Geospatial Modeling for Assessing Ground Water Resources: A Study in Dimapur Area, NE India

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Master of Technology in Remote Sensing and Geographic Information System

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Dedicated to my Parents

and teachers

CERTIFICATE

This is to certify that the project entitled **"Geospatial Modeling for Assessing Ground Water Resources: a Study in Dimapur Area, NE India"** is a bona fide record of work carried out by **Mr. Y. Benthungo Murry**. The report has been submitted in partial fulfilment of requirement for the award of Master of Technology in Remote Sensing and GIS in Natural Resource Management with specialisation in Geosciences, conducted at Indian Institute of Remote Sensing, Dehradun, during August 21, 2011 to August 16, 2013. The work has been carried out under the supervision of **Dr. S. K. Srivastav**, Scientist/Engineer- 'SG' and **Mr. Prasun Kumar Gupta,** Scientist/Engineer- 'SD', Geoinformatics Department.

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ABSTRACT

Ground water is a major source for all purposes of water requirements in India and it plays a vital role to human life and economic activity. The occurrence and distribution of ground water in the country varies significantly depending on geology, rainfall and geomorphology. The unplanned and non-scientific development of ground water resources has led to sharp depletion of the resources and also degradation of quality at many places. The prime focus of this study is for a holistic understanding of ground water occurrence, resources and quality in the study area by mapping prospective zones, estimating recharge and by evaluating the ground water quality parameters and their spatial distributions using geostatistical methods.

The present study area falls under Dimapur and Peren districts of the state of Nagaland and under Karbi Anglong district of Assam. With rapid growth of population and urbanization water requirements for drinking and other purposes is also increasing at high proportion in the area.

A ground water prospects map was prepared in ArcGIS by using LISS III data, survey of India Toposheets and existing literatures in conjunction with field work. Multi-criteria evaluation technique (AHP) was performed for all the thematic layers and their different classes. All the thematic layers were integrated in ArcGIS by using Index overlay and final ground water prospects map was prepared. The ground water prospects map was categorized into five zones - Very High, High, Moderate, Low and Very Low. Ground water recharge was estimated using lumped Water Balance approach (GEC,1997) and a distributed physical, hydrological model (VIC). Since there are no irrigation facilities in the study area, recharge estimation was made only for non- command area. More than 50 Water samples were collected from different sites in the study area during pre-monsoon and post monsoon in the year 2012. Preservation and transportation of the water samples to the laboratory followed standard methods. The physical and chemical parameters of the samples were analyzed in the laboratory following standard methods. Ionic balance was calculated for major cations and anions to verify the accuracy of the chemical analysis. Using the Trilinear diagram the ground water was classified into Ca^{2+} HCO_3 type, Ca^{2+} Na^+ HCO_3 Cl type, Ca^{2+} Na^+ HCO_3 type, Ca^{2+} Na^+ Cl type, Na^+ HCO_3Cl type and Na^+ HCO_3 type.

The chemical analysis results were compared with BIS: 10500 (2004) standards to examine the suitability for drinking purpose. Except Iron, nitrate and sulphate, all the parameters analyzed were found to be within the desirable limits of BIS: 10500 (2004) standards. The pH value shows that the ground water in the study area is neutral to slightly acidic in nature. Different spatial interpolation techniques such as IDW (Inverse Distance Weighting) and Kriging were tested to obtain the spatial distribution of ground water quality parameters. Results showed that IDW is the best interpolation method for the data.

This study demonstrates that integration of Remote Sensing, GIS, Traditional Fieldwork and Models provide a powerful tool in understanding the occurrence, resources and quality of ground water.

Key words: Geostatistical methods, ArcGIS, LISS III, Analytical Hierarchial Process, (GEC,1997) norms, VIC model, Ionic balance, Trilinear diagram, IDW, Kriging.

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1. INTRODUCTION

1.1 Background

Ground water constitutes about two thirds of the freshwater resources of the world. In India it is a major source for all purposes of water requirements. It plays a vital role in the country's economic development and in ensuring its food security. More than 90% of rural and nearly 30% of urban population depend on ground water for drinking water. It also accounts for nearly 60% of the total irrigation potential in the country (NRSA, 2008). The demand for ground water is increasing due to rapid growth in population, industrial development, urbanization and increase in agricultural activities. As per the Central Ground Water Board, 2009 report the Annual Replenishable Ground Water Resource for the entire country is 431 billion cubic meter (bcm), Net Annual Ground Water availability is 396 billion cubic meter whereas the Annual Ground Water draft for irrigation, domestic and Industrial is 243 billion cubic meter and the stage of Ground water Development for the country as a whole is 61%.

The occurrence and distribution of ground water in the country varies significantly depending on geology, rainfall and geomorphology. In regions like North West India ground water resources are depleting whereas the eastern parts of the country have plenty of ground water resources which remained unexploited. The distribution of rainfall also varies widely both in time and space. Most of rainfall (about 76%) occurs during the Monsoon months resulting into eight comparatively dry months. Similarly, the Meteorological subdivisions like North east India, coastal Karnataka and Goa receives more than 250cm of rainfall annually while West Rajasthan gets only about 30cm (IMD, 2011).

Although the ground water available in the country, in general, is potable and suitable for various uses, localized occurrence of ground water having various chemical constituents in excess of the limits prescribed for drinking water use have been reported in many states. Arsenic concentrations, above permissible level of 50 ppb, have been observed in the alluvial plains of Ganges covering six districts of West Bengal. Increasing incidence of fluoride concentrations (above permissible levels of 1.5 ppm) have also been reported from 69 districts in 14 Indian states (e.g. Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal). It is estimated that about 65% of Indian villages are exposed to fluoride risk (Kumar and Shah @www.indiawaterportal.org). All these areas excepting West Bengal were also reported to be associated with high levels of salinity risks. Presence of heavy metals in ground have also been reported from 40 districts in 13 Indian states (e.g. Andhra Pradesh, Assam, Bihar, Haryana, Himachal Pradesh, Karnataka, Madhya Pradesh, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, and West Bengal) and several blocks of NCT- Delhi (Kaur and Rani, 2006) and Gurgoan and Mewat districts (Kaur et al., 2008).

In the Northeast there are substantial unutilized ground water resources. The total water resource potential is estimated to be about 537.2 cubic Kilometers (30 percent of national total) and total replenishable ground water potential to be about 26.55 cubic kilometers per annum (6 percent of national total). In spite of the region's huge water resource potential, it still accounts for some of the most water – starved pockets of the country. The level of ground water development in the states of the Northeast is low. The ground water potential developed so far is about 4.3 percent.

In Nagaland, surface water in rivers, streams, ponds and natural springs and subsurface water occurring as ground water are the important sources of water for various uses. As per the assessment carried out by CGWB in the year 2009, the annual Replenishable Ground Water Availability is 0.38 bcm, the annual ground water Draft is 0.01 bcm (0.008 bcm) and stage of Ground water development is 2% (2.14 %). Entire state has been categorized as safe. Ground water has been partially harnessed for drinking and other purposes by construction of medium to deep tube wells in Dimapur. Although there is no data regarding extraction or extent of ground water usage, it is estimated that ground water meets more than 60% of water requirement in Dimapur. The dependency on ground water is expected to increase in future due to rapid growth in population and urbanization.

Remote sensing and GIS have emerged as very useful and complementary tools in ground water studies. Conventional surveys, apart from being unfeasible in the inaccessible and inhospitable terrain, are tedious, time consuming and inaccurate in mapping many features of regional nature due to lack of regional perspective. Satellite imagery by virtue of providing synoptic view of the terrain at regular intervals offer immense potential in generating the information on parameters required for ground water exploration, exploitation and development. Remote sensing and GIS have been increasingly used for recharge estimation, draft estimation, mapping of prospective Zones, identification of over exploited and under developed/ undeveloped areas and prioritization of areas for recharge structures which conjunctively facilitate systematic planning, development and management of ground water resources on a sustainable basis. This research work is an effort to have better understanding of the ground water occurrence, resources and quality in the study area by using Remote Sensing and GIS techniques in combination with field/existing data.

1.2. MOTIVATION AND PROBLEM STATEMENT

Water is a state subject (entry 17, List II) and the management of ground water resources is a prerogative of the concerned State Government. The unplanned and non-scientific development of ground water resources, mostly driven by individual initiatives has led to sharp depletion of the resources and also degradation of quality at many places. The adverse impacts can be observed in the form of long-term decline of ground water levels, de-saturation of aquifer zones, increased energy consumption for lifting water from progressively deeper levels and quality deterioration due to saline water intrusion in coastal area in different parts of the country. There is urgent need for coordinated efforts by all the stakeholders for evolving and implementing suitable ground water management strategies in the country.

In Nagaland exploitation of ground water is limited. Exploration by Central Ground water Board (CGWB) has revealed that the intermontane valleys as well as the Dimapur valley contain enormous ground water potentials. However, lack of information and absence of a knowledge-driven decision support system are major barriers for sound planning and strategies for development and management of ground water resources including their conservation, augmentation, protection from pollution and regulation of extraction.

The water resources in the state are also facing threat due to various natural and human influences. In hilly areas, most of the drinking water is harnessed from ponds, rivers and natural springs. However, many are becoming seasonal and polluted. The natural hydrological cycle has been altered due to deforestations and destruction of the catchment areas. This has resulted in reducing the infiltration capacity and the crucial link feeding the source of the rivers, streams and underground aquifers is being lost. Apart from this, pollution from untreated sewage, industrial effluent, agricultural run-off, etc are also contaminating the water sources.

With the population of Dimapur increasing at an alarming rate, water requirements for drinking and other purposes is also increasing at high proportion. As per the provisional population census 2011, Dimapur district has the highest urban population of 1,97,277 comprising 34% of the urban population of the state. To meet the growing demand for drinking, domestic and industrial sector and to address various issues related to ground water, there is an imperative need to prepare a comprehensive road map with identified strategies for scientific and sustainable management of the available ground water resources. The first step towards achievement of this task is creation of is a reliable hydrogeological database for exploration, assessment, development, management, and regulation of ground water, the lack of which is negatively impacting the planning and implementation of development and management initiatives. Therefore, a systematic hydrological study was carried out in the study area to provide scientific database on ground water.

1.3. AIMS & OBJECTIVES

The prime focus of this study is for a holistic understanding of ground water occurrence, resources and quality using geospatial modeling.

1. To Map prospective zones for ground water in the study area.

2. To estimate ground water recharge using lumped Water Balance approach (GEC methodology) and a distributed physical, hydrological model (VIC).
3. To evaluate the ground water quality in the study area and to determine spatial distribution of water quality parameters using geostatistical method.

1.4. RESEARCH QUESTIONS

1. Where are the ground water potential zones in the area?
2. How a distributed physical, hydrological model (VIC) performs for recharge estimation as compared to lumped Water Balance Approach (GEC methodology)?
3. What are the hydro-chemical characteristics of ground water in the area?

1.5. THESIS TRUCTURE

The whole thesis is divided into six chapters. The first chapter provides general introduction about the research work including problem statement, research objectives and questions. The second chapter deals with literature review in which the related works with respect to the research work are presented. In the third chapter information about the chosen study area is given. The fourth chapter gives description about the methodology and the materials/data used. Fifth chapter presents the findings of this research work and a detailed discussion on the results obtained. In the sixth chapter a conclusion is drawn based on the results obtained along with some recommendations.

2. LITERATURE REVIEW

2.1. Ground Water Prospects Zonation

Ground water targeting and prospects mapping is one of the thrust areas in ground water studies as it is integral for ground water exploration and development. It entails identification and mapping of prospective zones for ground water exploitation. The methodology for preparing ground water maps using satellite imagery has undergone many changes over the past decades. In the beginning, the remote sensing data, namely aerial photographs and satellite images were used mostly to update and refine the conventional hydrogeological maps prepared from ground surveys. Later, many organizations in the country including National Remote Sensing centre (NRSC)/ Department of Space (DOS), Central ground water Board (CGWB), ground water departments of different states, research laboratories and academic institutions have started preparing the ground water maps through a systematic visual interpretation of satellite data with limited field checks. The Department of Space (DOS) in association with State Remote Sensing Application Centers prepared district-wise 'ground water potential maps' at 1: 50,000 scale for the entire country during 1987-90 period. Subsequently, under Rajiv Gandhi National Drinking Water Mission (RGNDWM) project, initiated in late 1998 by the DOS, 'ground water prospects maps' at 1: 50,000 scale are being prepared (NRSA 2000, 2008). The mapping work has been carried out in different phases. About 83-95 % success rate has been reported by the line Depts. of the State by making use of the RGNDWM maps while implementing the drinking water supply schemes from ground water resources. Many other studies utilizing remote sensing and GIS techniques in ground water potential zoning have been carried out in India and abroad.

The most important aspect of remote sensing systems is the synoptic and temporal coverage of the Earth's surface which helps hydrologists improve the understanding of the geohydrological system, especially in inaccessible and unexplored areas (Hoffmann and Sander, 2007). Since, RS data have limitations with regard to depth penetration, a linkage between surface manifestations observed on remote sensing data and the subsurface hydrological phenomena has to be established (Jackson, 2002). It is pointed out by various researchers that RS data can be used in the best manner if they are integrated with field measurements, Geographical Informmation System (GIS) and modeling techniques (Becker, 2006; Meijerink et al., 2007).

A ground water prospects map can be prepared by using satellite data and GIS technique in conjunction with field work. The methodology may be divided into two main stages. The first stage involves the delineation of hydrogeomorphic units considering parameters influencing the hydrogeological properties. It consists of a) creation of individual thematic layers on lithology, geomorphology, lineaments, and hydrology along with base map details based on visual interpretation of satellite data in combination with field/existing data, and b) derivation of hydrogeomorphic units by integrating the thematic data. The second stage deals with the evaluation of hydrogeomorphic units based on hydrogeological characteristics of controlling parameters.

The data thus produced at different stages is organized into a digital database. The database consists of 1) basic data as different layers 2) individual thematic maps for all the four parameters and base map details and 3) integrated ground water prospects map as a final output.

2.2. Recharge Estimation

Ground water recharge may be defined as the 'downward flow of water reaching the water table, forming an addition to the ground water reservoir' (Lerner et al., 1990).

There are several techniques for ground water recharge assessment. These techniques can be largely classified into three groups – lumped water balance approach, tracer technique and discrete numerical modeling (Table2.1). These three techniques are again sub-divided into surface water, unsaturated zone and saturated zone on the basis of hydrologic sources or zones from which data are obtained.

Table 2.1: Various recharge estimation techniques (summarized by CGWB from Scanlon et al., 2002)

	Lumped water balance approach	Tracer	Numerical Modeling
Techniques based on surface water	▪ Base flow discharge ▪ Spring hydrograph analysis ▪ Channel-water budget ▪ Seepage meters	▪ Heat Tracers ▪ Isotopic tracers (stable isotopes of oxygen and hydrogen	Rainfall-runoff/watershed modeling (recharge estimated as balance term in water budget) (SWAT, HELP3, TOPO_IRM, PRZM-2, SMILE, ANSWERS, PERFECT,ETC; Jyrkama et al.2002)
Techniques based on unsaturated Zone	▪ Lysimeters ▪ Zero-fluz ▪ Darcy's Law	▪ Applied tracers (bromide, ^3H, dyes) ▪ Historical tracers (^3H, ^{36}Cl) ▪ Environmental tracers (Cl)	

Techniques based on saturated zone	▪ Water table fluctuation method ▪ Darcy's law	▪ Historical Tracers (^{3}H, $^{3}H/^{3}He$, CFC) ▪ Environmental tracers (Cl, ^{14}C)	Ground water flow modeling (recharge estimated by calibrating hydraulic heads) MODFLOW, MIKE-SHE, etc.

Lumped water balance approach

Lumped water balance approach, also known as continuity equation, involves the use of the principle of conservation of mass to account for the quantitative changes occurring on the various components of the hydrologic cycle.

Tracer techniques

Tracer techniques estimates ground water recharge by using environmental (Cl) and applied tracers such as bromide, chlorofluorocarbons (CFCs) and tritium/ helium-3, ^{18}O, visible dyes, etc. This technique identifies ground water recharge from river and other water bodies based on surface water studies. It is also used in both saturated and unsaturated zones to estimate recharge. Lerner et al. (1990) divided tracer technique into signature methods and throughput methods.

Numerical modeling

Numerical ground water modeling entails simulation of ground water flow equation in the specified spatial and time domain using discrete approach. It is a handy investigation tool for a number of applications including water balance.

Unsaturated-zone modeling is applied to estimate deep drainage flow below the root zone recharge in response to meteorological forcing. A number of approaches are used to simulate unsaturated flow, including soil-water storage-routing approaches (bucket model), quasi-analytical approaches, and numerical approaches to the Richards equation (Scanlon et al. 2002).

Different techniques of recharge estimation have been widely applied under various climatic and hydrogeological conditions all over the world. Recharge estimation using hydrograph separation, isotopic tracers (stable isotopes of oxygen and hydrogen), Lysimeters, soil moisture technique, Mixing-cell models (compartment models, lumped models and black-box models) and tracer techniques have been extensively experimented and used by many workers in different parts of the world. Three independent methods were used for comparative evaluation of recharge methods in the small watersheds in the rain forest belt of Nigeria. The methods include – recharge estimation using water level and porosity, base flow recession analysis and water balance method. The results shows that recharge values obtained from water balance method were constantly higher than values from other methods. However, these methods complement each other and can be used depending on the availability of data required for computations (Simmers, 1988). The CMB (chloride mass balance) approach has been extensively used for estimating low recharge rates, mainly because of the lack of other suitable methods. Low water fluxes ranging from 0.05 to 0.1 mm/ year have been estimated in arid regions in Australia and in the US. The storage concept using water table fluctuation has been used in various climatic conditions (Scanlon et al., 2002). Recharge rates estimated by this technique range from 5 mm/year in the Tabalah Basin of Saudi Arabia (Abdulrazzak et al. 1989) to 247 mm/ year in a small basin in a humid region of the eastern US (Rasmussen and Andreasen, 1959). Numerical modeling techniques have been extensively used by USGS for estimation of recharge in Regional Aquifer System Analysis (RASA)

The different techniques for recharge estimation have also been applied in various parts of India (Baweja & Karanth, 1980, Simmers, 1988, Karanth, 1987, Sharma, 1989, GEC- 1997, Kumar, 1997, Chatterjee and Jha, 2006). Recharge estimation based on hydrograph separation, Lysimeters, soil moisture techniques, saturated zone concept, CMB, tritium injection technique and numerical modeling techniques have been widely used by many workers and organizations in various parts of the country. However, based on experiences, many workers have advocated the use of multiple techniques given that certain uncertainties are associated with each technique and that different techniques complement each other.

In India, recharge estimation is carried out by using the methods recommended by the Ground Water Resource Estimation Committee (GEC, 1997) constituted by the government of India. GEC recommends the use of 'Water Table Fluctuation' (WTF) method and rainfall infiltration factor method for estimating ground water recharge.

In WTF method, pre-monsoon (April/May) and post-monsoon (October/November) water levels recorded in a ground water assessment unit are used to compute the water table fluctuation which is then multiplied by the relevant specific yield of the aquifer and the area occupied by it. Specific yield is calculated either through field studies or using norms recommended by GEC-1997 In areas, where WTF data are not available, 'rainfall infiltration factor' (RIF) method is used in which rainfall infiltration factor relevant for the formation is multiplied with average annual rainfall and rechargeable area to estimate recharge. GEC (1997) has recommended different rainfall infiltration factors for major lithological units of the country. The recharge from canals, applied irrigation, surface water bodies, etc. due to return flow or seepage, and draft from abstraction structures are accounted to quantify the total recharge, net ground water availability, and stage of ground water development.

2.3. VIC Model

In hydrological modeling mathematical expressions are applied to define quantitative relationship between inputs (e.g. flow-forming factors) and outputs (e.g. flow characteristics). The scope of hydrological modeling and its applications has expanded considerably over the past decades. Hydrologic modeling deals with the spatial processes of the hydrologic cycle and is often used to evaluate basin water resources as well as for impact assessment or more precisely water resources management. Numerous hydrologic models have been developed and they are used to determine the performance of watersheds under land use changes, climate change, and increased climate variability.

“Prior to the advent of the hydrograph by Sherman (1932), hydrologic modeling was mostly empirical and based on limited data. In those days, graphs, tables and simple analytical solution were the standard models, and hand calculations, in conjunction with slide rule, reflected computing prowess” (Singh and Fiorentino, 1996). With the advent of the hydrograph, hydrologic modeling has developed into data intensive, computer software driven science. Hydrologic models can be either lumped or spatially distributed; single-event or continuous simulation; empirical or physically-based; and stochastic or deterministic modeling. Today, there are models covering every aspect of water’s interaction with the environment.

VIC model is a semi-distributed macroscale hydrological model which represents surface energy, hydrological fluxes and states at scales ranging from large river basins to the entire globe. It is grid based and quantifies the dominant hydro-meteorological process taking place at the land surface atmospheric interface. VIC computes the vertical energy as well as moisture flux in grid cell based on specification at each grid cell considering soil properties and vegetation coverage. Generally, grid resolution ranges from 1/8 to 2 degree (http://www.hydro.washington.edu). To simulate streamflow, VIC uses a separate routing model based on a linear transfer function. VIC has been used widely in many areas ranging from water resources management to land atmosphere interactions and climate change.
Since its development, VIC has undergone many modifications and improvements to deal with complex hydrological processes. As compared to other land surface model, VIC has a unique characteristics such as: sub-grid variability in land surface vegetation classes; sub-grid variability in the soil moisture storage capacity; drainage from the lower soil moisture zone (baseflow) as a nonlinear recession; inclusion of topography that allows for orographic precipitation and temperature lapse rates resulting in more realistic hydrology in mountainous regions.

VIC model can be run in either a water balance mode or a water-and-energy balance mode. The water balance mode does not solve the surface energy balance and it requires considerably less computational time than other model modes although the exceptions to this are that the snow algorithm and the frozen soil algorithm which solve the surface energy balance. The full water-and-energy balance mode not only solves the complete water balance but also minimizes the surface energy balance error. The surface energy balance is closed through an iterative process and it requires more computational time than the water balance mode.

VIC has been well calibrated and applied in many large river basins over the continental US and in other parts of the world (Abdullah et al. 1996; Bowling et al. 2000; Lohmann et al. 1998b; Nijssen et al. 1997, 2001a; Shi et al., 2008 Su et al., 2005, 2006; Wood et al, 1997; Zhu and Lattenmaier, 2007). VIC has participated in the WCRP Intercomparision of Land Surface Parameterization Scheme (PILPS) project and the North American Land data Assimilation System (NLDAS), where it has performed well in comparisons to other schemes and to available observations (Bowling et al, 2003a, b; Lohmann et al., 2004; Nijssen et al. 2003; Wood et al., 1998). It has also been assessed using soil moisture observations in the U.S. (Maurer et al, 2002) and global snow cover extent data by (Nijssen et al, 2001b).

VIC has been used to provide a long-term data record of land surface budgets for the conterminous United States (1950-2000) (Maurer et al., 2002) and Mexico (1925- 2004) (Zhu and Lattenmaier,2007). Such data record have been used in many areas such as: simulating ensembles of streamflow and hydrologic variables for forecast purpose (Hamlet and Lattenmaier, 1999; Wood et al., 2002, 2005; Wood and Lattenmaier, 2006); reconstructing and analyzing drought events (Andreadis and Lattenmaier, 2006a; Sheffield et al., 2004a; Sheffield and wood, 2007; Wang et al., 2009); studying the North American monsoon telecommunications (Zhu and Lattenmaier, 2005; Zhu et al., 2007, 2009); drought prediction (Luo and wood, 2007); conducting hydrologic studies over the Pan-arctic region (Bohn et al., 2007; Bowling et al., 2003c; Lettenmaier and Su, 2009; Slater et al., 2007; Su et al., 2005, 2006); water management (Adam et al., 2007; Haddleland et al, 2006a, b, 2007); and many others.

2.3.1. Major Components of VIC Model

Vegetation cover

Vegetation library and vegetation parameter file represents all information related to vegetation in VIC model. The land cover (vegetation) classes with their leaf area index (LAI), canopy resistance, surface albedo and relative fraction of roots in each of the soil layers are specified in terms of fraction of grid cell they occupy. Infiltration, moisture flux between the soil layers and runoff are calculated according to the vegetation cover type. Baseflow and surface runoff are calculated independently for each vegetation type and then summed over the composition vegetation within each grid cell.

Soil Layers

Soil characteristics can be represented for a user defined number of vertical layers. There are usually two or three layers which are divided into thin upper layer and secondary set of layers. Soil parameter for each grid and soil layer is specified in user defined soil parameter file.

Rainfall

VIC model considers the sub-grid variability of precipitation as a function of rainfall intensity. Precipitation distribution can be expressed as follows,

$$\mu = (1 - e^{-aI})$$

Where, I = Precipitation intensity, a= coefficient which describes the effect of grid cell size and geography.

The fractional coverage changes according to the change in precipitation intensity of a storm. When intensity increases, the fractional coverage over a grid cell increases and when decreased fractional coverage also decreases. Before the occurrence of a storm the soil water content throughout the grid cell is set to average. Forcing data plays an important role and accordingly simulation can be done hourly, 3 hourly, daily or monthly.

Snow cover:

VIC model can make a reliable simulation of snow pack process in high altitude areas for a wide range of grid resolution. Effect of vegetation cover on snow accumulation and melt is described internally within the VIC model through a coupled snow model.

2.3.2. VIC Model Input Parameters

Soil parameters: The soil parameters file describes the soil properties for each grid cell in the model domain. It is also the main file that identifies the grid cells and their latitudes and longitudes (which is used to find the forcing files for the grid cells) for simulation. The 5-min Food and Agriculture organization data set (FAO, 1998b) can be used for deriving soil texture information and soil bulk densities.

Vegetation parameters: Land cover classification was based on the University of Maryland global vegetation classifications described by Hansen et. al (2000) which has 14 different classes and a spatial resolution of 1Km. The land cover types present in each grid cell in the model domain and the proportion of the grid cell occupied by each class are identified from these global data. The vegetation parameter uses the same grid cell numbering as the soil file (latitudes and longitudes are not included in the file) and describes the vegetation composition of each grid cell. This file cross-indexes each vegetation tile to the classes listed in the vegetation library.

Meteorological and Radiative Forcings: The VIC model is forced with meteorological data which include precipitation, temperature, wind speed, vapor pressure, incoming long wave and shortwave radiation, and air pressure.

Calibration: The VIC model like other physically based model has many parameters that must be specified (about 20, depending on how the term "parameter" is defined). The majority of these parameters can be derived from in situ measurement and remote sensing observation. It usually involves calibration of six parameters: a) the infiltration parameter (b_i), which controls the partitioning of rainfall into infiltration and direct runoff (a higher value of b_i gives lower infiltration and yields higher surface runoff); b) $D_2$and $D_{3,}$ which are the second and third soil layer thickness and effect the water available for transpiration and baseflow, respectively; c) Ds_{max}, Ds, and Ws, which are baseflow parameters and also are estimated via calibration. Ds_{max} is the maximum baseflow velocity, Ds is the fraction of maximum baseflow velocity, and Ws is the fraction of maximum soil moisture content of the third soil layer at which non-linear baseflow occurs. These three baseflow parameters determine how quickly the water stored in the third layer is evacuated as base flow (Liang et al., 1994). The three baseflow parameters and the third soil layer depth (d_3) (Niijssen et al., 2001a. Su et al., 2005) are used with only minor adjustment during the calibration, while the infiltration parameter (b_i) and the second soil depth (d_2) are independently and intensively calibrated.

2.4. GROUND WATER QUALITY

The overall goal of a ground water quality assessment is to obtain a comprehensive picture of the spatial distribution of ground water quality and of the changes in time that occur, either naturally, or under the influence of man (Wilkinson and Edworthy, 1981). Timely water quality management, and/ or pollution control measures can be taken based on comprehensive and appropriate water quality information obtained from well designed and executed assessment programme.

The chemical composition of ground water may influence its utility as sources of water. The types and concentrations of dissolved constituents in the ground water determine whether the resource, without prior treatment, is suitable for drinking-water supplies, industrial purpose, irrigation, or other uses. Changes in the concentrations of certain constituents of ground water, whether because of natural or anthropogenic causes, may alter its suitability as a source of water. Assessing ground-water quality and development strategies to protect aquifers from contamination are essential facets of water-resource planning.

Ground water contains many dissolved minerals and organic constituents in various concentrations. The most common dissolved mineral substances are sodium, calcium, magnesium, potassium, chloride, bicarbonate, and sulphate which are called common constituents. They are not harmful if they are within permissible limits. Ground water is less prone to bacterial pollution than surface water because the soil and rocks through which ground water flows screen out most of the bacteria. Major chemical elements including Na^+,

K^+, Ca^+, Mg^{2+}, Cl^-, HCO_3^-, and $SO4^{2-}$ are very important in classifying and assessing ground water quality.

The natural chemical composition of ground water is influenced mainly by type and depth of soils and subsurface geological formations through which ground water passes. Ground water quality is also influenced by contribution from atmosphere and surface water bodies and by anthropogenic factors as well. Inorganic contaminants including salinity, chloride, fluoride, nitrate, iron and arsenic are important in evaluating the suitability of ground water for drinking purposes. Once polluted, a ground water body could remain so for decades, or even for hundreds of years, because the natural processes of through-flushing are very slow.

There are several spatial interpolation methods such as Inverse Distance Weighting (IDW), Local Polynomial, Radial Basis and Kriging for spatial distribution of water quality parameters. Inverse distance weighting which is a deterministic and exact interpolation method is most appropriate for limited sample size and random data points. In exact interpolation the surface passes directly through the known points. IDW uses the neighbouring points to interpolate the area between the points based on a weighted distance function (Flock, et al., 2004). Kriging works best when additional data are available due to its dependence on the use of random functions; data requirements of stationary stochastic process and normal distribution; and interpolation based on statistical methods. Kriging is stochastic and can be exact or inexact based on the error associated with the data measures. The flexibility of kriging relies on the parameter settings and it also assesses autocorrelation and errors of the prediction (Haining, 2003). Nowadays, many variants of Kriging are in general use, these are: simple kriging, ordinary kriging universal kriging, block kriging, co-kriging and disjunctive kriging. A semivariogram is used to describe the structure of spatial variability. The semivariogram plays a vital role in the analysis of geostatistical data using the Kriging method. They take into account the spatial autocorrelation in data to create mathematical models of spatial correlation structures generally expressed by variograms (Gundogdu and Guney, 2007).

3. STUDY AREA

The study area largely falls under Dimapur and some parts of Peren districts of the state of Nagaland. A small part of the study area also falls under Karbi Anglong district of Assam. It lies between 25°33' and 25° 58' North latitudes and 93°32' and 93°49' East longitude and covers an area of about 688 km^2. It is covered by survey of India toposheets 83G/9, 83G/ 10, 83G/13, and 83G/14, and is bounded by two major rivers, Dhansiri in the West and Diphu (Chathe) in the North.

Dimapur, derived its name from a Kachari word 'Dimasa' after the river which flows through the district. It is located between 25˚ 39' 1.74" and 25˚58' 10" N latitude and 93˚32' 23.54" and 94 ˚2' 47.35"E longitude and is bounded by Peren district on the south and east, Karbi Anglong district of Assam on the west and Golaghat district of Assam in the west and north. The average elevation of the district is 260 meters above sea level and has an area of 927 sq km. The city has a heterogeneous mix of people from all over India, and for which it is also known as "mini India". According to 2011 census, Dimapur district has a population of 379, 769. The sex ratio is 916 females for every 1000 males.

Dimapur is an important commercial centre for the region, acting as a gateway to Nagaland and the neighbouring state of Manipur. This fast developing district is also the commercial hub of the state. It is connected by both rail and air. The National Highway 29 passes through the heart of this commercial centre of the state and is 74km from Kohima, the capital of Nagaland. A large part of the Dimapur district falls in the plains. Only the Medziphema sub divisions and few villages of Niuland sub divisions are located in the foothills.

Peren is one of the 11 districts of Nagaland and is located between 25˚30'40" and 25˚40' 50" N latitude and 93˚30' 40" and 93˚40' 50" E longitude. It is covered by the survey of India Toposheet No 83 G/6, 7, 10, 12, 14 and 15. The district has an area of about 1500 sq. km. and is bounded by the state of Assam on the west and southwest and Manipur on the east and south. The district has altogether 104 villages with a total population of 94,954 as per 2011census. Peren town is the district Headquarters and is located at a distance of 80 kilometers from the commercial town of Dimapur.

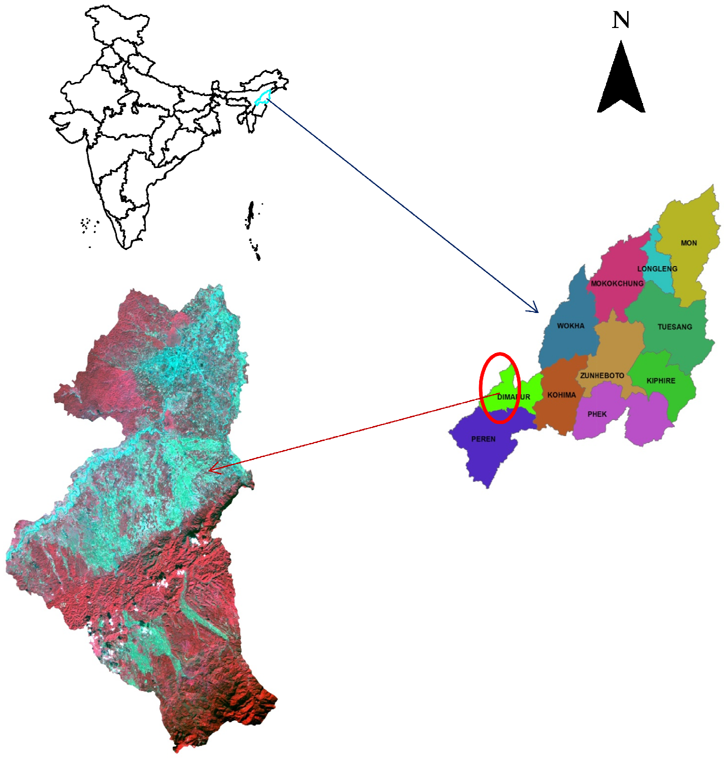

Figure 3.1: Map showing location of study area

3.1.1. Geomorphology

The study area can be divided into several geomorphic units such as alluvial plains, structural hills, residual hills, valleys and flood plains. Narrow to wide intermotane valleys are also found in the area. The hills are highly and moderately dissected and along the high hills the surface runoff is quite high and ground water recharge potential is low. In areas with undulating hills and isolated low hills, the ground water recharge is comparatively higher. The valley plains with flat gradient facilitate high ground water recharge. River terraces along the river valleys are very good conduit for ground water recharge.

3.1.2. Climate

Dimapur valley enjoys a subtropical type of climate with a maximum temperature of 37.06° C and a minimum of 12° C whereas the hilly areas under Peren experiences a cool and temperate climate with a maximum of 27˚ C and a minimum of 5 ˚ C. Average annual rainfall is 1025mm and occurs mostly from May to October and non-monsoon period is from November to May. The lower plain areas of the valley have a high relative humidity during summer season and ranges from 74% to 78%. However, it is lesser in the hilly areas.

3.1.3. Drainage

There are two main rivers in the study area namely, Dhansiri and Diphu (Chathe) rivers. These two rivers and their tributaries serve as the main source of water for irrigation and domestic purposes in Dimapur valley. Dhansiri river occupies the western margin of the study area and flows into Northeast direction and its important tributaries are Monglu, Langlong, Khuja Disa, Haza Disa, Langthai, Khova N, Disang N and Lahorijan N. Diphu river flows into Northerly direction and its main tributaries are Derker N, Kuki Pani, Hukha Phe Ru, Sojaker, Atu Ghoki, Dzumha, Theku Ru, Phetso Ru, Saisi N and Tomma N. Dhansiri river bed consist mainly of fine to sandy loam whereas the Diphu river bed is mostly made up of mantle of boulders, cobbles and gravels due to its fast flowing rate.

3.1.4. Geology

Geological formation of Dimapur area represents the frontal tract of the western most geotectonic framework of the Naga hill ranges known as "Naga Thrust", striking in a NE-SW direction. Rock formations encountered are the Tertiaries underlying the Quaternary deposit which forms part of the Northern extension of Arakhan Yoma Patkai range of Indo-Burma.

Dimapur area represents a sub-montane valley fills of Quaternary sediments lying over the Tertiary. It consists mainly of clays and pebbles. Thickness of Quaternary sediments gradually increases towards NorthWest of Naga Hills. They represent coalescence of outwash fan deposits formed by numerous streams due to steep fall on emerging out of the Talus slopes.

The hilly areas forming the southern part of the study area comprises geological formations ranging from Eocene to recent Age. It represents a fairly young mobile belt subjected to tectonic upheavals at different phases mostly during the Tertiary Period. The rocks found in these areas belong to Surma, Disang, Tipam, Barail and Dihing Groups of Tertiary and consists mainly of sandstones and shales.

3.1.5. Hydrogeology

Sub-surface data obtained from wells indicates three types of aquifer zones in Dimapur valley which are made up of medium to fine grained sand. The thickness of Aquifer zones and the depth at which they are encountered are 10m- 50m thick aquifers found within 100m depths, 8m- 40m thick aquifer within 200m and 12m-47m aquifer zone within 300m depth. Aquifer zones found within 150m depths have much higher discharge than the deeper aquifers. The discharge of these deep tube wells ranges from 15000 to 35000lp/h and their minimum drawdown is between 6-30m in Dimapur valley. Water table varies between 1.5-9.17m bgl and is shallow towards SE & SW of Dimapur. Ground water occurs in unconfined shallow aquifer and semi-confined to confined aquifer conditions in deeper aquifers.

The porosity and permeability of the sedimentary rocks in the hilly areas are partly due to coarser grain size of some rocks, weathering, fracturing and faulting. Ground water occurs in both unconfined and confined conditions. In the valley plains ground water occurs at shallow depths both under unconfined and confined conditions.

Ground water flows from South to North and deviate towards the Western direction. Recharge to both shallow and deep aquifer takes place mainly from precipitation. Inflows from rivers and streams to the highly permeable conglomeration of pebbles, cobbles and boulder terraces may also form a major proportion to ground water recharge. The slope of the country is from SE-NW and the drainage system emerging from the Hill ranges flows with the same trend. Although the nature of the ground water domain is yet to be established, it may be presumed that gradient of the flow would be in conformity with the trend of drainage slope.

4. MATERIALS/ DATA USED AND METHODOLOGY

4.1. MATERIALS/ DATA USED

1. IRS-P6 LISS III
2. CARTOSAT DEM
3. GEOLOGICAL MAP
4. ISRO-GBP LULC AND SOIL MAP
5. LITHOLOGS
6. WELL DATA, WATER QUALITY DATA AND METEOROLOGICAL DATA.
7. EXISTING RELEVANT LITERATURE.
8. SOI TOPOSHEET

SOFTWARE USED

9. ArcGIS 9.3
10. ERDAS IMAGINE 9.2
11. ROCKWORKS 15

4.2. METHODOLOGY:

The methodology used for this study is given below in the form of a flow chart (Figure 4.1).

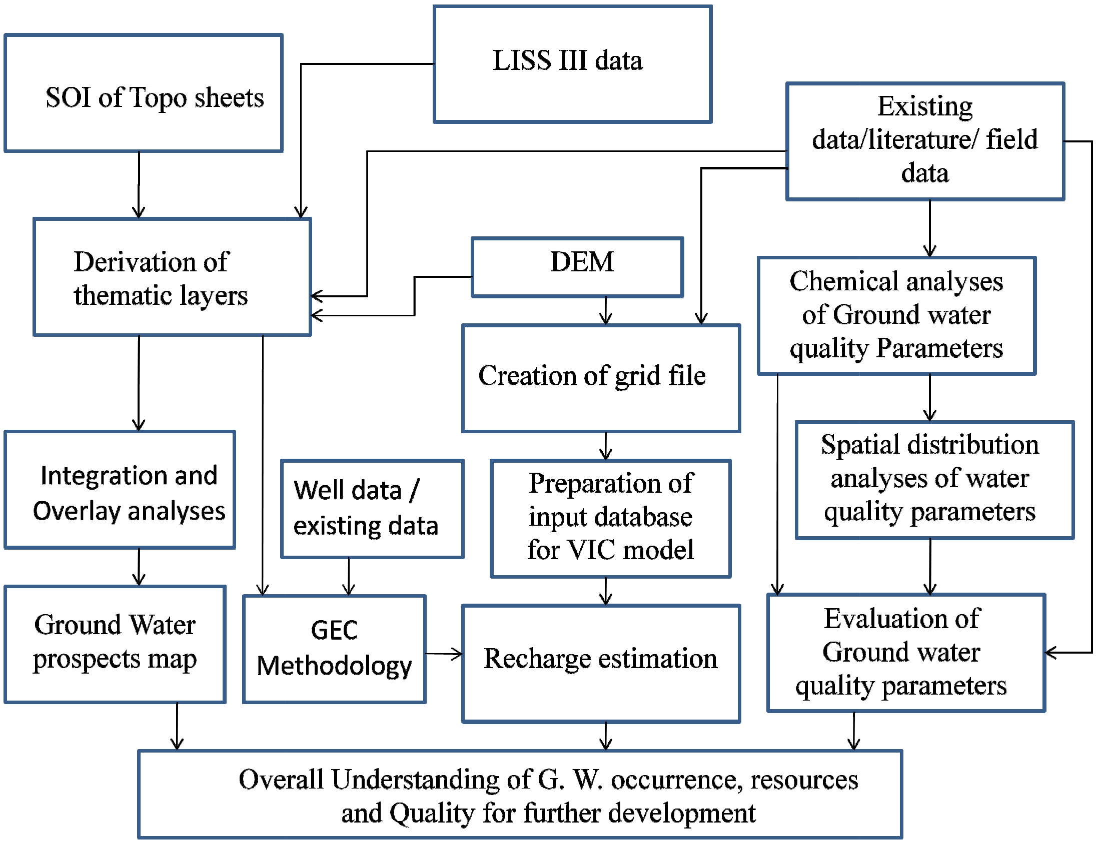

Figure 4.1: Flow chart showing the methodology

4.2.1. Methodology for Ground water prospecting

A ground water prospects map was prepared in ArcGIS by using LISS III data, survey of India Toposheets and existing literatures in conjunction with field work. The study area representing a watershed boundary was digitized from the survey of India Toposheets and it was compared with the watershed boundary derived from Cartosat DEM by using Hydrology in Arc GIS. The one derived from Cartosat DEM was used to generate all the thematic layers for ground water prospects mapping.

Geomorphology Map: Geomorphology map was prepared based on the visual interpretation of LISS III data and by using SOI Toposheets. All the landforms occurring in the area were mapped and they were represented as polygon layers.

Lithology Map: Lithology map was prepared in ArcGIS based on the visual interpretation of LISS III data and by using existing geological maps and literatures. All the rock formations in the study area were digitized as polygon features.

Drainage map: Drainage map was digitized from survey of India Toposheets in ArcGIS and it was updated by using the LISS III data. It was then compared with the stream network derived from Hydrology in ArcGIS. Drainage was digitized as lines as well as polygons. All the streams from 1st to 6th order including both perennial and ephemeral were mapped.

Drainage density map: Drainage density map was generated from drainage map by using spatial analyst tools in ArcGIS.

Slope map: Slope map was generated from Cartosat DEM in ArcGIS. It was divided into five classes.

Lineament map: Structural map was digitized in ArcGIS based on the visual interpretation of LISS III data and by using existing structural map and literatures of the study area. The structural features include faults, thrusts and fractures which are conduits and barriers for the movement of ground water. These structural features were represented as line features.

Lineament density map: Lineament density map was generated from lineament map by using spatial analyst tools in ArcGIS.

Multi-criteria evaluation technique (Analytical Hierarchial Process) was performed for all the thematic layers and their different classes. Each layer and class was assigned weight and rank depending on their suitability to hold ground water. All the thematic layers were then integrated in ArcGIS by using Index overlay and final ground water prospects map was prepared. The ground water potential index (GWPI) was determined by using the following formula:

GWPI = $(G_g{}^W G_g{}^r + D_g{}^W D_g{}^r + D_d{}^W D_d{}^r + L_h{}^W L_h{}^r + L_t{}^W {}_t{}^r + L_d{}^W L_d{}^r + S_s{}^W S_s{}^r)$/ Total Weight.

Where, G_g = geomorphology; D_g = drainage; D_d = drainage density; L_h = lithology; L_t = lineament; L_d = lineament density; S_s = slope. W represents the weight of a layer and r represents the rank of a class in the layer.

Field work / Data collection:

Field work was carried out in two phases. In the first phase, collection of samples and existing relevant data were done to provide information for mapping and accuracy estimation. In the second phase, the thematic maps prepared based on the satellite data were crossed-checked.

4.2.2. Methodology for Recharge Estimation by using GEC, 1997

Since there are no irrigation facilities in the study area, recharge estimation was made only for non- command area. The following two methods were employed to compute recharge:

a) Rainfall Infiltration Factor method
b) Water table fluctuation method

In Rainfall Infiltration Factor method, the area occupied by alluvium and sandstone with less than 20 Percent slope (rechargeable area) was multiplied with the relevant Rainfall infiltration factor and normal monsoon and non-monsoon rainfall to estimate recharge.

In Water Table Fluctuation method the following steps were followed:

(i) Recharge from Other sources (Tanks and Ponds) were computed.

(ii) Water Table Fluctuation was calculated for seven years from 2005 to 2011.

(iii) Gross ground water draft for all uses during monsoon season was calculated.

(iv) Change in ground water storage during monsoon season was calculated by multiplying the rechargeable area with the relevant specific yield and water table fluctuation.

(v) Gross ground water draft for all uses during monsoon season is added to change in ground water storage during monsoon, and recharge from other sources (Tanks and Ponds) during monsoon is subtracted from the resultant value to get the rainfall recharge during monsoon by ground water balance approach.

(vi) Rainfall recharge during monsoon by ground water balance approach is then normalized and compared with Rainfall Infiltration factor.

4.2.3. Methodology for Recharge Estimation by using VIC Model

Watershed delineation and stream network extraction

Watershed boundary and stream network were derived from Cartosat DEM (30 meters resolutions) by using Hydrology in Spatial Analyst Tools of Arc GIS 9.3. The process involves the following steps:

- Fill small sinks in the Digital Elevation Model
- Create Flow Directions
- Create Flow Accumulation
- Create Watershed Pour Points
- Delineate watersheds
- Calculate Watershed Area
- Analyze Watershed Stream Network.

Preparation of Grid files for the study area

A grid map having a size of 0.01 ° * 0.01 ° was generated by using Quantum GIS. Each grid is numbered starting from left top corner of the extent. The grid map was generated with ID, XMIN, XMAX, YMIN and YMAX Fields. Attributes such as Run grid, Grid number, Elevation, Slope, Average Annual Rainfall and Soil Texture were added to the Grid file.

Preparation of soil Parameter files

A GUI (Hydrological Modelling Tool (VIC)_v0.1 developed by IIRS under the aegis of IGBP) was used to prepare the soil parameter file. A soil map at 1: 250000 scale obtained from ISRO-GBP was rasterised and overlaid with the grid map to get dominant soil type in each grid. The grid file and the raster soil map were given as inputs in the GUI and a soil parameter file containing all other soil parameters for each of the textural class present in the study area was prepared. The sample soil parameter file with all parameters required is given in (Table 4.1).

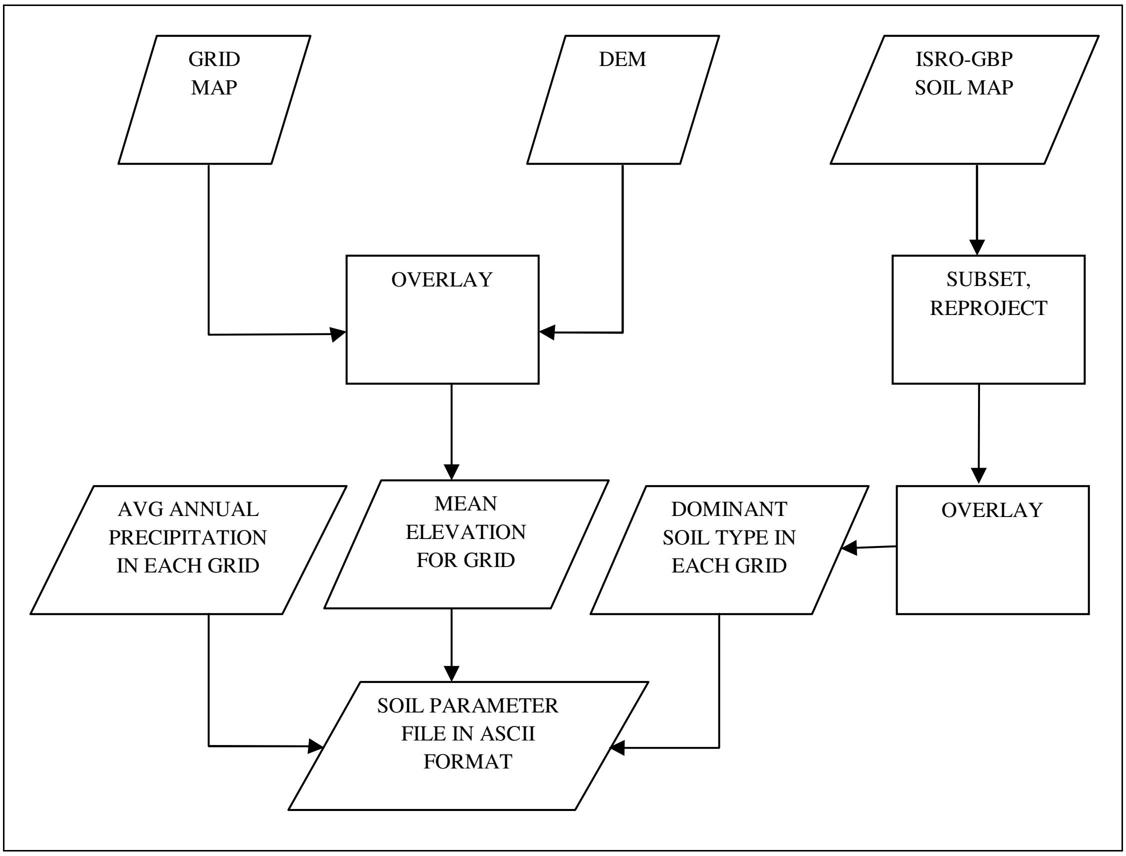

Figure 4.2: Flowchart for preparation of soil parameter file

Table 4.1: Soil parameter file

Variable name	Units	Number of Values	Description
Run_cell	N/A	1	1=Run Grid Cell, 0=do not Run
Gridcel	N/A	1	Grid cell number
Lat	degrees	1	Latitude of grid cell
Lon	degrees	1	Longitude of grid cell
Infilt	N/A	1	Variable infiltration curve parameter (b)
Ds	fraction	1	Fraction of Dsmax where non-linear baseflow begins
Dsmax	mm/day	1	Maximum velocity of baseflow
Ws	fraction	1	Fraction of Maximum soil moisture where non-linear baseflow occurs
C	N/A	1	Exponent used in baseflow curve, normally set to 2
Expt	N/A	Nlayer	Parameter describing the variation of Ksat with soil moisture
Ksat	mm/day	Nlayer	Saturated hydrologic conductivity
phi_s	mm/mm	Nlayer	Soil moisture diffusion parameter
init_moist	mm	Nlayer	Initial layer moisture content
Elev	m	1	Average elevation of grid cell
Depth	m	Nlayer	Thickness of each soil moisture layer
avg_T	C	1	Average soil temperature, used as the bottom boundary for soil heat flux solutions
Dp	m	1	Soil moisture damping depth (depth at which soil temperature remains constant throughout the year, 4m
Bubble	cm	Nlayer	Bubbling pressure of soil
Quartz	fraction	Nlayer	Quartz content of soil
Bulk_density	kg/m	Nlayer	Bulk density of soil layer
Soil_density	kg/m	Nlayer	Soil particle density, normally 2685 kg/m
off_gmt	hours	1	Time zone offset from GMT
Wcr_FRACT	fraction	Nlayer	Fraction soil moisture content at the critical point (~ 70% of field capacity) (fraction of maximum moisture)
Wpwp_FRACT	fraction	Nlayer	Fractional soil moisture content at the wilting point (fraction of maximum moisture)
Rough	m	1	Surface roughness of bare soil
Snow_rough	m	1	Surface roughness of snowpack
annual_prec	mm	1	Average annual precipitation
resid_moist	fraction	Nlayer	Soil moisture layer residual moisture

Fs_active	1 or 0	1	If set to 1, then frozen soil algorithm is activated for the grid cell. A 0 indicates that frozen soils are not computed even if soil temperatures fall below $0^{\circ}C$.

(Source: http:// www.hydro.washington.edu)

Preparation of Vegetation Parameter file

LULC Map for 2005 at 1:50000 scale obtained from ISRO-GBP was converted to raster and recoded with respect to USGS LULC classes. RootingDepths, a csv file, containing information about root zone thickness and fraction of root in each root zone was also prepared and vegetation library was taken from GLDAS. The recoded LULC raster, grid file, RootingDepths and vegetation library were used as inputs in the GUI (Hydrological Modelling Tool (VIC)_v0.1) to prepare the vegetation parameter file. Description of the variables required to be specified in the vegetation parameter file are given in Table 4.2. The list of various parameters required to be specified in the vegetation library file is given in Table 4.3.

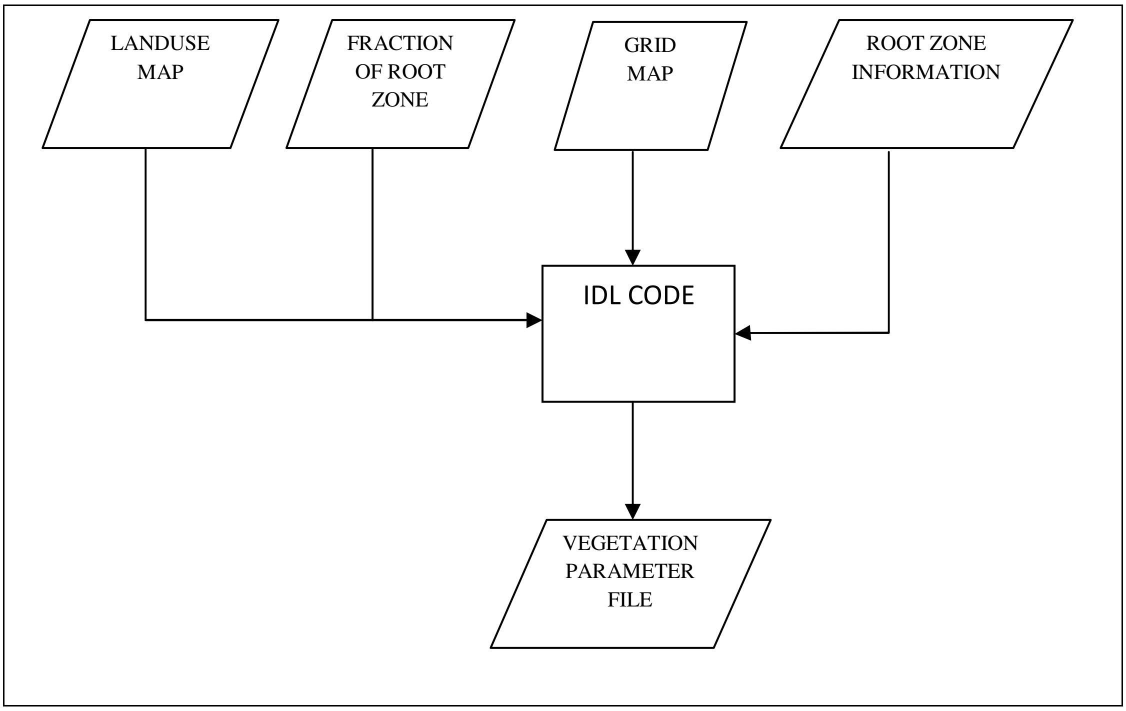

Figure 4.3: Flowchart for preparation of vegetation parameter file

Table 4.2: Vegetation Parameter file

Sl.No	Variable Name	Units	Description
1	Gridcel	N/A	Grid cell number
2	Vegetation_type-no	N/A	Number of vegetation types in a grid cell
3	Veg_class	N/A	Vegetation class identification number
4	Cv	fraction	Fraction of grid cell covered by vegetation type
5	Root_depth	m	Root Zone thickness (sum of depth is total depth of root penetration)
6	Root_fraction	fraction	Fraction of root in the current root zone

(Source: http:// www.hydro.washington.edu)

Table 4.3: Vegetation Library file

Variable Name	Units	Number of Values	Description
Veg_class	N/A	1	Vegetation class identification number (reference index for library table)
Overstory	N/A	1	Flag to indicate whether or not the current vegetation type has an overstory (TRUE for overstory present[e.g. trees], FALSE for overstory not present[e.g.grass])
Rarc	s/m	1	Architectural resistance of vegetation type (~ 2s/m)
Rmin	s/m	1	Minimum stomatal resistance of vegetation type (100s/m)
LAI		12	Leaf-area index of vegetation type
Albeto	fraction	12	Shortwave albeto for vegetation type
Rough	M	12	Vegetation roughness length (typically 0.123 * vegetation height)
Displacement	M	12	Vegetation displacement height (typically 0.67 * vegetation height)
Wind_h	M	1	Height at which wind speed is measured
RGL	W/m^2	1	Minimum incoming shortwave radiation at which there will be transpiration. For trees this is about 30 W/m^2, for crops about 100 W/m^2
Rad_atten	frac	1	Radiation attenuation factor. Normally set to 0.5, though may need to be adjusted for high latitudes.
Wind_atten	frac	1	Wind speed attenuation through the overstory. The default value has been 0.5

trunk-ratio	frac	1	Ratio of total tree height that is trunk (no branches). The default value has been 0.2
Comment	N/A	1	Comment block for vegetation type. Model skips end of line so spaces are valid entries.

(Source: http:// www.hydro.washington.edu)

Meteorological Forcing File

Meteorological data from weather station was obtained from Department of Soil and Water conservation, Government of Nagaland. The data from the weather station were arranged in columnar format (Tmax (˚C), Tmin (˚C), and rainfall (mm) and were saved by name data_yy_xx where yy and xx are the latitude and longitude of the weather station. This file and grid file were used to prepare the Forcing File.

Preparation of Global parameter file and VIC model simulation

The soil parameter file, vegetation parameter file, vegetation library file and Forcing file were used as inputs in the GUI (hydrological modeling tool, VIC, v0.1) to prepare the Global Parameter file. The Global Parameter file contains information like N- layers, Nodes, Time step, Start Year, Start Month, Start Day, Start Hour, End Year, End Month, End Day, Forcing Date, Force Year, Force Month, Force Day, Force Hour, Location of the output and input files, etc,. Global control parameters can be modified according to the input characteristics. VIC 4.0.6 source code was downloaded from the VIC website and the code was unzipped and untared into local source directory. Then VIC was compiled and run on Windows platform using Cygwin. The code was compiled using the make file included in the archive, by typing 'make'. The compiled code creates an executable entitled 'vicNl'. At the command prompt 'vicNl –g (global control file name)' was written to run the model (IIRS, technical report).

4.2.4. Methodology for evaluation of Ground Water quality Parameters and their spatial distribution by Using Interpolation methods

More than 50 Water samples were collected from open wells, tube wells, springs and rivers from different sites in the study area during pre-monsoon and post monsoon in the year 2012. The locations of the sites were obtained by using hand-held Global Positioning System (GPS) receiver. Samples were collected in clean plastic containers and labeled. The containers were thoroughly rinsed two to three times with the ground water to be sampled. In the case of bore wells and hand pumps, the samples were collected after pumping for few minutes. The water level and depth of the wells for each sampling locations were also recorded. Preservation and transportation of the water samples to the laboratory followed standard methods. The physical and chemical parameters of the samples were analyzed in the laboratory following standard methods (Table 4.4). The parameters analyzed include TDS, pH, Electrical conductivity (EC), sodium, magnesium, potassium, calcium, carbonate and bicarbonate, chlorides, fluorides, nitrate, nitrite and Iron. All the water quality parameters are expressed in mg/l except pH and EC. The chemical analysis results were compared with BIS: 10500 (2004) standards to determine the suitability for drinking purpose.

Table 4.4: Analytical Methods and Equipments Used

S. No.	Parameter	Method	Equipment
1.	pH	Electrometric	pH meter
2.	Electrical Conductivity	Electrometric	Conductivity meter
3.	TDS	Electrometric	TDS meter
4.	Sodium	Flame emission	Flame Photometer
5.	Potassium	Flame emission	Flame Photometer
6.	Calcium	Titration by EDTA	-
7.	Magnesium	Titration by EDTA	-
8.	Fluoride	Ion chromatography	Ion Chromatograph
9.	Chlorides	Ion chromatography	Ion Chromatograph
10.	Nitrate	Ion chromatography	Ion Chromatograph
11	Nitrite	Ion chromatography	Ion Chromatograph
12.	Bromide	Ion chromatography	Ion Chromatograph
13.	Sulphate	Ion chromatography	Ion Chromatograph
14.	Carbonates	Titration by H_2SO_4	-
15.	Bi-carbonates	Titration by H_2SO_4	-
16.	Iron	UV spectrophotometry	UV spectrophotometer

Ionic balance was calculated for major cations and anions to verify the accuracy of the chemical analysis. Then the chemical analysis data of all the samples were plotted on Piper Trilinear diagram. The Piper Trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram the ground water was classified into different hydrochemical facies.

Spatial interpolation techniques such as IDW and Kriging were used for predicting spatial distribution of ground water quality parameters including pH, TDS, EC, Potassium, sodium, calcium, magnesium, chlorides, sulphate, iron and bicarbonates. Then using cross-validation and validation, the best method for interpolation was selected for each parameter. The data for each parameter was subset into training set (75%) and testing set (25%). The first subset was used to develop a model for prediction and the second subset was used for validation. The predicted values were compared with the known values of the second subset using validation tools.

The IDW interpolation for each parameter was calculated using the parameters 5-10 neighbors with a power of 1 and 10-15 neighbors with a power of 1. These surfaces were compared to select the appropriate parameter settings.

In kriging exploratory data analysis (EDA) was performed to assess the statistical properties such as spatial data variability, spatial data dependence, and global trends. Histogram tools and QQPlots were used to check the normal distribution pattern. Transformations were used to make the data normally distributed. Trend analysis was made to know the presence of global trend and data detrending were performed using local polynomial interpolations. Directional influences were also removed from the data. Different types of Kriging methods were applied for all the parameters and semivariogram models were tested for each parameter. Prediction performances were assessed by cross validation.

Based on cross validation and validation results IDW was selected as the best interpolation method for spatial distribution of the water quality parameters.

5. RESULTS AND DISCUSSIONS

5.1. GROUND WATER POTENTIAL ZONNING

Geomorphology

The geomorphic units identified in the study area include alluvial plain, structural hills, intermontane valley fills, flood plains, residual hills, meander scars and ox-bow lakes. The alluvial plain and structural hills cover most part of the study area. The alluvial plain is found in the northern part of the study area whereas the structural hills occupy the southern part. The residual hills are the remnants of weathering and denudation. The flood plains show very good potential for ground water. The intermontane valley fills and alluvial plains also hold good potential for ground water. The structural hills and the residual hills act as runoff zones and thus are poor sites for ground water. Figure 5.1 shows the geomorphological map of the study area.

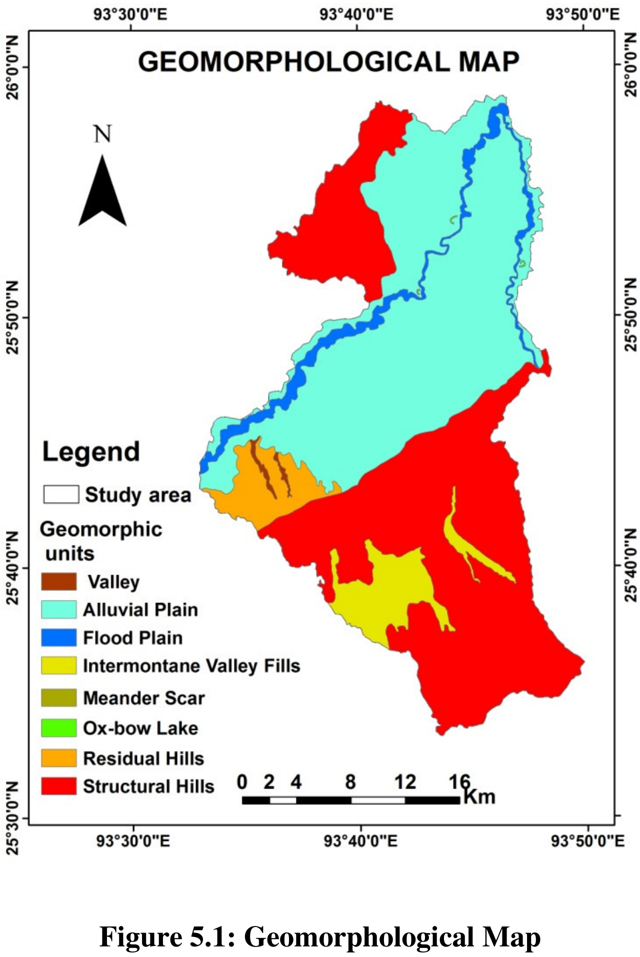

Figure 5.1: Geomorphological Map

Lithology

The study area is dominated by Quaternary sediments and Tertiary rocks. The Quaternary sediments consist mainly of clays, sand and pebbles whereas the Tertiary rocks consist mainly of sandstones and shales. The Quaternary sediments provide good scope for infiltration and recharge of ground water. Consequently, they have good potential for ground water. The Tertiary rocks which form the structural hills and residual hill act as runoff zones and thus have less potential for ground water. Figure 5.2 shows the geological map of the study area.

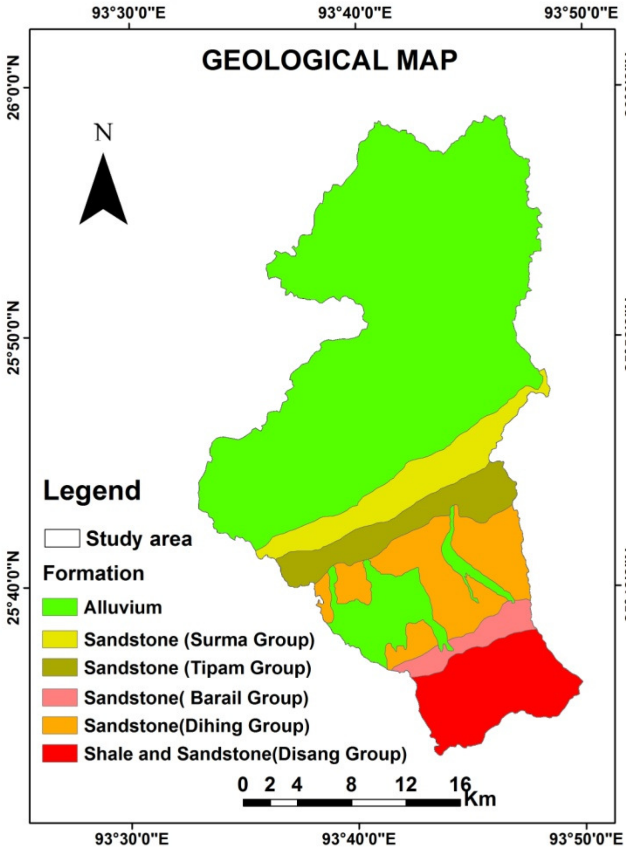

Figure 5.2: Geological map

Drainage

The overall drainage of the study area shows a dendritic pattern. The drainage density map was prepared and it was divided into 9 classes. The northern part exhibit coarse drainage density whereas the southern part shows fine drainage density. Ground water potential is poor in areas with very high drainage density as major part of the rainfall is lost as surface runoff with little infiltration to recharge the ground water. On the other hand, areas with low drainage density allow more infiltration to recharge the ground water and therefore have more potential for ground water. Figure 5.3 shows the drainage map and figure 5.4 shows the drainage density map of the study area.

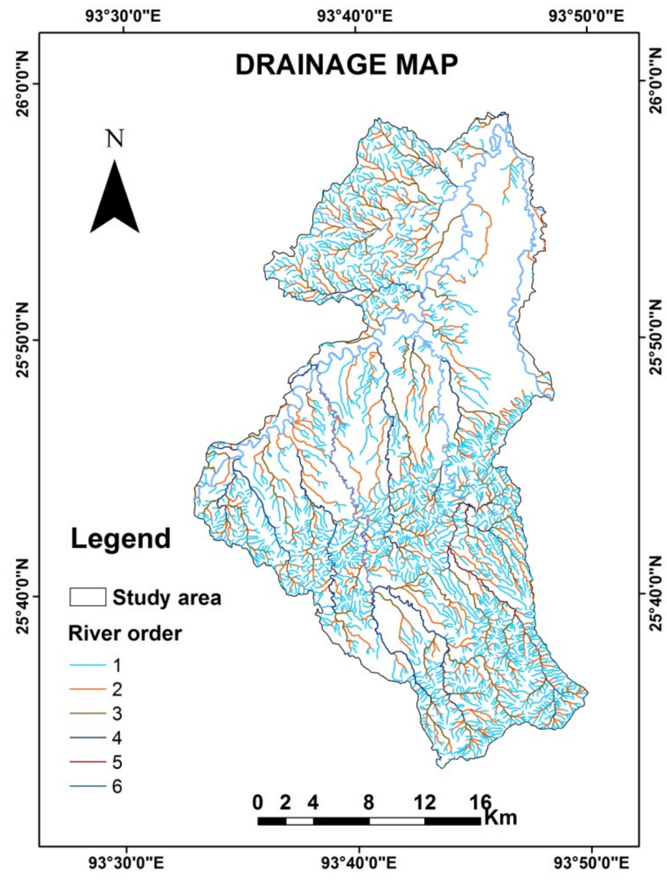

Figure 5.3: Drainage map

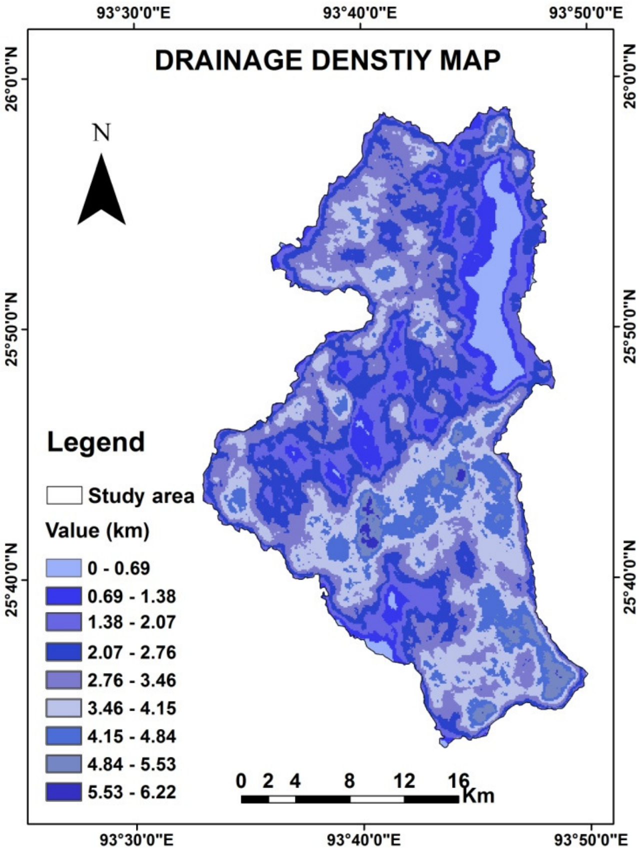

Figure 5.4: Drainage density map

Lineaments

Lineaments are very important from ground water point of view as they control the movement and storage of ground water. Both major and minor lineaments in the study area were delineated which include faults, fracture, cracks, etc. A lineament density map was prepared and it was divided into 9 classes. Areas with higher lineament density facilitate infiltration and recharge of ground water and therefore have good potential for ground water development. Figure 5.5 shows the lineament map and figure 5.6 shows the lineament density map of the study area.

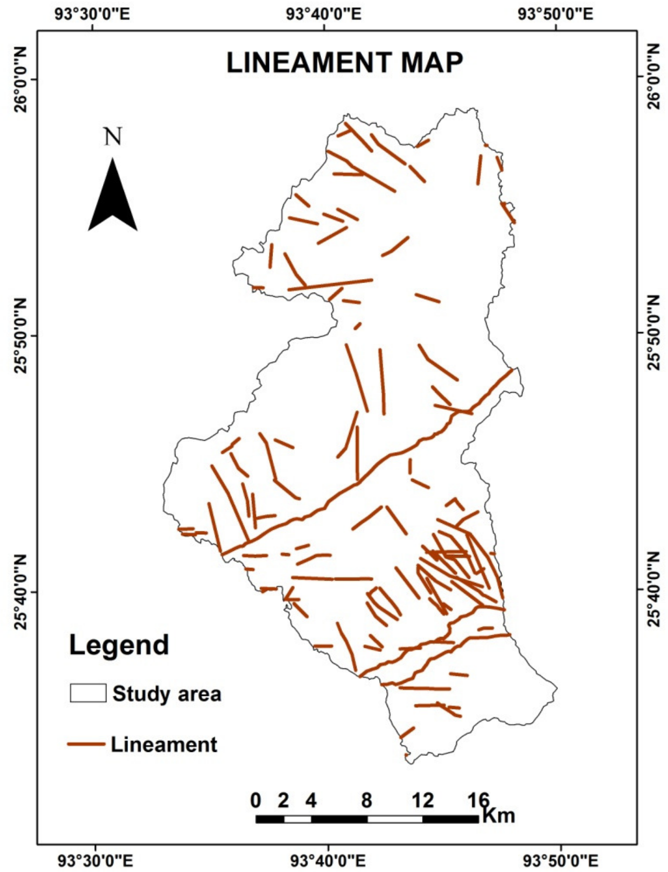

Figure 5.5: Lineament Map

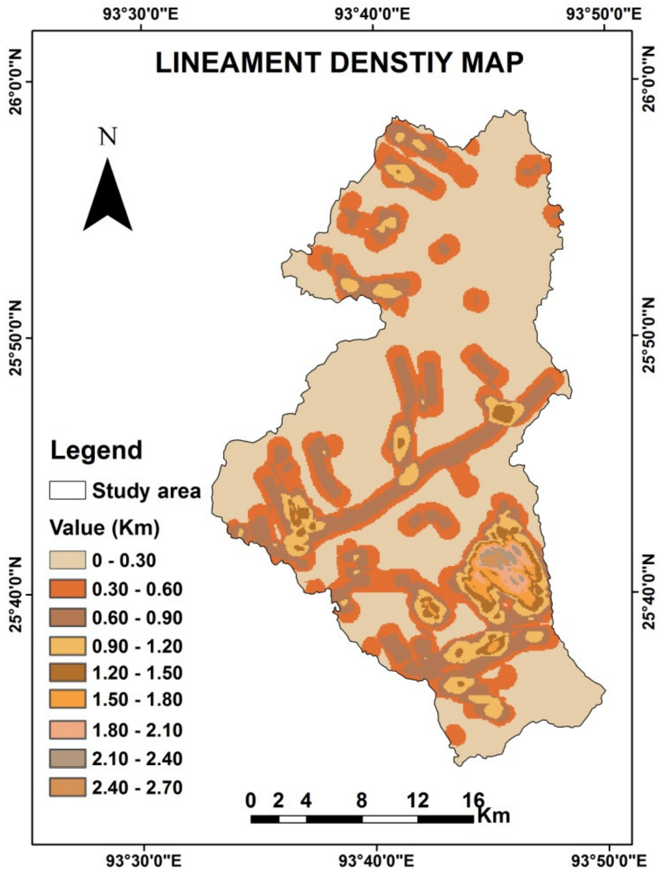

Figure 5.6: Lineament density map

Slope

Slope plays an important role in ground water recharge. Areas having more than 20 percent slopes have negligible ground water recharge. A slope map was prepared by using Carto-DEM. The central and northern part of the study area have very gentle slope which permit less runoff and have very good potential for ground water. On the other hand, there is an increase in slope towards the southern part of the study area and gentle slopes are found only in localized pockets. Areas with steep slopes facilitate high runoff and have poor potential for ground water. Figure 5.7 shows the slope map of the study area

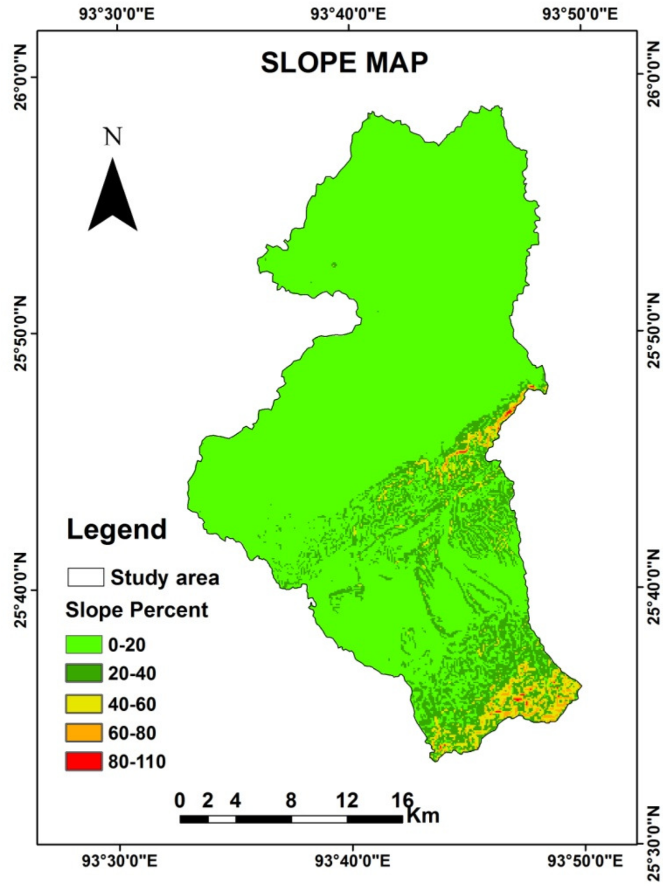

Figure 5.7: Slope map

Ground Water Prospects Map was prepared by integrating all the thematic layers in ArcGIS by using Index Overlay method. Based on the multi-criteria evaluation technique (AHP) each layer and class was assigned weight and rank (Table 5.1). The ground water prospects map thus prepared was categorized into five zones - Very High, High, Moderate, Low and Very Low. Very High potential areas cover 27.23284 sq km, High potential areas cover 349.052297 sq km area, Moderate potential areas cover 95.97496 sq km, Low potential areas cover 182.994 sq km and Very Low potential areas cover 64.247 sq km area. Figure 5.8 shows the ground water prospects map of the study area.

Table 5.1: Thematic Map Weight and Categories Ranking

Theme	Weight	Class	Rank
Geomorphology	4.66	Alluvial Plain	0.68
		Structural Hills	0.23
		Flood Plains	3.64
		Residual Hills	0.14
		Valleys	0.69
		Intermontane valley fills	0.69
		Meander Scar	1.50
		Ox-bow Lake	2.43
Lithology	2.61	Alluvium	7.32
		Sandstone	2.09
		Shale & Sandstone	0.59
Drainage density	1.43	0 - 0.69	3.30
		0.69 - 1.38	2.29
		1.38 - 2.07	1.57
		2.07 - 2.76	1.03
		2.76 - 3.46	0.70
		3.46 - 4.15	0.48
		4.15 - 4.84	0.31
		4.84 - 5.53	0.20
		5.53 - 6.22	0.11
Lineament density	0.87	0 - 0.69	0.16
		0.69 - 1.38	0.20
		1.38 - 2.07	0.30
		2.07 - 2.76	0.46
		2.76 - 3.46	0.70
		3.46 - 4.15	1.03
		4.15 - 4.84	1.54
		4.84 - 5.53	2.29
		5.53 - 6.22	3.34
Slope	0.42	0 - 20	5.82
		20 - 40	2.15
		40 -60	1.05
		60 -80	0.61
		80 - 110	0.37

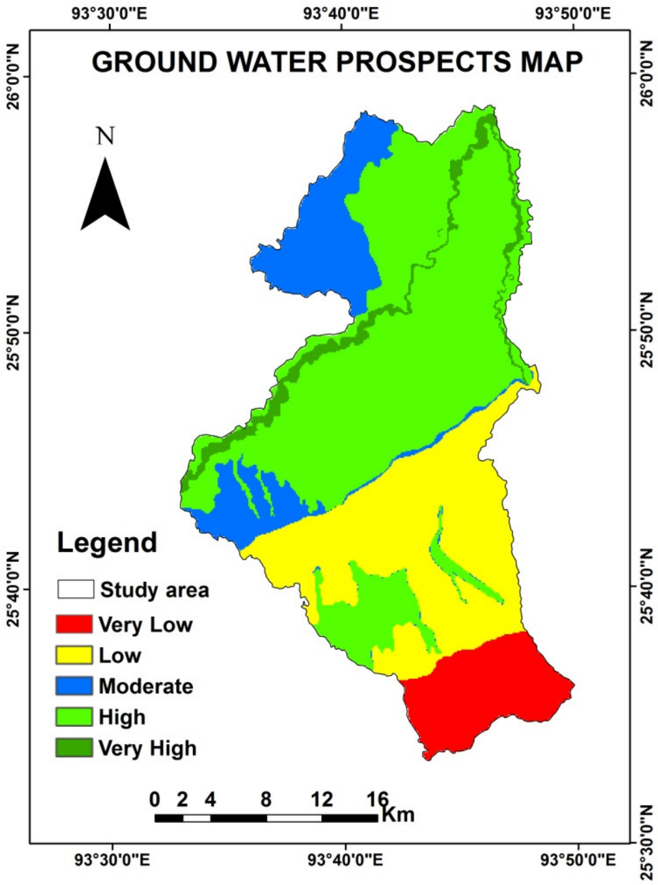

Figure 5.8: Ground water Prospects map

The ground water prospects map indicate that the flood plains which are composed of sand, silt and clay with nearly gentle slope has very good potential for ground water. The alluvial plains, the intermontane valley fills and valleys with gentle slopes also hold good potential for ground water. Structural hills and residual hills with high slopes show low to very low potential for ground water. The prepared ground water prospects map serves as a baseline for future ground water exploration.

5.2. GROUND WATER RECHARGE ESTIMATION

5.2.1. GEC (1997) Methodology

Ground water recharge estimation was made for non-command area following the norms recommended by the Ground Water Resource Estimation Committee (GEC, 1997). Two methods were used for the estimation namely, Rainfall Infiltration Factor and Water Table Fluctuation method.

Rainfall Infiltration Factor method

In Rainfall infiltration factor method the rechargeable area is multiplied with relevant rainfall infiltration factor and normal rainfall. The rainfall infiltration factor as a fraction is 0.22 for alluvium and 0.12 for sandstone. The normal rainfall during monsoon season is calculated at 912.07mm and 113.71mm for monsoon and non-monsoon seasons respectively. Rainfall recharge in non-command area by using Rainfall Infiltration Factor is estimated at 10991.88355 hectare meters for monsoon season and 1370.434537 hectare meters for non-monsoon season (Table 7).

Water Table Fluctuation method

In Water table fluctuation, the seasonal water table fluctuation varies from 0.28 to 4.92m. The average water table fluctuation is 1.959m. The specific yield for alluvium as a fraction is calculated as 0.11 whereas for sandstone it is 0.03. The recharge from 'other sources' during monsoon season is considered only for Ponds and Tanks as there is no significant ground water irrigation and water conservation structures in the study area and it is estimated at 53.18817142 hectare meters while the gross ground water draft for 'All uses' during monsoon season is estimated at 227.8614 hectare meter. The normal monsoon rainfall is calculated at 912.0714. Based on the availability of water table fluctuation data, rainfall recharge during monsoon is estimated for three years (2005 to 2007).Using normalization procedure the Rainfall recharge during monsoon season in non-command area is estimated at 11804.33107 hectare meters (Table 5.2).

Rainfall recharge during monsoon in non-command area after comparing results from Water Table Fluctuation method and Rainfall Infiltration Factor is estimated at 11804.33107 hectare meters (Table 5.3).

Table 5.2: Rainfall recharge in non-command area by RIF and WTF

Sl. No.	Description of Items	Quantity (ha.m)
1	Rainfall recharge in non-command area by rainfall infiltration factor method during	
	1. Monsoon season	10991.88
	2. Non-Monsoon season	1370.43
2	Rainfall recharge during monsoon season in non-command area by 'Water table Fluctuation Method'	11804.33

Table 5.3: Summary of recharge from rainfall in non-command area

Sl. no.	Description of Items	Quantity
1.	Area in Hectares	60948
2.	Recharge from rainfall during monsoon season by Water Table Fluctuation	
	a) in hectare meters	11804.33
	b) per unit in mm [(2a)/(1)]	193.68
3.	Recharge from rainfall during non-monsoon season (By rainfall infiltration factor method)	
	a) in hectare meters	1370.43
	b) per unit in mm [(3a)/(1)]	22.49
4	Annual recharge from rainfall in non-command area	
	a) in hectare meters [(2a) + (3a)]	13174.77
	b) per unit in mm [(2b) + (3b)]	216.16

5.2.2. VIC MODEL

The vegetation, soil and forcing data were applied to the VIC-2L model to simulate hydrological components such as surface runoff, evapotranspiration, soil moisture and baseflow for the study area. VIC was run for seven years from 2005 to 2011 and the output flux files contain fluxes of surface runoff, evapotranspiration, soil moisture and baseflow, at each grid. The baseflow which represents the simulated ground water recharge was compared with the recharge values estimated by GEC, 1997 methodology. Comparative analyses indicate that the baseflow simulated by VIC is in good agreement with the GEC, 1997 recharge estimates. VIC model also produces the spatial distribution of the hydrochemical components in the study area for different time periods. The simulated hydrological components of VIC from 2005-2011 is given in Table 5.4 and the simulated hydrological components for monsoon and non-monsoon for all the seven years is given in Table 5.5. Figure 5.9 shows the graphical representation of different hydrological components for seven years.

Table 5.4: VIC simulated hydrological components for each year (in mm)

Year	Precipitation	Surface runoff	Evapo-transpiration	Baseflow
2005	1041.9	226.54	623.35	82.90
2006	1160.9	286.57	622.84	245.56
2007	1476.4	357.88	781.28	321.94
2008	1138.8	298.73	609.25	254.48
2009	623.6	108.12	468.32	59.83
2010	863.4	162.05	614.69	85.46
2011	981.3	288.18	521.87	170.62
Total	7286.3	1728.07	4241.60	1220.81
Average	1040.9	246.87	605.94	174.40

Table 5.5: VIC simulated hydrological components for monsoon and non-monsoon (mm)

Monsoon				
Year	**Precipitation**	**Surface runoff**	**Evapo-transpiration**	**Baseflow**
2005	882.7	210.90	452.15	73.84
2006	1034.1	276.38	489.53	232.69
2007	1180.7	320.73	553.07	305.78
2008	1047.3	292.66	448.82	239.94
2009	601.2	106.92	426.39	47
2010	730	147.65	523.80	73.44
2011	908.5	282.80	461.36	158.64
Total	6384.5	1638.05	3355.12	1131.32
Average	912.07	234.01	479.30	161.62
Non-Monsoon				

Non-Monsoon				
Year	**Precipitation**	**Surface runoff**	**Evapo-transpiration**	**Baseflow**
2005	87.4	6.27	122.07	14.05
2006	280.8	32.90	218.79	14.14
2007	148.4	14.40	174.71	15.58
2008	22.4	1.20	81.36	14.35
2009	133.4	14.41	79.82	11.97
2010	72.8	5.38	86.07	11.94
Total	745.2	74.57	762.83	82.03
Average	124.2	12.43	127.14	13.67

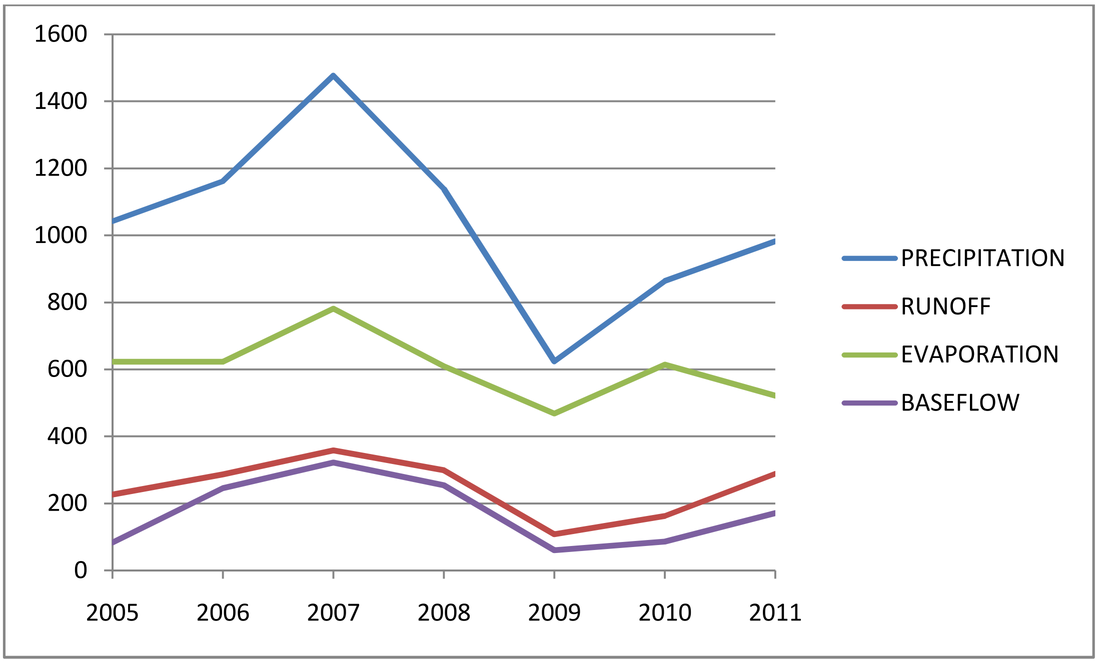

Figure 5.9: VIC simulated hydrological components from 2005-2011

Average annual baseflow is high in the northern part of the alluvium and low-lying areas of the Tertiary formations whereas it is low to moderate in other areas. Figure 5.10 shows the spatial distribution of average annual baseflow.

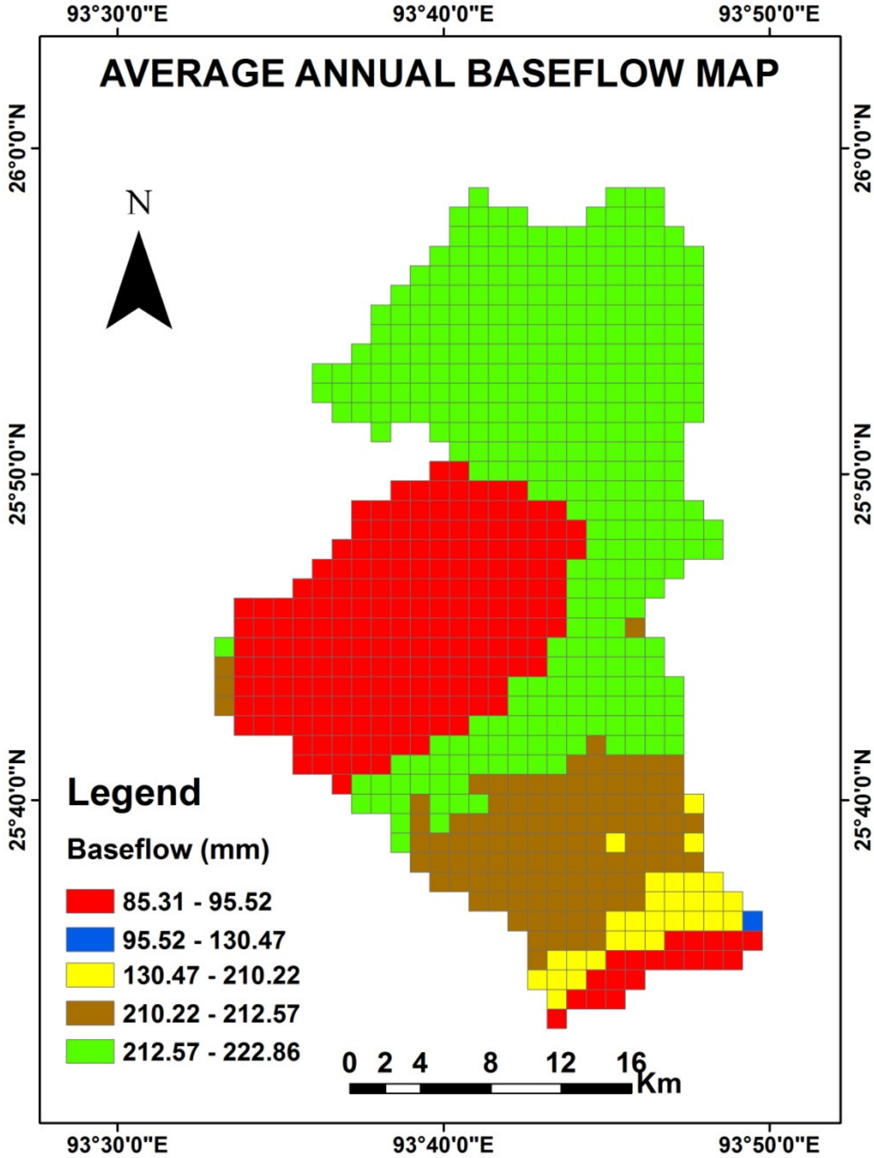

Figure 5.10: Map showing average annual baseflow

Average annual runoff is high in the western part of the alluvium and southern part of the Tertiary formations whereas it is moderate to low in the remaining areas. Figure 5.11 shows the spatial distribution of average annual runoff.

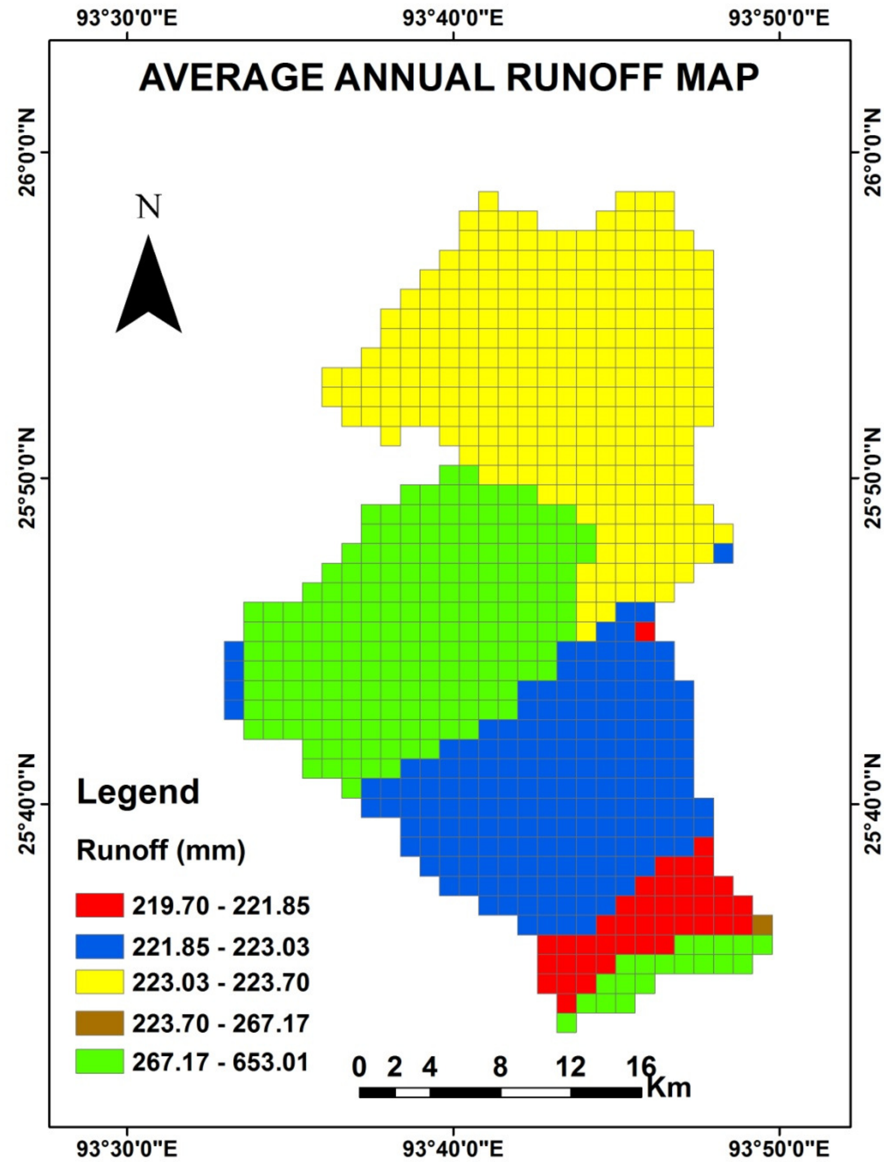

Figure 5.11: Map showing average annual runoff

Average annual evapo-transpiration is moderate to high in the vegetation covered areas of both Tertiary formations and alluvium whereas it is low in the build-up areas. Figure 5.12 shows the spatial distribution of average annual evapo-transpiration.

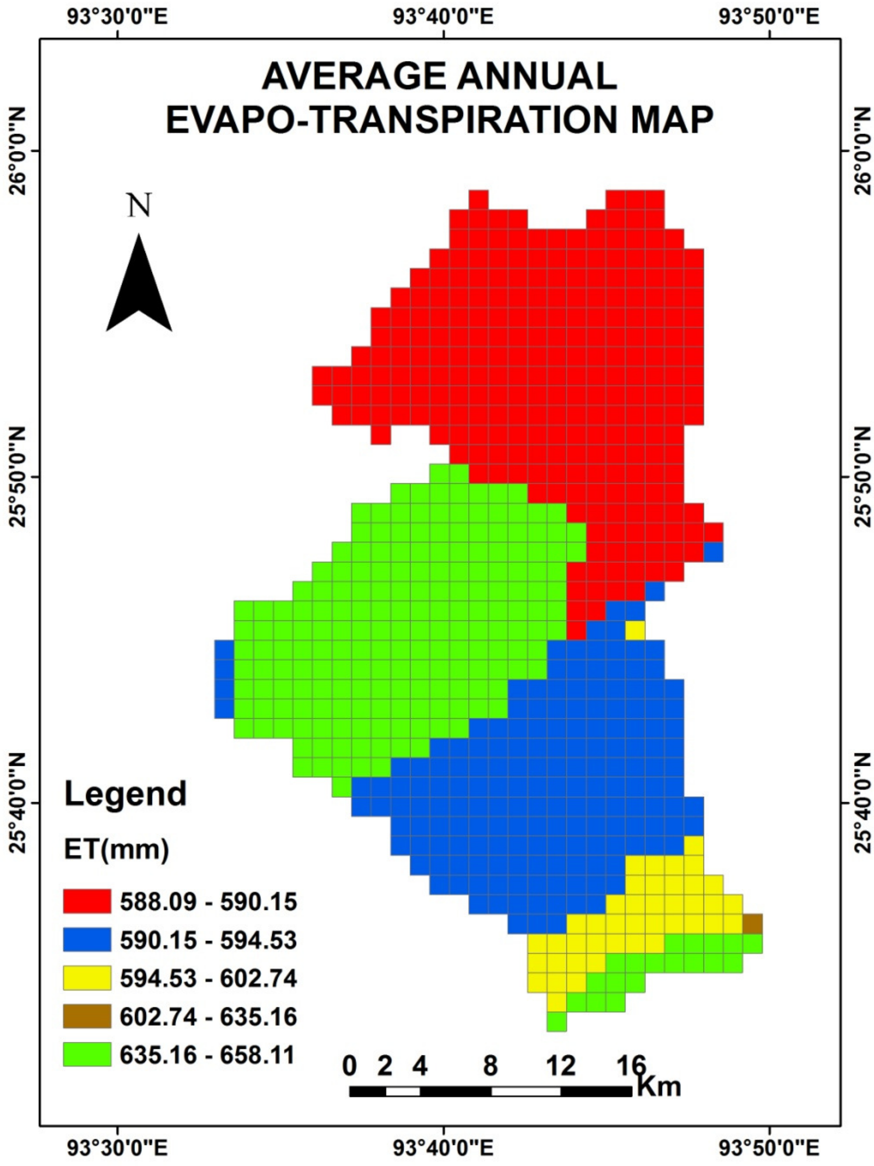

Figure 5.12: Map showing average annual evapo-transpiration

5.3. Evaluation of Ground Water quality Parameters and their spatial distribution by Interpolation methods

The chemical analyses of the water samples were carried out in the Soil Laboratory, IIRS, Dehradun and concurrently in the DGM, Dimapur, Nagaland. The accuracy of the chemical analyses was assessed by calculating the ionic balance errors for major anions and cations. Most of the samples have less than 10% error although some samples have errors between 10 to 20%.

The chemical analysis results were compared with BIS: 10500 (2004) standards to examine the suitability for drinking purpose. The results of the chemical analysis of the water quality parameters are given in Table 5.6. Except Iron, nitrate and sulphate, all the parameters analyzed were found to be within the desirable limits of BIS: 10500 (2004) standards. Iron exceeds the desirable limit in almost all the location and the permissible limit in 10 locations while nitrate exceeds the desirable limits in three locations and sulphate in one location. High nitrate concentrations may be due to use of nitrogen containing fertilizer, domestic and agriculture waste and anthropogenic activities. The natural sources of nitrate are atmosphere, legumes, plant debris and animal excrement. The concentration of iron is controlled by physico-chemical and microbiological factors. It is contributed to ground water mainly from sandstone rocks which contain oxides, carbonates, sulphides or iron clay minerals. Ground water, especially if it is acidic, in many places contains excessive amounts of iron as solubility increases in low pH (more acidic) ground water. High sulphate concentration may be due to oxidation of sulphite ores, gypsum and anhydrite.

Nitrate content in drinking water is considered important because of its undesirable effects on health. In higher concentrations, nitrates may cause a disease known as methaemoglobinaemia (blue babies) which commonly affects bottle-fed infants. Repeated ingestion of heavy doses of nitrates also causes carcinogenic diseases.

High concentrations of iron generally cause bitter and astringent taste to water. It causes reddish stains on plumbing fixture and clothing and can cause scaling which encrusts pipes. Excessive concentration may encourage bacterial activities in pipe and service mains, causing unpleasant odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but on exposure to air it causes precipitation of iron due to oxidation, resulting in the formation of rusty colour and turbidity.

Table 5.6: Results of the Chemical analysis of water quality parameters

S.No.	Na mg/l	K mg/l	Ca mg/l	Mg mg/l	F mg/l	Cl mg/l	NO_2 mg/l	Br mg/l	NO_3 mg/l	SO_4 mg/l	HCO_3 mg/l	Fe mg/l	pH	EC µs/cm	TDS ppm
W1	40.02	7.89	12.8	14.4	0	100.76	0	0	3.42	10.77	50.44	0.54	7.41	395	247.5
B1	21.1	2.25	4.8	5.76	0	31.42	0	0	17.97	6.25	44.62	0.35	6.49	182	115.8
W2	11.92	3.33	3.2	3.84	0	24.91	0	0	0	3.20	13.58	2.9	6	101	68.94
W3	22.96	0.18	9.6	9.6	0	12.27	0	0	0	5.54	116.4	3.46	6.86	229.2	142.8
W4	29.9	6.54	20.8	17.28	0	47.58	0	0	0	32.11	145.5	1.02	7.21	406.3	253.2
W5	5	1.42	2	2.88	0	3.88	0	0	0	3.75	17.46	0.37	5.79	53.54	33.64
W6	18.01	10.27	2	2.88	0	19.39	0	0	0	10.80	33.6	0.46	6.27	144.8	89.97
W7	30.33	0.53	17.6	10.56	0	41.94	0	0	11.62	28.60	46.56	0.22	7.42	320	199.2
W8	38.94	1.51	11.2	14.4	0	60.67	0	0	0	16.70	141.62	0.27	6.94	385.7	240.4
W9	15.74	5.65	2.3	4.8	0.15	31.93	0	0	2.86	4.05	31.04	0.44	5.94	142.4	89
W10	13.3	3.22	9.6	3.84	0.20	33.77	0	0	15.72	2.81	40.74	0.39	6.63	175.3	109.8
W11	2.22	0.57	2.2	3.84	0.14	2.11	0	0	4.75	0.49	19.4	0.47	6.28	36.96	23.13
W12	1.07	0.14	1.1	1.92	0	1.67	0	0	0	0.34	17.46	0.55	5.88	20.5	11.87
W13	1.26	0.87	12.4	2.88	0.14	1.57	0	0	4.73	0.70	31.04	0.67	6.72	53.31	34.3
W14	17.75	1.39	2.3	3.84	0.14	28.42	0	0	6.44	3.40	34.92	0.33	6.25	101	63.98
W15	19.47	1.43	12.8	19.2	0.16	29.02	0	0	26.05	1.73	52.38	0.98	6.33	162.4	100.2
W16	67.42	8.07	13.4	19.2	0.15	177.18	0	0	4.79	10.47	137.74	0.28	8.04	599.8	372.3
B2	17.25	2.25	17.6	7.68	0.24	4.10	0	0.76	0	0	118.34	4.64	6.87	209.8	128.3
W17	23.56	2.54	12.8	8.64	0.17	7.23	0	0	1.94	21.57	112.52	0.56	7.42	217.5	133.1
B3	14.2	1.56	9.6	7.68	0.22	1.33	0.82	0.84	0	0.96	124.16	4.76	6.77	181.1	111.3
B4	15.74	1.02	9.6	14.4	0.20	3.43	1.19	0.94	0	7.44	131.92	1.06	8.04	219.5	135
B5	9.5	1.51	14.4	10.56	0.17	1.61	0	0.75	0	7.22	108.64	4.08	6.87	184.8	113.9
T1	40.99	1.65	6.4	6.7	0.14	0.61	1.75	0.64	0	0	149.38	0.34	7.61	216.6	133.9
B6	23.7	1.9	20.8	8.6	0.08	86.90	0	0.74	0	5.01	21.34	4.75	7.20	253.5	157.2
W18	11.6	0.96	6.4	4.8	0.07	20.78	0	0	0.93	1.39	46.56	0.59	7.06	145.4	92.05
W19	95.21	5.19	48	28.8	0.16	11.24	0	1.85	1.31	246.35	248.32	2.6	7.81	774.7	484.3
W21	41.01	1.28	22.4	20.16	0.24	35.29	0	1.37	1.90	23.11	219.22	0.58	7.76	459.3	288.1
W23	8.33	8.64	11.2	7.68	0.11	17.11	0	0	8.69	4.77	77.6	0.38	7.55	162.3	99.46
W24	5.48	1.86	17.6	7.68	0.13	3.92	0	0.88	11.71	1.57	97	0.32	6.95	160.8	98.37
W25	1.95	0.35	12.2	3	0	0.85	0	0	2.46	0	36	0.44	6.30	28.1	17.63
W26	9.45	12.05	4.2	7.68	0.23	12.06	0	0	49.48	2.41	46.56	0.32	7.12	165.9	101.6
W27	7.4	0.8	13.8	0.96	0	5.27	0	0	4.95	5.55	26.2	0.56	6.28	58.55	35.32
W28	1.74	0.6	1.8	3.84	0.07	1.15	0	0	6.78	0.82	32.98	0.32	7.17	406.9	24.02
W30	13.5	4.6	2.1	4.8	0.08	29.84	0	0	3.60	1.89	29.1	0.54	6.74	127.5	83.61
B10	21.08	1.92	8.2	2.88	0.25	0.45	0	1.02	0.87	0	66.8	0.37	7.93	260.4	166.1
W32	33.59	1.08	20.8	6.72	0.33	32.46	0	0	72.81	0.80	23.28	0.61	6.22	199.9	123
W33	19.55	9.18	15.4	2.5	0.38	33.99	0	0	113.54	1.17	15	0.33	6.91	264.6	161.4
B8	0.89	1.38	7.4	8.3	0	1.044	0	0	0.92	0	44.8	0.4	6.25	45.83	27.93
B9	34.1	3.27	5.3	12.48	0.19	0.59	0	1.22	1.45	0	215.34	0.8	8.39	283.6	173.5
HP1	14.04	1.55	11.2	2.88	0	28.42	0	0	0	2.09	42.68	4.78	7.34	138	83.34
W35	4.13	1.57	4.8	5.76	0	3.63	0	0	7.73	1.09	44.62	0.58	6.87	82.26	48.56
B11	15.4	1.83	12.8	16.32	0.23	39.41	0	0	41.59	0	31.04	0.69	6.24	177.5	105.2
W36	15.74	13.49	5.3	12.48	0	46.24	0	0	25.46	2.71	62.08	0.47	7.03	221.4	129.9

The chemical analyses results shows the abundance of the major cations in the order Na> Ca> Mg> K whereas the abundance of anions are in the order HCO_3> Cl> SO_4> NO_3> Br> F> NO_2> CO_3. Statistical evaluation of the water quality parameters is given in Table 5.7.

The bicarbonate ion is the dominant cation and ranges from 13.58 mg/l to 248.32 mg/l with an average value of 76.33mg/l. The second most abundant cation is chloride and ranges 0.45 mg/l to 177.18 mg/l with an average of 22.94mg/l. The next dominant ion is sulphate which range from 0 to 246.35 mg/l with an average value of 10.65 mg/l. The nitrate, fluoride and bromide ions are below detectable level in many locations and have a maximum value of 113.54 mg/l, 0.381 mg/l and 1.85 mg/l respectively. Nitrite ion was detected only in three locations and carbonate ion was below detectable level in all the samples. The most dominant cation is sodium and ranges from 0.89mg/l to 95.21 mg/l with an average value of 95.21 mg/l. The second most dominant ion is calcium and ranges from 48 mg/l to 1.1 mg/l with an average value of 10.89 mg/ l. The next dominant ion is magnesium and ranges from 0.96 mg/l to 28.8 mg/l with an average value of 28.8 mg/l. Potassium ion ranges from 0.14 mg/l to 13.49 mg/l with an average value of 3.13 mg/l. Iron concentrations range from 0.22 mg/l to 4.78mg/ l in with an average value of 1.02 mg/ l. The pH of water is one of the most important water quality parameters with the optimum pH required in the range of 6.5 -8.5 as per BIS: 10500 (2004) standard. Beyond this range the water will affect the mucous membrane and/or the water supply system. The value of pH in the ground water samples varies from 5.79 to 8.39 with an average value of 6.94. It is below the desirable limit in 15 locations and in most of the locations it is below 7. The pH value shows that the ground water in the study area is neutral to slightly acidic in nature. The electrical conductivity (EC) of the ground water is due to the presence of various dissolved salts. All the samples have EC within the desirable limit and vary widely from 20.5µs/cm to 774.7 µs/cm at 17˚C to 19˚ C with a mean of 207.66µs/cm. Concentrations of TDS in water depend on the type of geological formation of the region and the solubility of the minerals. The TDS is within the desirable limit in all the samples and ranges from 11.87 mg/l to 484.3mg/l with an average value of 124.23 mg/l.

Table 5.7: Statistical evaluation of the water quality parameters

Parameter (in mg/l)	Min	Max	Mean	Median	Standard Deviation
Sodium	0.89	95.21	18.97	1.73	17.76
Potassium	0.14	13.49	3.13	1.61	3.28
Calcium	1.1	48	10.89	10.4	8.25
Magnesium	0.96	28.8	8.53	7.2	5.94
Chloride	0.45	177.18	22.94	12.17	31.88
Nitrite	0	1.75	0.08	0	0.32
Nitrate	0	113.54	9.58	1.77	20.88
Bicarbonate	13.58	248.32	76.33	46.56	61.39
Sulphate	0	246.35	10.65	2.25	35.72
Bromide	0	1.85	0.29	0	0.48
Fluoride	0	0.38	0.12	0.13	0.11
Iron	0.22	29	1.62	0.51	4.26
pH	5.79	8.39	6.94	6.87	0.68
EC	20.5	774.7	207.66	179.3	151.25
TDS	11.87	484.3	124.23	107.5	93.80

The chemical analysis data was plotted on a Trilinear diagram to classify the ground water into different hydrochemical facies. Figure 5.13 shows the Trilinear diagram for major cations and anions. Trilinear analysis indicates that 14 samples belongs to Ca^{2+} HCO_3 type, 11 samples to Ca^{2+} Na^{+} HCO_3 Cl type, 11 samples to Ca^{2+} Na^{+} HCO_3 type, 5 samples to Ca^{2+} Na^{+} Cl type, 3 samples to Na^{+} HCO_3Cl, 2 samples to Na^{+} HCO_3 type and 2 samples to Ca^{2+} HCO_3Cl type.

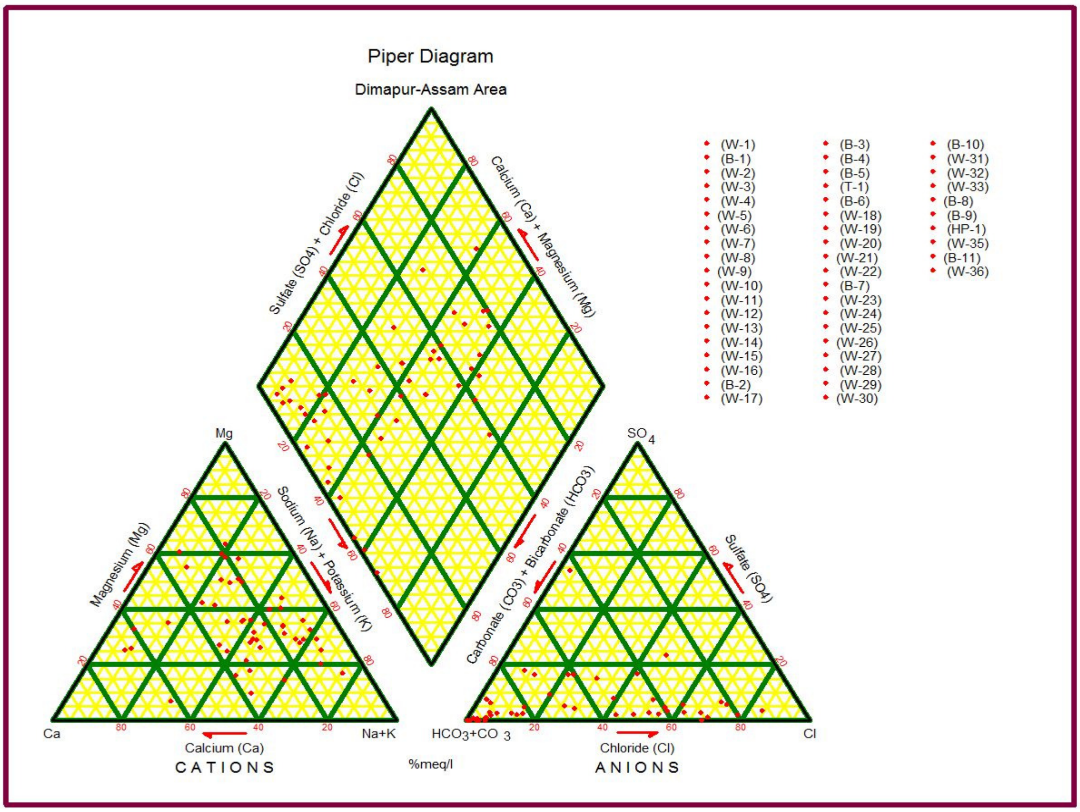

Figure 5.13: Trilinear Diagram

Different spatial interpolation techniques such as IDW (Inverse Distance Weighting) and Kriging were used to obtain the spatial distribution of ground water quality parameters. Results showed that IDW is the best interpolation method for the data.

Bicarbonate

The bicarbonate concentration increases towards the western part of the study area. The alluviums have higher bicarbonate values as compared to the Tertiary formations. Figure 5.14 shows the spatial distribution of bicarbonate in the study area.

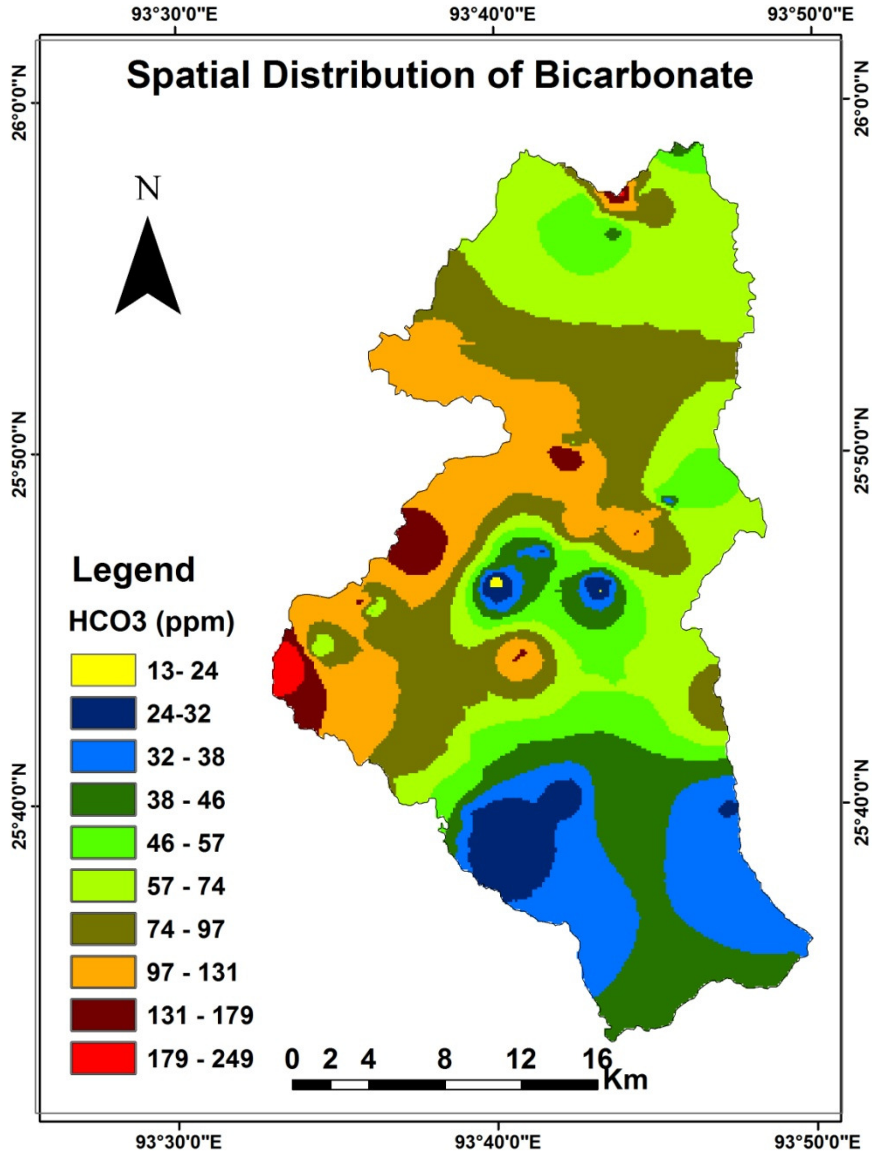

Figure 5.14: Spatial distribution of bicarbonate

Calcium

Calcium values increases towards the western part of the study area. Both the Tertiary formations and alluvium have more or less the same calcium concentrations. Figure 5.15 shows the spatial distribution of calcium in the study area.

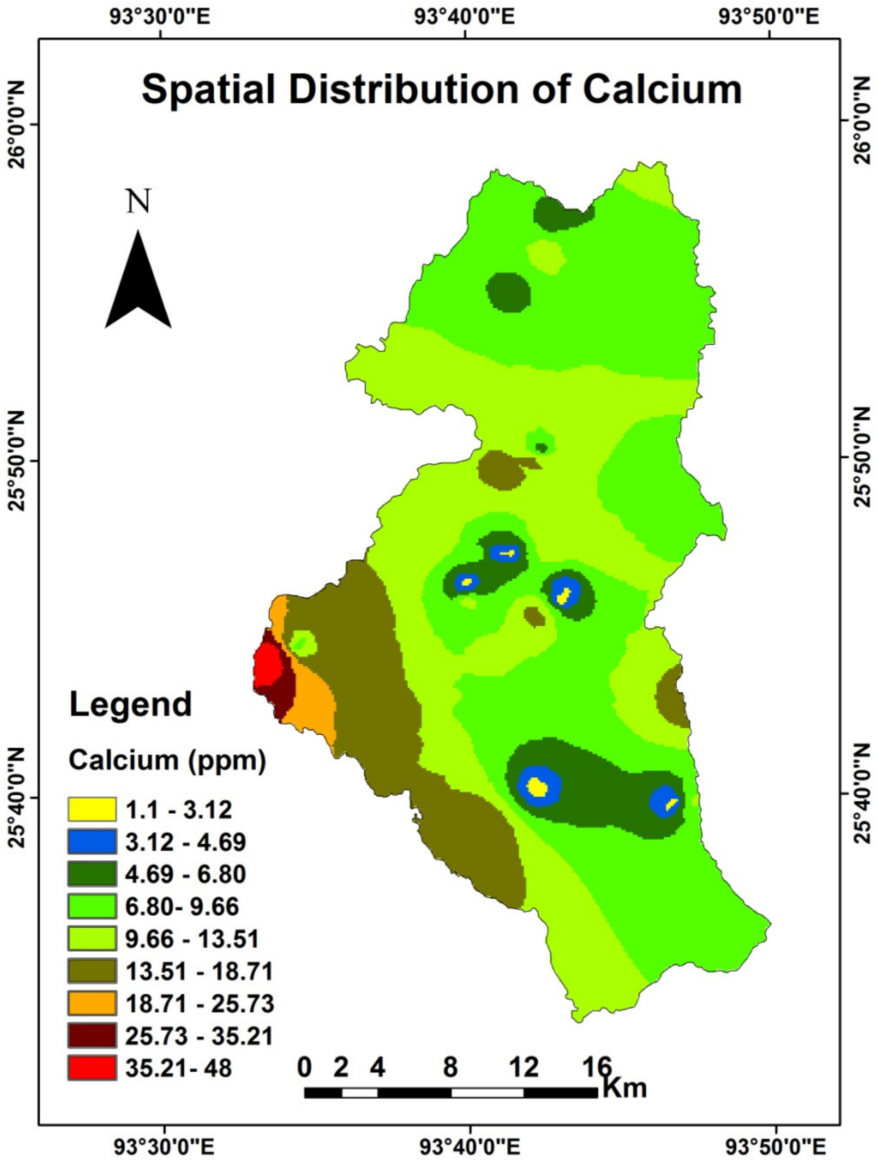

Figure 5.15: Spatial distribution of calcium

Chloride

Higher chloride concentrations are found in the eastern part of the study area. The alluviums have slightly higher chloride concentrations than the Tertiary formations. Figure 5.16 shows the spatial distribution of chloride in the study area.

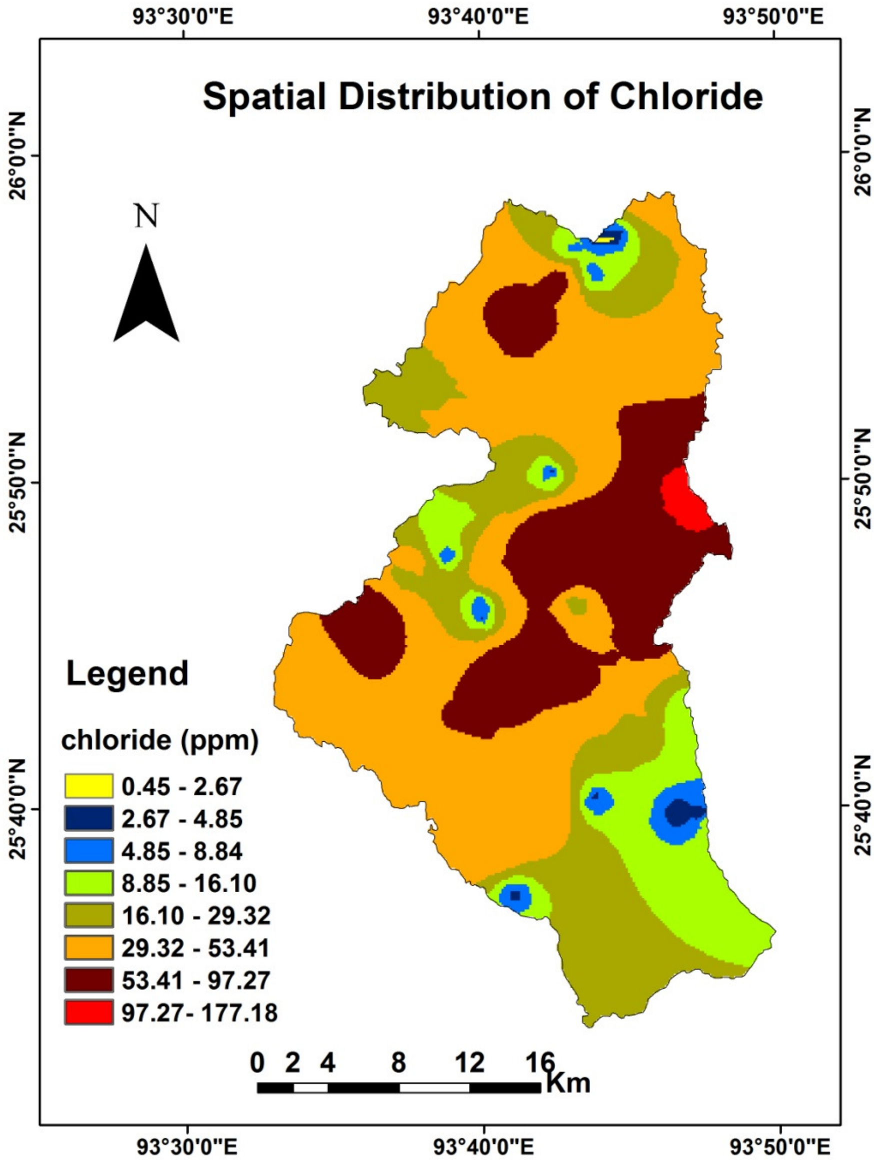

Figure 5.16: Spatial distribution of chloride

Iron

Iron content is higher in the western part of the study area. The alluviums have higher iron concentrations as compared to the Tertiary formations. Figure 5.17 shows the spatial distribution of Iron in the study area.

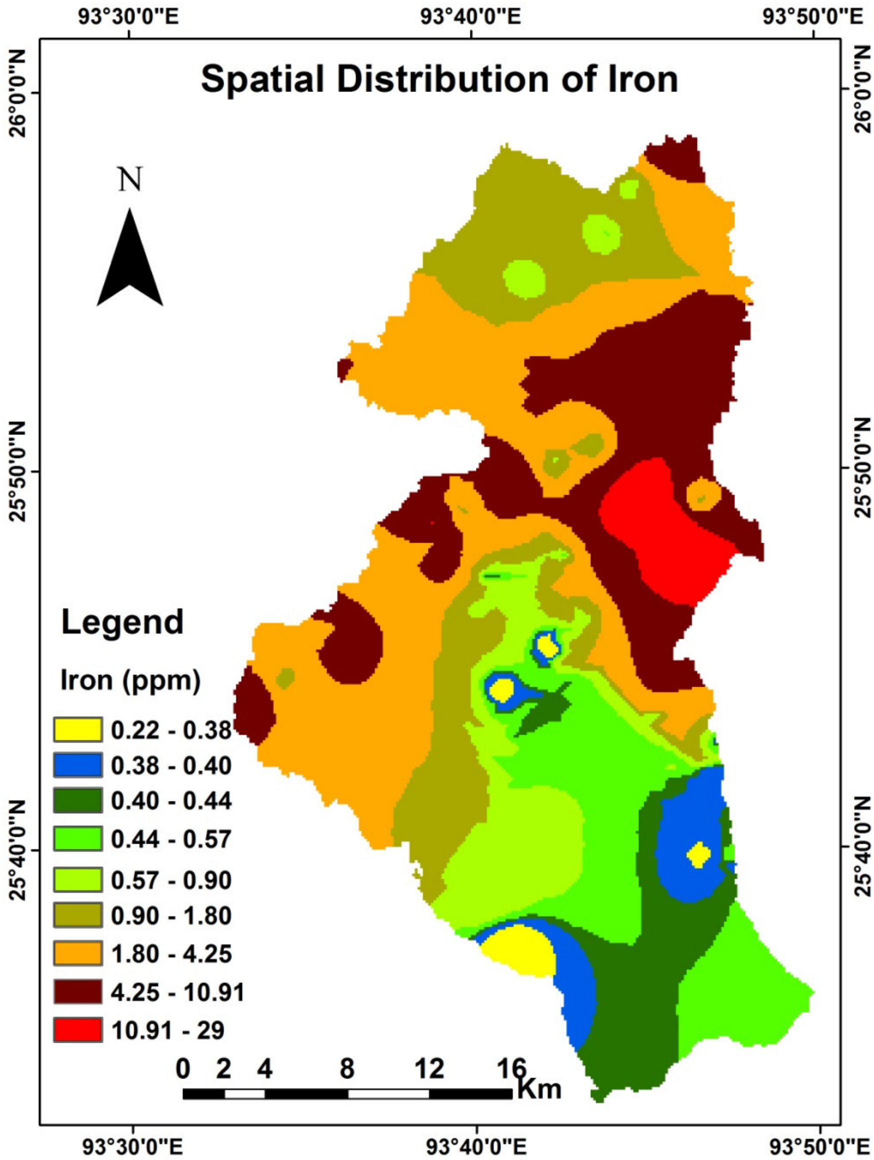

Figure 5.17: Spatial distribution of Iron

Magnesium

Higher magnesium concentrations are found in the western part of the study area. The alluviums have higher magnesium value than the Tertiary formations. Figure 5.18 shows the spatial distribution of magnesium in the study area.

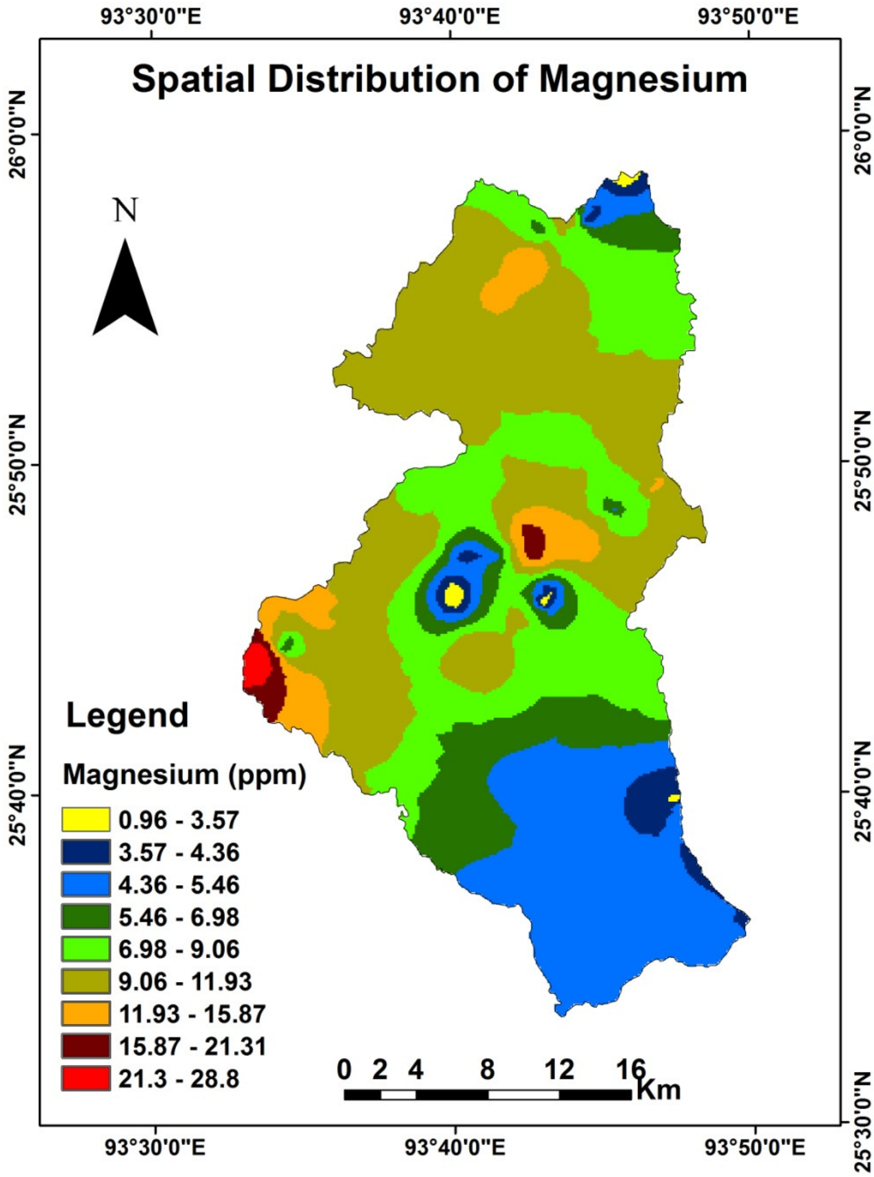

Figure 5.18: Spatial distribution of magnesium

pH

The western part of the study area contains higher pH values. The alluviums have slightly higher pH content than the Tertiary formations. Figure 5.19 shows the spatial distribution of pH in the study area.

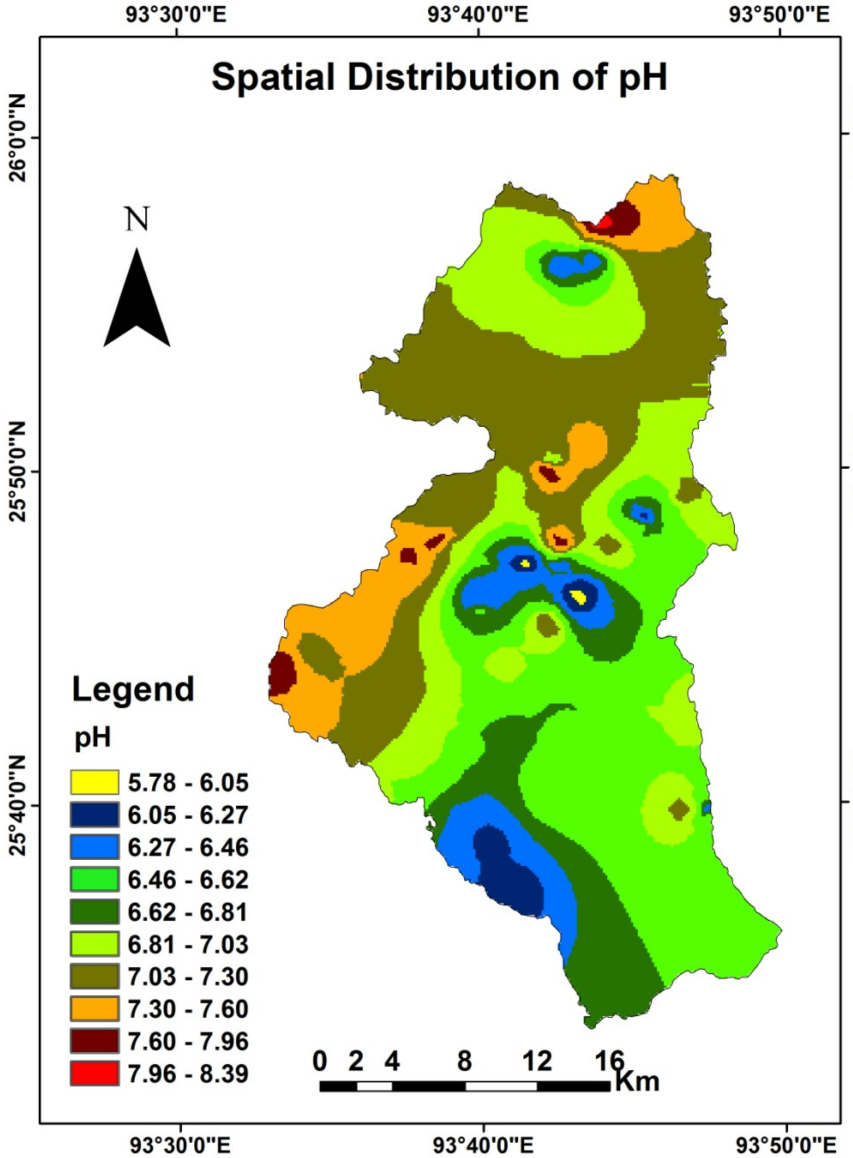

Figure 5.19: Spatial distribution of pH

Potassium

Potassium content is higher in the northern part of the study area. The alluviums have slightly higher Potassium concentrations. Figure 5.20 shows the spatial distribution of potassium in the study area.

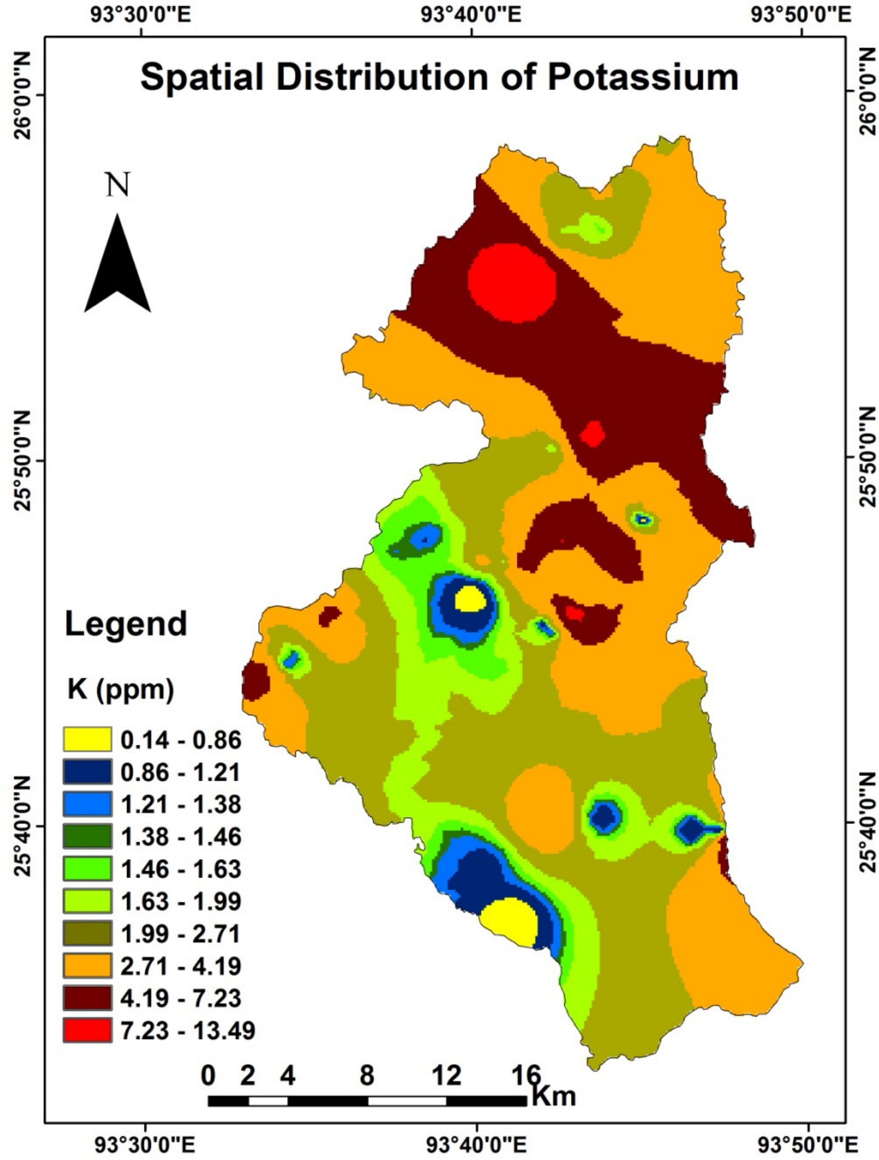

Figure 5.20: Spatial distribution of potassium

Sodium

Higher Sodium concentrations are found in the western part of the study area. The alluviums have higher Sodium concentrations as compared to the alluvium. Figure 5.21 shows the spatial distribution of sodium in the study area.

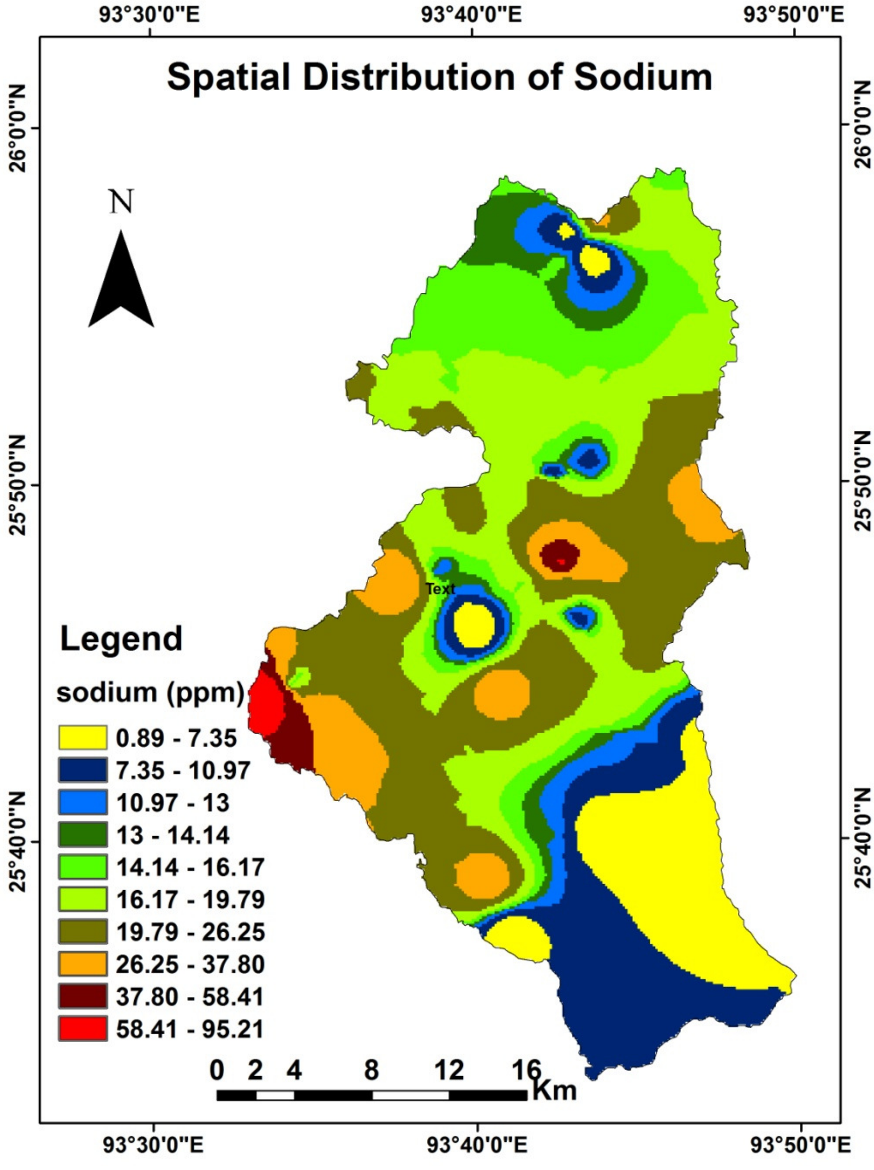

Figure 5.21: Spatial distribution of sodium

Sulphate

The sulphate concentration increases towards the western part of the study area. In general, sulphate content is slightly higher in the alluvium. Figure 5.22 shows the spatial distribution of sulphate in the study area.

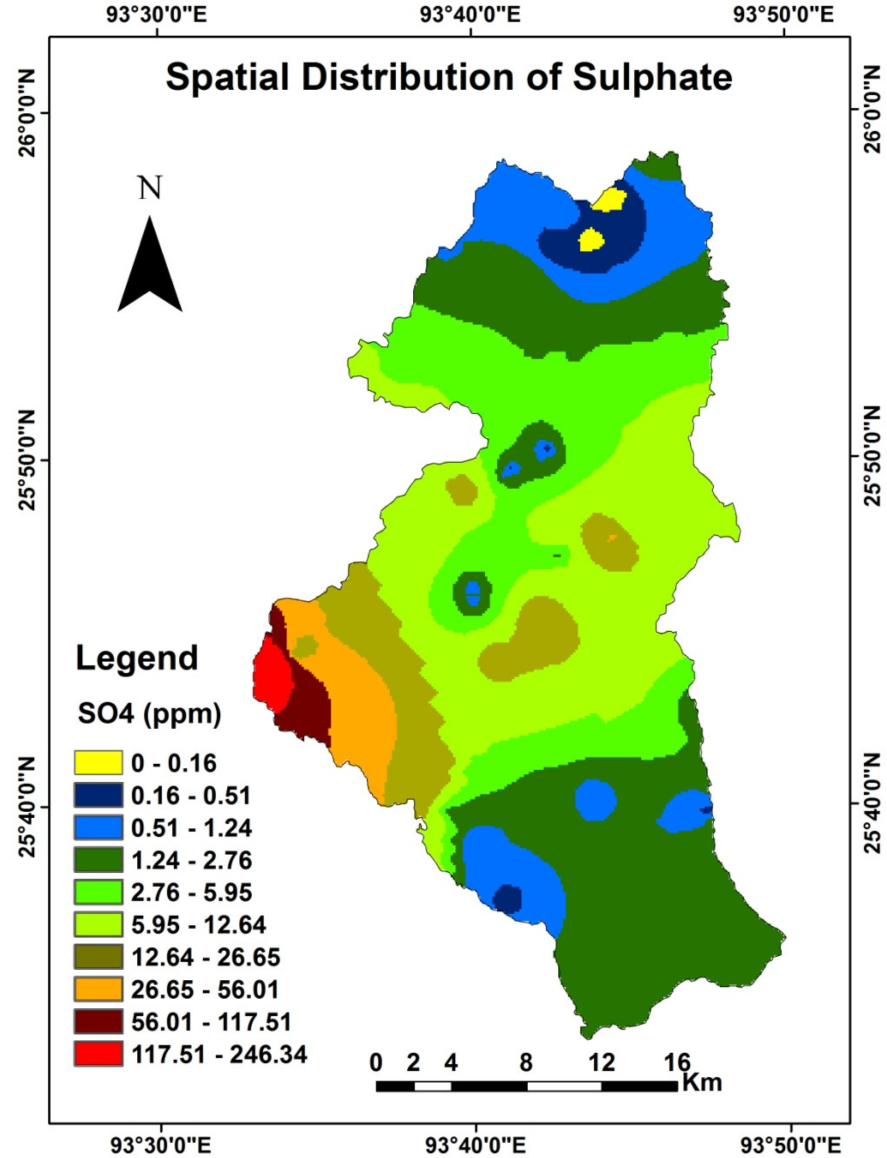

Figure 5.22: Spatial distribution of sulphate

EC

EC is higher in the western part of the study area. The alluviums show higher EC than the Tertiary formations. Figure 5.23 shows the spatial distribution of EC in the study area.

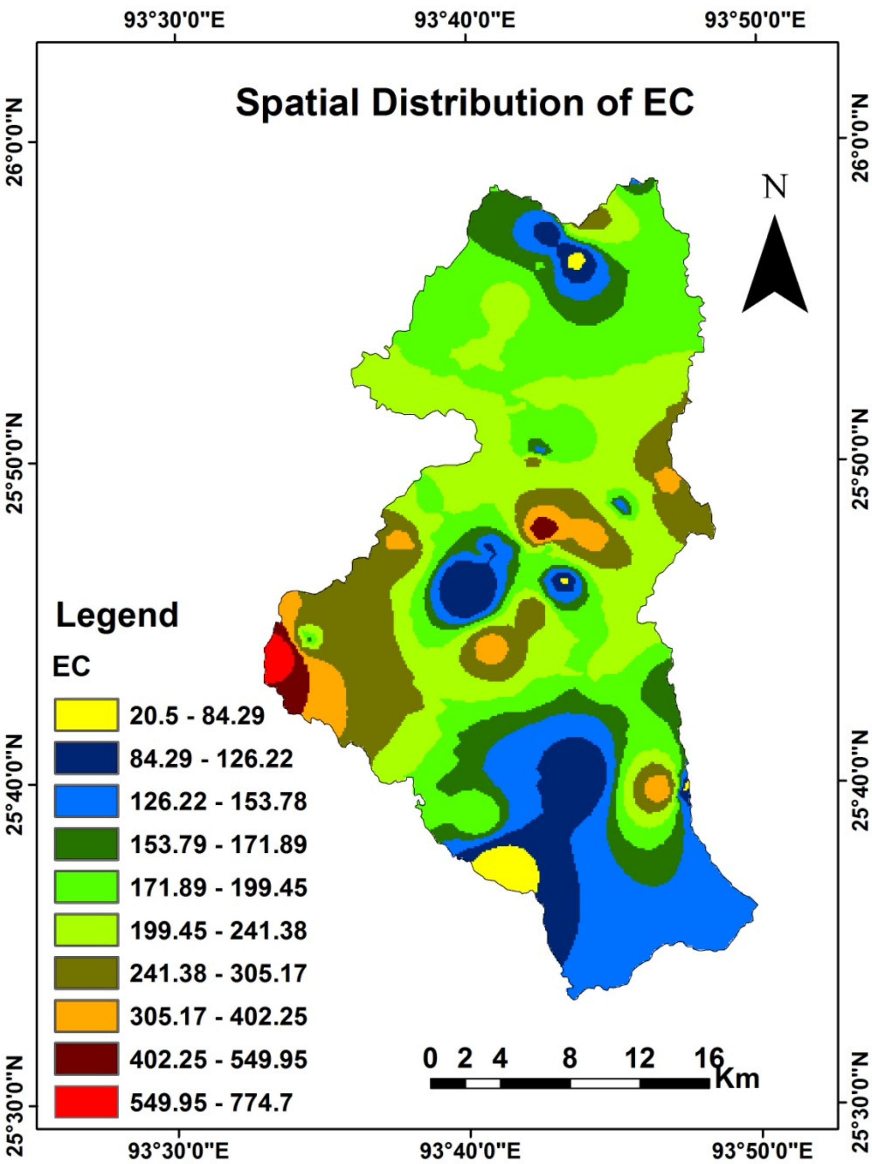

Figure 5.23: Spatial distribution of EC

TDS

TDS increases towards the western part of the study area. The alluviums have higher TDS than the Tertiary formations. Figure 5.24 shows the spatial distribution of TDS in the study area.

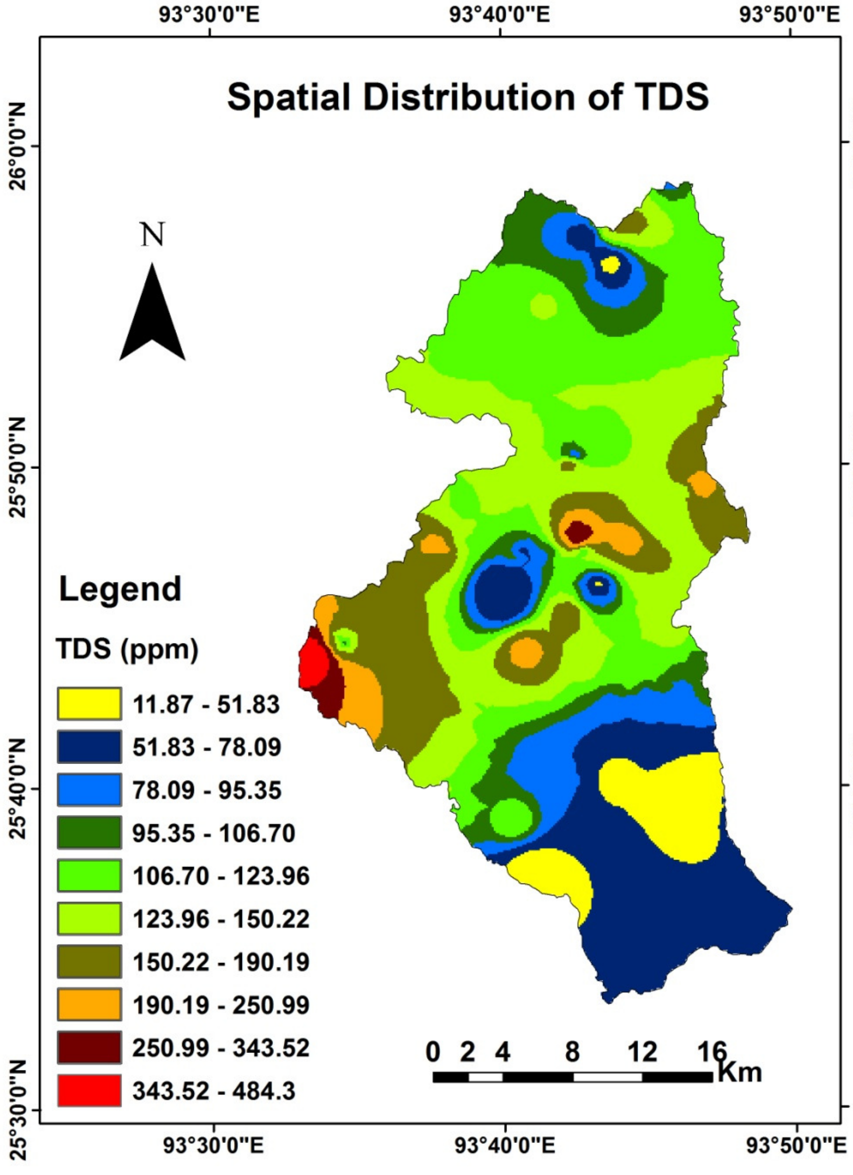

Figure 5.24: Spatial distribution of TDS

Interpolation was not applied for the remaining parameters, namely bromide, nitrite, fluoride and nitrate. The chemical analysis results show that these parameters are below detectable level in most of the location. The location and concentration maps for these parameters are given in Figure 5.25 to 5.28.

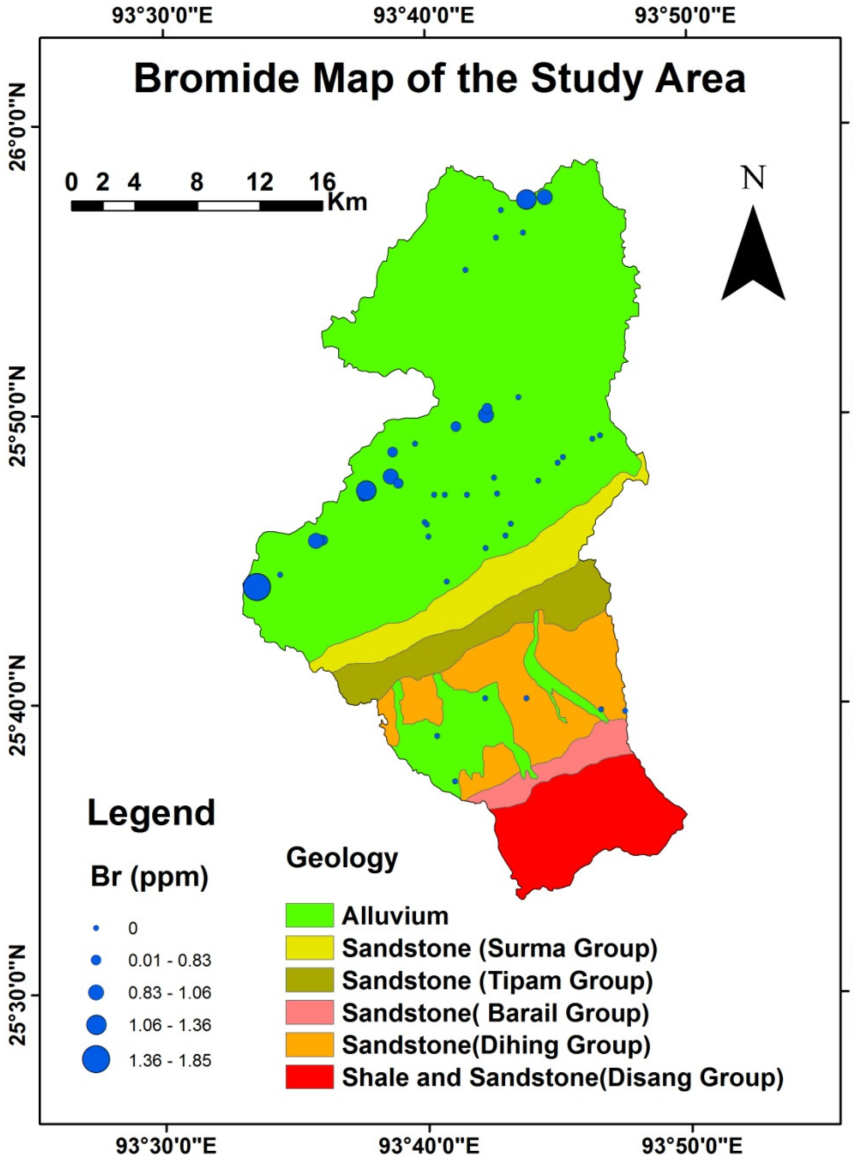

Figure 5.25: Spatial distribution of bromide

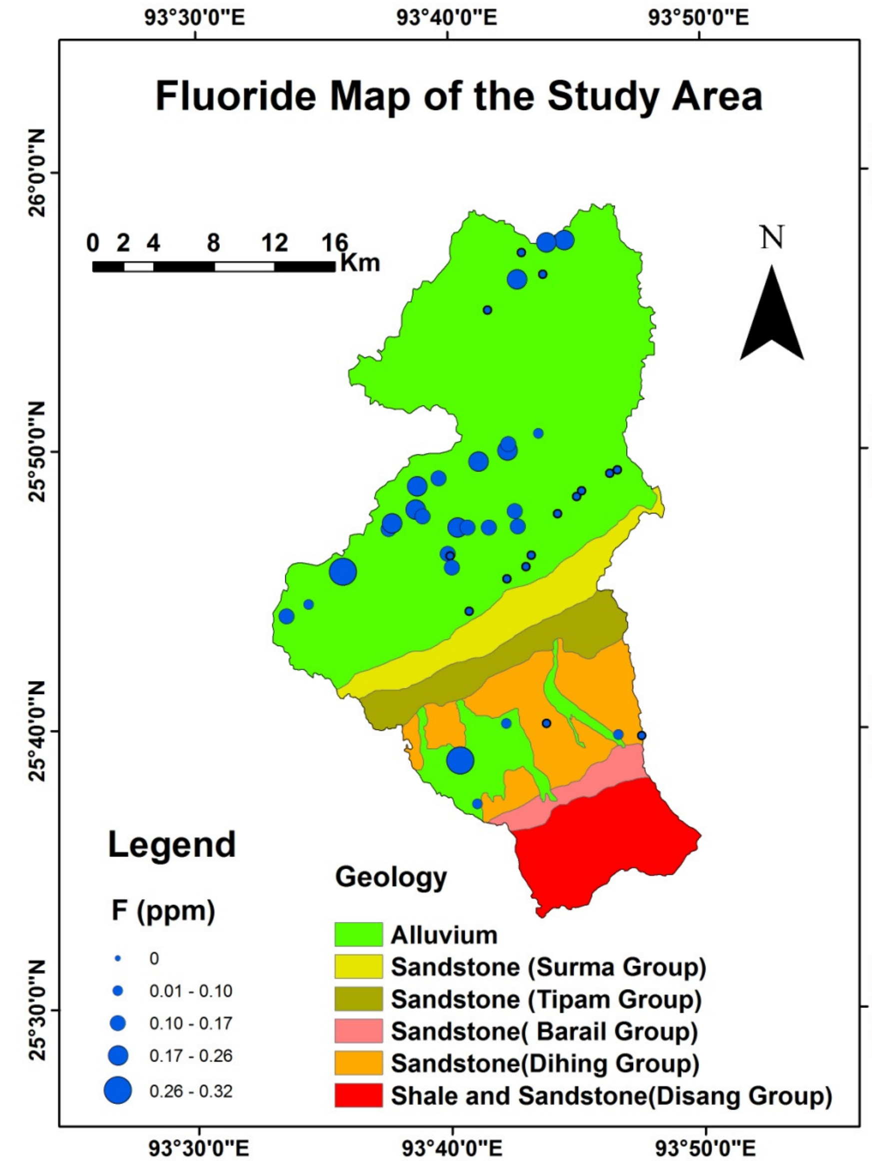

Figure 5.26: Spatial distribution of fluoride

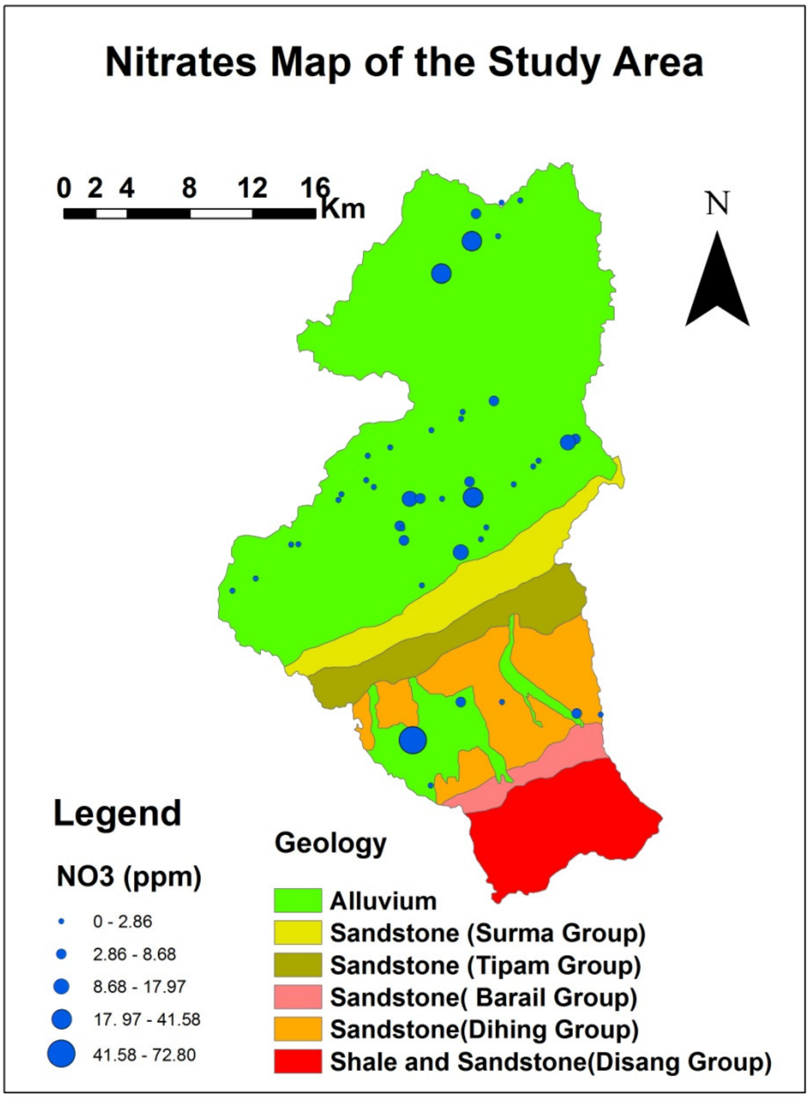

Figure 5.27: Spatial distribution of nitrate

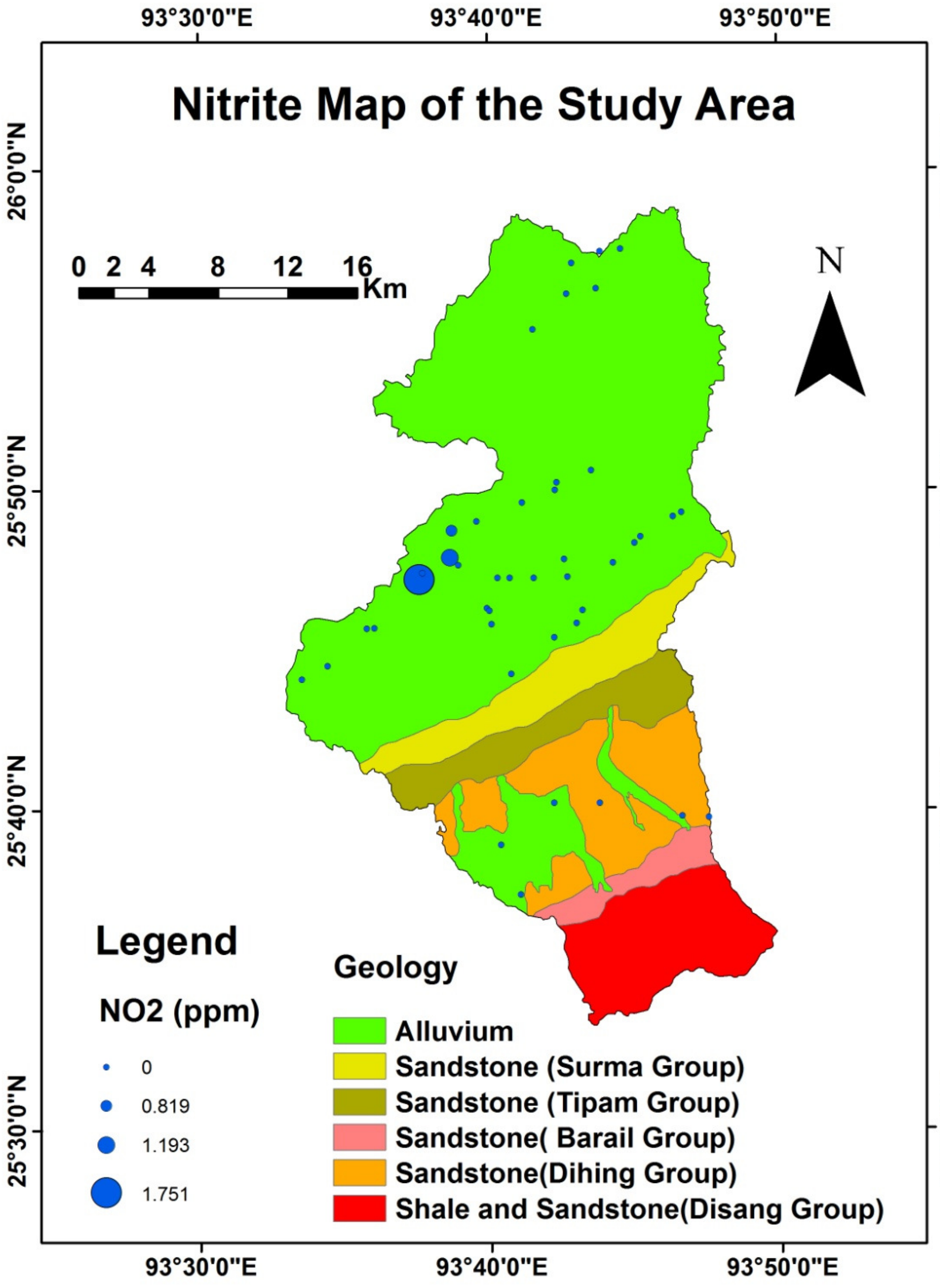

Figure 5.28: Spatial distribution of nitrite

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

Where are the ground water potential zones in the area?

The study area is divided into five categories of ground water potential zones-Very High, High, Moderate, Low and very Low. Very High potential areas covers 27.23284 sq km, High potential areas covers 349.052297 sq km area, Moderate potential areas covers 95.97496 sq km, Low potential areas covers 182.994 sq km and Very Low potential areas covers 64.247 sq km area. Thus, major portions of the study area (61%) has good to moderate potential for ground water while a significant part (34%) of the study area have poor to very poor potential. The excellent potential areas (about 4%) are mainly concentrated along the flood plains.

The flood plains which are composed of sand, silt and clay with nearly gentle slope have very good potential for ground water. The alluvial plains, the intermontane valley fills and valleys with gentle slopes also hold good potential for ground water. Structural hills and residual hills with high slopes show low to very low potential for ground water.

The present study has also demonstrated that an integrated approach involving remote sensing and GIS technique in conjunction with field data can be successfully used in identifying ground water potential zones in the area. The generated ground water potential map may be used as baseline data for exploration, and for the future development and management of ground water resources in the area.

How a distributed physical, hydrological model (VIC) performs for recharge estimation as compared to lumped Water Balance Approach (GEC methodology)?

The annual ground water recharge estimated by GEC method is 13174.77 hectare meter. The main source of ground water recharge in the study area is through rainfall. With an average rainfall of 1025.79 mm per annum the ground water recharge estimated by Water Table Fluctuation method (13174.77 ha.m) is about 17.74% of the annual rainfall and ground water recharge estimated by Rainfall Infiltration Factor method (12362.32 ha.m) is 16.64%. These estimations are found to be in good agreement with previous estimate carried out by CGWB for Dimapur district in 2009 which is estimated at 17022 ha.m.

By using VIC model ground water recharge (baseflow) is estimated at 174.4 mm. This estimation is very close to the estimation of GEC, 1997 which is estimated at 181.86 mm. Therefore, VIC model is found to be suitable for recharge estimation.VIC model also produces spatial distribution of hydrological components/ water balance components for different period of time.

What are the hydro-chemical characteristics of ground water in the area?

The chemical analyses results shows the abundance of the major cations in the order Na> Ca> Mg> K and the abundance of anions in the order HCO_3> Cl> SO_4> NO_3> Br> F> NO_2> CO_3 All the ground water quality parameters analyzed are well within the desirable limits of BIS: 10500 (2004) standards for drinking water except for Iron, nitrate and sulphate. Iron exceeds the desirable limit in almost all the location and the permissible limit in 10 locations. The incidence of high iron content is widespread in the study area and thus may be mainly due to water-rock interactions. Nitrate exceeds the desirable limits in three locations and sulphate in one location. The samples containing high nitrate concentrations were collected from build-up areas and thus it may be due to domestic waste (e.g. animal excrement) while high sulphate concentration may be due to oxidation of sulphite ores, gypsum and anhydrite. The pH value shows that the ground water in the study area is neutral to slightly acidic in nature. Using the Trilinear diagram the ground water in the study area is classified into Ca^{2+} HCO_3 type, Ca^{2+} Na^+ HCO_3Cl type, Ca^{2+} Na^+ HCO_3 type, Ca^{2+} Na^+ Cl type, Na^+ HCO_3Cl type, Na^+ HCO_3 type and Ca^{2+} HCO_3Cl type.

Most of the parameters have higher concentrations in the western part of the study area. Spatial analyses have indicated that the alluvium have higher concentrations of water quality parameters than the Tertiary formations. The main cause may be the flow of ground water from higher elevations of the Tertiary formations to the lower elevations of the alluvium. The ground water during its movement dissolves the minerals from the rocks and increases the concentrations of the different water quality parameters.

The above observations shows that ground water prospect mapping, recharge estimation and hydrochemical studies by using remote sensing, GIS, traditional fieldwork and models provide an immensely useful tool in understanding the occurrence, resources and quality of ground water in the area. This study provides useful database which may be used as a baseline for exploration, assessment, development, management, and regulation of ground water.

6.2. Recommendations

More exhaustive field investigations of well sites in relation to location, topography and structures as well as subsurface information such as pumping test and lithological log data may be made to improve the understanding of the hydrogeological conditions in the area.

Continuous strengthening, updating and improvement of database should be the endeavor to bring in further refinements in the assessment.

The actual specific yield values calculated by conducting pumping tests in the study area should be used for realistic recharge estimation.

The number of observation wells should be increased so as to adequately represent the actual site conditions.

Field validation of the estimates and refinements of norms for various parameters may be carried out in the study area.

Calibration of VIC model may be made on availability of discharge data.

Application of alternate methods for recharge assessment may be taken up to cross-check the assessment figures arrived at using GEC and VIC.

A study including various augmentation and conservation measures like artificial recharge and rainwater harvesting and ground water regulation may be carried out in the area to establish the linkage between the assessment and management of ground water.

In future assessment adequate planning of samples collection, handling, storage and analysis should be made. Sufficient samples should be collected for mapping spatial distribution of water quality parameters.

It is suggested that some low cost and easy to implement technique may be provided to the consumers for removing iron/ iron treatment.

Frequent monitoring of ground water levels, water quality and the amount of water abstracted should be made in the area to provide an early warning system for over-exploitation and water quality deterioration and also to provide essential background data for efficient ground water management. It assumes greater significance with competing demands for water in the area. The state government can institute legislations to protect the drinking sources.

Conjunctive use and management of surface and ground water should also be adopted/ encouraged.

Wherever there is a gap between demand and the resource augmentation of the ground water by way of constructing percolation tanks, check dams and other water harvesting structures should be taken up. Watershed management programmes also help in improving the ground water recharge thereby increasing its augmentation.

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Web Resources

http://www.hydro.washington.edu (accessed on 09/08/2012)

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Indian Standards on Drinking Water Quality

BIS: 10500 (2004)

Parameters/ Limits	TDS (mg/l)	pH	Ca (mg/l)	Mg (mg/l)	Fe (mg/l)	F (mg/l)	Cl (mg/l)	NO_3 (mg/l)	SO_4 (mg/l)
Desirable limit	500	6.5-8.5	75	30	0.3	1	250	45	200
Permissible limit	2000	No relaxation	200	100	1	1.5	1000	No relaxation	400