Morphometric analysis and runoff studies of Darna lake catchment

A Thesis Submitted to
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By

Jyoti Anilkumar Pathare
Research Student

Under the Guidance of

Dr. Sunil W. Gaikwad
Associate Professor
Department of Geography
S. P. College, Pune.

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CERTIFICATE

This is to certify that the work incorporated in the thesis entitled, "Morphometric Analysis and Runoff Studies of Darna Lake Catchment" submitted by Mrs. Jyoti Anilkumar Pathare for award of Ph.D degree in Geography in faculty of moral and social science to the Tilak Maharashtra Vidyapeeth, Pune, is her original work which was carried out by the candidate under my guidance and this work has not been submitted previously for any other degree or diploma to this or any other university. The material obtained from other sources have been duly acknowledged in this thesis.

Place : Pune
Date : 30/08/2017

(Dr. Sunil W. Gaikwad)
Supervisor
Associate Professor
Department of Geography
S.P. College, Pune,
Pune- 411001

DECLARATION

I hereby declare that the thesis entitled "Morphometric Analysis and Runoff Studies of Darna Lake Catchment" is the original research work carried out by me under the guidance of Dr. Sunil W. Gaikwad for the award of Ph.D. degree in Geography to the Tilak Maharashtra Vidyapeeth, Pune. This has been not submitted previously for the award of any degree or diploma in any other university.

Place : Pune
Date : 30/08/2017

(Jyoti Anilkumar Pathare)
Research student

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(Jyoti Anilkumar Pathare)
Research Student

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF PHOTOGRAPHS

CHAPTER-I

INTRODUCTION

1.1 Introduction

1.2 Review of literature

1.3 Selection of the problem

1.4 Objectives

CHAPTER-I
INTRODUCTION

1.1 Introduction:

The quantitative analysis of morphometric properties of a drainage basin has been useful in many application studies like estimation of runoff, flood discharge, ground water recharge, sediment yield soil as well as water conservation, environmental analysis etc. The various morphometric properties depend on several aspects like geology, tectonics, vegetation and climate etc. The quantitative analysis of morphometric parameters is found to be of immense utility in river basin evaluation, watershed prioritization for soil and water conservation and natural resources management. The influence of drainage morphometric system is very significant in understanding the landform processes, soil physical properties and erosion characteristics. The drainage characteristics reflect the influence of variation of these determinants such as topography, climate and geology from place to place. Detailed morphometric analysis provides an insight on basin evolution and further it is role on development of drainage morphometry on landforms and their characteristics. It is a vital tool in any hydrological investigation like assessment of groundwater potential and management, pedology and environmental assessment.

In the assessment of hydro geomorphic characteristics of a drainage basin, knowledge of relief and drainage characteristics have to be assessed because these characteristics provide very basic information of physical make up of a basin and help to infer hydrodynamics of a basin.The morphometric approach involving the analysis of Digital elevation model has largely helped in the logical assessment of hydrological character of the basin. The analysis of various linear, areal and relief aspects has revealed that the topographical configuration and geomorphic setting of the basin.

In India some regions are mainly affected by severe erosion include the severely eroded gullied lands along the banks of the rivers Yamuna, Chambal, Mahi and other west flowing rivers in Gujarat state and the southern rivers namely the Cauvery and the Godavari river systems. Sheet and rill erosion is the most severe problem in the catchments of these rivers. Nearly 3200 major and medium dams and barrages had been constructed in India by the year 2012. Among all of these dams around 1821 notable large dams in state of Maharashtra. As a result, agricultural production is greatly affected on the red soils, which cover an area of 720000 km^2 in the basins of the Chambal and Godavari (Verma et. al., 1968). The depth of these soils is limited to 200 mm, in most of these areas. The lateritic soils which are associated with rolling and undulating topography have been found to lose about 40001 km^2 of valuable topsoil annually due to erosion in Peninsular India (Ram Babu et. al., 1978).Heavy annual slope wash in every monsoon season is a common problem of these catchment areas and contributing high SDR (Sediment Delivery Rates) accompanied by heavy runoffs and soil loss every year. These kinds of problems have not only remained a geo-environmental problem but also proved to be very serious as far as agricultural productivity of the area is concerned. When a dam is constructed with reservoirs in slide-prone areas it may bring problem of reservoir siltation by wide-scale slides at the fringe areas of the reservoir. The problem is very acute in the reservoir areas of some dams constructed in the Himalayan terrain. Such kind of problem associated with Jaldhaka dam of the Darjeeling was built with its reservoir spread in highly slide-prone areas that gave rise to the problem of siltation. The problem of siltation became serious within one year of dam construction when there was flood in the river and large scale landslides took place in the catchment. A suspended silt content of 825 to 2517 gm/m^3 was recorded in the river water per month during the rainy season (June-July). More than 70% of these suspended particles contain minerals with hardness between 5 and 7. 5 in Mobs scale of hardness (Gangopadhyay, 1980).

Watershed management is the process of formulation carrying out a course of action that involves modification in the natural system of watershed to achieve specified objectives (Johnson et al. 2002). It further implies appropriate use of land and water resources of a watershed for optimum production with minimum hazard to natural resources (Osborne and Wiley 1988; Kessler et al. 1992).Consequently, the study helped in the identification and mapping the potentiality of land-water resource majorly contributes for the edibles of the basin. The study has demonstrated the significance of morphometry as well as utility of remote sensing and GIS technology in hydrological characterization of the basin at micro-watershed level.

Water is one of the essential natural resource, without which life cannot exist. Demand of water is increasing with the increase of population. We need water for agriculture, industry, human and cattle consumption. Therefore, it is very important to manage this very essential resource with sustainable manner. Hence, we need proper management and development planning to restore or recharge water where runoff is very high due to various topographical conditions. If proper management is planned that will not only control surface soil erosion but also recharge ground water. Remote Sensing and GIS have become proven tools for the management and development of water resources. Extensive studies on drainage morphology using statistical and empirical techniques have been made since 1940's by well-known scientists including Horton (1945), Schumm (1956), Chorley (1957), Morisawa (1962), Strahler (1964), Gregory and Walling (1973) and many others. In India also quite a number of studies have been, made and their works have been reviewed by Singh (1983). Several studies have been carried out worldwide and they have shown excellent results. Due to advancement in satellites and sensing technology, it is possible to map finer details of the earth surface and provide scope for micro level planning and management. Hydrologists and geomorphologists have recognized that certain relations are most important between runoff characteristics, and geographic and geomorphic characteristics of drainage basin systems. The study area that is taken has severe water crises during the summer season. The terrain is highly undulating with very high runoff which causes minimum recharge of ground water in spite of 3000 mm average annual rainfall. This high runoff also causes the erosion of very fertile soil.

Rivers have always been of supreme importance to man, providing focal points for habitation, cultivation, transportation, hydra power and recreation. To restore and save the limited and precious land resources from further degradation, their proper identification and mapping is a pre-requisite. During the last few decades, the ecological system in western Maharashtra has undergone prominent changes as a result of land degradation, urbanization and changes in agriculture patterns. This has resulted in uncontrolled exploitation of resources resulting in degradation of land and soil. It is observed that to be more severe in Western Ghats that has been affected by large-scale deforestation leading to soil erosion and other related problems. Morphometric characteristics like stream order, drainage density, slope, and channel length and relief aspects becomes important for understanding of hydrological behavior of drainage basin as well as study the nature of flood and geomorphological structure, it could be also helpful for further hydrological analysis.

Watersheds are important as the surface water features and storm water runoff within a watershed ultimately drain to other bodies of water. It is essential to consider these downstream impacts when developing and implementing water management and quality protection or restoration. Management of the environment has been principally focused on specific issues such as air, land, and water. Watershed management is a continuous process where data has to be collected, analyzed to identify issues and design plans to protect and promote resource sustainability. Thus the watershed level approach in managing of resources, the negative impacts on the system can be identified. Hence there is scope for improvement of resource sustainability for generations to come.

In western Maharashtra most of the watersheds exhibit high potential of surface runoff and soil loss. No efforts have been taken to properly undertake such kind of assessment. In the present study, prioritization of sub-watershed was carried out based on morphometric analysis and runoff estimation. While considering watershed conservation work, it is difficult task to take whole area at once. Thus, the whole basin is divided into several smaller sub-watershed units, by considering to drainage system. In the present study therefore emphasis is given an analysis of relief and terrain characteristics along with drainage characteristics of Darna Lake Catchment. The present study aims at water resource management for the prioritization of micro watershed based on morphometric analysis and runoff estimation using remote sensing and GIS techniques. This study is mainly helpful for the increasing agricultural based livelihood and also to supplying the greater level of irrigation facilities.The height and length of this lake is 28 m and 1634 m respectively and area 34750 ten cubic square meter. Darna reservoir catchment area, one of the sub-basins of upper Godavari drainage basin is not an exception for such kinds of problems.

Morphometric studies explore the relationship between streams and other components of drainage basin that estimates dynamic characteristics of basin region of the river. The study of drainage basin morphometry turn to be helpful for future planning of river training, watershed planning, soil and water conservation, prioritization and management in an effective manner as it could be integrated the long-time changes of the river. Drainage basin analysis is also very important in any hydrological investigation like assessment of groundwater potential and management. Various environmental hazards associated with hydrologic phenomena are most often correlates with the physiographic characteristics of drainage basins such as size, shape, slope of drainage area, drainage density, and of course length of the tributaries.

1.2 Review of Literature:

At the beginning of 20th century morphometric study of the river apply for the analysis of area height relationship, slope, relative relief, and terrain characteristics. The statistical methods apply for the analysis of drainage basin characteristics started after the publication of classical research paper of Horton, R.E. in 1945. Horton, R.E. (1945) "Erosional Development of Streams and their Drainage Basin" Hydro- physical Approach to Quantitative Morphology and, Strahler, A.N. (1957) "Quantitative Analysis Applied to Fluvially Eroded Landform" has been included the river morphometric character of stream order. Nowadays so many researchers widely used Geo-spatial techniques like GIS (Geographic Information System) and RS (Remote sensing) for quantitative study of drainage morphometry at national and international level. The morphometric characteristics of various basins have been studied by many scientists using conventional methods; Horton (1945), Strahler (1957).Determining geomorphic parameters in the past has been a tedious and time consuming process due to the efforts needed in delineation of watersheds and calculating the respective watershed areas. Remote sensing and GIS methods used for drainage Basin analysis by Nag (1998), Srinivasa (2004), Chopra et. al. (2005), Nookaratram et. al. (2005), Thakkar et. al. (2007), Bhatt et. al. (2007), Kar et. al. (2009) and Rao et. al.(2010) for detailed and exact study of different river basins.

Jain et. al. (2000) and Ratnam et. al. (2004) have been highlights that GIS is widely used for resources planning in watershed. Mark, (1983); Anderson, (2004), talks about using the presently available GIS techniques one has to go through tedious steps for generating these characteristics. Since the mid-1980s digital elevation models (DEMs) have been used to delineated drainage networks. Tarboton et. al.(1991, 2001) focused on watershed boundaries, to calculate slope characteristics, and to produce flow paths of surface runoff.

Chorley, (1969); Gregory and Walling (1973) highlighted the hydrological response of a river basin can be interrelated with the physiographic characteristics of the drainage basin, such as size, shape, slope, drainage density, size, and length of the streams etc. Shrimali et. al., (2001) has been presented a case study of the 42 km^2 Sukhana lake catchment in the Shiwalik hills for the delineation and prioritization of soil erosion areas by GIS and remote sensing. Srinivasa et. al., (2004) has used GIS techniques in morphometric analysis of sub-watersheds of Pawagada area, Tumkur district, Karnataka. Chopra et al., (2005) carried out morphometric analysis of Bhagra, Phungotri and Haramaja sub-watersheds of Gurdaspur district, Punjab. Nookaratnam et. al., (2005) carried out study on check dam positioning by prioritization of micro-watersheds using the sediment yield index (SYI) model and morphometric analysis using GIS.

Researchers from different places have done research on prioritization using morphometric parameters through the application of remote sensing and GIS. Biswas et. al., (1999) has been worked on watershed prioritization is the ranking of different sub-watersheds of a watershed according to the order in which they have to be taken for treatment and soil conservation measures. In the recent past, many researchers have found that GIS is important tool for analysis of drainage characteristics from different data sources (Thomasa et. al. 2010; Pate and Dholakia 2010; Kar et. al. 2009; Pankaj and Kumar 2009; Singh P.K. and Singh U.C. 2009; Das and Mukherjee 2005). Sabins (2000) has been talk about in his research work that Geographic information systems (GIS) and Remote Sensing through satellite images are new developments that give the opportunity to investigate large areas in a short time. Satellite images can give detailed information on surface geology, soils, vegetation, land use, landscape and can show structures and patterns that would be non recognizable from ground. These features can reveal important information that can lead not only to discover new resources, but also gives a better insight in the current resources used and the development options. The integration between GIS and Remote Sensing techniques is used in the present work essentially to study the drainage network and surface water potentiality in order to evaluate the degree of feeding to the groundwater aquifer in Ain Sukhna area, Egypt.

Nookaratnam et. al.,(2005) has been considered linear parameters such as drainage density, stream frequency, mean bifurcation ratio, drainage texture, length of overland flow have a direct relationship with erodibility while as, shape parameters such as elongation ratio, circularity ratio, form factor, basin shape and compactness coefficient have an inverse relationship with erodibility. Morphometric analysis could be used for prioritization of micro-watersheds by studying different linear and aerial parameters of the watershed even without the availability of soil maps. However, while considering watershed conservation work, it is not feasible to take the whole area at once. Thus, the whole basin is divided into several smaller units, as sub watersheds or micro watersheds, by considering its drainage system.

Amee, K. Thakkar, S. D. and Dhiman (2007) studied morphometric analysis and prioritization of mini watersheds in Mohr watershed, Gujarat state, India using remote sensing and GIS techniques. In this study, morphometric analysis and prioritization of the eight mini watersheds of Mohr watershed, located between Bayad taluka of Sabarkantha district and Kapadwanj taluka of Kheda district in Gujarat state, India, is carried out using Remote Sensing and GIS techniques. The morphometric parameters considered for analysis are stream length, bifurcation ratio, drainage density, stream frequency, texture ratio, form factor, circularity ratio, elongation ratio and compactness ratio. The highest bifurcation ratio among all the mini watersheds is 9.5 which indicate a strong structural control on the drainage. The maximum value of circularity ratio is 0.1197 for the mini watershed 5F2B5b3. The mini-watershed 5F2B5a2 has the maximum elongation ratio (0.66). The form factor values are in range of 0.29 to 0.34 which indicates that the Mohr watershed has moderately high peak flow for shorter duration. The compound parameter values are calculated and prioritization rating of eight mini watersheds in Mohr watershed is carried out.

Sreedevi et. al. (2009) and Rudraiah et. al., (2008) has carried out morphometric analysis using Remote Sensing and GIS techniques in the Sub-Basin of Kagna River Basin, Gulburga District, Karnataka, India. Esper, (2008) revealed that morphometric assessment helps to elaborate a primary hydrological diagnosis in order to predict approximate behavior of a watershed if correctly coupled with geomorphology and geology.

Akram Javed, Mohd Yousuf Khanday and Rizwan Ahmed, (2009) carried out prioritization of sub-watersheds based on morphometric and land use analysis using remote sensing and GIS Techniques. This study makes an attempt to prioritize sub-watersheds based on morphometric and land use characteristics using remote sensing and GIS techniques in Kanera watershed of Guna district, Madhya Pradesh. Various morphometric parameters, namely linear and shape have been determined for each sub-watershed and assigned rank on the basis of value relationship so as to arrive at a computed value for a final ranking of the sub-watersheds.

Mishra and Nagarajan (2010) has been studied on prioritization of watersheds based on morphometric characteristics, using remote sensing and GIS techniques on Tel river, Bhawani patna area in Kalahandi district, Odisha. For this studies they mainly highlights morphometric parameters for analysis such as stream length, bifurcation ratio, drainage density, stream frequency, texture ratio, form factor, circularity ratio, elongation ratio and compactness ratio. Ajibade, L.T. et. al. (2010) has been done pioneering work on morphometric analysis of Ogunpa and Ogbere drainage basins, Ibadan, Nigeria. The study further revealed that morphometric properties of Ogunpa drainage basin are likely to induce high magnitude flood compared to morphometric properties of Ogbere drainage basin and suggested a number of management practices that can be used in reducing rates of environmental degradation in the basins.

Sangita Mishra and R. Nagarajan (2010) has been worked on Morphometric analysis and prioritization of using GIS and Remote Sensing and done a case study on Tel river watershed of Odisha, India. Entire study area has been further divided into 12 sub-watersheds named SWS1 to SWS12 for this study. The compound parameter values of all morphometric parameters have been calculated and the sub-watershed with the lowest compound parameter is given the highest priority. The sub-watershed SWS1has a minimum compound parameter value of 4 is likely to be subjected to maximum soil erosion and susceptible to natural hazards.

Singh, Vineesha et. al. (2011) carried out Maingra basin morphometric parameters such as linear and areal aspects of the river basin were determined and computed. They considered parameters such as stream length, bifurcation ratio, drainage density, stream frequency, drainage texture, form factor, circularity ratio, elongation ratio, and compactness ratio etc. for analysis. Chavare, S. (2011) attempted a case study on Valheri river basin, tributary of Tapi River in Nandurbar District (M.S.) using GIS techniques for morphometric analysis. Gundekar, H.G. et al. (2011) has been studied morphometric analysis to determine the drainage basin characteristics of Dudhana river, which is sub-tributaries of Godavari river. In this study catchment was divided into seven sub-basins for analysis. This study mainly gives an information morphometric parameters of a watershed are valuable information to evaluate watershed capacity to produce runoff. Mean bifurcation ratio of this study shows that the drainage pattern is not much influenced by geological structures.

V. B. Rekha, A. V. George and M. Rita (2011) carried out morphometric analysis and micro-watershed prioritization of Peruvanthanam sub-watershed, the Manimala River Basin, Kerala, South India. A decisive evaluation and assessment of morphometric parameters and prioritization of micro-watersheds based on water holding capacity of Peruvanthanam sub-watershed have been achieved through measurement of linear, areal and relief aspects of basins by using remote sensing and GIS techniques, and it impose preparation of a detailed drainage map. For prioritization, 9 micro-watersheds are delineated and parameters such as Rb, Dd, Fs, Rt, Lof and Cc are calculated separately and prioritization has been done by using the Raster calculator option of Spatial analyst.

Parveen Reshma et. al. (2012) has done remarkable work for evaluate the drainage morphometric analysis with remote sensing and GIS approach concern of geomorphometric characterization and was carried out to describe the topography and drainage characteristics of watershed of Upper South Koel Basin, Jharkhand. The study deals with stream numbers, orders, lengths and other morphometric parameters like bifurcation ratio, drainage density, stream frequency, shape parameters etc. Dube, K. (2012), has been carried out work on environmental studies of Darna river with reference to water quality evaluation, to assess the impact of agriculture and domestic waste on the quality of surface water and to locate various sources and type of pollutants responsible for changes in river water quality.

J.S. John Wilson, N. Chandrasekar and N.S. Magesh (2012) worked on morphometric characteristics of major sub-watersheds of Aiyar and Karai-Pottanar basin, Tamil Nadu. In this study mean bifurcation ratio varies between 3.03 to 4.39 and falls under normal basin category. High bifurcation ratio determines that the region subjected to strong structural control on the drainage. Drainage density shows coarse drainage and texture shows fine drainage texture. The values of Cc for the study area vary between 0.28 to 0.30 that shows the study area is under the influence of high structural disturbance, low permeability, steep to very steep slope and high surface runoff.

T. A. Kanth and Zahoorul Hassan (2012) carried out work in Wular catchment using geo-spatial tools on morphometric analysis and prioritization of watersheds for soil and water resource management. This work is mainly highlights the detailed study of morphometric parameters such as linear and shape for nineteen sub-watersheds of Wular catchment and found to be of immense utility in watershed prioritization for soil and water conservation and natural resources management at micro level.

S.S. Panhalkar., S.P Mali., and C.T. Pawar (2012) worked on Morphometric analysis and watershed development prioritization of Hiranyakeshi Basin in Maharashtra, India. The main goal of this study was to prioritize the Hiranyakeshi basin on the basis of morphometric analysis and weightage has been assigned to each sub-watershed for watershed development. The compound parameter values are calculated and the sub-watershed with lowest compound weight is given highest priority.

Dhurvesh P Patel, Chintan A Gajjar, Prashant K Shrivastav, (2012) has been carried out prioritization of mini-watersheds by morphometric analysis using the linear parameters such as bifurcation ratio, drainage density, stream frequency, texture ratio, and length of overland flow and shape parameters such as form factor, shape factor, elongation ratio, compactness constant, and circularity ratio. After evaluation of the compound factors different prioritization ranks are assigned. Digital elevation model from Shuttle Radar Topography Mission, digitized contour and other thematic layers like drainage order, drainage density, and geology are created and analyzed over ArcGIS 9.1 platform. Combining all thematic layers with soil and slope map, the best feasibility of positioning check dams in mini watershed has been proposed, after validating the sites through the field surveys.

Rafiq Ahmad Hajam, Aadil Hamid, Naseer Ahmad Dar and Sami Ullah Bhat (2013) have been worked on to analyze the linear and areal morphometric characteristics of Vishav drainage basin in south-eastern part of Kashmir valley by using Geographical Information System (GIS). This study mainly associated with different geo-hydrological characteristics of the Vishav drainage basin which in turn help in the management of the water and other natural resources of the area. In the present study shows that stream segments up to 3rd order traverse parts of the high altitudinal zones, which are characterized by steep slopes, while the 4th, 5th and 6th order stream segments occur in comparatively flat lands wherein maximum infiltration of runoff occurs; these are important locations for constructing check dams.

Tolessa G. A. et. al. (2013) has been effort on morphometric analysis of Tandava river basin and focused on practicing water management activity and designing water harvesting project with minimum cost, efforts and time in reducing rates of natural vegetation. GIS can handle spatial data effectively and efficiently. Ali et. al., (2013) studied morphometric analysis of Banas river basin using remote sensing and GIS technology. The morphometric characteristics of drainage and its effect on hydrology of watershed by using SRTM data and GIS were studied and concluded that the study of these aspects were useful for rainwater harvesting and watershed management plans.

Shikalgar, R. S. (2013) carried out work on Watershed prioritization on the basis of morphometric parameters in Yerala river basin, Satara and Sangli districts. In this study twenty three sub-watersheds of Yerala river basin assess based on morphometric parameters for watershed management. The prioritization was carried out by assigning ranks to the individual indicators and a compound value was calculated. Watersheds with highest compound value were of low priority while those with lowest compound value were of high priority. This study revealed that among all twenty three sub-watersheds eight watersheds depicted into highest priority zone hence that watershed shows vulnerable soil erosion and there should be require immediate soil resource management measures.

Umair Ali and Syed Ahmad Ali (2014) has mainly work on Romushi -Sasar catchment of Kashmir valley, India for analysis of morphometric parameters using GIS and remote sensing and are found to be of immense utility in prioritization of watershed at micro-level. Based on morphometric analysis and the ranking of each parameter, the sub-watersheds have been classified into high, medium and low categories in terms of priority for conservation and management of resources. The result of this study shows that the results shows sub-watershed RSMW4 and RSMW5 has lowest compound parameter value of 2.22, 2.44 and depicted into high priority hence these sub-watersheds shows maximum soil erosion and suggested for soil and water conservation in a watershed.

Sinha, A. K., Singh, P. K., and Panday, D.(2015) has been taken effort on to prioritize sub-basins based on morphometric analysis using remote sensing and geographical information system (GIS) techniques in Jharol river basin of Udaipur district, Rajasthan, India. In this study on the basis of morphometric parameters prioritization rating has been assigned. Lowest value of compound parameter has given highest priority and that basin recommended for conservation planning.

Wandre, S. S., Rank, H. D. and Shinde, V. B. (2015) has been done pioneer work on the morphometric characteristics and prioritization of watersheds of Shetrunji river basin, which falling in the district of Bhavanagar, of the Gujarat state, India. In this study whole watershed has been divided into seventeen sub-watersheds and has been taken for prioritization based on morphometric analysis. Compound parameter has been calculated by using ranking methods to each watershed. Lowest compound value receives highest priority and indicated more soil erosion whereas, highest value shows lowest priority. The watershed 5G2B5d shows lowest compound value 6, indicates the highest priority and so it becomes more sensitive for soil erosion and applying soil conservation measures.

Dahiphale Pravin, Singh, P.K., Bhakar, S.R., Kothari Mahesh, Yadav, K.K. (2016) have been studied drainage characteristics of Jaisamand catchment of Rajasthan state. To delineated drainage pattern of this basin used ArcGIS-10 software for morphometric analysis and prioritization of different sub-basin was carried out for soil conservation measures.

N. Harish, P. Siva Kumar, M. Siva Raja , V. Lokesh, M.V. GopiSantosh Reddy, S.k. Shalisad, S. Sazid (2016) worked on hydrological assessment and characterization of the macro-watersheds of Pennar river sub-basin, Nellore, India. The Pennar river basin has been divided into twenty sub-watersheds for further application. This study mainly highlights significance of morphometry as well as efficiency of geo-spatial technology to understand hydrological behaviour of the particular basin at micro-watershed level.

Udoka Ubong Paulinus, Nwankwor Godwin Ifedilichukwu, Ahiarakwem Cosmas Ahamefula, Opara Alex Iheanyichukwu, Emberga Terhemba Theophilus, Inyang Godwin Edet (2016) have done pioneer work on Morphometric analysis of the sub-watersheds in Oguta area, South-eastern Nigeria using GIS and Remote Sensing. This study mainly highlights analysis of morphometric parameters and shown that morphometric characteristics becomes key indicator for assessing the geo-hydrological behaviour of the drainage basins and their vulnerability to flooding.

Syed Ahmad Ali, Mohsen Alhamed, and Umair Ali (2016) have been done remarkable work on assessment of various morphometric parameters is described using ArcGIS 10.2 software for Abdan Basin, Yemen. In this study all the morphometric parameters mathematically calculated and used for planning and development purposes for Abdan basin. The form factor is 0.135 that shows near to circular basin and 0.633 value of elongation ration indicated that the most of the basin area is of under high relief.

Girish Gopinath , Ajith G. Nair, G. K. Ambili and T. V. Swetha (2016) carried out worked on watershed prioritization based on morphometric analysis for

Kuttiyadi river basin in the South Indian state of Kerala. Morphometric parameter has been used for prioritization of watershed and priority has been employed for each basin. Finally, high priority sub-basin has been identified for immediate action with respect to soil conservation measures. It shows that morphometric analysis consider as a powerful tool in watershed planning.

Pramod Kumar Pandey and S. S. Das (2016) worked on morphometric analysis of Usri river basin, Chhota Nagpur plateau in India. In this study morphometric parameters has been analyzed and result shows that low drainage density, poor stream frequency, and moderately coarse drainage texture values of the basin indicate that the terrain has gentle slope. The bifurcation ratio between different successive orders varies but the mean ratio is low that suggests the higher permeability and lesser structural control.

Khosla et. al. (1960) focused on the basic requirements in designing soil and water projects, is the estimation of runoff resulted from precipitation. In order to achieve this purpose, various methods can be used. Ghafari et. al. (2009) has been highlighted that precipitation can be considered as the most important factor which is directly effective in hydrologic cycle. Determination of runoff resulted from precipitation is one of the most important factors in hydrologic problems analysis and water resources management. The relationship between precipitation and runoff is a complicated and non-linear relationship which is depended on several factors. Forecasting and determination of the quantitative amount of created and transported runoff to the outflow point of watershed are very important. Nearing et. al. (2005) remarked that recent studies have shown that, soil erosion and runoff are related with rainfall intensity, amount of precipitation, ground surface cover and vegetative cover also. Soil erosion is more affected than runoff. Davarirad (2006) evaluated the efficiency of some empirical methods and announced that, including Khosla, Coutgine, Turc, I.C.A.R (Indian Council of Agricultural Research), Justin and Lacey in the watershed of Namak lake and announced that I.C.A.R, Coutagine, Justin and Turc methods have more accuracy respectively comparing to other methods and Khosla method has not been proper. Zare et al. (2008) in addition to explain Khosla, Coutgine, Turc and Langbin formulations announced that, sometimes these methods have error compared to constant universal methods. Evaluation and measuring the amount of runoff and flow in watersheds is very important therefore, runoff estimation is needed for using empirical equations in the watersheds without measurement station.

Kirpich, (1940); Izzard, (1946); Aron and Egborge, (1973); Bedient and Huber, (1992); USDA-SCS, (1972); USDA-SCS, (1975); USDA-SCS,(1986); Many methods have been developed to estimate the time of concentration for specific watersheds. The simple and widely used methods of estimating the time of concentration is the Kirpich Method (Kirpich, 1940).

Singh (1992) focused that watershed coefficient generally depend on land use, slope and soil type of the watershed and are needs to calculate using rational method. Sikka and Selvi (2005) has been used the rational method for estimating peak flows and runoff coefficients of four small experimental watersheds of Nilgiris. Estimation of time of concentration (Tc) using empirical formulae and runoff coefficient from available tables is the major source of uncertainty in application of rational method. Sivapalan et al. (2005) has been talk about for generating runoff, runoff coefficient wisely used and it also becomes useful parameter to controls in a particular hydrologic units.

Sezen (2008) has been worked on determination of the runoff coefficient of basins by using GIS in Turkey for 48 sub-basins in western and southern part of Anatolia by using runoff data of 26 year record period. In this study explained relationship between the basin parameters and the runoff coefficient. This study also revealed that there is not a strong the relationship between the basin parameters and annual and seasonal runoff coefficients for the whole region, but there are significant relations between them for some basins.

Dhakal et. al. (2013) has been focused on estimation of rational runoff coefficients for Texas watersheds. Rational method has been used for estimation of peak runoff for small drainage basin. Results of his research show that many components of erosion response, such as threshold hydraulic conditions for rill erosion, rill network configuration and hill slope sediment delivery, are strongly affected by spatially variable and temporally dynamic soil properties.

Baidyanath Kumar (2015) has been worked on prioritization of watershed through surface runoff in Pambar river basin using SCS - CN method in the Pambar river basin, India. In this study mainly highlights that the watershed conservation priority number for the each watershed will be assigned according to the value generated from the runoff. Based on the runoff value the sub-watershed basin has been arranged in hierarchy manner. High value of peak runoff assigned high priority and as per priority level conservation measures has been applied.

1.3 Selection of the problem:

Most of the watersheds in western Maharashtra show the signs of excessive runoff and loss of soil. These kinds of problems are mainly evident in the form of gullied and ravenous topography. Heavy surface runoff and loss of soil mainly occur due to improper practicing of hill slope agriculture. Improper Management and assessment of irrigation projects of major and minor scale also support to many geo-environmental problems. These problems are indicated by evidences such as exposed hill slopes, sedimentation etc. As a result there is excessive surface runoff and high sediment yield mainly in rainy season. Yielding of sediments may give rise to siltation problem. It may eventually decline productivity, efficiency of land and finally increase the proportion of the watershed area. Such situation instigates various interlinked geo-environmental problems. Most of the existing irrigation projects in western Maharashtra show significant rate of siltation in the backwater area. Present study area i.e. Darna Lake Catchment is spread over 389.6 Sq. km. Area which is located in the western part of Maharashtra. This area is not exception to above mentioned problems and has not been so far studied in-depth by scholars. Further, the study area is familiar as well as more convenient to the researcher and easy for data collection. Therefore, Darna Lake Catchment area has been selected for the present study.

1.4 Objectives:

1 To perform the morphometric analysis of the Darna Lake Catchment focusing on areal, linear and relief aspects of the catchment necessarily helpful in understanding of terrain in general and behavior of streams in particular.
2 To estimate surface runoff using various empirical equations (Rational formula) of surface runoff estimation this will help to understand source areas of sediment yield.
3 To apply composite score for prioritization of sub basins for conservation planning based on morphometric analysis and surface runoff studies.
4 To emphasize the necessity of conservation planning with the help of GIS and to endorse the use of RS (Remote Sensing) in updating the data base for basin wise

inventory of the study area in the form of various thematic maps, as well as to prepare conservation plan in terms of CAT (Catchment Area Treatment).

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CHAPTER –II

STUDY AREA AND METHODOLOGY

2.1	Location
2.2	Geographical Study of the study area
2.2.1	Geology
2.2.2	Relief
2.2.3	Climate
2.2.4	Drainage pattern
2.2.5	Soil
2.2.6	Natural vegetation
2.2.7	Socio-economic Landscape
2.3	Database and methodology

CHAPTER –II

STUDY AREA AND METHODOLOGY

2.1 Location:

The study area extends between 19°36’ N to 19°48’ N latitudes and 73°39’ E to 73°44’E longitudes which comprises the area of Darna reservoir (Beale Lake) Lake Catchment and it covers around 389.6 sq. km. area.

Darna river is one of the tributaries of Godavari basin in Nashik district of Maharashtra state which rises on the northern slopes of Kulung hill at elevation 1040 meters in Sahyadri ranges about 13 km south-east of Igatpuri Tahsil. The upper catchment area receives high rainfall (3000-4000 mm.) and annual temperature ranges between 18°C to 38°C. It has long and meandering course and its bed is wide and sandy. On the right bank at Belu village, the river Darna confluences with river Kadva and on the left bank it has tributaries namely Vaki, Unduhol, Valdevi and other such as Bham nadi. They all hold little water during the summer season. In the study area among these tributaries only some tributaries depicted, that are namely Vaki and Bham nadi. Darna lake (Beale lake) is one of the important lake of upper Darna basin. It has elevation 561 m. Some other dams also located in the study area such as Taloshi dam, Shenwad dam, Bhavali dam and Tringalwadi dam (Fig.-2.1).

2.2 Geographical Profile of the Study Area:

Physical environment of the region generally consist relief, climate, geology, Natural vegetation and soil that are present in the region. A specific region of geography concerns itself with the study of the influence of natural environment. Variation among the physical aspects provides different area with variety of possibilities of development. The objective of this chapter is to examine physical and socio-economic scenario of the study area regarding geology, relief, climate, drainage pattern, soil, natural vegetation and its impacts on people’s occupation and economy.

2.2.1 Geology :

The study area mainly located Nashik district which is mainly part of the Great Deccan Trap and formed by volcanic eruption, 90% of the district area occupies basaltic lava flow.

Fig-.2.1

Darna Lake Catchment area located in Igatpuri tahsil of Nashik that shows prominent basaltic features and at west it shows flat-topped ranges separated by valleys as well as topography inclined from west to east. Lava flows generally occurred in sequential layer and vesicular at the top of the tableland. At the base of the trap quartz containing in vertical veins, zeolite minerals, crystals and apophyllite weathered into a gray soil. Most of the basalts in the study area are fine or coarse textured and nodular form. In the study area some area shows basalt form columnar structure and due to weathering process on it are form fantastic shapes. In minerals Iron ore is one of the important deposits in all over the study area and it is mainly consist of magnetite and limonite sands in irregular patches. Along the banks of the rivers in the flowing area, shallow alluvial formation occurs in narrow belt.

In the study area most of the area covered by pahoehoe lava flow (100-530 m) and (300-450 m) whereas only small amount of Megacryst lava flow M1 (50-100 m) observed towards west part of study area. Towards north-east part of the study area mainly consist Megacryst lava flow M2 (25-70 m) and north area mainly consist Dyke and sill of Basaltic and dolertic type of rocks (Fig.-2.2).

2.2.2 Relief:

Physiographically, Nashik district forms part of Western Ghat and Deccan Plateau that indicates varied nature of topography. Darna Lake Catchment area mostly covered by Western Ghat region and it shows highly rugged and dissected topography. Sahyadri is the main hill system in this region with highest peaks like Kalsubai (1646 mts.) and Trimbak (1294 mts). Satmala, Selbari and Dolbari hill ranges are located in the Nashik district. Godavari and the Girna is main river basin in the Nashik district. Generally slope decrease from west to east of the Nashik district exception of Sahyadri range. Drana Lake Catchment most of the area is surrounded by Anjaneri hill, Trimbaleshwar (Brahmagiri Dongar) and Kalsubai peak. The Trimbak-Anjaneri range stretches from Bhaskargad and Brahmagiri Dongar and runs through Igatpuri tahsil. Darna river rises on the northern slopes of Kulung hill at elevation 1040 meters in Sahyadri ranges. The study area is associated with moderate to steep slope and most of the cliff formation and waterfalls are observed in this area.

Fig-.2.2

Fig-.2.3

Anjaneri range runs east to west at the altitude of 1100 mts. which consist of irregular group of hills forming water divides between Godavari, Darna and Vaitarna river. On the southern boundary of the study area Kalsubai range stretches eastward which is highest peak in Maharashtra.

In the study areas most of the South, Southeast and Northeast area show high elevated topography that are mainly consist more than 700 mts. elevation. Therefore, this area shows steeper to moderate slope whereas, remaining area is show low elevation with gentle slope (Fig.-2.3).

2.2.3 Climate:

Nashik district has a pleasant climate and mainly divided among four seasons that are winter season from December to February, summer season from March to May, South-West monsoon from June to September and post- monsoon from October to November. Winter is very cool in the eastern part of the district than the other seasons, while Igatpuri and other Western part remain cool in the summer season also. Darna Lake Catchment area mainly consist most of the Igatpuri tahsil and experience monsoonal climate. The climate during South-West monsoon season is humid and dry while, in post-monsoon it becomes cold in winter.

2.2.3.1 Rainfall:

In the Nashik district considerable variation in receiving of rainfall. The rainfall of the district mainly depends on South-West monsoon. The annual rainfall of the Nashik district varies and it ranges from 500 mm to 3400 mm. The rainfall is maximum towards Western part of the district which consist Igatpuri tahsil and surrounding Western Ghat regions, whereas minimum rainfall towards eastern and north eastern part of Nashik district. Most of the study area means Darna Lake Catchment area has been depicted in Igatpuri tahsil. There is an uneven distribution of rainfall in Nashik district, Western track of the district received high rainfall than the central and eastern part of the district due to hilly and rugged topography towards Western part of the district. Igatpuri, Trimbakeshwar, Surgana and Peint tahsils are located in this area and among them Igatpuri received highest rainfall and Nandgaon, Yeola tahsils located towards eastern part of the Nashik district received scantly rainfall.

Most of the rainfall is received in month of June to September. Amount of rainfall is greater in July and August months. Average annual rainfall of the district is 1174.6 mm. In Western Ghats the rainfall is much heavier than the remaining parts of the Nashik district. Present study area is located towards Western part of Nashik hence, it receive highest rainfall than Eastern part of the area (Fig.-2.5). On an average at Igatpuri it is 3971 mm while it is decreases towards eastern part of the districts at Satana it is 477.3 mm due to local variations among the topography. The catchment area of Darna Lake receives high rainfall (3000-4000 mm.) in monsoon season and average monthly rainfall (300 to 784.92mm) observed in June, July and August month (Table -2.1 and Fig.-2.4). Igatpuri and Trimbakeshwar tahsils have found average rainfall more than 2000 mm. 88 percent of the total rainfall receives during South-West monsoon in the study area.

The number of rainy days is high towards west part of the district which varies from 89 to 102 days at Peint and Igatpuri respectively, whereas rainy days decreases from west to east and its ranges from 32 and 54 days at Satana and Dindori respectively.

Table 2.1 :Month-wise Average Annual Rainfall Darna Lake Catchment 1976-2014

Months	**Rainfall in mm**	**Months**	**Rainfall in mm**
January	0.12	July	784.92
February	0.00	August	691.55
March	0.00	September	263.64
April	1.25	October	58.40
May	5.87	November	5.37
June	300.65	December	1.22

Source: Hydrological Department, MERI, Nashik. (2014)

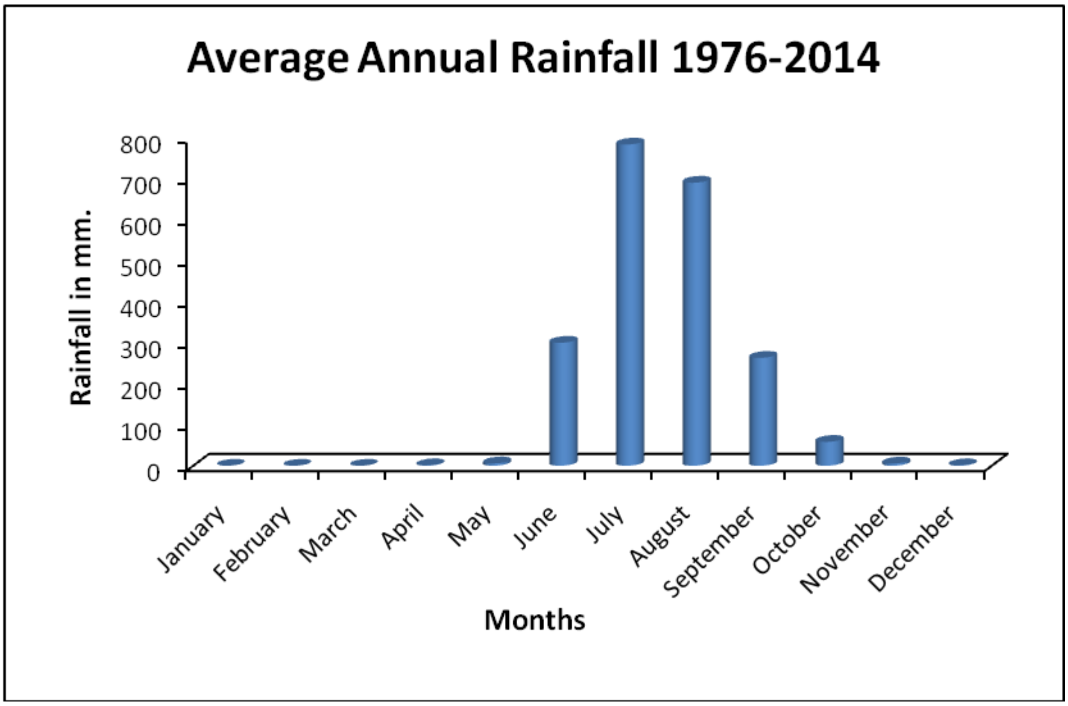


Fig.-2.4

2.2.3.2 Temperature-

Annual temperature range of the Nashik district is high. Temperature is maximum in the summer month and it is reaches upto 42.5 °C while; temperature becomes minimum in month of winter and reaches upto 5 °C. The average maximum temperature is 35°C and minimum is 18 °C during the year. In the Darna Lake Catchment area the temperature is much lower than the other part of the district due to presence of hilly and rugged topography. In the study area average temperature begin to increase latter half of the February and the average monthly maximum temperature is observed 36.51 °C in month of April. While, average temperature decreases latter half of December month and average minimum temperature is observed 11.06°C in month of January (Table-2.2 and Fig.-2.6).

In summer month some of the day temperature may go above 46 °C in the eastern part of the district due to low elevation than the Western Ghat region. Onset of the South-West monsoon in June month temperatures start to decrease and it remain low throughout the South-West monsoon season. After, the South-West monsoon season in the month of October daily average temperature increases by 2 or 3°C.

Fig-.2.5

From the month of November temperature decrease rapidly and in the month of December and January temperature reaches upto 5 °C. Association of Western Ghat disturbances in the winter season cold waves move across north India affect the district temperature and its drop the freezing point of the water and sometimes frost occur.

Table-2.2:Month-wise Average Temperature of Darna Lake Catchment 1999-2015

Months	Minimum	Maximum	Months	Minimum	Maximum
January	11.06	29.05	July	20.93	25.41
February	11.69	30.72	August	20.39	24.69
March	14.30	33.86	September	20.31	26.67
April	17.72	36.51	October	18.66	30.29
May	21.14	35.98	November	16.12	30.41
June	21.56	30.85	December	12.94	29.87

Source: Zonal Agricultural Research Station, Igatpuri.(2015)

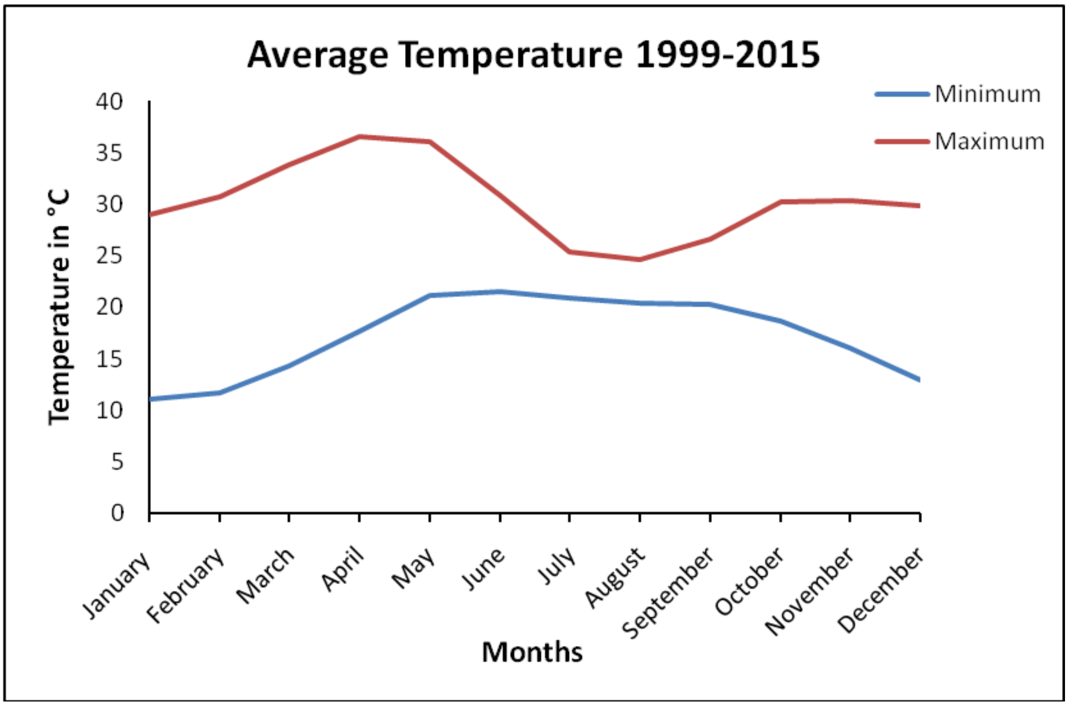


Fig.-2.6

2.2.3.3 Humidity:

Humidity largely depends on temperature and it shows the presence of water vapor in the air. In the study area in the South-West monsoon air becomes very humid and relative humidity becomes maximum that can be ranges from 65 to 95 percent whereas, in the post-monsoon especially in summer season air becomes very dry and the relative humidity ranges between 14 to 35 percent.

2.2.3.4 Wind:

Wind is variable in directions and light to moderate in nature. In the study area wind generally blowing from South-Westerly in South- West monsoon season and North- Westerly in post- monsoon season.

2.2.4 Drainage pattern:

In Nashik district mainly the Godavari and the Girna river and their tributaries form drainage pattern. In study area presence of hill and dissected topography numbers of small tributaries and streams are originates and flowing towards westward. Most of them are meandering through deep valleys, gorges and waterfalls. Darna river is one of the important river in the study area which is one of the tributaries of the Godavari river. Darna river rises on the northern slopes of Kulung hill at elevation 1040 meters in Sahyadri ranges about 13 km south-east of Igatpuri. This river has very long and meandering course and bed of the river is mostly sandy, wide and bank of the river broken by numerous small streams. On Darna river near Nandgaon village Darna reservoir (Beale Lake) is one of the important reservoirs of upper Darna basin with 561 m elevation.

In the study area on the left bank Vaki nadi meet to the Darna river whereas, on the right side Bham nadi meet to the Darna river. Vaki nadi rises in the Dhora hill flows southerly and running between Igatpuri and Ghoti. Bham nadi rises in Navricha Dongar and flows northerly and meet to Darna river on the right bank (Fig.-2.7). The bank and bed of the river is rocky, wide and hold less volume of water. All tributaries are seasonal and hold little water during the summer season. Most of the tributaries form dendritic pattern and near the confluence mostly forms rectilinear pattern (Fig.-3.1).Uneven topography and perennial source is in limited village, Darna river is formed east boundaries of study area.

2.2.5 Soil:

Soil is one of the important natural resource that becomes main function of topography, climate and vegetation. Nashik district is located on ‘Deccan trap’ hence;

Fig-.2.7

Fig-.2.8

parent material of soil is more or less uniform (Ray Chaudhari, 1964). Most of the soils in the Nashik district are weathering product of igneous rock especially of extrusive origin.

Due to heavy rainfall, Warm-humid climate and highly rugged dissected topography study area is mainly consist lateritic (red brown) soil on hill slope area, whereas loam and black soil appears in the Darna Lake Catchment area and bank of the river. Igatpuri, Trimbakeshwar tahsil of study area have mostly found lateritic (red brown) soil that are less common and is suitable for cultivation under heavy and consistence rainfall.

In the study area most of the South, South-East and North-West area shows hilly area hence it shows lateritic soil. It has less clay and silt but rich in iron content. The pH of this soil is 6.5 shows soil is neutral in nature. Thickness of the soil is varied between 30 to 120 cm and it is depending on slope of the area. The valleys are filled with weathered product of basalt of various shades from gray to black, washed down by rain. This soil is not suitable to the growth of large trees but it is very fertile for cereals and pulses. Most of the loam soil is appears in the east part of hill area, consist rich organic matter (Fig.-2.8). Black soil mainly found near bank of the Darna River of the study area and contains high aluminum, calcium carbonate, Magnesium with variable amounts of potash, low nitrogen and phosphorus which is more suitable for cultivation. Alluvial soil is mainly appears in the river basin due to depositional work of the river. On hill slopes area in Western Ghat light shallow soils are noticed and very coarse textured soils are appears on higher reliefs of the same area.

2.2.6 Natural vegetation:

The distribution of forest is not even because of variation among the topography, Climate, soil etc. Climate and topographic factors are more responsible for the differentiation among the forest which occurring in the Nashik district. In the study area moist humid climatic conditions and heavy rainfall are suitable for growth of natural vegetation. Inspite that situation this area have highly rugged topography, hilly area and lateritic soil on, hilltop area natural vegetation is not abundantly observed. Western part and Southern part of the study area is mainly consist tropical moist deciduous forest. Some regions also show the reserved and protected forest with the dominance of timber and fuel wood. Igatpuri and Trimbakeshwar tahsils in study area mostly covered tropical moist deciduous forest on hill slope region whereas, along the basin of Darna river due to influence of human most of the trees cut by them

Fig-.2.9

for different purposes. Some part of the study area of Sahyadri range very rugged and uneven and it is occupied by dry deciduous forest which is open and scattered.

In the study area South and South-East area covered by forest and wasteland whereas most of the North and central area shows agriculture land. Monsoonal deciduous forest and tropical moist deciduous forest which consist teak, sisum, khair and timber trees (Fig.-2.9)

2.2.7 Socio-economic Landscape:

Physical environment of the Nashik district including relief, climate, Natural vegetation and soil would be relevant to understand the role of cultural and socio-economic aspects for shaping land-use pattern in the study area. Present study area is mainly associated with hill and forest area which shows the shelter of tribal peoples. Igatpuri and Trimbakeshwar tahsils of study area are mainly the association of Varali and Thakar caste tribes and they mostly locate in isolated pockets.

The economy of the area largely depends on economically active population. If most of the peoples engaged in primary activity that shows area is not well developed. In Darna Lake Catchment area most of the peoples mostly engaged in primary activities such as agriculture, fishing, hunting, gathering of forest products and medicinal plants. Hence, it shows that the study area is not well developed and not economically strong. Most of the peoples have low income, illiteracy, unemployment, traditional cropping pattern as well as scarcity of water for cultivation that support low productivity of crops and shows low standard of living in the study area.

In the study area unskilled agriculture labor found. Most of the Peoples engaged in primary activities and most of they have less land holding and some are landless people so, poverty is the main problem of this area. Peoples mostly taking different types of crops like jawar, paddy, bajara and pulses. Paddy farming is main occupation due to warm and humid climate, red brown loam soil and high rainfall (Photo.-3). Rice milling is an old occupation in the study area. Large production of rice determines great development in the industrial sector during recent years. This development is marked in large-scale as well as in small-scale and cottage industries. Nowadays peoples marching urbanization and transport facility they improve their economic conditions and standard of living.

2.3 Database and Methodology:

The Data sources and methods that have been used to fulfill the objectives placed in the present study are provided as follows.

2.3.1 Data Sources:

Data for the present study acquired from the following sources.

- **Toposheet**–

S.O.I. Topographical maps based on 1:50000 scales (One inch toposheet) have been used for the preparation of base map. The Darna Lake catchment area covered in the Survey of India (SOI) Toposheet numbers 47 E/9 in B3 and C3 quadrants, 47 E/10 in B1 and C1 quadrants, 47 E/13 in A3 quadrant and 47 E/14 in A1 quadrant. These toposheets were published in 1977, 1975, 1976 and 1975 respectively.

- **Climatic Data**–

Rainfall data have been obtained from Hydrological Department MERI, Nashik for the period of 1976 to 2014. Temperature data has been collected from Zonal Agricultural Research Station, Igatpuri, for the period of 1999 to 2015.

2.3.2 Methodology and Data Analysis:

- **Digitization of layers-**

ArcGIS 9.2 and Global Mapper software have been used for digitization of contours and streams from topographical maps. These digitized layers are used for further analysis.

- **Morphometric Analysis-**

ArcGIS (version 9.2) and Global Mapper Softwares have been used to geo-reference and rectify topographical maps. These softwares have been utilized to digitize the stream network of Darna Lake Catchment. Strahler’s (1964) stream ordering method has been applied for the present study. The morphometric parameters have been calculated by using assorted formulas. The stream number of various order for study area were counted, whereas the stream length, basin length, area and perimeter were measured with the help of the above mentioned software.

The attribute were assigned to generate the digital data base for drainage layer of the Darna lake catchment. The essential parameters related to stream such as, length of stream, area and perimeter of basin etc. were obtained from the digitized drainage layer. The various morphometric parameters for the defined basin area have also calculated.

The formulas made by Horton (1945), Strahler (1964), Miller (1953) and Schumms (1956) were adopted for the calculation. Linear, areal and relief aspects of the Darna river network were computed. Attempt has been made; through morphometric analysis, to prioritize the sub basins of the entire Darna Lake Catchment and divided into 140 sub-basins. They are accordingly coded as DARN_A01 to DARN_A77 for first order sub basins, DARN_B01 to DARN_B39 for second order sub basins, DARN_C01 to DARN_C14 for third order sub basins, DARN_D01 to DARN_D07 for fourth order sub basins and DARN_E01 to DARN_E03 for fifth order sub basins as shown in figure 4.2.

Morphometric parameters for each delineated sub watershed area have been calculated. Prioritization rating of all the 140 sub-watersheds of Darna lake catchment is carried out by allotting ranks to the individual parameter. Compound value for all parameters has been calculated. Highest compound parameter value of sub watershed is assigned with lowest priority and vice versa. Accordingly an index of very high (< 25), high (26-50), medium (51-75), low (76-100) and very low (>100) priority has been orderly obtained. Sub-watersheds have been broadly classified into five priority zones as per their compound value. The high priority indicates a need of retrieval processes and an action plan for protection and conservation of soil.

Relief Analysis-

ArcGIS software version 9.2 and 10.2.2 are used for Contour digitization. Global Mapper software has been used to prepare DEM (Digital Elevation Model) of the study area. Different thematic maps such as Slope (percentage), Absolute Relief, Relative Relief and Dissection Index have been prepared.

Land Use / Land Cover Map-

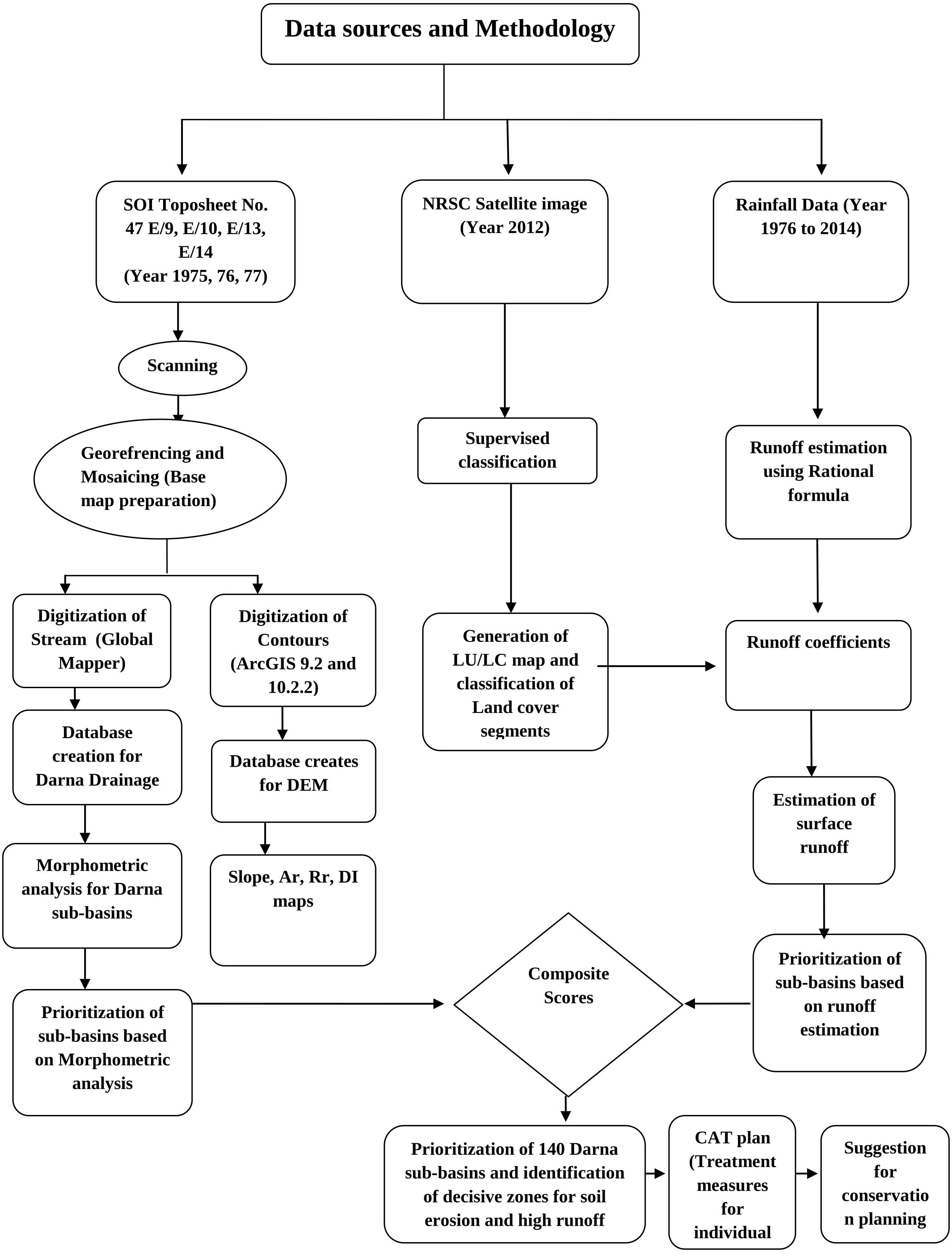
NRSC satellite image (Year 2012) has been used to prepare Land use / Land cover map. It has been processed and supervised classification has been adopted to classify land cover segments such as agricultural land, built up, forest and wasteland of study area has been applied.

Estimation of surface runoff-

Efforts have been made to estimate peak surface runoff of the entire Darna Lake Catchment which has been divided into 140 sub-basins. Rational formula has been employed to find out rainfall intensity, time of concentration and peak surface runoff volume for each of the 140 sub-basins. On the basis of the calculated peak surface runoff of individual sub watershed, priority ranking has been allotted. The sub-basins with the highest peak runoff value (low ranking) are assigned by highest priority and vice versa. Accordingly an index of very high (0-30), high (31-60), medium (61-90), low (91-120) and very low (121-150) priority has been orderly obtained. Sub-watersheds have been broadly classified into five priority zones as per their computed peak surface runoff value. The high priority indicates high runoff and low infiltration therefore, a need of step up and an action plan for protection and conservation of soil and water.

Finally composite scores of both the morphometric analysis and peak surface runoff have been considered. Composite scores are used to find out decisive zones of vulnerable soil loss and excessive surface runoff. Decisive zones have been thus identified and suggestions for further conservation, planning and management are given.

A detailed flow chart of methodology has been displayed below.



Data sources and Methodology
SOI Toposheet No. 47 E/9, E/10, E/13, E/14 (Year 1975, 76, 77)
NRSC Satellite image (Year 2012)
Rainfall Data (Year 1976 to 2014)
Scanning
Georefrencing and Mosaicing (Base map preparation)
Supervised classification
Runoff estimation using Rational formula
Digitization of Stream (Global Mapper)
Digitization of Contours (ArcGIS 9.2 and 10.2.2)
Generation of LU/LC map and classification of Land cover segments
Runoff coefficients
Database creation for Darna Drainage
Database creates for DEM
Estimation of surface runoff
Morphometric analysis for Darna sub-basins
Slope, Ar, Rr, DI maps
Composite Scores
Prioritization of sub-basins based on runoff estimation
Prioritization of sub-basins based on Morphometric analysis
Prioritization of 140 Darna sub-basins and identification of decisive zones for soil erosion and high runoff
CAT plan (Treatment measures for individual
Suggestion for conservatio n planning

References:

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CHAPTER-III

MORPHOMETRIC ANALYSIS OF DARNA LAKE CATCHMENT

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MORPHOMETRIC ANALYSIS OF DARNA LAKE CATCHMENT

3.1 Introduction:

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal, 1998; Obi Reddy et al., 2002).The morphometric analysis of the drainage basin and channel network play a dynamic role for understanding the hydro-geological behaviour of drainage basin and precise the prevalence of climate, geology, geomorphology and structure. Morphometric analysis provides quantitative explanation of any drainage basin to understand slope, geological and geomorphic history of drainage basin. Hydrological study such as potential, management of groundwater and environmental evaluation of drainage basin analysis becomes important.

Morphometric study of drainage basin also help to us for understanding landform processes, soil properties of basin area and it also found to be great importance for assessment of river basin, watershed prioritization for soil and water conservation and natural resource management. Today, Geographical Information System (GIS) techniques become one of the powerful tools for assessing various terrain and morphometric parameters of the drainage basins and watersheds.

Morphometric parameters quantitative study of a drainage basin has been useful in many application studies like estimation of runoff, ground water recharge, flood discharge, conservation of soil and water and environmental analysis etc.In the assessment of hydro geomorphic characteristics of a drainage basin, knowledge of relief and drainage characteristics have to be evaluated because these characteristics provide very basic information of physical make up of a basin and help to infer hydrodynamics of a basin.

3.2 Morphometric Analysis:

In Geomorphology major prominence is to describe the evolution and behaviour of surface drainage network which involves the measurement of various stream properties that are important for the hydrological studies point of view include the linear, areal and relief aspect of the watersheds i.e. Stream ordering, Stream length, Bifurcation ratio, basin area, perimeter of basin, Drainage density, Drainage frequency, circulatory ratio, Form factor and texture ratio etc. Morphometric analysis of the basin area is an important aspect for evaluation of the basin for conservation of soil and water.

3.2.1 Linear Aspects:

Linear aspects of the morphometric analysis of drainage basin consists aspect like stream order, stream length, mean stream length, bifurcation ratio and stream length ratio.

Table 3.1:Methods of Calculating Morphometric Linear parameters

Morphometric Parameters	Methods	References
Stream Order(u)	Hierarchical order	Strahler, 1964
Stream Length (Lu)	Length of the stream	Horton, 1945
Mean Stream Length (Lsm)	Lsm = Lu/Nu where, Lu=Stream length of order 'u' Nu=Total number of stream segments of order 'u'	Horton, 1945
Stream Length Ratio (Rl)	Rl=Lu/Lu-1; where Lu=Total stream length of order 'u', Lu-1=Stream length of next lower order.	Horton, 1945
Bifurcation Ratio (Rb)	Rb = Nu/ Nu+1; where, Nu=Total number of stream segment of order 'u'; Nu+1=Number of segment of next higher order	Schumm,1956

3.2.1.1 Stream Orders (u):

Separation of stream orders of the basin is an important stage for morphometric analysis of drainage basin. It precisely explains the hierarchical relationship between stream segments, their connectivity and the discharge of the contributing Catchments area. Strahler's method has been applied for this study, as per his definition smallest head order tributaries called first order streams. Where two first order streams meet, a second order stream created. Where two order streams meet, a third order stream created and so on. It has been find out that the study area shows six is the highest order. The total numbers of streams in Darna Lake Catchment are 1815 out of which 1380 are first order streams, 334 are second order streams, 79 are third order streams, 18 are fourth order streams, 3 is in the fifth order streams

Fig.-3.1

and 1 is in sixth order streams (Table-3.2 and Fig.-3.1). In the Study area the drainage basin area streams formed dendritic drainage pattern and number of streams decreases as the stream order increases.

Table 3.2: Stream Number and Stream Length

Stream Order(u)	Stream Number (Nu)	Stream Length(Lu) in km
1	1382	741.65
2	338	216.21
3	82	92.72
4	18	37.66
5	3	38.98
6	1	50.14

Source: Computed by researcher.

3.2.1.2 Stream Length (Lu):

On the basis of the law proposed by Horton in 1945 the stream length of the Study area has been calculated for various orders using Global Mapper software. Stream length is one of the important hydrological features of the basin area which becomes significant for the surface runoff characteristics. If the stream length is relatively small shows the basin area of steeper slopes and finer textures whereas; longer length of the stream segment shows flatter gradient. The length of first orders in Darna Lake Catchment is 741.65 km, second orders length is 216.21 km, third orders length is 92.72 km, fourth orders is 37.66 km, length of fifth order is 38.98 km and length of sixth order is 50.14 km (Table-3.2). All the figures of stream lengths for various stream orders in the study area shows that length is maximum for first order stream and it decreases as stream order is increases it indicates the terrain is consist high relief, moderately steeper slope with homogeneous weathering and erosional characteristics in Darna Lake Catchment.

3.2.1.3 Mean Stream Length (Lsm):

This method also proposed by Horton in 1945, as per this method it is calculated by dividing the total length of order "u" by the number of stream in the order. The mean stream length of the study area highlights the size and the contributing components of the drainage basin. The calculated mean stream length of Darna Lake Catchment is 0.54 for first orders, 0.65 for second order, 1.17 for third order, 2.09 for fourth, 12.99 for fifth and 50.14 for sixth order orders respectively (Table-3.3).

3.2.1.4 Stream Length Ratio (Rl):

Stream length ratio is defined as the ratio of the mean stream length of given order to the mean stream length to the next order and it has been shows the relationship between the surface flow and the discharge of the basin. The total stream length ratio of the study area is 2.972 which show that the youth stage of the Darna Lake Catchment area for geomorphic development (Table-3.3).

3.2.1.5 Bifurcation Ratio (Rb):

According to Mesa (2006) bifurcation ratio is a measure of the degree of ramification of the drainage network. The values usually range between 3 and 5 for network formed in homogeneous rocks (undergone minimum structural disturbances) and value with more than 10 shows the influence of structures (Chow Ven et al. 1988).In Darna Lake Catchment has been found that bifurcation ratio low in sixth order and high in fifth order. Natural drainage systems are generally characterised by bifurcation values between 3 to 5 (Strahler, 1960). Usually, high bifurcation ratio values (> 10) are characteristics of drainage systems developed over easily erodible rocks and areas underlain by heavily jointed rocks. Bifurcation ratio of the Darna Lake Catchment area is ranges between 3 to 6 that shows network formed in homogeneous rocks that undergone minimum structural disturbances as well as natural drainage system developed in study area (Table-3.3).

Table-3.3: Morphometric Analysis - Linear aspect in Darna Lake Catchment

Stream Order(u)	Stream Number(Nu)	Stream Length(Lu)in km	Bifurcation Ratio(Rb)	Mean Stream Length(Lsm)	Stream Length Ratio(Rl)
1	1380	741.65	-	0.54	-
2	334	216.21	4.13	0.65	1.20
3	79	92.72	4.23	1.17	1.8
4	18	37.66	4.39	2.09	1.79
5	3	38.98	06	12.99	6.21
6	1	50.14	03	50.14	3.86
Total/Mean	**1815**	**1177.36**	**21.75**	**67.58**	**2.972**
Mean Bifurcation Ratio=4.35					

Source: Computed by researcher.

Mean bifurcation ratio varies from 2.0 for flat or rolling basins to 3.0-4.0 for mountainous, hilly dissected basins (Horton, 1945). The mean bifurcation ratio, which is the average of bifurcation ratios of all orders, is 4.35. Thus the result shows that Darna Lake Catchment area is situated in a dissected or hilly area.

3.2.2 Areal Aspects:

Areal aspects of drainage basin include Drainage density, Stream frequency, Form Factor, Circularity Ratio, Length of Overland Flow and Elongation Ratio etc.

Table 3.4: Methods of Calculating Morphometric Areal Parameters

Morphometric Parameters	Methods	References
Basin Relief (Bh)	Vertical distance between the lowest and highest points of watershed.	Schumm,1956
Relief Ratio (Rh)	Rh=Bh/Lb; Where, Bh=Basin Relief; Lb=Basin Length	Schumm,1956
Ruggedness Number (Rn)	Rn = Bh×Dd Where, Bh =Basin relief; Dd=Drainage density	Schumm,1956
Drainage Density (Dd)	Dd = L/A where,bL=Total length of Streams; A=Area of watershed	Horton, 1945
Stream Frequency (Fs)	Fs = N/A where,N=Total number of streams; A=Area of watershed	Horton, 1945
Texture Ratio (Rt)	Rt= N1/P where,N1=Total number of first order streams; P=Perimeter of watershed	Horton, 1945
Form Factor (Ff)	Ff=A/(Lb) 2 ; where, A=Area of watershed, Lb=Basin length	Horton, 1945
Circularity Ratio (Rc)	Rc=4πA/P2 ; where, A=Area of watershed, π=3.14, P=Perimeter of watershed	Miller, 1953
Elongation Ratio (Re)	Re=2√(A/π)/Lb ; where, A=Area of watershed, π=3.14, Lb=Basin length	Schumm,1956
Length of Overland Flow (Lg)	Lg = 1/2Dd where,D d=Drainage density	Horton, 1945
Constant of Channel Maintenance(Cc)	Cc = 1/Dd where, Dd=Drainage density	Horton, 1945

3.2.2.1 Basin shape:

To know how river system geometry influences the spatial distribution of channel morphology basin shape becomes one of the important parameter in morphometric analysis. The shape of the basin mainly governs the rate at which the water is supplied to the main channel and it directly impacts the size of peak discharge. Basin shape is referred to as the shape of outline of drainage basin that is determined as shape of projected surface on the horizontal plane of the basin map (Suresh, 2000). Basin shape mainly used to description of basins overall potential for tributary confluences effects. Mulder and Syvitsky (1996) have indicated that a majority of rivers have elongated basins and have large average discharge. Elongation Ratio (Re), Circulatory Ratio (Rc) and Form Factor (Rf) are used for characterizing drainage basin shape, which is an important parameter from hydrological point of view. Darna Lake Catchment also shows elongated basin hence, it has correspondingly may have a lower potential for convergence effects.

3.2.2.2 Form Factor (Ff):

Form factor has been defined as the ratio of the basin area to square of the basin length (Horton 1932). Smaller the value of form factor, more elongated will be the basin and have lower peak flow of longer duration whereas; the basins form factor value is high have high peak flows of shorter duration. For Study area it has been find that 0.11 is the value of form factor in Darna Lake Catchment that shows more elongated basin and lower peak flow of longer duration (Table-3.8). Low value of form factor indicates high erosion and high form factor indicates low erosion. In Study area the value of form factor is 0.11 that indicates high erosion in Catchment area and leading to elongated shape of the basin.

3.2.2.3 Circularity Ratio (Rc):

Circularity is the ratio of the basin area to the area of a circle having the same circumference perimeter as the basin, which is dimensionless and expresses the degree of circularity of the basin (Miller 1953). According to Miller the basin of the circularity ratio ranges 0.4 to 0.5 which indicates strongly elongated and highly permeable homogenous geologic materials of the drainage basin. Less circularity ratio shows more runoff therefore, the low value of circularity ratio of study area is 0.37, which shows elongated basin, impermeable geologic material land high runoff in Darna Lake Catchment (Table-3.8).

3.2.2.4 Elongation Ratio (Re)-

It is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin (Schumm S.A., 1956). The Re values generally ranges between 0.6 and 0.1 over a wide variety of climate and geologic types. Values near to 1.0 are the characteristics of the region of very low relief, while values in the range of 0.6 – 0.8 usually occur in the areas of the high relief and steep ground slope (Strahler 1964). Low Re value is susceptible to high erosion and sediment yield. It indicates relief and steep slope (Singh and Singh ,1997). The elongation ratio of the Darna Lake Catchment is 0.38 which indicates that the study area is susceptible to high erosion, sediment yield and steep slope as well as it indicates more elongated shape of the basin (Table- 3.5).

Table 3.5: Index of Elongation Ratio of Darna Lake Catchment

Value of Elongation Ratio	Shape	Result
0.9 -0.1	Circular	
0.8 -0.9	Oval	
0.7 -0.8	Less Elongated	
0.5- 0.7	Elongation	
Less than 0.5	**More Elongated**	**0.38**

Source: Savindra Singh, Geomorphology.

3.2.2.5 Sinuosity Index:

Sinuosity indices explain the hydrological and topographical characteristics of drainage basins. Sinuosity index or sinuosity ratio of the river is the ratio of distance measured between two points along stream and straight line distance between two points. If the value of channel sinuosity is 1 means a straight course of channel whereas, value ranges 1.0 to 1.5 indicates sinuous shape and the value more than 1.5 represents a meandering course (Miller, 1968).

$$Channel\ Sinuosity = \frac{\text{Observed actual path of a Stream (OL)}}{\text{Expected straight path of a Stream (EL)}}$$ (Schumm, 1963).

$$Channel\ Sinuosity = \frac{58.93}{26.37}$$

= 2.23

The value of sinuosity index is 2.23 for Darna Lake Catchment which is more than 1.5 that shows that the river channel form meandering course (Photo.-2).

3.2.2.6 Drainage density (Dd):

Total length of all the streams in the watershed to the area of watershed is the Drainage density. It is expressed in terms of km/km ^{2}. Drainage density of the study area is helps to show the penetrability and porousness of the area and also becomes one of the important sign of landform elements in stream eroded topography. Low drainage density is the indications of highly resistant or permeable subsoil material, dense vegetation and low relief whereas; high drainage density indicates the impermeable subsurface material. The result shows the value 3.02 per square kilometers in study area suggesting that the Darna Lake Catchment area has high drainage density that indicates basin has impermeable sub soil and sparse vegetation cover (Table-3.8). Drainage basin with high Dd indicates that a large proportion of the precipitation runoff. On the other hand, a low drainage density indicates the most rainfall infiltrates the ground and few channels are required to carry the runoff (Roger, 1971). Therefore, high drainage density of Darna Lake Catchment also shows high runoff.

Because of little vegetation and low permeability in Darna Lake Catchment high rainfall intensity occurs and large volume of overland flow is produced during and immediately after the rain spell. In such areas deep gullies formed known as badland.

3.2.2.7 Stream Frequency(Fs):

Stream frequency is defined as the total number of stream segment of all order per unit area. The value of stream frequency reveals positive correlation with drainage density value in the watershed indicates the increase in stream numbers with respect to increase in drainage density (Horton 1945). The stream frequency of Darna Lake Catchment area is 4.66 per square km which can be indicates that study area possess higher relief and moderately sloping topography (Table-3.6). Due to impermeable subsurface material the surface runoff is high and infiltration capacity is low within the study area.

Generally, greater the drainage density and stream frequency indicates runoff is faster. In Darna Lake Catchment area both are high hence it shows more runoff in the study area.

Table 3.6: Darna Lake Catchment Stream Frequency

Types	Value	Results
Very Poor	Less than 2	
Poor	2 to 4	
Moderate	**4 to 6**	**4.66**
High	6 to 8	
Very High	More than 8	

Source: Savindra Singh, Geomorphology.

3.2.2.8 Constant of Channel Maintenance (Cc):

The constant channel maintenance is considered as a property of landforms or used the inverse of drainage density (Schumm 1956). The constant of channel maintenance indicates the relative size of landform units in a drainage basin and has a specific genetic connotation (Strahler, 1957). The constant of channel maintenance of the Darna Catchment area is 0.33 km/km^2 (Table-3.8). The study area shows high drainage density and high constant of channel maintenance. This area consist resistant rocks, all streams require large amounts of runoff and so the constant of channel maintenance is high.This area is under the influence of high structural disturbance, steep to very steep slope and high surface runoff.

3.2.2.9 Area Ratio:

Sub stream area lowest for first order but in case of fifth order streams area increases with increasing order. In the Darna Lake Catchment Area ratios find between 0.22 to 4.03 highest for sixth order and lowest for fifth order (Table-3.7). Area ratio has increased with increasing orders upto third order.

Area ratio Ra = A / A-1

= 19.8/19.8-1, = 1.053191

Table 3.7: Area Ratio Analysis

Sr. No.	Stream order	Stream number	Area in Km^2	Mean Area	Area Ratio
1	1	1380	20.8	0.02	-
2	2	334	38.8	0.12	0.54
3	3	79	32.8	0.42	1.18
4	4	18	45	2.5	0.73
5	5	3	202.1	67.37	0.22
6	6	1	50.1	50.1	4.03

Source: Computed by Researcher.

3.2.2.10 Ruggedness Number (Rn):

It is the product of maximum basin relief and drainage density. An extreme high value of ruggedness number occurs when both the variables of basin relief and drainage density is high and slope is not only high but long as well (Strahler, 1956). The ruggedness number of the Study area is 2.86 that indicate that the area is much rugged with high relief and high drainage density. High Rn values of basin indicates that the area is characterized by dynamic geomorphic processes, long and steep slopes interrupted by sharp breaks of slopes due to rejuvenation processes, high susceptibility to soil erosion and mass movement and high response to an increase in peak discharge.

3.2.2.11 Texture Ratio (Rt):

Texture ratio is an expression of the relative channel spacing in fluvial dissected terrain. It depends on a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development of a basin (Smith, 1950).Texture ratio is also one of the important factors in the morphometric analysis of the drainage basin which depends on the underlying lithology, infiltration capacity and relief aspects of the terrain. The texture ratio of the Darna Lake Catchment is 15.85 which have been categorized as to the presence of high reliefs. The high values of the drainage texture for the basin indicate intermediate to fine texture (Smith 1950). Rock type is an important control on the drainage texture. In areas underlain by resistant and hard rocks, such as basalt, granite, gneiss etc. the drainage is coarse textured. In Darna Lake Catchment area is generally shows fine to intermediate texture.

3.2.2.12 Length of Overland Flow (Lg):

Length of overland flow is the length of water over the ground before it gets concentrated into definite stream channels. This factor is inversely relates to the average slope of the channel and is quite synonymous with the length of sheet flow to a large degree. It is approximately equals to half of reciprocal of drainage density (Horton 1945). Length of overland flow was described by Horton (1933 – 1945) as a component of total runoff in a drainage basin. When the rainfall intensity exceeds soil infiltration capacity, the excess water flows over the land surface as overland flow (Suresh, 2000). The Study area shows the value of length of overland flow is 0.17 means study area is structurally complex due to the low value of length of overland flow. On an average most of the drainage basins in its youth stages have minimum length of overland is found. Length of overland flow is also affected by other factors like rainfall intensity, infiltration rate, soils, vegetation covers etc.

Table 3.8: Areal Aspects of Darna Lake Catchment

Morphometric parameters	**Symbols/ formula**	**Value**
Area (Sq. Km)	A	389.6
Perimeter (Km)	P	114.53
Basin order	-	6
Drainage Density (Km/sq.km)	Dd=Lu/A	3.02
Stream Frequency	Fs=Ns/A	4.66
Texture Ratio	Rt=Ns/P	15.85
Basin length (km)	Lb	58.93
Elongation Ratio	$Re=2\sqrt{(A/\pi)}/Lb$	0.38
Circularity Ratio	$Rc=4\pi A/P^2$	0.37
Form factor Ratio	$Ff=A/Lb^2$	0.11
Length of Overland Flow (Lg)	Lg= 1/2Dd	0.17
Constant of Channel Maintenance (Cc)	Cc=1/Dd	0.33
Basin Relief (Bh)	Highest elevation – lowest elevation	1530-582=948m (0.948km)
Relief Ratio	Rh=Bh/Lb; Where, Bh=Basin relief; Lmb=Basin length	0.02
Ruggedness Number(Rn)	Rn=Bh*Dd or Dd*(Bh/1000)	2.86
Infiltration Number	If= Dd*Fs	14.07

Source: Computed by Researcher.

Where,

Lu= Total stream length of all orders

Ns= Total no. of streams of all orders

N1 = Total no. of 1^{st} order streams

π =3.14

3.2.2.13 Infiltration Number (If):

Infiltration number is determined by multiplying the value of drainage density (Dd) and stream frequency (Fs). It is expressed by formula If= Dd * Fs where, Dd is the Drainage density and Fs is the stream frequency. The Infiltration number of the Darna Lake Catchment is 14.07. Higher the value of infiltration number indicates lower the infiltration capacity and higher runoff therefore, in study area infiltration number is high it indicates lower infiltration capacity and high runoff.

3.2.3Relief Aspects:

3.2.3.1 DEM of the Study Area-

The Digital Elevation Model for the present study area prepared from topographical Maps, which highlights attributes of terrain, such as elevation at any point, slope and aspect as well as finding features on the terrain, such as drainage basins and watersheds, drainage networks and channel of Darna Lake Catchments. In the study area high elevation is observed towards South, South-eastern and some parts of North and North-West area that shows steeper slopes whereas, low elevation observed towards North, North-eastern and some parts of North-western part that shows gentle slope. Maximum elevation is 1520 mts and low elevation is 560 mts observed in the study area (Fig.-3.2).Digital Elevation Model provides information of hydrological parameters such are flow paths and slope that may serve as input into a rainfall-runoff model for flood forecast and flood prediction. For hydrological modelling of watershed there should be precise knowledge of topography and this information can got from DEM, hence for Darna Lake Catchment area Digital Elevation Model prepared with the help of ArcGIS 9.2. With the help of DEM of study area slope aspects and maximum runoff basins easily recognised and it is helpful for further watershed management of the study area.

3.2.3.2Absolute relief:

Absolute relief indicates maximum elevation point in a river basin. The maximum altitude value has taken within square grid of drainage network. It gives an elevation of any area from mean sea level in accurate figure. The topography of this area varied. The highest elevation zone was found in Western and Southern and South-eastern part of the study area, lowest elevation observed in the North-East, northern and some western part of the study area. Some small pockets of low absolute relief were also illustrated in the central part of the study area (Fig.-3.3). The whole study area is divided into five categories which are as follows: (1) low Absolute relief (<700m), (2) moderate to low Absolute relief (700-800m), (3) moderate Absolute relief (800-900m), (4) high Absolute relief (900-1000m), and (5) very high Absolute relief (>1000m) (Table-3.9).

Fig.-3.2

Fig.-3.3

Table 3.9: Relief Aspects - Absolute Relief

Absolute relief classes (in mts.)	Area in km^2
<700	166
700-800	111.2
800-900	71.2
900-1000	16.2
>1000	25
Total	**389.6**

Source: Computed by Researcher.

In study area maximum area has been covered less than 700 mts means in low absolute relief and minimum area 900-1000 mts means in high Absolute relief.

3.2.3.3 Relative relief (Rr):

Relative relief is the difference between of maximum and minimum relief within the grid. The relative relief represents actual variation of altitude in a unit area with respect to its local base level. Relative relief is closely related with slopes and it is more significant and useful for understanding the morphogenesis of the region. In the study area relative relief classified as : (1) low Relative relief (<200m), (2) moderate to low Relative relief (200-300m), (3) moderate Relative relief (300-400m), (4) high Relative relief (400-500m), and (5) very high Relative relief (>500m) (Table-3.10).

The relative relief map of Darna Lake Catchment gives a clear picture of the nature and amount of local relief of study area. In the study area maximum area covered by < 200mts low relative relief area whereas, minimum area shows high relative relief area which is located at South and South-West and South-East part of study area and generally consist very high and high relative relief (Fig.-3.4).

Table 3.10: Relief Aspects- Relative Relief (Rr)

Relative relief classes (in mts)	Area in km^2
<200	282.2
200-300	78.2
300-400	17
400-500	8
>500	4.2
Total	**389.6**

Source: Computed by Researcher.

Fig.-3.4

3.2.3.4 Dissection Index (DI)-

Dissection index is the ratio of maximum relative relief to maximum absolute relief. It is an important morphometric indicator of the nature and magnitude of dissection of terrain (Singh, 2000). DI is related to active tectonics and concave drainage profile development along the profile at lower altitude. The areas with high DI indicate high relative relief where slope of the land is steep (Deen, 1982). Based on DI values, the study area has been classified into five major classes such as: (1) low DI (< 10), (2) medium to low DI (10-20), (3) medium DI (20-30), (4) high DI (30-40), and (5) very high DI (>40).In Dissection Index map of study area low DI found towards North, North-East and some part of the South-West area whereas very high DI observed in some very small pocket area of the study area. In Darna Lake Catchment area maximum part is covered with medium and medium to low DI value. Very high DI value indicates high relief and steeper slope, medium to low DI shows low relief, moderate slope and youth stage of the river. In present study area, central part of the study area shows low DI value means low relief, moderate slope and youth stage of the river whereas; very high DI Value found in South and South-East part of study area which indicates high relief, steeper slope.(Fig.-3.5).

3.2.3.5 Percentage slope map:

Hill slope is an important component of the complex landscape that forms a drainage basin (Chorley,1958). Slope analysis is an important parameter in geomorphic studies. A detailed understanding of slope distribution helps in planning for various aspects like, settlement, agriculture, planning of engineering structure, etc. It helps to understand and identify the area prone to soil erosion and runoff. In study area maximum area shows the slope less than 50 Percentage means less than 26 degree whereas, maximum slope observed Southern, South-Eastern and western part of the Darna Lake Catchment. This maximum slope means area shows steeper slope and could be support to soil erosion and high surface runoff (Fig.-3.6).

Fig-3.5

Fig-3.6

3.3 Geomorphic map of Darna Lake Catchment:

For Darna Lake Catchment area Geomorphic map has been prepared which shows variation in geomorpholgical structures. Mostly South, South-West and North-West part of the study area shows structural origin- moderately dissected lower plateau. Maximum area of the study area shows denudational origin – moderately dissected lower plateau. Highly dissected lower plateau only observed in some marginal area of West part and in the central part of study area in pocket form. Anthropogenic origin and terrain mainly found in Lake area of Darna river whereas low dissected hills and valleys located at South-east part of the study area (Fig.-3.7).

Fig-3.7

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CHAPTER-IV

ESTIMATION OF SURFACE RUNOFF

4.4.1.3 Catchment Area (A)

4.4.1.4 Time of Concentration

4.4.1.5 Peak runoff by volume

CHAPTER-IV
ESTIMATION OF SURFACE RUNOFF

4.1 Introduction:

Direct runoff means the part of the total runoff that are not store on land or infiltrated into the soil and which are contain into streams. Runoff is mainly depends on rainfall, that is only independent parameter for runoff estimation. Runoff can be varying in size from smallest to larger rivers. Primary and natural supplier of water to any basin is only precipitation.The design of a drainage structure requires the hydrologic analysis of the peak rate of runoff, the volume of runoff and the time distribution of flow from the contributing drainage area (Virginia Department of Transportation, 2002; Washington State Department of Transportation, 1997). Still, the relation between the amount of rainfall in a drainage basin and runoff amount from the basin is complex due to inadequacy in data availability of study area. In accuracy in estimation of surface runoff can result in either a small drainage structure that causes potential hazards, inconvenience, and drainage problems; or an extra-large, inefficient drainage structure.

Runoff, which may be variously referred to as stream flow, stream or river discharges or catchment yield, normally expressed as a volume per unit of time. The cusec, i.e., one cubic metre per second is a commonly used unit. Runoff may also be expressed as a depth equivalent over a catchment, i.e., millimetres per day or month or year.

4.2 Components of Surface runoff:

The invariable misuse of runoff terms has resulted in much confusion and ambiguity about the sources and components of runoff. (Freeze, 1972) provided a consistent aid unambiguous terminology which has been adopted with only slight modification. Generally diverse catchment areas total runoff divided into four components such as channel precipitation, overland flow, interflow and groundwater flow.

4.2.1 Channel Precipitation:

Direct rainfall onto the water surfaces of streams, lakes, and reservoirs makes an immediate input to stream flow. Channel precipitation amount is small percentage in relation to other components as catchment area covered by water surfaces. The water surface for most catchments does not exceed 5 per cent of the total area even at high water levels (Linsley et al, 1938). In the study area most of the Darna Lake Catchments containing a large area of lake hence, channel precipitation may make a substantial contribution to stream flow.

4.2.2 Overland Flow:

Overland flow comprises the water which, failing to infiltrate the surface, travels over the ground surface towards a stream channel.

4.2.3 Interflow:

Water which penetrates into soil and moves laterally through upper soil part to stream channels either as unsaturated flow or, more usually , as shallow hovering saturated flow above the main ground water level is known as interflow. In the time of heavy rainfall interflow observed more. Experimental evidence has long indicated that interflow may account for up to 85 percent of total runoff (Hertzler, 1939).

4.2.4 Groundwater Flow:

Most of the rainwater which infiltrated into the soil layer generally reaches the main stream as a groundwater. Commonly this flow shows the important long lasting component of total runoff and being important during absent of runoff.

4.3 Factors affecting on surface runoff:

4.3.1 Factors Affecting the Total Volume of Runoff:

The most obvious and probably the most effective influence on the total volume of runoff is the long-term balance between the amount of water gained by catchment area in the form of precipitation, and the amount of water lost from that catchment area in the form of evapotranspiration. It should be noted, however, that the effect of area may depend upon the prevailing climatic regime.

Slope, soil, and rock type may indirectly influence the total runoff from a catchment through their effects in delaying water movement after precipitation thereby possibly affecting the amount of evapotranspiration. In general, the highest annual runoff would be expected from steeply sloping areas having thin soils and impermeable rocks. Finally, the average height of the catchment may affect total runoff, again indirectly, through its direct orographic influence on precipitation amounts.

4.3.2 Factors Affecting the Distribution of Runoff:

Hydrologist viewed meteorological factor mainly affected on distribution of runoff as compare to other such as environmental and catchment factor.

4.3.2.1 Meteorological Factors:

Precipitation is the basic component of stream flow, hence meteorological factors are more importance and their variation with time tends to be closely related to similar variations of runoff.

4.3.2.2 Types of Precipitation:

Precipitation generally occurred either in rainfall or as snowfall or in other forms such as hail and so on affected on distribution of runoff. Precipitation falling as rain directly contributes to runoff, but the extent to which it does so will depend upon the interaction of several meteorological and other factors.

4.3.2.3 Rainfall Intensity and Duration (Rainfall Pattern):

If the rainfall is heavy and duration of rainfall is more, runoff will be more and long-lasting whereas, showery rainfall with low intensity shows absence of runoff as it is completely lost in infiltration and evaporation. In the study area of Darna Lake Catchment rainfall is heavy that shows ensuing runoff.

If the duration of the rainfall is more then it shows greater potential of runoff whereas, less duration of rainfall then potential of the runoff will be lower as because only part of the catchment will be contributing to runoff before rainfall ceases. In this context, it is noticeable that the importance of rainfall duration will tend to vary with the size and nature of the catchment.

4.3.2.4 Rainfall Distribution:

Distribution of rainfall in the catchment area is generally depends on relationship between rainfall and runoff. If the volume of rainfall equally distributed in whole catchment with lower intensities less likely to produce base flow than same volume of rain falling in a small and localized part of the catchment.

4.3.2.5 Weather conditions:

Any regions temperature also affects on runoff to a great extent. If temperature is high it makes surface dry and when rain occurs more water is absorbed by the ground surface. Evaporation rate will also be more if temperature is high. In present study area temperature mostly observed low throughout the area hence, runoff would be high, due to less evaporation rate.

4.3.3 Catchment Factors:

Catchment factors such as shape of the basin, topography and soil type remain constant for long period in the area but some factors those mainly associated with land use change rapidly. Hence, such factors are much more difficult to apply accurately for determinations of catchment area.

4.3.3.1 Topography:

Topographical factor mainly associated with slope of the area. If the surface slope is steeper runoff will be more and water pass rapidly over the slope as compare to gentle slope. If there are local depressions water will be held up in depressions forming lakes, ponds etc., in the catchment. In the Darna Lake Catchment area most of the part covered by moderate to steeper slopes hence more water will over the surface rapidly flow as a runoff.

4.3.3.2 Shape and size of the catchment:

Shape and size of the catchment also affected on distribution of runoff in catchment area and its effects on flood intensities. In fern shaped catchment area runoff observed less, in fan shaped runoff outlet is more. If catchment area is long and narrow tributaries of the main channel likely to join it hence, after a heavy rainfall over the catchment area, the runoff peaks of the these tributaries will have left the catchment before those of the upstream tributaries have moved very far down the main stream. Circular catchment area, the tributaries often tend to come together and join the main stream near the centre of the area (Parde, 1955). Elongated catchments are subject to high runoff peaks. In present study area catchment area have elongated shape that shows high runoff peaks.

4.3.3.3 Geology:

Geological variation in catchment area mainly influence on runoff of the catchment. It generally consist types of the rocks in which catchment area has been eroded and structural formations. In Darna Lake Catchment area most of the area covered by dyke, sill Basaltic and dolertic type of rocks that shows high runoff peaks can be occurred in this geological structures(Fig.2.2).

4.3.3.4 Soil:

Infiltration characteristics of the area and its effects on the character of rainfall in the form of overland flow, groundwater flow and so on mainly associated with type as well as texture of the soil. Sandy soils associated with high infiltration rates than fine grained textured soil. Hence, fine grained soil such as clay soil generats less volume of quick flow. In the study area most of the area covered by loamy sandy soils with coarse texture and contains less clay and silt that shows moderate infiltration rate.

4.3.3.5 Vegetation:

Hydrologist received more attention to the vegetation cover effects on distribution of runoff in catchment area because indirectly vegetation may influence runoff through its effect on soil type. If region is associated with some species of vegetal cover in the catchment sunrays cannot reach the ground and evaporation loss will be reduces. In the study area south and south east area covered by forest such as Monsoonal deciduous forest and tropical moist deciduous forest and wasteland whereas most of the north and central area shows agriculture land which shows high runoff over the wasteland area (Fig. 2.9).

4.3.3.6 Drainage Network:

Many physical characteristics of the catchment area associated with character of the drainage pattern. If the influence of the drainage network on runoff concerns the presence of lakes and swamps in a catchment area. Where these occur, they tend to 'absorb' high runoff peaks and which is particularly beneficial in catchments which generate large volumes of quickflow. In Darna Lake Catchment such kind of the situation occurred that shows high runoff peaks and it will generate large volume of quickflow.

4.3.4 Human Factors:

Human interference in catchment area can be changed pattern and distribution of runoff in the form of urbanization and impermeable surfaces. In the study area most of the area covered by less vegetation and some extent away from urbanization that shows this area is less affected by human factors.

4.3.4.1 Hydraulic structures:

Many of the world's large rivers flow can be controlled by dams and reservoirs those are mostly constructed for different purposes such as water supply, power generation or irrigation etc. These hydraulic structures effect on flood peaks as like as natural lakes particularly in those areas where multipurpose schemes are in action. In study area such kind of the hydraulic structures means Darna Lake constructed artificially that can be affected on stream flow. Due to that channel straightening and enlargement modified and it reduce discharge as well as water level of the channel.

4.3.4.2 Agricultural techniques:

Use of different agricultural techniques and practices also becomes one of the important aspects of human influence on runoff. In generally, if forest is replaced by crops or other lower growing vegetation it will increase runoff in catchment area. In Darna Lake Catchment area agricultural area observed that indicates high runoff in the area.

4.3.4.3 Urbanization:

Urbanization mainly affects on runoff due to increase of settlement and construction of roads and pavements that can be reduced infiltration capacity. In Darna Lake Catchment area some area covered by settlement and other subsidiary features like roads hence infiltration capacity is low in that area.

4.3.4.4 Severity of flooding:

Due to increase in rainfall intensity and duration it will also affects on reduction in infiltration capacity. In study area rainfall intensity and duration is high that shows low infiltration capacity and severity of flooding.

4.4 Empirical Formulas:

4.4.1 Rational Methods:

It is an important method that shows relation between peak flow and rainfall intensity that has been widely accepted by hydraulic engineers; yet origin of the rational method is unclear. Kuichling (1889), who was first mention this method in United States scientific literature. This method is also known as Lloyd-Davis method in England, which was published in 1906(Chow, 1964). This method is comparatively very simple to apply but simplicity of the equation deceptive due to the critical value of the rainfall intensity through the medium of time of concentration with the consideration of basin size, shape as well as variation in rainfall duration, intensity, distribution and frequency; all that can be considered as determining value (National Resources Committee, 1939).

Virginia Department of Transportation (VDOT) (2002) suggested the use this method for assess the design-storm peak runoff from small basins with area up to 200 acres(2ha) and for up to 300 acres(3ha) in low-lying tidewater areas. The method uses an empirical equation that integrates basin and precipitation characteristics to estimate peak discharges (Chow, 1964). Validation of the Rational Method is difficult because direct measurement of some hydrologic characteristics used in the method is not easily accomplished.

This method is one of the imperative measures for determining runoff from small catchments and depends on maximum rates of runoff that occurs over drainage basin where rainfall distributed evenly and watersheds all part contribute to flow. Estimation of runoff from catchments by this method can be useful for conservation and utilization of water for different purposes that are required for the economic planning of the basin.

This method is mainly use to find out exact relationship between rainfall and runoff. For this some constants are established in the equation which quietly gives accurate outputs for a particular region. Practically all the methods those are use for prediction and forecasting of runoff contain approximation and considered as misleading. The main drawbacks of these methods are the difficulty of knowing the exact conditions under which they are apply. Among the all methods rational method is one of the earliest and best known method to estimate peak flows. In rational method by using rainfall intensity, watershed area and coefficient of runoff determines peak flow. This method generally recommended for natural watersheds that contains basin area less than 5 mi^2 , in that time of concentration, infiltration and detention of surface are not becomes large influences. Following equations can be used in rational method to calculate rainfall intensity, time of concentration and peak flow.

4.4.1.1 Rainfall Intensity (I):

Rainfall intensity shows the severity of the rainfall. It is mainly associated with rainfall and period which is generally equal to time of concentration (t) and is used to calculate the peak flow in rational method. The Rational Method uses a rainfall intensity to represent the average intensity for a storm of a given frequency for a selected duration (Viessman and others; 1977). The rainfall intensity value which is used in the Rational Method has been selected according to the required return period for the formulation of the arrangement under the study area.

$$I = \frac{K(T)^a}{(t+b)^n}$$

Where; I = Intensity in Millimetre per hour

T = Return period in years (10 years)

t = Time of concentrations in hours

K, a.b.n = Values of corresponding study area

K = 3.483

a = 0.1267

b = 0.00

n = 0.4853

As the size of the basin decreases the variability of the rainfall intensity becomes more valid. Hence, Darna Lake Catchment area has been divided into 140 sub-basins (Fig.-4.2). Rainfall intensity of the study area measured in millimetre per hour. It is observed that rainfall intensity is high in DARN_B17 which is 2113.58 mm/hr (211.36/hr) which generally consist some part of Kanchangaon village and very low in DARN_B28 which is 291 mm/hr (29.10 cm/hr) that consist some part of Pimpalgaon and Khairgaon village(Table - 4.2 and Fig.-4.3).

4.4.1.2 Runoff Coefficient (C):

Runoff Coefficient shows ratio of runoff to rainfall. This input variable is most difficult variable among all variables for estimation. Coefficient value is different as per wetting and seasonal conditions as well as land cover. For this study coefficient are applicable for 10 years and it is taken as per land cover such as agriculture land(0.4), barren(0.16), built up(0.5), forest(0.3) and scrub land (0.22) (Table- 4.1 and Fig.-4.1). Rational Runoff Coefficient for Rational Method, C (Subramanya, 2008) value has been employed for this study area. Runoff coefficient is a dimensionless empirical coefficient which is related to basin properties such as evapotranspiration, infiltration and interception etc. Always the value of runoff coefficient ranges from 0 to 1 in that if the value is 0 it shows no runoff generates on the basins whereas if value is 1 it shows all of the rain falling in the basins generates runoff. The coefficient of runoff is the most subjective parameter estimated in the rational method.

In Darna Lake Catchment area most of the area covered by barren land (191 sq. km.) and moderates to steep basin, little vegetation as well as resistant surface that shows high runoff coefficient (Fig.-4.1 & Appendix-G).

Table 4.1: Coefficients for Darna Lake Catchment

Sr. No.	**Land Cover**	**Rational Runoff Coefficient for Rational Method, C (Subramanya, 2008)**
1	Agriculture land	0.4
2	Barren	0.16
3	Built up	0.5
4	Forest	0.3
5	Scrub land	0.22

Source: Subramanya, 2008.

Fig-4.1

Fig-4.2

4.4.1.3 Catchment Area (A):

Catchment area is the causative factor that runoff into the drain. In the study area Darna Lake Catchment area divided into different part such as agriculture land, barren land, built up, forest and scrub land (Table- 4.1).

Total of the study area is 35351.78 hectares. Maximum area covered by DARN_E01 sub-basin of fifth order which is 7509.31 hectares which lies northwest part of Darna Lake Catchment consist Tirangwadi, Bhavali, Kurnoli, Pardevi,Waki, Korapgaon and Pimpalgaon Bhatata villages Whereas, minimum area covered by DARN_A66 sub-basin of first order which is 5.67 hectares(Table- 4.2 and Fig.-4.3)

4.4.1.4 Time of Concentration(t):

Time of concentration means the time required for a particle of water to travel from the most hydraulically distant point in the basin to the outlet (Wigham, 1970), and the time required for a flood wave to travel from the most hydraulically distant point to the outlet (National Resources Committee, 1939). Time of concentration generally associated with slope of the ground, length of the flow and surface cover. It is one of the important parameter which is essential in hydrology to compute the response of a watershed to a rain event as well as peak discharge. Time of concentration of a watershed is mainly associated with physical uniqueness of the watershed and direct runoff.

For measure time of concentration in Darna Lake Catchment rational formula has been applied. Normally, when time of concentration compute for a reservoir or a lake catchment area it is very small and it can be assumed as zero.

For calculation of Time of Concentration Darna Lake Catchment following equations are used.

$$\boldsymbol{t = 0.01947(k)^{0.77}}$$

t = Time of concentration in minutes

$$\boldsymbol{k = \sqrt{L^3 \div H}}$$

Where,

L=Difference in elevation between most remote point and outlet in Meters

H= Maximum length of travel in meters

In the study area time of concentration is 0.02 in a minute observed in DARN_B17 covered Kanchangaon village some part, 0.03 in a minute observed in

Fig-4.3

DARN_A01, DARN_A02, DARN_A04,DARN_A36, DARN_A37, DARN_A61 and DARN_A71 that mainly consist Nandgaon Bk., Deole, Khambale, Ghoti Bk. and Sakur whereas 1.29 and 1.38 in a minute in DARN_E03, DARN_B28 respectively that shows part of Khairgaon, Kurngwadi, Nirpan, Majargaon, Udadawane, Talogha and Kaluste villages (Table- 4.2 and Fig.-4.3). This time of concentration can be useful for hydrologist for further assessment of flood risk.

According to Pavlovic & Moglen (2008), such parameter reflects how fast the watershed responds to rainfall events.

4.4.1.5 Peak runoff by volume:

It is very difficult task to estimating of peak runoff by volume from a specific watershed in response to a specific rainfall event. To find out watershed runoff first successful method was developed by USDA-SCS and second early method was the Rational method. For this study rational method applied for compute of peak runoff. Magnitude of peak flow generally affected by drainage an area of a basin. Terrain slope of an area also affects the total volume of runoff.

Greater velocities can be produces over steeper slope of the channel and it can be allowed higher removal of runoff from the watershed area.

The rational formula is used for peak volume of runoff is -

$$Q = \frac{CIA}{360}$$

Where;

Q = The peak discharge or the quantity of runoff in (m^3/s)

C = Coefficient of runoff

I = Rainfall intensity, in Millimetre per hour; and

A = area of the watershed, in Hectare.

In the study area of Darna Lake Catchment, peak volume has been computed sub-basin wise. It shows that lowest value of peak volume is observed in DARN_A66 sub-basin which is 15.30m^3/s that consist part of Sakur village whereas, highest value of peak volume is observed in DARN_E01 sub-basin which is 13973023.53 m^3/s (Table-4.2 and Fig.-4.3) and consist part of Tirangwadi, Bhavali, Kurnoli, Pardevi,Waki, Korapgaon and Pimpalgaon Bhatata villages.

Table 4.2: Priority Levels Ranking Result of Peak Surface Runoff

Sub-basin	I (cm /hrs)	I (mm/hrs)	t in min	t in hrs	Area in hec	Q (m3/s)	Ranking	Priority Class	Priority level
DARN_A01	184.77	1847.66	0.03	0.001	28.66	949.45	79	Medium	3
DARN_A02	183.61	1836.12	0.03	0.001	43.06	2624.08	50	High	2
DARN_A03	135.00	1350.02	0.06	0.001	34.73	1266.31	69	Medium	3
DARN_A04	201.00	2010.01	0.03	0.000	29.09	1379.30	66	Medium	3
DARN_A05	138.82	1388.19	0.06	0.001	19.04	385.78	108	Low	4
DARN_A06	136.08	1360.79	0.06	0.001	64.33	3714.07	42	High	2
DARN_A07	121.22	1212.24	0.07	0.001	16.00	225.62	123	Very Low	5
DARN_A08	86.92	869.18	0.14	0.002	12.85	86.91	132	Very Low	5
DARN_A09	118.70	1187.04	0.08	0.001	25.21	355.24	109	Low	4
DARN_A10	99.63	996.32	0.11	0.002	15.55	189.31	125	Very Low	5
DARN_A11	111.57	1115.66	0.09	0.001	34.07	921.64	81	Medium	3
DARN_A12	123.54	1235.40	0.07	0.001	43.14	962.15	78	Medium	3
DARN_A13	83.32	833.19	0.16	0.003	38.84	621.95	92	Low	4
DARN_A14	102.80	1027.96	0.10	0.002	24.24	412.73	103	Low	4
DARN_A15	94.52	945.16	0.12	0.002	31.71	525.02	96	Low	4
DARN_A16	108.80	1087.99	0.09	0.002	12.05	110.08	129	Very Low	5
DARN_A17	121.06	1210.58	0.07	0.001	9.78	89.27	131	Very Low	5
DARN_A18	116.81	1168.05	0.08	0.001	8.77	65.65	135	Very Low	5
DARN_A19	124.41	1244.06	0.07	0.001	27.02	614.13	93	Low	4
DARN_A20	130.60	1306.01	0.06	0.001	15.75	227.52	122	Very Low	5
DARN_A21	83.35	833.48	0.16	0.003	25.00	313.48	112	Low	4
DARN_A22	100.69	1006.92	0.11	0.002	20.67	333.74	110	Low	4
DARN_A23	97.79	977.86	0.11	0.002	28.98	403.53	106	Low	4
DARN_A24	97.83	978.26	0.11	0.002	45.56	1050.40	74	Medium	3
DARN_A25	78.92	789.23	0.18	0.003	52.30	1143.89	73	Medium	3
DARN_A26	113.87	1138.71	0.08	0.001	65.43	2466.72	52	High	2
DARN_A27	105.04	1050.44	0.10	0.002	18.45	238.31	119	Low	4
DARN_A28	108.95	1089.47	0.09	0.002	16.86	215.65	124	Very Low	5
DARN_A29	89.03	890.35	0.14	0.002	52.86	1442.42	63	Medium	3
DARN_A30	117.37	1173.71	0.08	0.001	42.24	1531.11	60	High	2
DARN_A31	106.64	1066.40	0.09	0.002	24.74	440.41	101	Low	4
DARN_A32	101.75	1017.54	0.10	0.002	44.78	1006.21	76	Medium	3
DARN_A33	127.91	1279.10	0.07	0.001	43.55	1420.83	64	Medium	3
DARN_A34	114.31	1143.11	0.08	0.001	29.28	520.92	97	Low	4
DARN_A35	116.67	1166.65	0.08	0.001	75.18	3267.42	45	High	2
DARN_A36	189.38	1893.76	0.03	0.000	17.85	493.31	98	Low	4
DARN_A37	193.36	1933.57	0.03	0.000	15.09	295.23	113	Low	4
DARN_A38	127.78	1277.81	0.07	0.001	24.43	404.21	104	Low	4
DARN_A39	95.00	949.97	0.12	0.002	50.08	1177.73	72	Medium	3
DARN_A40	93.83	938.26	0.12	0.002	90.25	5800.44	33	High	2
DARN_A41	86.77	867.73	0.15	0.002	40.65	879.21	82	Medium	3

Sub-basin	I (cm /hrs)	I (mm/hrs)	t in min	t in hrs	Area in hec	Q (m3/s)	Ranking	Priority Class	Priority level
DARN_A42	87.69	876.91	0.14	0.002	34.66	563.49	94	Low	4
DARN_A43	126.87	1268.73	0.07	0.001	43.33	1639.85	59	High	2
DARN_A44	127.62	1276.16	0.07	0.001	16.83	232.55	121	Very Low	5
DARN_A45	115.10	1151.02	0.08	0.001	19.85	236.56	120	Low	4
DARN_A46	138.00	1379.97	0.06	0.001	16.82	132.41	128	Very Low	5
DARN_A47	79.59	795.88	0.17	0.003	8.16	40.79	138	Very Low	5
DARN_A48	79.93	799.31	0.17	0.003	9.67	46.76	137	Very Low	5
DARN_A49	131.02	1310.21	0.06	0.001	8.96	56.21	136	Very Low	5
DARN_A50	92.94	929.41	0.13	0.002	23.03	293.42	115	Low	4
DARN_A51	86.02	860.24	0.15	0.002	18.28	148.33	127	Very Low	5
DARN_A52	99.44	994.36	0.11	0.002	23.72	418.85	102	Low	4
DARN_A53	121.24	1212.44	0.07	0.001	30.67	641.27	90	Medium	3
DARN_A54	50.79	507.86	0.44	0.007	46.89	664.41	89	Medium	3
DARN_A55	130.45	1304.53	0.06	0.001	24.96	562.91	95	Low	4
DARN_A56	102.89	1028.93	0.10	0.002	44.63	1472.92	62	Medium	3
DARN_A57	84.92	849.15	0.15	0.003	42.90	830.32	83	Medium	3
DARN_A58	111.45	1114.49	0.09	0.001	29.38	682.86	88	Medium	3
DARN_A59	98.97	989.74	0.11	0.002	73.44	3621.48	43	High	2
DARN_A60	86.59	865.91	0.15	0.002	36.98	759.47	85	Medium	3
DARN_A61	189.90	1899.03	0.03	0.000	17.08	403.96	105	Low	4
DARN_A62	78.42	784.18	0.18	0.003	48.26	1301.78	68	Medium	3
DARN_A63	126.85	1268.54	0.07	0.001	45.58	1974.63	56	High	2
DARN_A64	130.45	1304.52	0.06	0.001	47.67	2523.97	51	High	2
DARN_A65	90.15	901.46	0.13	0.002	17.58	250.71	117	Low	4
DARN_A66	82.31	823.05	0.16	0.003	**5.67**	**15.30**	140	Very Low	5
DARN_A67	115.52	1155.16	0.08	0.001	17.87	173.59	126	Very Low	5
DARN_A68	103.86	1038.57	0.10	0.002	19.79	242.27	118	Low	4
DARN_A69	88.24	882.44	0.14	0.002	12.09	84.44	133	Very Low	5
DARN_A70	130.08	1300.84	0.06	0.001	27.37	733.94	86	Medium	3
DARN_A71	194.36	1943.60	0.03	0.000	22.66	759.89	84	Medium	3
DARN_A72	135.42	1354.23	0.06	0.001	16.12	294.35	114	Low	4
DARN_A73	64.86	648.65	0.26	0.004	36.41	641.06	91	Medium	3
DARN_A74	89.82	898.17	0.14	0.002	25.62	327.18	111	Low	4
DARN_A75	73.78	737.84	0.20	0.003	11.31	38.82	139	Very Low	5
DARN_A76	67.67	676.68	0.24	0.004	14.57	74.19	134	Very Low	5
DARN_A77	72.62	726.19	0.21	0.003	16.49	101.53	130	Very Low	5
DARN_B01	123.01	1230.13	0.07	0.001	43.33	1743.88	58	High	2
DARN_B02	104.04	1040.37	0.10	0.002	136.92	11483.92	23	Very High	1
DARN_B03	95.34	953.41	0.12	0.002	84.70	4194.86	38	High	2
DARN_B04	88.68	886.76	0.14	0.002	28.22	470.29	99	Low	4
DARN_B05	113.82	1138.19	0.08	0.001	112.50	9088.28	27	Very High	1
DARN_B06	105.21	1052.15	0.10	0.002	51.14	1818.36	57	High	2
DARN_B07	100.10	1000.99	0.11	0.002	87.69	3474.22	44	High	2

Sub-basin	I (cm /hrs)	I (mm/hrs)	t in min	t in hrs	Area in hec	Q (m3/s)	Ranking	Priority Class	Priority level
DARN_B08	91.41	914.09	0.13	0.002	74.53	2366.61	53	High	2
DARN_B09	103.64	1036.43	0.10	0.002	108.87	5796.87	34	High	2
DARN_B10	98.38	983.77	0.11	0.002	138.73	10667.14	24	Very High	1
DARN_B11	74.13	741.31	0.20	0.003	153.75	9880.29	25	Very High	1
DARN_B12	90.95	909.54	0.13	0.002	55.89	1360.73	67	Medium	3
DARN_B13	65.10	651.00	0.26	0.004	169.90	8490.49	29	Very High	1
DARN_B14	55.00	549.96	0.37	0.006	513.34	62930.51	12	Very High	1
DARN_B15	112.60	1126.03	0.08	0.001	392.47	76518.64	11	Very High	1
DARN_B16	138.25	1382.52	0.06	0.001	86.00	6350.14	32	High	2
DARN_B17	**211.36**	**2113.58**	**0.02**	**0.000**	43.11	3031.96	48	High	2
DARN_B18	59.52	595.20	0.32	0.005	105.77	3959.60	40	High	2
DARN_B19	77.73	777.25	0.18	0.003	67.24	2312.17	54	High	2
DARN_B20	73.43	734.27	0.20	0.003	116.05	6664.34	31	High	2
DARN_B21	67.37	673.66	0.24	0.004	121.48	4642.82	36	High	2
DARN_B22	90.00	900.01	0.13	0.002	97.75	6687.83	30	Very High	1
DARN_B23	92.75	927.54	0.13	0.002	29.44	458.28	100	Low	4
DARN_B24	91.23	912.34	0.13	0.002	59.87	1485.76	61	Medium	3
DARN_B25	102.29	1022.92	0.10	0.002	67.01	3046.29	47	High	2
DARN_B26	43.39	433.91	0.61	0.010	57.57	995.37	77	Medium	3
DARN_B27	32.77	327.75	1.08	0.018	71.07	1209.68	71	Medium	3
DARN_B28	**29.10**	**291.00**	**1.38**	**0.023**	60.29	718.87	87	Medium	3
DARN_B29	33.03	330.29	1.06	0.018	70.02	944.24	80	Medium	3
DARN_B30	39.89	398.91	0.72	0.012	130.80	3898.26	41	High	2
DARN_B31	37.27	372.73	0.83	0.014	69.35	1025.51	75	Medium	3
DARN_B32	33.09	330.91	1.06	0.018	90.67	1393.07	65	Medium	3
DARN_B33	36.33	363.27	0.87	0.015	96.88	2097.53	55	High	2
DARN_B34	104.50	1045.04	0.10	0.002	271.37	51571.48	14	Very High	1
DARN_B35	80.81	808.06	0.17	0.003	186.24	17594.27	22	Very High	1
DARN_B36	76.53	765.30	0.19	0.003	34.24	401.87	107	Low	4
DARN_B37	153.97	1539.72	0.04	0.001	38.14	1236.33	70	Medium	3
DARN_B38	71.94	719.40	0.21	0.004	29.56	289.82	116	Low	4
DARN_B39	74.00	739.96	0.20	0.003	81.33	3069.64	46	High	2
DARN_C01	64.26	642.64	0.27	0.004	139.02	5519.14	35	High	2
DARN_C02	76.28	762.80	0.19	0.003	458.39	89922.21	9	Very High	1
DARN_C03	92.88	928.80	0.13	0.002	207.13	17844.09	21	Very High	1
DARN_C04	101.26	1012.57	0.11	0.002	233.55	31047.06	17	Very High	1
DARN_C05	112.92	1129.23	0.08	0.001	125.10	9348.15	26	Very High	1
DARN_C06	104.91	1049.06	0.10	0.002	144.02	8650.71	28	Very High	1
DARN_C07	72.13	721.35	0.21	0.004	265.92	25903.54	19	Very High	1
DARN_C08	41.59	415.92	0.66	0.011	110.72	2761.02	49	High	2
DARN_C09	37.84	378.45	0.80	0.013	347.02	20564.76	20	Very High	1
DARN_C10	52.22	522.20	0.41	0.007	124.00	4441.67	37	High	2
DARN_C11	34.24	342.44	0.99	0.016	159.76	4041.57	39	High	2

Sub-basin	I (cm /hrs)	I (mm/hrs)	t in min	t in hrs	Area in hec	Q (m3/s)	Ranking	Priority Class	Priority level
DARN_C12	70.20	701.99	0.22	0.004	417.24	83538.99	10	Very High	1
DARN_C13	90.98	909.80	0.13	0.002	278.92	43384.19	15	Very High	1
DARN_C14	104.31	1043.08	0.10	0.002	439.46	99530.39	7	Very High	1
DARN_D01	73.13	731.32	0.21	0.003	737.18	184828.14	5	Very High	1
DARN_D02	42.34	423.40	0.64	0.011	736.92	117693.10	6	Very High	1
DARN_D03	57.12	571.16	0.34	0.006	259.18	26087.86	18	Very High	1
DARN_D04	37.39	373.92	0.82	0.014	1283.71	342345.99	4	Very High	1
DARN_D05	32.87	328.69	1.07	0.018	536.17	56059.32	13	Very High	1
DARN_D06	39.10	391.01	0.75	0.013	677.64	93185.87	8	Very High	1
DARN_D07	39.06	390.63	0.75	0.013	420.90	38107.83	16	Very High	1
DARN_E01	50.67	506.68	0.44	0.007	**7509.31**	**13973023.53**	1	Very High	1
DARN_E02	33.97	339.65	1.00	0.017	6898.87	8141632.53	2	Very High	1
DARN_E03	30.06	300.58	1.29	0.021	6295.07	7003743.48	3	Very High	1
Total Area					35351.78				

Source: Computed by Researcher.

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CHAPTER-V

PRIORITIZATION OF SUB BASINS FOR CONSERVATION PLANNING

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PRIORITIZATION OF SUB BASINS FOR CONSERVATION PLANNING

5.1 Introduction - Watershed Prioritization:

For development of any country watersheds plays an important role. Prioritization of a watershed has a significance importance for resources management and it becomes one of the important aspects of planning for development, implementation and management of resources over a watershed region. A watershed is an ideal component for management of natural resources particularly land and water resources for mitigation the impact of natural resources and achieving sustainable development. Watershed and hydrological units that lies in large basins becomes more efficient components for assessment of the resources and further planning as well as implementation. The proper management of watershed needs utilization of various aspects like, land, water, soil, and forest resources of a particular watershed for better production and lesser hazard to natural resources (Biswas et. al., 1999).

Watershed prioritization means different sub watersheds of a watershed ranking as per study criteria for further action and conservation. This kind of study quite difficult and expensive hence, requires finding out smaller sub watersheds in a watershed that could be suitable for more inventive and targeted resource management programme.

The present study highlights the usefulness of GIS for morphometric analysis and prioritization of the sub-basins of Darna watershed of Western Maharashtra, India. The main application of remote sensing and GIS is that to analysis of morphometric parameters at micro level that can be use for immense utility in watershed prioritization for natural resources management. Morphometric analysis of drainage is of incredible importance for proper planning of watershed as it gives information about the basin characteristics in terms of slope, topography, soil conditions, runoff characteristics and surface water potential etc. Therefore, for this study morphometric analysis and runoff studies criteria used in Darna Lake Catchment area for determine priority for conservation planning. To detection of these critical sub-basins that need to be soil and water conservation measures on special basis, is particularly important in the areas that are close to the reservoir. The study area is also associated with reservoir hence; it is very difficult work to detection of these critical sub-basins that need to be applying conservative measures. It is practically not possible to take whole watershed area at a time for conservation work. Therefore, whole basin can be divided into several sub units, as Sub-basins by considering its drainage system.

5.2 Morphometric Analysis of Darna Lake Catchment Sub-basin:

The morphometric assessment helps to elaborate a primary hydrological diagnosis in order to predict approximate behaviour of a watershed if correctly coupled with geomorphology and geology (Esper, 2008).Thus, Watershed prioritization on the basis of morphometric parameters is essential in order to invent a sustainable watershed management plan.

5.2.1 Linear Aspects of the Darna Lake Catchment:

5.2.1.1 Stream Order (u):

Stream ordering is the primary step taken in drainage basin analysis, where hierarchical ranking is done to existing streams of different extents and pattern. In the present study of Darna Lake Catchment, ranking of streams has been carried out based on the method proposed by Strahler (1964). The study area is a 6^{th} order watershed covering an area of 389.6 km^2. All the 140 Sub-basins are of 6^{th} order Sub-basins. The total numbers of 1815 streams were identified of which are divided in different individual stream order assigning order wise with DARN_A01 to DARN_E03. The highest number of stream segments is found in Sub-basin DARN_E01 which shows fifth order basin that consist 330 streams of first order, 82 second order, 21 third order, 4 streams of four order. Total 438 streams were identified in DARN_E01 basin. This basin generally covered Tiranglwadi, Bhavali, Kurnoli, Pardevi,Vaki, Korapgaon and Pimpalgaon Bhatata villages and located southwest part of study area(Appendix-D and Fig.-4.3).

5.2.1.2 Stream Length (Lu):

To describe runoff and watershed features stream length considered one of the important and suggestive variables for sequential development of stream segments. Generally, smaller length of streams found in hilly areas and longer streams on flat areas with gentle slope. In Drana Lake Catchment area stream numbers are counted and lengths of these streams measured using GIS software. Stream length ranges from 0.033 to 178 km. Maximum stream length found in DARN_E01 sub-basin towards South western side of the study area (Appendix-D).

5.2.1.3 Mean stream Length (Lsm):

According to Strahler (1964), the stream length is a characteristic property related to the drainage network components and its associated watersheds. Mean stream length expose the characteristic size of components of a drainage network and its contributing surfaces. Most of the times in a watershed mean stream length observed highest for highest order and lowest for lower order. Therefore, in the study area mean stream length varies from 0.033 to 16.77 km. The highest mean stream length is found in DARN_E01 sub-basin of study area which consist highest order means fifth order stream in all the 140 Sub-basins (Appendix-D).

5.2.1.4 Stream Length Ratio (Rl):

Stream length ratio is defined as the ratio between the mean stream lengths of one order with that of the next lower order of the stream segments. The stream length ratio between the streams of different orders of the study area shows a change in each Sub-basin. Highest stream length ratio is observed 4.85 for DARN_A54 Sub-basin which consist Pimpalgaon mor and Khirgaon villages (Appendix-D and Fig.-4.3). This stream length ratio indicates variation in slope and topography and the youth stage of geomorphic development in the streams of the study area (Vittala et al., 2004).

5.2.1.5 Bifurcation Ratio (Rb):

Bifurcation ratio describes the branching pattern of a drainage network and is defined as ratio between the total numbers of stream segments of a given order to that of the next higher order in a basin (Schumm, 1956). Bifurcation ratio generally ranges from 1.0 to 6.0 for watersheds in which geologic structures do not distort the drainage pattern (Strahler, 1964). The Rb in the Darna drainage watershed varies from 1 to 6 (Appendix-D). The Rb is highest in the DARN_B10,B11 and B15 Sub-basin with Rb value of 6 consist part of Waghere and Ghoti Bk. villages that are located central part of study area(Fig.-4.3). In these villages of study area higher value of Rb indicates a strong structural control in the drainage pattern, whereas the lower values of Rb in remaining Sub-basin mostly all first orders Sub-basin indicate that the Sub-basins are less affected by structural disturbances (Strahler, 1964).

5.2.2 Areal Aspects of the Darna Sub-basin:

5.2.2.1 Drainage Density (Dd):

Drainage density is defined as the total length of streams of all orders per drainage area. Drainage density varies with climate, rock type, relief, infiltration rate, vegetation cover and landscape evolution processes. According to Nag (1998), low drainage density generally results in the areas of highly resistant or permeable subsoil material, dense vegetation and low relief. High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief. The Dd value in the study area ranges from 0.4 to 5.8 km/km^2 . The highest drainage density (5.8 km/km^2) observed in DARN_C07 that consist part of Waghere and Somaj village. Sub-basins with high drainage density show weak impermeable subsurface material, sparse vegetation and mountainous relief. Lowest drainage density observed in DARN_A59 (0.4 km/km^2) in Belgaon Tarhale village. Sub-basins with low drainage density indicate highly permeable subsoil material under dense vegetation cover and low relief. Most of the study area shows high drainage density which, indicates that Darna Lake Catchment area associate with weak impermeable subsurface material, sparse vegetation and mountainous relief. (Appendix-D)

5.2.2.2 Stream Frequency (Fs):

Stream frequency or channel frequency is the total number of stream segments of all orders per unit area. The stream frequency value of the 140 Sub-basin of Darna Lake Catchment is varies from 0.6 to 17.6 per square km. The value of stream frequency exhibits positive correlation with the drainage density value of the area indicating increase in channel numbers with respect to the increase in Dd value. The Fs value has been observed highest in DARN_A66 and lowest in DARN_B14 Sub-basins of the study area (Appendix-D). Generally, greater the drainage density and stream frequency indicates runoff is faster. In Darna Lake Catchment area most of the sub-basins shows high drainage density and stream frequency hence it shows more runoff in the study area

5.2.2.3 Texture Ratio (Rt):

In the study area of 140 Sub-basins texture ratio varies from 0.2 to 8.3. Highest texture ratio associated with DARN_E01 means fifth order Sub-basin and lowest associated with DARN_A59 means first order Sub-basin (Appendix-D). Moderate to highest texture ratio of sub-basins indicates intermediate to fine texture of the basin.

5.2.2.4 Form factor (Ff):

In 140 Sub-basins of the Darna Lake Catchment Ff value range from 0.13 to 0.86. The highest value is associated with DARN_D03 Sub-basin means fourth order shows circular watershed and it consist Khambale, Manikkhamb and Waki villages that are located northern part of study area(Fig.-4.3). The lowest value is associated with DARN_A62 Sub-basin means first order shows elongated watershed with flatter peak flow for longer duration. Flood flows of such elongated basins are easier to manage than from the circular basin.

5.2.2.5 Circulatory ratio (Rc):

In the present study, Rc values ranges from 0.245to 0.8369. Low Rc values, indicate that the Sub-basins are mainly elongated which is observed in DARN_A59 sub-basin of study area and high Rc values indicate that Sub-basins are primarily circular. Most of the Rc value found more than 0.4 which indicates strongly elongated and homogenous geologic materials of the study area (Appendix-D).

5.2.2.6 Elongation ratio (Re):

The Re values in the present study ranges from 0.46 to 1.0 indicating moderate to low relief in the study area. Values near to 1.0 are the characteristics of the region of very low relief, which observed in DARN_C09 means third order sub-basin in Khairgaon and Deole village, whereas low Re value observed in DARN_A17 Sub-basin means first order watershed in Samnere village (Appendix-D and Fig.-4.3).

5.2.2.7 Length of overland flow (Lg):

It is the length of water over the ground before it gets concentrated into definite stream channels (Horton, 1945). The length of overland flow approximately equals to the reciprocal of drainage density. The Lg values of the study area shows variations from 0.2 to 2.89 indicating comparatively moderate relief of the area (Appendix-D). Highest Lg value has been observed in DARN_C07 sub-basin which covered part of Waghere Village.

5.2.2.8 Constant channel of maintenance (Cc):

The constant channel maintenance of the different Sub-basins of study area is ranges from 0.17 to 2.48km^2/km. The highest Cc value observed in DARN_A59 and lowest observed in DARN_C07 (Appendix-D). Most of the sub-basins depicted in high value of Cc. Hence, this study area consist resistant Basalt rock, all streams require large amounts of runoff, low permeability and so the constant channel of maintenance is high. Darna Lake Catchment has low constant channel maintenance in the bed of the river.

5.2.3 Relief aspects of the watershed:

5.2.3.1 Relief ratio (Rr):

The elevation difference between the highest and lowest points on the valley floor of a watershed is known as the total relief of that watershed. The maximum relief to horizontal distance along the watershed parallel to the principal drainage line is termed as relief ratio (Schumm, 1956). The relief ratio has direct relationship between the relief and channel gradient. In the study area, the values of relief ratio are ranging from 0.003 to 0.107 indicating moderate relief (Appendix-D).

5.3 Prioritization of Sub-basins:

5.3.1 Prioritization of Sub-basins on the basis of Morphometric Analysis:

Prioritization of basin into sub-basins is essential for spot out sensitive zones in the study area that are shows high erosion activities. Identified sensitive zones of the study area with the help of prioritization basis would be taking consideration for further conservative planning.

In the present study the compound parameter values of morphometric parameters for all 140 sub-basins of Darna Lake Catchment are computed and priority ranking is shown in Table 5.1. The DARN_D03 sub-basin with a compound parameter value of 28.2 is ranked highest in terms of erosion in the area followed by DARN_D04, DARN_C01, DARN_D01, DARN_D02, DARN_C14, DARN_C13, DARN_E01 and so on. Accordingly, conservation measures are sought starting from the sub-basin DARN_D03 and followed by other sub-basins depending upon their priority level. Table 5.1demonstrate the priority ranking of different 140 sub-basins through a pyramid chart. The final prioritized map of the study area showing different sub-basins with their priority ranking is shown in (Fig.-5.1).

Table-5.1: Prioritization Compound Ranking Result of Morphometric Analysis

Sub-basin	Dd	Fs	Rt	Ff	Rc	Re	Rn	Cc	Lg	Total	Compound Parameter	Priority	Priority class	Priority level
DARN_D03	4	12	10	1	32	36	18	137	4	254	28.2	1	Very High	1
DARN_D04	29	60	4	5	7	22	6	112	29	274	30.4	2	Very High	1
DARN_C01	14	14	15	25	16	25	25	127	14	275	30.6	3	Very High	1
DARN_D01	22	34	7	30	12	6	24	119	22	276	30.7	4	Very High	1
DARN_D02	13	28	5	48	21	16	12	128	13	284	31.6	5	Very High	1
DARN_C14	17	16	6	33	25	18	35	124	17	291	32.3	6	Very High	1
DARN_C13	38	32	12	27	11	5	37	103	38	303	33.7	7	Very High	1
DARN_E01	25	47	1	29	49	4	7	116	25	303	33.7	7	Very High	1
DARN_B06	12	11	17	15	3	62	43	129	12	304	33.8	8	Very High	1
DARN_C10	20	19	19	26	33	43	20	121	20	321	35.7	9	Very High	1
DARN_C02	31	50	11	16	42	8	27	110	31	326	36.2	10	Very High	1
DARN_D05	23	36	9	35	81	30	4	118	23	359	39.9	11	Very High	1
DARN_B23	34	10	33	7	8	77	51	107	34	361	40.1	12	Very High	1
DARN_C09	28	48	13	83	39	1	9	113	28	362	40.2	13	Very High	1
DARN_B27	5	23	25	69	46	53	5	136	5	367	40.8	14	Very High	1
DARN_D07	39	64	14	6	61	28	16	102	39	369	41.0	15	Very High	1
DARN_C05	45	53	32	3	5	32	60	96	45	371	41.2	16	Very High	1
DARN_E03	30	61	2	55	82	12	1	111	30	384	42.7	17	Very High	1
DARN_C04	63	54	21	4	52	2	55	78	63	392	43.6	18	Very High	1
DARN_B24	47	29	31	38	28	33	49	94	47	396	44.0	19	Very High	1
DARN_D06	16	37	8	75	105	9	8	125	16	399	44.3	20	Very High	1
DARN_C07	1	62	16	92	44	27	22	140	1	405	45.0	21	Very High	1
DARN_B02	41	65	22	46	40	14	46	100	41	415	46.1	22	Very High	1
DARN_C06	51	39	23	57	53	11	50	90	51	425	47.2	23	Very High	1
DARN_B04	18	6	35	49	35	108	40	123	18	432	48.0	24	Very High	1
DARN_E02	46	75	3	36	116	13	2	95	46	432	48.0	24	Very High	1
DARN_B01	21	26	41	56	9	79	61	120	21	434	48.2	25	Very High	1
DARN_C03	32	38	18	87	85	19	39	109	32	459	51.0	26	High	2
DARN_B38	24	2	20	89	75	87	34	117	24	472	52.4	27	High	2
DARN_C11	50	69	34	88	50	29	14	91	50	475	52.8	28	High	2
DARN_B12	60	58	54	58	17	39	53	81	60	480	53.3	29	High	2
DARN_A49	9	5	38	72	15	133	71	132	9	484	53.8	30	High	2
DARN_B29	27	22	27	110	79	70	11	114	27	487	54.1	31	High	2
DARN_C12	69	102	30	31	65	20	31	72	69	489	54.3	32	High	2
DARN_B13	61	116	72	37	19	15	30	80	61	491	54.6	33	High	2
DARN_A77	54	42	55	42	4	110	44	87	54	492	54.7	34	High	2
DARN_C08	6	21	29	120	99	71	10	135	6	497	55.2	35	High	2
DARN_B21	82	99	51	17	13	63	38	59	82	504	56.0	36	High	2
DARN_B19	65	77	71	32	47	37	42	76	65	512	56.9	37	High	2
DARN_B37	19	7	26	77	76	94	76	122	19	516	57.3	38	High	2
DARN_B10	37	67	24	94	72	45	41	104	37	521	57.9	39	High	2
DARN_B36	8	15	49	66	100	114	29	133	8	522	58.0	40	High	2
DARN_B11	33	74	28	98	87	34	28	108	33	523	58.1	41	High	2
DARN_B26	3	25	43	108	127	73	15	138	3	535	59.4	42	High	2
DARN_A51	93	56	57	2	1	106	80	48	93	536	59.6	43	High	2
DARN_B17	77	24	45	47	27	56	127	64	77	544	60.4	44	High	2
DARN_B07	70	73	46	64	63	41	58	71	70	556	61.8	45	High	2
DARN_A69	44	18	53	70	57	121	59	97	44	563	62.6	46	High	2
DARN_B16	43	72	40	97	34	68	69	98	43	564	62.7	47	High	2

Sub-basin	Dd	Fs	Rt	Ff	Rc	Re	Rn	Cc	Lg	Total	Compound Parameter	Priority	Priority class	Priority level
DARN_B28	11	30	42	131	117	90	3	130	11	565	62.8	48	High	2
DARN_A72	49	41	64	34	31	119	88	92	49	567	63.0	49	High	2
DARN_A27	76	57	66	12	10	126	84	65	76	572	63.6	50	High	2
DARN_A47	2	3	44	122	94	137	32	139	2	575	63.9	51	Medium	3
DARN_A36	87	51	56	18	2	93	130	54	87	578	64.2	52	Medium	3
DARN_A37	58	31	60	45	23	105	121	83	58	584	64.9	53	Medium	3
DARN_B08	74	59	48	81	104	17	62	67	74	586	65.1	54	Medium	3
DARN_A48	7	8	52	123	103	134	36	134	7	604	67.1	55	Medium	3
DARN_A46	80	43	65	50	26	103	104	61	80	612	68.0	56	Medium	3
DARN_A76	83	27	63	74	56	117	54	58	83	615	68.3	57	Medium	3
DARN_B32	35	78	59	132	115	50	13	106	35	623	69.2	58	Medium	3
DARN_A34	79	97	92	9	43	80	85	62	79	626	69.6	59	Medium	3
DARN_A75	10	13	61	130	107	132	33	131	10	627	69.7	60	Medium	3
DARN_A18	71	4	39	101	45	127	100	70	71	628	69.8	61	Medium	3
DARN_B09	42	55	37	136	134	44	48	99	42	637	70.8	62	Medium	3
DARN_B18	26	71	47	115	128	86	23	115	26	637	70.8	62	Medium	3
DARN_B25	97	76	76	14	93	58	82	44	97	637	70.8	62	Medium	3
DARN_A52	110	82	81	24	14	82	108	31	110	642	71.3	63	Medium	3
DARN_A65	72	49	80	53	89	92	66	69	72	642	71.3	63	Medium	3
DARN_A70	108	92	83	28	6	67	119	33	108	644	71.6	64	Medium	3
DARN_B34	75	136	95	68	51	31	52	66	75	649	72.1	65	Medium	3
DARN_A74	36	89	88	86	41	125	45	105	36	651	72.3	66	Medium	3
DARN_A14	105	83	84	39	20	85	102	36	105	659	73.2	67	Medium	3
DARN_A28	48	45	73	99	71	120	70	93	48	667	74.1	68	Medium	3
DARN_A16	15	17	67	128	112	131	57	126	15	668	74.2	69	Medium	3
DARN_A11	100	105	96	11	18	100	98	41	100	669	74.3	70	Medium	3
DARN_A45	59	68	79	71	59	104	97	82	59	678	75.3	71	Medium	3
DARN_A08	55	20	62	119	84	136	64	86	55	681	75.7	72	Medium	3
DARN_A67	116	52	75	8	66	99	125	25	116	682	75.8	73	Medium	3
DARN_B30	85	122	110	80	86	42	21	56	85	687	76.3	74	Medium	3
DARN_A22	102	70	74	76	22	102	101	39	102	688	76.4	75	Medium	3
DARN_A17	57	9	50	106	91	140	95	84	57	689	76.6	76	Low	4
DARN_A41	98	114	116	22	78	46	75	43	98	690	76.7	77	Low	4
DARN_A20	67	35	69	100	58	123	99	74	67	692	76.9	78	Low	4
DARN_B15	114	133	58	21	101	35	90	27	114	693	77.0	79	Low	4
DARN_A68	90	66	82	62	68	96	89	51	90	694	77.1	80	Low	4
DARN_A61	86	46	70	90	37	98	129	55	86	697	77.4	81	Low	4
DARN_A35	124	138	132	19	29	10	117	17	124	710	78.9	82	Low	4
DARN_A57	107	117	113	44	60	49	81	34	107	712	79.1	83	Low	4
DARN_A66	89	1	36	112	108	138	87	52	89	712	79.1	83	Low	4
DARN_A58	91	98	99	67	69	61	91	50	91	717	79.7	84	Low	4
DARN_A60	125	109	104	59	24	48	110	16	125	720	80.0	85	Low	4
DARN_A73	136	108	108	20	55	52	106	5	136	726	80.7	86	Low	4
DARN_B35	112	110	77	61	133	23	74	29	112	731	81.2	87	Low	4
DARN_B31	66	81	90	138	129	69	19	75	66	733	81.4	88	Low	4
DARN_A09	40	88	91	107	77	124	67	101	40	735	81.7	89	Low	4
DARN_B03	84	93	100	116	126	21	65	57	84	746	82.9	90	Low	4
DARN_A38	106	84	87	54	36	122	118	35	106	748	83.1	91	Low	4
DARN_A07	101	40	68	103	48	139	111	40	101	751	83.4	92	Low	4
DARN_A05	53	63	85	117	90	112	93	88	53	754	83.8	93	Low	4
DARN_A10	88	33	78	85	113	130	86	53	88	754	83.8	93	Low	4

Sub-basin	Dd	Fs	Rt	Ff	Rc	Re	Rn	Cc	Lg	Total	Compound Parameter	Priority	Priority class	Priority level
DARN_A39	78	130	125	82	54	81	63	63	78	754	83.8	93	Low	4
DARN_A53	126	100	93	63	38	60	133	15	126	754	83.8	93	Low	4
DARN_B14	137	140	138	23	109	3	68	4	137	759	84.3	94	Low	4
DARN_A23	122	95	103	10	88	88	116	19	122	763	84.8	95	Low	4
DARN_A12	73	119	120	73	73	83	83	68	73	765	85.0	96	Low	4
DARN_A71	94	79	89	60	83	89	132	47	94	767	85.2	97	Low	4
DARN_A64	129	128	114	51	30	40	135	12	129	768	85.3	98	Low	4
DARN_A32	92	124	124	79	80	55	79	49	92	774	86.0	99	Low	4
DARN_A29	62	132	126	104	62	101	47	79	62	775	86.1	100	Low	4
DARN_B20	103	112	106	105	97	57	56	38	103	777	86.3	101	Very Low	5
DARN_A31	95	85	98	93	102	75	94	46	95	783	87.0	102	Very Low	5
DARN_A50	81	80	102	111	120	78	72	60	81	785	87.2	103	Very Low	5
DARN_B33	52	103	117	135	136	84	17	89	52	785	87.2	103	Very Low	5
DARN_B22	115	104	115	43	135	59	92	26	115	804	89.3	104	Very Low	5
DARN_A44	113	44	86	65	118	116	123	28	113	806	89.6	105	Very Low	5
DARN_A63	68	126	123	113	74	95	78	73	68	818	90.9	106	Very Low	5
DARN_A55	104	86	94	124	95	74	112	37	104	830	92.2	107	Very Low	5
DARN_A01	119	94	97	40	70	135	139	22	119	835	92.8	108	Very Low	5
DARN_A54	56	127	131	126	124	107	26	85	56	838	93.1	109	Very Low	5
DARN_A13	134	113	119	78	92	54	114	7	134	845	93.9	110	Very Low	5
DARN_A24	138	125	121	13	64	113	131	3	138	846	94.0	111	Very Low	5
DARN_B39	111	91	105	139	131	64	73	30	111	855	95.0	112	Very Low	5
DARN_A02	135	118	118	41	67	118	140	6	135	878	97.6	113	Very Low	5
DARN_A04	99	96	109	84	106	111	134	42	99	880	97.8	114	Very Low	5
DARN_A21	117	87	107	133	121	72	103	24	117	881	97.9	115	Very Low	5
DARN_A30	96	115	130	134	123	51	96	45	96	886	98.4	116	Very Low	5
DARN_A19	118	90	101	95	96	128	126	23	118	895	99.4	117	Very Low	5
DARN_B05	120	111	129	121	139	26	113	21	120	900	100.0	118	Very Low	5
DARN_A06	64	134	136	118	122	109	77	77	64	901	100.1	119	Very Low	5
DARN_A42	123	106	111	127	98	91	109	18	123	906	100.7	120	Very Low	5
DARN_A25	132	131	134	52	125	97	107	9	132	919	102.1	121	Very Low	5
DARN_A26	121	135	137	114	132	24	115	20	121	919	102.1	121	Very Low	5
DARN_A43	131	120	128	91	111	66	137	10	131	925	102.8	122	Very Low	5
DARN_A59	140	137	140	96	140	7	138	1	140	939	104.3	123	Very Low	5
DARN_A33	130	121	127	109	110	76	136	11	130	950	105.6	124	Very Low	5
DARN_A56	128	123	133	137	130	38	122	13	128	952	105.8	125	Very Low	5
DARN_A15	133	101	112	102	114	129	128	8	133	960	106.7	126	Very Low	5
DARN_A03	109	107	122	129	119	115	120	32	109	962	106.9	127	Very Low	5
DARN_A62	127	129	135	140	138	65	105	14	127	980	108.9	128	Very Low	5
DARN_A40	139	139	139	125	137	47	124	2	139	991	110.1	129	Very Low	5

Source: Computed by Researcher.

Fig-5.1

5.3.2 Prioritization of Sub-basins on the basis of Peak surface Runoff:

Soil erosion of any basin is directly associated with runoff, hence in this study morphometric analysis as well as runoff analysis becomes one of the effective technique for prioritization of 140 Sub-basin. Runoff values have been calculated by rational methods of each basin of the study area and organized hierarchically. Sub-basin which assigned priority rank one shows high amount of runoff and less infiltration whereas; low priority value of sub-basins indicates more infiltration than runoff. Appendix-E shows the priority ranking of different 140 Sub-basins on the basis of peak runoff. In the present study area the watershed priority map shows sub-basin DARN_E01, DARN_E02, DARN_E03, DARN_D01, DARN_D02, DARN_D03, DARN_D04 and other 23 sub-basins of high priority whereas, DARN_A07, DARN_A08, DARN_A10, DARN_A16, DARN_A17, DARN_A18 and other 13 first order sub-basins are in lowest priority level (Fig.-5.2).

5.3.3 Composite scores of Morphometric and Runoff analysis:

In the present study area of Darna Lake Catchment both the parameters morphometric and runoff has been taken into consideration for identification of sensitive zones. Both the parameter values for 140 Sub-basins have been organized hierarchically. Average values of priority at both levels have been considered for identification of sensitive area that shows high erosion activities and runoff. In this study area DARN_B02, DARN_C02, DARN_C04, DARN_C05, DARN_C06, DARN_C07, DARN_C09, DARN_C13, DARN_C14, DARN_D01, DARN_D02, DARN_D03, DARN_D04, DARN_D05, DARN_D06, DARN_D07, DARN_E01, DARN_E02 and DARN_E03 these sub-basins identified for further action (Table-6.1). The final composite prioritized map of the study area on the basis of morphometric analysis and peak surface runoff showing different sub-basins with their priority ranking is shown in Table- 5.2 and Fig.-5.3.

Fig.-5.2

Table-5.2: Prioritization Compound Scores Result of Morphometric Analysis and Peak Surface Runoff

Sub-basin	Priority Level of Morphometry	Priority Level of Peak surface runoff	Average	Priority Class	Priority
DARN_B02	1	1	1	Very High	1
DARN_C02	1	1	1	Very High	1
DARN_C04	1	1	1	Very High	1
DARN_C05	1	1	1	Very High	1
DARN_C06	1	1	1	Very High	1
DARN_C07	1	1	1	Very High	1
DARN_C09	1	1	1	Very High	1
DARN_C13	1	1	1	Very High	1
DARN_C14	1	1	1	Very High	1
DARN_D01	1	1	1	Very High	1
DARN_D02	1	1	1	Very High	1
DARN_D03	1	1	1	Very High	1
DARN_D04	1	1	1	Very High	1
DARN_D05	1	1	1	Very High	1
DARN_D06	1	1	1	Very High	1
DARN_D07	1	1	1	Very High	1
DARN_E01	1	1	1	Very High	1
DARN_E02	1	1	1	Very High	1
DARN_E03	1	1	1	Very High	1
DARN_B01	1	2	1.5	High	2
DARN_B06	1	2	1.5	High	2
DARN_B10	2	1	1.5	High	2
DARN_B11	2	1	1.5	High	2
DARN_B13	2	1	1.5	High	2
DARN_C01	1	2	1.5	High	2
DARN_C03	2	1	1.5	High	2
DARN_C10	1	2	1.5	High	2
DARN_C12	2	1	1.5	High	2
DARN_B07	2	2	2	High	2
DARN_B16	2	2	2	High	2
DARN_B17	2	2	2	High	2
DARN_B19	2	2	2	High	2
DARN_B21	2	2	2	High	2
DARN_B24	1	3	2	High	2
DARN_B27	1	3	2	High	2
DARN_B34	3	1	2	High	2
DARN_C08	2	2	2	High	2
DARN_C11	2	2	2	High	2
DARN_B04	1	4	2.5	Medium	3

Sub-basin	Priority Level of Morphometry	Priority Level of Peak surface runoff	Average	Priority Class	Priority
DARN_B08	3	2	2.5	Medium	3
DARN_B09	3	2	2.5	Medium	3
DARN_B12	2	3	2.5	Medium	3
DARN_B14	4	1	2.5	Medium	3
DARN_B15	4	1	2.5	Medium	3
DARN_B18	3	2	2.5	Medium	3
DARN_B23	1	4	2.5	Medium	3
DARN_B25	3	2	2.5	Medium	3
DARN_B26	2	3	2.5	Medium	3
DARN_B28	2	3	2.5	Medium	3
DARN_B29	2	3	2.5	Medium	3
DARN_B30	3	2	2.5	Medium	3
DARN_B35	4	1	2.5	Medium	3
DARN_B37	2	3	2.5	Medium	3
DARN_A11	3	3	3	Medium	3
DARN_A27	2	4	3	Medium	3
DARN_A35	4	2	3	Medium	3
DARN_A64	4	2	3	Medium	3
DARN_A70	3	3	3	Medium	3
DARN_A72	2	4	3	Medium	3
DARN_B03	4	2	3	Medium	3
DARN_B05	5	1	3	Medium	3
DARN_B22	5	1	3	Medium	3
DARN_B32	3	3	3	Medium	3
DARN_B36	2	4	3	Medium	3
DARN_B38	2	4	3	Medium	3
DARN_A02	5	2	3.5	Low	4
DARN_A06	5	2	3.5	Low	4
DARN_A12	4	3	3.5	Low	4
DARN_A14	3	4	3.5	Low	4
DARN_A22	3	4	3.5	Low	4
DARN_A26	5	2	3.5	Low	4
DARN_A29	4	3	3.5	Low	4
DARN_A30	5	2	3.5	Low	4
DARN_A32	4	3	3.5	Low	4
DARN_A34	3	4	3.5	Low	4
DARN_A36	3	4	3.5	Low	4
DARN_A37	3	4	3.5	Low	4
DARN_A39	4	3	3.5	Low	4
DARN_A40	5	2	3.5	Low	4
DARN_A41	4	3	3.5	Low	4

Sub-basin	Priority Level of Morphometry	Priority Level of Peak surface runoff	Average	Priority Class	Priority
DARN_A43	5	2	3.5	Low	4
DARN_A45	3	4	3.5	Low	4
DARN_A49	2	5	3.5	Low	4
DARN_A51	2	5	3.5	Low	4
DARN_A52	3	4	3.5	Low	4
DARN_A53	4	3	3.5	Low	4
DARN_A57	4	3	3.5	Low	4
DARN_A58	4	3	3.5	Low	4
DARN_A59	5	2	3.5	Low	4
DARN_A60	4	3	3.5	Low	4
DARN_A63	5	2	3.5	Low	4
DARN_A65	3	4	3.5	Low	4
DARN_A69	2	5	3.5	Low	4
DARN_A71	4	3	3.5	Low	4
DARN_A73	4	3	3.5	Low	4
DARN_A74	3	4	3.5	Low	4
DARN_A77	2	5	3.5	Low	4
DARN_B20	5	2	3.5	Low	4
DARN_B31	4	3	3.5	Low	4
DARN_B33	5	2	3.5	Low	4
DARN_B39	5	2	3.5	Low	4
DARN_A01	5	3	4	Very Low	5
DARN_A03	5	3	4	Very Low	5
DARN_A04	5	3	4	Very Low	5
DARN_A05	4	4	4	Very Low	5
DARN_A08	3	5	4	Very Low	5
DARN_A09	4	4	4	Very Low	5
DARN_A16	3	5	4	Very Low	5
DARN_A18	3	5	4	Very Low	5
DARN_A23	4	4	4	Very Low	5
DARN_A24	5	3	4	Very Low	5
DARN_A25	5	3	4	Very Low	5
DARN_A28	3	5	4	Very Low	5
DARN_A33	5	3	4	Very Low	5
DARN_A38	4	4	4	Very Low	5
DARN_A46	3	5	4	Very Low	5
DARN_A47	3	5	4	Very Low	5
DARN_A48	3	5	4	Very Low	5
DARN_A54	5	3	4	Very Low	5
DARN_A56	5	3	4	Very Low	5
DARN_A61	4	4	4	Very Low	5

Sub-basin	Priority Level of Morphometry	Priority Level of Peak surface runoff	Average	Priority Class	Priority
DARN_A62	5	3	4	Very Low	5
DARN_A67	3	5	4	Very Low	5
DARN_A68	4	4	4	Very Low	5
DARN_A75	3	5	4	Very Low	5
DARN_A76	3	5	4	Very Low	5
DARN_A07	4	5	4.5	Very Low	5
DARN_A10	4	5	4.5	Very Low	5
DARN_A13	5	4	4.5	Very Low	5
DARN_A15	5	4	4.5	Very Low	5
DARN_A17	4	5	4.5	Very Low	5
DARN_A19	5	4	4.5	Very Low	5
DARN_A20	4	5	4.5	Very Low	5
DARN_A21	5	4	4.5	Very Low	5
DARN_A31	5	4	4.5	Very Low	5
DARN_A42	5	4	4.5	Very Low	5
DARN_A50	5	4	4.5	Very Low	5
DARN_A55	5	4	4.5	Very Low	5
DARN_A66	4	5	4.5	Very Low	5
DARN_A44	5	5	5	Very Low	5

Source: Computed by Researcher.

Fig-5.3

5.4 Prioritization of Sub-basins for Conservation Planning:

In the world some areas of a watershed has been considered more responsible for high amount of runoff and soil losses, the study area of Darna Lake Catchment also one of the area that considered as more critical for high runoff and soil losses in western Maharashtra. For this study not only morphometric analysis but also runoff values has been considered at micro-level. Whole catchment area of Darna Lake divided into 140 Sub-basins on the basis of stream order. Morphometric parameters such as stream frequency, bifurcation ratio, drainage density, circularity ratio, form factor and so on computed sub-basin wise as they have direct relation with erosion, infiltration then compound parameter values of all 140 Sub-basins are computed and priority ranking is presented in Table 5.1. These 140 sub-basins peak runoff computed by rational method and priority ranking is presented in Appendix-E. Finally, Composite ranking of both studies has been computed in Table 5.2. On the basis of this composite ranking of morphometric analysis and runoff studies identified critical zones of study area where high erosion activities take place. Hence; prioritization of sub-basins becomes useful for identify critical zones that helpful to appropriate conservation measures taken into consider in study area.

Composite scores of both values all 140 Sub-basins divided into five priority level for conservation planning. Priority level 1 for very high watersheds which consist 19 Sub-basin, priority level 2 for high watershed consist 19 Sub-basins, priority level 3 for medium watershed consist 27 Sub-basins, priority level 4 for low watershed consist 36 Sub-basins and priority level 5 very low watersheds consist 39 Sub-basins for conservation planning of the study area. Remote sensing and GIS are the most advanced tools have been used for these studies on prioritization of micro-watersheds for their development and management. Holistic integrated planning, involving remote sensing and GIS has been found to be effective in planning for regional development based on watershed approach.

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CHAPTER-VI

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

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6.1 Discussion:

Natural resources are limited as well as unevenly found on the earth surface. Natural resources such as land and water are important for human beings and environment. Their appropriate utilization is essential for every nation and specifically for over-populated countries. Hence there is need of proper sustainable utilization of watershed in our country.

A prioritization technique has been introduced by various watershed resource development programmes. It plays a vital role for planning and management of natural resources for sustainable development. Prioritization is a technique that gives rank for different sub basins as per order in which that has to be taken for development. The morphology of individual sub basins can be understood by this method. Remote sensing (RS) and Geographical information System (GIS) techniques are helpful for formation of data. Further it becomes useful for framing appropriate measures in critically affected areas at micro level. Nookaratnam et al's. (2005) finding proposes site suitability for check dam through prioritization in micro-watersheds by applying morphometric analysis. Suitable sites for water harvesting structures can be identified by GIS Techniques (Chowdhary et al. 2009). The availability of resources, limitation in administration and political considerations are some limitations for implementation of watershed management programmes in few areas.

Remote sensing gives versatile recent information of natural resources, GIS has the potential to detain, accumulate, operate, analyze and retrieval of numerous layers resource information in spatial forms. In the present work an attempt has been made to study, morphometric analysis and estimation of peak surface runoff which has been considered for prioritization of Darna Lake Catchment area.

Darna Lake Catchment area is located at Igatpuri tahsil of Nashik district of Maharashtra. The study area consists of prominent basaltic features. The study area is characterised by flat-topped hill ranges which are separated by valleys. The relief are slanting towards east of the study area. Most of the study area shows moderate to steeper slope with formation of cliff and waterfall. Sequential layer of Lava flows are generally occurred in study area whereas vesicular lava is observed at the top of the plateau. Iron ore is the important and predominant mineral deposit seen all over the study area. The minerals are mainly consists of limonite and magnetite sands in patches. A narrow belt of thin alluvial formation is found along the bank of Darna river and its tributaries. Most of the study area is covered by pahoehoe lava flow (100-530 m and 300-450 m) while only a small amount of Megacryst lava flow M1 (50-100 m) observed towards western part. Megacryst lava flow M2 (25-70 m) which is located at north-east part and north area largely consist of Dyke and sill of Basaltic and dolertic types of Igneous rock (Fig.2.2).

The catchment area of Darna Lake receives high rainfall (3000-4000 mm.). An average monthly rainfall which ranges from 300 to 784.92 mm in monsoon especially in months of June, July and August (Table -2.1 and Fig.-2.4). In Nashik district overall temperature reaches upto 42.5 °C in summer while; it becomes minimum in winter and reaches upto 5 °C. In Lake Catchment area of Darna average temperature starts increasing by the end of February and the average monthly maximum temperature is observed at 36.51 °C in the month of April. Even as, average temperature decreases by the end of December, an average minimum temperature of 11.06°C is observed in the month of January (Table-2.2 and Fig.-2.6). In the Darna Lake Catchment area the temperature is much lower than the remaining part of the district due to high elevated topography. In monsoon the relative humidity ranges approximately from 65 to 95 % whereas, in the post- monsoon especially in summer it ranges between 14 to 35 % which shows dry air. On an averagely wind generally blows with 5.5 km per hour speed and denotes south –westerly in monsoon and north- westerly direction in post monsoon.

Darna Lake Catchment area is situated in Western Ghat and it shows highly undulated and dissected topography. Vaki nadi and Bham nadi are main tributaries of Darna river in study area. Vaki nadi rises in the Dhora hill, flows in south direction to meet Darna river from left bank while Bham nadi rises in Navricha Dongar and flows northerly to meet the right bank of Darna. The bank and bed of the Darna river is rocky and wide. Tributaries of Darna river are non-perennial and hold little water in the course during the summer season.

Lateritic (red brown) soil is found on the slopes of the hills, whereas sandy loam and black soil appear in the Lake Catchment and near the banks of Darna river.

Loam soil which appears in the east part of hilly region; consist of rich organic matter (Fig.-2.8). pH of the soil is 6.5 which shows neutral nature. Forest and wasteland cover South and South-East part of study area and agricultural land appears in north and central area. Monsoonal deciduous forest and tropical moist deciduous forest are observed in study area, which predominantly consist of trees like teak, sisum, khair and timber (Fig. 2.9). The economy of this area is primarily based on primary activities such as agriculture and forestry. Mostly small land holders and landless people are more in proportion; hence poverty is the central problem of this area.

The present study focused on all aspects of morphometry of Darna Lake Catchment. In this catchment area there are 1815 streams in total, out of which 1380 are first order, 334 are second order, 79 are third order, 18 are fourth order, 3 are in fifth order and 1 is in the sixth order. Dendritic drainage pattern has been formed by all streams in the Catchment area of Darna Lake. The length of all the streams of first order in Darna Lake Catchment is 741.65 km, second has 216.21 km, third is 92.72 km, fourth has 37.66 km, fifth order is 38.98 km and length of sixth order is 50.14 km. The calculated mean stream length for Lake Catchment area of Darna is 0.54 for first orders, 0.65 for the second, 1.17 for the third, 2.09 for fourth, 12.99 for fifth and 50.14 for sixth orders. The total stream length ratio of the study area is 2.97, that indicates youth stage of the Darna river for geomorphic development. The bifurcation ratio of the Darna Lake Catchment area ranges 3 to 6. This bifurcation value illustrate network formed in homogeneous rocks. It endures minimum structural instability and well developed natural drainage system in catchment area. The mean bifurcation ratio is 4.35. Thus the result shows that Darna Lake Catchment area is located in a dissected or hilly area.

In aerial aspects, form factor value of Darna Lake Catchment observed to be 0.11. It shows basin as more elongated in nature and the lower peak flow remains for longer duration. It also exhibits high erosion in catchment area that leads to elongated shape of the basin. Circularity ratio of study area is 0.37, which reveals elongated basin, impermeable geologic structure and high runoff in Darna Lake Catchment. The Re value of the Darna Lake Catchment is 0.38 which indicates that the drainage basin is more elongated with moderate relief and more or less steeper slope.

Sinuosity index is 2.23 for study area, which is more than 1.5 which in turn that indicates that Darna river channel form meandering path. The value of drainage density is 3.02 per square kilometer in study area suggesting that the Darna Lake

Catchment area has high drainage density. It indicates Darna basin has impervious sub soil and sparse vegetation.

The constant of channel maintenance of Darna Catchment area is low i.e. 0.36 km/km^2. The stream frequency of study area is 4.66 per square km, which endorses moderate to high relief, high runoff and low penetration capacity. Darna river bed which is mostly made up of basalt hard rock, denotes poor erodibility and low porosity.

This area is associated with high structural disturbance, steep to very steep gradient and heavy surface runoff. Area ratio is found between 0.22 and 4.03, which is highest for the sixth order and lowest for the fifth stream order. Area ratio increases with increase in stream orders upto third order. The ruggedness number of the study area is 2.86. It reveals that the present study area is having large extent rugged with low drainage density and relief. The texture ratio of the Darna Lake Catchment is 15.85 which fall into high reliefs category. The length of overland flow for study area is low i.e. 0.17. It exhibits the catchment area as structurally complex and also indicates that the drainage basin is in youth stage.

The Western, Southern and South eastern part of the study area consists of high elevation whereas low elevation is observed in the North-East, Northern and some of the Western part. In the central part of the study area few pockets of low absolute relief are observed. It is found that in the present study, low absolute relief area (less than 700 m) is maximum and high Absolute relief area (900-1000 m) is minimum. A very high relative relief is observed in the southern part and in few pockets of high relative relief in the South -Eastern part of the study area. However, maximum area comes under lowest relative relief in study area.

Low DI value has been observed in the central part of the study area. It indicates moderate slope and youth stage of Darna river. Maximum area denotes less than 50 percentage slope, whereas maximum slope is observed in Southern, South-Eastern and Western part of the study area (Fig.-3.6). Therefore, it has been suggested that the attempted results can be utilized for hydrological and physical explanation as well as environmental management in the Darna Lake Catchment.

The estimation of surface runoff rational formula has been employed to find out rainfall intensity, runoff coefficient, time of concentration and peak volume of runoff. It is observed that rainfall intensity is high in DARN_B17 which is 2113.58 mm/hr (211.36cm/hr) and very low in DARN_B28 which is 291 mm/hr (29.10 cm/hr) shown in table 4.2. For this study coefficient are applicable for 10 years and it is taken as per land cover such as agriculture land(0.4), barren(0.16), built up(0.5), forest(0.3) and scrub land (0.22). Rational Runoff Coefficient for Rational Method, C (Subramanya, 2008) values has been employed for this study area (Table-4.1). It shows that most of the area covered by barren land (191.19 sq.km.) and moderates to steep basin, sparse vegetation as well as resistant surface that shows high runoff .

All the calculating area of the study area is 35351.78 hectares. Maximum area covered by DARN_E01 sub-basin of fifth order which is 7509.31 hectares and minimum area covered by DARN_A66 sub-basin of first order which is 5.67 hectares. In the study area time of concentration is 0.02 in a minute observed in DARN_B17, 0.03 in a minute observed in DARN_A01, DARN_A02, DARN_A04, DARN_A36, DARN_37, DARN_61 and DARN_A71 and and 1.29 and 1.38 in a minute in DARN_E03, DARN_B28 respectively(Table-4.2). This time of concentration can be useful for hydrologist for further assessment of flood risk. In the study area of Darna Lake Catchment, peak volume has been computed sub-basin wise. It shows that lowest value of peak volume is observed in DARN_A66 sub-basin which is 15.30m^3/s whereas, highest value of peak volume is observed in DARN_E01 sub-basin which is 13973023.53 m^3/s, which consist Tirangwadi, Bhavali, Kurnoli, Pardevi,Waki, Korapgaon and Pimpalgaon Bhatata villages and located southwest part of study area (Fig.-4.3).

The present study reveals the importance of GIS for prioritization of the sub basins of Darna Lake Catchment. The streams law says, “Lower the order higher the number of streams”, and has been applied in the case of this watershed. The highest Rb value observed to be sub-basins for DARN_B10, DARN_B11 and DARN_B15 which is 6. It reveals a strong structural control in the drainage pattern. The lower Rb value is found mostly in all first orders sub-basin, which exhibits that these sub basins are not much affected by structural disturbances (Strahler, 1964).

The highest drainage density (5.8 Km/Km^2) is observed in DARN_C07, reveals basin shows weak non-porous subsurface material, sparse vegetation and hilly topography. The lowest drainage density observed in DARN_A59 (0.4 Km/Km^2), reveals highly porous subsoil material under a thick vegetation cover and a low elevated topography. Most of the study area shows high drainage density which, indicates that Darna Lake Catchment area associate with weak impermeable subsurface material, sparse vegetation and mountainous relief.

The values of form factor, circulatory and elongation ratio propose that most of the Darna sub basins are elongated in character and associated with high to moderate relief. The prioritization outputs of sub-basin shows that sub-basins DARN_D03, DARN_D04 bear more erosion. These basins seek immediate attention and suitable soil conservation measures ought to be taken. Apart from these sub basins other 25 high priority sub-basins of Darna Lake Catchment (Table-5.1) also need more attention as they are more vulnerable to soil erosion.

In this study area sub-basins namely DARN_B02, DARN_B05, DARN_B10, DARN_B11, DARN_B13, DARN_B14, DARN_B15, DARN_B22, DARN_B34, DARN_B35, DARN_C02, DARN_C03, DARN_C04, DARN_C05, DARN_C06, DARN_C07, DARN_C09, DARN_C12, DARN_C13, DARN_C14, DARN_D01, DARN_D02, DARN_D03, DARN_D04, DARN_D05, DARN_D06, DARN_D07, DARN_E01, DARN_E02 and DARN_E03 are identified for excess runoff based on peak surface runoff further suitable action is recommended. Composite scores of all 140 sub basins in study area have been divided into five priority levels for conservative planning. The composite scores of 19 sub-basins come under priority level 1 (very high), 19 sub-basins come under priority level 2 (high), 27 sub-basins come under priority level 3 (medium), 36 sub-basins come under priority level 4 (low) and 39 sub-basins come under priority level 5 (very low).

A decisive zone within the study area with high erosion activities has been recognized by considering the composite ranking of morphometry and runoff. Hence, prioritization of Darna sub-basins becomes helpful for identification of critical zones and recommendation of appropriate conservation measures in the study area.

Finally, the sub-basins DARN_E01, DARN_E02 and DARN_E03 shows the highest priority; hence it implies a high degree of erosion and surface runoff in Darna Lake Catchment. These basins have a very high possibility to applying conservative remedies. Thus**,** firstly conservation remedies can apply to sub-basins DARN_E01, DARN_E02, DARN_E03 and then to the other sub basins of Darna catchment depending upon their priority as shown in table 5.2.

Based on composite scores sub-basins DARN_E01, DARN_E02, DARN_E03, DARN_D01, DARN_D02, DARN_D03, DARN_D04, DARN_D05, DARN_D06, DARN_D07, DARN_C02, DARN_C04, DARN_C05, DARN_C06, DARN_C07, DARN_C09, DARN_C13, DARN_C14 and DARN_B02 fall in very high priority. Among these sub-basins DARN_E01, DARN_E02, and DARN_E03 consist maximum area that lies towards North-West and South side of study area and consist of Tirangwadi, Bhavali, Kurnoli, Pardevi, Vaki, Korapgaon, Pimpalgaon Bhatata, Ambegaon, Talegaon, Girnare, Taloshi and Gavhande villages (Fig.-4.3).

Therefore, conservative measures for the identified sub basins to protect the land resources from erosion and to reduce natural hazards are the need of the hour. Taking this into consideration, substantial investments have to be made towards the Darna Catchment development programme. It is essential to plan the actions on priority basis to attain productive results. This also assists the challenging areas to arrive at appropriate solution.

6.2 Conclusions:

In the present study firstly, critical sub-basins are evaluated by applying hydro-geomorphic evaluation and runoff studies for conservative planning. Secondly, the effects of all measured parameters are tested for Darna lake environment in instances of erosion and severe runoff. It is clearly found that there is a close association among physical features, LC/LU and geomorphic processes. A major area of Darna Lake Catchment is characterized by barren and Scrub land (238.22 sq. km.), thin vegetation (62.21 sq.km.) and moderate to steeper gradient, which mainly promote to degradation of the land surface (Appendix-G and Appendix-H).

The major findings which have led to the following conclusion have been made with an eye on conservation planning.

1. The DARN_D03 sub-basin recorded a low compound parameter value of 28.2. It is ranked as the highest in terms of erosion followed by DARN_D04, DARN_C01, DARN_D01, DARN_D02, DARN_C14, DARN_C13, DARN_E01 and other 19 sub-basins (Table-5.1). These sub basins cover 289.99 sq. km. area i.e. 83% of the total land surface area. These sub basins located to the North-West, South and West part of the study area, represent villages namely Umbarkon, samnere, Waghere and Manik khamb etc. which are associated with more proportion of barren land (79.20 sq.km.) and moderately dissected topography. Thus, these sub basins have been suggested for conservation measures, starting from DARN_D03 and followed by others based on their level of priority.
2. The empirical rational formula used to calculate runoff and it is found there is a great deal of runoff in the case of sub basins of the Western, Southern and Northern part of the Darna lake catchment (which mainly consist of fourth and

fifth order). They are DARN_E01, DARN_E02, DARN_E03, DARN_D01, DARN_D02, DARN_D03, DARN_D04 and 23 others sub-basins (Table-4.2) and it covers 210 sq. Km. area which is 61 % of the total study area. These areas considered for contributing severe runoff. This area is associated with structural and denudation in origin along with the highly dissected lower plateau especially at Talegaon village and Igatpuri (Fig.-3.8 and Fig.-4.3). Barren and scrub land (169.98 sq.km,) are observed in this area. It reveals that land use and land cover play a vital role in determining geomorphic process in terms of the surface runoff in the study area.

3. LU/LC analysis highlights the area that is categorized by wasteland (Barren and Scrub total land is 238.22 sq.km.), thin vegetation, highly uneven and dissect topography. It causes geo-environmental issues like degradation of soil and high runoff (Appendix-G).
4. The composite score highlights sub basins such as DARN_B02, DARN_C02, DARN_C04, DARN_C05, DARN_C06, DARN_C07, DARN_C09, DARN_C13, DARN_C14, DARN_D01, DARN_D02, DARN_D03, DARN_D04, DARN_D05, DARN_D06, DARN_D07, DARN_E01, DARN_E02 and DARN_E03 for high priority level. These basins cover 278.17 sq. Km. area, which is 78.75 % of the total land surface area and is located mainly in the North, North-West and South part of the study area (Fig.-5.3). It is associated with considerable soil erosion and excessive surface runoff.
5. There is a dearth of proper conservation plans for water and soil, which in turn leads to soil erosion, loss, degradation and excess runoff and thereby heavy siltation in Darna Lake Catchment.

6.3 Recommendations :

In the present study it is found that hill slope areas are associated with soil erosion and severe surface runoff. The researcher also tries to highlight the fact that in Darna lake catchment facing improper management of soil and water conservation techniques area used. The uncovered hill slopes (barren) subsequently lead to soil erosion in streams and gullies due to excess surface runoff. These also support siltation, sedimentation and encroachment over the lake catchment area.

The following measures have been suggested to prevent the soil erosion; severe surface runoff and thereby sedimentation of Darna Lake to maintain storage capacity.

6.3.1 Treatment Measures: Engineering Measures:

Gully Erosion Control Measures:

The gully plugging measures include vegetative plantings and brushwood check dams, boulder checks, earthen bunds or a combination of both and sand bag plugs etc. Gully Plug is the effective method to slow down the speed of flowing water of the stream in any area.

6.3.1.1 Boulder Gully Plug (BGP):

Using local boulders across gullies for gully plugging helps to captures the sediment. It is helpful in transferring low rainfall to stop the soil erosion.

6.3.1.2 Earthen Gully Plug (EGP):

The present study reveals that there are 77 first order basins. EGP should be applied at intersection points of these streams. This will help in reducing high peak flow of rain water in monsoon.

6.3.1.3 Bench Terracing (BT):

In Darna Lake Catchment area, most of the southern part of the Darna Lake Catchment consists of moderate to steeper slopes. Bench terracing techniques can be applied for this area to reduce soil erosion.

6.3.1.4 Continuous Contour Trenches (CCT):

The sub basins DARN_E01, DARN_E02 and DARN_E03 (Fig.-4.2) are located on hill slopes, where the velocity of runoff is observed to be high. These basins cover more than 50 % area of the total land surface area of Darna Lake Catchment. These sub basins are situated at south and north-western side of the study area, where CCT method can be applied to reduce velocity of runoff.

6.3.1.5 Percolation Tank (PT):

Percolation tanks are the structures for recharging ground water. These are generally constructed across streams and bigger gullies in order to impound a part of the runoff water. In Darna Lake Catchment also suffers high runoff hence, this method should be applied in this area to increase the ground water level and reduce runoff.

6.3.1.6 Cement Bund (CB):

The study area consists of hilly zones and dissected plateau. Hence, at the end point of EGP suggested above, cement bunds should construct to reduce high runoff and consequently prevent soil erosion.

6.3.1.7 Check Dam (CD):

Check dams should be constructed in the confluence of two streams, which will help to stabilize the slope and control gully erosion. This will lead to growth of vegetation in Darna Lake Catchment area in order to check soil erosion and surface runoff.

6.3.2 Biological Measures:

1. Locally grown plants like timber, neem, teak, khair etc. should be planted to reduce wasteland and degraded patches in study area. It will also be helpful to increase an area under the permanent cover of vegetation.
2. The fodder plantation (Fast growing species such as different varieties of grass) should be planted on agricultural bund along Darna river channel (Fig.-4.1) for re-establishment of declined area.
3. Medicinal and horticultural plants can be grown along the adjacent part of the villages namely Ghoti, Khambale, Ubhade, Samnere etc. where slope segments are less than two percent(Fig.-3.6, Fig.-4.3 and Photo.-6 and 16).
4. To regenerate wasteland, to reduce soil erosion and runoff, comprehensive programmes like Tree plantation, Agro-Socio forestry, Fuel wood plantation etc. should be implemented. These will not only serve as conservative measures but also help in producing employment among local people.

Table-6.1: Suggested Catchment Area Treatment (CAT) Plan for Darna Lake Catchment

Sub –basin Code	Priority Level for CP	Area (Sq. Km.)	Suggested Measures
DARN_B02, DARN_C02, DARN_C04, DARN_C05, DARN_C06, DARN_C07, DARN_C09, DARN_C13, DARN_C14, DARN_D01, DARN_D02, DARN_D03, DARN_D04, DARN_D05, DARN_D06, DARN_D07, DARN_E01, DARN_E02, DARN_E03	**Very High**	278.17 (78.75 %)	PT, BGP, CCT, BT, fodder Plantation, Horticulture
DARN_B01, DARN_B06, DARN_B07, DARN_B10, DARN_B11, DARN_B13, DARN_B16, DARN_B17, DARN_B19, DARN_B21, DARN_B24, DARN_B27, DARN_B34, DARN_C01, DARN_C03, DARN_C08, DARN_C10, DARN_C11, DARN_C12	**High**	24.55 (6.95 %)	BT, CB, PT, Agro-forestry and fodder plantation, Mixed vegetation

DARN_A11, DARN_A27, DARN_A35, DARN_A64, DARN_A70, DARN_A72, DARN_B03, DARN_B04, DARN_B05, DARN_B08, DARN_B09, DARN_B12, DARN_B14, DARN_B15, DARN_B18, DARN_B22, DARN_B23, DARN_B25, DARN_B26, DARN_B28, DARN_B29, DARN_B30, DARN_B32, DARN_B35, DARN_B36, DARN_B37, DARN_B38	**Medium**	25.88 (7.33 %)	CD, PT, EGP, Afforestation
DARN_A02, DARN_A06, DARN_A12, DARN_A14, DARN_A22, DARN_A26, DARN_A29, DARN_A30, DARN_A32, DARN_A34, DARN_A36, DARN_A37, DARN_A39, DARN_A40, DARN_A41, DARN_A43, DARN_A45, DARN_A49, DARN_A51, DARN_A52, DARN_A53, DARN_A57, DARN_A58, DARN_A59, DARN_A60, DARN_A63, DARN_A65, DARN_A69, DARN_A71, DARN_A73, DARN_A74, DARN_A77, DARN_B20, DARN_B31, DARN_B33, DARN_B39	**Low**	15.12 (4.28 %)	EGP, BGP, CB, horticulture, medicinal plant species and Fodder plantation
DARN_A01, DARN_A03, DARN_A04, DARN_A05, DARN_A07, DARN_A08, DARN_A09, DARN_A10, DARN_A13, DARN_A15, DARN_A16, DARN_A17, DARN_A18, DARN_A19, DARN_A20, DARN_A21, DARN_A23, DARN_A24, DARN_A25, DARN_A28, DARN_A31, DARN_A33, DARN_A38, DARN_A42, DARN_A44, DARN_A46, DARN_A47, DARN_A48, DARN_A50, DARN_A54, DARN_A55, DARN_A56, DARN_A61, DARN_A62 DARN_A66, DARN_A67, DARN_A68, DARN_A75, DARN_A76	**Very Low**	9.51 (2.69%)	EGP, Timber, Horticulture, Fodder plantation

BGP- Boulder Gully plug, CB- Cement bund, PT- Percolation tank, CP - Conservation Planning, BT- Bench terracing , CD-Check dams, CCT - Continuous contour Trenches, EGP - Earthen Gully Plug, BGP- Boulder Gully Plug

6.3.3 Treatment Measures for Individual Sub basins:

Priority Level –I (Very high):

This level consists of DARN_B02, DARN_C02, DARN_C04, DARN_C05, DARN_C06, DARN_C07, DARN_C09, DARN_C13, DARN_C14, DARN_D01, DARN_D02, DARN_D03, DARN_D04, DARN_D05, DARN_D06, DARN_D07, DARN_E01, DARN_E02 and DARN_E03 sub-basins (Fig.-5.3). These sub basins cover 278.17 (78.75 %) area and is associated with wasteland (scrub and barren - 193.63 sq.km.). This area is characterized by gullies and hill slopes, therefore it is considered as highly susceptible to erosion and surface runoff (Photo.-5 and 8). Thus, this area has been suggested for engineering measures such as Percolation Tanks, Boulder Gully Plugs, BT and CCT etc. which become important remedies as well as biological measures like fodder plantation, horticulture, tree plantation where slope is below five percent. (Fig.- 6.1).

Priority Level –II (High):

The second priority level comprises of DARN_B01, DARN_B06, DARN_B07,DARN_B10,DARN_B11,DARN_B13,DARN_B16,DARN_B17,DARN_B19,DARN_B21,DARN_B24,DARN_B27,DARN_B34,DARN_C01,DARN_C03, DARN_C08, DARN_C10, DARN_C11 and DARN_C12 sub-basins. These sub-basins show substantial slope variations and have mostly barren land (12.46 sq.km.). The forest is observed to be scattered in patches of this area. Around 25.88 Sq. km (6.95 %) land surface area of Darna Lake Catchment falls in second priority level (Table-6.1). This area represents gentle to moderate slope hence bench terracing(BT), percolation tank and Cement bund are suggested for this entire area (Fig.-6.1). Apart from this the biological measures like Agro-forestry and fodder plantation such as home-grown species (grasses, fuel wood, and legumes etc.) have been suggested for the area where slope is very low. It will help to sustain mixed vegetation in steep precipitous and susceptible catchment area.

Priority Level –III (Medium):

The sub basins DARN_A11, DARN_A27, DARN_A35, DARN_A64, DARN_A70, DARN_A72, DARN_B03, DARN_B04, DARN_B05,DARN_B08, DARN_B09,DARN_B12,DARN_B14,DARN_B15,DARN_B18,DARN_B22,DARN_B23,DARN_B25,DARN_B26,DARN_B28,DARN_B29,DARN_B30,DARN_B32, DARN_B35, DARN_B36, DARN_B37, DARN_B38 are depicted for third priority level. The total land surface area of these sub basins is 25.88 Sq. km (7.33 %).The maximum area from this level falls into scrub and agriculture land and are associated with a less elevated topography. Thus, Farm bunds have been suggested especially for agriculture land in this zone. It will help to minimize soil erosion and surface runoff for conserving water resources. The check dams, percolation tank and EGP (Fig.-6.1) also have been suggested at the confluence point of first order streams to increase infiltration capacity. Apart from this afforestation, comprehensive programme should be taken into consideration. It will be helpful in the revival and regeneration of wasteland and also for controlling the soil erosion.

Fig.-6.1

Priority Level –IV (Low):

In fourth priority level sub basins DARN_A02, DARN_A06, DARN_A12, DARN_A14, DARN_A22, DARN_A26, DARN_A29, DARN_A30, DARN_A32, DARN_A34, DARN_A36, DARN_A37, DARN_A39, DARN_A40, DARN_A41, DARN_A43, DARN_A45, DARN_A49, DARN_A51, DARN_A52, DARN_A53, DARN_A57, DARN_A58, DARN_A59, DARN_A60, DARN_A63, DARN_A65, DARN_A69, DARN_A71, DARN_A73, DARN_A74, DARN_A77,DARN_B20, DARN_B31, DARN_B33, and DARN_B39 are depicted. This area is located around Darna river channel with a gentle slope and covers 15.12 Sq.Km.((4.28 %) area (Table-6.1). The land is associated with scrub land, agriculture and built up area (Fig.-4.1). This area comprises low watershed hence appropriate crop rotation and fodder plantation are suggested for this area. EGP, BGP and cement bund also are recommended for this area (Fig.-6.1). Horticulture species (Mango, Custard Apple, Cashew nut etc.) and medicinal plant (Khair, Neem etc.) should be recommended for susceptible area.

Priority Level –V (Very Low):

In level fifth sub basins DARN_A01, DARN_A03, DARN_A04, DARN_A05, DARN_A07, DARN_A08, DARN_A09, DARN_A10, DARN_A13, DARN_A15, DARN_A16, DARN_A17, DARN_A18, DARN_A19, DARN_A20, DARN_A21, DARN_A23, DARN_A24, DARN_A25, DARN_A28, DARN_A31, DARN_A33, DARN_A38, DARN_A42, DARN_A44, DARN_A46, DARN_A47, DARN_A48, DARN_A50, DARN_A54, DARN_A55, DARN_A56, DARN_A61, DARN_A62 DARN_A66, DARN_A67, DARN_A68, DARN_A75 and DARN_A76 etc. all the first order sub-basins are depicted. It covers 9.51 sq. Km (2.69 %). area (Table-6.1). EGP has been suggested towards end point of first order streams (Fig.-6.1). The dominance of wasteland (scrub and barren) are potential areas relegate with plantation of timber, horticulture and fodder crops.

Natural resources hold a key position in the development process of any region. Morphometry of the basin and its functional interaction with surrounding environment is highly dynamic in nature. Data generated (DEM, LU/LC, Quantitative parameters etc.) through RS and GIS techniques have huge applicability for such a study. A prioritization of sub basins should lead to the development of the conservation of soil resources. However there is an urgent need to implement the suggested measures in order to minimize soil erosion, to improve seeping capacity of rainwater and the mitigation of hazard (flood). Such studies have abundant potential to attract attention of geomorphologist, experts belongs from administration, policy makers and regional planners for further in-depth study and better planning of Darna Lake Catchment. Therefore, there is significant scope for researchers and planners for morphometric analysis for basin, investigation and experiments in lake catchment areas to conserve natural resources and planning.

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References:

Zete, A. M. (2014): "Geomorphic assessment of problem of siltation a case study of Tavarja dam in Latur district Maharashtra" Published Ph.D.Thesis, Savitribai Phule Pune University, Pune.

Darna Lake Catchment: Location Map of the Study Area

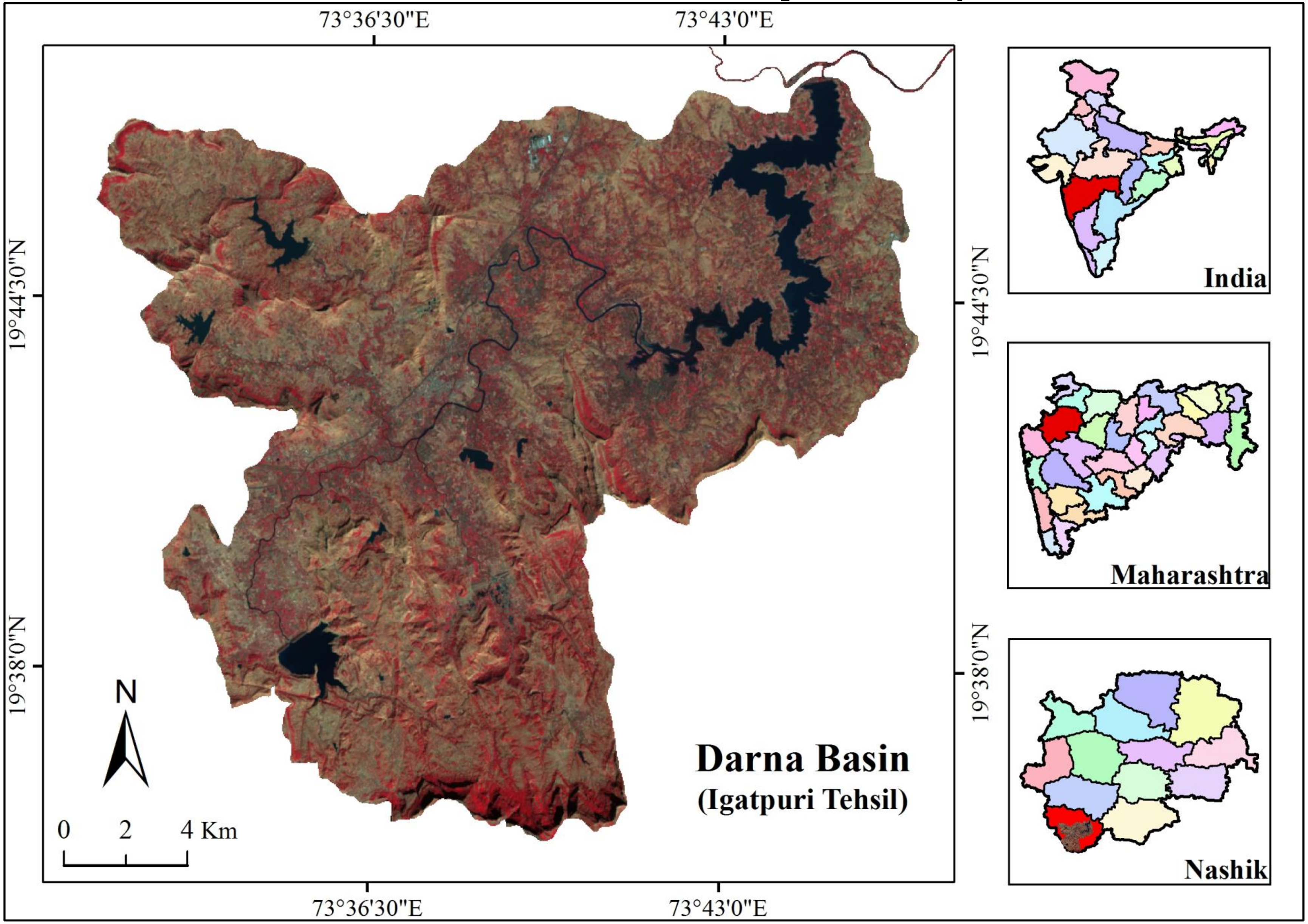
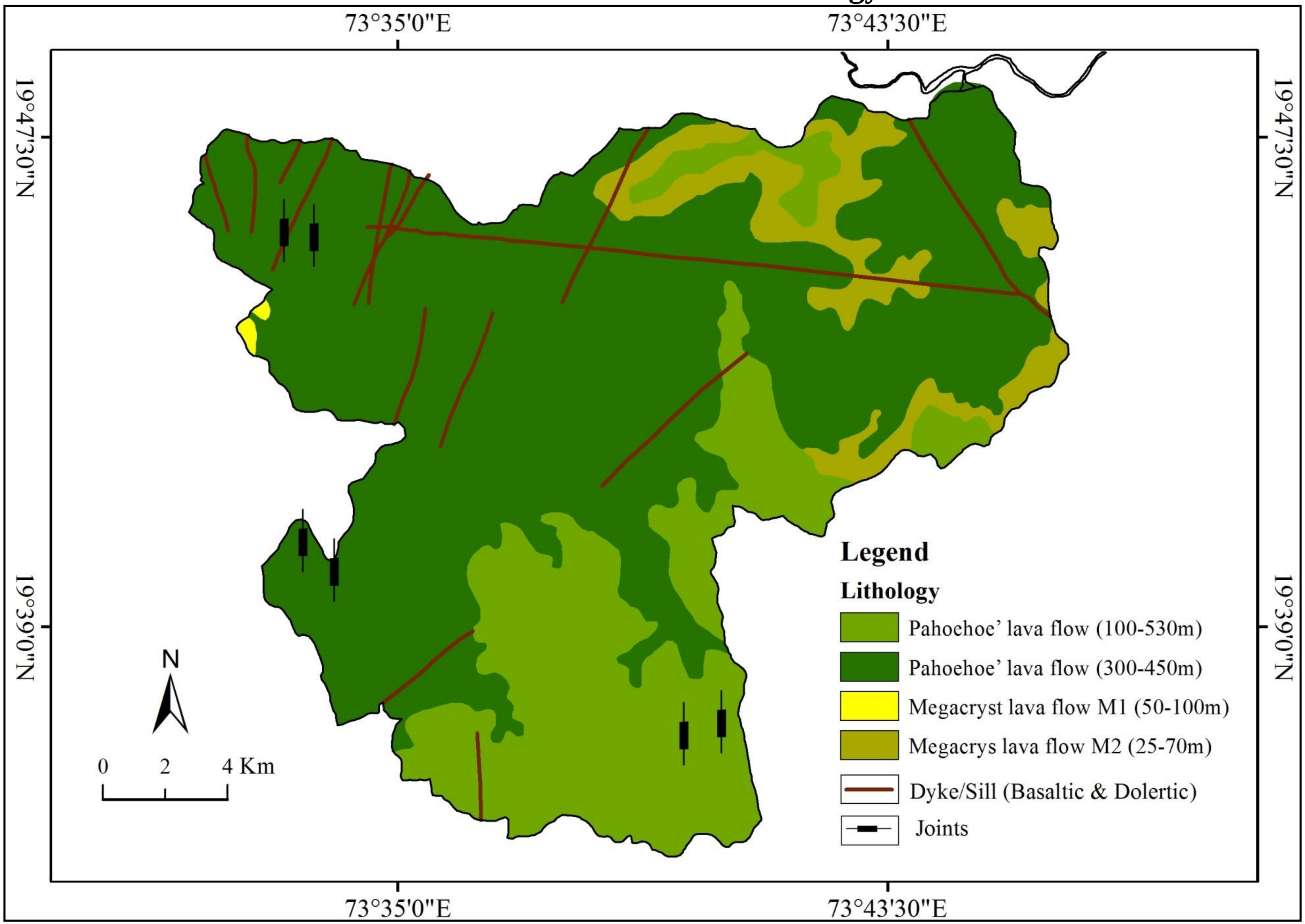


Fig.-2.1

Darna Lake Catchment: Geology



Source: Geological Survey of India, 2001. **Fig.-2.2**

Darna Lake Catchment: Relief Map

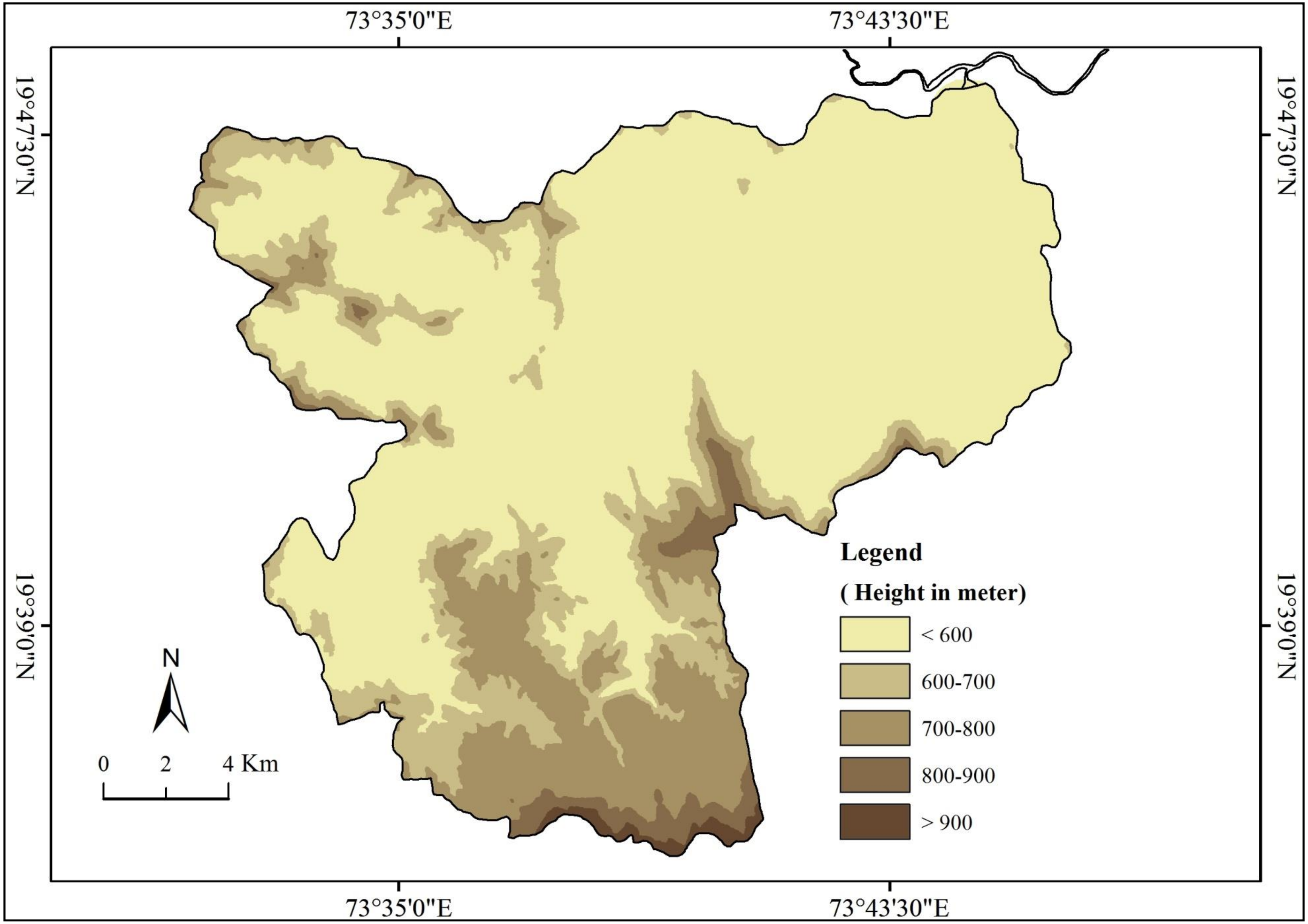


Fig.-2.3

Darna Lake Catchment: Rainfall Map

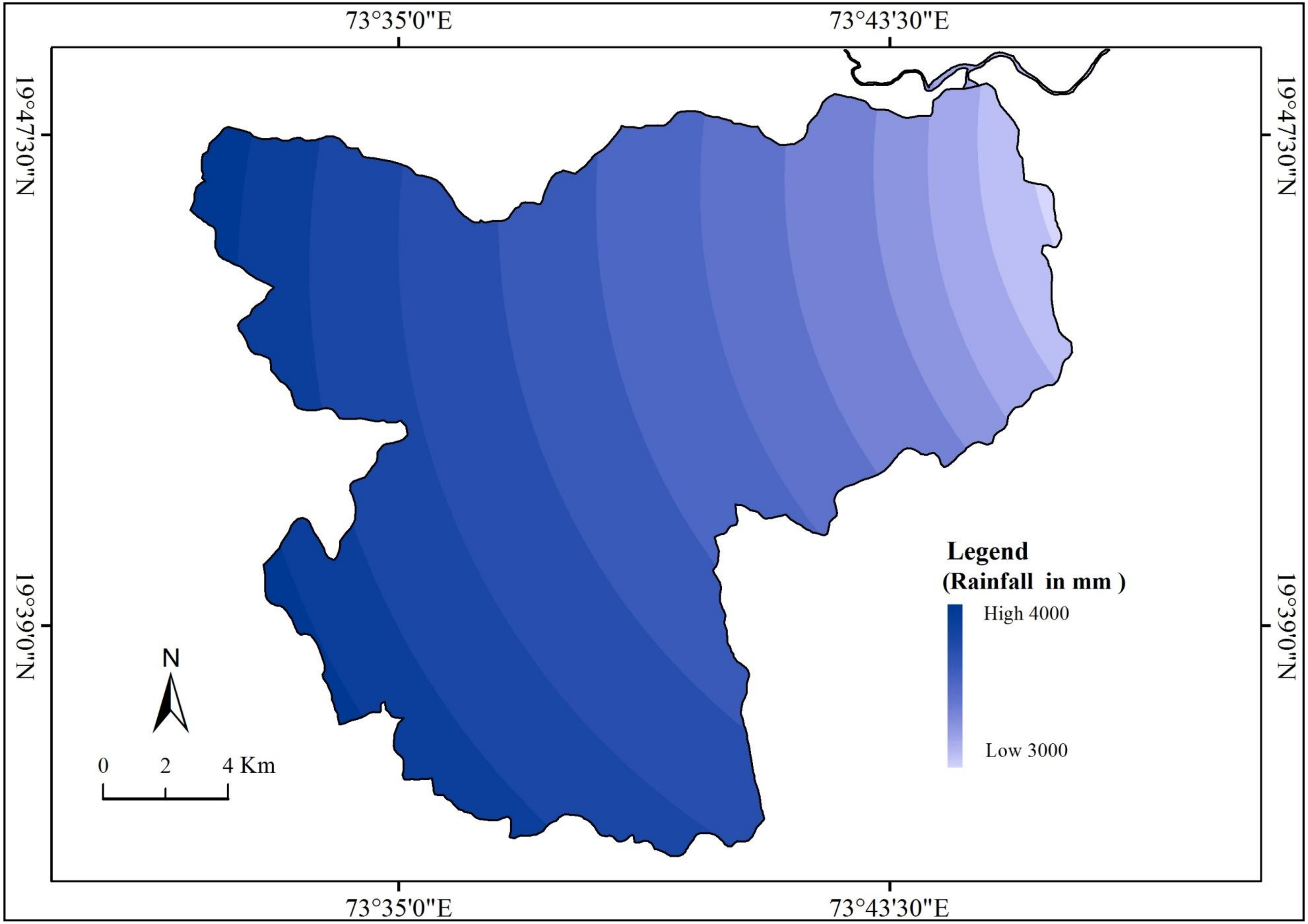


Fig.-2.5

Darna Lake Catchment: Darna River and Major Tributaries

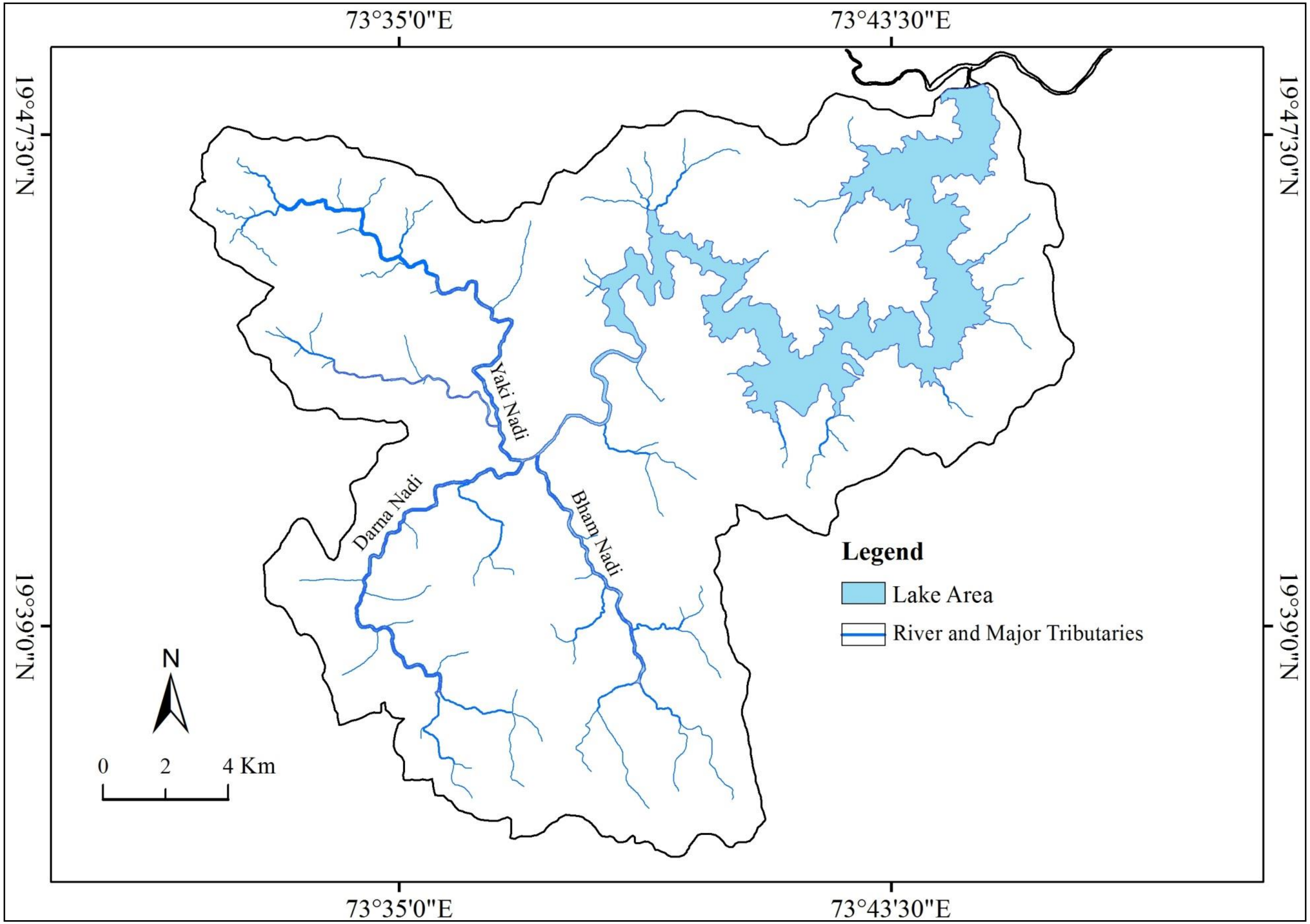
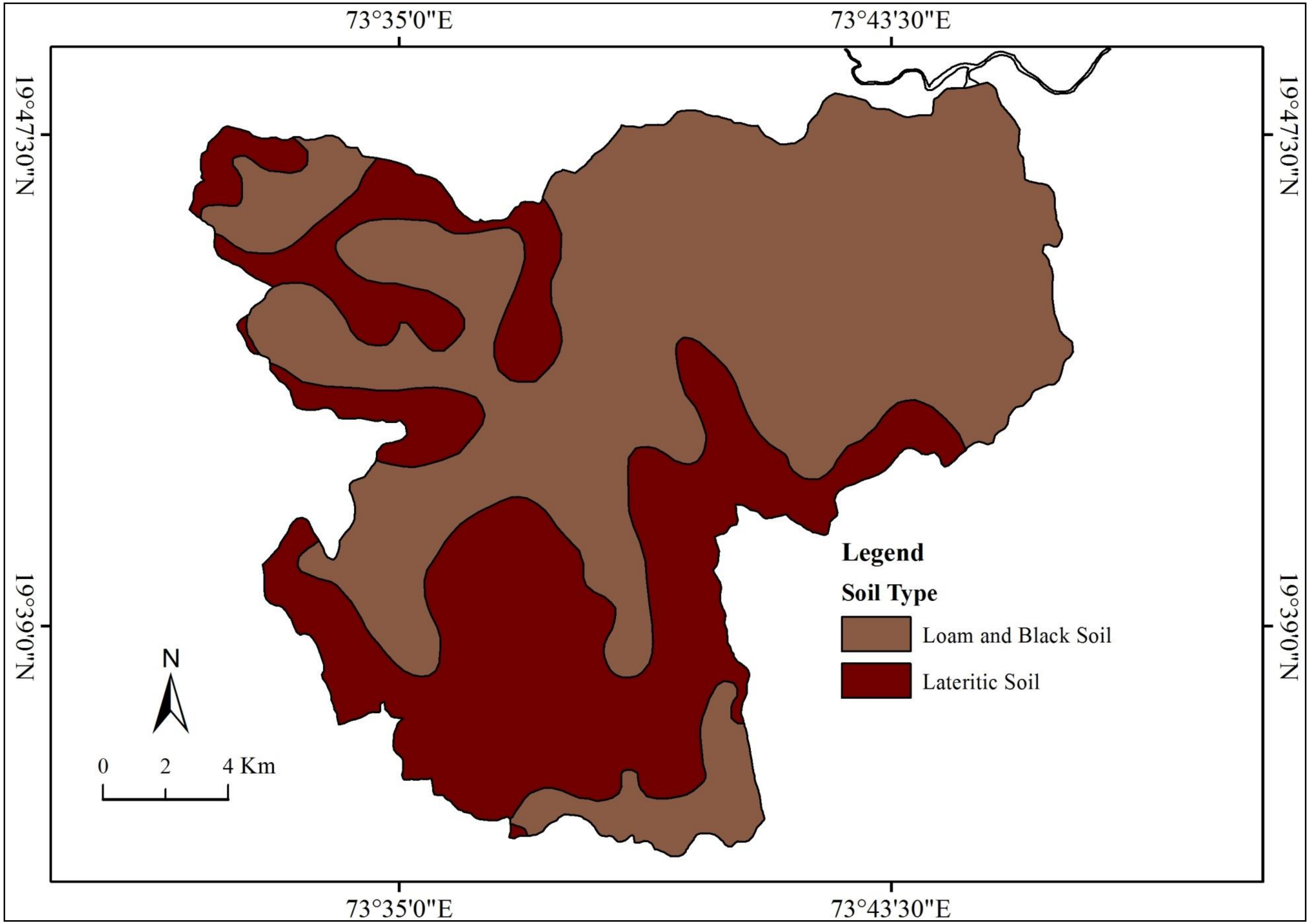


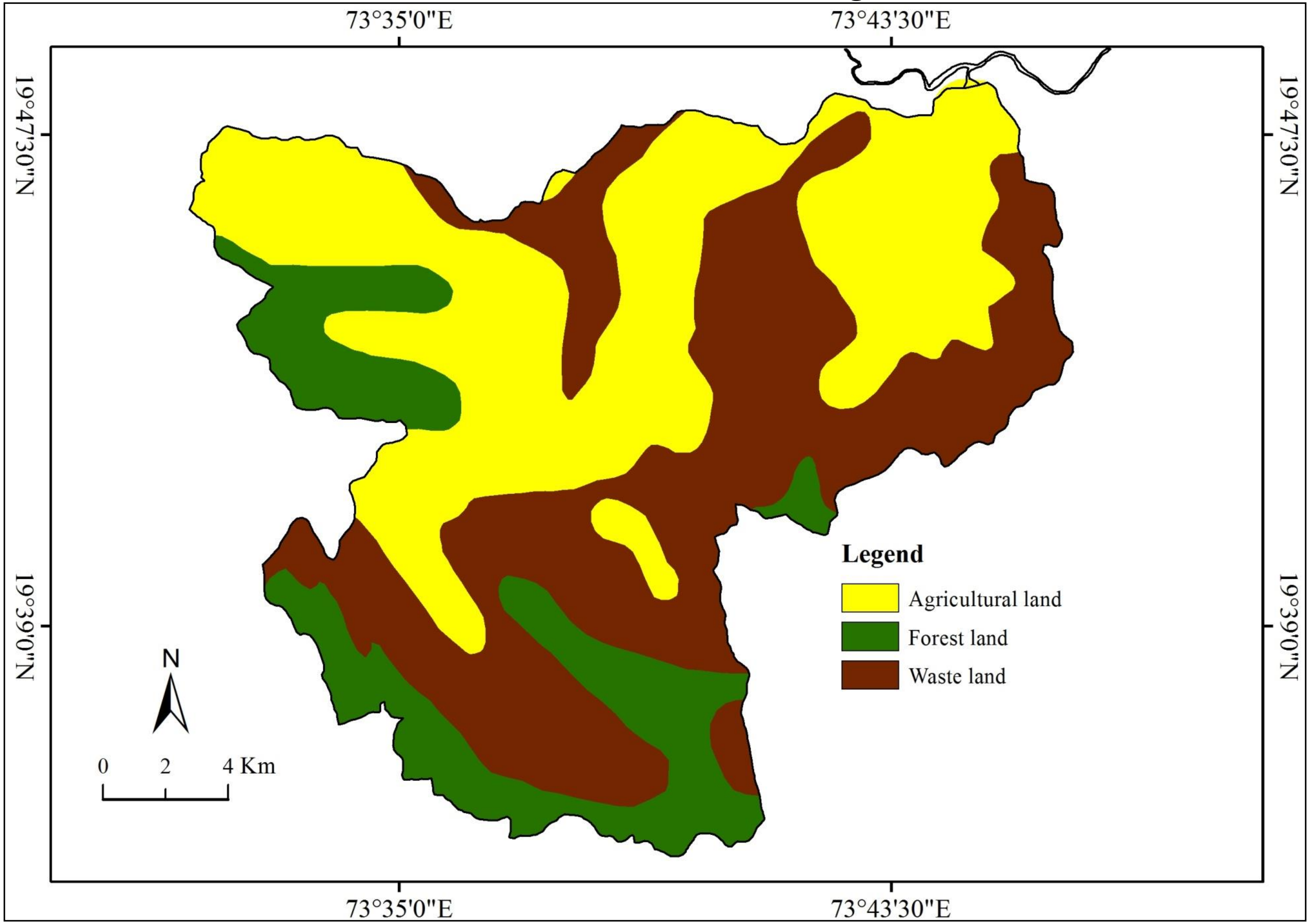
Fig.-2.7

Darna Lake Catchment: Soil Map



Source: National Soil Maps (ESDAC) 1996. **Fig.-2.8**

Darna Lake Catchment: Natural Vegetation



Source: Government of Maharashtra, Forest Map, 2011. **Fig.-2.9**

Darna Lake Catchment: Stream Order-wise Drainage Pattern

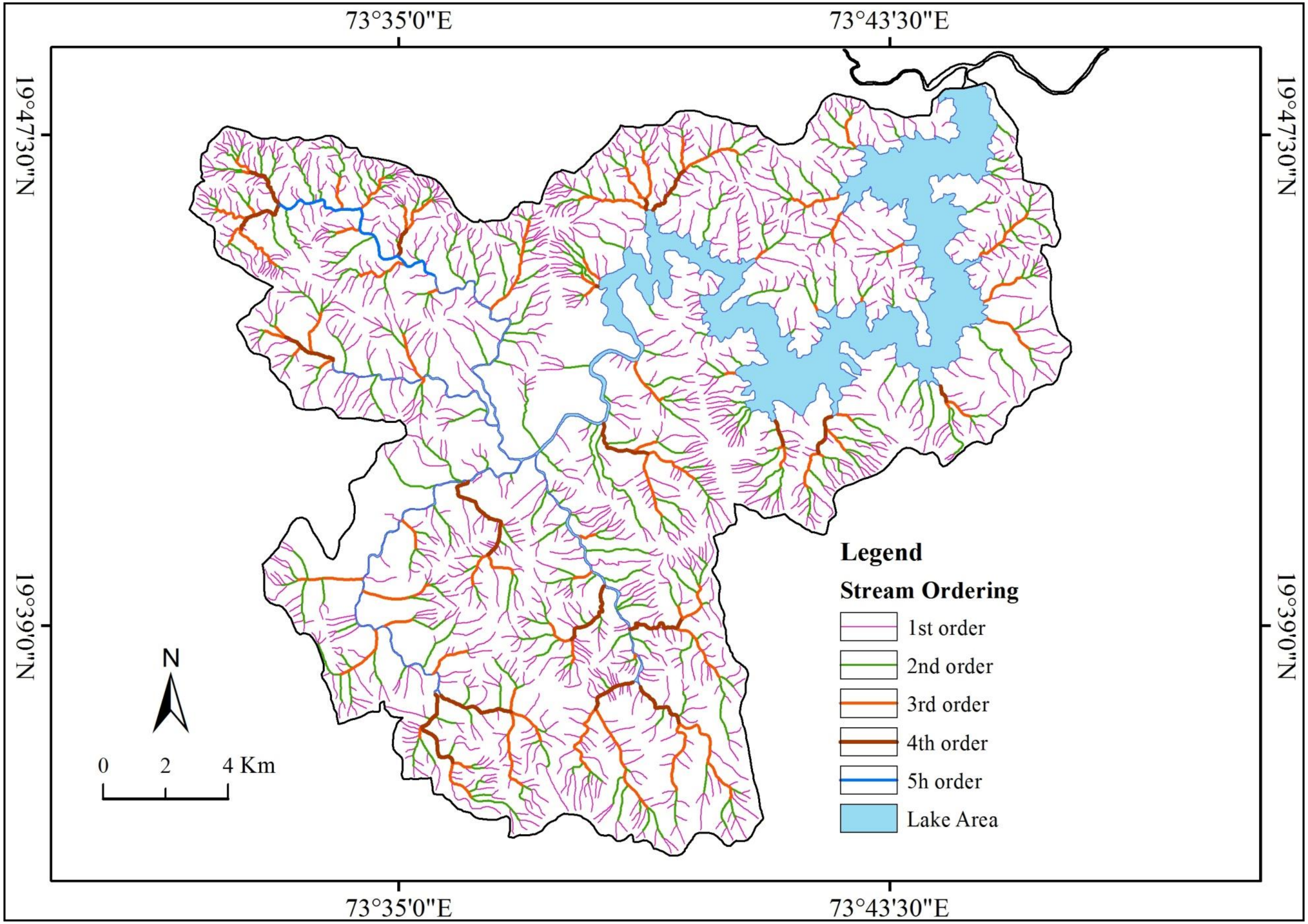


Fig.-3.1

Darna Lake Catchment: DEM

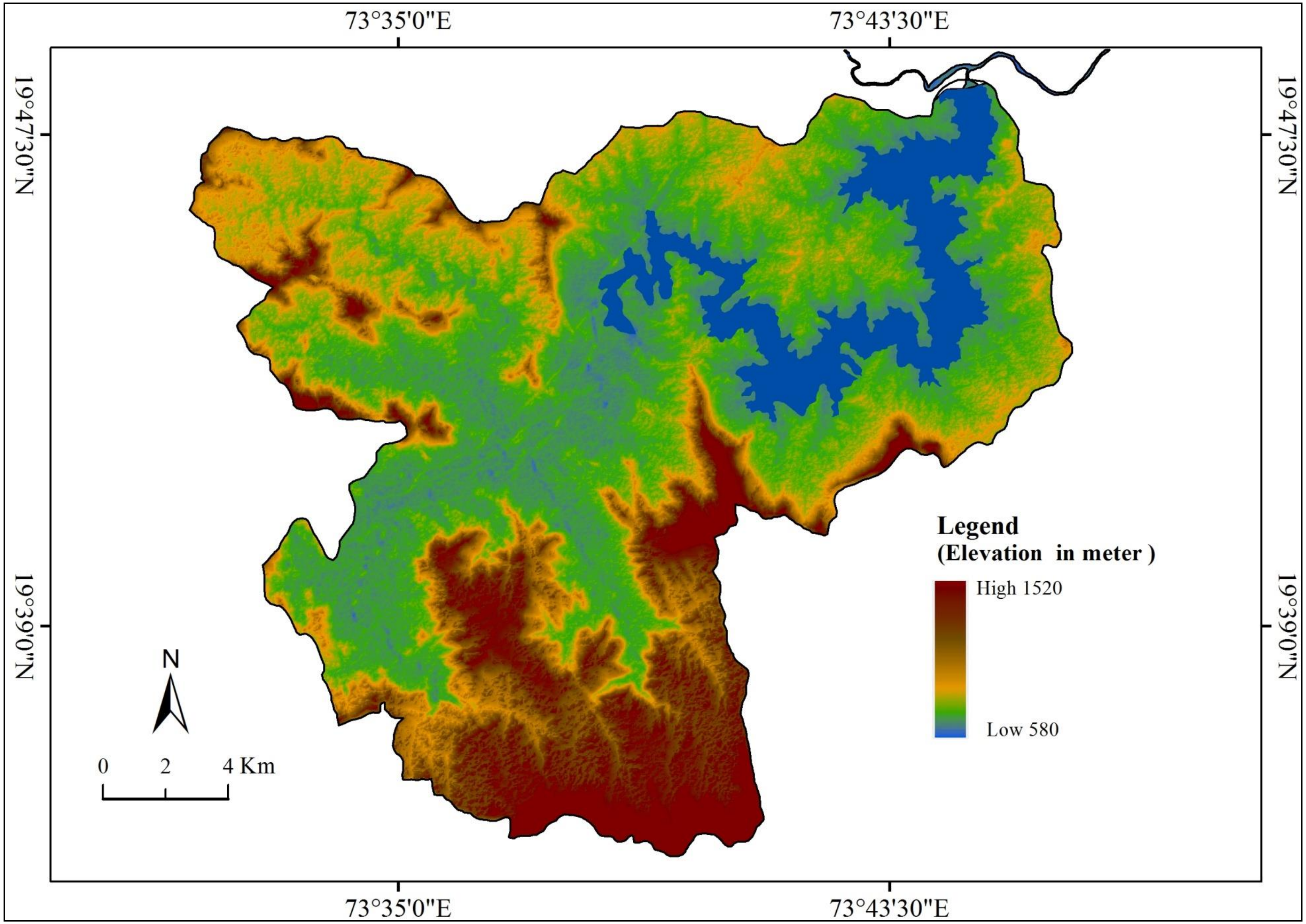


Fig.-3.2

Darna Lake Catchment: Absolute Relief Map

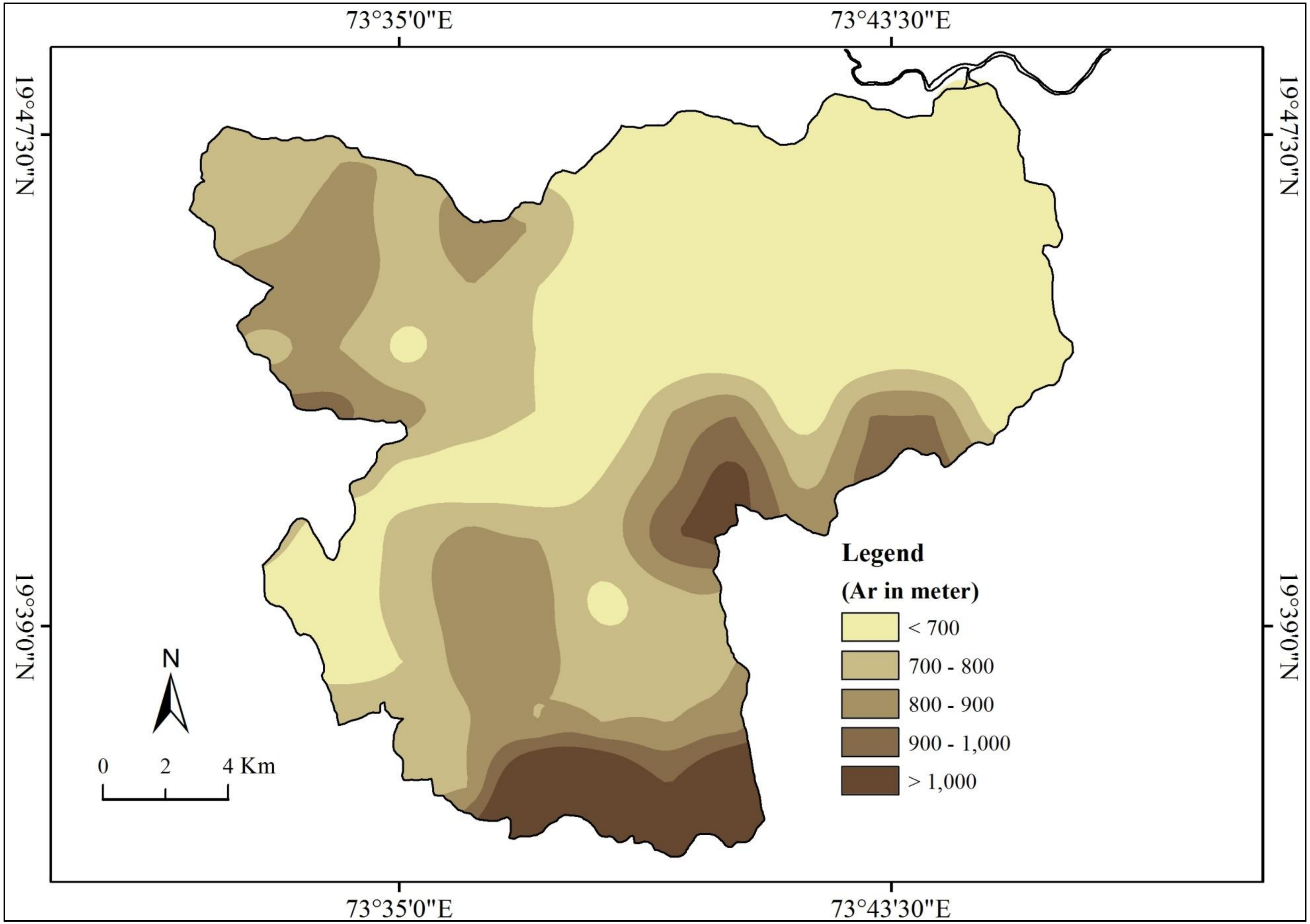


Fig.-3.3

Darna Lake Catchment: Relative Relief Map

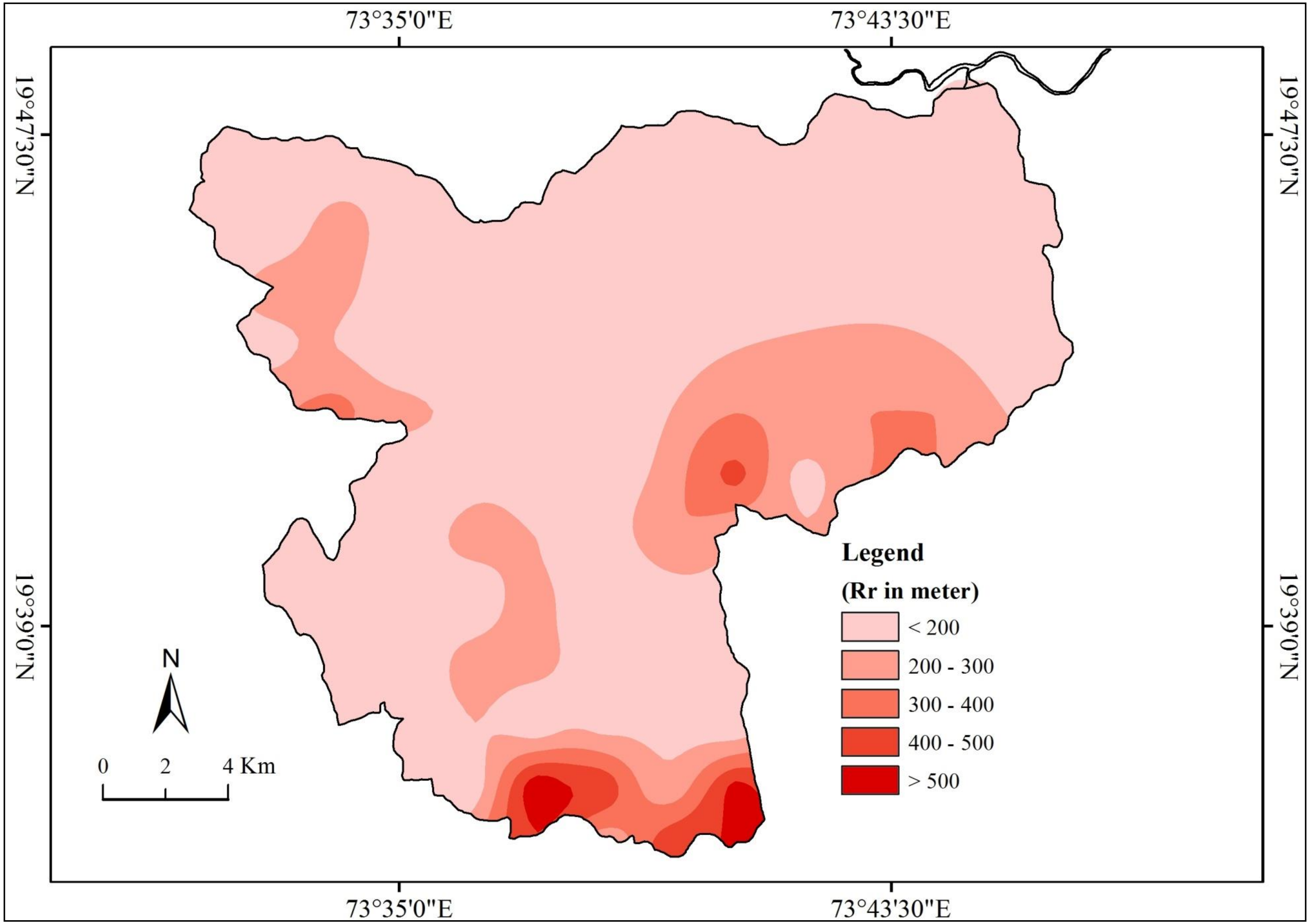


Fig.-3.4

Darna Lake Catchment: Dissection Index

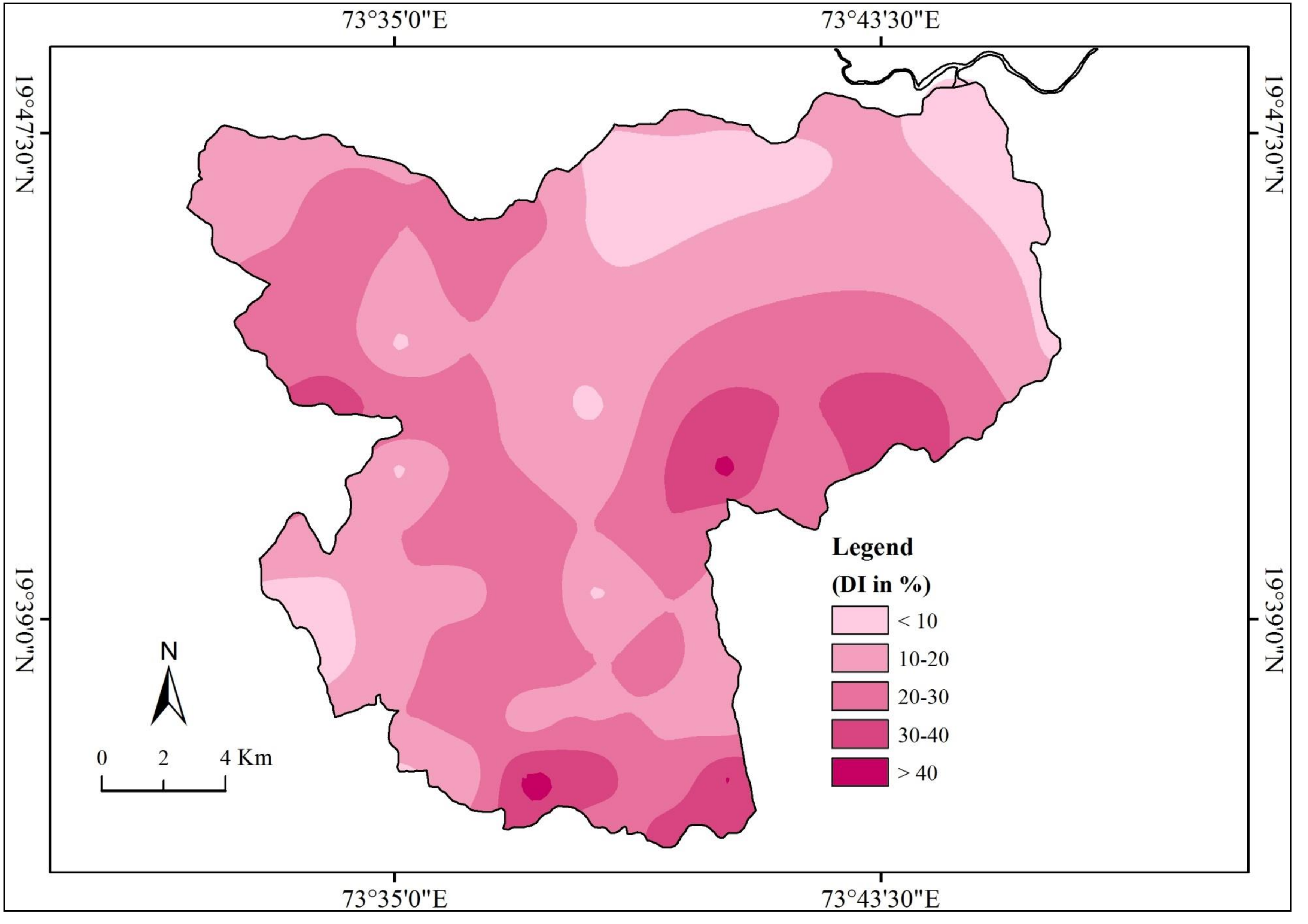


Fig.-3.5

Darna Lake Catchment: Percentage Slope Map

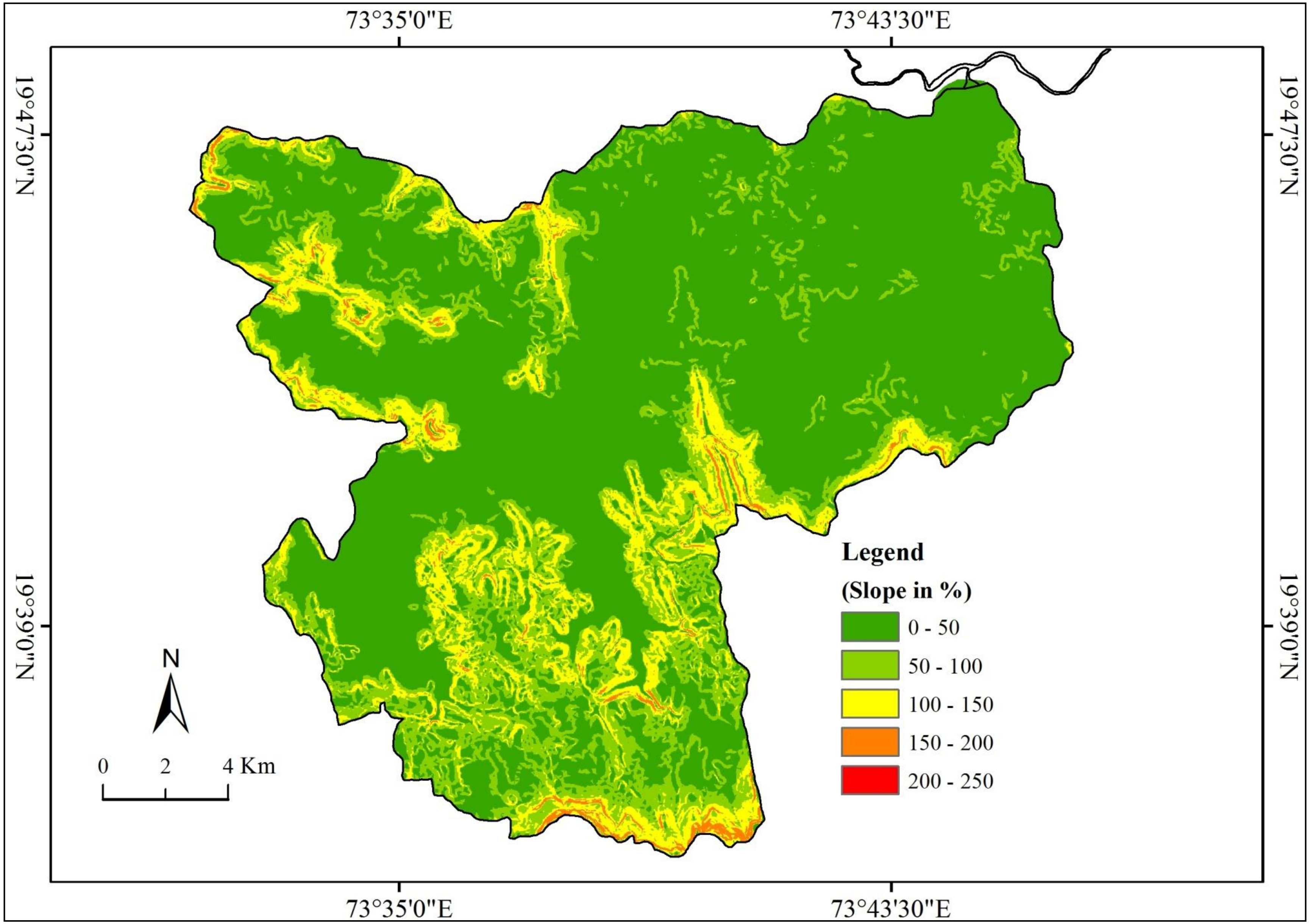
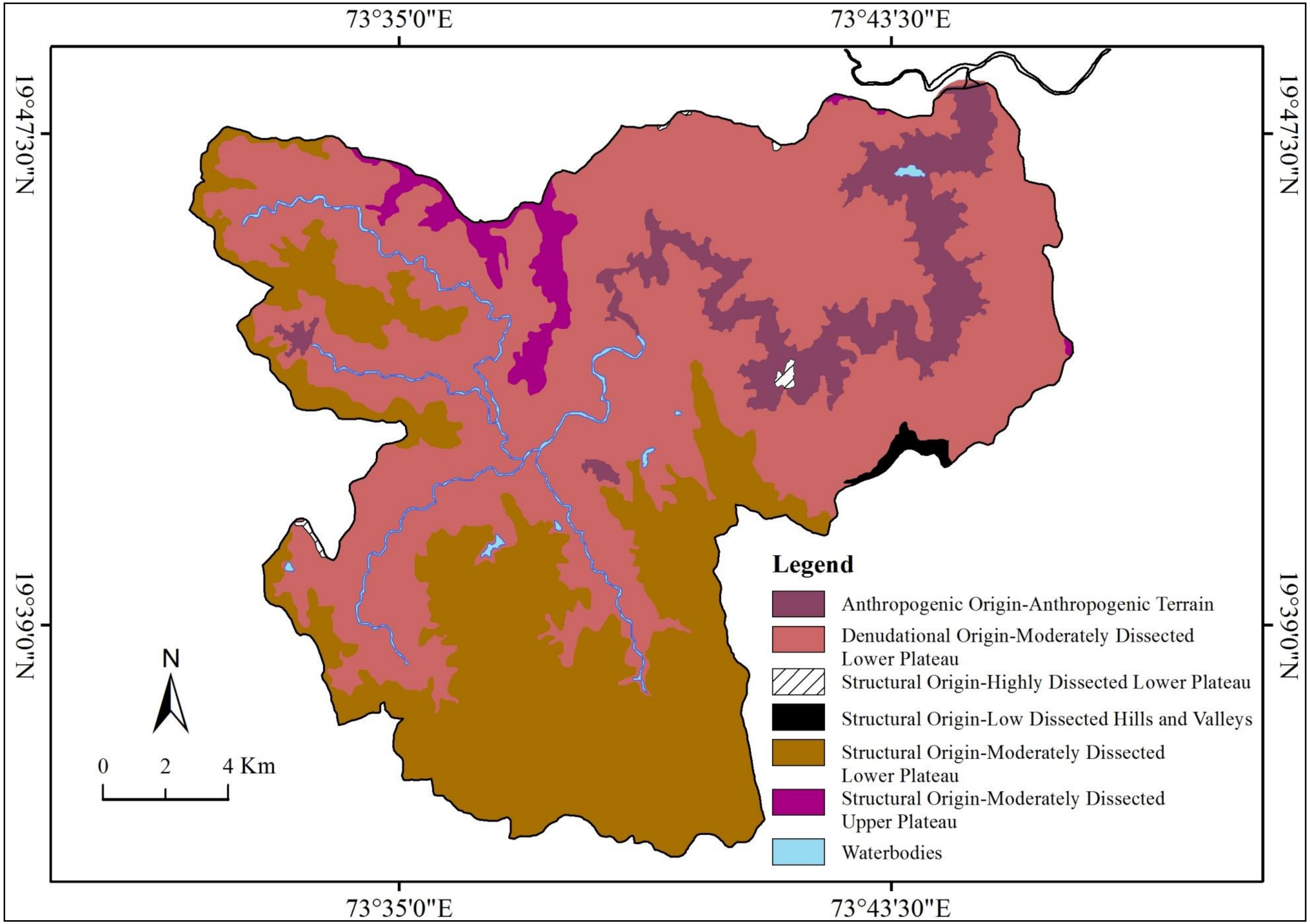


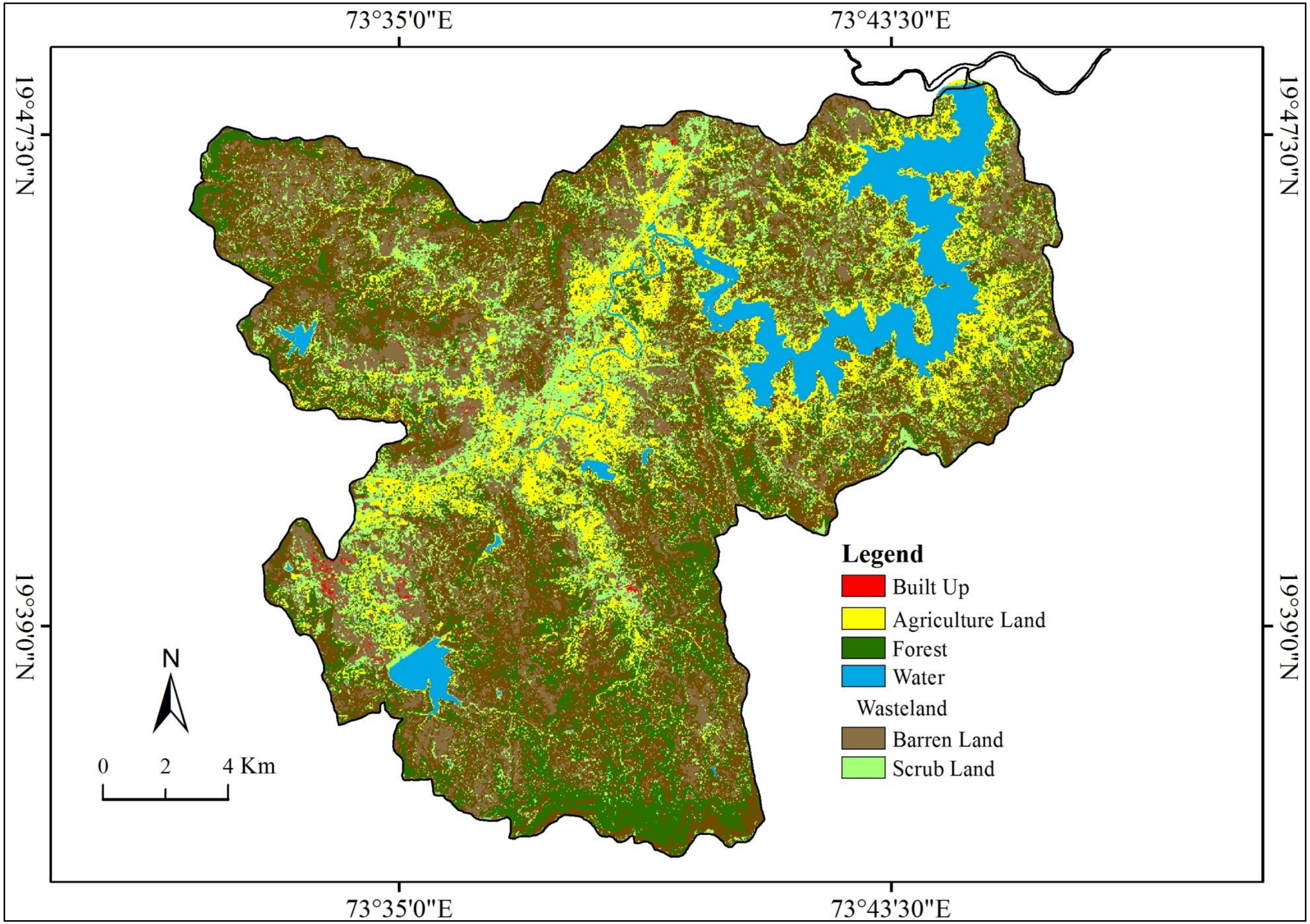
Fig.-3.6

Darna Lake Catchment: Geomorphic Map



Source: Bhuvan, 2005-2006. **Fig.-3.7**

Darna Lake Catchment: Land Use / Land Cover Map



Source: Landsat 8 OLI, 2012.

Fig.-4.1

Darna Lake Catchment: Stream orders

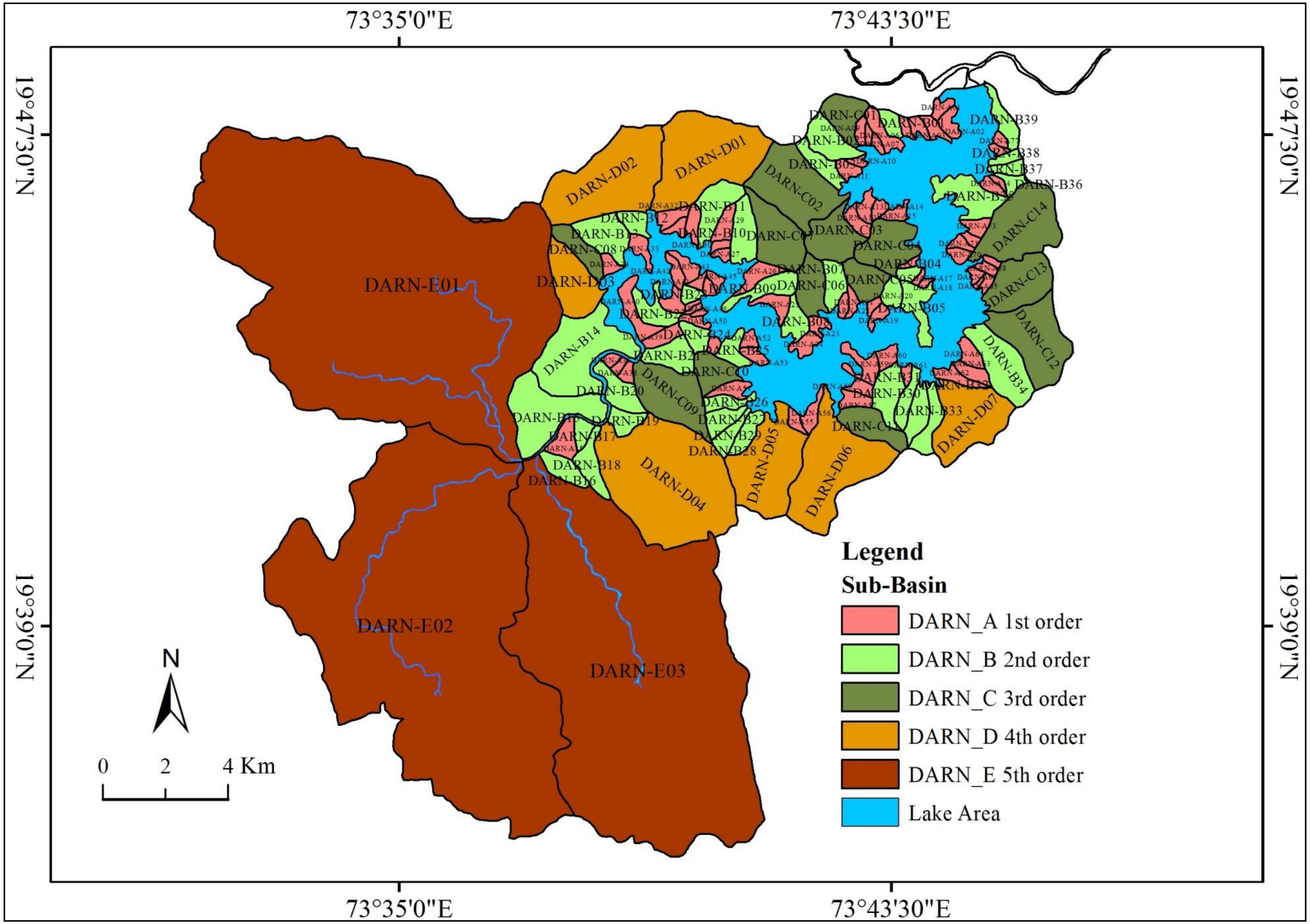
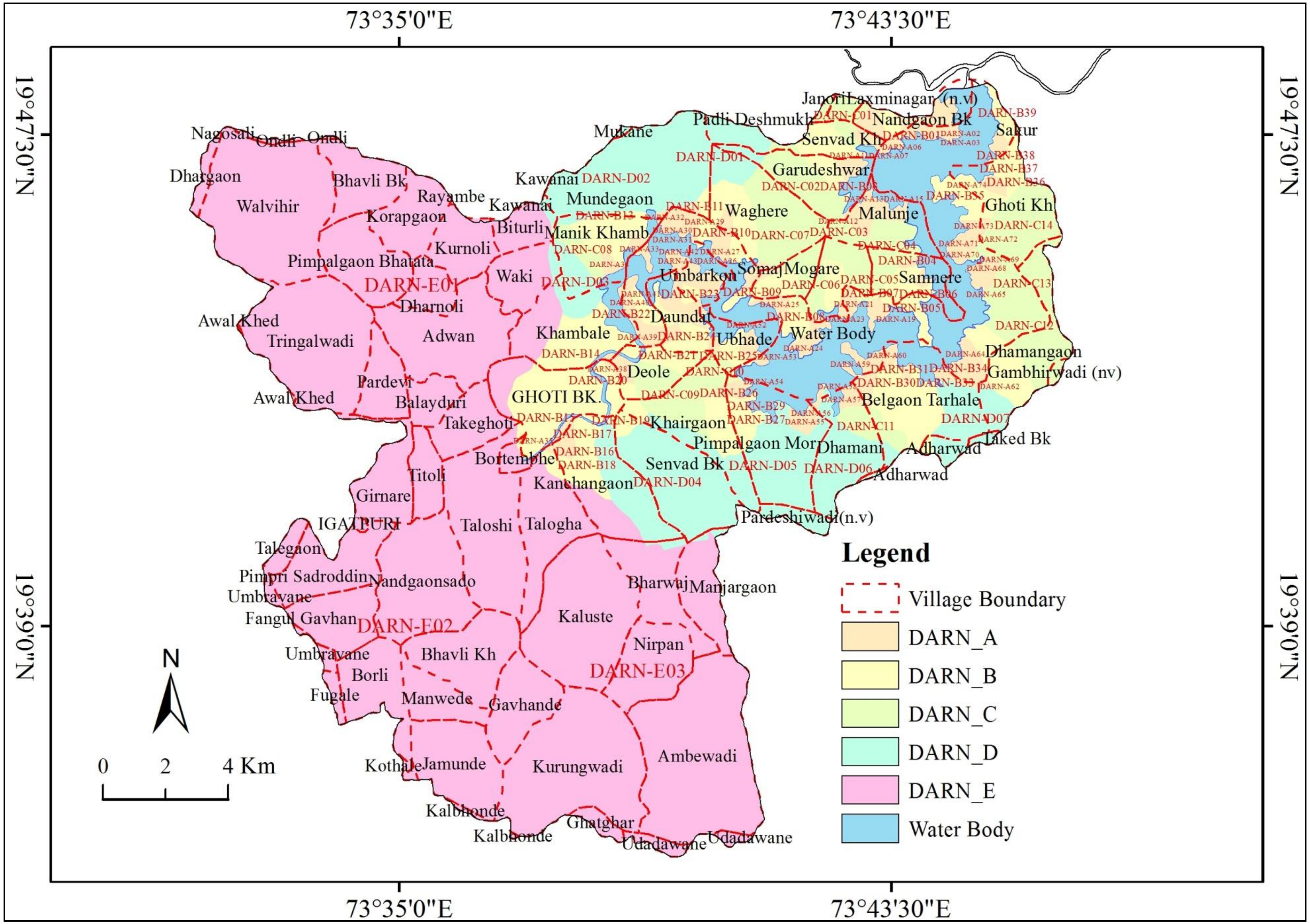


Fig.-4.2

Darna Lake Catchment: Sub-basins and Village boundary overlay



Source: MRSAC, 2015.

Fig.-4.3

Darna Lake Catchment: Prioritization of Sub-basins for Conservation Planning (Based on Morphometric Analysis)

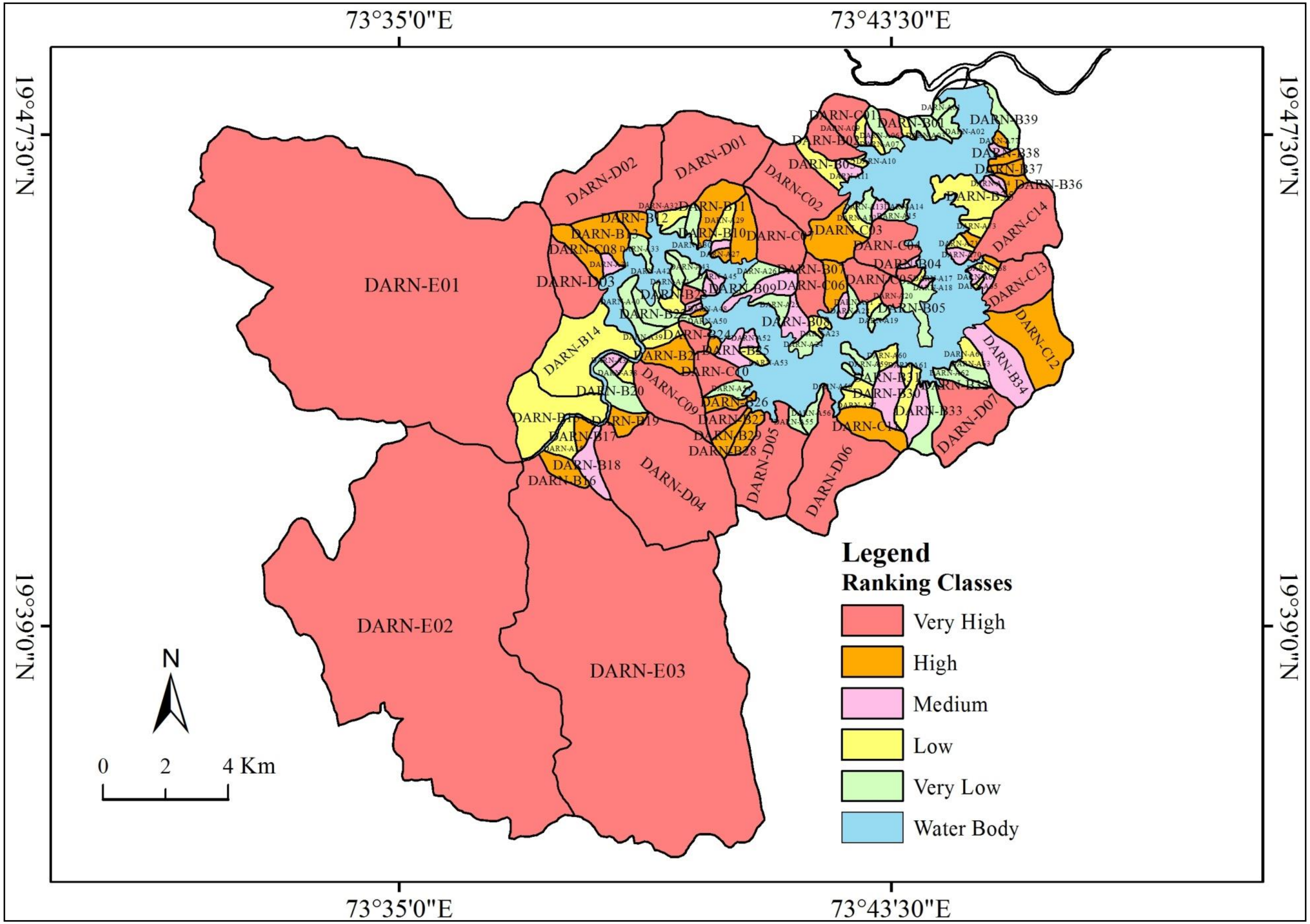


Fig.-5.1

Darna Lake Catchment: Prioritization of Sub-basins (Based on Peak Surface Runoff)

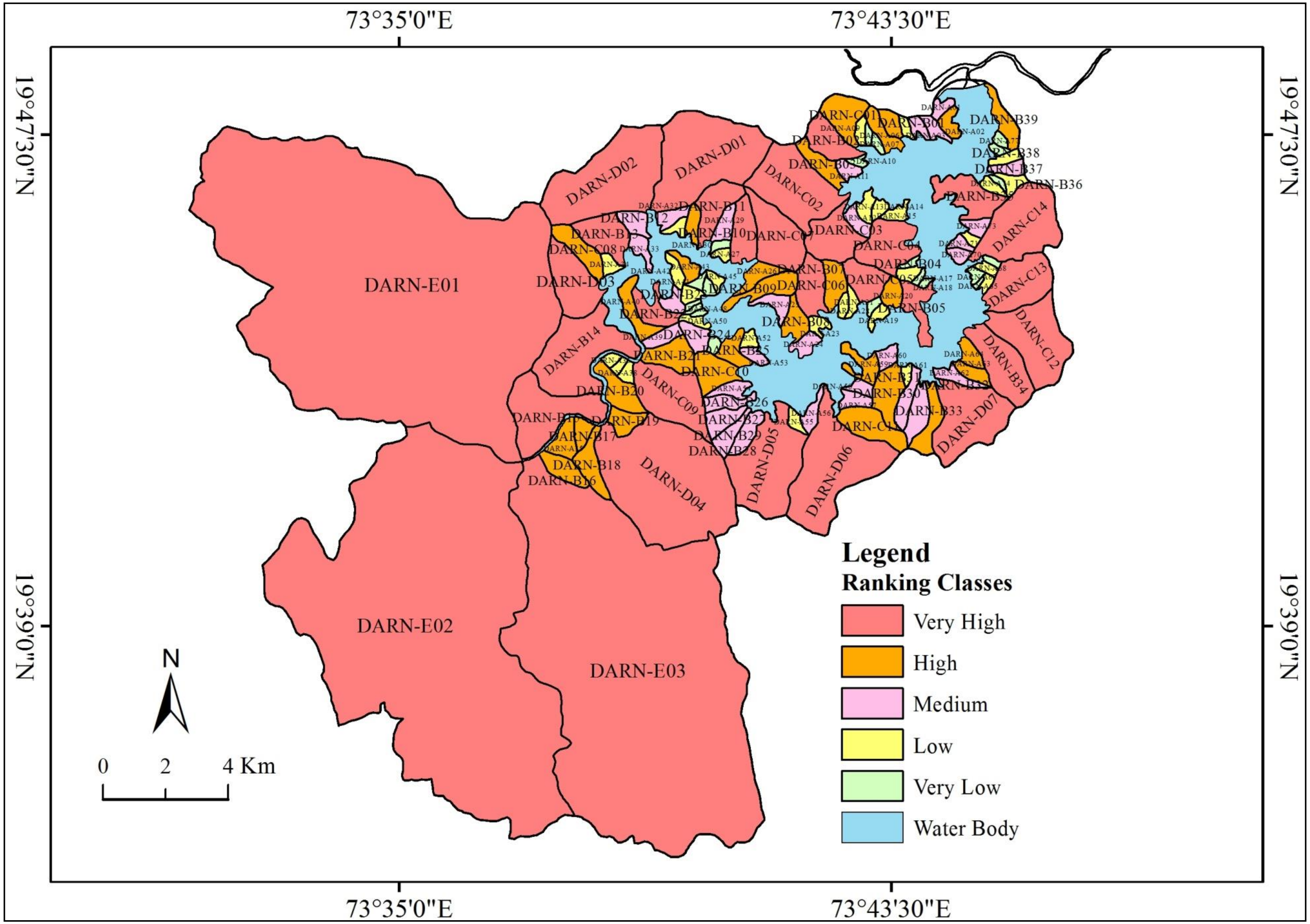


Fig.-5.2

Darna Lake Catchment: Composite Score Map (Based on Morphometric Analysis and Peak Surface runoff)

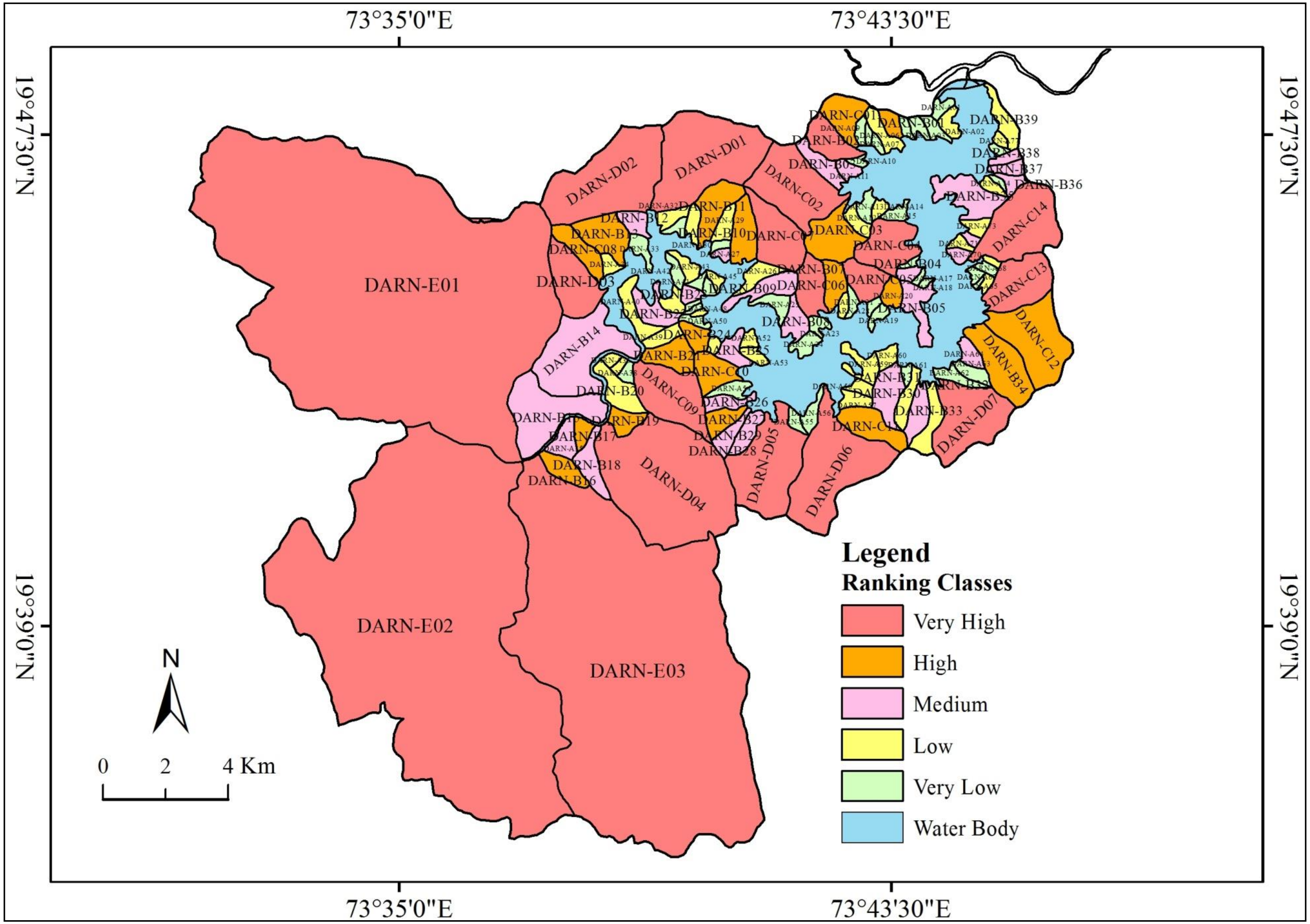


Fig.-5.3

Darna Lake Catchment -Catchment Area Treatment (CAT) Plan Map

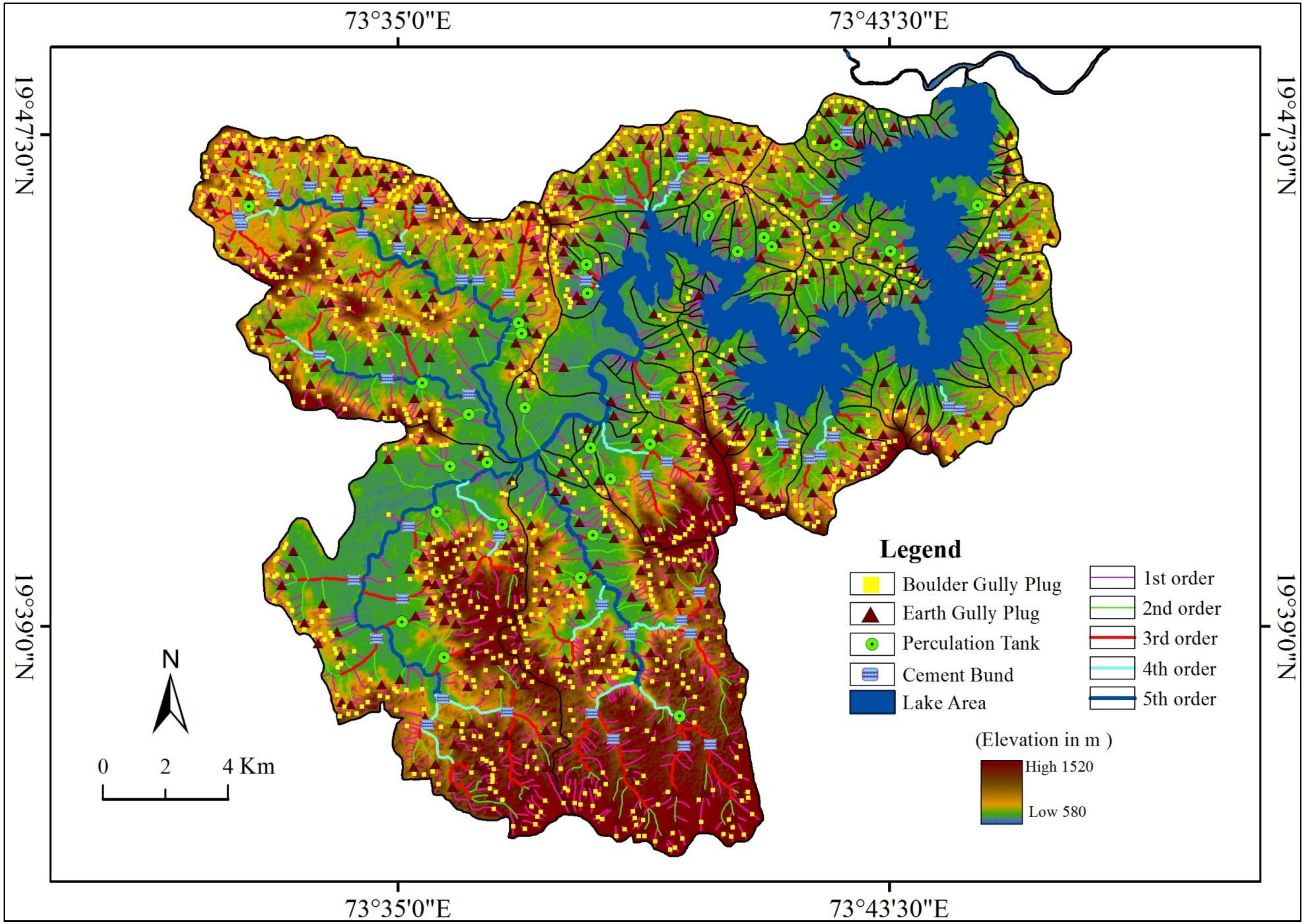


Fig.-6.1

APPENDIX-A

Darna Lake Catchment Average Rainfall 1976-2014

Years	January	February	March	April	May	June	July	August	September	October	November	December	Total
1976	0	0	0	0	0	406.6	1495.43	765.23	455.8	18	34.6	0	3175.66
1977	0	0	0	0	126.2	550.8	1073.4	675	369.8	9	35	0	2839.2
1978	0	0	0	0	0	588.4	562	872.6	355	40	84.2	0	2502.2
1979	0	0	0	0	0	440.4	628.4	1122.6	129.6	80.8	0	0	2401.8
1980	0	0	0	0	0	546.4	927	1349.2	317.5	0	0	25.2	3165.3
1981	0	0	0	0	0	289.1	1382.8	868.58	346.4	18	11	0	2915.88
1982	0	0	0	0	0	97.9	926.8	737.26	89.2	15	0	0	1866.16
1983	0	0	0	0	0	156.2	757	747	252.8	93.6	0	0	2006.6
1984	0	0	0	0	0	315.8	1002.4	832.92	111.2	77.1	0	0	2339.42
1985	0	0	0	0	0	71.3	579.7	603.4	89.4	30.6	0	0	1374.4
1986	0	0	0	0	0	323.6	600.7	556.4	11.4	0	0	17.2	1509.3
1987	0	0	0	0	16.1	66.7	550.8	569.17	128.5	46	5	0	1382.27
1988	0	0	0	47.2	0	120.4	800.7	378.3	393.3	4.25	0	0	1744.15
1989	0	0	0	0	0	37.7	549.3	494.1	188.4	18.1	0	0	1287.6
1990	0	0	0	0	17.25	172.6	1096	781.2	248	130.4	0	0	2445.45
1991	0	0	0	0	0	598.6	1008.4	460.5	0	0	0	0	2067.5
1992	0	0	0	0	0	106	230.2	583.6	402	34	0	0	1355.8
1993	0	0	0	0	27	328	985.4	428.8	237.8	251.2	0	0	2258.2
1994	0	0	0	0	0	349.2	1795.8	1388.4	655.6	56	2.2	5	4252.2
1995	0	0	0	0	0	20	655.4	112.2	169	7	0	0	963.6
1996	0	0	0	0	0	447.2	431.4	151.4	199.8	110.3	0	0	1340.1
1997	0	0	0	0	0	390.8	339.2	664.6	146.8	10	0	0	1551.4
1998	0	0	0	0	0	390.8	539.2	664.6	417.4	156.4	36.6	0	2205

Years	January	February	March	April	May	June	July	August	September	October	November	December	Total
1999	0	0	0	0	3.2	270	720.8	349	157.4	185.2	0	0	1685.6
2000	0	0	0	0	36.2	246.4	594.4	294.8	146.4	118.4	0	0	1436.6
2001	0	0	0	0	0	470.4	617.4	N.A.	N.A.	N.A.	0	0	1087.8
2002	0	0	0	0	0	513.6	91	382	40.2	1.6	N.A	N.A	1028.4
2003	4.7	0	0	1.7	2.8	461.4	872.8	457.4	162	0	0.9	N.A.	1963.7
2004	N.A	N.A	N.A	N.A	N.A	284	255	1654.4	119.8	51	N.A	N.A	2364.2
2005	N.A	N.A	N.A	N.A	N.A	717.2	981.6	659.4	787.8	135	N.A	N.A	3281
2006	N.A	N.A	N.A	N.A	N.A	275	1622	1903.6	114.2	56.2	N.A	N.A	3971
2007	N.A	N.A	N.A	N.A	N.A	352.2	384.6	844	247.4	0	N.A	N.A	1828.2
2008	N.A	N.A	N.A	N.A	N.A	102.6	605.6	1382.2	537.2	142.6	N.A	N.A	2770.2
2009	N.A	N.A	N.A	N.A	N.A	17.2	875.2	143.9	378.4	7	N.A	N.A	1421.7
2010	N.A	N.A	N.A	N.A	N.A	206.1	707.4	626.4	314.3	54.2	N.A	N.A	1908.4
2011	N.A	N.A	N.A	N.A	N.A	352	573.8	840.2	415.4	60.8	0	N.A	2242.2
2012	N.A	N.A	N.A	N.A	N.A	162.4	746.6	535.83	278.8	95.2	N.A	N.A	1818.83
2013	N.A	N.A	N.A	N.A	N.A	400.8	1147.4	543.4	351.2	82.4	N.A	N.A	2525.2
2014	N.A	N.A	N.A	N.A	N.A	79.6	899	547	516.6	82.4	N.A	N.A	2124.6
Total	4.7	0	0	48.9	228.75	11725.4	30612.03	26970.59	10281.8	2277.75	209.5	47.4	82406.82
Average	0.12	0.00	0.00	1.25	5.87	300.65	784.92	691.55	263.64	58.40	5.37	1.22	2113.00

Source: Hydrological Department, MERI, Nashik., Note: Rainfall in mm.

APPENDIX-B

Darna Lake Catchment Average Maximum Temperature 1999-2015

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1999	29.05	30.55	34.78	35.60	34.18	29.25	26.14	24.63	25.98	29.40	30.65	30.32
2000	30.58	30.60	32.88	37.22	33.68	28.43	25.04	25.93	26.18	30.83	30.98	30.46
2001	29.18	32.88	32.88	36.48	36.13	29.00	24.42	24.40	27.40	28.93	30.98	30.04
2002	27.08	30.60	34.53	37.36	36.70	32.48	25.84	24.18	26.96	32.30	30.83	31.42
2003	29.73	32.03	34.58	36.78	36.93	32.53	25.46	24.98	25.48	30.80	31.38	30.40
2004	29.30	31.40	36.38	36.40	35.35	30.73	25.66	24.25	26.80	28.90	29.80	29.10
2005	27.30	28.85	33.53	36.38	36.05	32.80	25.28	24.88	26.60	29.60	30.10	30.34
2006	29.75	32.40	32.78	36.40	36.65	30.03	24.74	23.70	27.26	30.03	29.60	29.78
2007	29.58	30.03	33.05	37.46	36.08	31.88	25.62	24.65	27.06	30.90	30.63	28.66
2008	29.48	28.40	34.98	36.12	35.38	29.65	25.32	24.13	27.04	30.53	31.43	30.60
2009	30.55	32.28	35.33	38.04	36.33	34.80	25.46	25.03	27.92	29.60	28.10	28.24
2010	28.43	30.33	34.73	37.28	36.90	28.80	25.60	25.58	26.96	29.85	29.38	27.86
2011	29.28	29.85	33.53	35.68	35.18	29.50	25.36	24.65	25.56	30.40	31.18	31.14
2012	28.53	31.18	33.58	36.84	35.75	30.44	24.93	24.50	25.86	30.08	30.08	30.36
2013	30.25	30.93	34.35	35.26	36.25	28.68	24.14	23.60	26.26	28.70	29.90	28.62
2014	28.05	28.45	31.83	36.76	36.83	33.80	26.20	25.33	26.66	31.65	30.78	30.16
2015	27.85	31.50	31.93	34.56	37.25	31.60	26.72	25.30	27.34	32.43	31.25	30.30
Total	**493.93**	**522.23**	**575.58**	**620.62**	**611.58**	**524.37**	**431.93**	**419.68**	**453.32**	**514.90**	**517.00**	**507.80**
Average	**29.05**	**30.72**	**33.86**	**36.51**	**35.98**	**30.85**	**25.41**	**24.69**	**26.67**	**30.29**	**30.41**	**29.87**

Source: Zonal Agricultural Research Station, Igatpuri, Note: Temperature in °C.

APPENDIX-C
Darna Lake Catchment Average Minimum Temperature 1999-2015

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1999	9.15	12.83	13.65	16.20	20.80	21.20	20.62	20.30	20.16	18.95	16.18	14.34
2000	11.53	9.63	11.53	19.72	21.63	22.23	21.50	21.73	21.14	18.78	15.60	12.08
2001	12.60	9.30	13.80	17.42	22.30	22.15	21.54	21.13	20.90	19.30	16.43	14.58
2002	11.28	13.45	16.38	18.72	24.03	22.75	21.82	20.93	20.04	20.80	17.30	13.28
2003	14.98	13.55	15.63	18.90	21.65	22.08	21.96	20.63	20.90	18.98	17.78	13.96
2004	10.65	12.53	16.63	19.02	23.28	22.95	21.60	20.48	20.92	18.68	18.55	10.74
2005	10.35	11.10	14.45	20.68	20.78	21.93	22.66	21.83	21.18	18.28	13.48	12.36
2006	10.38	12.68	14.28	16.70	21.15	22.08	20.90	20.65	20.80	19.48	17.40	13.54
2007	11.83	13.10	14.78	18.30	21.28	21.20	21.32	20.48	20.64	17.60	15.50	12.24
2008	9.25	8.78	14.63	17.04	20.33	21.25	19.94	19.70	19.78	15.55	13.73	13.90
2009	13.83	13.03	13.73	16.18	18.48	21.95	19.82	18.98	19.32	17.25	16.38	14.10
2010	13.25	12.13	14.48	16.84	19.40	20.70	19.76	19.48	19.58	18.63	17.93	11.88
2011	9.18	10.83	12.68	14.88	19.88	20.05	19.16	19.08	18.36	16.60	11.95	9.86
2012	6.88	8.75	12.78	17.28	20.10	21.88	20.80	20.15	20.08	18.65	15.33	12.22
2013	10.65	13.75	13.13	15.90	20.78	19.90	18.86	19.58	19.88	19.20	15.80	13.10
2014	10.73	10.88	15.73	18.94	21.03	19.95	21.56	20.53	20.64	20.25	16.93	13.50
2015	11.50	12.48	14.85	18.46	22.50	22.35	21.98	21.00	20.88	20.33	17.78	14.26
Total	**187.98**	**198.75**	**243.08**	**301.18**	**359.35**	**366.58**	**355.80**	**346.60**	**345.20**	**317.28**	**274.00**	**219.94**
Average	**11.06**	**11.69**	**14.30**	**17.72**	**21.14**	**21.56**	**20.93**	**20.39**	**20.31**	**18.66**	**16.12**	**12.94**

Source: Zonal Agricultural Research Station, Igatpuri., Note: Temperature in °C.

APPENDIX-D
Sub Basin-wise Morphometric Analysis of Darna Lake Catchment

Sub-basin	Stream Order (u)	Stream Number (Nu)	Bifurcation Ratio (Rb)	Length in Km.(Nu)	Mean Length in Km.	Length ratio	Area in Km^2	Mean Area in Km^2	Area ratio	Basin Perim -eter	P^2	Basin Length Km	L^2
DARN-A01	1	1	0.00	0.31	0.31	0.00	0.29	0.29	0.00	2.56	6.56	0.89	0.79
DARN-A02	1	1	1.00	0.30	0.30	0.97	0.43	0.43	1.50	3.11	9.69	1.09	1.18
DARN-A03	1	1	1.00	0.46	0.46	1.54	0.35	0.35	0.81	3.22	10.37	1.35	1.82
DARN-A04	1	1	1.00	0.49	0.49	1.05	0.29	0.29	0.84	2.81	7.92	1.01	1.03
DARN-A05	1	1	1.00	0.54	0.54	1.10	0.19	0.19	0.66	2.18	4.75	0.96	0.92
DARN-A06	1	1	1.00	1.63	1.63	3.03	0.65	0.65	3.40	4.48	20.11	1.77	3.14
DARN-A07	1	1	1.00	0.26	0.26	0.16	0.16	0.16	0.25	1.84	3.37	0.79	0.63
DARN-A08	1	1	1.00	0.35	0.35	1.35	0.13	0.13	0.80	1.77	3.13	0.79	0.62
DARN-A09	1	1	1.00	0.78	0.78	2.24	0.25	0.25	1.96	2.44	5.94	1.04	1.08
DARN-A10	1	1	1.00	0.31	0.31	0.39	0.16	0.16	0.62	2.08	4.33	0.74	0.55
DARN-A11	1	1	1.00	0.56	0.56	1.83	0.34	0.34	2.19	2.55	6.52	0.87	0.76
DARN-A12	1	1	1.00	0.97	0.97	1.73	0.43	0.43	1.27	3.16	9.97	1.21	1.47
DARN-A13	1	1	1.00	0.28	0.28	0.29	0.39	0.39	0.90	3.13	9.82	1.16	1.35
DARN-A14	1	1	1.00	0.36	0.36	1.30	0.24	0.24	0.62	2.16	4.66	0.81	0.66
DARN-A15	1	1	1.00	0.23	0.23	0.64	0.32	0.32	1.31	3.00	9.03	1.12	1.25
DARN-A16	1	1	1.00	0.49	0.49	2.12	0.12	0.12	0.38	1.83	3.35	0.79	0.63
DARN-A17	1	1	1.00	0.26	0.26	0.52	0.10	0.10	0.81	1.56	2.43	0.65	0.42
DARN-A18	1	1	1.00	0.21	0.21	0.83	0.09	0.09	0.90	1.36	1.84	0.58	0.34
DARN-A19	1	1	1.00	0.30	0.30	1.40	0.27	0.27	3.08	2.63	6.90	1.01	1.02
DARN-A20	1	1	1.00	0.39	0.39	1.30	0.16	0.16	0.58	1.85	3.44	0.78	0.61
DARN-A21	1	1	1.00	0.28	0.28	0.72	0.25	0.25	1.59	2.78	7.70	1.17	1.36

Sub-basin	Stream Order (u)	Stream Number (Nu)	Bifurcation Ratio (Rb)	Length in Km.(Nu)	Mean Length in Km.	Length ratio	Area in Km^2	Mean Area in Km^2	Area ratio	Basin Perim -eter	P^2	Basin Length Km	L^2
DARN-A22	1	1	1.00	0.32	0.32	1.16	0.21	0.21	0.83	2.00	4.00	0.85	0.72
DARN-A23	1	1	1.00	0.28	0.28	0.85	0.29	0.29	1.40	2.68	7.17	0.80	0.64
DARN-A24	1	1	1.00	0.28	0.28	1.00	0.46	0.46	1.57	3.19	10.17	1.02	1.03
DARN-A25	1	1	1.00	0.41	0.41	1.47	0.52	0.52	1.15	4.07	16.54	1.25	1.55
DARN-A26	1	1	1.00	0.63	0.63	1.54	0.65	0.65	1.25	4.83	23.38	1.76	3.09
DARN-A27	1	1	1.00	0.41	0.41	0.65	0.18	0.18	0.28	1.83	3.34	0.64	0.41
DARN-A28	1	1	1.00	0.49	0.49	1.22	0.17	0.17	0.91	1.97	3.87	0.80	0.65
DARN-A29	1	1	1.00	1.34	1.34	2.72	0.53	0.53	3.13	3.42	11.70	1.45	2.09
DARN-A30	1	1	1.00	0.74	0.74	0.55	0.42	0.42	0.80	3.62	13.12	1.52	2.30
DARN-A31	1	1	1.00	0.44	0.44	0.60	0.25	0.25	0.59	2.56	6.57	0.96	0.93
DARN-A32	1	1	1.00	0.81	0.81	1.84	0.45	0.45	1.81	3.26	10.60	1.25	1.56
DARN-A33	1	1	1.00	0.35	0.35	0.43	0.44	0.44	0.97	3.47	12.03	1.38	1.91
DARN-A34	1	1	1.00	0.64	0.64	1.85	0.29	0.29	0.67	2.47	6.12	0.78	0.62
DARN-A35	1	1	1.00	0.71	0.71	1.12	0.75	0.75	2.57	3.86	14.90	1.33	1.76
DARN-A36	1	1	1.00	0.35	0.35	0.50	0.18	0.18	0.24	1.65	2.74	0.64	0.41
DARN-A37	1	1	1.00	0.39	0.39	1.12	0.15	0.15	0.85	1.72	2.94	0.65	0.42
DARN-A38	1	1	1.00	0.34	0.34	0.87	0.24	0.24	1.62	2.23	4.96	0.86	0.74
DARN-A39	1	1	1.00	1.10	1.10	3.20	0.50	0.50	2.05	3.29	10.81	1.33	1.76
DARN-A40	1	1	1.00	0.53	0.53	0.48	0.90	0.90	1.80	6.05	36.65	2.15	4.60
DARN-A41	1	1	1.00	0.68	0.68	1.29	0.41	0.41	0.45	3.09	9.58	0.98	0.97
DARN-A42	1	1	1.00	0.33	0.33	0.49	0.35	0.35	0.85	3.00	8.97	1.33	1.78
DARN-A43	1	1	1.00	0.34	0.34	1.03	0.43	0.43	1.25	3.47	12.04	1.26	1.59
DARN-A44	1	1	1.00	0.20	0.20	0.58	0.17	0.17	0.39	2.22	4.91	0.74	0.55

Sub-basin	Stream Order (u)	Stream Number (Nu)	Bifurcation Ratio (Rb)	Length in Km.(Nu)	Mean Length in Km.	Length ratio	Area in Km^2	Mean Area in Km^2	Area ratio	Basin Perim -eter	P^2	Basin Length Km	L^2
DARN-A45	1	1	1.00	0.52	0.52	2.64	0.20	0.20	1.18	2.08	4.34	0.82	0.68
DARN-A46	1	1	1.00	0.37	0.37	0.71	0.17	0.17	0.85	1.81	3.29	0.70	0.50
DARN-A47	1	1	1.00	0.43	0.43	1.16	0.08	0.08	0.49	1.44	2.07	0.63	0.40
DARN-A48	1	1	1.00	0.44	0.44	1.02	0.10	0.10	1.19	1.60	2.57	0.70	0.48
DARN-A49	1	1	1.00	0.39	0.39	0.90	0.09	0.09	0.93	1.30	1.69	0.55	0.31
DARN-A50	1	1	1.00	0.50	0.50	1.27	0.23	0.23	2.57	2.64	6.99	1.01	1.01
DARN-A51	1	1	1.00	0.33	0.33	0.66	0.18	0.18	0.79	1.66	2.74	0.59	0.35
DARN-A52	1	1	1.00	0.30	0.30	0.92	0.24	0.24	1.30	2.10	4.41	0.76	0.58
DARN-A53	1	1	1.00	0.26	0.26	0.86	0.31	0.31	1.29	2.50	6.27	1.00	1.00
DARN-A54	1	1	1.00	1.26	1.26	4.86	0.47	0.47	1.53	3.85	14.82	1.55	2.40
DARN-A55	1	1	1.00	0.38	0.38	0.30	0.25	0.25	0.53	2.52	6.36	1.13	1.27
DARN-A56	1	1	1.00	0.36	0.36	0.95	0.45	0.45	1.79	3.96	15.70	1.70	2.89
DARN-A57	1	1	1.00	0.60	0.60	1.66	0.43	0.43	0.96	3.06	9.37	1.09	1.19
DARN-A58	1	1	1.00	0.56	0.56	0.93	0.29	0.29	0.68	2.58	6.66	0.99	0.98
DARN-A59	1	1	1.00	0.30	0.30	0.53	0.73	0.73	2.50	6.13	37.61	1.66	2.77
DARN-A60	1	1	1.00	0.34	0.34	1.16	0.37	0.37	0.50	2.69	7.22	1.08	1.17
DARN-A61	1	1	1.00	0.36	0.36	1.05	0.17	0.17	0.46	1.86	3.47	0.79	0.62
DARN-A62	1	1	1.00	0.39	0.39	1.10	0.48	0.48	2.82	4.48	20.03	1.90	3.59
DARN-A63	1	1	1.00	1.12	1.12	2.83	0.46	0.46	0.94	3.25	10.56	1.45	2.11
DARN-A64	1	1	1.00	0.38	0.38	0.34	0.48	0.48	1.05	3.08	9.48	1.19	1.41
DARN-A65	1	1	1.00	0.43	0.43	1.11	0.18	0.18	0.37	2.09	4.35	0.73	0.53
DARN-A66	1	1	1.00	0.11	0.11	0.26	0.06	0.06	0.32	1.24	1.54	0.51	0.26
DARN-A67	1	1	1.00	0.20	0.20	1.82	0.18	0.18	3.15	2.00	4.01	0.61	0.37

Sub-basin	Stream Order (u)	Stream Number (Nu)	Bifurcation Ratio (Rb)	Length in Km.(Nu)	Mean Length in Km.	Length ratio	Area in Km^2	Mean Area in Km^2	Area ratio	Basin Perim -eter	P^2	Basin Length Km	L^2
DARN-A68	1	1	1.00	0.38	0.38	1.91	0.20	0.20	1.11	2.12	4.49	0.80	0.64
DARN-A69	1	1	1.00	0.36	0.36	0.94	0.12	0.12	0.61	1.62	2.63	0.64	0.41
DARN-A70	1	1	1.00	0.38	0.38	1.05	0.27	0.27	2.26	2.15	4.61	0.83	0.69
DARN-A71	1	1	1.00	0.41	0.41	1.07	0.23	0.23	0.83	2.34	5.47	0.85	0.72
DARN-A72	1	1	1.00	0.47	0.47	1.16	0.16	0.16	0.71	1.80	3.23	0.65	0.43
DARN-A73	1	1	1.00	0.25	0.25	0.53	0.36	0.36	2.26	2.80	7.86	0.93	0.86
DARN-A74	1	1	1.00	0.81	0.81	3.30	0.26	0.26	0.70	2.30	5.28	0.95	0.91
DARN-A75	1	1	1.00	0.49	0.49	0.60	0.11	0.11	0.44	1.75	3.07	0.77	0.60
DARN-A76	1	1	1.00	0.31	0.31	0.63	0.15	0.15	1.29	1.78	3.16	0.71	0.50
DARN-A77	1	1	1.00	0.45	0.45	1.46	0.16	0.16	1.13	1.65	2.73	0.67	0.45
DARN-B01	1	2	0.00	1.29	0.65	0.00	0.44	0.34		2.79	7.80	1.16	1.34
	2	1	2.00	0.37	0.37	0.58	0.44	0.44	1.29				
DARN-B02	1	6	0.00	3.10	0.52		1.37	0.23		5.31	28.23	1.97	3.86
	2	1	6.00	1.14	1.14	2.20	1.37	1.37	6.00				0.00
DARN-B03	1	2	0.00	1.40	0.70		0.85	0.60		5.18	26.83	2.02	4.07
	2	1	2.00	0.39	0.39	0.55	0.85	0.85	1.40				
DARN-B04	1	2	0.00	1.02	0.51		0.28	0.14		2.39	5.70	0.91	0.83
	2	1	2.00	0.08	0.08	0.16	0.28	0.28	2.00				
DARN-B05	1	2	0.00	1.03	0.51		1.13	1.09		7.06	49.82	2.33	5.45
	2	1	2.00	0.11	0.11	0.21	1.13	1.13	1.03				
DARN-B06	1	4	0.00	1.62	0.40		0.51	0.13		2.82	7.93	1.08	1.17
	2	1	4.00	0.55	0.55	1.36	0.51	0.51	4.00				
DARN-B07	1	3	0.00	1.02	0.34		0.88	0.86		4.42	19.57	1.69	2.86

Sub-basin	Stream Order (u)	Stream Number (Nu)	Bifurcation Ratio (Rb)	Length in Km.(Nu)	Mean Length in Km.	Length ratio	Area in Km^2	Mean Area in Km^2	Area ratio	Basin Perim -eter	P^2	Basin Length Km	L^2
	2	1	3.00	1.12	1.12	3.29	0.88	0.88	1.02				
DARN-B08	1	3	0.00	1.50	0.50		0.75	0.25		4.49	20.13	1.62	2.61
	2	1	3.00	0.17	0.17	0.33	0.75	0.75	3.00				
DARN-B09	1	5	0.00	1.99	0.40		1.09	0.55		6.35	40.33	2.55	6.49
	2	1	5.00	1.29	1.29	3.25	1.09	1.09	1.99				
DARN-B10	1	6	0.00	3.01	0.50		1.39	0.23		5.65	31.94	2.28	5.22
	2	1	6.00	1.37	1.37	2.74	1.39	1.39	6.00				
DARN-B11	1	6	0.00	3.42	0.57		1.54	0.45		6.16	37.90	2.42	5.88
	2	1	6.00	1.82	1.82	3.19	1.54	1.54	3.42				
DARN-B12	1	2	0.00	1.40	0.70		0.56	0.28		3.26	10.66	1.32	1.75
	2	1	2.00	0.03	0.03	0.05	0.56	0.56	2.00				
DARN-B13	1	3	0.00	3.45	1.15		1.70	0.49		5.71	32.63	2.14	4.59
	2	1	3.00	0.90	0.90	0.78	1.70	1.70	3.45				
DARN-B14	1	2	0.00	2.35	1.17		5.13	2.57		11.87	140.91	3.50	12.26
	2	1	2.00	0.79	0.79	0.67	5.13	5.13	2.00				
DARN-B15	1	6	0.00	2.18	0.36		3.92	1.80		10.12	102.36	3.05	9.27
	2	1	6.00	2.34	2.34	6.44	3.92	3.92	2.18				
DARN-B16	1	3	0.00	1.61	0.54		0.86	0.29		4.16	17.34	1.80	3.25
	2	1	3.00	0.96	0.96	1.78	0.86	0.86	3.00				
DARN-B17	1	2	0.00	0.76	0.38		0.43	0.57		2.90	8.43	1.10	1.22
	2	1	2.00	0.19	0.19	0.50	0.43	0.43	0.76				
DARN-B18	1	4	0.00	2.01	0.50		1.06	0.26		5.91	34.95	2.25	5.04
	2	1	4.00	1.90	1.90	3.78	1.06	1.06	4.00				

Sub-basin	Stream Order (u)	Stream Number (Nu)	Bifurcation Ratio (Rb)	Length in Km.(Nu)	Mean Length in Km.	Length ratio	Area in Km^2	Mean Area in Km^2	Area ratio	Basin Perim -eter	P^2	Basin Length Km	L^2
DARN-B19	1	2	0.00	1.48	0.74		0.67	0.45		3.76	14.17	1.33	1.76
	2	1	2.00	0.19	0.19	0.25	0.67	0.67	1.48				
DARN-B20	1	2	0.00	1.52	0.76		1.16	0.58		5.46	29.79	2.18	4.75
	2	1	2.00	0.28	0.28	0.37	1.16	1.16	2.00				
DARN-B21	1	3	0.00	2.05	0.68		1.21	0.59		4.75	22.53	1.67	2.79
	2	1	3.00	0.54	0.54	0.79	1.21	1.21	2.05				
DARN-B22	1	2	0.00	0.78	0.39		0.98	0.49		6.19	38.30	1.64	2.69
	2	1	2.00	0.32	0.32	0.83	0.98	0.98	2.00				
DARN-B23	1	2	0.00	0.97	0.48		0.29	0.30		2.29	5.24	0.78	0.62
	2	1	2.00	0.04	0.04	0.07	0.29	0.29	0.97				
DARN-B24	1	3	0.00	1.44	0.48		0.60	0.20		3.43	11.76	1.27	1.62
	2	1	3.00	0.33	0.33	0.68	0.60	0.60	3.00				
DARN-B25	1	2	0.00	0.72	0.36		0.67	0.94		4.12	16.97	1.24	1.53
	2	1	2.00	0.45	0.45	1.25	0.67	0.67	0.72				
DARN-B26	1	3	0.00	2.58	0.86		0.58	0.19		4.31	18.57	1.58	2.48
	2	1	3.00	0.39	0.39	0.46	0.58	0.58	3.00				
DARN-B27	1	4	0.00	2.72	0.68		0.71	0.26		3.87	14.96	1.55	2.40
	2	1	4.00	0.66	0.66	0.97	0.71	0.71	2.72				
DARN-B28	1	3	0.00	1.90	0.63		0.60	0.20		4.19	17.59	1.79	3.19
	2	1	3.00	0.70	0.70	1.11	0.60	0.60	3.00				
DARN-B29	1	4	0.00	1.70	0.43		0.70	0.41		4.06	16.52	1.76	3.08
	2	1	4.00	0.83	0.83	1.96	0.70	0.70	1.70				
DARN-B30	1	2	0.00	2.05	1.02		1.31	0.65		5.67	32.18	2.14	4.57

Sub-basin	Stream Order (u)	Stream Number (Nu)	Bifurcation Ratio (Rb)	Length in Km.(Nu)	Mean Length in Km.	Length ratio	Area in Km^2	Mean Area in Km^2	Area ratio	Basin Perim -eter	P^2	Basin Length Km	L^2
	2	1	2.00	0.70	0.70	0.68	1.31	1.31	2.00				
DARN-B31	1	2	0.00	0.74	0.37		0.69	0.94		4.81	23.09	2.17	4.72
	2	1	0.97	0.97	0.97	2.63	0.69	0.69	0.74				
DARN-B32	1	3	0.00	2.13	0.71		0.91	0.30		5.08	25.84	2.20	4.84
	2	1	3.00	0.77	0.77	1.08	0.91	0.91	3.00				
DARN-B33	1	2	0.00	1.40	0.70		0.97	0.69		6.21	38.55	2.37	5.61
	2	1	2.00	1.40	1.40	2.01	0.97	0.97	1.40				
DARN-B34	1	3	0.00	4.01	1.34		2.72	0.91		7.59	57.57	3.02	9.12
	2	1	3.00	2.04	2.04	1.52	2.72	2.72	3.00				
DARN-B35	1	4	0.00	1.28	0.32		1.86	1.46		8.27	68.37	2.45	6.00
	2	1	4.00	0.96	0.96	3.01	1.86	1.86	1.28				
DARN-B36	1	2	0.00	1.16	0.58		0.35	0.18		3.03	9.15	1.08	1.17
	2	1	2.00	0.39	0.39	0.67	0.35	0.35	2.00				
DARN-B37	1	3	0.00	1.03	0.34		0.38	0.37		2.99	8.97	1.15	1.33
	2	1	3.00	0.45	0.45	1.31	0.38	0.38	1.03				
DARN-B38	1	3	0.00	0.62	0.21		0.30	0.10		2.63	6.90	1.03	1.07
	2	1	3.00	0.48	0.48	2.30	0.30	0.30	3.00	2.63	6.90		0.00
DARN-B39	1	2	0.00	0.49	0.24		0.82	1.68		5.41	29.22	2.37	5.60
	2	1	2.00	0.53	0.53	2.17	0.82	0.82	0.49				
DARN-C01	1	8	0.00	3.26	0.41		1.40	0.17		5.16	26.58	1.85	3.42
	2	3	2.67	1.29	0.43	1.05	1.40	0.47	2.67				
	3	1	3.00	1.15	1.15	2.68	1.40	1.40	3.00				
DARN-C02	1	20	0.00	10.73	0.54		4.59	0.23		9.77	95.36	3.24	10.48

Sub-basin	Stream Order (u)	Stream Number (Nu)	Bifurcation Ratio (Rb)	Length in Km.(Nu)	Mean Length in Km.	Length ratio	Area in Km^2	Mean Area in Km^2	Area ratio	Basin Perim -eter	P^2	Basin Length Km	L^2
	2	5	4.00	3.28	0.66	1.22	4.59	0.92	4.00				
	3	1	5.00	1.66	1.66	2.54	4.59	4.59	5.00				
DARN-C03	1	10	0.00	5.38	0.54		2.07	0.21		7.11	50.56	2.72	7.40
	2	2	5.00	1.06	0.53	0.99	2.07	1.04	5.00				
	3	1	2.00	0.61	0.61	1.15	2.07	2.07	2.00				
DARN-C04	1	8	0.00	4.77	0.60		2.34	0.29		7.08	50.11	2.14	4.59
	2	2	4.00	0.57	0.28	0.48	2.34	1.17	4.00				
	3	3	0.67	0.53	0.18	0.63	2.34	0.78	0.67				
DARN-C05	1	4	0.00	2.86	0.72		1.25	0.31		4.57	20.93	1.56	2.45
	2	2	2.00	0.76	0.38	0.53	1.25	0.63	2.00				
	3	1	2.00	0.11	0.11	0.28	1.25	1.25	2.00				
DARN-C06	1	6	0.00	2.05	0.34		1.44	0.24		5.57	31.07	2.11	4.46
	2	2	3.00	1.96	0.98	2.87	1.44	0.72	3.00				
	3	1	2.00	0.18	0.18	0.19	1.44	1.44	2.00				
DARN-C07	1	11	0.00	11.00	1.00		2.66	0.24		7.46	55.60	3.14	9.85
	2	2	5.50	4.00	2.00	2.00	2.66	1.33	5.50				
	3	1	2.00	0.41	0.41	0.21	2.66	2.66	2.00				
DARN-C08	1	5	0.00	2.93	0.59		1.11	0.22		5.36	28.78	2.32	5.36
	2	2	2.50	1.45	0.73	1.24	1.11	0.55	2.50				
	3	1	2.00	0.84	0.84	1.16	1.11	1.11	2.00				
DARN-C09	1	15	0.00	7.65	0.51		3.47	0.23		8.45	71.41	3.50	12.22
	2	4	3.75	3.13	0.78	1.54	3.47	0.87	3.75				
	3	1	4.00	1.66	1.66	2.12	3.47	3.47	4.00				

Sub-basin	Stream Order (u)	Stream Number (Nu)	Bifurcation Ratio (Rb)	Length in Km.(Nu)	Mean Length in Km.	Length ratio	Area in Km^2	Mean Area in Km^2	Area ratio	Basin Perim -eter	P^2	Basin Length Km	L^2
DARN-C10	1	7	0.00	3.35	0.48		1.24	0.18		5.00	24.97	1.75	3.07
	2	2	3.50	1.09	0.54	1.14	1.24	0.62	3.50				
	3	1	2.00	0.31	0.31	0.57	1.24	1.24	2.00				
DARN-C11	1	5	0.00	2.61	0.52		1.60	0.32		5.81	33.79	2.40	5.76
	2	2	2.50	1.51	0.75	1.44	1.60	0.80	2.50				
	3	1	2.00	0.54	0.54	0.71	1.60	1.60	2.00				
DARN-C12	1	9	0.00	7.11	0.79		4.18	0.46		9.68	93.68	3.31	10.94
	2	3	3.00	1.46	0.49	0.62	4.18	1.39	3.00				
	3	1	3.00	1.68	1.68	3.46	4.18	4.18	3.00				
DARN-C13	1	13	0.00	6.07	0.47		2.79	0.21		7.16	51.30	2.64	6.97
	2	4	3.25	0.92	0.23	0.49	2.79	0.70	3.25				
	3	1	4.00	1.82	1.82	7.91	2.79	2.79	4.00				
DARN-C14	1	28	0.00	11.51	0.41		4.40	0.16		9.28	86.08	3.41	11.62
	2	8	3.50	3.61	0.45	1.10	4.40	0.55	3.50				
	3	1	8.00	2.10	2.10	4.66	4.40	4.40	8.00				
DARN-D01	1	35	0.00	19.12	0.55		7.38	0.21		11.68	136.34	4.35	18.92
	2	9	3.89	4.27	0.47	0.87	7.38	0.82	3.89				
	3	2	4.50	2.98	1.49	3.14	7.38	3.69	4.50				
	4	1	2.00	1.76	1.76	1.18	7.38	7.38	2.00				
DARN-D02	1	37	0.00	19.51	0.53		7.38	0.20		11.93	142.44	4.65	21.61
	2	9	4.11	5.32	0.59	1.12	7.38	0.82	4.11				
	3	3	3.00	5.28	1.76	2.98	7.38	2.46	3.00				
	4	1	3.00	0.34	0.34	0.20	7.38	7.38	3.00				

Sub-basin	Stream Order (u)	Stream Number (Nu)	Bifurcation Ratio (Rb)	Length in Km.(Nu)	Mean Length in Km.	Length ratio	Area in Km^2	Mean Area in Km^2	Area ratio	Basin Perim -eter	P^2	Basin Length Km	L^2
DARN-D03	1	15	0.00	8.34	0.56		2.59	0.17		7.21	52.01	2.82	7.93
	2	5	3.00	2.97	0.59	1.07	2.59	0.52	3.00				
	3	3	1.67	1.08	0.36	0.61	2.59	0.86	1.67				
	4	1	3.00	0.04	0.04	0.11	2.59	2.59	3.00				
DARN-D04	1	53	0.00	28.17	0.53		12.84	0.24		14.87	221.21	5.07	25.75
	2	11	4.82	9.82	0.89	1.68	12.84	1.17	4.82				
	3	3	3.67	5.44	1.81	2.03	12.84	4.28	3.67				
	4	1	3.00	2.13	2.13	1.17	12.84	12.84	3.00				
DARN-D05	1	24	0.00	13.94	0.58		5.37	0.22		11.27	127.06	3.79	14.38
	2	7	3.43	3.60	0.51	0.89	5.37	0.77	3.43				
	3	2	3.50	1.71	0.86	1.67	5.37	2.68	3.50				
	4	1	2.00	0.82	0.82	0.96	5.37	5.37	2.00				
DARN-D06	1	31	0.00	17.41	0.56		6.79	0.22		13.55	183.60	4.85	23.47
	2	8	3.88	5.72	0.72	1.27	6.79	0.85	3.88				
	3	3	2.67	2.47	0.82	1.15	6.79	2.26	2.67				
	4	1	3.00	1.41	1.41	1.71	6.79	6.79	3.00				
DARN-D07	1	15	0.00	8.51	0.57		4.22	0.28		9.63	92.67	2.94	8.62
	2	4	3.75	3.04	0.76	1.34	4.22	1.05	3.75				
	3	2	2.00	1.16	0.58	0.76	4.22	2.11	2.00				
	4	1	2.00	0.54	0.54	0.92	4.22	4.22	2.00				
DARN-E01	1	330	0.00	178.88	0.54		75.24	0.23		39.89	1590.89	13.79	190.25
	2	82	4.02	49.39	0.60	1.11	75.24	0.92	4.02				
	3	21	3.90	20.73	0.99	1.64	75.24	3.58	3.90				

Sub-basin	Stream Order (u)	Stream Number (Nu)	Bifurcation Ratio (Rb)	Length in Km.(Nu)	Mean Length in Km.	Length ratio	Area in Km^2	Mean Area in Km^2	Area ratio	Basin Perim -eter	P^2	Basin Length Km	L^2
	4	4	5.25	12.91	3.23	3.27	75.24	18.81	5.25				
	5	1	4.00	16.78	16.78	5.20	75.24	75.24	4.00				
DARN-E02	1	234	0.00	123.40	0.53		69.05	0.30		44.88	2014.43	13.63	185.89
	2	60	3.90	40.04	0.67	1.27	69.05	1.15	3.90				
	3	15	4.00	18.93	1.26	1.89	69.05	4.60	4.00				
	4	3	5.00	9.23	3.08	2.44	69.05	23.02	5.00				
	5	1	3.00	13.37	13.37	4.35	69.05	69.05	3.00				
DARN-E03	1	260	0.00	143.44	0.55		63.00	0.24		38.88	1511.65	13.88	192.54
	2	56	4.64	39.09	0.70	1.27	63.00	1.12	4.64				
	3	12	4.67	19.33	1.61	2.31	63.00	5.25	4.67				
	4	4	3.00	8.47	2.12	1.31	63.00	15.75	3.00				
	5	1	4.00	8.83	8.83	4.17	63.00	63.00	4.00				

Source: Computed by Researcher.

APPENDIX-D1
Morphometric Analysis of Darna Lake Catchment

Sub-basin	Dd	Fs	Rt	Ff	Rc	Re	Lg	Cc	Rr	Rn
DARN_A01	1.08	3.47	0.39	0.37	0.55	0.51	0.54	0.93	0.11	0.01
DARN_A02	0.70	2.32	0.32	0.36	0.56	0.66	0.35	1.44	0.09	0.01
DARN_A03	1.32	2.86	0.31	0.19	0.42	0.67	0.66	0.76	0.08	0.03
DARN_A04	1.67	3.43	0.36	0.28	0.46	0.68	0.83	0.60	0.07	0.02
DARN_A05	2.80	5.23	0.46	0.21	0.51	0.67	1.40	0.36	0.07	0.06
DARN_A06	2.50	1.54	0.22	0.21	0.41	0.69	1.25	0.40	0.06	0.07
DARN_A07	1.62	6.25	0.54	0.25	0.60	0.49	0.81	0.62	0.06	0.03
DARN_A08	2.72	7.78	0.57	0.21	0.52	0.50	1.36	0.37	0.05	0.11
DARN_A09	3.11	3.97	0.41	0.23	0.53	0.64	1.55	0.32	0.05	0.09
DARN_A10	1.97	6.43	0.48	0.28	0.45	0.57	0.99	0.51	0.05	0.06
DARN_A11	1.65	2.94	0.39	0.45	0.66	0.71	0.82	0.61	0.04	0.05
DARN_A12	2.25	2.32	0.32	0.29	0.54	0.75	1.12	0.44	0.04	0.07
DARN_A13	0.72	2.58	0.32	0.29	0.50	0.84	0.36	1.39	0.04	0.03
DARN_A14	1.50	4.13	0.46	0.37	0.65	0.75	0.75	0.67	0.04	0.04
DARN_A15	0.73	3.15	0.33	0.25	0.44	0.57	0.36	1.37	0.03	0.02
DARN_A16	4.07	8.30	0.55	0.19	0.45	0.56	2.04	0.25	0.03	0.12
DARN_A17	2.64	10.23	0.64	0.23	0.51	0.46	1.32	0.38	0.03	0.05
DARN_A18	2.43	11.40	0.74	0.26	0.60	0.60	1.21	0.41	0.03	0.05
DARN_A19	1.10	3.70	0.38	0.27	0.49	0.59	0.55	0.91	0.03	0.02
DARN_A20	2.46	6.35	0.54	0.26	0.58	0.64	1.23	0.41	0.03	0.05
DARN_A21	1.12	4.00	0.36	0.18	0.41	0.78	0.56	0.89	0.03	0.04

Sub-basin	Dd	Fs	Rt	Ff	Rc	Re	Lg	Cc	Rr	Rn
DARN_A22	1.57	4.84	0.50	0.29	0.65	0.70	0.78	0.64	0.03	0.05
DARN_A23	0.96	3.45	0.37	0.46	0.51	0.74	0.48	1.04	0.03	0.03
DARN_A24	0.61	2.20	0.31	0.44	0.56	0.67	0.31	1.64	0.03	0.02
DARN_A25	0.78	1.91	0.25	0.34	0.40	0.71	0.39	1.28	0.02	0.04
DARN_A26	0.96	1.53	0.21	0.21	0.35	0.98	0.48	1.04	0.02	0.03
DARN_A27	2.21	5.42	0.55	0.45	0.69	0.61	1.10	0.45	0.02	0.07
DARN_A28	2.93	5.93	0.51	0.26	0.55	0.66	1.47	0.34	0.02	0.09
DARN_A29	2.54	1.89	0.29	0.25	0.57	0.71	1.27	0.39	0.02	0.15
DARN_A30	1.74	2.37	0.28	0.18	0.40	0.85	0.87	0.57	0.02	0.05
DARN_A31	1.78	4.04	0.39	0.27	0.47	0.77	0.89	0.56	0.02	0.05
DARN_A32	1.82	2.23	0.31	0.29	0.53	0.84	0.91	0.55	0.02	0.07
DARN_A33	0.79	2.30	0.29	0.23	0.45	0.77	0.40	1.26	0.02	0.02
DARN_A34	2.19	3.42	0.40	0.48	0.60	0.76	1.09	0.46	0.02	0.07
DARN_A35	0.95	1.33	0.26	0.43	0.63	0.99	0.47	1.05	0.02	0.03
DARN_A36	1.98	5.60	0.60	0.44	0.82	0.72	0.99	0.51	0.02	0.02
DARN_A37	2.62	6.63	0.58	0.36	0.64	0.70	1.31	0.38	0.02	0.03
DARN_A38	1.41	4.09	0.45	0.33	0.62	0.65	0.70	0.71	0.02	0.03
DARN_A39	2.20	2.00	0.30	0.28	0.58	0.76	1.10	0.46	0.02	0.11
DARN_A40	0.58	1.11	0.17	0.20	0.31	0.87	0.29	1.71	0.02	0.02
DARN_A41	1.67	2.46	0.32	0.42	0.53	0.87	0.83	0.60	0.02	0.08
DARN_A42	0.96	2.89	0.33	0.20	0.49	0.73	0.48	1.05	0.02	0.04
DARN_A43	0.79	2.31	0.29	0.27	0.45	0.80	0.39	1.27	0.02	0.02
DARN_A44	1.17	5.94	0.45	0.30	0.43	0.67	0.58	0.86	0.02	0.02
DARN_A45	2.62	5.04	0.48	0.29	0.58	0.70	1.31	0.38	0.02	0.05

Sub-basin	Dd	Fs	Rt	Ff	Rc	Re	Lg	Cc	Rr	Rn
DARN_A46	2.18	5.94	0.55	0.34	0.64	0.70	1.09	0.46	0.02	0.04
DARN_A47	5.23	12.25	0.70	0.20	0.50	0.49	2.61	0.19	0.02	0.26
DARN_A48	4.51	10.34	0.62	0.20	0.47	0.53	2.26	0.22	0.02	0.23
DARN_A49	4.39	11.16	0.77	0.29	0.66	0.54	2.20	0.23	0.02	0.09
DARN_A50	2.18	4.34	0.38	0.23	0.41	0.77	1.09	0.46	0.02	0.09
DARN_A51	1.81	5.47	0.60	0.53	0.84	0.70	0.91	0.55	0.02	0.07
DARN_A52	1.28	4.22	0.48	0.41	0.68	0.76	0.64	0.78	0.02	0.04
DARN_A53	0.85	3.26	0.40	0.31	0.61	0.82	0.42	1.18	0.02	0.02
DARN_A54	2.69	2.13	0.26	0.20	0.40	0.69	1.35	0.37	0.01	0.43
DARN_A55	1.54	4.01	0.40	0.20	0.49	0.77	0.77	0.65	0.01	0.03
DARN_A56	0.82	2.24	0.25	0.15	0.36	0.90	0.41	1.23	0.01	0.02
DARN_A57	1.41	2.33	0.33	0.36	0.57	0.86	0.70	0.71	0.01	0.07
DARN_A58	1.90	3.40	0.39	0.30	0.55	0.82	0.95	0.53	0.01	0.06
DARN_A59	0.40	1.36	0.16	0.27	0.25	0.99	0.20	2.48	0.01	0.01
DARN_A60	0.93	2.70	0.37	0.32	0.64	0.86	0.46	1.08	0.01	0.04
DARN_A61	2.10	5.85	0.54	0.28	0.62	0.71	1.05	0.48	0.01	0.02
DARN_A62	0.82	2.07	0.22	0.13	0.30	0.81	0.41	1.22	0.01	0.04
DARN_A63	2.45	2.19	0.31	0.22	0.54	0.72	1.23	0.41	0.01	0.07
DARN_A64	0.81	2.10	0.32	0.34	0.63	0.90	0.40	1.24	0.01	0.02
DARN_A65	2.42	5.69	0.48	0.33	0.51	0.73	1.21	0.41	0.01	0.10
DARN_A66	1.95	17.64	0.81	0.22	0.46	0.49	0.97	0.51	0.01	0.06
DARN_A67	1.12	5.60	0.50	0.48	0.56	0.71	0.56	0.89	0.01	0.02
DARN_A68	1.94	5.05	0.47	0.31	0.55	0.72	0.97	0.52	0.01	0.06
DARN_A69	2.98	8.27	0.62	0.29	0.58	0.65	1.49	0.34	0.01	0.12

Sub-basin	Dd	Fs	Rt	Ff	Rc	Re	Lg	Cc	Rr	Rn
DARN_A70	1.38	3.65	0.47	0.40	0.75	0.80	0.69	0.72	0.01	0.03
DARN_A71	1.79	4.41	0.43	0.31	0.52	0.73	0.90	0.56	0.01	0.02
DARN_A72	2.91	6.20	0.56	0.38	0.63	0.66	1.46	0.34	0.01	0.06
DARN_A73	0.68	2.75	0.36	0.42	0.58	0.85	0.34	1.48	0.01	0.04
DARN_A74	3.18	3.90	0.44	0.28	0.61	0.63	1.59	0.31	0.01	0.16
DARN_A75	4.35	8.84	0.57	0.19	0.46	0.54	2.17	0.23	0.01	0.26
DARN_A76	2.12	6.86	0.56	0.29	0.58	0.67	1.06	0.47	0.01	0.13
DARN_A77	2.74	6.06	0.61	0.36	0.76	0.68	1.37	0.37	0.01	0.16
DARN_B01	3.83	6.89	0.72	0.32	0.70	0.77	1.91	0.26	0.01	0.11
DARN_B02	3.09	5.11	1.13	0.36	0.61	0.99	1.54	0.32	0.01	0.15
DARN_B03	2.11	3.54	0.39	0.21	0.40	0.98	1.06	0.47	0.01	0.11
DARN_B04	3.90	10.63	0.84	0.34	0.62	0.69	1.95	0.26	0.01	0.19
DARN_B05	1.01	2.67	0.28	0.21	0.28	0.97	0.51	0.99	0.01	0.03
DARN_B06	4.23	9.78	1.42	0.44	0.81	0.82	2.12	0.24	0.01	0.17
DARN_B07	2.43	4.56	0.68	0.31	0.56	0.90	1.22	0.41	0.01	0.12
DARN_B08	2.24	5.37	0.67	0.29	0.47	0.99	1.12	0.45	0.01	0.11
DARN_B09	3.01	5.51	0.79	0.17	0.34	0.89	1.51	0.33	0.01	0.15
DARN_B10	3.16	5.05	1.06	0.27	0.55	0.88	1.58	0.32	0.01	0.19
DARN_B11	3.40	4.55	0.97	0.26	0.51	0.92	1.70	0.29	0.01	0.34
DARN_B12	2.57	5.37	0.61	0.32	0.66	0.90	1.28	0.39	0.01	0.13
DARN_B13	2.56	2.35	0.53	0.37	0.65	0.99	1.28	0.39	0.01	0.31
DARN_B14	0.61	0.58	0.17	0.42	0.46	1.00	0.31	1.64	0.01	0.09
DARN_B15	1.15	1.78	0.59	0.42	0.48	0.91	0.58	0.87	0.01	0.06
DARN_B16	2.98	4.65	0.72	0.26	0.62	0.79	1.49	0.34	0.01	0.09

Sub-basin	Dd	Fs	Rt	Ff	Rc	Re	Lg	Cc	Rr	Rn
DARN_B17	2.21	6.96	0.69	0.35	0.64	0.84	1.10	0.45	0.01	0.02
DARN_B18	3.69	4.73	0.68	0.21	0.38	0.74	1.85	0.27	0.01	0.55
DARN_B19	2.48	4.46	0.53	0.38	0.60	0.91	1.24	0.40	0.01	0.17
DARN_B20	1.55	2.59	0.37	0.24	0.49	0.83	0.78	0.64	0.01	0.12
DARN_B21	2.13	3.29	0.63	0.44	0.68	0.81	1.07	0.47	0.01	0.21
DARN_B22	1.13	3.07	0.32	0.36	0.32	0.83	0.56	0.89	0.01	0.06
DARN_B23	3.40	10.19	0.87	0.48	0.71	0.77	1.70	0.29	0.01	0.14
DARN_B24	2.95	6.68	0.87	0.37	0.64	0.93	1.47	0.34	0.01	0.15
DARN_B25	1.73	4.48	0.49	0.44	0.50	0.83	0.87	0.58	0.01	0.07
DARN_B26	5.15	6.95	0.70	0.23	0.39	0.77	2.58	0.19	0.01	1.08
DARN_B27	4.74	7.04	1.03	0.30	0.60	0.85	2.37	0.21	0.01	1.66
DARN_B28	4.31	6.64	0.72	0.19	0.43	0.73	2.15	0.23	0.01	1.94
DARN_B29	3.62	7.14	0.98	0.23	0.53	0.78	1.81	0.28	0.01	1.23
DARN_B30	2.10	2.29	0.35	0.29	0.51	0.90	1.05	0.48	0.01	0.61
DARN_B31	2.47	4.33	0.42	0.15	0.38	0.78	1.23	0.40	0.01	0.72
DARN_B32	3.20	4.42	0.59	0.19	0.44	0.86	1.60	0.31	0.01	1.18
DARN_B33	2.89	3.09	0.32	0.17	0.32	0.75	1.44	0.35	0.01	1.01
DARN_B34	2.23	1.47	0.40	0.30	0.59	0.93	1.11	0.45	0.01	0.13
DARN_B35	1.20	2.68	0.48	0.31	0.34	0.98	0.60	0.83	0.01	0.08
DARN_B36	4.40	8.52	0.66	0.30	0.48	0.67	2.20	0.23	0.01	0.31
DARN_B37	3.85	10.46	1.00	0.29	0.54	0.72	1.93	0.26	0.01	0.08
DARN_B38	3.71	13.50	1.14	0.28	0.54	0.74	1.85	0.27	0.01	0.26
DARN_B39	1.24	3.66	0.37	0.15	0.35	0.81	0.62	0.81	0.01	0.09
DARN_C01	4.08	8.60	1.55	0.41	0.66	0.97	2.04	0.25	0.01	0.49

Sub-basin	Dd	Fs	Rt	Ff	Rc	Re	Lg	Cc	Rr	Rn
DARN_C02	3.42	5.67	2.05	0.44	0.60	0.99	1.71	0.29	0.01	0.38
DARN_C03	3.41	6.28	1.41	0.28	0.51	0.98	1.70	0.29	0.01	0.20
DARN_C04	2.51	5.57	1.13	0.51	0.59	1.00	1.26	0.40	0.01	0.13
DARN_C05	2.98	5.60	0.87	0.51	0.75	0.93	1.49	0.34	0.01	0.12
DARN_C06	2.90	6.25	1.08	0.32	0.58	0.99	1.45	0.34	0.01	0.15
DARN_C07	5.80	5.26	1.48	0.27	0.60	0.96	2.90	0.17	0.01	0.58
DARN_C08	4.71	7.23	0.93	0.21	0.48	0.78	2.36	0.21	0.01	1.32
DARN_C09	3.59	5.76	1.78	0.28	0.61	1.12	1.79	0.28	0.01	1.36
DARN_C10	3.83	8.06	1.40	0.40	0.62	0.90	1.92	0.26	0.01	0.61
DARN_C11	2.91	5.01	0.86	0.28	0.59	0.96	1.46	0.34	0.01	1.14
DARN_C12	2.45	3.11	0.93	0.38	0.56	0.98	1.22	0.41	0.01	0.29
DARN_C13	3.15	6.45	1.82	0.40	0.68	1.00	1.58	0.32	0.01	0.22
DARN_C14	3.91	8.40	3.02	0.38	0.64	0.99	1.96	0.26	0.01	0.23
DARN_D01	3.81	6.37	3.00	0.39	0.68	1.00	1.91	0.26	0.01	0.50
DARN_D02	4.13	6.77	3.10	0.34	0.65	0.99	2.06	0.24	0.01	1.20
DARN_D03	4.79	9.26	2.08	0.86	0.63	0.91	2.40	0.21	0.00	0.72
DARN_D04	3.55	5.30	3.56	0.50	0.73	0.98	1.77	0.28	0.00	1.63
DARN_D05	3.74	6.34	2.13	0.37	0.53	0.95	1.87	0.27	0.00	1.83
DARN_D06	3.98	6.33	2.29	0.29	0.46	0.99	1.99	0.25	0.00	1.51
DARN_D07	3.14	5.22	1.56	0.49	0.57	0.96	1.57	0.32	0.00	1.04
DARN_E01	3.70	5.82	8.27	0.40	0.59	1.00	1.85	0.27	0.00	1.52
DARN_E02	2.97	4.53	5.21	0.37	0.43	0.99	1.48	0.34	0.00	2.46
DARN_E03	3.48	5.29	6.69	0.33	0.52	0.99	1.74	0.29	0.00	3.31

Source: Computed by Researcher.

APPENDIX-E

Sub Basin-wise Priority Analysis based on Peak Surface Runoff of Darna Lake Catchment

Sub-Basin Code	Priority	Priority Class	Priority Level
DARN-A01	79	Medium	3
DARN-A02	50	High	2
DARN-A03	69	Medium	3
DARN-A04	66	Medium	3
DARN-A05	108	Low	4
DARN-A06	42	High	2
DARN-A07	123	Very Low	5
DARN-A08	132	Very Low	5
DARN-A09	109	Low	4
DARN-A10	125	Very Low	5
DARN-A11	81	Medium	3
DARN-A12	78	Medium	3
DARN-A13	92	Low	4
DARN-A14	103	Low	4
DARN-A15	96	Low	4
DARN-A16	129	Very Low	5
DARN-A17	131	Very Low	5
DARN-A18	135	Very Low	5
DARN-A19	93	Low	4
DARN-A20	122	Very Low	5
DARN-A21	112	Low	4

Sub-Basin Code	Priority	Priority Class	Priority Level
DARN-A22	110	Low	4
DARN-A23	106	Low	4
DARN-A24	74	Medium	3
DARN-A25	73	Medium	3
DARN-A26	52	High	2
DARN-A27	119	Low	4
DARN-A28	124	Very Low	5
DARN-A29	63	Medium	3
DARN-A30	60	High	2
DARN-A31	101	Low	4
DARN-A32	76	Medium	3
DARN-A33	64	Medium	3
DARN-A34	97	Low	4
DARN-A35	45	High	2
DARN-A36	98	Low	4
DARN-A37	113	Low	4
DARN-A38	104	Low	4
DARN-A39	72	Medium	3
DARN-A40	33	High	2
DARN-A41	82	Medium	3
DARN-A42	94	Low	4
DARN-A43	59	High	2
DARN-A44	121	Very Low	5
DARN-A45	120	Low	4

Sub-Basin Code	Priority	Priority Class	Priority Level
DARN-A46	128	Very Low	5
DARN-A47	138	Very Low	5
DARN-A48	137	Very Low	5
DARN-A49	136	Very Low	5
DARN-A50	115	Low	4
DARN-A51	127	Very Low	5
DARN-A52	102	Low	4
DARN-A53	90	Medium	3
DARN-A54	89	Medium	3
DARN-A55	95	Low	4
DARN-A56	62	Medium	3
DARN-A57	83	Medium	3
DARN-A58	88	Medium	3
DARN-A59	43	High	2
DARN-A60	85	Medium	3
DARN-A61	105	Low	4
DARN-A62	68	Medium	3
DARN-A63	56	High	2
DARN-A64	51	High	2
DARN-A65	117	Low	4
DARN-A66	140	Very Low	5
DARN-A67	126	Very Low	5
DARN-A68	118	Low	4
DARN-A69	133	Very Low	5

Sub-Basin Code	Priority	Priority Class	Priority Level
DARN-A70	86	Medium	3
DARN-A71	84	Medium	3
DARN-A72	114	Low	4
DARN-A73	91	Medium	3
DARN-A74	111	Low	4
DARN-A75	139	Very Low	5
DARN-A76	134	Very Low	5
DARN-A77	130	Very Low	5
DARN-B01	58	High	2
DARN-B02	23	Very High	1
DARN-B03	38	High	2
DARN-B04	99	Low	4
DARN-B05	27	Very High	1
DARN-B06	57	High	2
DARN-B07	44	High	2
DARN-B08	53	High	2
DARN-B09	34	High	2
DARN-B10	24	Very High	1
DARN-B11	25	Very High	1
DARN-B12	67	Medium	3
DARN-B13	29	Very High	1
DARN-B14	12	Very High	1
DARN-B15	11	Very High	1
DARN-B16	32	High	2

Sub-Basin Code	Priority	Priority Class	Priority Level
DARN-B17	48	High	2
DARN-B18	40	High	2
DARN-B19	54	High	2
DARN-B20	31	High	2
DARN-B21	36	High	2
DARN-B22	30	Very High	1
DARN-B23	100	Low	4
DARN-B24	61	Medium	3
DARN-B25	47	High	2
DARN-B26	77	Medium	3
DARN-B27	71	Medium	3
DARN-B28	87	Medium	3
DARN-B29	80	Medium	3
DARN-B30	41	High	2
DARN-B31	75	Medium	3
DARN-B32	65	Medium	3
DARN-B33	55	High	2
DARN-B34	14	Very High	1
DARN-B35	22	Very High	1
DARN-B36	107	Low	4
DARN-B37	70	Medium	3
DARN-B38	116	Low	4
DARN-B39	46	High	2
DARN-C01	35	High	2

Sub-Basin Code	Priority	Priority Class	Priority Level
DARN-C02	9	Very High	1
DARN-C03	21	Very High	1
DARN-C04	17	Very High	1
DARN-C05	26	Very High	1
DARN-C06	28	Very High	1
DARN-C07	19	Very High	1
DARN-C08	49	High	2
DARN-C09	20	Very High	1
DARN-C10	37	High	2
DARN-C11	39	High	2
DARN-C12	10	Very High	1
DARN-C13	15	Very High	1
DARN-C14	7	Very High	1
DARN-D01	5	Very High	1
DARN-D02	6	Very High	1
DARN-D03	18	Very High	1
DARN-D04	4	Very High	1
DARN-D05	13	Very High	1
DARN-D06	8	Very High	1
DARN-D07	16	Very High	1
DARN-E01	1	Very High	1
DARN-E02	2	Very High	1
DARN-E03	3	Very High	1

Source: Computed by Researcher.

APPENDIX-F
Sub Basin-wise Surface Peak Runoff Estimation

Subbasin	High Elev.	Low Elev.	L (Diff)	L^3	Basin Length in meter (H)	L^3/H	K	$K^{(0.77)}$	t in min	t in hrs	$(T)^a$	$K(T)^a$	$(t+b)^n$	I (cm /hrs)	I (mm/hrs)	Area in hec.	C in hec	Q in hec.
DARN-A01	580	570	10	1000	309.60	3.23	1.80	1.57	0.03	0.00	1.34	4.66	0.03	184.77	1847.66	28.66	6.45	949.45
DARN-A02	580	570	10	1000	299.39	3.34	1.83	1.59	0.03	0.00	1.34	4.66	0.03	183.61	1836.12	43.06	11.95	2624.08
DARN-A03	590	570	20	8000	461.84	17.32	4.16	3.00	0.06	0.00	1.34	4.66	0.03	135.00	1350.02	34.73	9.72	1266.31
DARN-A04	580	570	10	1000	485.92	2.06	1.43	1.32	0.03	0.00	1.34	4.66	0.02	201.00	2010.01	29.09	8.49	1379.30
DARN-A05	590	570	20	8000	536.17	14.92	3.86	2.83	0.06	0.00	1.34	4.66	0.03	138.82	1388.19	19.04	5.25	385.78
DARN-A06	600	570	30	27000	1626.44	16.60	4.07	2.95	0.06	0.00	1.34	4.66	0.03	136.08	1360.79	64.33	15.27	3714.07
DARN-A07	590	570	20	8000	259.58	30.82	5.55	3.74	0.07	0.00	1.34	4.66	0.04	121.22	1212.24	16.00	4.19	225.62
DARN-A08	610	570	40	64000	350.00	182.86	13.52	7.43	0.14	0.00	1.34	4.66	0.05	86.92	869.18	12.85	2.80	86.91
DARN-A09	600	570	30	27000	782.92	34.49	5.87	3.91	0.08	0.00	1.34	4.66	0.04	118.70	1187.04	25.21	4.27	355.24
DARN-A10	600	570	30	27000	306.62	88.06	9.38	5.61	0.11	0.00	1.34	4.66	0.05	99.63	996.32	15.55	4.40	189.31
DARN-A11	600	570	30	27000	561.78	48.06	6.93	4.44	0.09	0.00	1.34	4.66	0.04	111.57	1115.66	34.07	8.73	921.64
DARN-A12	610	580	30	27000	969.48	27.85	5.28	3.60	0.07	0.00	1.34	4.66	0.04	123.54	1235.40	43.14	6.50	962.15
DARN-A13	610	570	40	64000	279.13	229.29	15.14	8.10	0.16	0.00	1.34	4.66	0.06	83.32	833.19	38.84	6.92	621.95
DARN-A14	600	570	30	27000	362.46	74.49	8.63	5.26	0.10	0.00	1.34	4.66	0.05	102.80	1027.96	24.24	5.96	412.73
DARN-A15	600	570	30	27000	231.25	116.76	10.81	6.25	0.12	0.00	1.34	4.66	0.05	94.52	945.16	31.71	6.31	525.02
DARN-A16	600	570	30	27000	491.12	54.98	7.41	4.68	0.09	0.00	1.34	4.66	0.04	108.80	1087.99	12.05	3.02	110.08
DARN-A17	590	570	20	8000	257.68	31.05	5.57	3.75	0.07	0.00	1.34	4.66	0.04	121.06	1210.58	9.78	2.72	89.27
DARN-A18	590	570	20	8000	212.79	37.60	6.13	4.04	0.08	0.00	1.34	4.66	0.04	116.81	1168.05	8.77	2.31	65.65
DARN-A19	580	560	20	8000	298.19	26.83	5.18	3.55	0.07	0.00	1.34	4.66	0.04	124.41	1244.06	27.02	6.58	614.13
DARN-A20	590	570	20	8000	386.76	20.68	4.55	3.21	0.06	0.00	1.34	4.66	0.04	130.60	1306.01	15.75	3.98	227.52

Sub basin	High Elev.	Low Elev.	L (Diff)	L^3	Basin Length in meter (H)	L^3/H	K	$K^{(0.77)}$	t in min	t in hrs	$(T)^a$	$K(T)^a$	$(t+b)^n$	I (cm /hrs)	I (mm/hrs)	Area in hec.	C in hec	Q in hec.
DARN-A21	610	570	40	64000	279.64	228.86	15.13	8.10	0.16	0.00	1.34	4.66	0.06	83.35	833.48	25.00	5.42	313.48
DARN-A22	600	570	30	27000	324.48	83.21	9.12	5.49	0.11	0.00	1.34	4.66	0.05	100.69	1006.92	20.67	5.77	333.74
DARN-A23	600	570	30	27000	277.41	97.33	9.87	5.83	0.11	0.00	1.34	4.66	0.05	97.79	977.86	28.98	5.13	403.53
DARN-A24	600	570	30	27000	278.02	97.12	9.85	5.82	0.11	0.00	1.34	4.66	0.05	97.83	978.26	45.56	8.48	1050.40
DARN-A25	620	570	50	125000	407.88	306.46	17.51	9.06	0.18	0.00	1.34	4.66	0.06	78.92	789.23	52.30	9.98	1143.89
DARN-A26	610	580	30	27000	626.75	43.08	6.56	4.26	0.08	0.00	1.34	4.66	0.04	113.87	1138.71	65.43	11.92	2466.72
DARN-A27	600	570	30	27000	406.95	66.35	8.15	5.03	0.10	0.00	1.34	4.66	0.04	105.04	1050.44	18.45	4.43	238.31
DARN-A28	600	570	30	27000	494.70	54.58	7.39	4.66	0.09	0.00	1.34	4.66	0.04	108.95	1089.47	16.86	4.23	215.65
DARN-A29	630	570	60	216000	1343.66	160.76	12.68	7.07	0.14	0.00	1.34	4.66	0.05	89.03	890.35	52.86	11.03	1442.42
DARN-A30	610	580	30	27000	737.00	36.63	6.05	4.00	0.08	0.00	1.34	4.66	0.04	117.37	1173.71	42.24	11.12	1531.11
DARN-A31	590	560	30	27000	441.16	61.20	7.82	4.87	0.09	0.00	1.34	4.66	0.04	106.64	1066.40	24.74	6.01	440.41
DARN-A32	610	570	40	64000	813.57	78.67	8.87	5.37	0.10	0.00	1.34	4.66	0.05	101.75	1017.54	44.78	7.95	1006.21
DARN-A33	590	570	20	8000	345.99	23.12	4.81	3.35	0.07	0.00	1.34	4.66	0.04	127.91	1279.10	43.55	9.18	1420.83
DARN-A34	600	570	30	27000	639.82	42.20	6.50	4.22	0.08	0.00	1.34	4.66	0.04	114.31	1143.11	29.28	5.60	520.92
DARN-A35	600	570	30	27000	713.57	37.84	6.15	4.05	0.08	0.00	1.34	4.66	0.04	116.67	1166.65	75.18	13.41	3267.42
DARN-A36	570	560	10	1000	353.25	2.83	1.68	1.49	0.03	0.00	1.34	4.66	0.02	189.38	1893.76	17.85	5.25	493.31
DARN-A37	580	570	10	1000	394.85	2.53	1.59	1.43	0.03	0.00	1.34	4.66	0.02	193.36	1933.57	15.09	3.64	295.23
DARN-A38	590	570	20	8000	344.12	23.25	4.82	3.36	0.07	0.00	1.34	4.66	0.04	127.78	1277.81	24.43	4.66	404.21
DARN-A39	610	560	50	125000	1100.05	113.63	10.66	6.19	0.12	0.00	1.34	4.66	0.05	95.00	949.97	50.08	8.91	1177.73
DARN-A40	600	560	40	64000	527.06	121.43	11.02	6.35	0.12	0.00	1.34	4.66	0.05	93.83	938.26	90.25	24.66	5800.44
DARN-A41	620	570	50	125000	677.52	184.50	13.58	7.45	0.15	0.00	1.34	4.66	0.05	86.77	867.73	40.65	8.97	879.21
DARN-A42	610	570	40	64000	367.00	174.39	13.21	7.29	0.14	0.00	1.34	4.66	0.05	87.69	876.91	34.66	6.68	563.49
DARN-A43	590	570	20	8000	331.24	24.15	4.91	3.41	0.07	0.00	1.34	4.66	0.04	126.87	1268.73	43.33	10.74	1639.85
DARN-A44	590	570	20	8000	341.75	23.41	4.84	3.37	0.07	0.00	1.34	4.66	0.04	127.62	1276.16	16.83	3.90	232.55

Sub basin	High Elev.	Low Elev.	L (Diff)	L^3	Basin Length in meter (H)	L^3/H	K	$K^{(0.77)}$	t in min	t in hrs	$(T)^a$	$K(T)^a$	$(t+b)^n$	I (cm /hrs)	I (mm/hrs)	Area in hec.	C in hec	Q in hec.
DARN-A45	590	570	20	8000	196.70	40.67	6.38	4.16	0.08	0.00	1.34	4.66	0.04	115.10	1151.02	19.85	3.73	236.56
DARN-A46	590	570	20	8000	519.38	15.40	3.92	2.87	0.06	0.00	1.34	4.66	0.03	138.00	1379.97	16.82	2.05	132.41
DARN-A47	620	570	50	125000	426.61	293.01	17.12	8.91	0.17	0.00	1.34	4.66	0.06	79.59	795.88	8.16	2.26	40.79
DARN-A48	620	570	50	125000	436.55	286.33	16.92	8.83	0.17	0.00	1.34	4.66	0.06	79.93	799.31	9.67	2.18	46.76
DARN-A49	590	570	20	8000	393.48	20.33	4.51	3.19	0.06	0.00	1.34	4.66	0.04	131.02	1310.21	8.96	1.72	56.21
DARN-A50	610	570	40	64000	500.99	127.75	11.30	6.47	0.13	0.00	1.34	4.66	0.05	92.94	929.41	23.03	4.93	293.42
DARN-A51	620	580	40	64000	331.18	193.25	13.90	7.59	0.15	0.00	1.34	4.66	0.05	86.02	860.24	18.28	3.40	148.33
DARN-A52	600	570	30	27000	303.39	88.99	9.43	5.63	0.11	0.00	1.34	4.66	0.05	99.44	994.36	23.72	6.39	418.85
DARN-A53	590	570	20	8000	259.80	30.79	5.55	3.74	0.07	0.00	1.34	4.66	0.04	121.24	1212.44	30.67	6.21	641.27
DARN-A54	730	570	160	4096000	1262.53	3244.27	56.96	22.48	0.44	0.01	1.34	4.66	0.09	50.79	507.86	46.89	10.04	664.41
DARN-A55	600	580	20	8000	384.43	20.81	4.56	3.22	0.06	0.00	1.34	4.66	0.04	130.45	1304.53	24.96	6.22	562.91
DARN-A56	610	580	30	27000	364.29	74.12	8.61	5.25	0.10	0.00	1.34	4.66	0.05	102.89	1028.93	44.63	11.55	1472.92
DARN-A57	620	570	50	125000	603.44	207.15	14.39	7.79	0.15	0.00	1.34	4.66	0.05	84.92	849.15	42.90	8.21	830.32
DARN-A58	610	580	30	27000	558.62	48.33	6.95	4.45	0.09	0.00	1.34	4.66	0.04	111.45	1114.49	29.38	7.51	682.86
DARN-A59	600	570	30	27000	295.93	91.24	9.55	5.68	0.11	0.00	1.34	4.66	0.05	98.97	989.74	73.44	17.94	3621.48
DARN-A60	600	560	40	64000	343.01	186.58	13.66	7.49	0.15	0.00	1.34	4.66	0.05	86.59	865.91	36.98	8.54	759.47
DARN-A61	590	580	10	1000	358.54	2.79	1.67	1.48	0.03	0.00	1.34	4.66	0.02	189.90	1899.03	17.08	4.48	403.96
DARN-A62	630	580	50	125000	394.10	317.18	17.81	9.18	0.18	0.00	1.34	4.66	0.06	78.42	784.18	48.26	12.38	1301.78
DARN-A63	610	580	30	27000	1117.01	24.17	4.92	3.41	0.07	0.00	1.34	4.66	0.04	126.85	1268.54	45.58	12.30	1974.63
DARN-A64	600	580	20	8000	384.41	20.81	4.56	3.22	0.06	0.00	1.34	4.66	0.04	130.45	1304.52	47.67	14.61	2523.97
DARN-A65	600	560	40	64000	425.44	150.43	12.27	6.89	0.13	0.00	1.34	4.66	0.05	90.15	901.46	17.58	5.69	250.71
DARN-A66	590	560	30	27000	110.29	244.82	15.65	8.31	0.16	0.00	1.34	4.66	0.06	82.31	823.05	5.67	1.18	15.30
DARN-A67	600	580	20	8000	200.52	39.90	6.32	4.13	0.08	0.00	1.34	4.66	0.04	115.52	1155.16	17.87	3.03	173.59
DARN-A68	600	570	30	27000	382.95	70.51	8.40	5.15	0.10	0.00	1.34	4.66	0.04	103.86	1038.57	19.79	4.24	242.27

Sub basin	High Elev.	Low Elev.	L (Diff)	L^3	Basin Length in meter (H)	L^3/H	K	$K^{(0.77)}$	t in min	t in hrs	$(T)^a$	$K(T)^a$	$(t+b)^n$	I (cm /hrs)	I (mm/hrs)	Area in hec.	C in hec	Q in hec.
DARN-A69	620	580	40	64000	379.55	168.62	12.99	7.20	0.14	0.00	1.34	4.66	0.05	88.24	882.44	12.09	2.85	84.44
DARN-A70	590	570	20	8000	378.65	21.13	4.60	3.24	0.06	0.00	1.34	4.66	0.04	130.08	1300.84	27.37	7.42	733.94
DARN-A71	590	580	10	1000	405.94	2.46	1.57	1.41	0.03	0.00	1.34	4.66	0.02	194.36	1943.60	22.66	6.21	759.89
DARN-A72	600	580	20	8000	469.60	17.04	4.13	2.98	0.06	0.00	1.34	4.66	0.03	135.42	1354.23	16.12	4.85	294.35
DARN-A73	630	570	60	216000	246.65	875.73	29.59	13.58	0.26	0.00	1.34	4.66	0.07	64.86	648.65	36.41	9.77	641.06
DARN-A74	630	580	50	125000	814.84	153.40	12.39	6.94	0.14	0.00	1.34	4.66	0.05	89.82	898.17	25.62	5.12	327.18
DARN-A75	640	580	60	216000	491.55	439.43	20.96	10.41	0.20	0.00	1.34	4.66	0.06	73.78	737.84	11.31	1.67	38.82
DARN-A76	630	570	60	216000	309.34	698.25	26.42	12.44	0.24	0.00	1.34	4.66	0.07	67.67	676.68	14.57	2.71	74.19
DARN-A77	640	580	60	216000	451.40	478.51	21.87	10.76	0.21	0.00	1.34	4.66	0.06	72.62	726.19	16.49	3.05	101.53
DARN-B01	600	570	30	27000	947.53	28.49	5.34	3.63	0.07	0.00	1.34	4.66	0.04	123.01	1230.13	43.33	11.78	1743.88
DARN-B02	620	570	50	125000	1789.38	69.86	8.36	5.13	0.10	0.00	1.34	4.66	0.04	104.04	1040.37	136.92	29.02	11483.92
DARN-B03	620	570	50	125000	1121.55	111.45	10.56	6.14	0.12	0.00	1.34	4.66	0.05	95.34	953.41	84.70	18.70	4194.86
DARN-B04	620	570	50	125000	760.97	164.26	12.82	7.13	0.14	0.00	1.34	4.66	0.05	88.68	886.76	28.22	6.76	470.29
DARN-B05	600	570	30	27000	625.23	43.18	6.57	4.26	0.08	0.00	1.34	4.66	0.04	113.82	1138.19	112.50	25.55	9088.28
DARN-B06	610	570	40	64000	973.06	65.77	8.11	5.01	0.10	0.00	1.34	4.66	0.04	105.21	1052.15	51.14	12.17	1818.36
DARN-B07	570	520	50	125000	1455.51	85.88	9.27	5.55	0.11	0.00	1.34	4.66	0.05	100.10	1000.99	87.69	14.25	3474.22
DARN-B08	620	570	50	125000	895.20	139.63	11.82	6.70	0.13	0.00	1.34	4.66	0.05	91.41	914.09	74.53	12.51	2366.61
DARN-B09	620	570	50	125000	1753.37	71.29	8.44	5.17	0.10	0.00	1.34	4.66	0.04	103.64	1036.43	108.87	18.50	5796.87
DARN-B10	630	570	60	216000	2292.04	94.24	9.71	5.76	0.11	0.00	1.34	4.66	0.05	98.38	983.77	138.73	28.14	10667.14
DARN-B11	670	570	100	1000000	2333.51	428.54	20.70	10.31	0.20	0.00	1.34	4.66	0.06	74.13	741.31	153.75	31.21	9880.29
DARN-B12	600	550	50	125000	871.60	143.41	11.98	6.77	0.13	0.00	1.34	4.66	0.05	90.95	909.54	55.89	9.64	1360.73
DARN-B13	690	570	120	1728000	2011.82	858.92	29.31	13.48	0.26	0.00	1.34	4.66	0.07	65.10	651.00	169.90	27.64	8490.49
DARN-B14	720	570	150	3375000	1593.23	2118.34	46.03	19.08	0.37	0.01	1.34	4.66	0.08	55.00	549.96	513.34	80.25	62930.51
DARN-B15	620	570	50	125000	2732.77	45.74	6.76	4.36	0.08	0.00	1.34	4.66	0.04	112.60	1126.03	392.47	62.33	76518.64

Sub basin	High Elev.	Low Elev.	L (Diff)	L^3	Basin Length in meter (H)	L^3/H	K	$K^{(0.77)}$	t in min	t in hrs	$(T)^a$	$K(T)^a$	$(t+b)^n$	I (cm /hrs)	I (mm/hrs)	Area in hec.	C in hec	Q in hec.
DARN-B16	600	570	30	27000	1770.37	15.25	3.91	2.85	0.06	0.00	1.34	4.66	0.03	138.25	1382.52	86.00	19.23	6350.14
DARN-B17	580	570	10	1000	635.84	1.57	1.25	1.19	0.02	0.00	1.34	4.66	0.02	211.36	2113.58	43.11	11.98	3031.96
DARN-B18	720	570	150	3375000	2432.37	1387.54	37.25	16.21	0.32	0.01	1.34	4.66	0.08	59.52	595.20	105.77	22.64	3959.60
DARN-B19	640	570	70	343000	1031.25	332.61	18.24	9.35	0.18	0.00	1.34	4.66	0.06	77.73	777.25	67.24	15.93	2312.17
DARN-B20	640	560	80	512000	1135.32	450.97	21.24	10.52	0.20	0.00	1.34	4.66	0.06	73.43	734.27	116.05	28.16	6664.34
DARN-B21	670	570	100	1000000	1398.28	715.16	26.74	12.56	0.24	0.00	1.34	4.66	0.07	67.37	673.66	121.48	20.42	4642.82
DARN-B22	620	570	50	125000	823.82	151.73	12.32	6.91	0.13	0.00	1.34	4.66	0.05	90.00	900.01	97.75	27.37	6687.83
DARN-B23	610	570	40	64000	495.60	129.14	11.36	6.50	0.13	0.00	1.34	4.66	0.05	92.75	927.54	29.44	6.04	458.28
DARN-B24	620	570	50	125000	886.07	141.07	11.88	6.72	0.13	0.00	1.34	4.66	0.05	91.23	912.34	59.87	9.79	1485.76
DARN-B25	610	570	40	64000	836.86	76.48	8.75	5.31	0.10	0.00	1.34	4.66	0.05	102.29	1022.92	67.01	16.00	3046.29
DARN-B26	770	560	210	9261000	1229.63	7531.56	86.78	31.09	0.61	0.01	1.34	4.66	0.11	43.39	433.91	57.57	14.34	995.37
DARN-B27	920	570	350	42875000	1267.94	33814.63	183.89	55.42	1.08	0.02	1.34	4.66	0.14	32.77	327.75	71.07	18.70	1209.68
DARN-B28	1020	570	450	91125000	1426.01	63901.92	252.79	70.81	1.38	0.02	1.34	4.66	0.16	29.10	291.00	60.29	14.75	718.87
DARN-B29	910	570	340	39304000	1211.37	32445.91	180.13	54.55	1.06	0.02	1.34	4.66	0.14	33.03	330.29	70.02	14.70	944.24
DARN-B30	860	570	290	24389000	2064.37	11814.27	108.69	36.97	0.72	0.01	1.34	4.66	0.12	39.89	398.91	130.80	26.90	3898.26
DARN-B31	860	570	290	24389000	1435.61	16988.62	130.34	42.52	0.83	0.01	1.34	4.66	0.13	37.27	372.73	69.35	14.28	1025.51
DARN-B32	950	580	370	50653000	1576.85	32122.96	179.23	54.34	1.06	0.02	1.34	4.66	0.14	33.09	330.91	90.67	16.72	1393.07
DARN-B33	930	580	350	42875000	2199.31	19494.73	139.62	44.84	0.87	0.01	1.34	4.66	0.13	36.33	363.27	96.88	21.46	2097.53
DARN-B34	640	580	60	216000	3167.01	68.20	8.26	5.08	0.10	0.00	1.34	4.66	0.04	104.50	1045.04	271.37	65.47	51571.48
DARN-B35	640	570	70	343000	1269.74	270.13	16.44	8.63	0.17	0.00	1.34	4.66	0.06	80.81	808.06	186.24	42.09	17594.27
DARN-B36	650	580	70	343000	949.14	361.38	19.01	9.66	0.19	0.00	1.34	4.66	0.06	76.53	765.30	34.24	5.52	401.87
DARN-B37	570	550	20	8000	933.49	8.57	2.93	2.29	0.04	0.00	1.34	4.66	0.03	153.97	1539.72	38.14	7.58	1236.33
DARN-B38	640	570	70	343000	681.67	503.17	22.43	10.97	0.21	0.00	1.34	4.66	0.06	71.94	719.40	29.56	4.91	289.82
DARN-B39	640	570	70	343000	792.61	432.75	20.80	10.35	0.20	0.00	1.34	4.66	0.06	74.00	739.96	81.33	18.36	3069.64

Sub basin	High Elev.	Low Elev.	L (Diff)	L^3	Basin Length in meter (H)	L^3/H	K	$K^{(0.77)}$	t in min	t in hrs	$(T)^a$	$K(T)^a$	$(t+b)^n$	I (cm /hrs)	I (mm/hrs)	Area in hec.	C in hec	Q in hec.
DARN-C01	690	570	120	1728000	1877.38	920.43	30.34	13.84	0.27	0.00	1.34	4.66	0.07	64.26	642.64	139.02	22.24	5519.14
DARN-C02	680	570	110	1331000	3619.32	367.75	19.18	9.72	0.19	0.00	1.34	4.66	0.06	76.28	762.80	458.39	92.58	89922.21
DARN-C03	630	570	60	216000	1684.87	128.20	11.32	6.48	0.13	0.00	1.34	4.66	0.05	92.88	928.80	207.13	33.39	17844.09
DARN-C04	620	570	50	125000	1547.88	80.76	8.99	5.42	0.11	0.00	1.34	4.66	0.05	101.26	1012.57	233.55	47.26	31047.06
DARN-C05	620	580	40	64000	1420.64	45.05	6.71	4.33	0.08	0.00	1.34	4.66	0.04	112.92	1129.23	125.10	23.82	9348.15
DARN-C06	620	570	50	125000	1870.87	66.81	8.17	5.04	0.10	0.00	1.34	4.66	0.04	104.91	1049.06	144.02	20.61	8650.71
DARN-C07	670	570	100	1000000	2016.33	495.95	22.27	10.91	0.21	0.00	1.34	4.66	0.06	72.13	721.35	265.92	48.62	25903.54
DARN-C08	850	570	280	21952000	2323.42	9448.16	97.20	33.92	0.66	0.01	1.34	4.66	0.11	41.59	415.92	110.72	21.58	2761.02
DARN-C09	950	570	380	54872000	3504.03	15659.70	125.14	41.21	0.80	0.01	1.34	4.66	0.12	37.84	378.45	347.02	56.37	20564.76
DARN-C10	730	570	160	4096000	1465.41	2795.12	52.87	21.23	0.41	0.01	1.34	4.66	0.09	52.22	522.20	124.00	24.69	4441.67
DARN-C11	970	580	390	59319000	2218.18	26742.16	163.53	50.64	0.99	0.02	1.34	4.66	0.14	34.24	342.44	159.76	26.60	4041.57
DARN-C12	690	570	120	1728000	3012.10	573.69	23.95	11.54	0.22	0.00	1.34	4.66	0.07	70.20	701.99	417.24	102.68	83538.99
DARN-C13	640	570	70	343000	2395.31	143.20	11.97	6.76	0.13	0.00	1.34	4.66	0.05	90.98	909.80	278.92	61.55	43384.19
DARN-C14	630	570	60	216000	3135.41	68.89	8.30	5.10	0.10	0.00	1.34	4.66	0.04	104.31	1043.08	439.46	78.17	99530.39
DARN-D01	700	570	130	2197000	4767.54	460.82	21.47	10.60	0.21	0.00	1.34	4.66	0.06	73.13	731.32	737.18	123.42	184828.14
DARN-D02	870	580	290	24389000	2839.77	8588.38	92.67	32.70	0.64	0.01	1.34	4.66	0.11	42.34	423.40	736.92	135.80	117693.10
DARN-D03	720	570	150	3375000	1950.83	1730.03	41.59	17.65	0.34	0.01	1.34	4.66	0.08	57.12	571.16	259.18	63.44	26087.86
DARN-D04	1030	570	460	97336000	5827.57	16702.68	129.24	42.24	0.82	0.01	1.34	4.66	0.12	37.39	373.92	1283.71	256.76	342345.99
DARN-D05	1060	570	490	117649000	3532.99	33300.13	182.48	55.10	1.07	0.02	1.34	4.66	0.14	32.87	328.69	536.17	114.52	56059.32
DARN-D06	950	570	380	54872000	4173.39	13148.06	114.67	38.53	0.75	0.01	1.34	4.66	0.12	39.10	391.01	677.64	126.61	93185.87
DARN-D07	900	570	330	35937000	2719.07	13216.65	114.96	38.60	0.75	0.01	1.34	4.66	0.12	39.06	390.63	420.90	83.44	38107.83
DARN-E01	980	570	410	68921000	20981.99	3284.77	57.31	22.59	0.44	0.01	1.34	4.66	0.09	50.67	506.68	7509.31	1322.08	13973023.53
DARN-E02	1400	570	830	571787000	20467.03	27936.98	167.14	51.50	1.00	0.02	1.34	4.66	0.14	33.97	339.65	6898.87	1250.84	8141632.53
DARN-E03	1520	570	950	857375000	15955.41	53735.68	231.81	66.24	1.29	0.02	1.34	4.66	0.16	30.06	300.58	6295.07	1332.53	7003743.48

APPENDIX-G
Sub Basin-wise Surface Land Use /Land Cover

Sub Basin	Agriculture Land	Barren Land	Built Up Area	Forest Area	Scrub Land	Water Body
DARN-A01	0.08	0.11	0.00	0.05	0.04	0.01
DARN-A02	0.22	0.06	0.00	0.08	0.02	0.05
DARN-A03	0.18	0.06	0.00	0.05	0.05	0.01
DARN-A04	0.15	0.06	0.00	0.05	0.02	0.01
DARN-A05	0.08	0.05	0.00	0.03	0.01	0.00
DARN-A06	0.21	0.25	0.00	0.09	0.05	0.04
DARN-A07	0.06	0.05	0.00	0.04	0.01	0.01
DARN-A08	0.03	0.08	0.00	0.01	0.01	0.00
DARN-A09	0.02	0.18	0.00	0.01	0.03	0.00
DARN-A10	0.08	0.02	0.00	0.03	0.01	0.02
DARN-A11	0.12	0.11	0.00	0.07	0.02	0.02
DARN-A12	0.03	0.29	0.00	0.03	0.09	0.00
DARN-A13	0.07	0.20	0.00	0.03	0.08	0.00
DARN-A14	0.06	0.11	0.00	0.06	0.01	0.00
DARN-A15	0.08	0.11	0.00	0.04	0.06	0.03
DARN-A16	0.05	0.03	0.00	0.02	0.01	0.01
DARN-A17	0.05	0.01	0.00	0.01	0.00	0.02
DARN-A18	0.04	0.04	0.00	0.01	0.00	0.00
DARN-A19	0.13	0.04	0.00	0.02	0.03	0.05
DARN-A20	0.06	0.03	0.00	0.03	0.03	0.00
DARN-A21	0.08	0.07	0.00	0.04	0.01	0.05
DARN-A22	0.10	0.04	0.00	0.04	0.02	0.01

Sub Basin	Agriculture Land	Barren Land	Built Up Area	Forest Area	Scrub Land	Water Body
DARN-A23	0.05	0.13	0.00	0.04	0.04	0.03
DARN-A24	0.16	0.08	0.00	0.02	0.06	0.13
DARN-A25	0.12	0.26	0.00	0.04	0.07	0.04
DARN-A26	0.07	0.45	0.00	0.06	0.07	0.00
DARN-A27	0.07	0.04	0.00	0.04	0.04	0.00
DARN-A28	0.06	0.06	0.00	0.03	0.02	0.00
DARN-A29	0.13	0.29	0.00	0.04	0.07	0.00
DARN-A30	0.17	0.15	0.00	0.06	0.04	0.00
DARN-A31	0.11	0.07	0.00	0.01	0.05	0.00
DARN-A32	0.09	0.18	0.00	0.04	0.13	0.00
DARN-A33	0.15	0.15	0.00	0.02	0.11	0.00
DARN-A34	0.10	0.07	0.00	0.01	0.11	0.00
DARN-A35	0.19	0.31	0.01	0.02	0.23	0.00
DARN-A36	0.11	0.02	0.00	0.01	0.03	0.00
DARN-A37	0.08	0.02	0.00	0.00	0.05	0.00
DARN-A38	0.07	0.07	0.00	0.01	0.08	0.00
DARN-A39	0.07	0.30	0.00	0.04	0.09	0.00
DARN-A40	0.31	0.19	0.00	0.31	0.09	0.01
DARN-A41	0.10	0.23	0.00	0.04	0.04	0.00
DARN-A42	0.05	0.21	0.00	0.05	0.04	0.00
DARN-A43	0.16	0.16	0.00	0.06	0.06	0.00
DARN-A44	0.04	0.06	0.00	0.04	0.03	0.00
DARN-A45	0.06	0.04	0.00	0.02	0.04	0.04
DARN-A46	0.03	0.03	0.00	0.01	0.03	0.07
DARN-A47	0.03	0.03	0.00	0.01	0.00	0.00

Sub Basin	Agriculture Land	Barren Land	Built Up Area	Forest Area	Scrub Land	Water Body
DARN-A48	0.03	0.06	0.00	0.01	0.01	0.00
DARN-A49	0.02	0.03	0.00	0.01	0.00	0.03
DARN-A50	0.05	0.15	0.00	0.02	0.01	0.00
DARN-A51	0.02	0.11	0.00	0.03	0.03	0.00
DARN-A52	0.10	0.08	0.00	0.03	0.01	0.01
DARN-A53	0.09	0.05	0.00	0.06	0.07	0.04
DARN-A54	0.13	0.19	0.00	0.05	0.06	0.02
DARN-A55	0.08	0.07	0.00	0.07	0.03	0.00
DARN-A56	0.13	0.13	0.00	0.15	0.04	0.00
DARN-A57	0.05	0.25	0.00	0.07	0.06	0.00
DARN-A58	0.09	0.10	0.00	0.08	0.02	0.00
DARN-A59	0.26	0.27	0.00	0.11	0.08	0.02
DARN-A60	0.07	0.13	0.00	0.12	0.03	0.02
DARN-A61	0.05	0.07	0.00	0.05	0.01	0.00
DARN-A62	0.15	0.19	0.00	0.10	0.03	0.00
DARN-A63	0.19	0.14	0.00	0.09	0.04	0.00
DARN-A64	0.22	0.10	0.00	0.13	0.02	0.00
DARN-A65	0.08	0.01	0.00	0.07	0.00	0.00
DARN-A66	0.01	0.01	0.00	0.02	0.00	0.02
DARN-A67	0.01	0.11	0.00	0.03	0.03	0.00
DARN-A68	0.04	0.10	0.00	0.03	0.02	0.00
DARN-A69	0.03	0.06	0.00	0.03	0.01	0.00
DARN-A70	0.13	0.06	0.00	0.03	0.03	0.01
DARN-A71	0.09	0.05	0.00	0.06	0.02	0.00
DARN-A72	0.07	0.03	0.00	0.06	0.01	0.00

Sub Basin	Agriculture Land	Barren Land	Built Up Area	Forest Area	Scrub Land	Water Body
DARN-A73	0.13	0.14	0.00	0.07	0.02	0.00
DARN-A74	0.05	0.17	0.00	0.01	0.02	0.00
DARN-A75	0.01	0.07	0.00	0.01	0.03	0.00
DARN-A76	0.01	0.09	0.00	0.03	0.02	0.00
DARN-A77	0.04	0.06	0.00	0.02	0.05	0.00
DARN-B01	0.17	0.12	0.00	0.11	0.04	0.00
DARN-B02	0.25	0.79	0.00	0.21	0.12	0.00
DARN-B03	0.19	0.37	0.00	0.17	0.11	0.01
DARN-B04	0.08	0.13	0.00	0.05	0.02	0.00
DARN-B05	0.40	0.19	0.00	0.21	0.14	0.18
DARN-B06	0.17	0.16	0.00	0.10	0.04	0.05
DARN-B07	0.07	0.56	0.00	0.08	0.15	0.01
DARN-B08	0.11	0.40	0.00	0.05	0.16	0.02
DARN-B09	0.16	0.57	0.00	0.10	0.23	0.03
DARN-B10	0.26	0.65	0.00	0.24	0.23	0.00
DARN-B11	0.43	0.68	0.00	0.10	0.32	0.00
DARN-B12	0.09	0.35	0.00	0.01	0.10	0.00
DARN-B13	0.15	1.14	0.00	0.11	0.30	0.00
DARN-B14	1.14	1.53	0.07	0.23	2.05	0.12
DARN-B15	0.89	1.03	0.09	0.19	1.58	0.15
DARN-B16	0.29	0.30	0.00	0.09	0.18	0.00
DARN-B17	0.27	0.05	0.00	0.01	0.10	0.00
DARN-B18	0.38	0.25	0.00	0.11	0.11	0.20
DARN-B19	0.26	0.24	0.00	0.05	0.12	0.00
DARN-B20	0.54	0.26	0.00	0.07	0.29	0.00

Sub Basin	Agriculture Land	Barren Land	Built Up Area	Forest Area	Scrub Land	Water Body
DARN-B21	0.19	0.67	0.01	0.06	0.29	0.00
DARN-B22	0.46	0.31	0.00	0.13	0.07	0.00
DARN-B23	0.07	0.11	0.00	0.05	0.04	0.02
DARN-B24	0.06	0.43	0.00	0.02	0.09	0.00
DARN-B25	0.22	0.24	0.00	0.11	0.09	0.01
DARN-B26	0.19	0.21	0.00	0.11	0.06	0.00
DARN-B27	0.19	0.18	0.00	0.28	0.07	0.00
DARN-B28	0.14	0.23	0.00	0.19	0.05	0.00
DARN-B29	0.15	0.32	0.00	0.11	0.11	0.00
DARN-B30	0.24	0.75	0.00	0.17	0.14	0.00
DARN-B31	0.16	0.33	0.00	0.08	0.10	0.01
DARN-B32	0.15	0.41	0.00	0.14	0.21	0.00
DARN-B33	0.23	0.37	0.00	0.22	0.16	0.00
DARN-B34	0.77	1.07	0.01	0.57	0.29	0.00
DARN-B35	0.55	0.81	0.00	0.24	0.22	0.05
DARN-B36	0.02	0.27	0.00	0.02	0.04	0.00
DARN-B37	0.06	0.26	0.00	0.03	0.03	0.00
DARN-B38	0.01	0.22	0.00	0.03	0.03	0.00
DARN-B39	0.22	0.34	0.00	0.14	0.12	0.00
DARN-C01	0.05	1.14	0.00	0.06	0.14	0.00
DARN-C02	0.74	2.57	0.01	0.72	0.54	0.01
DARN-C03	0.13	1.32	0.01	0.22	0.38	0.01
DARN-C04	0.54	1.06	0.00	0.29	0.42	0.03
DARN-C05	0.19	0.68	0.00	0.17	0.20	0.00
DARN-C06	0.06	0.99	0.00	0.08	0.31	0.01

Sub Basin	Agriculture Land	Barren Land	Built Up Area	Forest Area	Scrub Land	Water Body
DARN-C07	0.32	1.58	0.00	0.35	0.41	0.00
DARN-C08	0.17	0.67	0.00	0.14	0.13	0.00
DARN-C09	0.30	2.18	0.01	0.30	0.68	0.00
DARN-C10	0.21	0.78	0.00	0.13	0.12	0.00
DARN-C11	0.18	0.84	0.00	0.18	0.37	0.01
DARN-C12	1.18	1.48	0.01	1.04	0.46	0.00
DARN-C13	0.70	1.25	0.00	0.44	0.39	0.00
DARN-C14	0.42	2.80	0.00	0.55	0.61	0.01
DARN-D01	1.14	3.54	0.05	0.61	2.02	0.00
DARN-D02	0.86	4.43	0.02	0.99	1.08	0.00
DARN-D03	0.89	1.00	0.00	0.39	0.31	0.00
DARN-D04	1.72	7.15	0.02	2.42	1.25	0.27
DARN-D05	0.74	2.66	0.00	1.41	0.55	0.00
DARN-D06	0.77	4.07	0.02	1.00	0.89	0.04
DARN-D07	0.61	2.48	0.01	0.63	0.48	0.00
DARN-E01	5.31	48.19	0.24	10.89	9.82	0.64
DARN-E02	6.34	38.63	0.58	11.68	9.16	2.61
DARN-E03	5.46	33.72	0.09	18.99	4.63	0.05
Total	**46.36**	**191.20**	**1.29**	**62.21**	**47.02**	**5.43**

Source : Landsat8 OLI (2012), Note: Area in km^2

APPENDIX-H
Sub Basin-wise Slope Area

Sub-Basin	Slope Classes in Percentage						
	0-30	30-60	60-90	90-120	120-150	150-180	180-210
DARN-A01	0.2611					0.0051	0.0217
DARN-A02	0.4306						
DARN-A03	0.3371					0.0003	0.0118
DARN-A04	0.2766					0.0018	0.0134
DARN-A05	0.1778					0.0020	0.0115
DARN-A06	0.6393	0.0012				0.0044	0.0059
DARN-A07	0.1512	0.0088					
DARN-A08	0.1285						
DARN-A09	0.2521						
DARN-A10	0.1527	0.0027					
DARN-A11	0.3389	0.0018					
DARN-A12	0.4314						
DARN-A13	0.3883						
DARN-A14	0.2424						
DARN-A15	0.3106	0.0064					
DARN-A16	0.1192	0.0014					
DARN-A17	0.0966	0.0011					
DARN-A18	0.0875	0.0008					
DARN-A19	0.2702						
DARN-A20	0.1575						
DARN-A21	0.2445	0.0055					

Sub-Basin	0-30	30-60	60-90	90-120	120-150	150-180	180-210
DARN-A22	0.2067						
DARN-A23	0.2552	0.0346					
DARN-A24	0.4491	0.0064					
DARN-A25	0.5136	0.0094					
DARN-A26	0.6543						
DARN-A27	0.1845						
DARN-A28	0.1686						
DARN-A29	0.5286						
DARN-A30	0.4224						
DARN-A31	0.2474						
DARN-A32	0.4478						
DARN-A33	0.4346	0.0008					
DARN-A34	0.2895	0.0032					
DARN-A35	0.7518						
DARN-A36	0.1785						
DARN-A37	0.1509						
DARN-A38	0.2443						
DARN-A39	0.5008						
DARN-A40	0.8989	0.0036					
DARN-A41	0.4028	0.0036					
DARN-A42	0.3429	0.0036					
DARN-A43	0.4333						
DARN-A44	0.1683						
DARN-A45	0.1940	0.0045					
DARN-A46	0.1682						

Sub-Basin	0-30	30-60	60-90	90-120	120-150	150-180	180-210
DARN-A47	0.0816						
DARN-A48	0.0967						
DARN-A49	0.0896						
DARN-A50	0.2294	0.0009					
DARN-A51	0.1828						
DARN-A52	0.0001	0.2371					
DARN-A53	0.0027	0.3040					
DARN-A54	0.0270	0.4419					
DARN-A55	0.2496						
DARN-A56	0.4460	0.0003					
DARN-A57	0.4290						
DARN-A58	0.2938						
DARN-A59	0.7342	0.0002					
DARN-A60	0.3698						
DARN-A61	0.1708						
DARN-A62	0.4826						
DARN-A63	0.4558						
DARN-A64	0.4767						
DARN-A65	0.1758						
DARN-A66	0.0567						
DARN-A67	0.1787						
DARN-A68	0.1978						
DARN-A69	0.1200	0.0009					
DARN-A70	0.2737						
DARN-A71	0.2266						

Sub-Basin	0-30	30-60	60-90	90-120	120-150	150-180	180-210
DARN-A72	0.1612						
DARN-A73	0.3623	0.0018					
DARN-A74	0.2514	0.0049					
DARN-A75	0.1109	0.0022					
DARN-A76	0.1414	0.0043					
DARN-A77	0.1585	0.0064					
DARN-B01	0.4146					0.0053	0.0157
DARN-B02	1.3369					0.0121	0.0217
DARN-B03	0.8360					0.0060	0.0060
DARN-B04	0.2790	0.0032					
DARN-B05	1.1186	0.0064					
DARN-B06	0.0704						
DARN-B07	0.8769						
DARN-B08	0.7435	0.0018					
DARN-B09	1.0706	0.0154	0.0027				
DARN-B10	1.3873						
DARN-B11	1.5280	0.0095					
DARN-B12	0.5548	0.0041					
DARN-B13	1.6717	0.0273					
DARN-B14	4.8440	0.2745	0.0149				
DARN-B15	3.7614	0.1554	0.0078				
DARN-B16	0.8600						
DARN-B17	0.4311						
DARN-B18	0.9865	0.0711					
DARN-B19	0.6668	0.0056					

Sub-Basin	0-30	30-60	60-90	90-120	120-150	150-180	180-210
DARN-B20	1.1559	0.0045					
DARN-B21	1.1903	0.0245					
DARN-B22	0.9703	0.0073					
DARN-B23	0.2908	0.0036					
DARN-B24	0.5896	0.0091					
DARN-B25	0.6692	0.0009					
DARN-B26	0.4608	0.0884	0.0264				
DARN-B27	0.4338	0.1910	0.0519	0.0312	0.0027		
DARN-B28	0.2865	0.1823	0.0880	0.0420	0.0040		
DARN-B29	0.4373	0.2186	0.0421	0.0027			
DARN-B30	1.2641	0.0378	0.0014	0.0031	0.0020		
DARN-B31	0.5948	0.0747	0.0217	0.0023			
DARN-B32	0.6965	0.1526	0.0343	0.0172	0.0043	0.0007	
DARN-B33	0.6821	0.1328	0.1063	0.0157	0.0003		0.0335
DARN-B34	2.6741	0.0018				0.0119	0.0287
DARN-B35	1.8536	0.0088					
DARN-B36	0.3299	0.0105				0.0044	0.0072
DARN-B37	0.3530	0.0100					0.0193
DARN-B38	0.2797	0.0002				0.0045	0.0118
DARN-B39	0.6856	0.0327				0.0324	0.0693
DARN-C01	1.2810	0.0291				0.0220	0.0636
DARN-C02	4.5492	0.0157				0.0009	0.0194
DARN-C03	2.0676	0.0036					
DARN-C04	2.3332	0.0023					
DARN-C05	1.2492	0.0018					

Sub-Basin	0-30	30-60	60-90	90-120	120-150	150-180	180-210
DARN-C06	1.4402						
DARN-C07	2.6571	0.0020					
DARN-C08	0.9396	0.1287	0.0352	0.0037			
DARN-C09	2.9282	0.4740	0.0508	0.0173			
DARN-C10	1.0657	0.1743					
DARN-C11	1.3003	0.1852	0.0682	0.0222	0.0071		0.0152
DARN-C12	4.0141	0.0236				0.0319	0.1131
DARN-C13	2.7336	0.0100				0.0099	0.0393
DARN-C14	4.2533	0.0246				0.0265	0.0990
DARN-D01	7.2034	0.0392				0.0382	0.1013
DARN-D02	6.8451	0.2761	0.0645	0.0013		0.0555	0.1389
DARN-D03	2.2405	0.3171	0.0342				
DARN-D04	8.3534	3.6806	0.5883	0.1416	0.0382		0.0391
DARN-D05	3.7992	1.0963	0.3191	0.0780	0.0078	0.0006	0.0645
DARN-D06	5.2997	0.9619	0.2549	0.0633	0.0064	0.0039	0.1987
DARN-D07	3.8122	0.1406	0.0751	0.0436	0.0155	0.0354	0.0962
DARN-E01	61.3089	10.5757	2.0540	0.2809	0.0318	0.0689	0.9232
DARN-E02	56.4416	10.2665	1.1199	0.1698	0.0528	0.1426	0.8596
DARN-E03	45.5641	12.8846	2.9614	0.7958	0.1592	0.0127	0.6176

Source: Computed by Researcher, Note: Area in km²

Photo 1: Darna River Channel

Photo 2: Darna River Meandering Channel at Ghoti Bridge

Photo 3: Darna River Meandering Channel and harvested Paddy crops

Photo 4: Slope Morphology in Study area

Photo 5: Wasteland and Scrubland

Photo 6: Wasteland at Ubhade Village in Study area

Photo 7: Wasteland at Dhamangaon Village in Study area

Photo 8: Gully erosion in Study area


Photo 9: Agriculture land and crop along Darna River Channel

Photo 10: Settlement Pattern


Photo 11: Relief Morphology and Natural Vegetation


Photo 12: Mesa, Buttes Relief Features and Natural Vegetation

Photo 13: Darna Lake Reservoir

Photo 14: Darna Lake Reservoir Wall

Photo 15: Darna River Wide Channel

Photo 16: Barren Land at Samnere Village in Study area

Abstract

Morphometric Analysis and Runoff Studies of Darna Lake Catchment

Natural resources are limited as well as unevenly found on the earth surface. Natural resources such as land and water are important for human beings and environment. Their appropriate utilization is essential for every nation and specifically for over-populated countries. Hence there is need of proper sustainable utilization of watershed in our country. A prioritization technique has been introduced by various watershed resource development programmes. It plays a vital role for planning and management of natural resources for sustainable development. Prioritization is a technique that gives rank for different sub basins as per order in which that has to be taken for development. The morphology of individual sub basins can be understood by this method. Remote sensing (RS) and Geographical information System (GIS) techniques are helpful for formation of data. Further it becomes useful for framing appropriate measures in critically affected areas at micro level. Remote sensing gives versatile recent information of natural resources, GIS has the potential to detain, accumulate, operate, analyze and retrieval of numerous layers resource information in spatial forms. The present research work has undertaken to study, morphometric analysis estimation of and peak surface runoff which has been considered for prioritization of Darna Lake Catchment area.

The quantitative analysis of morphometric parameters is found to be of immense utility in river basin evaluation, watershed prioritization for soil and water conservation and natural resources management. As far the researcher concerned, the notable research work on this topic has been carried out by Nag (1998), Srinivasa (2004), Chopra et. al. (2005), Nookaratnam et. al. (2005), Thakkar et. al. (2007), Bhatt et. al. (2007), Kar et. al. (2009) and Rao et. al.(2010) for prioritization of different river basins using GIS and RS techniques. Nookaratnam et al's. (2005) finding proposes site suitability for check dam through prioritization in micro-watersheds by applying morphometric analysis. Suitable sites for water harvesting structures can be identified by GIS Techniques (Chowdhary et al. 2009). Akram Javed, Mohd Yousuf Khanday and Rizwan Ahmed, (2009) carried out the study on prioritize sub-watersheds based on morphometric and land use characteristics using remote sensing and GIS techniques in Kanera watershed of Guna district, Madhya

Pradesh. S.S. Panhalkar., S.P Mali., and C.T. Pawar (2012) worked on Morphometric analysis and watershed development prioritization of Hiranyakeshi Basin in Maharashtra, India. The main goal of this study was to prioritize the Hiranyakeshi basin on the basis of morphometric analysis and weightage has been assigned to each sub-watershed for watershed development. The compound parameter values are calculated and the sub-watershed with lowest compound weight is given highest priority. Umair Ali and Syed Ahmad Ali (2014) has mainly work on Romushi-Sasar catchment of Kashmir valley, India for analysis of morphometric parameters using GIS and remote sensing and are found to be of immense utility in prioritization of watershed at micro-level. The result of this study shows that the results shows sub-watershed RSMW4 and RSMW5 has lowest compound parameter value of 2.22, 2.44 and depicted into high priority hence these sub-watersheds shows maximum soil erosion and suggested for soil and water conservation in a watershed.

Most of the watersheds in western Maharashtra show the signs of excessive runoff and loss of soil. These kinds of problems are mainly evident in the form of gullied and ravenous topography. Heavy surface runoff and loss of soil mainly occur due to improper practicing of hill slope agriculture. These problems are indicated by evidences such as exposed hill slopes, sedimentation etc. As a result there is excessive surface runoff and high sediment yield mainly in rainy season. Yielding of sediments may give rise to siltation problem. It may eventually decline productivity, efficiency of land and finally increase the proportion of the watershed area. Such situation instigates various interlinked geo-environmental problems.

Darna Lake Catchment is selected as study area for present study. The study area extends between 19°36' N to 19°48' N latitudes and 73°39' E to 73°44'E longitudes, which comprises 389.6 Sq. Km area. Darna river is one of the tributaries of Godavari river which, rises on the northern slopes of Kulung hill at elevation 1040 meters in Sahyadri ranges. This area is not exception to above mentioned problems and has not been so far studied in-depth by scholars. Further, the study area is familiar as well as more convenient to the researcher and easy for data collection. Therefore, Darna Lake Catchment area has been selected for the present study.

The upper catchment area receives high rainfall (3000-4000 mm.) and In Lake Catchment area of Darna average temperature starts increasing by the end of February and the average monthly maximum temperature is observed at 36.51 °C in the month of April. The study area consists of prominent basaltic features. Most of the study areas show moderate to steeper slope with formation of cliff and waterfall. Sequential layer of Lava flows are generally occurred in study area whereas vesicular lava is observed at the top of the plateau. Vaki nadi and Bham nadi are main tributaries of Darna river in study area. Lateritic (red brown) soil is found on the slopes of the hills whereas sandy loam and black soil appear in the Lake Catchment and near the banks of Darna river. Monsoonal deciduous forest and tropical moist deciduous forest are observed in study area, which predominantly consist of trees like teak, sisum, khair and timber.

Present work has been studied by purporting following objectives-

1. To perform the morphometric analysis of the Darna Lake Catchment focusing on areal, linear and relief aspects of the catchment necessarily helpful in understanding of terrain in general and behavior of streams in particular.
2. To estimate surface runoff using various empirical equations (Rational formula) of surface runoff estimation this will help to understand source areas of sediment yield.
3. To apply composite score for prioritization of sub basins for conservation planning based on morphometric analysis and surface runoff studies.
4. To emphasize the necessity of conservation planning with the help of GIS and to endorse the use of RS (Remote Sensing) in updating the data base for basin wise inventory of the study area in the form of various thematic maps, as well as to prepare conservation plan in terms of CAT (Catchment Area Treatment).

The Data sources and methods that have been used to fulfil the objectives placed in the present study are provided as follows.

Database and Methodology:

The Data sources and methods that have been used to fulfil the objectives placed in the present study are provided as follows.

Data Sources:

- **Toposheet**–

S.O.I. Topographical maps based on 1:50000 scales (One inch toposheet) have been used for the preparation of base map. The Darna Lake catchment area covered in the Survey of India (SOI) Toposheet numbers 47 E/9 in B3 and C3 quadrants, 47 E/10 in B1 and C1 quadrants, 47 E/13 in A3 quadrant and 47 E/14 in A1 quadrant. These toposheets were published in 1977, 1975, 1976 and 1975 respectively.

- **Climatic Data**–

Rainfall data have been obtained from Hydrological Department MERI, Nashik for the period of 1976 to 2014. Temperature data has been collected from Zonal Agricultural Research Station, Igatpuri, for the period of 1999 to 2015.

Methodology and Data Analysis:

- **Digitization of layers-**

ArcGIS 9.2 and Global Mapper software have been used for digitization of contours and streams from topographical maps. These digitized layers are used for further analysis.

- **Morphometric Analysis-**

ArcGIS (version 9.2) and Global Mapper Softwares have been used to geo-reference and rectify topographical maps. These softwares have been utilized to digitize the stream network of Darna Lake Catchment. Strahler's (1964) stream ordering method has been applied for the present study. The morphometric parameters have been calculated by using assorted formulas. The stream number of various order for study area were counted, whereas the stream length, basin length, area and perimeter were measured with the help of the above mentioned software.

The attribute were assigned to generate the digital data base for drainage layer of the Darna lake catchment. The essential parameters related to stream such as, length of stream, area and perimeter of basin etc. were obtained from the digitized drainage layer. The various morphometric parameters for the defined basin area have also calculated.

The formulas made by Horton (1945), Strahler (1964), Miller (1953) and Schumms (1956) were adopted for the calculation. Linear, areal and relief aspects of the Darna river network were computed. Attempt has been made; through morphometric analysis, to prioritize the sub basins of the entire Darna Lake Catchment and divided into 140 sub-basins. They are accordingly coded as DARN_A01 to DARN_A77 for first order sub basins, DARN_B01 to DARN_B39 for second order sub basins, DARN_C01 to DARN_C14 for third order sub basins, DARN_D01 to DARN_D07 for fourth order sub basins and DARN_E01 to DARN_E03 for fifth order sub basins as shown in Figure 4.2.

Morphometric parameters for each delineated sub watershed area have been calculated. Prioritization rating of all the 140 sub-watersheds of Darna lake catchment is carried out by allotting ranks to the individual parameter. Compound value for all parameters has been calculated. Highest compound parameter value of sub watershed is assigned with lowest priority and vice versa. Accordingly an index of very high (< 25), high (26-50), medium (51-75), Low (76-100) and very low (>100) priority has been orderly obtained. Sub-watersheds have been broadly classified into five priority zones as per their compound value. The high priority indicates a need of retrieval processes and an action plan for protection and conservation of soil.

Relief Analysis-

ArcGIS software version 9.2 and 10.2.2 are used for Contour digitization. Global Mapper software has been used to prepare DEM (Digital Elevation Model) of the study area. Different thematic maps such as Slope (percentage), Absolute Relief, Relative Relief and Dissection Index have been prepared.

Land Use / Land Cover Map-

NRSC satellite image (Year 2012) has been used to prepare Land use / Land cover map. It has been processed and supervised classification has been adopted to classify land cover segments such as agricultural land, built up, forest and wasteland of study area has been applied.

Estimation of surface runoff-

Efforts have been made to estimate peak surface runoff of the entire Darna Lake Catchment which has been divided into 140 sub-basins. Rational formula has been employed to find out rainfall intensity, time of concentration and peak surface runoff volume for each of the 140 sub-basin. On the basis of the calculated peak surface runoff of individual sub watershed, priority ranking has been allotted. The sub-basins with the highest peak runoff value (low ranking) are assigned by highest priority and vice versa.

Finally composite scores of both the morphometric analysis and peak surface runoff have been considered. Composite scores are used to find out decisive zones of vulnerable soil loss and excessive surface runoff. Decisive zones have been thus identified and suggestions for further conservation, planning and management are given.

Darna catchment area has 1815 streams in total, out of which 1380 are first order streams, 334 are second order streams, 79 are third order streams, 18 are fourth order streams, 3 are in fifth order and 1 is in the sixth order. The length of all the streams of first order in Darna Lake Catchment is 741.65 km, second has 216.21 km, third is 92.72 km, fourth has 37.66 km, fifth order is 38.98 km and length of sixth order is 50.14 km. The calculated mean stream length for Lake Catchment area of Darna is 0.54 for first orders, 0.65 for the second, 1.17 for the third, 2.09 for fourth, 12.99 for fifth and 50.14 for sixth orders. The total stream length ratio of the study area is 2.37, that indicates youth stage of the Darna river for geomorphic development. The bifurcation ratio of the Darna Lake Catchment area ranges 3 to 6. This bifurcation value illustrate network formed in homogeneous rocks. It endures minimum structural instability and well developed natural drainage system in catchment area. The mean bifurcation ratio is 4.35. Thus, the result shows that Darna Lake Catchment area is located in a dissected or hilly region. In aerial aspects, form factor value of Darna Lake Catchment observed to be 0.11. It shows basin as more elongated in nature and the lower peak flow remains for longer duration. It also exhibits high erosion in catchment area that leads to elongated shape of the basin. Circularity ratio of study area is 0.37, which reveals elongated basin, impermeable geologic structure and high runoff in Darna Lake Catchment. The Re value of the Darna Lake Catchment is 0.38 which indicates that the drainage basin is more elongated with moderate relief and more or less steeper slope. Sinuosity index is 2.23 for study area, which is more than 1.5; it indicates that Darna river channel form meandering path. The value of drainage density is 3.02 per square kilometer in study area suggesting that the Darna Lake Catchment area has high drainage density. It shows that Darna basin has impermeable sub soil and sparse vegetation. The constant of channel maintenance of Darna Catchment area is low i.e. 0.36 km/km^2. The stream frequency of study area is 4.66 per square km, which endorses high relief, high runoff and low penetration capacity. Darna river bed which is mostly made up of basalt hard rock, denotes poor erodibility and low porosity. This area is associated with high structural disturbance, steep to very steep gradient and heavy surface runoff. Area ratio is between 0.22 and 4.03 and it increases with increase in stream orders upto third order. The ruggedness number of the study area is 2.86. It reveals that the present study area is having large extent rugged relief. The texture ratio of the Darna Lake Catchment is 15.85 which fall into high reliefs category. The length of overland flow for study area is low i.e. 0.17. It exhibits the catchment area as structurally complex and also indicates that the drainage basin is in youth stage. Low DI value has been observed in the central part of the study area. It indicates moderate slope and youth stage of Darna river. Therefore, it has been suggested that the attempted results can be utilized for hydrological and physical explanation as well as environmental management in the Darna Lake Catchment.

The estimation of surface runoff rational formula has been employed to find out rainfall intensity, runoff coefficient, time of concentration and peak volume of runoff. It is observed that rainfall intensity is high in DARN _B17 which is 2113.58 mm/hr (211.36cm/hr) and very low in DARN_B28 which is 291 mm/hr (29.10 cm/hr).For this study coefficient are applicable for 10 years and it is taken as per land cover such as agriculture land(0.4), barren(0.16), built up(0.5), forest(0.3) and scrub land (0.22). Rational Runoff Coefficient for Rational Method, C (Subramanya, 2008) values has been employed for this study area. It shows that most of the area covered by barren land and moderates to steep basin, sparse vegetation as well as resistant surface that shows high runoff coefficient. All the calculating area of the study area is 35351.78 hectares (353.51 sq.km.). Maximum area covered by DARN_E01 sub-basin of fifth order which is 7509.31 hectares (75.09 sq.km) and minimum area covered by DARN_A66 sub-basin of first order which is 5.67 hectares (0.056 sq.km.). In the study area time of concentration is 0.02 in a minute observed in DARN_B17, 0.03 in a minute observed in DARN_A01, DARN_A02, DARN_A04, DARN_A36, DARN_37, DARN_61 and DARN_A71 and 1.29 and 1.38 in a minute in DARN_E03, DARN_B28 respectively. This time of concentration can be useful for hydrologist for further assessment of flood risk. In the study area of Darna Lake Catchment, peak volume has been computed sub-basin wise. It shows that lowest value of peak volume is observed in DARN_A66 sub-basin which is 15.30m^3/s whereas, highest value of peak volume is observed in DARN_E01 sub-basin which is 13973023.53 m^3/s, which consist Tirangwadi, Bhavali, Kurnoli, Pardevi,Waki, Korapgaon and Pimpalgaon Bhatata villages and located southwest part of study area.

The present study reveals the importance of GIS for prioritization of the sub basins of Darna Lake Catchment. The streams law says, “Lower the order higher the number of streams”, and has been applied in the case of this watershed. The highest Rb value observed to be sub-basins for DARN_B10, DARN_B11 and DARN_B15 which is 6. It reveals a strong structural control in the drainage pattern. The lower Rb value is found mostly in all first orders sub-basin, which exhibits that these sub basins are not much affected by structural disturbances (Strahler, 1964).The highest drainage density (5.8 Km/Km^2) is observed in DARN_C07. This sub-basin shows weak non-porous subsurface material, thin vegetation and hilly topography. The lowest drainage density observed in DARN_A59 (0.4 Km/Km^2), reveals highly porous subsoil material under a thick vegetation cover and a low elevated topography. Most of the study area shows high drainage density which, indicates that Darna Lake Catchment area associate with weak impermeable subsurface material, sparse vegetation and mountainous relief. The values of form factor, circulatory and elongation ratio propose that most of the Darna sub basins are elongated in character and associated with high to moderate relief. The prioritization outputs of sub-basin shows that sub-basins DARN_D03, DARN_D04 and DARN_E01 bear more erosion. These basins seek immediate attention and suitable soil conservation measures ought to be taken. Apart from these sub basins other high priority sub-basins of Darna Lake Catchment also need more attention as they are more vulnerable to soil erosion.

In this study area sub-basins namely DARN_E01, DARN_E02, DARN_E03, DARN_D01, DARN_D02, DARN_D03, DARN_D04 and other 23 sub-basins are identified for excess runoff based on peak surface runoff further suitable action is recommended. Composite scores of all 140 sub basins in study area have been divided into five priority levels for conservative planning. The composite scores of 19 sub-basins come under priority level 1 (very high), 19 sub-basins come under priority level 2 (high), 27 sub-basins come under priority level 3 (medium), 36 sub-basins come under priority level 4 (low) and 39 sub-basins under priority level 5 (very low).

A decisive zone within the study area with high erosion activities has been recognized by considering the composite ranking of morphometry and runoff. Hence, prioritization of Darna sub-basins becomes helpful for identification of critical zones and recommendation of appropriate conservation measures in the study area.

Finally, the sub-basin DARN_E01, DARN_E02 and DARN_E03 shows the highest priority; hence it implies a high degree of erosion and surface runoff in Darna Lake Catchment. This basin has a very high possibility to applying conservative remedies. Thus**,** firstly conservation remedies can apply to sub-basin DARN_E01 and then to the other sub basins of Darna catchment depending upon their priority.

Based on composite scores sub-basins DARN_E01, DARN_E02, DARN_E03, DARN_D01, DARN_D02, DARN_D03, DARN_D04, DARN_D05, DARN_D06, DARN_D07, DARN_C02, DARN_C04, DARN_C05, DARN_C06, DARN_C07, DARN_C09, DARN_C13, DARN_C14 and DARN_B02 fall in very high priority. Among these sub-basins DARN_E01, DARN_E02, and DARN_E03 consist maximum area that lies towards North-West and South side of study area and consist of Tirangwadi, Bhavali, Kurnoli, Pardevi, Vaki, Korapgaon, Pimpalgaon Bhatata, Ambegaon, Talegaon, Girnare, Taloshi and Gavhande villages.

Therefore, conservative measures for the identified sub basins to protect the land resources from erosion and to reduce natural hazards are the need of the hour. Taking this into consideration, substantial investments have to be made towards the Darna Catchment development programme. It is essential to plan the actions on priority basis to attain productive results. This also assists the challenging areas to arrive at appropriate solution. The major findings which have led to the following conclusion have been made with an eye on conservation planning.

1. The DARN_D03 sub-basin recorded a low compound parameter value of 28.2. It is ranked as the highest in terms of erosion followed by DARN_D04, DARN_C01, DARN_D01, DARN_D02, DARN_C14, DARN_C13, DARN_E01 and other 19 sub-basins. These sub basins cover 289.99 sq. km. area i.e. 83% of the total land surface area. These sub basins located to the North-West, South and West part of the study area, represent villages namely Umbarkon, Samnere, Waghere and Manik khamb etc. which are associated with more proportion of barren land (79.20 sq.km.) and moderately dissected topography. Thus, these sub basins have been suggested for conservation measures, starting from DARN_D03 and followed by others based on their level of priority.
2. The empirical rational formula used to calculate runoff and it is found there is a great deal of runoff in the case of sub basins of the Western, Southern and Northern part of the Darna lake catchment (which mainly consist of fourth and fifth order). They are DARN_E01, DARN_E02, DARN_E03, DARN_D01, DARN_D02, DARN_D03, DARN_D04 and 23 others sub-basins and it covers 210 sq. Km. area which is 61 % of the total study area. These areas considered for contributing severe runoff. This area is associated with structural and denudation in origin along with the highly dissected lower plateau especially at Talegaon village and Igatpuri. Barren and scrub land (169.98 sq.km,) are observed in this area. It reveals that land use and land cover play a vital role in determining geomorphic process in terms of the surface runoff in the study area.
3. LU/LC analysis highlights the area that is categorized by wasteland (Barren and Scrub total land is 238.22 sq.km.), thin vegetation, highly uneven and dissect topography. It causes geo-environmental issues like degradation of soil and high runoff.

4. The composite score highlights sub basins such as DARN_B02, DARN_C02, DARN_C04, DARN_C05, DARN_C06, DARN_C07, DARN_C09, DARN_C13, DARN_C14, DARN_D01, DARN_D02, DARN_D03, DARN_D04, DARN_D05, DARN_D06, DARN_D07, DARN_E01, DARN_E02 and DARN_E03 for high priority level. These basins cover 278.17 sq. Km. area, which is 78.75 % of the total land surface area and is located mainly in the North, North-West and South part of the study area. It is associated with considerable soil erosion and excessive surface runoff.
5. There is a dearth of proper conservation plans for water and soil, which in turn leads to soil erosion, loss, degradation and excess runoff and thereby heavy siltation in Darna Lake Catchment.

The strategic recommendations has been suggested for prevention of soil erosion, severe surface runoff and thereby sedimentation of Darna Lake to maintain storage capacity. This study has identified that there is scope to introduce treatment measures such as engineering measures and biological measures. Treatment measures for individual sub-basins are suggested on the basis of priority level i.e. very high, high, medium, low and very low. In very high priority level there are 19 sub-basins which covers about 78.75% area where, PT, BGP, CCT, BT, fodder Plantation and Horticulture etc. measures are recommended. For second priority level GCS, BT, CB, Agro-forestry, fodder plantation and mixed vegetation etc. measures are suggested. This priority level consists of 6.95 % land surface area with 19 sub- basins. In medium priority level CD, PT, EGP, Afforestation etc. measures are suggested. This level consists of 27 sub-basins and covers 7.33 % land surface area. EGP, BGP,CB, horticulture, medicinal plant species and Fodder plantation measures are suggested for low priority level which covers 15.12 % land surface area and 36 sub-basins. Finally, for very low priority level EGP, Timber, Horticulture and Fodder plantation has been suggested. This priority level has 39 sub-basins and covers 9.51 % area.

This study may be useful for understanding morphometric analysis for basin, investigation and experiments in Darna Lake Catchment area to conserve natural resources and for useful to their better planning. This study may attract attention of geomorphologist, experts belongs to administration, policy maker and regional planner for further in-depth study and better planning and further management of Darna Lake Catchment.

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