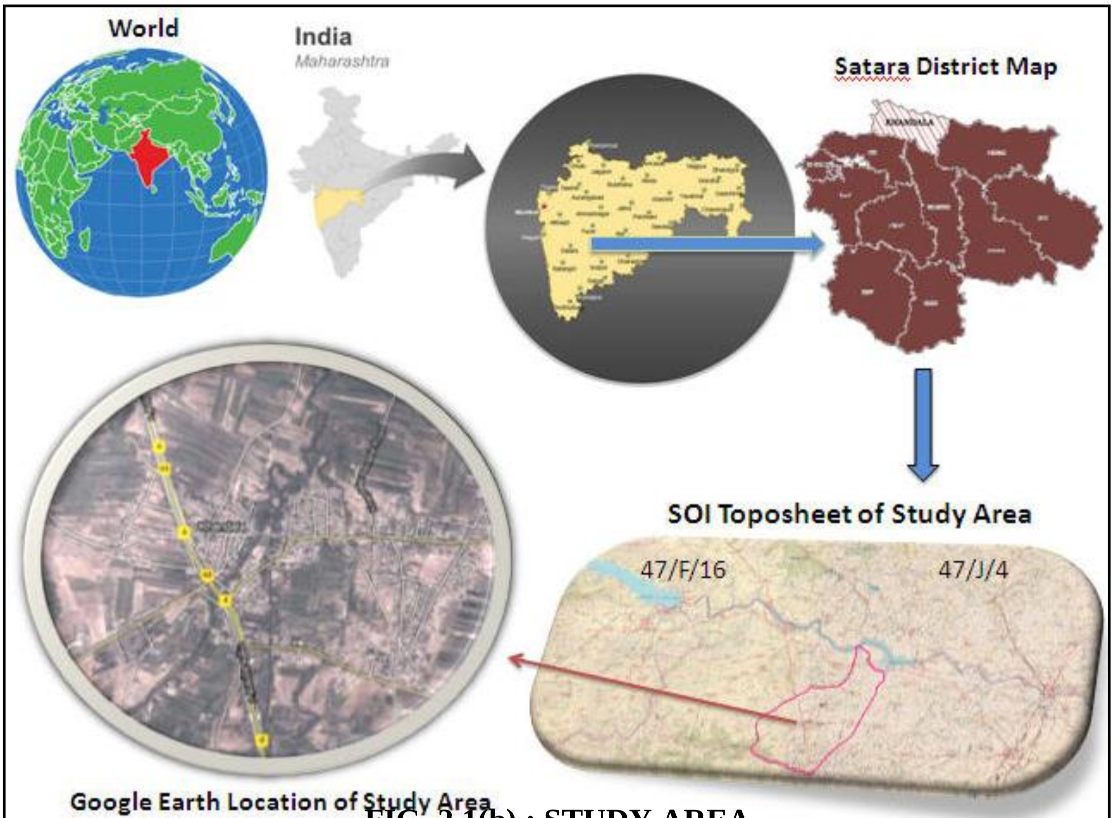

FIG. 2.1(b) : STUDY AREA

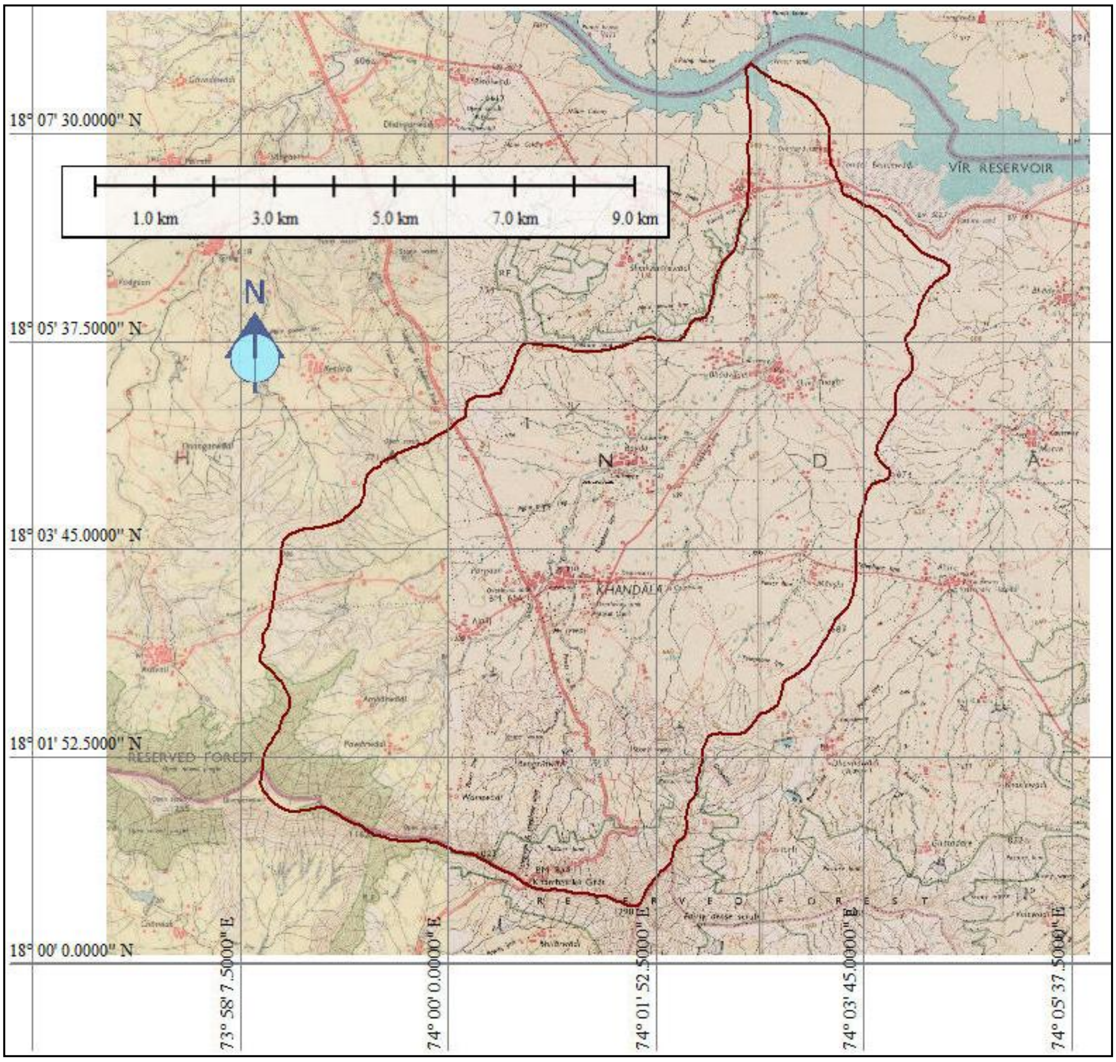

FIG 2.2: TOPOGRAPHIC MAP OF STUDY AREA

2.1.3 Geology

Entire watershed is having single geological formation which consists of Deccan trap or basalt formed, from lava came out through numerous fissures and aligned flows in horizontal strata, which gives the step like appearance to the hill slopes and hence called as traps. It is formed during the geological period from Eocene to upper cretaceous. It has specific gravity 2-9. Varied colors like gray dark, gray brown etc. are observed. Soils formed form this rock are deep basaltic with high shrinks well potentials. The basaltic flows are of the two types

1. 'Pahoehoe' flow
2. 'Aa' flow

The ‘ Pahohoe flows’ weathered easily and gave rise to mature type of the topography with smooth hill slope and conical peaks. Broad valleys are common. The product of the weathering includes small-sub rounded fragments. ‘Aa flows’ main section comprise of dark grey, fresh basalt. Over this is found a section of flow breccia which is also surrounded by angular block of vesicular trap cemented by glass or zeolitic or very fine grained altered basalt.

2.1.4 Climate

The climate of the district is on the whole tropical. The winter season is from December to about the middle of February followed by summer season which last up to May. June to September is the south-west monsoon season, whereas October and November constitute the post-monsoon season. The mean minimum temperature is 15° C and mean maximum temperature is 36° C at Satara town in the district.

Distribution of monsoon in the district is unequal from part to part and ranges between 500 mm. to 6000 mm. The western mountains tahsils including Mahableshwar, Patan, Wai, and Jaoli receives 2500mm. to 6000 mm. rainfall, which can be termed as heavy rainfall zone. The isohyets run in north-south direction and vary close in north western part of the region. In this zone, the rainfall decreases rapidly from western part towards the eastern side. The central plain zone, including tahsils of Satara, Karad and western part of Koregaon lies in moderate rainfall zone, which receives 1000 mm. to 2500 mm. precipitation. In this zone, rainfall decreases from west to east. The north eastern part of the region including Phaltan, Khandala, Man, Khatav and eastern part of Koregaon tahsil receive 500 to 1000 mm. rainfall, and lies in the eastern low rainfall zone.

Table 2.0 : Rainfall and Temperature

Sr.No.	Tahsils	Average Annual Rainfall in mm.	Average Annual Temperature in °C	
			Maximum	Minimum
1	Mahableshwar	6126.4	31.5	12.7
2	Jaoli	1712.2	34.7	13.9
3	Wai	734.6	35.4	14.1
4	Patan	1882.5	35.1	14.0
5	Satara	1132.1	35.3	14.2
6	Khandala	503.8	36.2	15.3
7	Khatav	512.2	36.5	15.4
8	Man	496.2	37.2	14.9
9	Phaltan	557.1	36.9	14.8
10	Koregaon	714.7	35.5	15.1
11	Karad	713.1	33.5	16.3
	District Average	1371.3	35.25	14.60

2.1.5 Drainage Pattern

Drainage pattern is defined as the spatial relationship between individual stream courses in area. These patterns are controlled by factors such as slope, climate, vegetation and hard rock resistance to erosion. Drainage is mainly governed by the geological formation present in an area. Change in geology is usually reflected in change in drainage pattern. In the study area the drainage pattern is dendritic i.e. tree like branching of streams indicating homogeneity in lithology and lacks structural control. Dendritic patterns are typical of adjusted systems, erodible sediments and uniformly dipping bedrock.

2.1.6 Soil

Black cotton soil is the predominant soil type found here as is the case with most of the districts on the Deccan Plateau. In lateritic soil covers many parts of the Western tahsils of Mahabaleshwar, Javali, Wai and Patan it is typically clayey in nature and reddish in color. Black cotton soil is found in the central part of the district.

Soil fertility is especially high in the valleys of the rivers Krishna, Venna, Kudali, Koyna and Kole.

2.1.7 Natural Vegetation

The watershed has mixed deciduous type of vegetation with thin shrubs predominant on hills and hill slopes. Some of the important species are enlisted below.

Dominant Tress & Shrubs in the Study area

Table 2.1: Botanical Names of Trees in Study Area

Sr. No.	Local name	Botanical name
1	Mango	*Mangifera Indica*
2	Khair	*Accacia catechu*
3	Hirada	*Terminalia chebula*
4	Behada	*Terminalia belerica*
5	Umber	*Ficus racemosa*
6	Jambhul	*Syzigium cumini*
7	Phanas	*Artocarpus indica*
8	Ain	*Terminalia formardasa*
9	Teak	*Tectona grandis*
10	Babhul	*Accacia arabica*
11	Ghaneri	*Lantana caimera*
12	Ghaypat	*Agave sisolona*
13	Rui	*Calotropis gigantia*

(Source: Khandala Forest office)

In the present study area, patches of reserved forest are observed along the hill slopes. Within the forest area itself, there are cultivated patches of grazing land.

2.1.8 Socio-economic Aspects

The study area covers about 13 villages. The major villages being Khandala and Shivajinagar settlements. The National Highway No.4 passes through Khandala settlement. It reaches to Khambatki ghat. Highest elevation is 1280 meters, where as the state highway passes from Loni and Tandal Bendewadi settlement. The transport facilities are good in the study area. The agriculture production is at the tanks which are created by people near the area. The canal is also seen near the Khandala area. The Khandala is having the various facilities such as dispensary, post office, PWD, Market (on Sunday) etc. The other settlements which are connected to Khandala are Ajnuj. Bavda, Mavshi, Shivajinagar and Bhadvade.

Table 2.2: Villages in Study area

Sr. No.	Villages	Latitude	Longitude
1.	Loni	18°07′0.28″ N	74°02′43.95″ E
2.	Tondal Bendewadi	18°07′13.73″ N	74°03′26.94″ E
3.	Bhadvade	18°05′27.73″ N	74°02′30.27″ E
4.	Shivajinagar	18°05′18.75″ N	74°02′59.25″ E
5.	Bavda	18°04′34.08″ N	74°01′36.35″ E
6.	Paragaon	18°03′29.79″ N	74°00′31.03″ E
7.	Ajnuj	18°02′59.51″ N	74°00′9.16″ E
8.	Ambarwadi	18°02′19.98″ N	73°59′14.21″ E
9.	Pawarwadi	18°01′55.59″ N	73°59′28.79″ E
10.	Wanewadi	18°01′30.07″ N	74°00′4.11″ E
11.	Bengrutwadi	18°01′48.86″ N	74°01′2.15″ E
12.	Khandala	18°03′28.67″ N	74°01′4.11″ E
13.	Mavshi	18°03′30.56″ N	74°03′18.54″ E

(Source: SOI Toposheet 47/J/4 and 47/F/16)

2.2 Relief Analysis

The area exhibits extremely steep slope especially in the upper reaches of area, in fact these valley catchments are covered with reserved forest. The altitude varies between a minimum of around 580 meters near the outlet and a maximum of above 1250 meters on the ridges of the basin boundary mostly at the southern water divide. Hilly undulated area and hillocks are present particularly in the southern part of watershed.

In the study area the streams are non-perennial with dry tanks which are used for agriculture use and home use where the rainfall is high at the upper hills where as the at lower level the rainfall goes on decreasing as it reach to Nira river. In drainage basin the left hand side streams of second order are parallel to each other whereas at right hand side second & third order streams are parallel.

Relief Analysis is a main or initial step in geomorphological studies to understand the terrain characteristics of an area, relief aspects of the drainage basins are related to the study of three dimensional features of the basins involving area, volume and altitude of vertical dimension of landforms where in different morphometric methods are used to analyze terrain characteristics, which are result of basin processes. Thus, this aspect includes the analysis of the relationships between area and altitude, altitude and slope angle, average slope, relative relief, dissection index, profiles of terrains and rivers, etc.

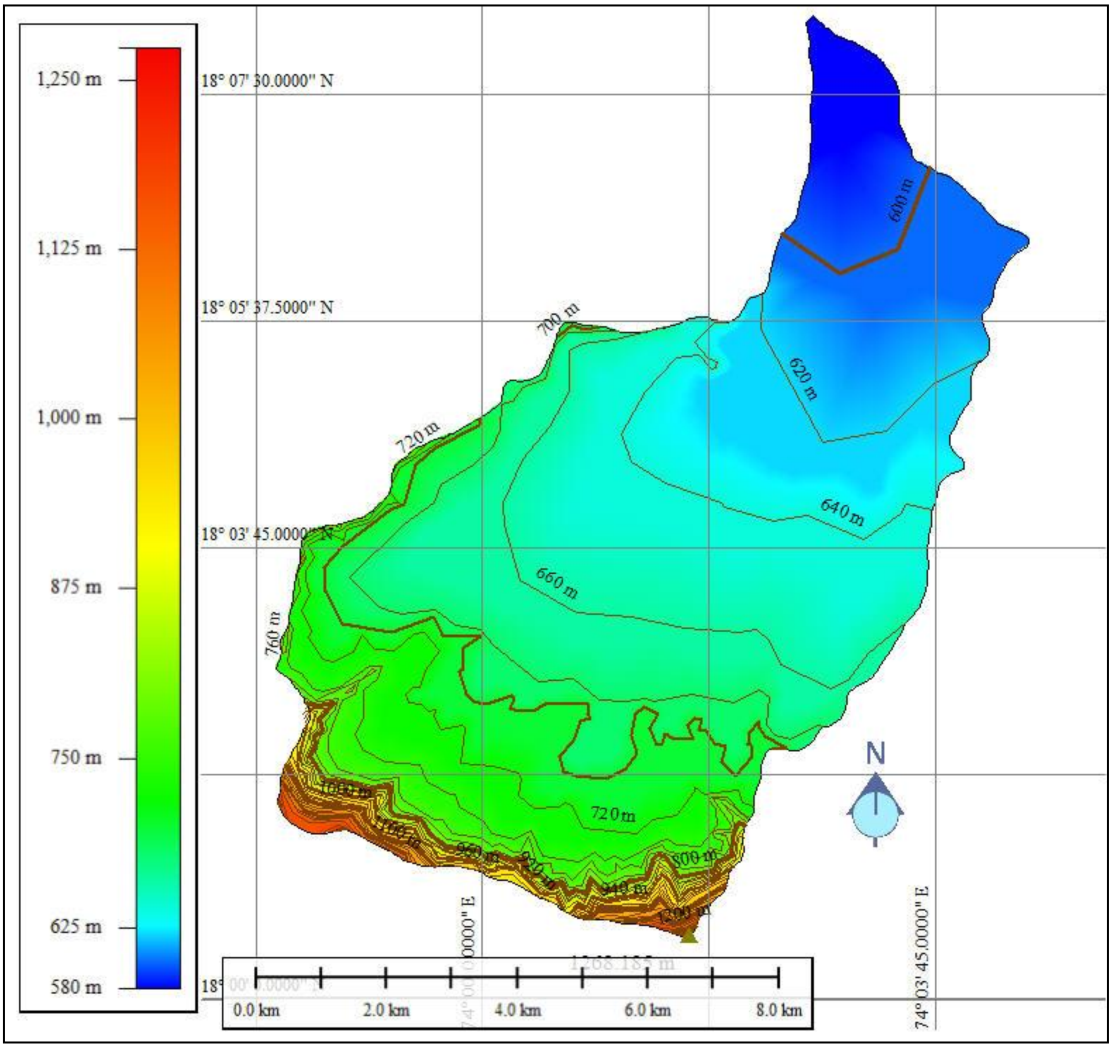

FIG. 2.3 : CONTOUR MAP OF STUDY AREA

2.2.1 Absolute Relief

The map (Fig. 2.4) indicates the maximum height in river basin and it can be determined by the values of maximum contour passing in an area. In every quadrant there is a maximum contour passing. It can be represented by taking the maximum value and X-Y coordinates in a surfer and it gives the contour map of maximum values.

The contour map has been divided into equal grids. A grid of the size 0.9 X 0.9 cm has been superimposed on contour map and the highest values of each square is considered. With the help of these values, isopleth map are prepared which depicts and gives idea about the highest relief of the area.

The calculated absolute relief increases from 578 m to 1250 m towards the hill tops in the study area.

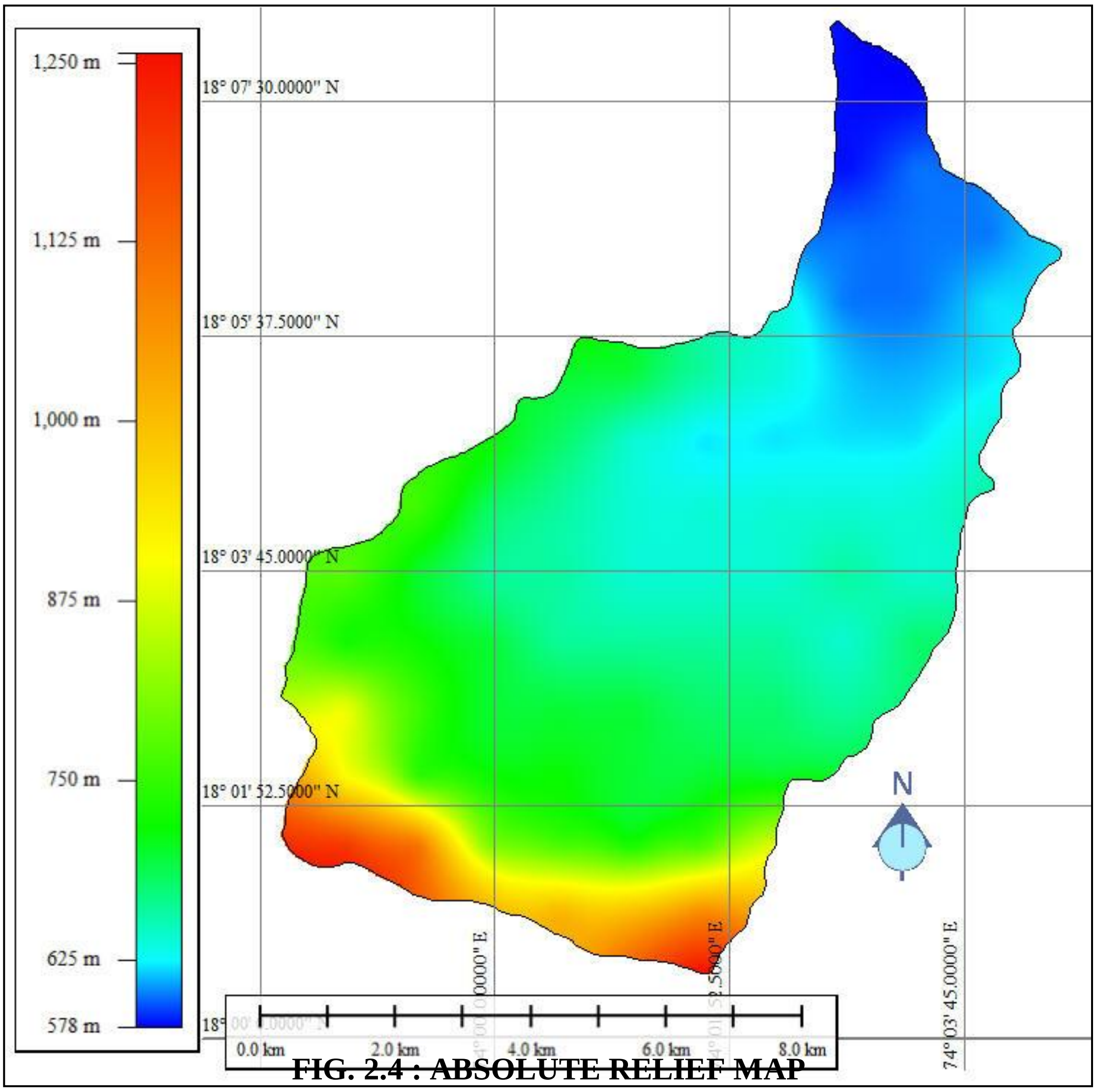

FIG. 2.4 : ABSOLUTE RELIEF MAP

2.2.2 Relative Relief

It is often important to relate the altitude of the highest and lowest points in any particular area that is to ascertain the amplitude of available relief. It is useful to read this analysis of vegetation land utilization and settlement in relation to local relief. Relative relief map (Fig. 2.5) determined by taking difference of maximum value and minimum value. It can be represented by taking the difference value and X-Y coordinates in surfer; it gives the relative relief of study area which varies between less than 1 m to above 400 m.

2.2.3 Dissection Index

Dissection Index (Fig. 2.6) gives the better understanding of the degree of dissection of the landscape. Dissection Index (%) expresses a ratio of the maximum relative relief to the maximum absolute relief. It is calculated by using the formula-

$$\% \text{ D.I.} = \frac{\text{Relative Relief}}{\text{Absolute Relief}} \times 100$$

Dissection index is also used as morphometric determinant of the stage of cycle of erosion wherein old, mature, and young stages are related to dissection indices, in between 1% to 35% i.e. moderate relative relief observed in valley floor area and very high dissection index which is above 35% observed in eastern margins of study area.

2.2.4 DEM (Digital Elevation Model)

A Digital Elevation Model (DEM) is a digital representation of ground surface topography or terrain. It is also widely known as a Digital Terrain Model (DTM). A DEM (Fig. 2.7, 2.8) can be represented as raster (a grid of squares) or as a triangular irregular network. DEMs are commonly built using remote sensing techniques; however, they may also be built from land surveying. DEMs are used often in geographic information systems, and are the most common basis for digitally produced relief maps.

An attempt has been made to generate DEMs using survey of India's Topographical map on 1:50000 scale. DEM (Digital Elevation Model) has been prepared using Surfer version 8 and Global Mapper version 11 software to get the perspective view of the study area.

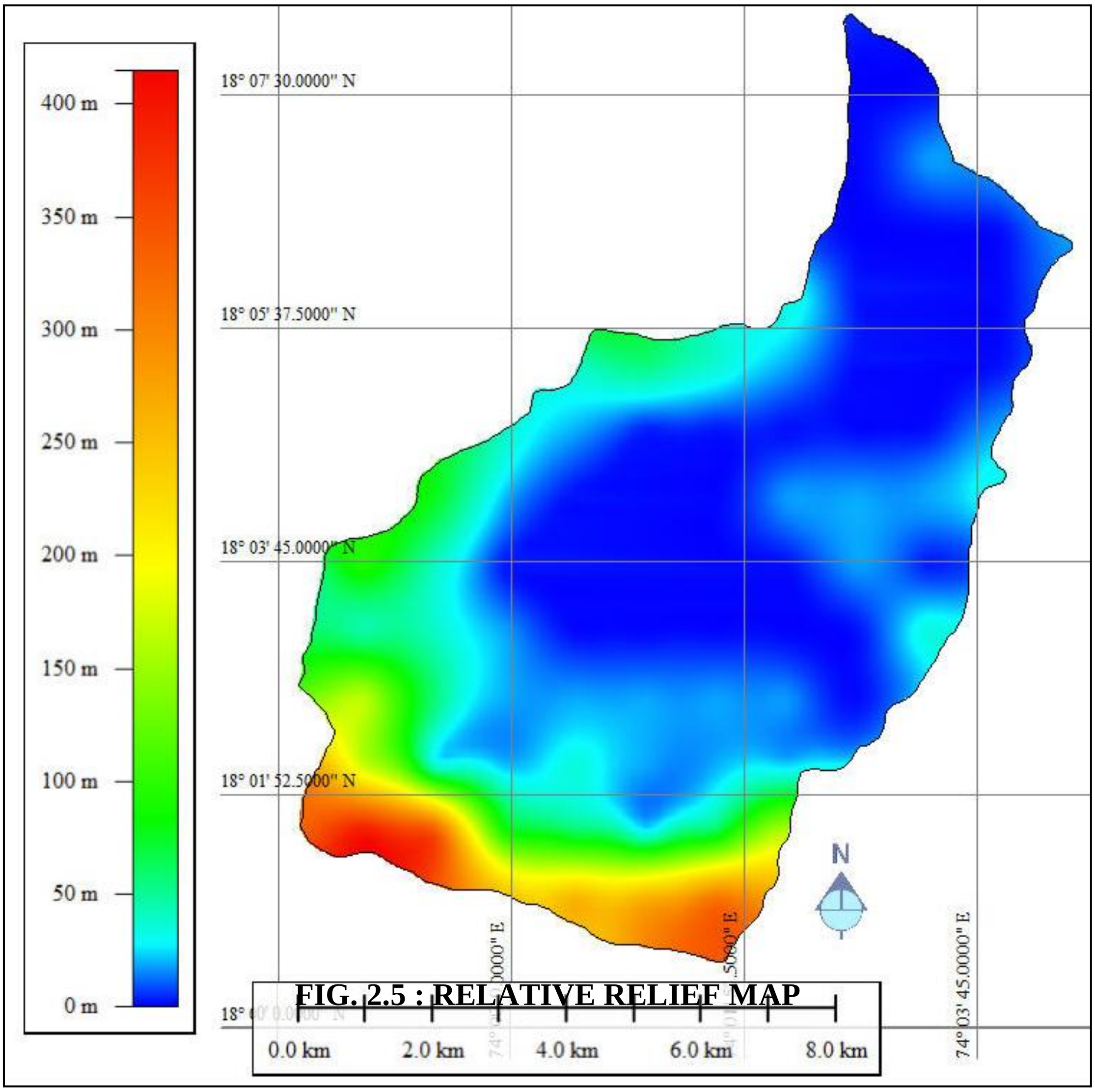

FIG. 2.5 : RELATIVE RELIEF MAP

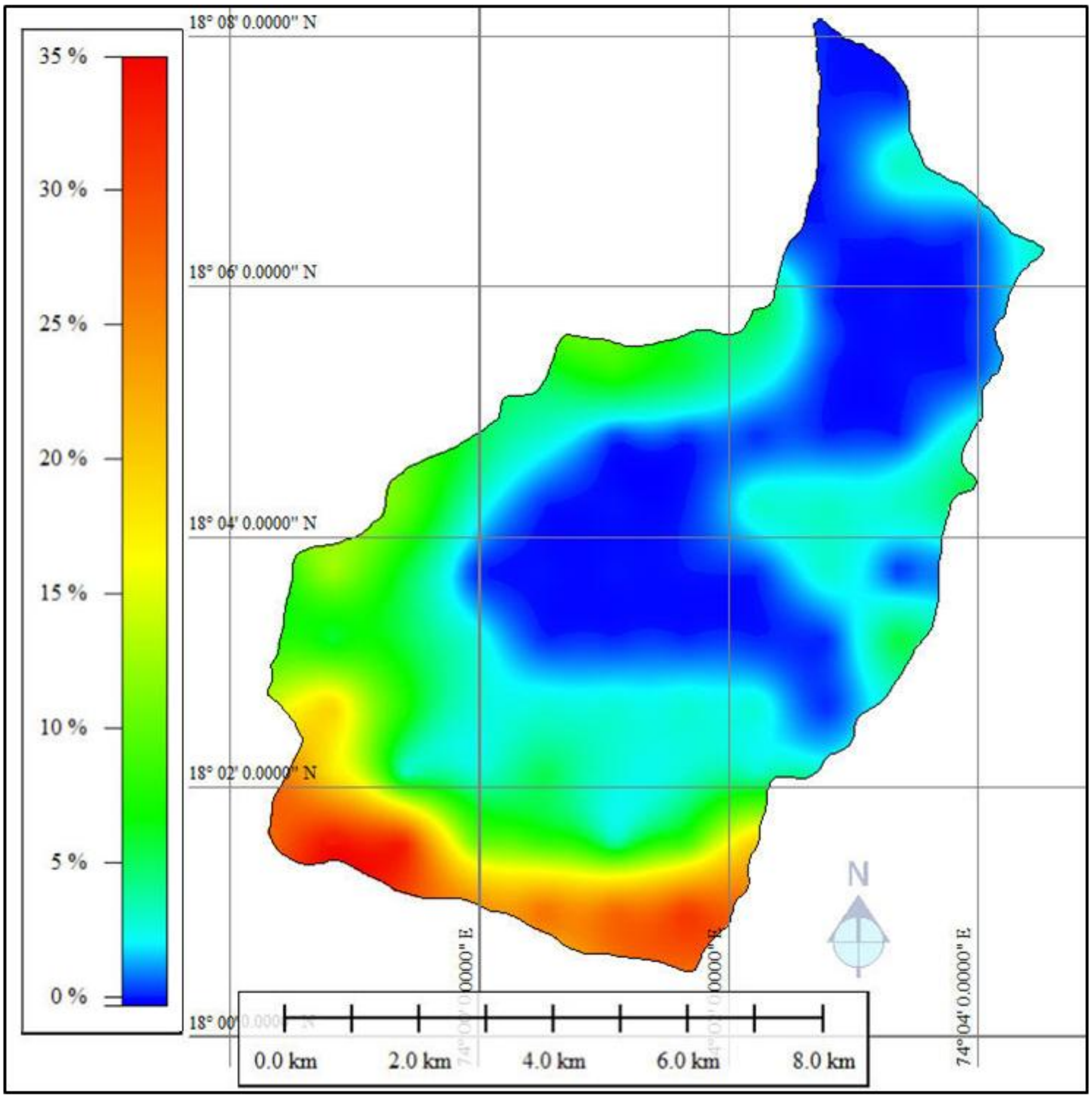

FIG. 2.6 : DISSECTION INDEX MAP

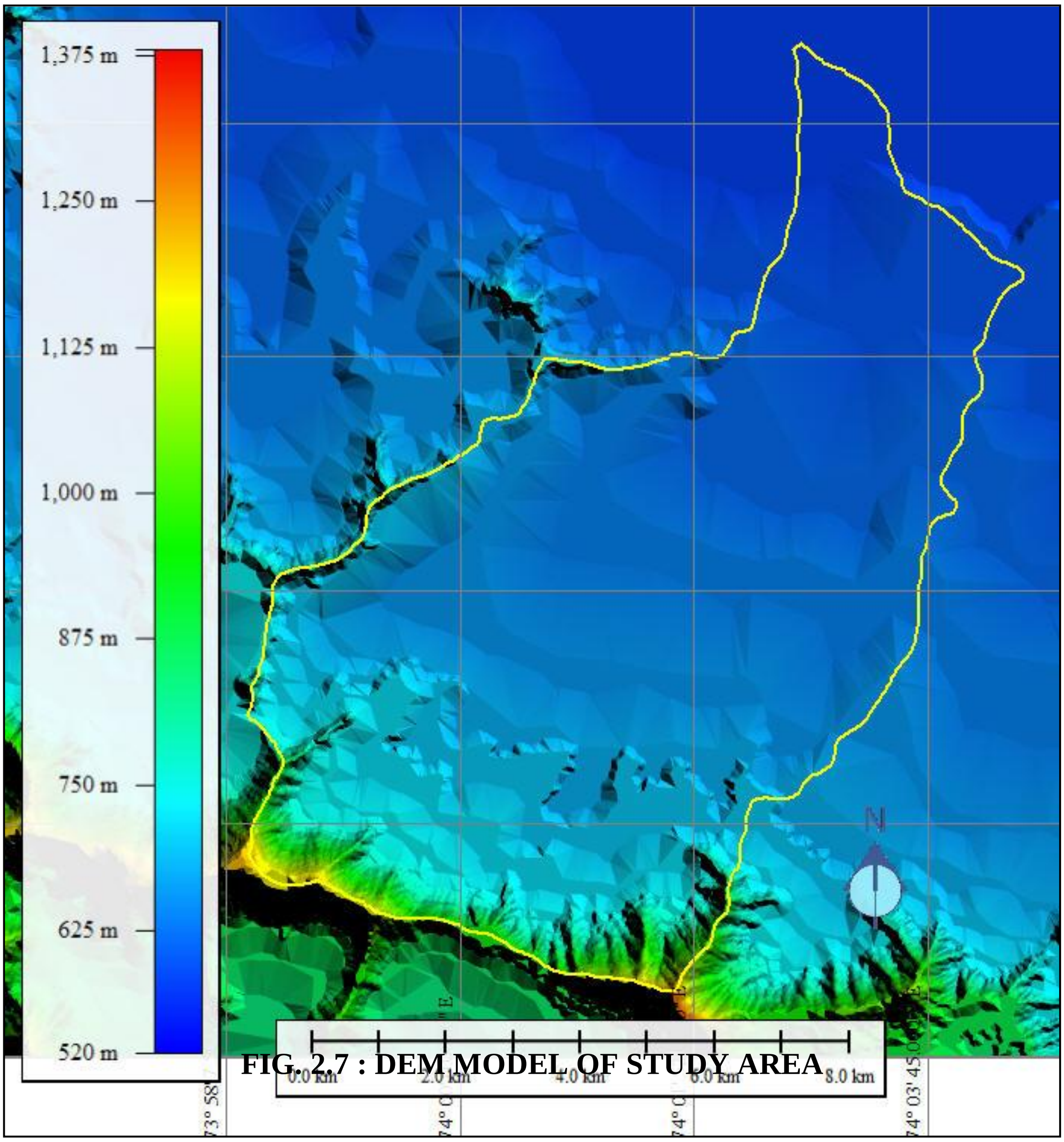

FIG. 2.7 : DEM MODEL OF STUDY AREA

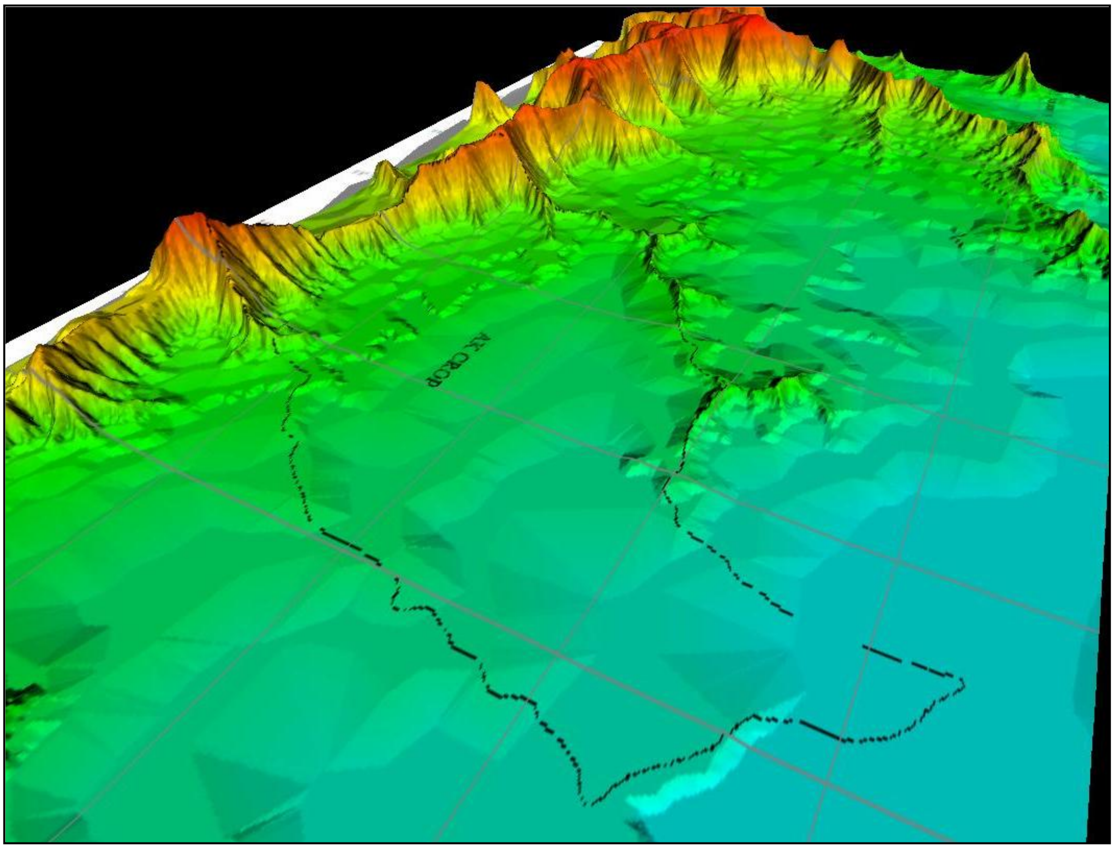

FIG. 2.8 : 3D MODEL OF STUDY AREA

2.2.5 Slope map

It is a map showing the variation in slope or the first derivative of a DEM. A neighborhood operation is carried out on a DEM in order to get a measure of the steepness of an area of the earth's surface identifying the maximum rate of change from each cell to its neighbors. The output slope grid theme represents the degree of slope (usually measured in degrees or percent) for each cell location.

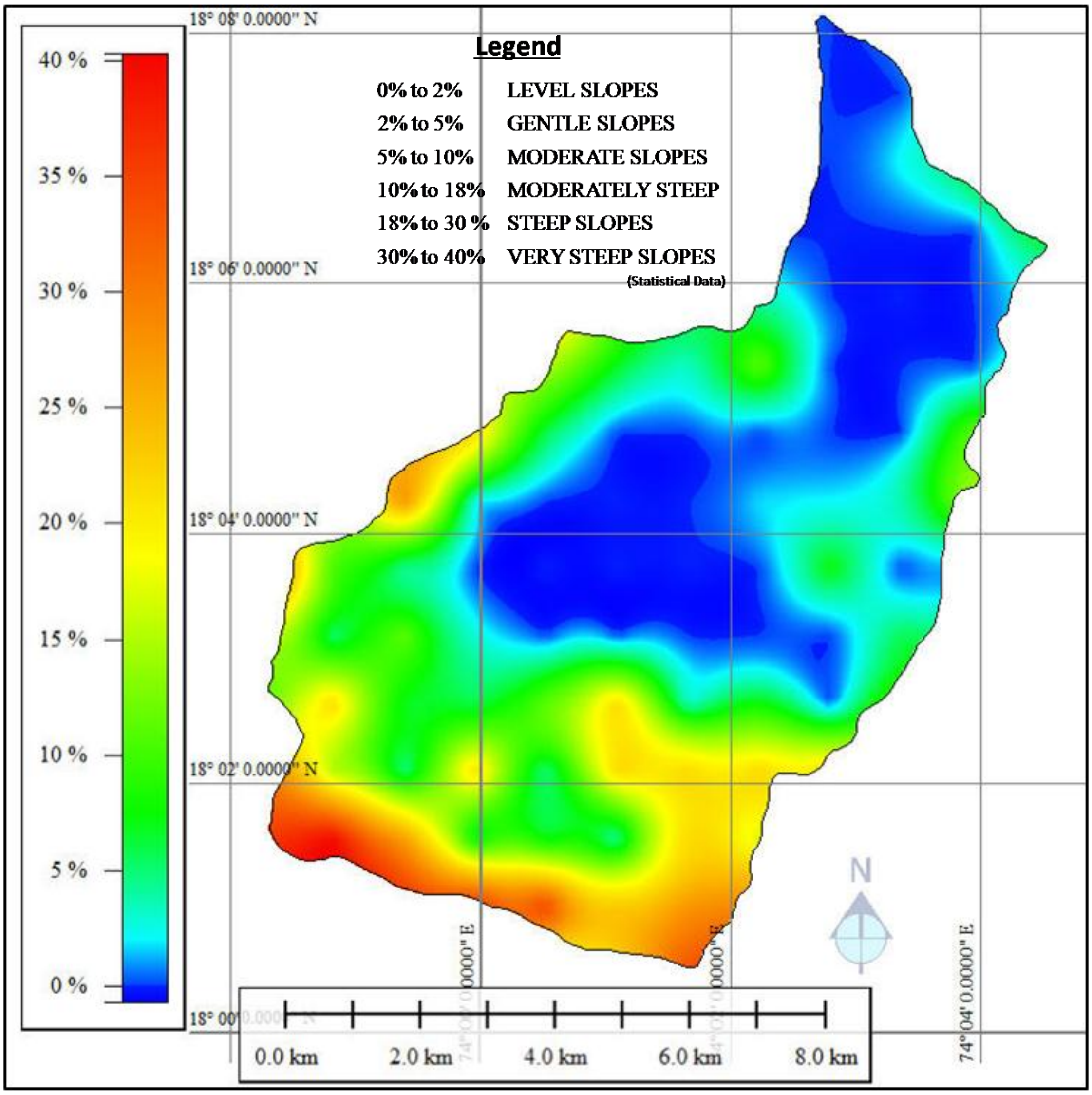

FIG. 2.9 : SLOPE MAP IN PERCENTAGE

A slope can be defined as the angular inclination of a terrain between hilltop and valley bottom, resulting from the combination of many factors like geological structure, absolute and relative relief, climate, vegetation cover, drainage texture etc. (Savindra Singh & Srivastava, 1998).

Percentage slope map prepared for the Khandala basin shows very distinct variation throughout the area. Hillocks and hill offshoots exhibit very steep slope and range above 40% whereas pediments and valley floors are characterized by below 10% of slope.

2.2.6 Geomorphological Mapping

This is a mapping technique that is of great value in applied geomorphology. The maps are of use mainly in landuse planning, hydrological engineering, civil engineering, soil surveying and conservation but in fact the range of applications is immense. The maps are also useful in agriculture and forestry. Potential utilization is for soil erosion control, reclamation of destroyed or new areas, soil reclamation, drainage and irrigation. It is an effective way to study landscape. A geomorphic map shows distribution of different surface units. It guides about interpretations of age and genesis of these units where surface unit correspond to underlying rocks or sediments, geomorphic map is useful proxy for a geological Map.

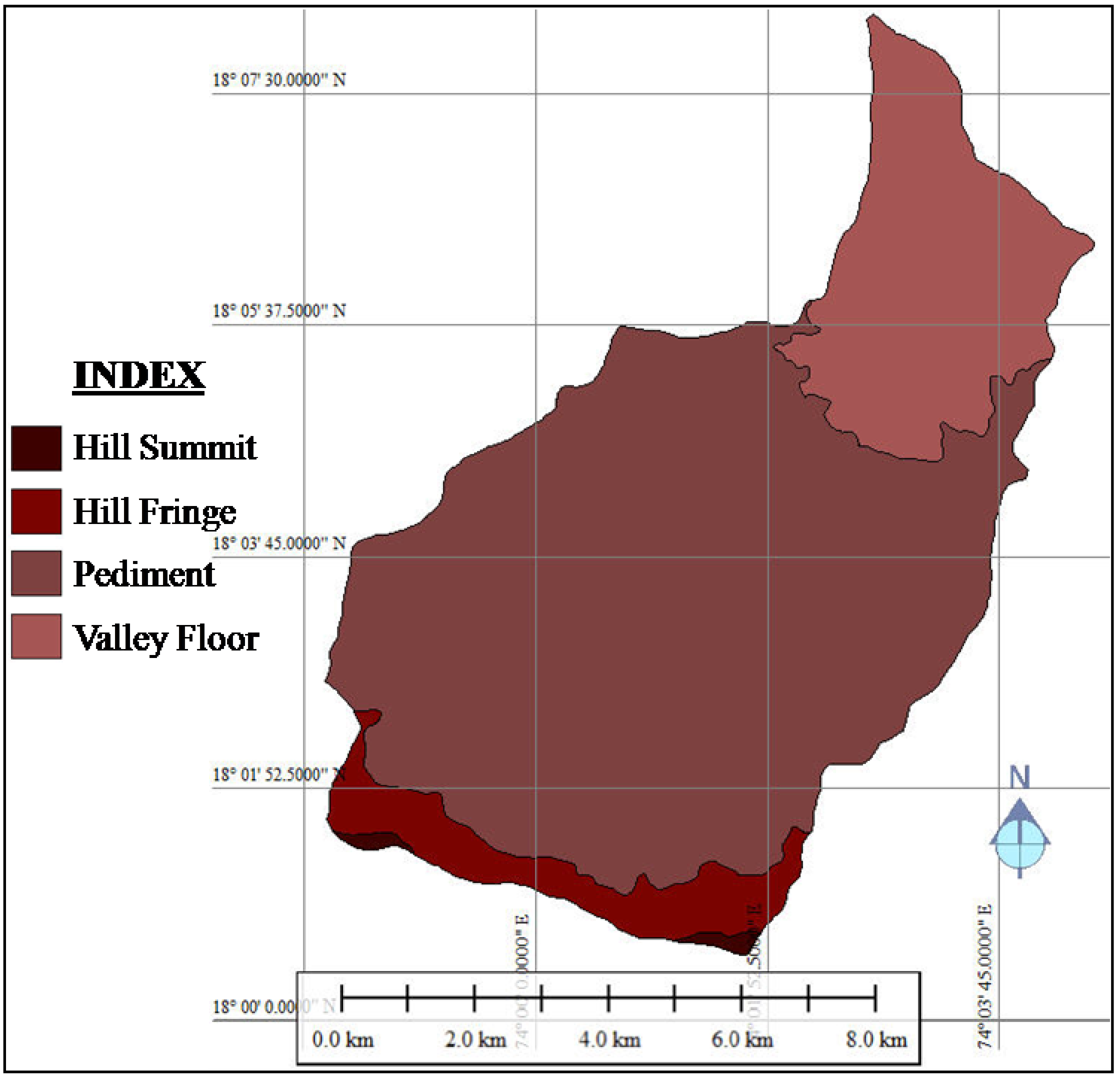

FIG. 2.10 : GEOMORPHOLOGICAL MAP

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3 Database & Methodology

3.1 Database and Methodology

The study of Pedogeomorphic approach for Prioritization of Sub-Watersheds for Conservation Planning of Khandala basin has been taken into consideration in the present study. The sources of data and methods of analysis are as follows

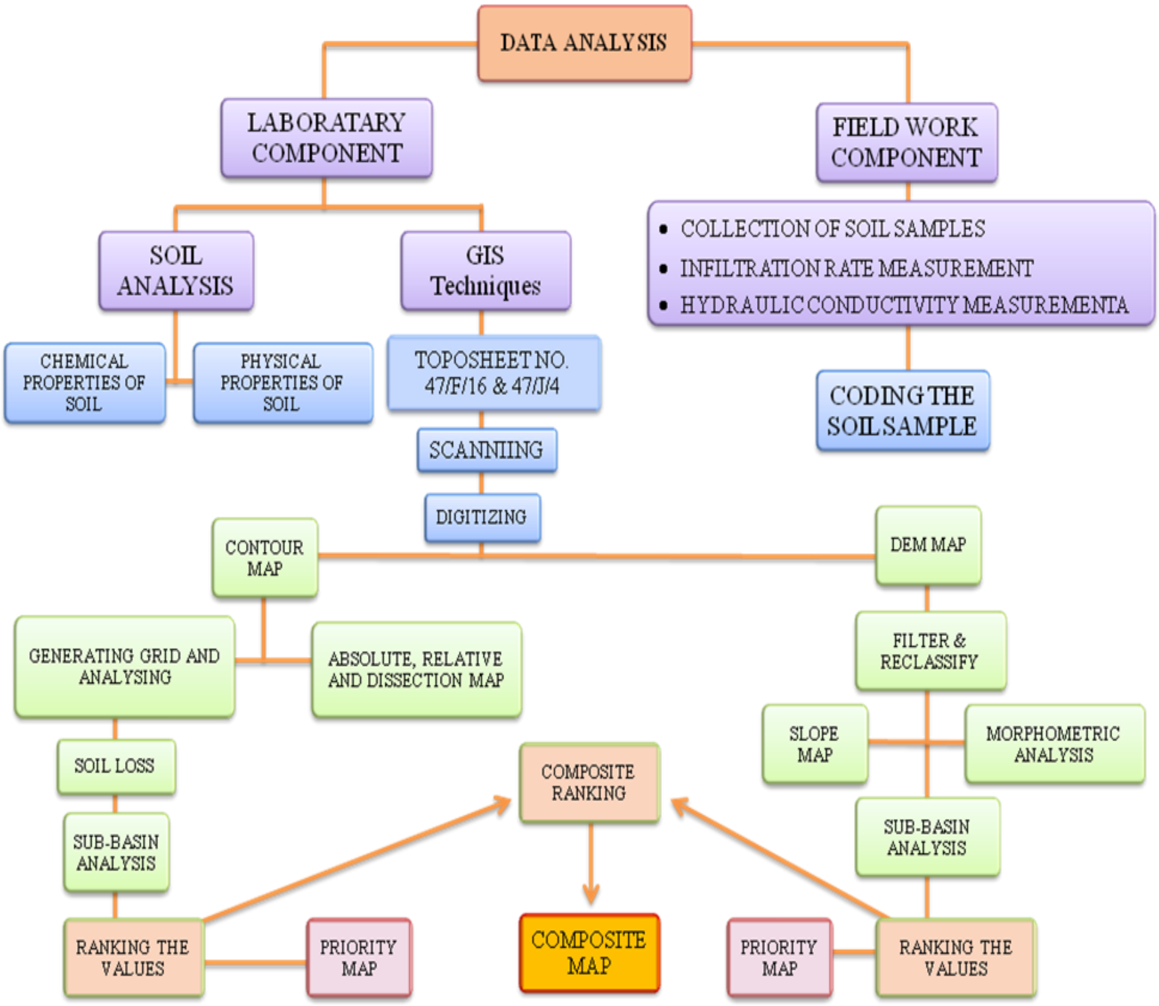

FIG. 3.1: FLOW DIAGRAM OF METHODOLOGY

3.2 Fieldwork Component

Field visit is necessary to understand the actual relief features of study area. The present study area is located in satara district. The first field visit carried out to know about the altitudinal variation, stream flow, settlement, agricultural patterns and some general information is collected by the local people. Khandala basin is the part of Nira river where the water is collected in veer dam. The general information about veer dam and its surrounding is collected and compared with the topographical data and with water resource department.

The second field visit is planned to collect the soil sample and GPS survey to know about the actual soil properties and vegetation cover. In order to collect samples for the present study a detail plan of field work has been prepared, which involves the soil survey at reconnaissance level. A pilot survey was carried out and field work was carried out. Field component has been summarized as below:

1. Soil Sample Collection: The collection of soil samples was done according to variation in slopes using core tube. Soil survey was performed to infer soil's physical & chemical properties and to measure field infiltration rates and hydraulic conductivity of the soil.
2. GPS survey: The entire catchment area was tracked with the help of GPS. The soil sample points were tracked by using GPS.
3. Locating benchmark and spot heights with the help of Global Positioning System (GPS) device and Survey of India (SOI) toposheets.
4. Geomorphological Mapping (Field Mapping): This is done to map the landforms by symbols.

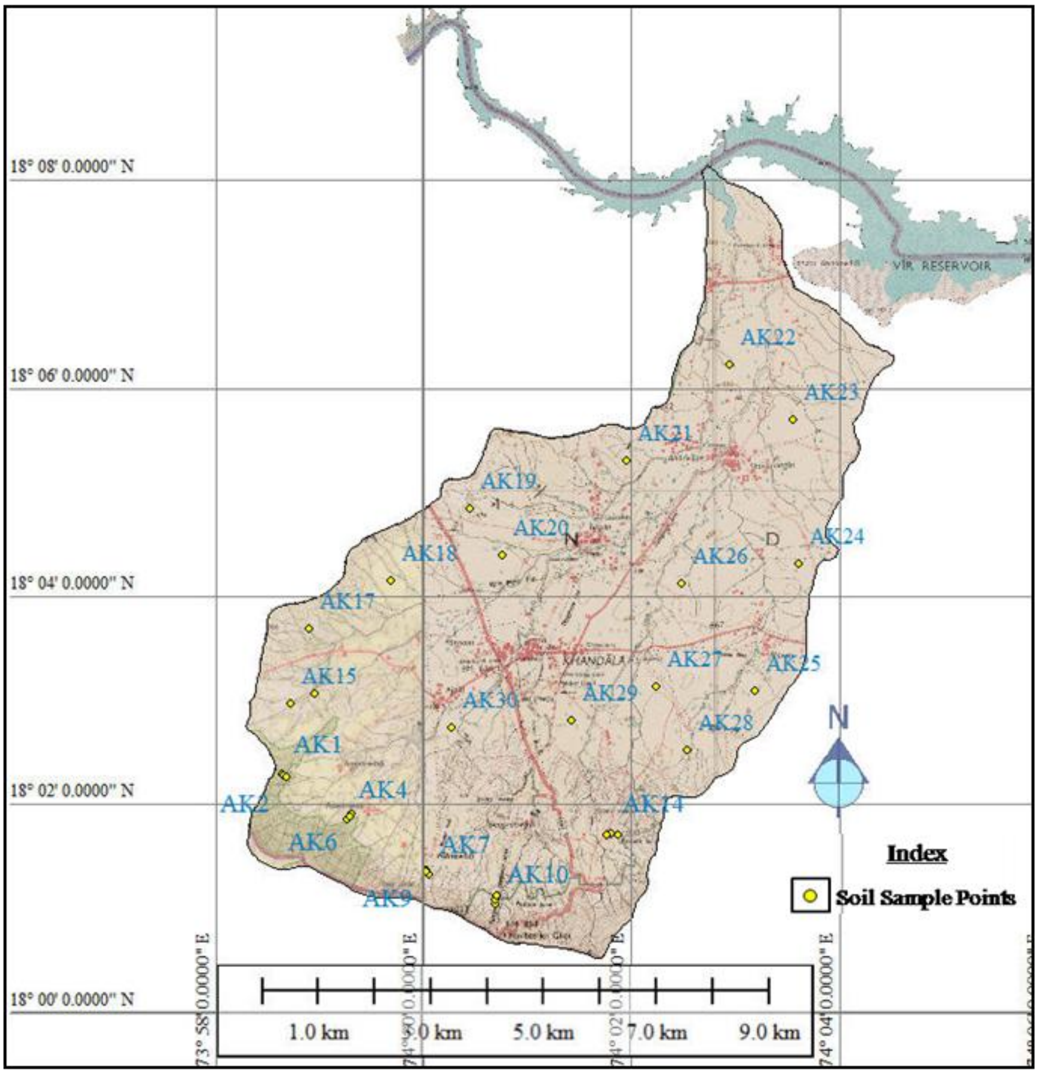

FIG. 3.2 : SOIL SAMPLE LOCATION MAP

3.3 Laboratory Components

Laboratory components for the study included hardware materials like the computer, scanner and printers. Since the nature of the study is Geomorphology-based, the data has been analyzed in the soil lab for various properties of soil such as textural analysis, soil pH, bulk density, specific gravity, electric conductivity, content of nitrogen, phosphorous, potassium and etc. has been analyzed.

3.3.1 Soil analysis

Various methods have been used to determine physical & chemical properties of soil samples. Details of these procedures are outlined in the following lines.

Procedures followed to determine physical properties of soil

i) The Moisture Content:

The % moisture loss is calculated by drying out soil samples in oven at 105°C & it is reweighed.

ii) Textural Analysis:

Osborne's Beaker method has been used to separate soil particles from each other & to determine % proportion of soil fraction, such as coarse sand, fine sand, silt & clay. The coarse sand is obtained by rubbing the sample on 1.18 mm sieve. 10 gm portion of this soil is mixed with 20ml H_2O_2, 10ml of water & 10 ml of 1 N, the solution is washed through 0.2 mm sieve. The residue is dried in the oven & acquired as coarse sand.

Fine sand formation has been determined using setting velocity time 10cm column (4 min. 48 se.). The decantation is repeated thrice. Osborne's Beaker method has been slightly modified to determine of silt & clay. Fraction is treated with NaOH (1 N.) & IN HCL to disassociate clay fractions from the sample 21 min 54 sec. is the setting velocity time for silt has been observed. The material is transferred to porcelain dish, dried in oven & weighed.

Percentage has been calculated accordingly.

$$\text{\% of Coarse Sand} = \frac{\text{Weight of Coarse sand}}{\text{Weight of Soil taken}} \times 100$$

$$\% \text{ of Fine Sand} = \frac{\text{Weight of Fine sand}}{\text{Weight of Soil taken}} \times 100$$

$$\% \text{ of Silt} = \frac{\text{Weight of Silt sand}}{\text{Weight of Soil taken}} \times 100$$

$$\% \text{ of Clay} = 100 - (\% \text{ of Coarse Sand} + \% \text{ of Fine Sand} + \% \text{ of Silt})$$

iii) Soil pH:

The potential developed in a system is measured to scale with help of pH meter (1: 5 soil water ratio). Soil below pH 7.0 is acidic and above pH 7.0 is alkaline pH 7.0 is supposed to be neutral. Soil falling between pH 6.5 to 8.0 is generally suitable for most of the common crops. If the soil is highly acidic (soil with pH less than 5.0)

Table 3.1: pH distribution Table

pH	Description
4.0	Intensely Acidic
4.5	Very Strongly Acidic
5.0	Strongly Acidic
5.5	Medium Acidic
6.0	Slightly Acidic
6.5	Very Slightly Acidic
7.0	Neutral
7.5	Slightly Alkaline
8.0	Medium Alkaline
8.5	Strongly Alkaline
9.0	Very Strongly Alkaline
9.5	Intensely Alkaline
10.0	Very Intensely Alkaline

(Source: Soil Kit Chart from Soil Lab)

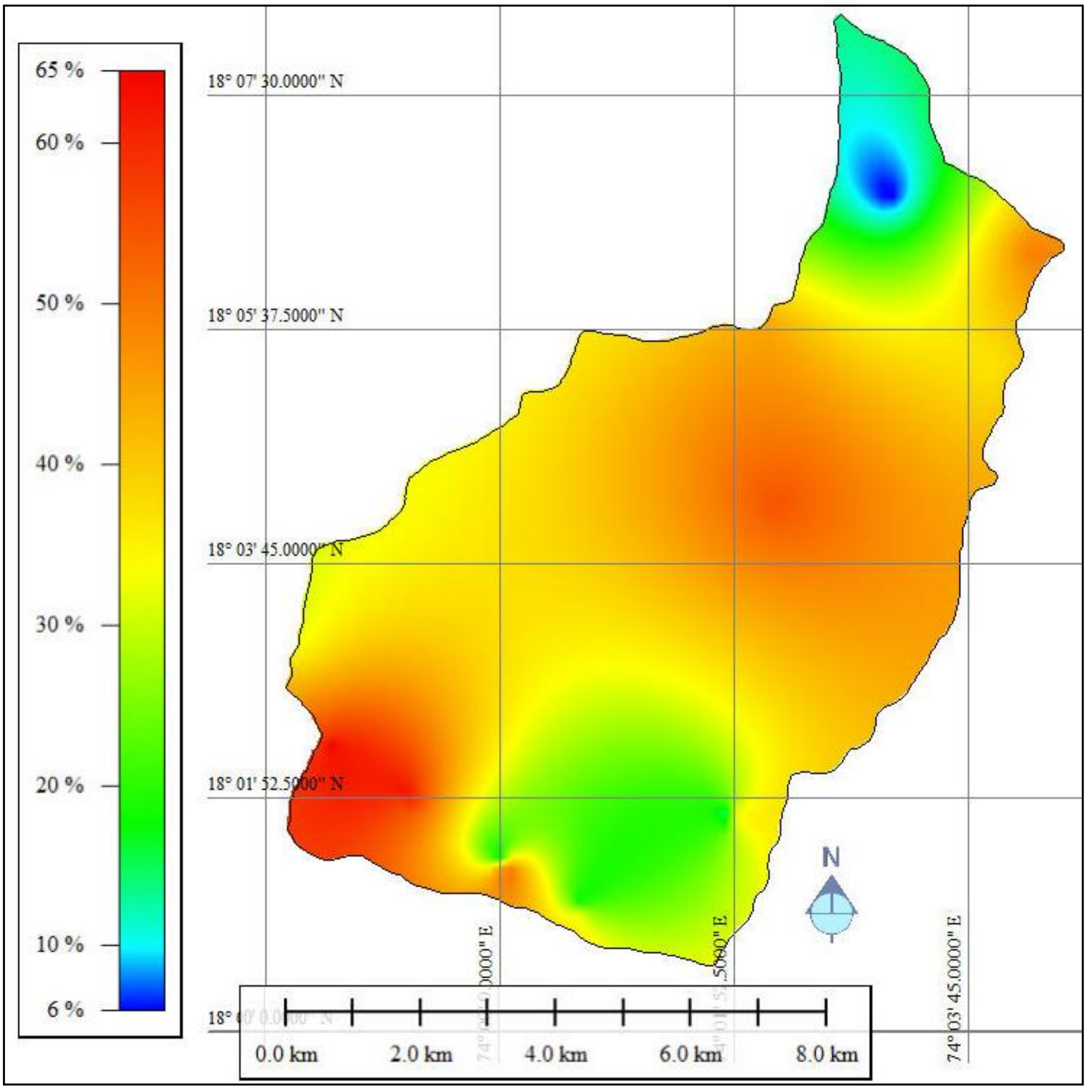

FIG 3.3 : PERCENTAGE OF COARSE SAND DISTRIBUTION

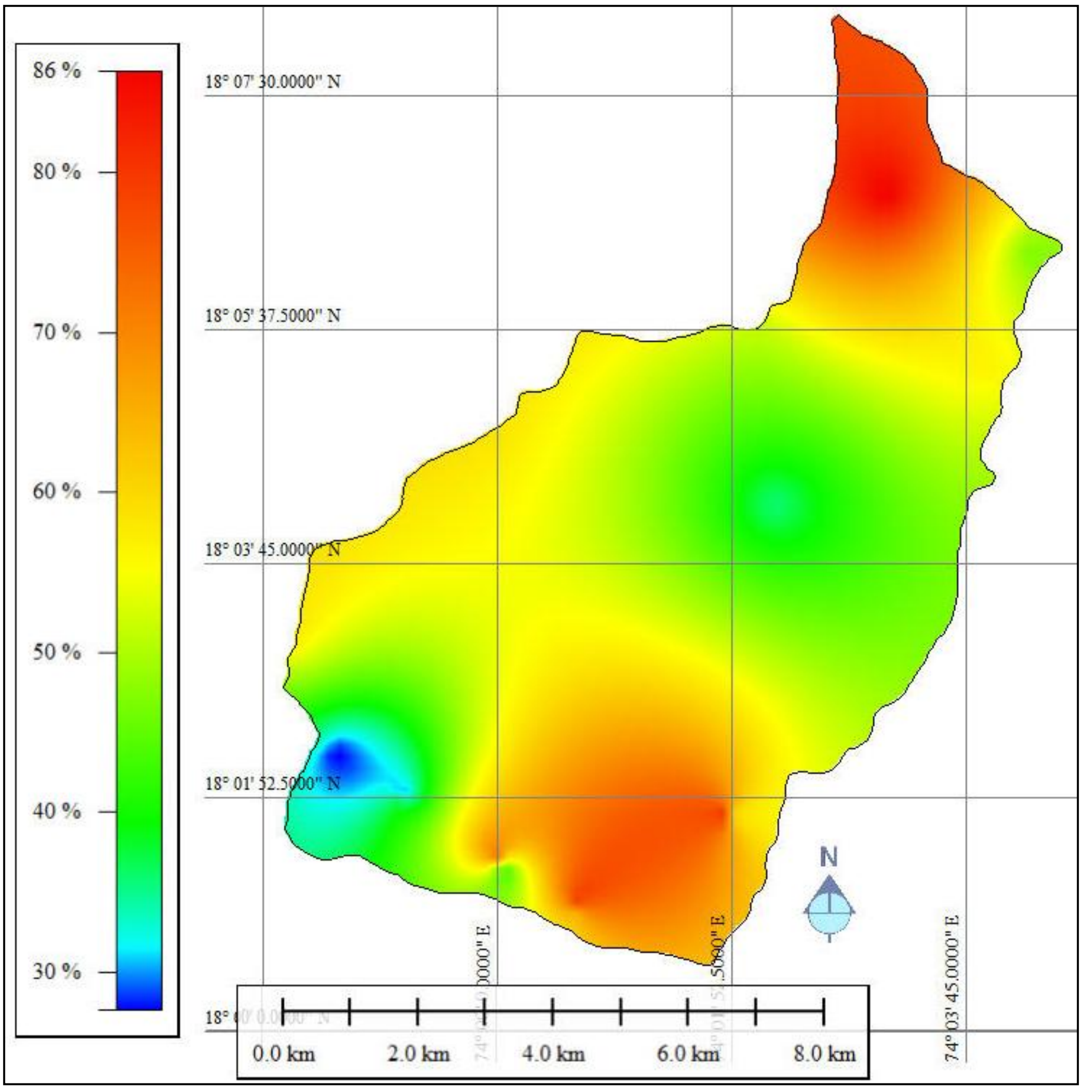

FIG 3.4 : PERCENTAGE OF FINE SAND DISTRIBUTION

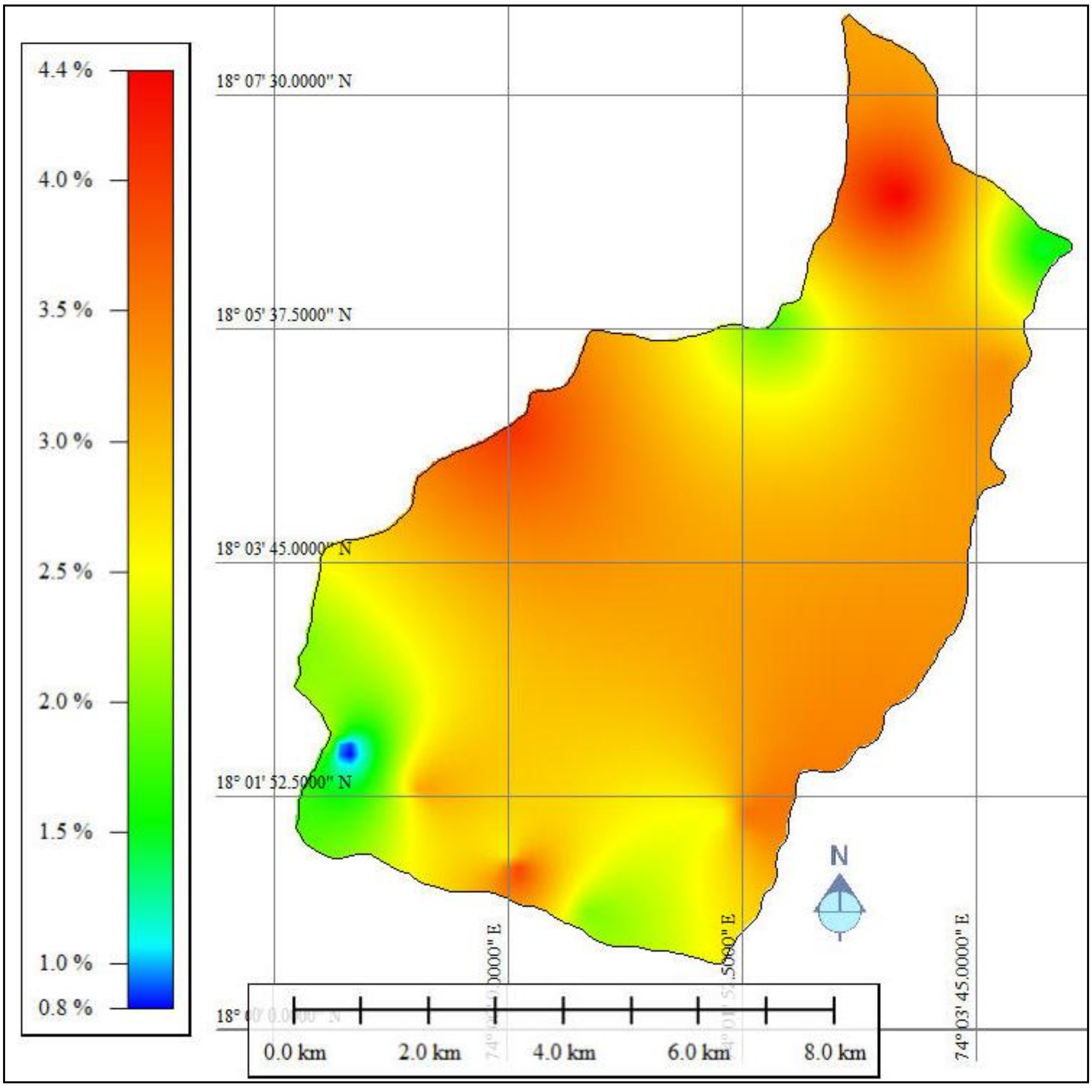

FIG 3.5 : PERCENTAGE OF SILT SAND DISTRIBUTION

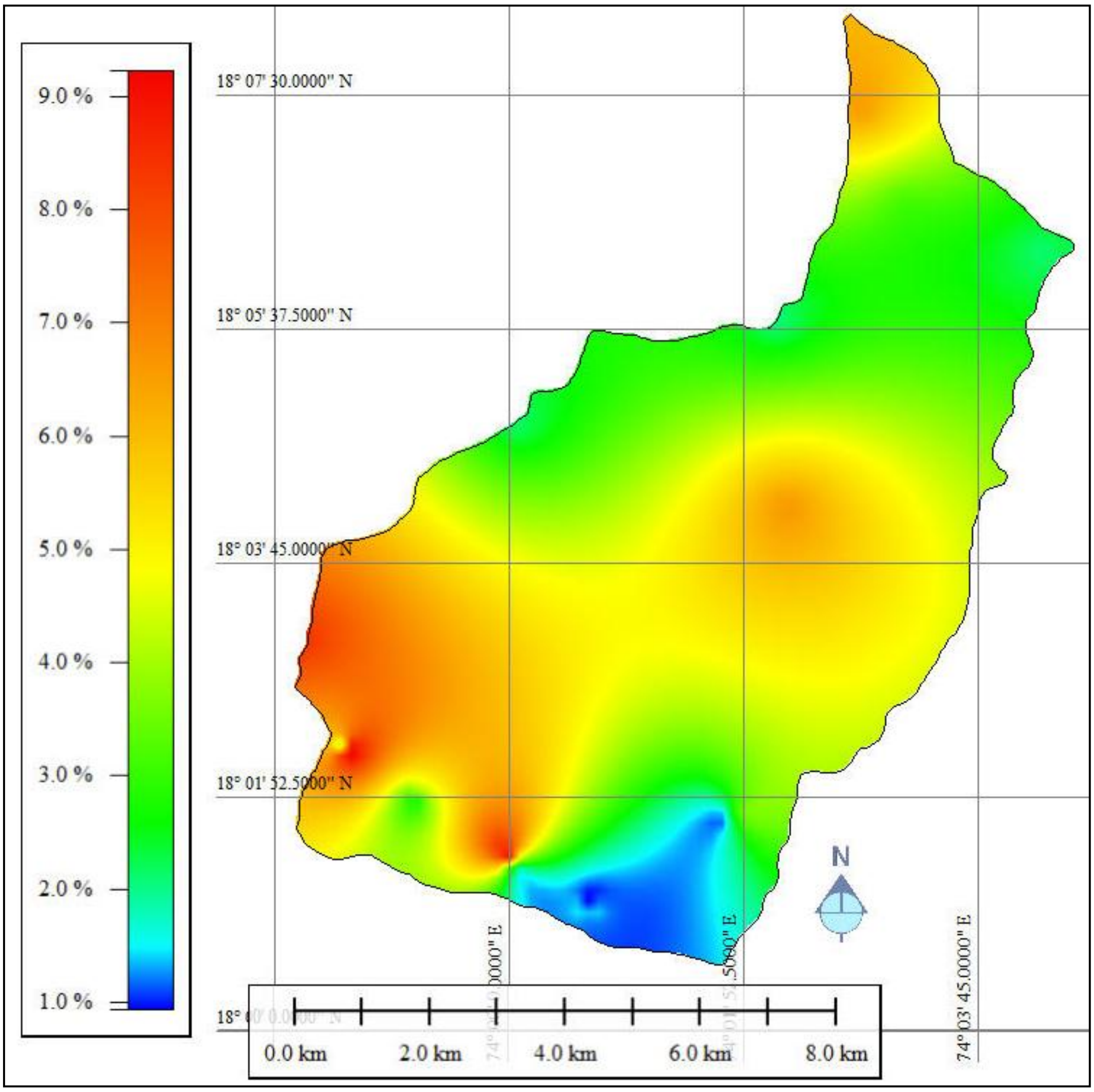

FIG 3.6 : PERCENTAGE OF CLAY SAND DISTRIBUTION

iv) Determination of Organic Matter and Organic Carbon:

Organic matter present in the soil is digested with excess of potassium dichromate and H_2SO_4 residue. Unutilized dichromate is then titrated with ferrous ammonium sulphate. The elementary carbon present as graphite or charcoal is not obtained by this method only organic carbon is determined. Recovery of carbon in this method is not 100 % only about 60% – 90% of total organic matter is recovered depending upon the kind.

$$\% \text{ of Carbon} = \frac{3.951}{W}\left[1 - \frac{T}{S}\right]$$

Where W = Weight of soil taken,

T = mean reading of particular soil sample

S = mean reading of blank titration

% of Organic Matter = % of Carbon × 1.724

v) Determination of NPK:

The proper time to take a sample is that before the fertilizer is applied. The fertility level of a field is not constant throughout the year. During the rapid plant growth, high percentage of available nutrients (as N, P and K) will be in the plant and not in the soil. To estimate pre-plant fertilizer needs, samples should be taken during the early stages of seed bed preparation. The best time for taking samples is before sowing. If the soil sample is wet, the soil must be air dried under shade before testing.

Table 3.2: Table for Nitrogen in Soil (N)

Amount of available Nitrogen in soil		Approximate quantity of available Nitrogen present in Kg/ Acre
Low (< 100 Kg. / Acre)	L_1	25 Kg. / Acre
	L_2	80 Kg. / Acre
Medium (100 – 200 Kg. / Acre)	M_1	125 Kg. / Acre
	M_2	175 Kg. / Acre
High (> 200 Kg. / Acre)	H_1	225 Kg. / Acre
	H_2	300 Kg. / Acre

Table 3.3: Table for Phosphorous in Soil (P)

Amount of available Phosphorous in soil		Approximate quantity of available Phosphorous present in Kg/ Acre
Low (< 10 Kg. / Acre)	L_1	2 Kg. / Acre
	L_2	8 Kg. / Acre
Medium (10 – 20 Kg. / Acre)	M_1	11 Kg. / Acre
	M_2	18 Kg. / Acre
High (> 20 Kg. / Acre)	H_1	22 Kg. / Acre
	H_2	25 Kg. / Acre

Table 3.4: Table for Potassium in Soil (K)

Amount of available Potassium in soil		Approximate quantity of available Potassium present in Kg/ Acre
Low (< 50 Kg. / Acre)	L_1	20 Kg. / Acre
	L_2	40 Kg. / Acre
Medium (50 – 120 Kg. / Acre)	M_1	60 Kg. / Acre
	M_2	120 Kg. / Acre
High (> 120 Kg. / Acre)	H_1	150 Kg. / Acre
	H_2	200 Kg. / Acre

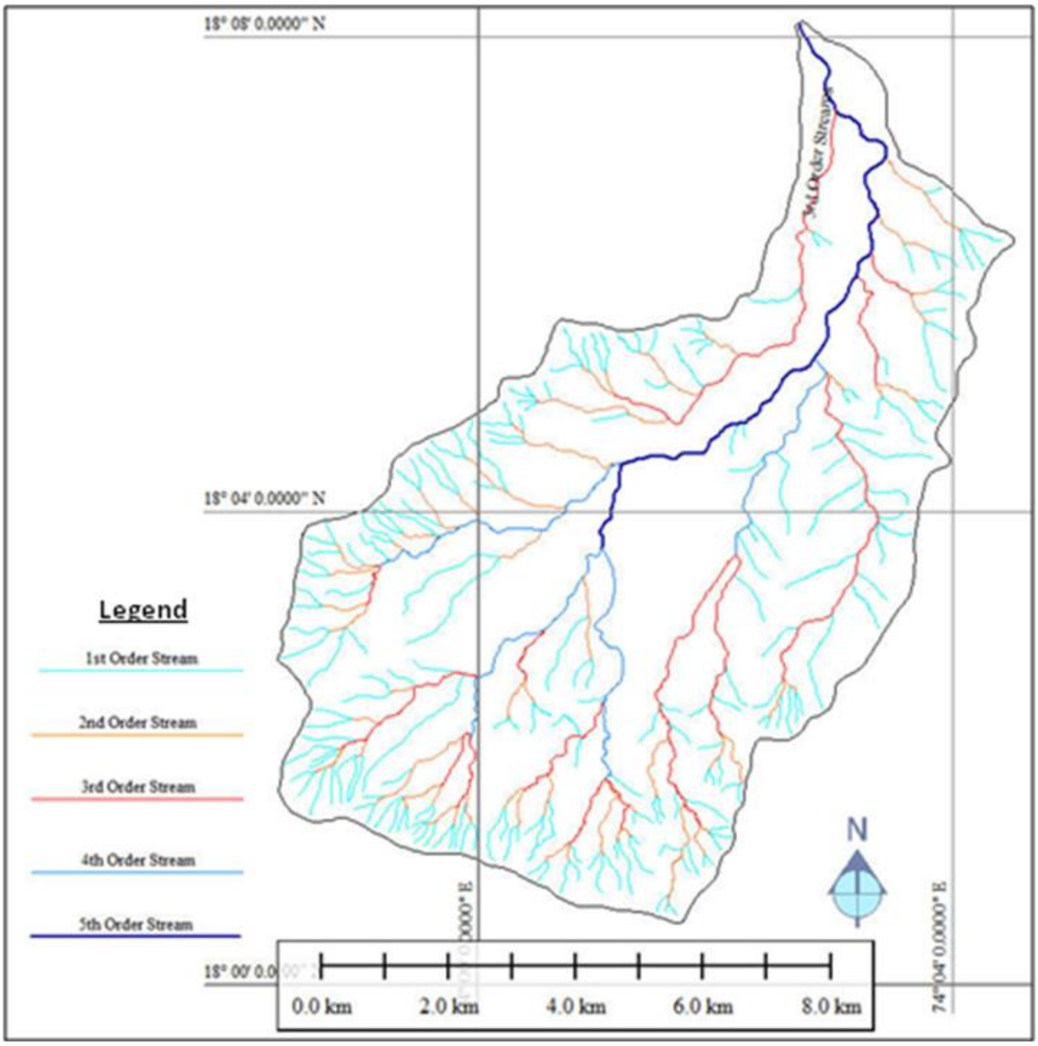

FIG. 3.7: STREAM ORDER MAP OF STUDY AREA

(A. N. STRAHLER METHOD)

The soil data has been processed into GIS software and various maps have been prepared. The steps involved are as follows:

- Raster Map Creation /Scanning
- Geometric Transformation / Georeferencing
- Digitization
- Analysis and results

3.3.2 Raster Map Creation / Scanning

Scanning is a digitizing method that converts an analog map into a scanned file, which is converted back to vector format through tracing (Verbyla and Chang 1997). Scanning converts the map into a binary scanned file in raster format.

The toposheets of the study area have been scanned and analyzed with the help of software, which gives the raster format file. The raster file helps in the digitizing the contours, streams and the area.

3.3.3 Geometric Transformation/Georeferencing

Georeferencing is the process of converting a digital map or an image from one coordinate system to another, using a set of control points and transformation equations (Chang, 2002). In the present study, four control points (Ground Control Points) with known longitude and latitude values were digitized. Georeferencing was carried out in Global Mapper. DIVA GIS software was used to convert degrees – minutes – seconds into degrees – decimal units.

All the toposheets are georeferenced and further used for obtaining different maps. The google earth image and toposheets are superimposed on one another, the google earth image gives the actual view of study area. Google earth image gives the aerial view of area which helps in the identifying the hills, plains, water bodies and transport network.

3.3.4 Digitization

The process involves the conversion of Raster data into Vector format. In the present study, various entities like watershed boundary, streams of various orders, etc. were digitized on separate layers. The every contour has been digitized and given the respective altitudinal value to the contour, which helps to generate the relief map. The relief map has been compared with aster data, which gives the clear idea about the altitudinal variation in the study area. The streams are also digitized which helps to know about the flow of water. The relief and streams together gives the ideal of soil sampling on the field.

The proper digitization helps in preparing the various maps, which are required for analysis. For digitization the software used was Global Mapper.

3.3.5 Morphometric Analysis

The Khandala watershed is divided into eleven sub-watersheds with codes KD1 to KD11. Morphometric parameters like stream order, stream length, bifurcation ratio, drainage density, drainage frequency, relief ratio, elongation ratio, circularity ratio and compactness constant are calculated. Prioritization rating of all the eleven sub-watersheds of khandala watershed is carried out by calculating the compound parameter values. The sub-watershed with the lowest compound parameter value is given the highest priority.

3.3.6 Relief Analysis

Contour map, TIN (Triangular Irregular Network) and DEM (Digital Elevation Model) Maps were prepared in Global Mapper Software. Slope map (percentage) was also prepared in Global Mapper Software. Absolute Relief, Relative Relief and Dissection Index maps were prepared in Surfer Software.

3.3.7 Preparation of Thematic Maps:

A thematic map shows the spatial distribution of one or more specific data themes for selected geographic areas. A thematic map focuses on the spatial variability of a specific distribution or theme, whereas a reference map focuses on the location and names of features. Thematic maps normally include some location or reference information, such as place names or major water bodies, to help map readers familiarize themselves with the geographic area covered on the map.

Various thematic maps have been prepared in Surfer Software by the technique of spatial interpolation.

3.3.8 Soil Loss Estimation using STEHLIK'S equation:

The soil loss has been estimated by using soil parameters and relief parameters. The collected soil samples have been analyzed in the soil lab. The various physical and chemical properties of soil have been obtained and various map haven been prepared. The Land Use and Land Cover map has been prepared with the help of Google Earth Image, Toposheet and Satellite Image. The Land Use and Land Cover map help to know about the vegetation cover and agricultural patterns.

Various soil and relief parameters help to obtain total soil loss of study area. The output map helps to understand the major area of soil loss in the study area. In the present study area, soil loss has been estimated by using Stehlik's equation which gives the clear idea about the major soil loss area.

The annual rate of soil erosion was calculated by using the Stehlik's equation:

$$X = D*G*P*S*L*O$$

Where,

X = The mean annual soil loss

D = The climatic factor expressed in terms of precipitation

G = The petrological factor

P = The erodibility of the soil

S = The slope steepness

L = The slope length factor

O = The vegetation factor

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4 Basin Morphometry and Soil Characteristics

4.1 Introduction

Knowledge of hydro-geomorphology is important for planning and management activities. The study of geomorphic parameters and hydrological characteristics of the basin is important to understand the hydrologic characteristics of the different basins. The important geomorphic properties have to be quantified first from the available topographical map of the basin. Hence, the quantitative analysis of drainage networks is very useful for determination of the hydraulic properties of the basin, delineation of the drainage basin, extraction of stream orders, hydrological length, etc was performed in Global Mapper Version 12.00 and BASIN 4 software.

4.2 Basin Morphometry

In the present study, Morphometric characteristics have been considered for prioritization of sub- basin. The digitization of drainage pattern was carried out with the help of GIS software. The stream ordering using Strahler's method is used in the present study. The fundamental parameters namely: stream length, number of streams, perimeter, area and length of basin are derived from the drainage layer. Morphometric analysis using manual methods i.e. measurement of area using dot grid method or by planimeter and measurement of length using curvimeter or roltameter are time consuming. On higher scale map like 1:50,000It is more difficult. The ordering, lengths, area, perimeter etc can be easily estimated using Geographic Information System (GIS) technique. Use of GIS helps to make the task comparatively easier and also accurate as well. To quantify the various geomorphological parameters of watershed, the digitized drainage and interpolated contours maps were used. Important parameters thus derived by GIS analysis are listed in Table 3.

Drainage information for this map has been derived from SOI toposheet 47/J/4 and 47/F/16. The drainage pattern present in SOI topographic sheet was digitized. A drainage map of Khandala watershed was prepared. In this watershed, various streams forming a dendritic pattern are present. Drainage pattern is characterized by different tributaries in different directions.

The watershed is divided into eleven sub-watersheds with codes AK1 to AK11. Morphometric parameters like stream order, length of stream, bifurcation ratio, drainage density, frequency, relief, elongation ratio, circularity ratio and compactness constant are calculated. The geomorphological parameters are important for the hydrological studies that consist of aerial, linear and relief parameters of the watersheds.

The morphometric aspects of the channel system are stream order, stream length and stream frequency, drainage texture, mean bifurcation ratio, drainage density, form factor, circulatory ratio, length of overland flow, Basin Slope.

Stream order : The Khandala river is a 5^{th} order stream covering an area of 76.018 sq km. The variation in stream order and area of the sub-basins are considered due to physiographical and structural aspect of the region.

Stream length : The stream length is determined by computing the length of streams in the basin of study area. The number of stream in sub basins is calculated with the different methods. The GIS techniques is used to calculate the stream length of study area, The Khandala watershed is having 11 sub-basins. In General, length of stream segments decrease as the stream order increase.

Stream Length ratio : According to the stream length law the mean stream length segments of each orders in the basin tends to geometric series with stream length which is increasing towards higher stream orders. The stream length ratio between different sub-basins shows an increasing trend in stream length ratio from lower order to higher order representing the nature of geomorphic stage in sub-basin.

Stream Frequency : The stream frequencies of all the sub-watersheds are mentioned in Table 4.1. High value of drainage frequency in sub-watersheds from 3 to 11 produces more runoff in comparison with 1 and 2.

Drainage Texture :

The drainage texture represents the different aspects of study area such as natural factors which includes climate, rainfall, vegetation, rock and soil, infiltration capacity, relief etc. The analysis of all the aspects of study area is important to know the drainage texture of study area. The amount of soil includes the rate of surface runoff which affects the drainage texture of an area. The soft or weak rocks produce a fine texture, whereas massive and resistant rocks cause coarse texture. The texture of the rock is depends on type of vegetation and climate. So it is necessary to obtain the different data collection of study area.

Drainage Texture can be calculated by formula

$$Rt = \frac{Nu}{P}$$

Where Nu = Total no. of stream segments of order u

P = Perimeter (km)

Table 4.1 : Drainage Texture Analysis

Name of Sub-basins	Sub-basin Code	Rt
KD1	1 order_1	0.63898
KD2	1 order_2	0.56561
KD3	2 order_1	0.2388
KD4	2 order_2	0.38425
KD5	3 order_1	0.47728
KD6	3 order_2	0.33837
KD7	3 order_3	0.33446
KD8	4 order_1	0.96834
KD9	4 order_2	0.65495
KD10	4 order_3	0.97515
KD11	4 order_4	0.78783

Mean Bifurcation Ratio :

Bifurcation Ratio is the ratio of number of stream segments of one order to the number of the next higher order.

$$Rb = \frac{Nu}{Nu + 1}$$

$$Rbm = \text{Average Rb of all orders}$$

Where Rb = Bifurcation Ratio

Nu = Total no. of stream segments of order u

Nu + 1 = Number of segments of the next higher order

Table 4.2 : Mean bifurcatin ratio

Name of Sub-basins	Sub-basin Code	Rbm
KD1	1 order_1	0
KD2	1 order_2	1
KD3	2 order_1	0.75
KD4	2 order_2	1.5
KD5	3 order_1	1.05556
KD6	3 order_2	1.38889
KD7	3 order_3	1.38889
KD8	4 order_1	1.38889
KD9	4 order_2	1.22917
KD10	4 order_3	1.47917
KD11	4 order_4	1.47917

Drainage Density :

Drainage Density is the element of drainage analysis which gives a good quantitative results for dissection analysis. It is the part of climate, lithology, structures and relief history of the region and can ultimately has been used as an indicator to express these variables and also the landform of morphogenesis. Drainage density is determined as the total streams length of all orders to total drainage area. The drainage density indicates a quantitative measure of the average length of the overland flow which gives at least some idea of the drainage efficiency of the low drainage density generally gives highly resistant areas or permeable of sub soil, thick vegetation and low height. Drainage density is high which is the result of weak sub surface material. Low density leads to coarse drainage texture while high drainage density determines fine drainage texture. The low drainage density indicates higher infiltration and wells in study area are having good water potential leads to high specific capacity. In the high drainage density areas the infiltration is less and surface runoff is more.

$$D = \frac{Lu}{A}$$

Where Lu = Total stream length of order u

A = Area of the Basin (km^2)

Table 4.3 : Drainage Density

Name of Sub-basins	Sub-basin Code	D
KD1	1 order_1	3.17698
KD2	1 order_2	4.10189
KD3	2 order_1	1.33021
KD4	2 order_2	1.81829
KD5	3 order_1	1.06812
KD6	3 order_2	1.1637
KD7	3 order_3	1.25542
KD8	4 order_1	1.19688
KD9	4 order_2	1.41072
KD10	4 order_3	1.49605
KD11	4 order_4	1.19623

Stream Frequency :

A measure of topographic texture expressed as the ratio of the number of streams in a drainage basin to the area of the basin. It is also known as channel frequency.

$$Fs = \frac{Nu}{A}$$

Where Nu = Total no. of stream segments of order u

A = Area of the Basin (km^2)

Table 4.4 : Stream Frequency

Name of Sub-basins	Sub-basin Code	Fs
KD1	1 order_1	14.8298
KD2	1 order_2	8.45401
KD3	2 order_1	1.7203
KD4	2 order_2	3.0822
KD5	3 order_1	1.39072
KD6	3 order_2	1.93122
KD7	3 order_3	1.80108
KD8	4 order_1	1.6105
KD9	4 order_2	2.06472
KD10	4 order_3	2.11212
KD11	4 order_4	1.49309

Form Factor :

Form Factor indicates the analysis of basin area and basin length.

$$Rf = \frac{A}{Lb^2}$$

Where A = Area of the Basin (km^2)

Lb^2 = Basin length

Table 4.5 : Form Factor

Name of Sub-basins	Sub-basin Code	Rf
KD1	1 order_1	0.02753
KD2	1 order_2	0.03784
KD3	2 order_1	0.01326
KD4	2 order_2	0.02395
KD5	3 order_1	0.10154
KD6	3 order_2	0.02223
KD7	3 order_3	0.02329
KD8	4 order_1	0.02531
KD9	4 order_2	0.02187
KD10	4 order_3	0.02905
KD11	4 order_4	0.03393

Circulatory Ratio :

Circulatory ratio is the significant ratio which indicates the stage of dissection in the study region.

$$Rc = \frac{4\pi A}{P^2}$$

Where A = Area of the Basin (km^2)

P = Perimeter (km)

π = 3.14

Table 4.6 : Circulatory Ratio

Name of Sub-basins	Sub-basin Code	Rc
KD1	1 order_1	0.3458
KD2	1 order_2	0.47529
KD3	2 order_1	0.16654
KD4	2 order_2	0.30083
KD5	3 order_1	0.20573
KD6	3 order_2	0.27923
KD7	3 order_3	0.29254
KD8	4 order_1	0.31795
KD9	4 order_2	0.27467
KD10	4 order_3	0.36482
KD11	4 order_4	0.42622

Length of Overland Flow :

Length of overland flow is the ratio of Drainage density of study area.

$$Lg = \frac{1}{D \times 2}$$

Where D = Drainage Density

Table 4.7 : Length of Overland Flow

Name of Sub-basins	Sub-basin Code	Lg
KD1	1 order_1	1.58849
KD2	1 order_2	2.05094
KD3	2 order_1	0.66511
KD4	2 order_2	0.90914
KD5	3 order_1	0.53406
KD6	3 order_2	0.58185
KD7	3 order_3	0.62771
KD8	4 order_1	0.59844
KD9	4 order_2	0.70536
KD10	4 order_3	0.74803
KD11	4 order_4	0.59811

Basin Slope :

Basin slope is the ratio of basin relief to the basin length in present study area.

$$Bs = \frac{Br}{Bl}$$

Where Br = Basin relief in m

Bl = Basin length in m

Table 4.8 : Basin Slope

Name of Sub-basins	Sub-basin Code	Bs
KD1	1 order_1	0.00447
KD2	1 order_2	0.00509
KD3	2 order_1	0.00392
KD4	2 order_2	0.00365
KD5	3 order_1	0.0164
KD6	3 order_2	0.00431
KD7	3 order_3	0.00564
KD8	4 order_1	0.02631
KD9	4 order_2	0.03819
KD10	4 order_3	0.03743
KD11	4 order_4	0.01762

Table 4.9 : Formulae for computation of morphometric parameters

Parameter	Formula
Stream Order	Hierarchical rank
Mean Stream Length (Lsm)	Lsm = Lu ÷ Nu Where Lu = Total stream length of order u Nu = Total no. of stream segments of order u
Stream Length Ratio (RL)	RL = Lu ÷ Lu-l Where Lu = Total stream length of order u
Drainage Texture (Rt)	Rt = Nu ÷ P Where Nu = Total no. of stream segments of order u P = Perimeter (km)
Drainage Density (D)	D = Lu ÷ A Where Lu = Total stream length of order u A = Area of the Basin (km2)
Length of Over land flow (Lg)	Lg = 1 ÷ (D × 2) Where D = Drainage Density
Bifurcation Ratio (Rb)	Rb = Nu ÷ Nu+l Where Nu = Total no. of stream segments of order u Nu+l = Number of segments of the next higher order
Basin length (Lb)	$Lb = 1.312 \times A^{0.568}$ Where A = Area of the Basin (km^2)
Relief Ratio (Rh)	Rh = H ÷ Lb Where H = Total Relative relief of the basin in kilometer. Lb = Basin length
Elongation Ratio (Re)	$Re = (2/Lb) \times (A/P\,i\,)^{0.5}$ Where A = Area of the basin Pi = Pi' value i.e. 3.14
Mean bifurcation ratio (Rbm)	Rbm = Average Rb of all orders
Stream Frequency (Fs)	Fs = Nu ÷ A Where Nu = Total no. of stream segments of order u
Form Factor (Rf)	$Rf = A \div Lb^2$ Where A = Area of the basin Lb = Basin length

Parameter	Formula
Circularity Ratio (Rc)	$Rc = 4 \times Pi \times A/P^2$ Where Pi = Pi' value i.e. 3.14 A = Area of the basin P = Perimeter (km)
Compactness Coefficient (Cc)	$Cc = 0.2821P \div A^{0.5}$ Where P = Perimeter (km) A = Area of the basin
Shape factor (Bs)	$Bs = Lb^2 \div A$ Where Lb = Basin length A = Area of the basin
Texture ratio (T)	$T = N1 \div P$ Where N1 = Total no of first order streams P = Perimeter (km)

4.3 Hydrological Characteristics

4.3.1 Infiltration Capacity of the Soil

Infiltration rate refers to the volume (flux) of water per unit area that enters the soil per unit time. It arises in time during any single precipitation event, typically decreasing significantly as the soil ‘wets up’. If precipitation continues long enough, the infiltration rate will become constant (steady state).

As long as the precipitation enters the soil, no overland flow will occur. If the infiltration rate becomes lower than the precipitation rate, free water will accumulate on the soil surface. Surface storage or depression storage refers to the amount of water that can be held at soil surface before overland flow occurs. Roughly tilled fields can hold considerable amount of water in small depressions, while a smooth soil surface will cause overland flow as soon as the precipitation rate exceeds the infiltration rate.

The infiltration behavior of soils depends to a great extent on the soil type. In general, coarse – textured gravels and sands have higher infiltration capacity than fine textural clays. While infiltration into most gravely or sandy soils will occur through pores, in case of fine textured clays and loam which is depend on aggregation to level the high infiltration rates.

In the study area, field experiments of infiltration rate measurements have been carried out using core tubes. Core tubes were inserted at the depth of 5 cm, water was added to the level of constant water head mark and then rate of water loss from the core tube was measured after 2 minutes interval, then applying the following formula, infiltration rates were calculated.

$$\text{Infiltration Capacity} = \frac{\Delta Q}{\Delta A} \times \Delta T$$

Where,

ΔQ is the change in volume of water in cylinder during time ΔT

(ΔQ = volume: $\pi r^2 h$)

ΔA is cross sectional area of the cylinder ($\Delta A = \pi r^2$)

T = Time

4.3.2 Hydraulic Conductivity :

Spatial patterns and variations of different attributes relating to landform, land use, wasteland and their spatial association are brought out in the study.

Chart I : Hydraulic Conductivity

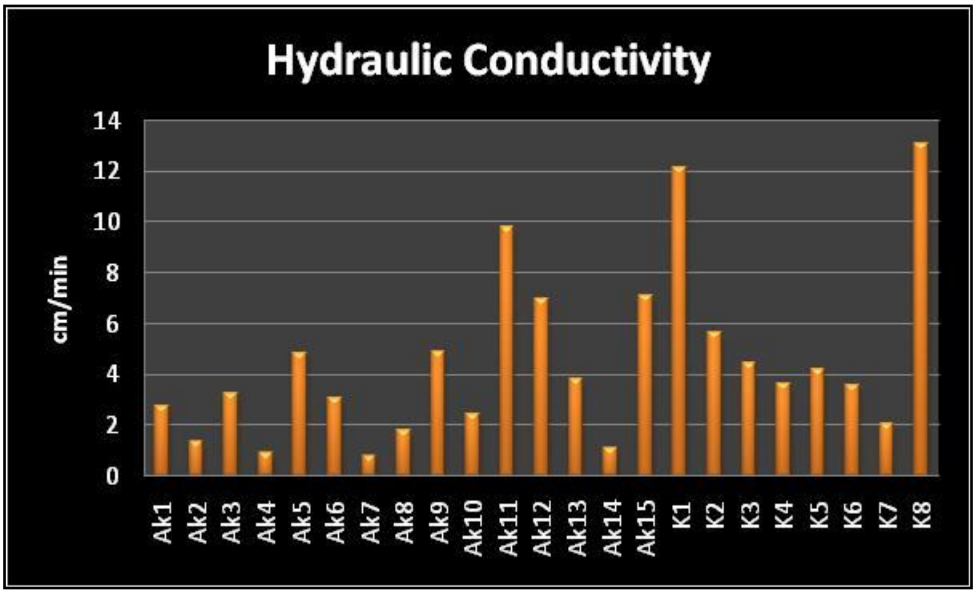
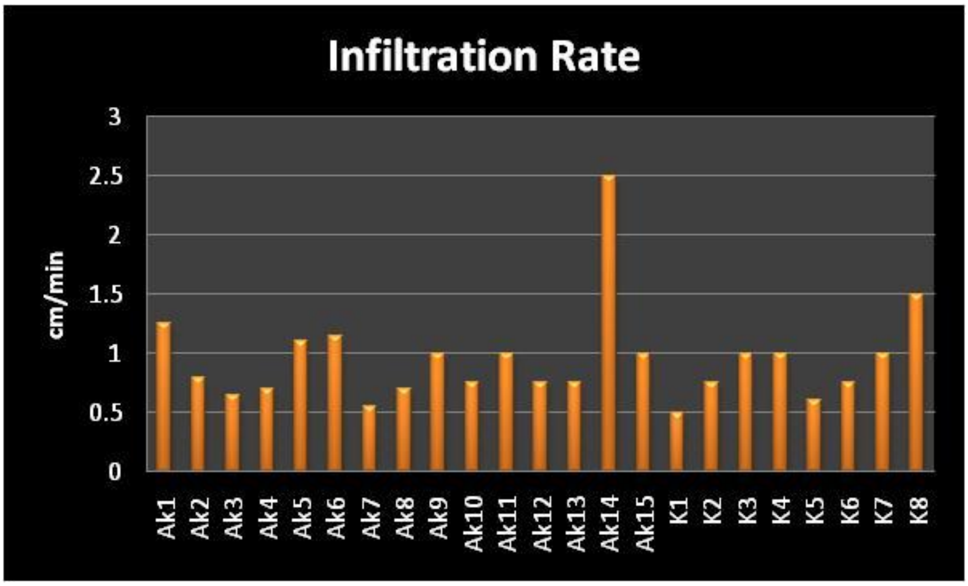


Chart II : Infiltration Rate



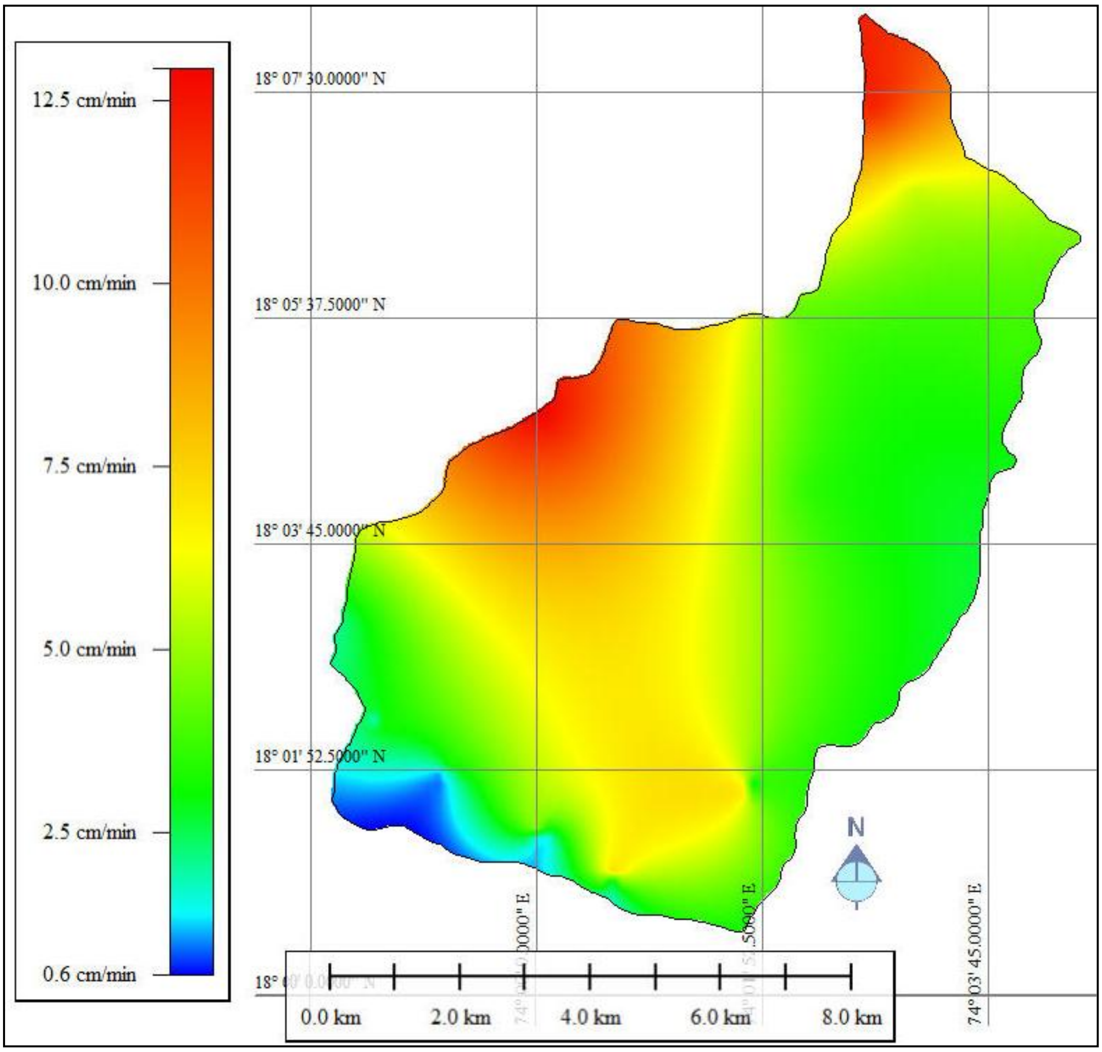


FIG 4.1 : HYDRAULIC CONDUCTIVITY

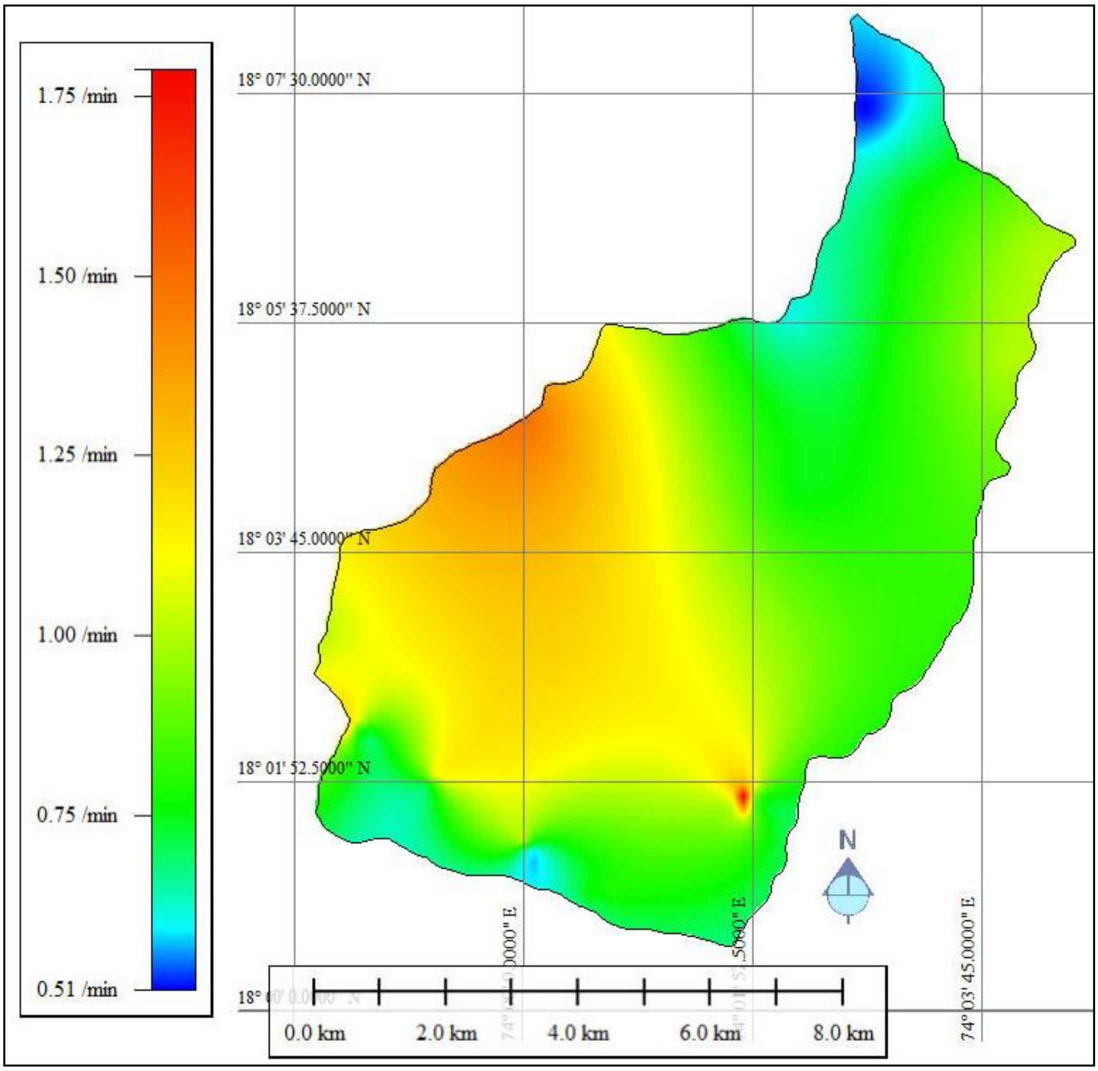


FIG 4.2 : INFILTRATION RATE

4.3.3 Soil Textural Analysis :

Osborne's beaker method has been used to separate soil particles from each other and to determine percentage proportion of soil fraction, such as coarse sand, fine sand, silt and clay.

Considering the triangular diagram of the soil texture, determination of different types of soil has been accomplished.

It is observed that, soil type in the area varies from sandy to sandy clay loam in the study area owing mainly to different geomorphic processes.

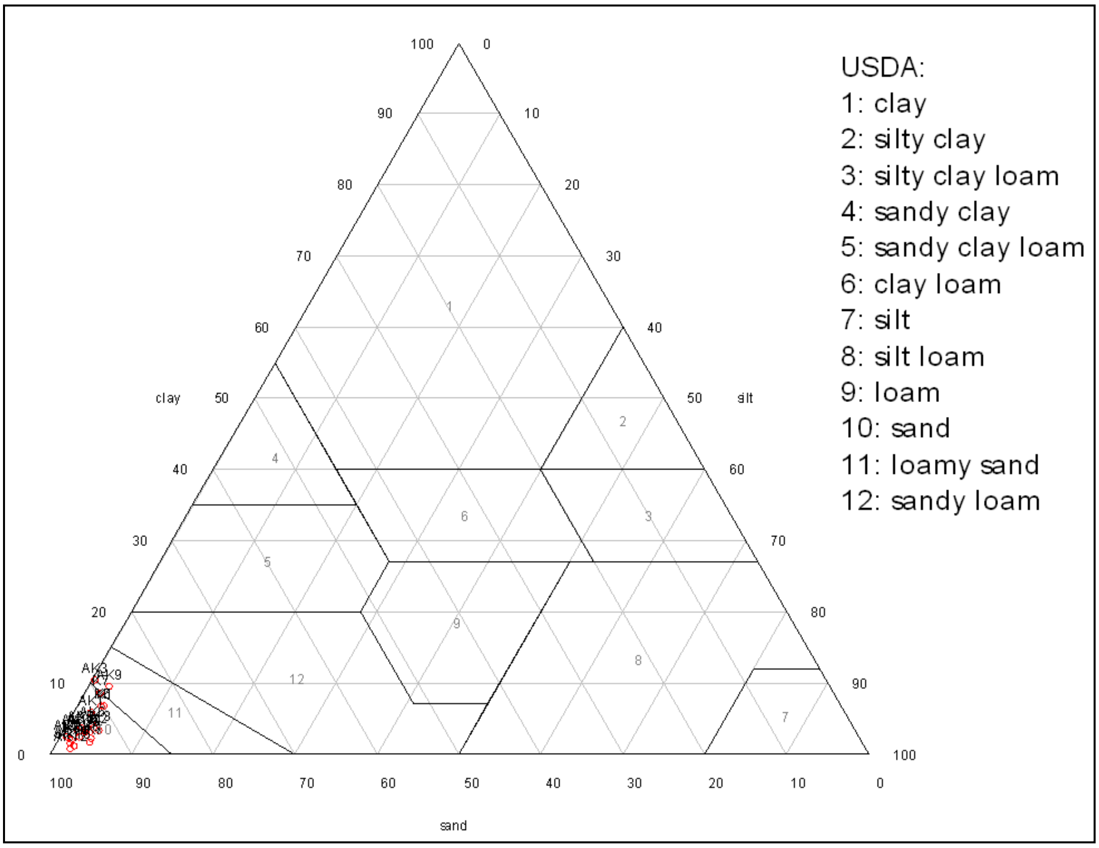


FIG 4.3 : TRIANGULAR DIAGRAM

BULK DENSITY

Bulk density refers to the overall density of soil. It is mass of mineral soil divided by the overall volume occupied by soil water and air. Bulk density of soil is the ratio of its mass to its volume. The soil samples collected from the field with the help of core tube are the analyzed in the laboratory. The bulk density is determined by applying following formula:

$$\text{Bulk Density} = W/V$$

$$V = \pi r^2 h$$

Where, W = Oven dried weight of the soil removed from core tube (gm).

V = Volume of the soil sample (cm^3)

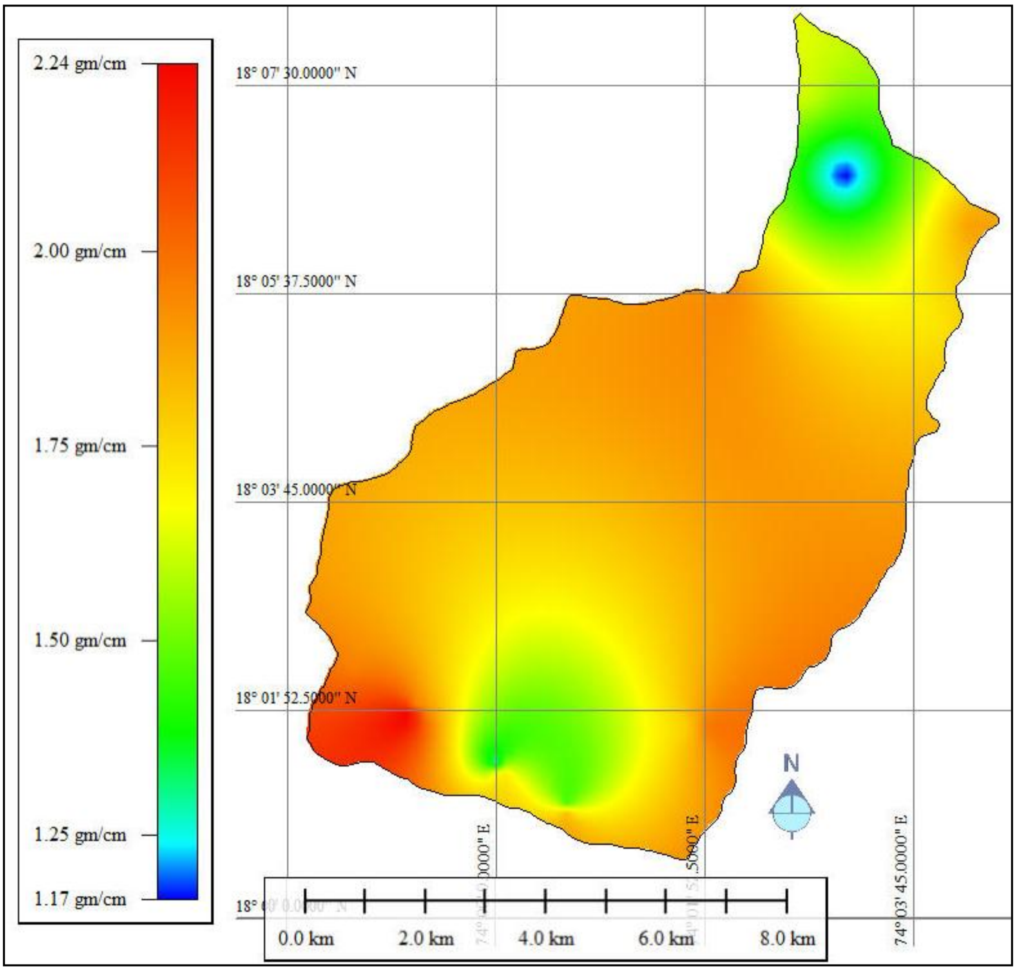


FIG 4.4 : BULK DENSITY

Organic Matter Distribution :

The organic matter has been determined by applying Walkely and Black method which is required for determination of 'P' factor of erodibility in Stehlik's Soil Loss equation.

The organic matter in the soil is derived from plants and animals. In a forest, leaf litter material falls on to forest floor. Sometimes it is referred as organic matter. When the material decomposes to the point at which cannot be recognizable so it is termed as organic matter of soil. In some case the organic matter is split into a stable substances which further decomposes so it is called as humus. The organic matter of soil comprises all the organic matter in the soil material that is not been decayed.

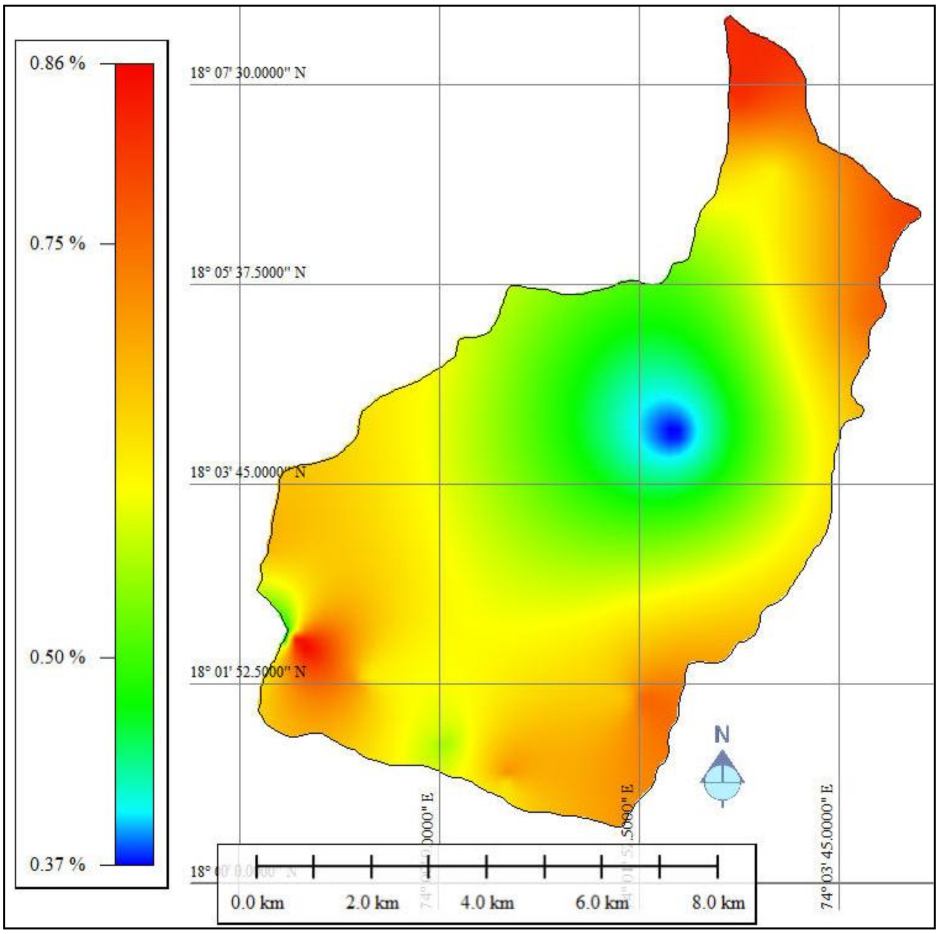
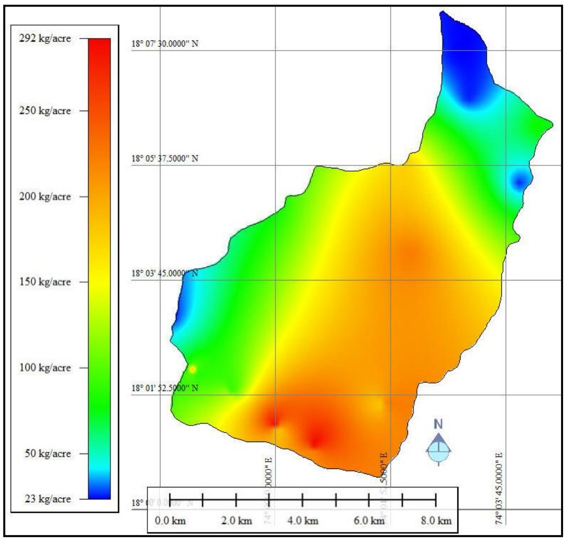


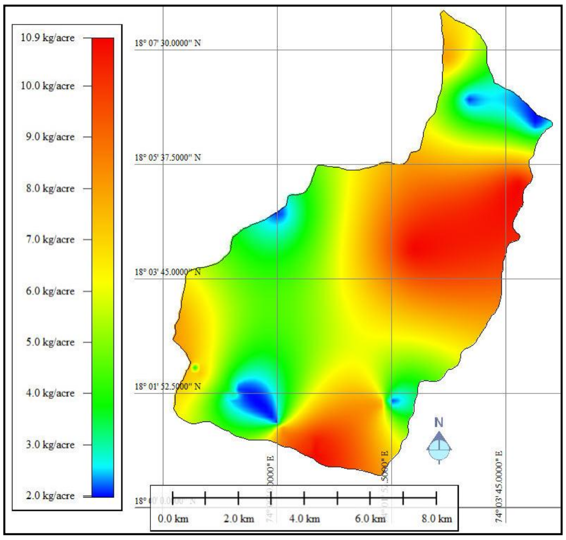
FIG 4.5 : ORGANIC MATTER DISTRIBUTION

Nitrogen, Potassium, Phosphorous :

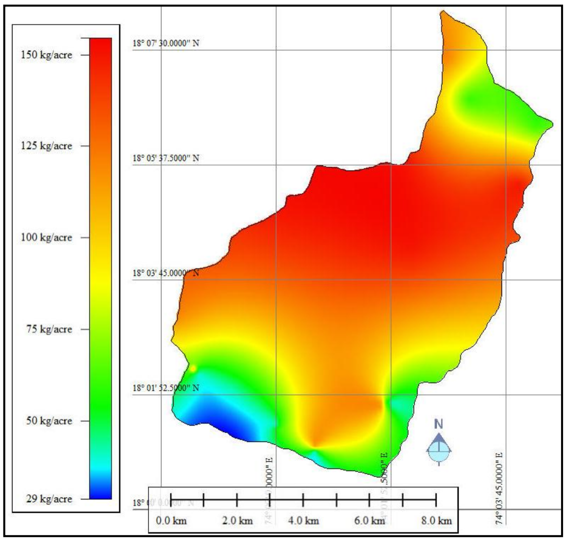
The content of Nitrogen, Phosphorus and Potassium was determined by using qualitative method of Soil Testing Kit.



NITROGEN CONTENT (N)



PHOSPHOROUS CONTENT (P)



POTASSIUM CONTENT (K)

FIG 4.6 : NITROGEN POTASSIUM PHOSPHOROUS

4.4 LAND USE AND LAND COVER ANALYSIS :

The Land Use and Land Cover map gives the clear ideal about the vegetation cover, settlements, canal, streams etc. The map has been obtained by combining the Google Earth Image, Toposheet and Satellite Image. The various software has been used to obtain the LU/LC map of study area.

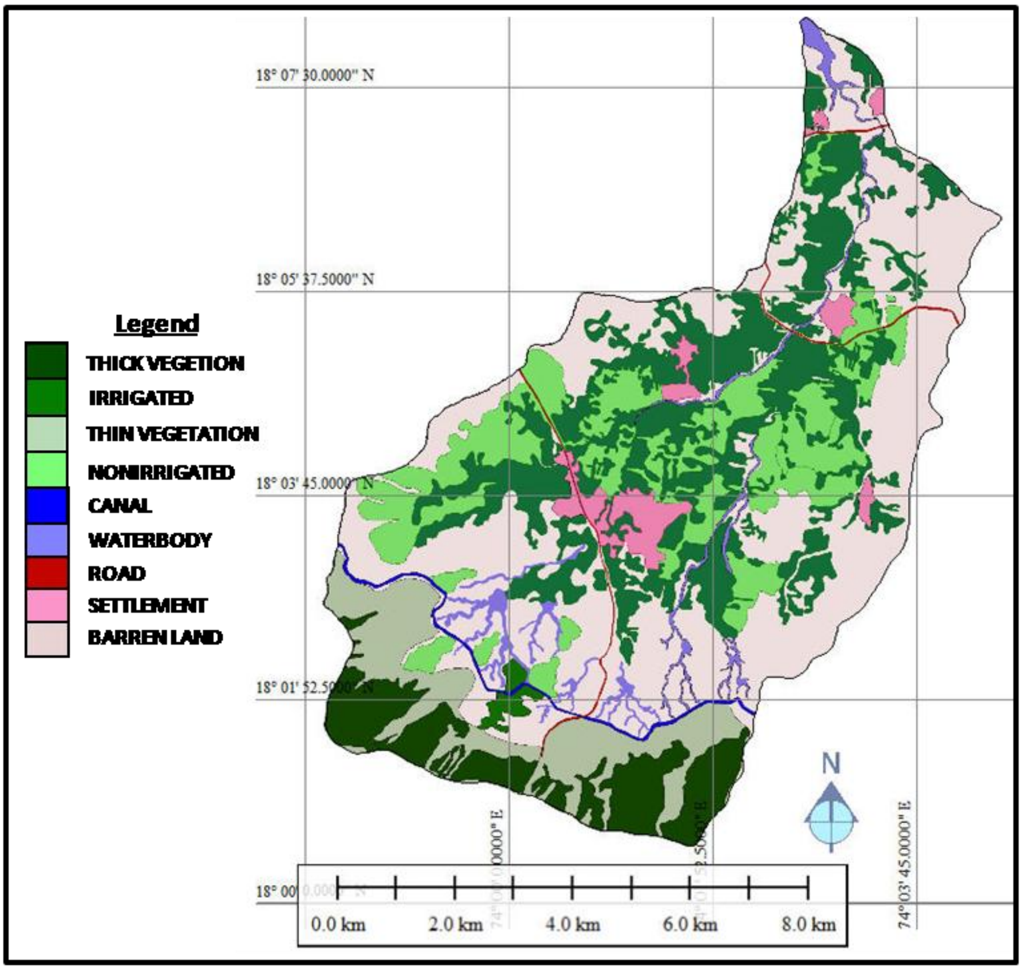


FIG 4.7 : LAND USE / LAND COVER

4.5 Estimation of Soil Loss Using Stehlik's Method

It is difficult task to monitor the soil loss in the field directly due to lack of appropriate techniques. In order to understand the soil loss due to erosion, there is no substitute for empirical equations. There are many methods used to compute the soil loss viz. USLE (Universal Soil Loss Equation), RUSLE (Revised Universal Soil Loss Equation), Stehlik's Soil Loss Equation, MMF (Morgan, Morgan and Finney Model), etc. The USLE predicts the long term average annual rate of soil erosion based on rainfall pattern, soil type, topography, slope, crop system and management practices. The Stehlik's method and MMF model have been widely used for predicting the annual rate of soil loss.

A method was developed by Stehlik (1975) for predicting the annual rate of soil erosion in Czechoslovakia. The basic Stehlik's equation is as follows:

The mean annual soil loss is **X = D*G*P*S*L*O**

STEHLIK's METHOD FOR SOIL LOSS ESTIMATION:

The annual rate of soil erosion was calculated by using the Stehlik's equation:

$$X = D*G*P*S*L*O$$

Where, X = the mean annual soil loss

D = the climatic factor expressed in terms of precipitation

G = the petrological factor

P = the erodibility of the soil

S = the slope steepness

L = the slope length factor

O = the vegetation factor

'D' FACTOR:

This is the climatic factor expressed in terms of precipitation falling at intensities (mm min^{-1}) equal to or greater than $\sqrt{5t}$ where t is the duration of the rainfall (min). The value of D factor is estimated from mean annual precipitation (R) by using the equation:

$$D = 0.001\,4\,R - 0.38$$

'G' FACTOR:

This is the petrological factor and assesses the rock type according to the permeability of its weathered debris. The values of G for each grid cell are computed on the basis of following criteria table:

Table 4.10 : Table for 'G' Factor

Permeability of rock	Granulation of weathered debris	G
Low	Fine	1.5-1.3
Slight	Sandy loam	1.3-1.1
Moderate	Loamy sand	1.1-0.9
High	Coarse sand to stony	0.9-0.7

'P' FACTOR:

This expresses the erodibility of the soil based on the percentage of particles smaller than 0.1 mm in size and the organic matter content. The values of P factor are decided by using the following table:

Table 4.11 : Table for 'P' Factor

Type of Soil	Content of clay (<0.01 mm) [%]	Content of humus		
		<2%	2-3%	>3%
Sandy	<10	1.4	1.1	1
Loamy sand to sandy loam	10-30	1.5	1.25	1.75
Loamy	30-45	1.25	1	0.8
Clay/ loam	45-60	1.4	1.15	0.9
Clay	>60	1.5	1.25	1

'S' FACTOR:

This expresses the slope steepness according to the relationship:

$$\mathbf{S = 0.24 + 0.106\ s + 0.0028\ s^2}$$

Where, s is the slope in per cent.

Table 4.12 : Table for 'S' Factor

Slope Gradient (%)	Slope Factor (S)
5	0.35
7	0.65
9	1
12	1.45
15	2
20	3
30	5.35
40	8.61
50	12.02

'L' FACTOR:

This is the slope length factor. This is calculated by using the following criteria table:

Table 4.13 : Table for 'L' Factor

Slope Length (m)	Slope length Factor (L)
20	1
50	1.6
100	2.5
150	3.2
200	3.8
250	4.3
>300	5

‘O’ FACTOR:

This is the vegetation factor and is dependent upon the percentage cover of the vegetation. The following table gives the values of O:

Table 4.14 : Table for ‘O’ Factor

Vegetation Cover (%)	Vegetation factor (O)
100	0.2
95	0.25
90	0.3
80	0.4
70	1
60	1.22
50	2
40	2.5
20	3.2
0	4

The values of the above factors are calculated on the basis of criteria presented in Zachar (1982).

Soil Loss Estimation Using the Stehlik’s Equation:

The Khandala watershed was divided into 108 grid cells of the dimension of 15″ * 15″. The values for each grid cell for each factor were calculated on the basis of the above criteria tables and equations. The mean annual soil loss calculated in mm y^{-1} was converted to m y^{-1}. Then the mean annual soil loss was converted into kg m^{-2} y^{-1} by multiplying the soil loss X (m y^{-1}) by the bulk density of the soil (kg/m^3). The maximum soil loss in the watershed is 32 kg m^{-2} y^{-1}. The average annual soil loss in the Khandala watershed is 12.80 kg m^{-2} y^{-1}.

The results of this calculation are most sensitive to changes in slope steepness. In absolute terms, however, changes in slope steepness and slope length affect the predictions of the equation about equally. At lower level of sensitivity, the Stehlik equation gives more importance to changes in the rainfall factor and less importance to changes in soil erodibility.

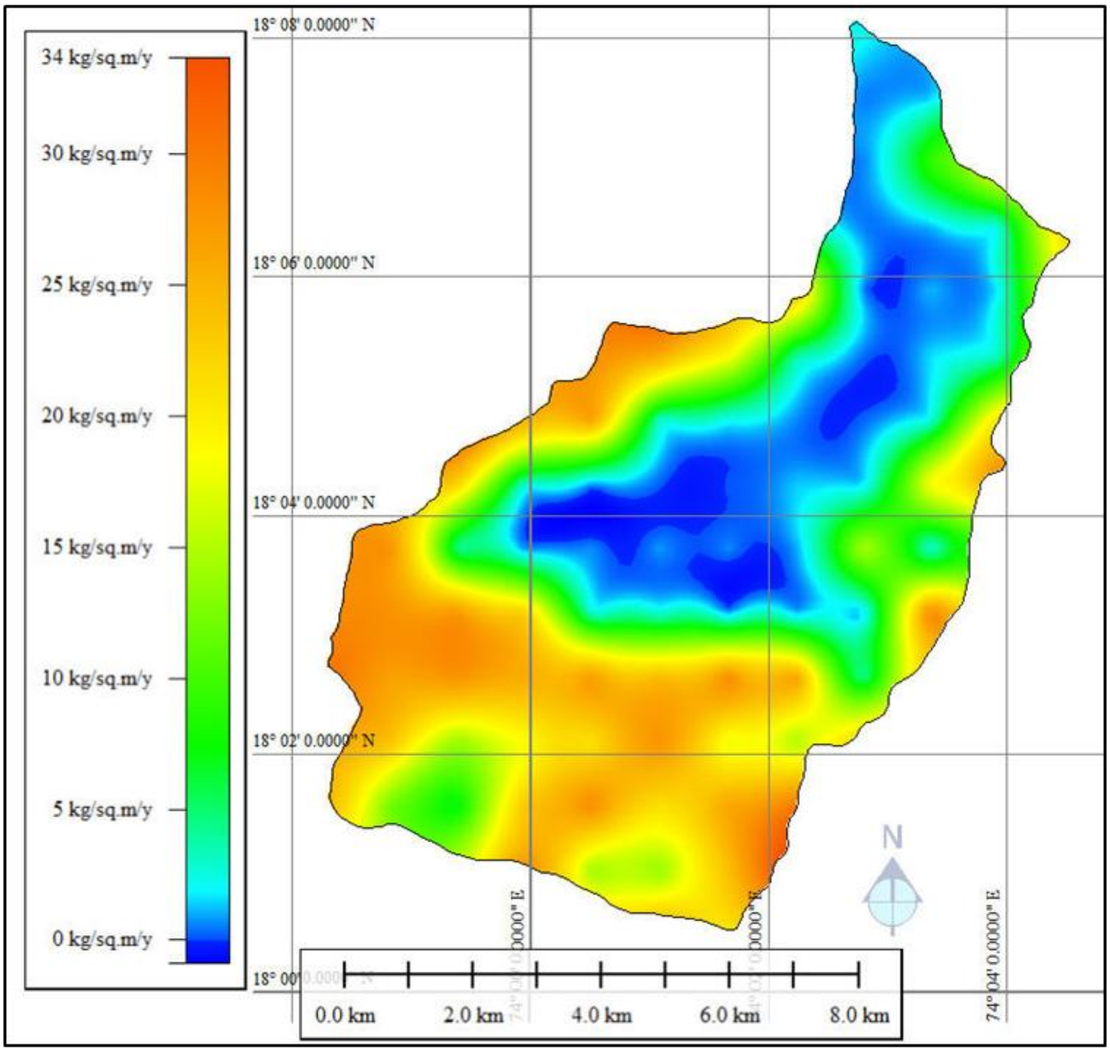


FIG. 4.8: ESTIMATION OF SOIL LOSS

Table 4.15 : Calculation table for Soil Loss

1	GRID	D	G	P	S	L	O	SOIL LOSS X (mm/y)	Bulk Density	SOIL LOSS X (kg/m^2/y)
2	1	0.829684	0.99	1.4	0.24849792	1	3.2	0.914426243	1.65	1.508803302
3	9	0.834626	0.99	1.4	0.37574528	1	3.2	1.390908791	1.63	2.267181329
4	24	0.838462	0.99	1.4	0.24956268	1	1	0.29001887	1.61	0.46693038
5	25	0.831784	1	1.4	0.29261228	1	2	0.681492596	1.53	1.042683671
6	26	0.82498	0.99	1.4	1.03450668	1	3.2	3.785209558	1.58	5.980631101
7	27	0.818176	0.99	1.4	1.70640012	1	4	7.740175903	1.67	12.92609376
8	39	0.843866	0.99	1.4	0.24637008	1	1.22	0.351547905	1.42	0.499198026
9	40	0.836334	1	1.4	0.48438672	5	2.5	7.089408954	1.34	9.499807998
10	41	0.829628	1	1.4	1.14688908	3.2	3.2	13.64057919	1.58	21.55211511
11	42	0.822502	0.99	1.4	1.96391552	1	4	8.955358712	1.73	15.49277057
12	53	0.855164	0.99	1.4	0.39274988	1	3.2	1.489630925	1.65	2.457891025
13	54	0.848276	0.99	1.4	0.26238348	1	1	0.308487022	1.42	0.438051571
14	55	0.840884	1	1.4	0.27636368	1	2.5	0.813364288	1.38	1.122442718
15	56	0.83387	1	1.4	0.32880272	1	3.2	1.228320684	1.68	2.063578749
16	57	0.82694	0.99	1.4	1.04872428	3.2	3.2	12.30831237	1.85	22.77037788
17	65	0.880952	0.98	1.4	3.24782592	3.8	4	59.66816591	1.87	111.5794703
18	66	0.874204	0.99	1.4	1.880672	5	3.2	36.45936169	1.88	68.54359997
19	67	0.867246	0.99	1.4	0.93103692	3.8	3.2	13.60836702	1.88	25.58373
20	68	0.860288	0.99	1.4	0.71780172	5	3.2	13.69403939	1.83	25.06009208
21	69	0.853078	1	1.4	0.27636368	1	0.4	0.132025474	1.64	0.216521778
22	70	0.845994	1	1.4	0.272052	1	2.5	0.805540259	1.59	1.280809012
23	71	0.83919	1	1.4	0.272052	1	3.2	1.022798864	1.74	1.779670024
24	72	0.831714	0.99	1.4	0.60044688	5	3.2	11.07469609	1.85	20.48818777
25	79	0.893468	0.98	1.4	3.50620032	3.2	3.2	44.01186739	1.88	82.74231069
26	80	0.886244	0.99	1.4	2.42022348	3.2	3.2	30.44191471	1.89	57.5352188
27	81	0.878992	0.99	1.4	1.10326188	5	3.2	21.50536153	1.9	40.86018691
28	82	0.871936	1	1.4	0.65284608	5	2.5	9.961699993	1.93	19.22608099
29	83	0.865482	1	1.4	1.51724588	2.5	0.4	1.838408598	1.9	3.492976337
30	84	0.857712	0.99	1.4	0.33877868	1	0.4	0.161094525	1.79	0.288359199
31	85	0.850404	0.99	1.4	0.26345552	1	3.2	0.993678299	1.72	1.709126674
32	86	0.843264	1	1.4	0.33544832	1	4	1.584080356	1.72	2.724618212
33	93	0.905676	1	1.4	4.88125452	3.2	4	79.22136443	1.87	148.1439515
34	94	0.898494	1	1.4	3.55444368	2.5	4	44.71104848	1.88	84.05677114
35	95	0.891242	1	1.4	0.95176272	3.8	3.2	14.44062349	1.88	27.14837217
36	96	0.884116	1	1.4	0.31447308	1	3.2	1.245577454	1.9	2.366597162
37	97	0.876878	1	1.4	0.27636368	1	3.2	1.085670795	1.92	2.084487926
38	98	0.869514	1	1.4	0.29152512	1	1	0.354879242	1.9	0.674270561
39	99	0.86243	0.99	1.4	0.26238348	1	0.4	0.125453726	1.85	0.232089393
40	100	0.855122	0.99	1.4	0.3488	1	2.5	1.033493608	1.8	1.860288495
41	101	0.847814	0.99	1.4	1.59297792	2.5	4	18.71860889	1.8	33.69349601
42	106	0.925612	0.97	1.4	4.58112128	5	4	115.1676569	1.89	217.6668716
43	107	0.91829	1	1.4	2.88346368	5	4	74.13996416	1.87	138.641733
44	108	0.911024	1.04	1.4	4.701675	3.2	3.2	63.86218232	1.85	118.1450373
45	109	0.903618	1.05	1.4	0.71136912	5	0.25	1.181155917	1.84	2.173326888
46	110	0.896436	1.05	1.4	0.30132972	1	0.4	0.158832212	1.85	0.293839591
47	111	0.889156	1.04	1.4	0.26774928	1	0.2	0.06932624	1.87	0.129640069
48	112	0.881666	1.02	1.4	0.24424448	1	0.2	0.061501691	1.89	0.116238195
49	113	0.874274	1	1.4	0.4053	5	0.3	0.74412083	1.91	1.421270785
50	114	0.867078	0.99	1.4	0.49030412	5	0.2	0.589232835	1.88	1.10775773
51	115	0.859602	0.99	1.4	0.69215532	5	2.5	10.30799554	1.86	19.1728717
52	116	0.852322	0.98	1.4	1.711392	3.2	3.2	20.49308135	1.85	37.9122005
53	121	0.931016	0.98	1.4	5.81455248	1.6	4	47.53434617	1.89	89.83991427
54	122	0.923596	1.04	1.4	1.84294992	5	1.22	15.11773705	1.86	28.11899092
55	123	0.91626	1.1	1.4	0.90496512	5	0.3	1.915413517	1.82	3.486052602

Continue……..

1	GRID	D	G	P	S	L	O	SOIL LOSS X (mm/y)	Bulk Density	SOIL LOSS X (kg/m^2/y)
56	124	0.90884	1.11	1.4	0.35103312	1	0.4	0.198310876	1.8	0.356959577
57	125	0.901322	1.1	1.4	0.31447308	1	1	0.436499918	1.8	0.785699853
58	126	0.893986	1.08	1.4	0.299147	1	1.22	0.493318033	1.82	0.897838821
59	127	0.886566	1.04	1.4	0.28501392	1	1	0.367907396	1.86	0.684307756
60	128	0.879328	1.01	1.4	0.28501392	1	1.22	0.432340792	1.9	0.821447505
61	129	0.871908	0.99	1.4	1.033088	3.2	2	7.99008103	1.9	15.18115396
62	130	0.864432	0.98	1.4	0.31117968	1	2.5	0.922648299	1.9	1.753031768
63	131	0.8569	0.98	1.4	0.74497152	1	3.2	2.802682506	1.9	5.325096761
64	136	0.936462	0.98	1.4	2.972928	3.8	4	58.05936075	1.9	110.3127854
65	137	0.92893	1.1	1.4	1.02883532	5	3.2	23.54884209	1.86	43.80084628
66	138	0.921328	1.18	1.4	1.58973008	3.8	3.2	29.42261572	1.8	52.9607083
67	139	0.913936	1.19	1.4	0.53935488	5	3.2	13.13969779	1.75	22.99447114
68	140	0.906656	1.17	1.4	0.299147	1	2.5	1.110659915	1.73	1.921441653
69	141	0.899054	1.12	1.4	0.388203	1	2.5	1.368140603	1.77	2.421608867
70	142	0.891242	1.06	1.4	0.272052	1	0.4	0.14392673	1.83	0.263385917
71	143	0.884074	1.02	1.4	0.250628	1	1.22	0.386016835	1.89	0.729571817
72	144	0.87671	1	1.4	0.299147	1	1	0.367171233	1.92	0.704968767
73	145	0.869108	0.98	1.4	0.84939372	5	4	20.25661623	1.93	39.09526932
74	151	0.910912	0.98	1.4	2.0025	5	4	50.05333912	1.95	97.60401129
75	152	0.934152	1.26	1.4	3.38462208	5	4	111.5465924	1.9	211.9385256
76	153	0.92669	1.28	1.4	1.170363	5	4	38.87076259	1.8	69.96737267
77	154	0.919102	1.28	1.4	0.97959312	3.8	4	24.52398437	1.68	41.20029374
78	155	0.910828	1.24	1.4	1.669947	2.5	3.2	21.12412694	1.65	34.85480946
79	156	0.903926	1.14	1.4	3.127923	1.6	3.2	23.10424493	1.7	39.27721638
80	157	0.896296	1.07	1.4	0.734592	5	3.2	15.78081573	1.81	28.56327647
81	158	0.888904	1.02	1.4	1.10181632	3.2	3.2	14.32162261	1.91	27.35429918
82	159	0.881134	0.99	1.4	0.38139948	1	4	1.86313909	1.95	3.633121225
83	160	0.873714	0.97	1.4	1.30964352	2.5	3.2	12.43117414	1.96	24.36510131
84	166	0.947298	1.16	1.4	5.28811008	5	1	40.67645875	2.04	82.97997586
85	167	0.939486	1.66	1.4	2.76718992	5	1.22	36.85490011	2.04	75.18399623
86	168	0.93194	1.2	1.4	1.08451328	4.3	1	7.301306236	1.86	13.5804296
87	169	0.924366	1.42	1.4	3.20765612	1.6	2.5	23.57806374	1.59	37.48912135
88	170	0.916526	1.3	1.4	1.01469612	5	3.2	27.08146535	1.53	41.43464199
89	171	0.909008	1.15	1.4	3.66509568	1.6	4	34.32881973	1.63	55.95597616
90	172	0.90128	1.04	1.4	3.70974848	1.6	4	31.15627643	1.8	56.08129757
91	173	0.893804	1	1.4	3.63175308	1.6	4	29.08483585	1.96	57.00627827
92	174	0.885978	0.98	1.4	2.92602732	1.6	4	22.76330933	1.98	45.07135247
93	180	0.960346	1.12	1.4	7.06006572	5	1	53.15603005	2.1	111.6276631
94	181	0.95259	1.23	1.4	7.486043	5	1	61.39902673	2.12	130.1659367
95	182	0.944862	1.28	1.4	8.11146732	5	1.22	83.77909144	2.16	180.9628375
96	183	0.937162	1.26	1.4	4.87120172	5	2	80.52845478	1.98	159.4463405
97	184	0.929406	1.78	1.4	1.40986572	5	3.2	52.24578315	1.41	73.66655425
98	185	0.921426	1.21	1.4	1.21625168	5	4	37.96883899	1.47	55.81419331
99	186	0.913824	1.08	1.4	0.96564992	5	4	26.68480635	1.58	42.16199404
100	187	0.90562	1	1.4	3.79294668	3.2	3.2	49.24370659	1.79	88.14623479
101	188	0.89848	0.97	1.4	3.19922508	5	4	78.06978361	1.99	155.3588694
102	198	0.942174	1.23	1.4	7.623392	5	3.2	197.8939409	1.96	387.8721242
103	199	0.934474	1.06	1.4	7.19383632	5	2.5	124.7015032	1.8	224.4627057
104	200	0.926746	0.99	1.4	6.428075	5	2.5	103.2083652	1.66	171.3258862
105	201	0.918724	1	1.4	4.112352	5	0.3	7.934044606	1.7	13.48787583
106	202	0.910968	0.97	1.4	5.23615488	5	0.4	12.95523727	1.84	23.83763657
107	203	0.903072	0.96	1.4	5.07651728	5	3.2	98.58424102	1.96	193.2251124
108	215	0.931926	0.97	1.4	5.13291648	5	4	129.9198145	1.93	250.7452419
109	216	0.923722	0.96	1.4	4.77365648	5	3.2	94.82256561	1.89	179.214649
110	217	0.916246	0.95	1.4	6.57354128	5	2.5	100.1320575	1.92	192.2535504

Average Annual Soil Loss is 12.80 kg/m^2/y

4.5.1 Correlation Matrix

Coefficient of Correlation :

For expressing the degree of relationship quantitatively between two sets of measures or variables, we usually consider the index which is known as coefficient of correlation. It is a ratio which determines the extent at which one variable are compared by changes in the other variable. It involves number of units and which ranges from – 1 (indicating perfect negative correlation) to + 1 (indicating perfect positive correlation). The coefficient of correlation is zero in some cases, which determines zero correlation between two sets of measures.

Matrix of Correlation Coefficients

	VAR1	VAR2	VAR3	VAR4	VAR5	VAR6	VAR7	VAR8
VAR1	1	-.993 [6]	-.552 [6]	-.202 [6]	-.172 [6]	.162 [6]	.512 [6]	.343 [6]
VAR2		1	.487 [6]	.095 [6]	.222 [6]	-.074 [6]	-.427 [6]	-.274 [6]
VAR3			1	.367 [6]	-.673 [6]	-.897 [6]	-.955 [6]	-.959 [6]
VAR4				1	-.092 [6]	-.504 [6]	-.596 [6]	-.354 [6]
VAR5					1	.838 [6]	.597 [6]	.756 [6]
VAR6						1	.912 [6]	.947 [6]
VAR7							1	.943 [6]
VAR8								1

VAR1 -	Coarse Sand	VAR2 -	Fine Sand
VAR3 -	Silt	VAR4 -	Clay
VAR5 -	Soil Loss	VAR6 -	Organic Matter
VAR7 -	Slope	VAR8 -	Rainfall

Table 4.16 : Range of Computed Correlation Coefficient

The range of computed correlation coefficient	Interpretation
0 (zero value)	Zero relation, absolutely no relationship.
From 0.00 to ± 0.20	Slight, almost negligible relationship.
From ± 0.21 to ± 0.40	Low correlation, substantial but small relationship.
From ± 0.41 to ± 0.70	Moderate correlation, substantial but small relationship.
From ± 0.71 to ± 0.90	High correlation, marked relationship.
From ± 0.91 to ± 0.99	Very high correlation, quite dependable relationship.
± 1	Perfect correlation, almost identical or opposite relationship.

Interpretation:

- There is slight, almost negligible correlation between coarse sand content and soil loss.
- There is low correlation between fine sand content and soil loss.
- There is moderately high correlation between silt content and soil loss.
- There is slight, almost negligible correlation between clay content and soil loss.
- There is high correlation between organic matter content and soil loss. As the organic matter content increases, the soil loss increases.
- There is moderately high correlation between slope and soil loss. As the slope increases, the soil loss increases.
- There is high correlation between rainfall and soil loss. As the rainfall increases, the soil loss increases.

❑❑❑

5 Prioritization of Sub-Watersheds for Conservation Planning

5.1 Criteria and Ranking system

Watershed prioritization has gained importance in natural resource management, especially in the context of watershed management. Morphometric analysis has been commonly applied to prioritization of watersheds. The study area is basically composed of 11 sub-basins of Khandala watershed.

The analysis of various soil parameters has been analyzed such as Drainage texture (Rt), Mean Bifurcation ratio, Drainage Density (D), Stream Frequency (Fs), Form Factor (Rf), Circulatory Ratio (Rc), Length of Overland Flow, Basin Slope (Bs) and Soil loss (Sl). The Khandala watershed consists of 11 sub-basins which are as follows :

Table 5.0 : Stream order and Stream Number of Sub-Basin

Sr. No.	Sub-Basin Name	Sub-Basin Code	Stream Order	Total Number of Streams
1.	KD1	1 order_1	1	1
2.	KD2	1 order_2	1	1
3.	KD3	2 order_1	1	4
			2	1
4.	KD4	2 order_2	1	3
			2	1
5.	KD5	3 order_1	1	23
			2	6
			3	1
6..	KD6	3 order_2	1	5
			2	2
			3	1
7.	KD7	3 order_3	1	5
			2	2
			3	1
8.	KD8	4 order_1	1	57
			2	9
			3	3

Sr. No.	Sub-Basin Name	Sub-Basin Code	Stream Order	Total Number of Streams
9.	KD9	4 order_2	1	25
			2	9
			3	3
			4	1
10.	KD10	4 order_3	1	43
			2	14
			3	4
			4	1
11.	KD11	4 order_4	1	35
			2	11
			3	2
			4	1

The 11 sub-basins includes different types of stream order and stream number, according to single sub-basins i.e KD1 (1 order_1) and KD2 (1 order_2) includes only 1 stream, KD3 (2 order_1) consists of total 5 streams, KD4 (2 order_2) includes 4 streams, KD5 (3 order_1) includes total 30 streams, KD6 (3 order_2) includes total 8 streams, KD7 (3 order_3) includes total 8 streams, KD8 (4 order_1) includes total 69 streams, KD9 (4 order_2) includes 38 streams, KD10 (4 order_3) includes total 62 streams, KD11 includes 49 streams and the 5th order stream includes in the Khandala basin which connects to Nira river basin.

The Basin morphometry is calculated, which includes the linear properties, Areal properties and relief properties (refer Appendic). Various parameters are calculated such as bifurcation ratio, basin perimeter, basin length, drainage density, stream frequency, length ratio, length of overland flow, form factor, relief ratio, texture ratio, basin relief, basin length, basin slope etc.

The values of each order are calculated and at last the average is taken into consideration. From KD3 (2 order_1) to KD11 (4 order_4) the average values of every parameter is taken into consideration, which indicates the parameter values of that respective sub-basin in an study area. The calculated values of each parameter is different, the ranking method has been used to know the priority levels of each parameter. The lowest values are given as 1 rank where as highest values are given 10 rank. The ranking ranges from 1 to 10, from lowest to highest.

The Drainage texture (Rt) value ranges from 0.04 to 0.94, so for this range of values the ranking is given from lowest to highest. i.e. Class interval is 0.10, ranking ranges from below 0.04 as 1 Rank and above 0.94 as 10 Rank.

The Mean bifurcation ratio (Rbm) value ranges from 0.2 to 1.8, so for this range of values the ranking is given from lowest to highest. i.e. Class interval is 0.2, ranking ranges from below 0.2 as 1 Rank and above 1.8 as 10 Rank.

So for every parameter the ranking values are given and final ranking tables gives the priority level of sub-basin.

5.1.1 Morphometric Analysis

The soil parameter plays an important role in prioritization of sub-basin according to the Drainage Texture, Mean Bifurcation Ratio, Drainage Density, Stream Frequency, Form Factor, Circulatory Ratio, Length of Overland Flow and Basin Slope. All soil parameter are calculated and ranking is given to obtain the priority level of sub-basins.

Table 5.1 : Values of Morphometric Analysis

Sub-basin Code	Stream Order	Stream Number	Rt	Rbm	D	Fs	Rf	Rc	Lg	Bs
I	II	III								
1 order_1	1	1	0.63898	0	3.17698	14.829754	0.02753	0.3458	1.58849	0.0044728
1 order_2	1	1	0.56561	1	4.10189	8.4540144	0.03784	0.47529	2.05094	0.0050905
2 order_1	2	5	0.2388	0.75	1.33021	1.7202963	0.01326	0.16654	0.66511	0.0039163
2 order_2	2	4	0.38425	1.5	1.81829	3.082196	0.02395	0.30083	0.90914	0.0036503
3 order_1	3	30	0.47728	1.05556	1.06812	1.3907239	0.10154	0.20573	0.53406	0.0163993
3 order_2	3	8	0.33837	1.38889	1.1637	1.9312238	0.02223	0.27923	0.58185	0.0043142
3 order_3	3	8	0.33446	1.38889	1.25542	1.8010765	0.02329	0.29254	0.62771	0.005644
4 order_1	3	69	0.96834	1.38889	1.19688	1.6104954	0.02531	0.31795	0.59844	0.0263136
4 order_2	4	38	0.65495	1.22917	1.41072	2.0647174	0.02187	0.27467	0.70536	0.0381937
4 order_3	4	62	0.97515	1.47917	1.49605	2.1121169	0.02905	0.36482	0.74803	0.0374332
4 order_4	4	49	0.78783	1.47917	1.19623	1.4930947	0.03393	0.42622	0.59811	0.0176217

Rt = Drainage Texture **Rbm = Mean Bifurcation Ratio**

D = Drainage Density **Fs = Stream Frequency**

Rf = Form Factor **Rc = Circulatory Ratio**

Lg = Length of Overland Flow **Bs = Basin Slope**

Table 5.2 : Class Interval of Morphometric Analysis

RANKING	Rt	Rbm	D	Fs	Rf	Rc	Lg	Bs
1	< 0.04	< 0.2	< 3	< 2	< 0.01	< 0.04	< 1.5	< 0.005
2	0.14-0.24	0.2-0.4	3-6	2-4	0.01-0.02	0.04-0.08	1.5-3	0.005-0.010
3	0.24-0.34	0.4-0.6	6-9	4-6	0.02-0.03	0.08-0.12	3-4.5	0.010-0.015
4	0.34-0.44	0.6-0.8	9-12	6-8	0.03-0.04	0.12-0.16	4.5-6	0.015-0.020
5	0.44-0.54	0.8-1	12-15	8-10	0.04-0.05	0.16-0.20	6-7.5	0.020-0.025
6	0.54-0.64	1-1.2	15-18	10-12	0.05-0.06	0.20-0.24	7.5-9	0.025-0.030
7	0.64-0.74	1.2-1.4	18-21	12-14	0.06-0.07	0.24-0.28	9-10.5	0.030-0.035
8	0.74-0.84	1.4-1.6	21-24	14-16	0.07-0.08	0.28-0.32	10.5-12	0.035-0.040
9	0.84-0.94	1.6-1.8	24-27	16-18	0.08-0.09	0.32-0.36	12.5-14	0.040-0.045
10	> 0.94	> 1.8	> 27	> 18	> 0.09	> 0.36	> 14	> 0.045

Rt = Drainage Texture **Rbm = Mean Bifurcation Ratio**

D = Drainage Density **Fs = Stream Frequency**

Rf = Form Factor **Rc = Circulatory Ratio**

Lg = Length of Overland Flow **Bs = Basin Slope**

Table 5.3 : Final Ranking Score of Morphometric Analysis

Sub-basin Code	Stream Order	Stream Number	Rt	Ranking	Rbm	Ranking	D	Ranking	Fs	Ranking
1 order_1	1	1	0.63898	**6**	0	**1**	3.17698	**2**	14.82975	**8**
1 order_2	1	1	0.56561	**6**	1	**5**	4.10189	**2**	8.454014	**5**
2 order_1	2	5	0.2388	**2**	0.75	**4**	1.33021	**1**	1.720296	**1**
2 order_2	2	4	0.38425	**4**	1.5	**8**	1.81829	**1**	3.082196	**2**
3 order_1	3	30	0.47728	**5**	1.05556	**6**	1.06812	**1**	1.390724	**1**
3 order_2	3	8	0.33837	**3**	1.38889	**7**	1.1637	**1**	1.931224	**1**
3 order_3	3	8	0.33446	**3**	1.38889	**7**	1.25542	**1**	1.801077	**1**
4 order_1	3	69	0.96834	**10**	1.38889	**7**	1.19688	**1**	1.610495	**1**
4 order_2	4	38	0.65495	**7**	1.22917	**7**	1.41072	**1**	2.064717	**2**
4 order_3	4	62	0.97515	**10**	1.47917	**8**	1.49605	**1**	2.112117	**2**
4 order_4	4	49	0.78783	**8**	1.47917	**8**	1.19623	**1**	1.493095	**1**

5.1.2 Soil Loss Estimation

Analysis of soil loss has estimated using Stehlik's Equation

$$X = D*G*P*S*L*O$$

Where, X = the mean annual soil loss

D = the climatic factor expressed in terms of precipitation

G = the petrological factor

P = the erodibility of the soil

S = the slope steepness

L = the slope length factor

O = the vegetation factor

The every aspect consists of average calculated value, which is categorized into class intervals (Table 5.4) and ranking has been done according to the class interval. The highest value of class interval is given high ranking where as lowest value of class interval is given lower ranking (Table 5.4). The combined or average values of soil loss taken into consideration, according to sub-basins the ranking are done (Table 5.5).

Table 5.4 : Class Interval and Values of Soil Loss Estimation

Sub-basin Code	Stream Order	Stream Number	Soil Loss (Sl) ($kg/m^2/y$)
1 order_1	1	1	0.61
1 order_2	1	1	0.8
2 order_1	2	5	21.5
2 order_2	2	4	9.6
3 order_1	3	30	30
3 order_2	3	8	16.2
3 order_3	3	8	23.6
4 order_1	3	69	34
4 order_2	4	38	28
4 order_3	4	62	29
4 order_4	4	49	30

RANKING	Soil Loss (Sl) ($kg/m^2/y$)
1	< 4
2	4-8
3	8-12
4	12-16
5	16-20
6	20-24
7	24-28
8	28-32
9	32-36
10	> 36

Table 5.5 : Final Ranking Score of Soil Loss Estimation

Sub-basin Code	Stream Order	Stream Number	Soil Loss (Sl) (kg/m^2/y)	Ranking
I	II	III		
1 order_1	1	1	0.61	**1**
1 order_2	1	1	0.8	**1**
2 order_1	2	5	21.5	**6**
2 order_2	2	4	9.6	**3**
3 order_1	3	30	30	**8**
3 order_2	3	8	16.2	**5**
3 order_3	3	8	23.6	**6**
4 order_1	3	69	34	**9**
4 order_2	4	38	28	**7**
4 order_3	4	62	29	**8**
4 order_4	4	49	30	**8**

5.1.3 Composition of Morphometric Analysis and Soil Loss

The combination of Morphometric Analysis and soil loss gives the clear idea about the changes in priority levels. The soil parameters which include every aspect as mentioned above (Table 5.1 and 5.3). The soil loss is the major factor which determines the change in priority levels after combining the Morphometric Analysis and soil loss. The ranking table of soil parameter and soil loss together gives the new ranking scheme (Table 5.6 and 5.8).

The changes in Composite map represent the changes in priority level as per sub-basins in Khandala watershed.

Table 5.6 : Composite values of Morphometric Analysis and Soil loss

Sub-basin Code	Stream Order	Stream Number	Rt	Rbm	D	Fs	Rf	Rc	Lg	Bs	Sl
I	II	III									
1 order_1	1	1	0.63898	0	3.17698	14.829754	0.02753	0.3458	1.58849	0.0044728	0.61
1 order_2	1	1	0.56561	1	4.10189	8.4540144	0.03784	0.47529	2.05094	0.0050905	0.8
2 order_1	2	5	0.2388	0.75	1.33021	1.7202963	0.01326	0.16654	0.66511	0.0039163	21.5
2 order_2	2	4	0.38425	1.5	1.81829	3.082196	0.02395	0.30083	0.90914	0.0036503	9.6
3 order_1	3	30	0.47728	1.05556	1.06812	1.3907239	0.10154	0.20573	0.53406	0.0163993	30
3 order_2	3	8	0.33837	1.38889	1.1637	1.9312238	0.02223	0.27923	0.58185	0.0043142	16.2
3 order_3	3	8	0.33446	1.38889	1.25542	1.8010765	0.02329	0.29254	0.62771	0.005644	23.6
4 order_1	3	69	0.96834	1.38889	1.19688	1.6104954	0.02531	0.31795	0.59844	0.0263136	34
4 order_2	4	38	0.65495	1.22917	1.41072	2.0647174	0.02187	0.27467	0.70536	0.0381937	28
4 order_3	4	62	0.97515	1.47917	1.49605	2.1121169	0.02905	0.36482	0.74803	0.0374332	29
4 order_4	4	49	0.78783	1.47917	1.19623	1.4930947	0.03393	0.42622	0.59811	0.0176217	30

Rt = Drainage Texture **Rbm = Mean Bifurcation Ratio**

D = Drainage Density **Fs = Stream Frequency**

Rf = Form Factor **Rc = Circulatory Ratio**

Lg = Length of Overland Flow **Bs = Basin Slope**

Sl = Soil Loss

Table 5.7 : Class Interval of Composite Morphometric Analysis and Soil Loss

RANKING	Rt	Rbm	D	Fs	Rf	Rc	Lg	Bs	Sl
1	< 0.04	< 0.2	< 3	< 2	< 0.01	< 0.04	< 1.5	< 0.005	< 4
2	0.14-0.24	0.2-0.4	3-6	2-4	0.01-0.02	0.04-0.08	1.5-3	0.005-0.010	4-8
3	0.24-0.34	0.4-0.6	6-9	4-6	0.02-0.03	0.08-0.12	3-4.5	0.010-0.015	8-12
4	0.34-0.44	0.6-0.8	9-12	6-8	0.03-0.04	0.12-0.16	4.5-6	0.015-0.020	12-16
5	0.44-0.54	0.8-1	12-15	8-10	0.04-0.05	0.16-0.20	6-7.5	0.020-0.025	16-20
6	0.54-0.64	1-1.2	15-18	10-12	0.05-0.06	0.20-0.24	7.5-9	0.025-0.030	20-24
7	0.64-0.74	1.2-1.4	18-21	12-14	0.06-0.07	0.24-0.28	9-10.5	0.030-0.035	24-28
8	0.74-0.84	1.4-1.6	21-24	14-16	0.07-0.08	0.28-0.32	10.5-12	0.035-0.040	28-32
9	0.84-0.94	1.6-1.8	24-27	16-18	0.08-0.09	0.32-0.36	12.5-14	0.040-0.045	32-36
10	0.94 >	1.8 >	27 >	18 >	0.09 >	0.36 >	14 >	0.045 >	36 >

Rt = Drainage Texture

D = Drainage Density

Rf = Form Factor

Lg = Length of Overland Flow

Sl = Soil Loss

Rbm = Mean Bifurcation Ratio

Fs = Stream Frequency

Rc = Circulatory Ratio

Bs = Basin Slope

Table 5.8 : Final Ranking Score of Composite Morphometric Analysis and Soil Loss

Sub-basin Code	Stream Order	Stream Number	Rt	Ranking	Rbm	Ranking	D	Ranking	Fs	Ranking
I	II	III								
1 order_1	1	1	0.63898	**6**	0	**1**	3.17698	**2**	14.82975	**8**
1 order_2	1	1	0.56561	**6**	1	**5**	4.10189	**2**	8.454014	**5**
2 order_1	2	5	0.2388	**2**	0.75	**4**	1.33021	**1**	1.720296	**1**
2 order_2	2	4	0.38425	**4**	1.5	**8**	1.81829	**1**	3.082196	**2**
3 order_1	3	30	0.47728	**5**	1.05556	**6**	1.06812	**1**	1.390724	**1**
3 order_2	3	8	0.33837	**3**	1.38889	**7**	1.1637	**1**	1.931224	**1**
3 order_3	3	8	0.33446	**3**	1.38889	**7**	1.25542	**1**	1.801077	**1**
4 order_1	3	69	0.96834	**10**	1.38889	**7**	1.19688	**1**	1.610495	**1**
4 order_2	4	38	0.65495	**7**	1.22917	**7**	1.41072	**1**	2.064717	**2**
4 order_3	4	62	0.97515	**10**	1.47917	**8**	1.49605	**1**	2.112117	**2**
4 order_4	4	49	0.78783	**8**	1.47917	**8**	1.19623	**1**	1.493095	**1**

Continue……..

Table 5.8 : Final Ranking Score of Composite Morphometric Analysis and Soil Loss

Sub-basin Code	Stream Order	Stream Number	Rf	Ranking	Rc	Ranking	Lg	Ranking	Bs	Ranking	Sl	Ranking
I	II	III										
1 order_1	1	1	0.02753	**3**	0.3458	**9**	1.58849	**1**	0.0044728	**1**	0.61	**1**
1 order_2	1	1	0.03784	**4**	0.47529	**10**	2.05094	**2**	0.0050905	**2**	0.8	**1**
2 order_1	2	5	0.01326	**2**	0.16654	**5**	0.66511	**1**	0.0039163	**1**	21.5	**6**
2 order_2	2	4	0.02395	**3**	0.30083	**8**	0.90914	**1**	0.0036503	**1**	9.6	**3**
3 order_1	3	30	0.10154	**10**	0.20573	**6**	0.53406	**1**	0.0163993	**4**	30	**8**
3 order_2	3	8	0.02223	**3**	0.27923	**7**	0.58185	**1**	0.0043142	**1**	16.2	**5**
3 order_3	3	8	0.02329	**3**	0.29254	**8**	0.62771	**1**	0.005644	**2**	23.6	**6**
4 order_1	3	69	0.02531	**3**	0.31795	**8**	0.59844	**1**	0.0263136	**6**	34	**9**
4 order_2	4	38	0.02187	**3**	0.27467	**7**	0.70536	**1**	0.0381937	**8**	28	**7**
4 order_3	4	62	0.02905	**3**	0.36482	**9**	0.74803	**1**	0.0374332	**8**	29	**8**
4 order_4	4	49	0.03393	**4**	0.42622	**10**	0.59811	**1**	0.0176217	**4**	30	**8**

5.2 Prioritization of sub-watersheds based on basin morphometric characteristics and soil loss estimation.

Prioritization of sub-watersheds is done according to the analysis by ranking the value of different parameters, such as soil textural properties, relief properties and soil loss. The present study area is divided into 11 sub-basins, where every values of parameter is calculated and given a ranking according to the class intervals as mentioned in above table (Table 5.8). The morphometric characteristics of watershed and soil properties, soil loss estimation plays an important role in prioritization of watersheds. The average soil loss is 12 $kg/m^2/y$, which determines the considerable soil loss in the study area. Maximum soil loss estimated to the tune of 34 $kg/m^2/y$ where as minimum is 5 $kg/m^2/y$. (Table 4.5 and Fig 4.8).

The Prioritization of sub-watersheds is done according to the composition of soil loss estimation and morphometric analysis of watersheds. The results of which are displayed in Table 5.9, 5.10 and 5.11, Fig 5.1,5.2 and 5.3.

Name	Basin-Code	Area in Sq. km	Area in Percentage
KD1	1 order_1	0.11	0.1
KD2	1 order_2	0.19	0.3
KD3	2 order_1	2.34	3.1
KD4	2 order_2	1.04	1.4
KD5	3 order_1	11.57	15.4
KD6	3 order_2	2.22	3.0
KD7	3 order_3	2.38	3.2
KD8	4 order_1	22.98	30.5
KD9	4 order_2	7.40	9.8
KD10	4 order_3	11.81	15.7
KD11	4 order_4	13.20	17.5

Table 5.9 : RANKING TABLE FOR MORPHOMETRIC ANALYSIS

Name	Sub-basin Code	Stream Order	Stream Number	Rt	Rbm	D	Fs	Rf	Rc	Lg	Bs	Average Value	Final Ranking	Priority
KD1	1 order_1	1	1	0.6390	0	3.1770	14.8298	0.0275	0.3458	1.5885	0.0045		**3**	**Medium**
	Ranking			6	1	2	8	3	9	2	1	**4**		
KD2	1 order_2	1	1	0.5656	1	4.1019	8.4540	0.0378	0.4753	2.0509	0.0051		**4**	**Low**
	Ranking			6	5	2	5	4	10	2	2	**4.5**		
KD3	2 order_1	2	5	0.2388	0.75	1.3302	1.7203	0.0133	0.1665	0.6651	0.0039		**2**	**High**
	Ranking			2	4	1	1	2	5	1	1	**2.125**		
KD4	2 order_2	2	4	0.3842	1.5	1.8183	3.0822	0.0240	0.3008	0.9091	0.0037		**3**	**Medium**
	Ranking			4	8	1	2	3	8	1	1	**3.5**		
KD5	3 order_1	3	30	0.4773	1.0556	1.0681	1.3907	0.1015	0.2057	0.5341	0.0164		**4**	**Low**
	Ranking			5	6	1	1	10	6	1	4	**4.25**		
KD6	3 order_2	3	8	0.3384	1.3889	1.1637	1.9312	0.0222	0.2792	0.5818	0.0043		**2**	**high**
	Ranking			2	7	1	1	3	7	1	1	**2.875**		
KD7	3 order_3	3	8	0.3345	1.3889	1.2554	1.8011	0.0233	0.2925	0.6277	0.0056		**3**	**Medium**
	Ranking			2	7	1	1	3	8	1	2	**3.125**		
KD8	4 order_1	3	69	0.9683	1.3889	1.1969	1.6105	0.0253	0.3179	0.5984	0.0263		**4**	**Low**
	Ranking			10	7	1	1	3	8	1	5	**4.5**		
KD9	4 order_2	4	38	0.6549	1.2292	1.4107	2.0647	0.0219	0.2747	0.7054	0.0382		**4**	**Low**
	Ranking			7	7	1	2	3	7	1	8	**4.5**		
KD10	4 order_3	4	62	0.9751	1.4792	1.4961	2.1121	0.0290	0.3648	0.7480	0.0374		**5**	**Very low**
	Ranking			10	8	1	2	3	9	1	8	**5.25**		
KD11	4 order_4	4	49	0.7878	1.4792	1.1962	1.4931	0.0339	0.4262	0.5981	0.0176		**4**	**Low**
	Ranking			8	8	1	1	4	10	1	4	**4.625**		

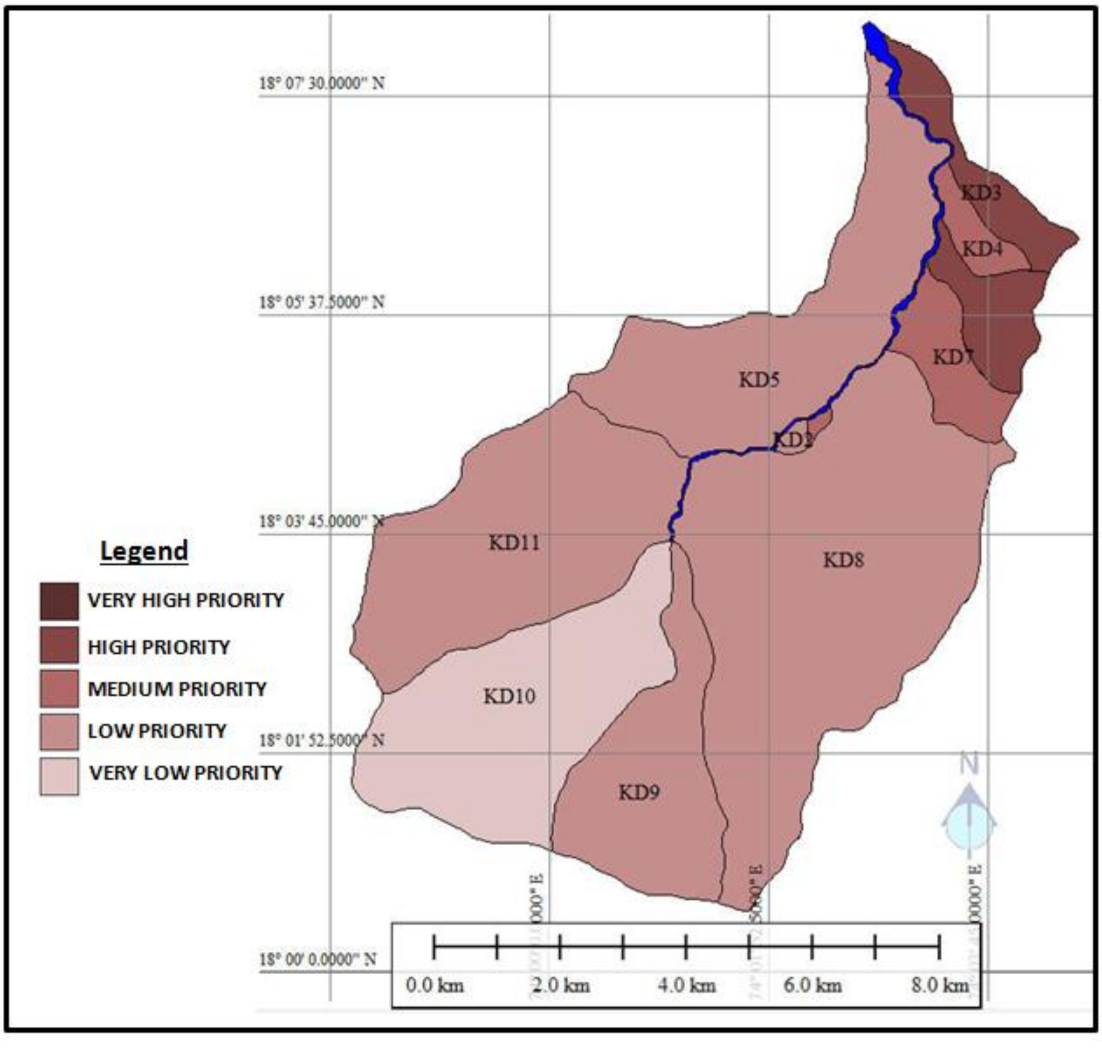


FIG 5.1 : Prioritization of watershed based on morphometric Analysis

Table 5.10 : RANKING TABLE FOR SOIL LOSS ESTIMATION

Name	Sub-basin Code	Stream Order	Stream Number	Soil Loss (Sl)	Final Ranking	Priority
KD1	1 order_1	1	1	0.6100	1	very high
	Ranking			1		
KD2	1 order_2	1	1	0.8000	1	very high
	Ranking			1		
KD3	2 order_1	2	5	21.5000	5	very low
	Ranking			6		
KD4	2 order_2	2	4	9.6000	2	high
	Ranking			3		
KD5	3 order_1	3	30	30.0000	5	very low
	Ranking			8		
KD6	3 order_2	3	8	16.2000	4	low
	Ranking			5		
KD7	3 order_3	3	8	23.6000	5	very low
	Ranking			6		
KD8	4 order_1	3	69	34.0000	5	very low
	Ranking			9		
KD9	4 order_2	4	38	28.0000	5	very low
	Ranking			7		
KD10	4 order_3	4	62	29.0000	5	very low
	Ranking			8		
KD11	4 order_4	4	49	30.0000	5	very low
	Ranking			8		

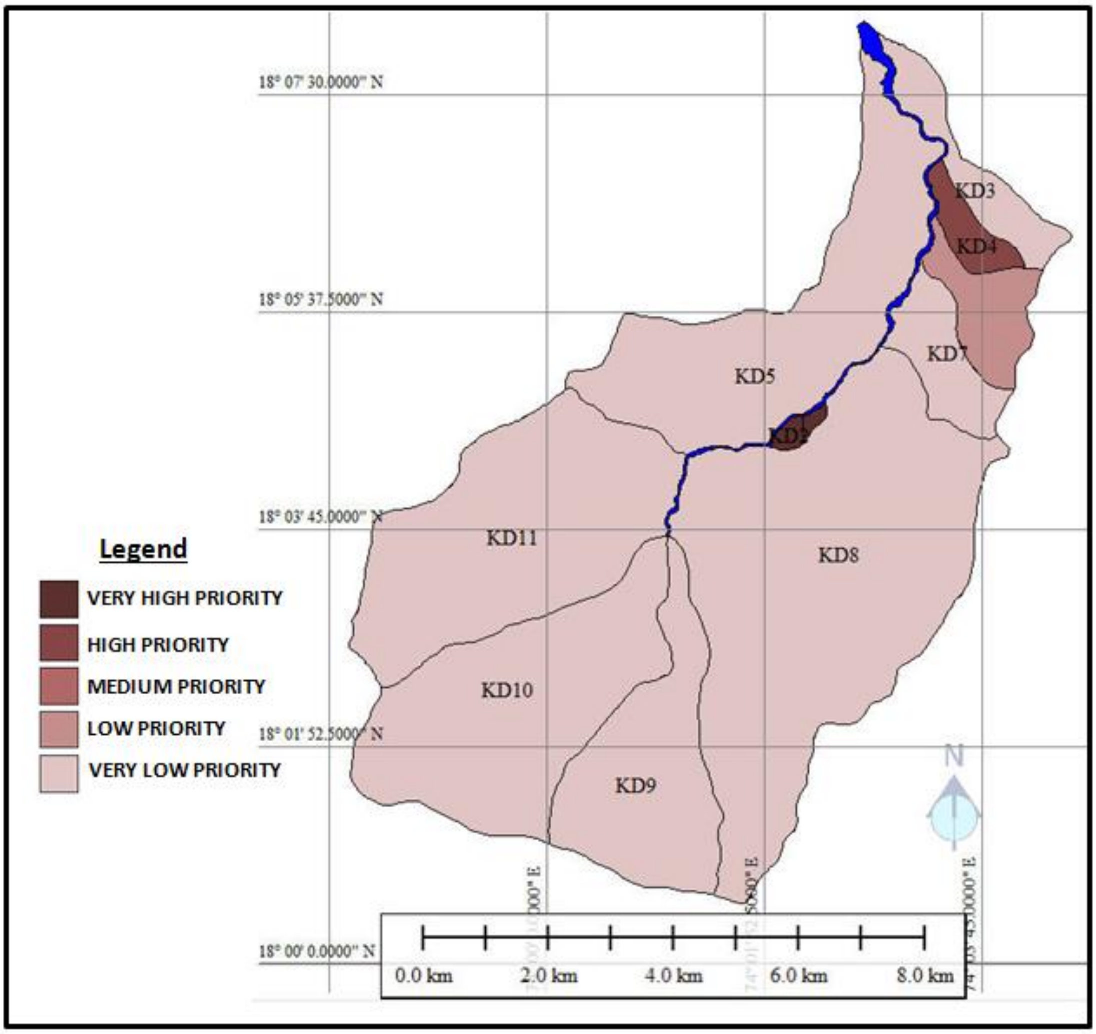


FIG 5.2 :Prioritization of watershed based on Soil Loss Estimation

Table 5.11 : COMPOSITE RANKING FOR PRIORITIZATION OF WATERSHEDS

Name	Sub-basin Code	Stream Order	Stream Number	Rt	Rbm	D	Fs	Rf	Rc	Lg	Bs	Sl	Average Value	Final Ranking	Priority
KD1	1 order_1	1	1	0.6390	0	3.1770	14.8298	0.0275	0.3458	1.5885	0.0045	0.6100		**3**	**Medium**
	Ranking			6	1	2	8	3	9	2	1	1	3.666667		
KD2	1 order_2	1	1	0.5656	1	4.1019	8.4540	0.0378	0.4753	2.0509	0.0051	0.8000		**4**	**low**
	Ranking			6	5	2	5	4	10	2	2	1	4.111111		
KD3	2 order_1	2	5	0.2388	0.75	1.3302	1.7203	0.0133	0.1665	0.6651	0.0039	21.5000		**2**	**high**
	Ranking			2	4	1	1	2	5	1	1	6	2.555556		
KD4	2 order_2	2	4	0.3842	1.5	1.8183	3.0822	0.0240	0.3008	0.9091	0.0037	9.6000		**3**	**Medium**
	Ranking			4	8	1	2	3	8	1	1	3	3.444444		
KD5	3 order_1	3	30	0.4773	1.0556	1.0681	1.3907	0.1015	0.2057	0.5341	0.0164	30.0000		**4**	**low**
	Ranking			5	6	1	1	10	6	1	4	8	4.666667		
KD6	3 order_2	3	8	0.3384	1.3889	1.1637	1.9312	0.0222	0.2792	0.5818	0.0043	16.2000		**3**	**Medium**
	Ranking			2	7	1	1	3	7	1	1	5	3.111111		
KD7	3 order_3	3	8	0.3345	1.3889	1.2554	1.8011	0.0233	0.2925	0.6277	0.0056	23.6000		**3**	**Medium**
	Ranking			2	7	1	1	3	8	1	2	6	3.444444		
KD8	4 order_1	3	69	0.9683	1.3889	1.1969	1.6105	0.0253	0.3179	0.5984	0.0263	34.0000		**4**	**low**
	Ranking			10	7	1	1	3	8	1	5	9	5		
KD9	4 order_2	4	38	0.6549	1.2292	1.4107	2.0647	0.0219	0.2747	0.7054	0.0382	28.0000		**4**	**low**
	Ranking			7	7	1	2	3	7	1	8	7	4.777778		
KD10	4 order_3	4	62	0.9751	1.4792	1.4961	2.1121	0.0290	0.3648	0.7480	0.0374	29.0000		**5**	**very low**
	Ranking			10	8	1	2	3	9	1	8	8	5.555556		
KD11	4 order_4	4	49	0.7878	1.4792	1.1962	1.4931	0.0339	0.4262	0.5981	0.0176	30.0000		**4**	**low**
	Ranking			8	8	1	1	4	10	1	4	8	5		

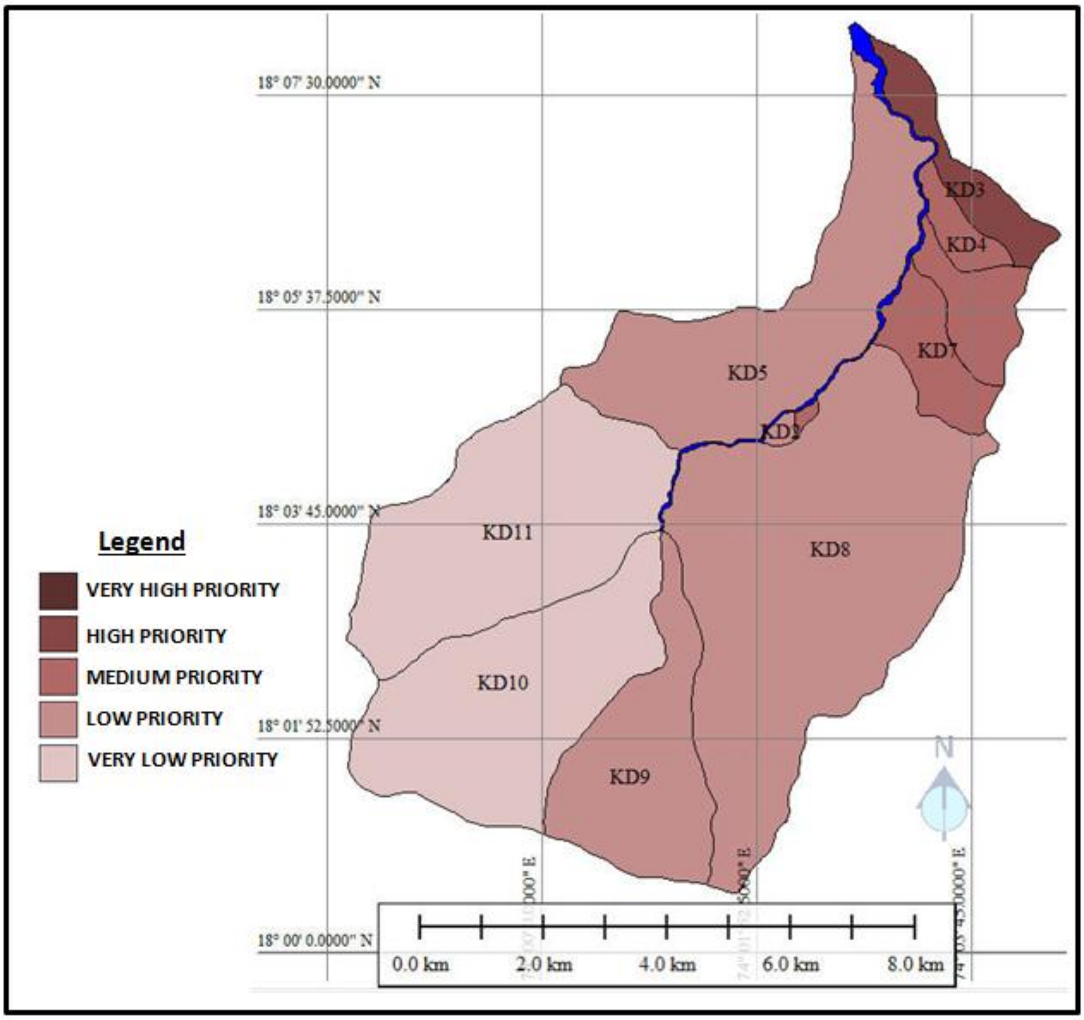
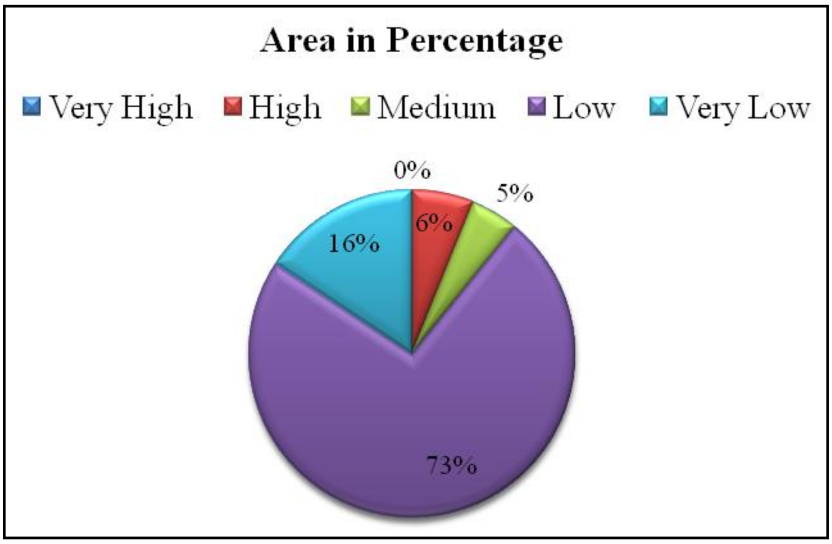


FIG 5.3 : Composite map for Prioritization of watersheds

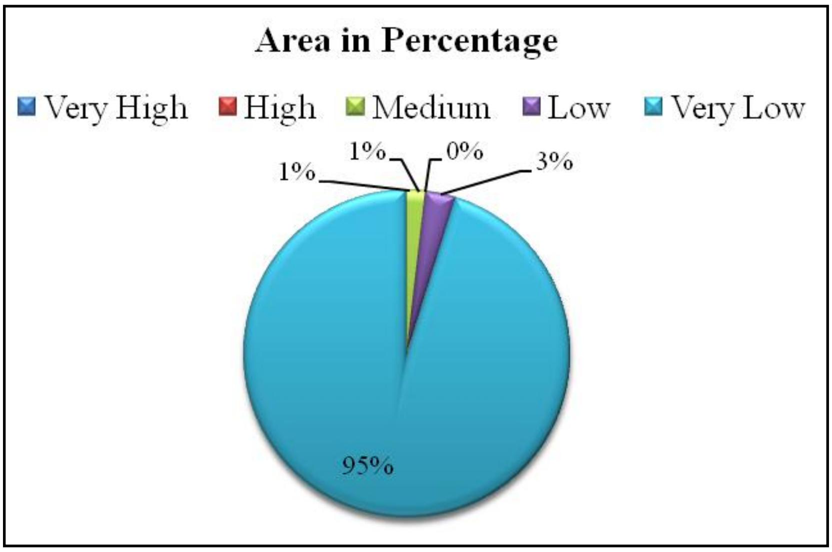
Morphometric Analysis :

The morphometric properties of soil gives the different values for different parameter, these values are different for different sub-basin. The high priority level zone covers an area near about 6% of total area, medium priority level zone cover an area of 5% of total area, low priority level zone covers an area of 73% of total area, very low priority level zone covers an area of 16%. The maximum area is covers by low priority level zone where the high drainage density and stream frequency is observed. (Table 5.9 and Fig 5.1)



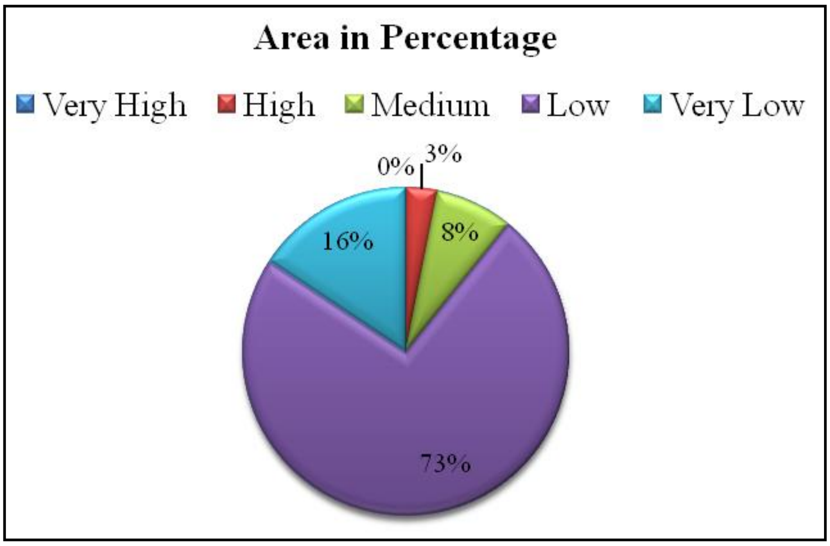
Soil Loss Estimation :

The soil loss gives the different values for different sub-basin. The high priority and very high priority level zone covers an area 1% of total area, low priority level zone covers an area of 3% of total area, very low priority level zone covers an area of 95%. The maximum area is covers by low priority level zone (Table 5.10 and Fig 5.2)



Composition of Morphometric and Soil loss :

The composition of morphometric and soil loss gives different ranking values. The high priority level zone covers an area 3% of total area, medium priority level zone cover an area of 8% of total area, low priority level zone covers an area of 73% of total area, very low priority level zone covers an area of 16%. The maximum area is covers by low priority level zone (Table 5.11 and Fig 5.3)



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6 Findings, Conclusion and Suggestions

6.1 Findings and conclusions

1. It is observed that in the study area four distinct geomorphic units i.e. Hill summit (1%), hill fringe (7%), pediment summit (71%) and valley floor (21%) can be identified. This units however are subject to various geomorphic processes leading to soil loss, runoff etc. It is also observed that, being a semi arid zone, soil environment is very conducive for such kind of processes (soil loss and runoff) as it can be inferred from textural analysis, that entire area is predominantly characterized by sandy soil environment, indicative of high runoff and soil erosion.
2. Infiltration rates and hydraulic conductivity observations made in the field also confirm that, soil environment is very prone to erosion. According to land use/ land cover analysis, it is observed that most of land surfaces are of wasteland type and subjected to degradation. It is also inferred that there is a strong relationship exist between geomorphic processes and soil environment.
3. As far as slope morphology is concerned, slope is from 0 to 40% and mainly comprises the pediment (55.84 sq. km) 73% surface. According to basin morphometric analysis it is observed that 2 watersheds comprising about 6 % area is subject to severe land degradation in terms of soil loss and runoff. The maximum soil loss in Khandala watershed noticed to 32.80 $kg/m^2/y$. The average annual soil loss in Khandala watershed was 12.80 $kg/m^2/y$. The soil loss increases due to increase in slope and rainfall.
4. Composite map prepared from morphometric analysis and soil loss estimation clearly gives the idea of entire watershed, these watersheds needed urgent conservation planning measures in the study area.

Physical, chemical and hydrological properties of soil, soil loss, geomorphic units, land use/land cover classes were analyzed for every slope unit of the Khandala Watershed. A ridge to valley approach is necessary for holistic development of the watershed. The steep slope (18-30%) and very steep (above 30%) units can be managed in terms of soil loss control and more land cover can be brought under forest cover especially from wasteland category. The gullies in these units can be treated with biological and engineering measures to control soil erosion.

Then the moderately steep slope (10-18%) and moderate slope (5-10%) units have high soil loss which can be reduced by soil erosion control measures like trenching, contour bunding etc. More barren land can be brought under forest cover through afforestation programmes. In the gentle slope units (2-5%) barren land can be brought under cultivation by improving soil fertility, irrigation, applying fertilizer etc. Also the soil loss can be controlled easily by terracing, ridges and furrows etc. Lastly in the level slope (below 2%) units, barren land can be brought under settlements or agriculture.

6.2 Suggestions

Promotion of agro-forestry & horticulture. Encouraging people's participation through community organization and capacity building. Drainage Line treatment by vegetative and engineering structures. Development of small water Harvesting Structures. Afforestation of degraded forest and non forest wasteland. Development and conservation of common Property Resources. Planning for land conservation should be prioritized based on the severity of the degradational problems arising owing to water and wind erosions and anthropogenic activities. Afforestation activities like agroforestry, silviculture and social forestry should be adopted to protect agricultural lands from further deterioration arising out of degradational processes. Afforestation of degraded and wastelands should be given priority.

As conservation and land rehabilitation measures are highly expensive, the area for reclamation should be prioritized based on the severity of the land degradation, the nature of the extent of the problem and the proposed land use. The maps and the data given in this publication can be effectively used for such initiatives.

The database and GIS-based maps generated in the study can be used most effectively by the National and State Planning Commissions/ departments to assign high priority to areas identified as degraded and wastelands. Soil conservation approach is to minimize the silt content which goes to the reservoir. Conserve maximum amounts of water in the soil profile, to promote growth of crops, vegetables, trees etc.

Collection of surplus run-off for meeting the drinking water requirement of cattle and human population in study areas for partially irrigating a small patch of land. Improve the main and on-farm irrigation systems for increased productivity and increased area under irrigation to achieve optimum productivity per unit land and water. The balancing of non-agricultural (industrial, domestic and human settlement) uses of land and water with agriculture, animal husbandry, and allied uses of land and water. Generation of income and employment in harmony with land and agro-climatic conditions.

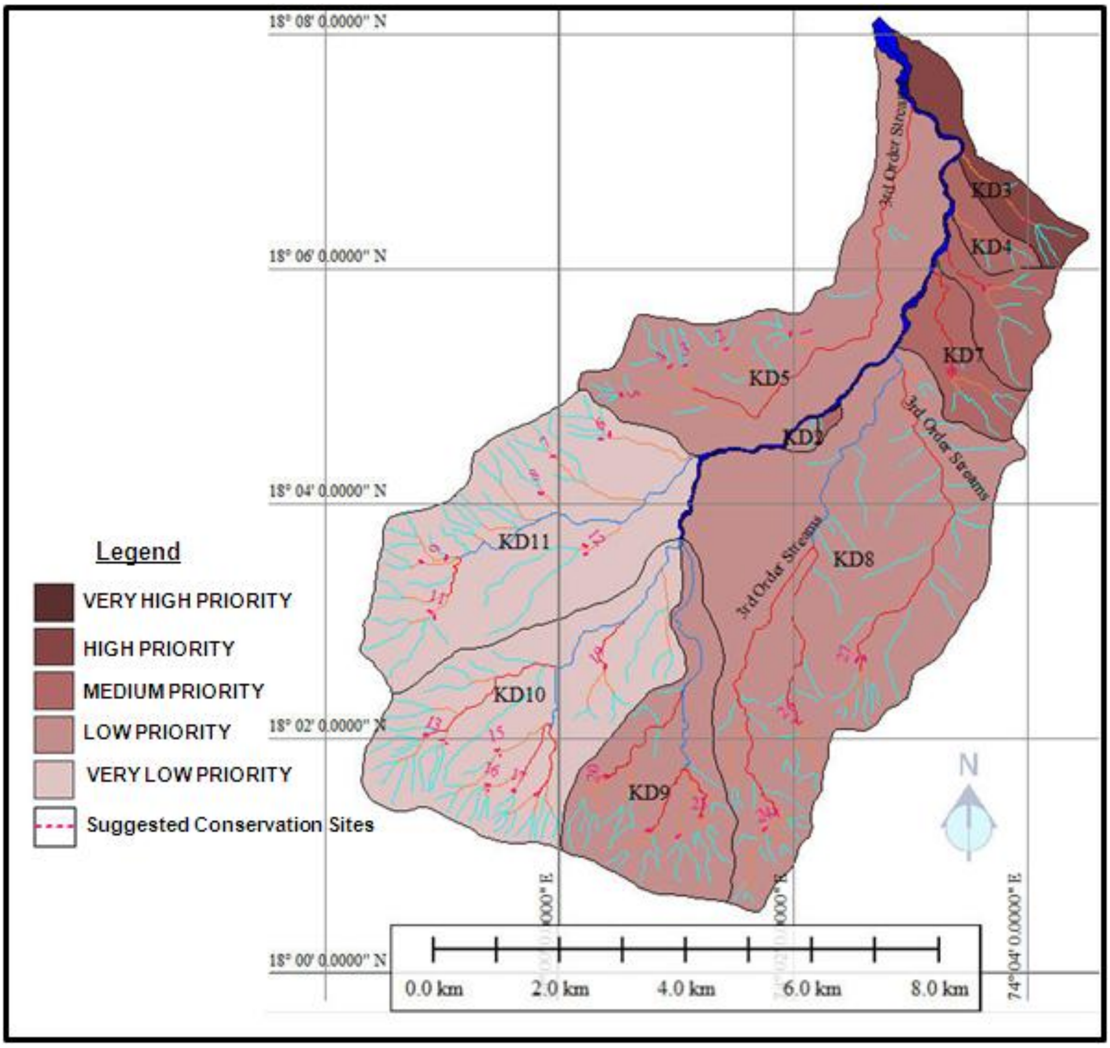

FIG 6.1 : SUGGESTED CONSERVATION MAP BASED ON PRIORITIZATION OF WATERSHEDS

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Sub-basin Code	Stream Order	Stream number	Length in Km.	Mean Length L	Area in Km2	Mean Area(Km2)	Bifurcation ratio	Basin perimeter	P	Basin Length Km	Length M	L 2	Drainage Density	Stream Frequency
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**15**	**16**
1 order_1	1	1	0.21423	0.21423	0.067432	0.067432		1.565	2.449225	1.565	1565	2.449225	3.176978289	14.82975442
1 order_2	1	1	0.4852	0.4852	0.118287	0.118287	1	1.768	3.125824	1.768	1768	3.125824	4.101887781	8.454014389
2 order_1	1	4	2.20523	0.5513075	1.453238	0.3633095	0.25	10.469	109.599961	10.469	10469	109.599961	1.517459632	2.75247413
	2	1	1.661	1.661	1.453238	1.453238	4	10.469	109.599961	10.469	10469	109.599961	1.142964883	0.688118533
				1.661										
2 order_2	1	3	1.29673	0.432243333	0.648888	0.216296	0.333333333	5.205	27.092025	5.205	5205	27.092025	1.998388011	4.623294005
	2	1	1.063	1.063	0.648888	0.648888	0	5.205	27.092025	5.205	5205	27.092025	1.638187176	1.541098002
				1.063										
3 order_1	1	23	10.27	0.446521739	7.1905	0.312630435	0.043478261	20.952	438.986304	8.415	8415	70.812225	1.428273416	3.198664905
	2	6	5.34604	0.891006667	7.1905	1.198416667	3.833333333	20.952	438.986304	8.415	8415	70.812225	0.743486545	0.834434323
	3	1	7.425	7.425	7.1905	7.1905	6	20.952	438.986304	8.415	8415	70.812225	1.032612475	0.139072387
				7.425										
3 order_2	1	5	2.97364	0.594728	1.380817	0.2761634	0	7.881	62.110161	7.881	7881	62.110161	2.153536638	3.621044642
	2	2	0.86595	0.432975	1.380817	0.6904085	2.5	7.881	62.110161	7.881	7881	62.110161	0.627128722	1.448417857
	3	1	0.98096	0.98096	1.380817	1.380817	2	7.881	62.110161	7.881	7881	62.110161	0.71041999	0.724208928
				0.98096										
3 order_3	1	5	2.66416	0.532832	1.480596	0.2961192	0	7.973	63.568729	7.973	7973	63.568729	1.799383492	3.377018444
	2	2	0.94717	0.473585	1.480596	0.740298	2.5	7.973	63.568729	7.973	7973	63.568729	0.639722112	1.350807378
	3	1	1.965	1.965	1.480596	1.480596	2	7.973	63.568729	7.973	7973	63.568729	1.327168248	0.675403689
				1.965										
4 order_1	1	57	30.81924	0.540688421	14.28132	0.250549474	0	23.752	564.157504	23.752	23752	564.157504	2.158010604	3.991227702
	2	9	6.49089	0.72121	14.28132	1.586813333	6.333333333	23.752	564.157504	23.752	23752	564.157504	0.454502105	0.630193848
	3	3	13.969	4.656333333	14.28132	4.76044	3	23.752	564.157504	23.752	23752	564.157504	0.978130873	0.210064616
				4.656333										
4 order_2	1	25	12.79922	0.5119688	4.601114	0.18404456	0	14.505	210.395025	14.505	14505	210.395025	2.781765459	5.433466765
	2	9	4.47537	0.497263333	4.601114	0.511234889	2.777777778	14.505	210.395025	14.505	14505	210.395025	0.972670966	1.956048035
	3	3	4.37803	1.459343333	4.601114	1.533704667	3	14.505	210.395025	14.505	14505	210.395025	0.95151522	0.652016012
	4	1	4.311	4.311	4.601114	4.601114	3	14.505	210.395025	14.505	14505	210.395025	0.936947009	0.217338671
				4.311										
4 order_3	1	43	25.47056	0.592338605	7.338609	0.170665326	0	15.895	252.651025	15.895	15895	252.651025	3.470761285	5.859421043
	2	14	8.542228	0.610159143	7.338609	0.524186357	3.071428571	15.895	252.651025	15.895	15895	252.651025	1.164011872	1.907718479
	3	4	5.76206	1.440515	7.338609	1.83465225	3.5	15.895	252.651025	15.895	15895	252.651025	0.785170596	0.545062423
	4	1	4.141	4.141	7.338609	7.338609	4	15.895	252.651025	15.895	15895	252.651025	0.564275873	0.136265606
				4.141										
4 order_4	1	35	24.05383	0.687252286	8.204436	0.234412457	0	15.549	241.771401	15.549	15549	241.771401	2.931807866	4.265984889
	2	11	9.83971	0.894519091	8.204436	0.745857818	3.181818182	15.549	241.771401	15.549	15549	241.771401	1.199315834	1.340738108
	3	2	0.803926	0.401963	8.204436	4.102218	5.5	15.549	241.771401	15.549	15549	241.771401	0.097986748	0.243770565
	4	1	4.56	4.56	8.204436	8.204436	2	15.549	241.771401	15.549	15549	241.771401	0.555796888	0.121885283
				4.56										

Sub-basin Code	Const.of Ch. Maint.	Length Ratio	Length of Overland F.	Const.of Ch. Maint.	Form factor	4ii*a	Circularity Ratio		Circularity Ratio	Height Km.	Height in M	
1	17	18	19	20	21	22	23		24	25	26	
1 order_1	0.314764505	#VALUE!	1.588489145	0.314764505	0.027531974	0.84694592		0.785	0.345801598			
		0										
1 order_2	0.24379019	2.264855529	2.050943891	0.24379019	0.037841862	1.48568472	0.475293785	0.785	0.475293785	0.8	800	
2 order_1	0.658996114	1.136247939	0.758729816	0.658996114	0.013259476	18.25266928		0.785	0.166539013		0	
	0.87491752	3.012837663	0.571482441	0.87491752	0.013259476	18.25266928		0.785	0.166539013		0	
2 order_2	0.500403322	0.260230785	0.999194006	0.500403322	0.023951255	8.15003328	0.300827763	0.785	0.300827763	0.8	800	
	0.610430856	2.459262915	0.819093588	0.610430856	0.023951255	8.15003328		0.785	0.300827763		0	
3 order_1	0.700146056	0.42005808	0.714136708	0.700146056	0.101543201	90.31268		0.785	0.205730063		0	
	1.345014254	1.995438494	0.371743272	1.345014254	0.101543201	90.31268		0.785	0.205730063		0	
	0.968417508	8.333270982	0.516306237	0.968417508	0.101543201	90.31268	0.205730063	0.785	0.205730063		0	
											0	
3 order_2	0.464352443	0.080098047	1.076768319	0.464352443	0.022231741	17.34306152	0.279230664	0.785	0.279230664	0.708	708	
	1.59456897	0.728021886	0.313564361	1.59456897	0.022231741	17.34306152	0.279230664	0.785	0.279230664	0.7	700	
	1.407618048	2.265627346	0.355209995	1.407618048	0.022231741	17.34306152	0.279230664	0.785	0.279230664	0.854	854	
											0	
3 order_3	0.555745901	0.543174034	0.899691746	0.555745901	0.023291263	18.59628576		0.785	0.292538266		0	
	1.563178732	0.888807354	0.319861056	1.563178732	0.023291263	18.59628576		0.785	0.292538266		0	
	0.753483969	4.149202361	0.663584124	0.753483969	0.023291263	18.59628576		0.785	0.292538266		0	
											0	
4 order_1	0.463389753	0.275159502	1.079005302	0.463389753	0.02531442	179.3733792		0.785	0.317949115		0	
	2.200209833	1.33387358	0.227251052	2.200209833	0.02531442	179.3733792	0.317949115	0.785	0.317949115	0.74	740	
	1.022358079	6.456279493	0.489065437	1.022358079	0.02531442	179.3733792		0.785	0.317949115		0	
4 order_2	0.359483937	0.109951071	1.39088273	0.359483937	0.02186893	57.78999184		0.785	0.274673756		0	
	1.028096895	0.971276635	0.486335483	1.028096895	0.02186893	57.78999184		0.785	0.274673756		0	
	1.050955338	2.934749529	0.47575761	1.050955338	0.02186893	57.78999184	0.274673756	0.785	0.274673756	1.2	1200	
	1.067296219	2.954068382	0.468473504	1.067296219	0.02186893	57.78999184		0.785	0.274673756			
											0	
4 order_3	0.288121227	0.137401671	1.735380642	0.288121227	0.029046425	92.17292904		0.785	0.364823096		0	
	0.859097767	1.030085053	0.582005936	0.859097767	0.029046425	92.17292904	0.364823096	0.785	0.364823096	0.92	920	
	1.273608571	2.360884069	0.392585298	1.273608571	0.029046425	92.17292904		0.785	0.364823096			
	1.772182806	2.874666352	0.282137936	1.772182806	0.029046425	92.17292904		0.785	0.364823096			
4 order_4	0.341086471	0.16596288	1.465903933	0.341086471	0.033934684	103.0477162		0.785	0.426219626			
	0.83380872	1.301587655	0.599657917	0.83380872	0.033934684	103.0477162		0.785	0.426219626			
	10.2054617	0.449362126	0.048993374	10.2054617	0.033934684	103.0477162		0.785	0.426219626			
	1.799218421	11.34432771	0.277898444	1.799218421	0.033934684	103.0477162	0.426219626	0.785	0.426219626	0.9	900	

Sub-basin	Stream	stream No	Relief ratio	Rugg No.RN		Lemnisca	Area	Texture	Max. height	Min.Height	Basin	Basin	Basin
Code	Order				4*a	te method	Ratio	ratio	in M	in M	relief in M	Length M	slope
1	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**
1 order_1	1	1	0	0	0	0	0	0.638977636	628	621	7	1565	0.004472843
1 order_2	1	1		0	0	0	0	0.56561086	631	622	9	1768	0.005090498
2 order_1	1	4	0	0	0	0	0	0.382080428	619	578	41	10469	0.003916324
0	2	1	0	0	0	0	4	0.095520107	619	578	41	10469	0.003916324
2 order_2	1	3	0	0	0	0	0	0.576368876	616	597	19	5205	0.003650336
0	2	1	0	0	0	0	3	0.192122959	616	597	19	5205	0.003650336
3 order_1	1	23	0	0	0	0	0	1.097747232	717	579	138	8415	0.016399287
0	2	6	0	0	28.762	0.406172804	3.83333333	0.286368843	717	579	138	8415	0.016399287
0	3	1	0	0	28.762	0.406172804	6	0.047728141	717	579	138	8415	0.016399287
3 order_2	1	5	0	0	0	0	0	0.634437254	634	600	34	7881	0.004314173
0	2	2	0.088821216	0.438990105	5.523268	0.088926963	2.5	0.253774902	634	600	34	7881	0.004314173
0	3	1	0.108361883	0.606698672	5.523268	0.088926963	2	0.126887451	634	600	34	7881	0.004314173
3 order_3	1	5	0	0	0	0	0	0.627116518	645	600	45	7973	0.005644049
0	2	2		0	5.922384	0.093165053	2.5	0.250846607	645	600	45	7973	0.005644049
0	3	1		0	5.922384	0.093165053	2	0.125423304	645	600	45	7973	0.005644049
4 order_1	1	57		0	0	0	0	2.399797912	1250	625	625	23752	0.026313574
0	2	9	0.031155271	0.336331558	57.12528	0.10125768	6.33333333	0.37891546	1250	625	625	23752	0.026313574
0	3	3		0	57.12528	0.10125768	3	0.126305153	1250	625	625	23752	0.026313574
4 order_2	1	25		0	0	0	0	1.723543606	1196	642	554	14505	0.038193726
0	2	9		0	18.404456	0.087475719	2.77777778	0.620475698	1196	642	554	14505	0.038193726
0	3	3	0.082730093	1.141818264	18.404456	0.087475719	3	0.206825233	1196	642	554	14505	0.038193726
0	4	1	0	0	18.404456	0.087475719	3	0.068941744	1196	642	554	14505	0.038193726
4 order_3	1	43		0	0		0	2.705253224	1238	643	595	15895	0.037433155
0	2	14	0.057879836	1.070890922	29.354436	0.116185699	3.07142857	0.88078012	1238	643	595	15895	0.037433155
0	3	4	0	0	29.354436	0.116185699	3.5	0.251651463	1238	643	595	15895	0.037433155
0	4	1	0	0	29.354436	0.116185699	4	0.062912866	1238	643	595	15895	0.037433155
4 order_4	1	35	0	0	0	0	0	2.250948614	924	650	274	15549	0.017621712
0	2	11	0	0	32.817744	0.135738734	3.18181818	0.707440993	924	650	274	15549	0.017621712
0	3	2	0	0	32.817744	0.135738734	5.5	0.128625635	924	650	274	15549	0.017621712
0	4	1	0.057881536	0.5002172	32.817744	0.135738734	2	0.064312818	924	650	274	15549	0.017621712
							0						

Sub-basin	Channel	Direct		Sinuosity			
Code	**Length in km**	**Length in Km**		**Index**	**Min**	**max**	**Average**
1	**X**	**Y**	**X-Y**	**X-Y/Y**			
1 order_1					**0.03**	**0.61**	**0.32**
1 order_2	1.768	1.5	0.268	0.178666667	0.28	0.8	**0.54**
2 order_1					0.6	21.5	**11.05**
0					0.6	21.5	**11.05**
2 order_2	5.205	1.7	3.505	2.061764706	0.4	9.6	**5**
0					0.4	9.6	**5**
3 order_1					0.1	30	**15.05**
0					0.1	30	**15.05**
0	8.415	2.7	5.715	2.116666667	0.1	30	**15.05**
3 order_2	7.881	0.6	7.281	12.135	0.1	16.2	**8.15**
0	7.881	0.65	7.231	11.12461538	0.1	16.2	**8.15**
0	7.881	0.4	7.481	18.7025	0.1	16.2	**8.15**
3 order_3					0.1	23.6	**11.85**
0					0.1	23.6	**11.85**
0					0.1	23.6	**11.85**
4 order_1					0.1	34	**17.05**
0	23.752	1.4	22.352	15.96571429	0.1	34	**17.05**
0					0.1	34	**17.05**
4 order_2					0.1	28	**14.05**
0					0.1	28	**14.05**
0	14.505	3.4	11.105	3.266176471	0.1	28	**14.05**
0					0.1	28	**14.05**
4 order_3					0.1	29	**14.55**
0	15.895	1.5	14.395	9.596666667	0.1	29	**14.55**
0	15.895	2.5	13.395	5.358	0.1	29	**14.55**
0	15.895	3.5	12.395	3.541428571	0.1	29	**14.55**
4 order_4					0.1	30	**15.05**
0	15.549	1.2	14.349	11.9575	0.1	30	**15.05**
0					0.1	30	**15.05**
0	15.549	0.9	14.649	16.27666667	0.1	30	**15.05**

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Photo Plate of Study Area

Photo Plate No. 1

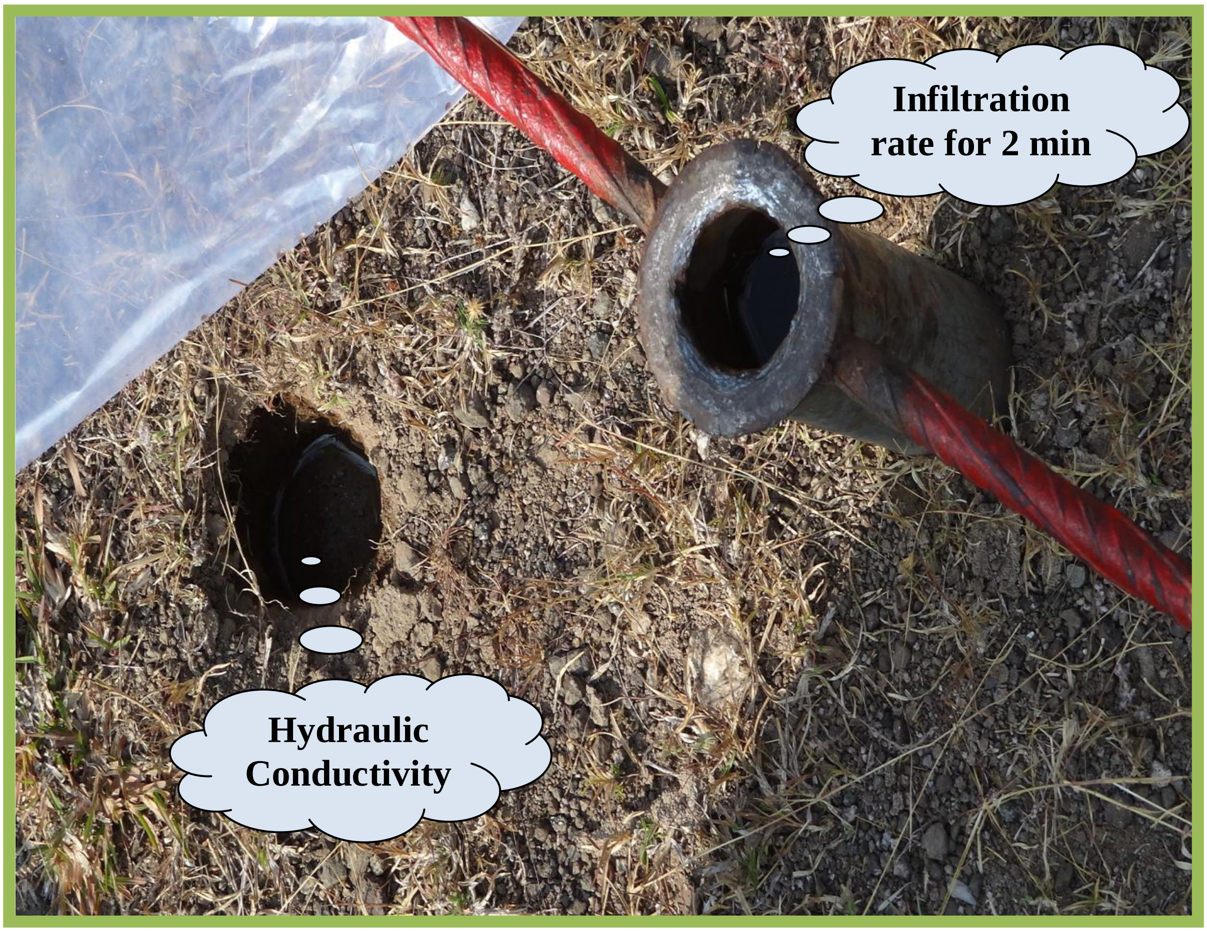
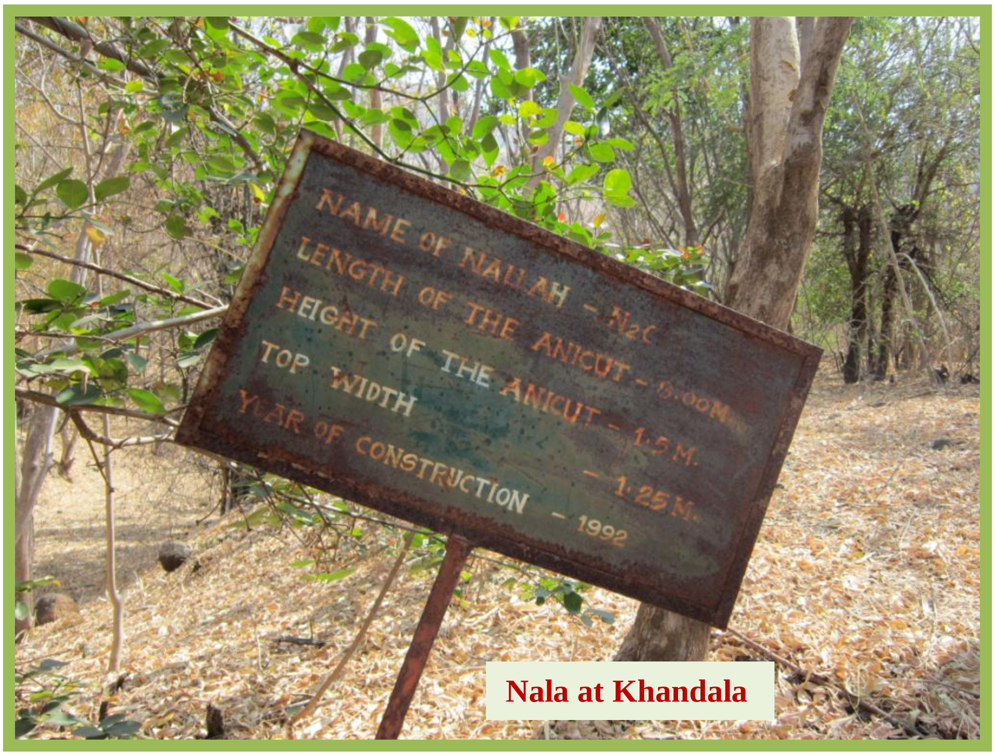


Photo Plate No. 2

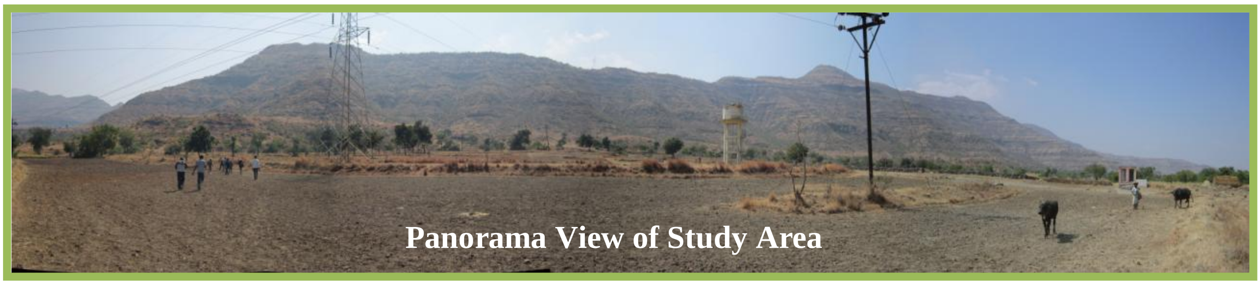
Photo Plate No. 3

Photo Plate No. 4



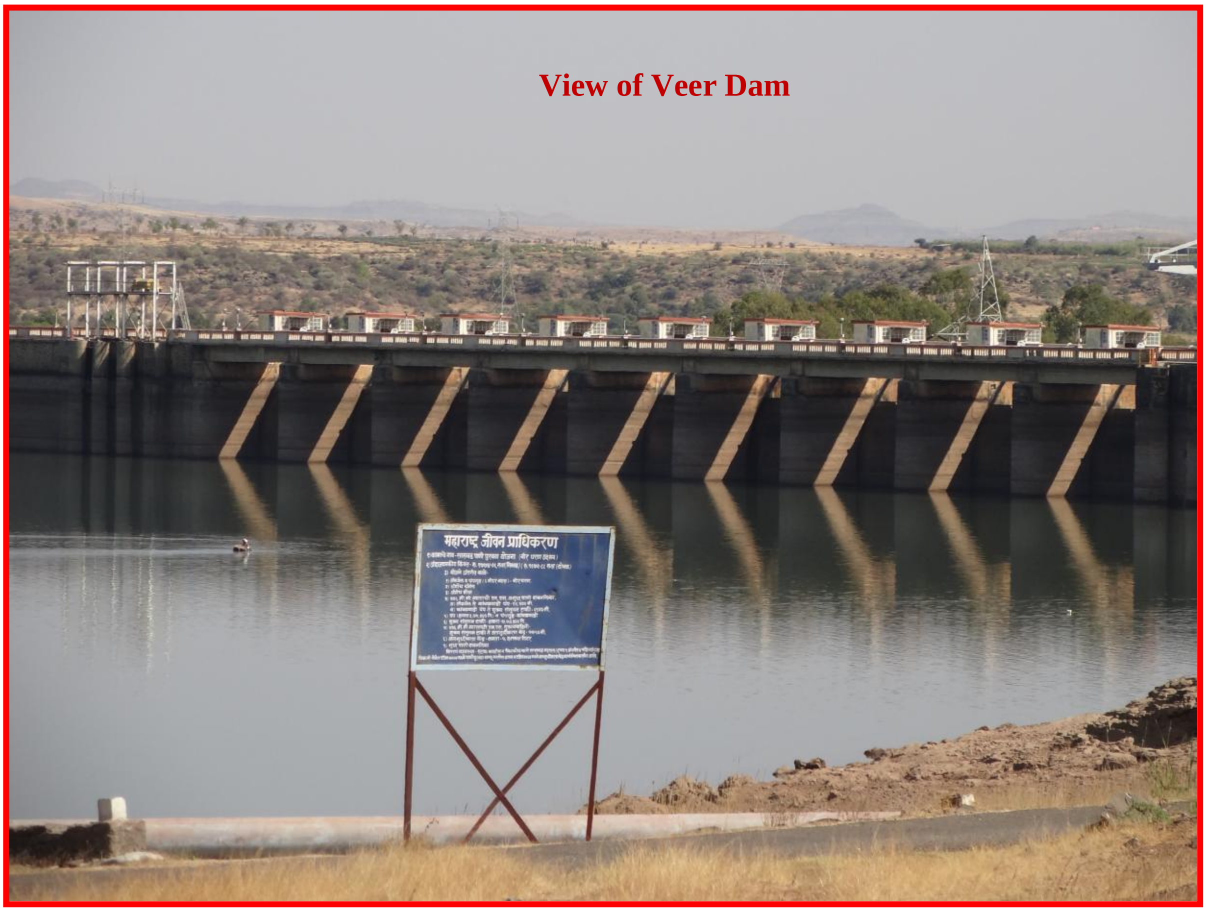
Nala at Khandala

Photo Plate No. 5



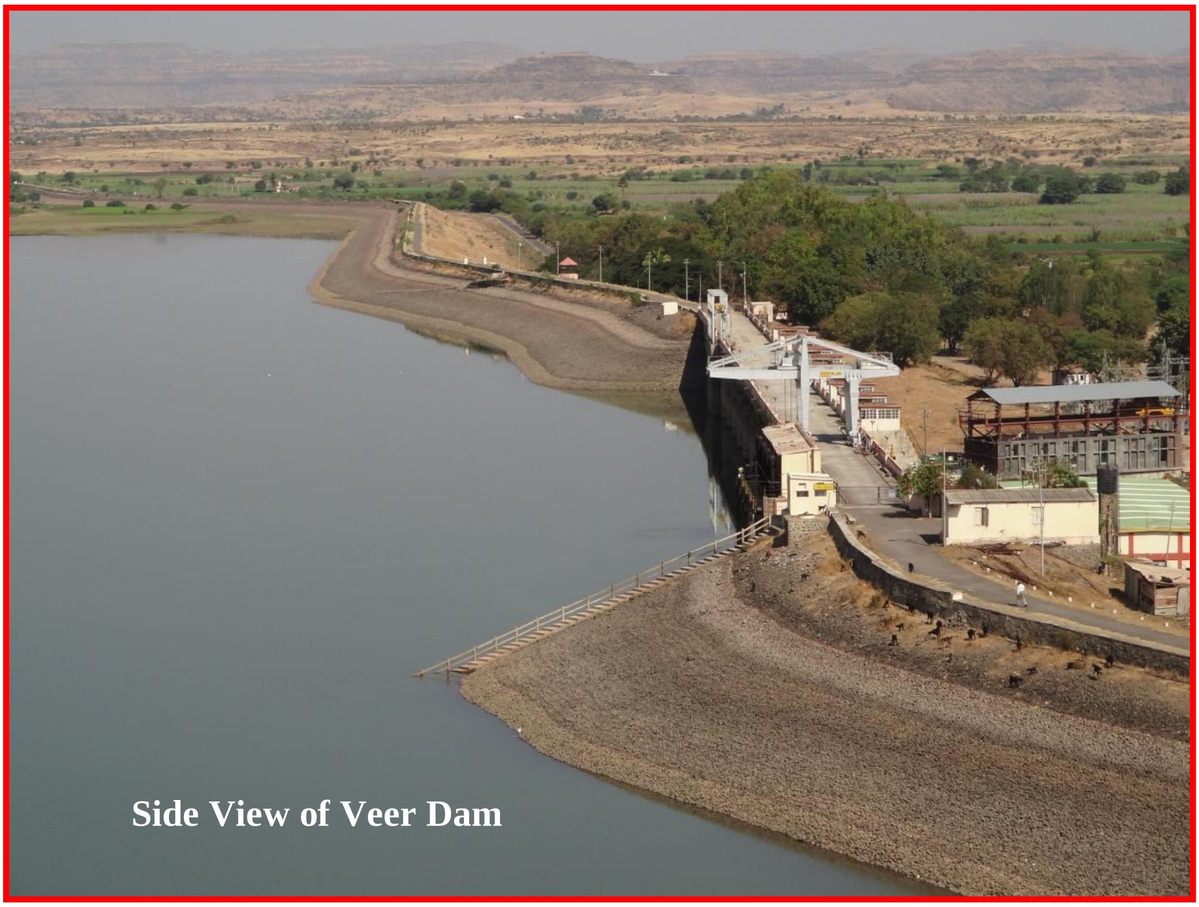
Panorama View of Study Area

Photo Plate No. 6



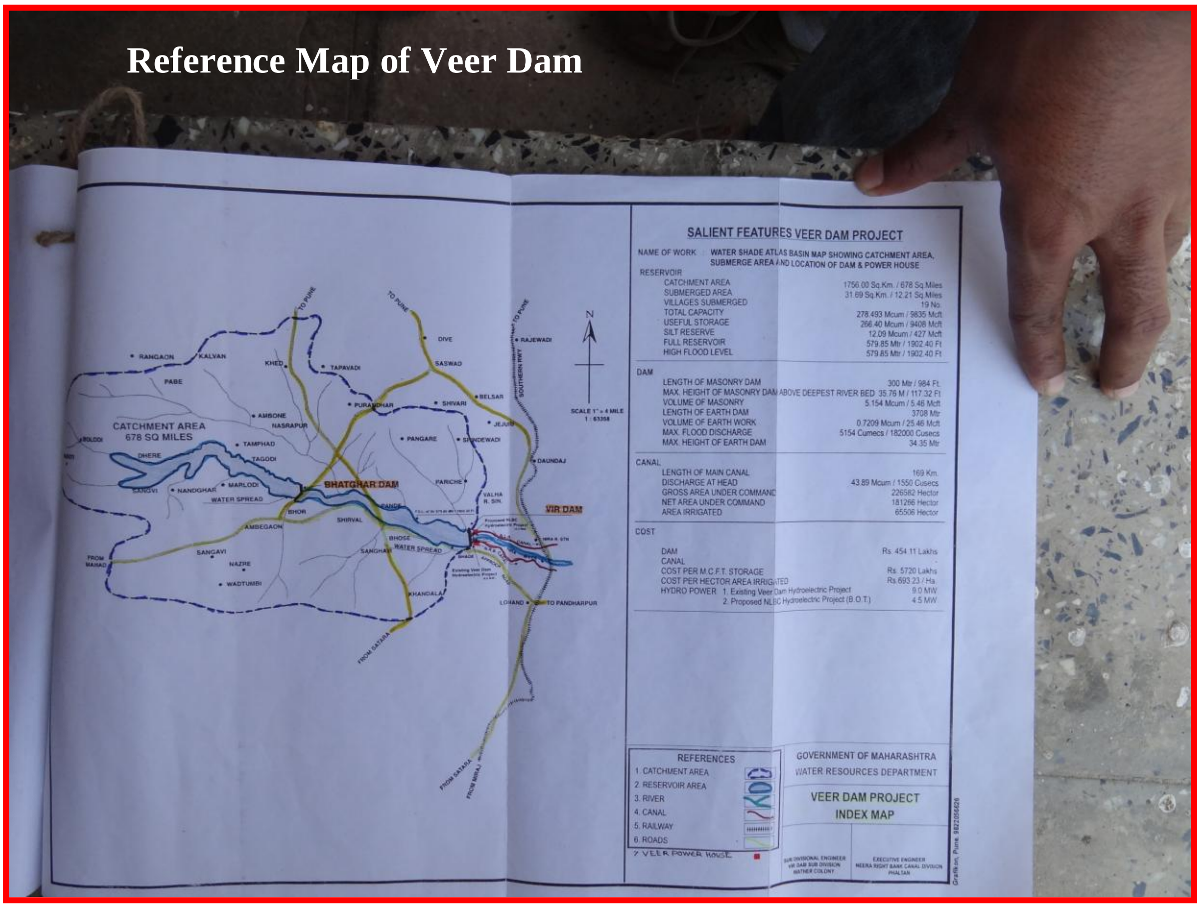
View of Veer Dam

Photo Plate No. 7



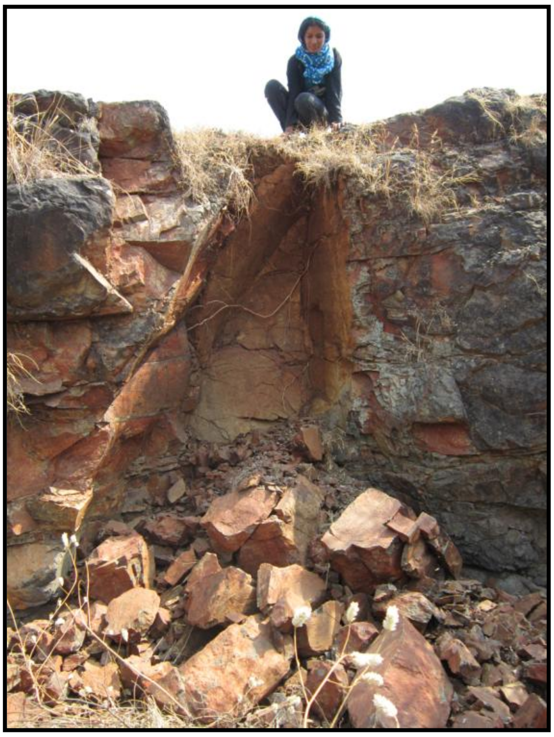
Side View of Veer Dam

Photo Plate No. 8



Reference Map of Veer Dam

Photo Plate No. 9



Rock instability at study area

Photo Plate No. 10

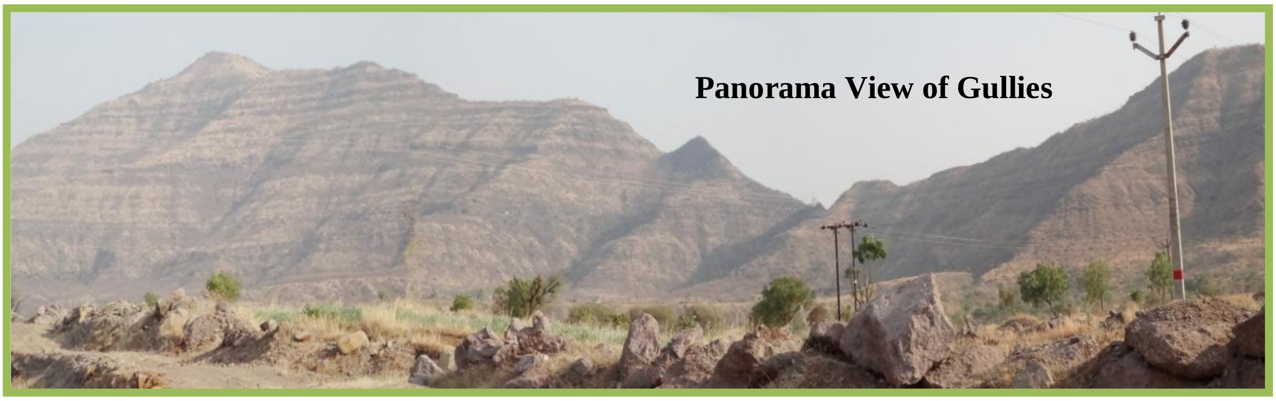
Photo Plate No. 11

Panorama View

Photo Plate No. 12

Panorama View of Study Area

Photo Plate No. 13



Panorama View of Gullies

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