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IDENTIFICATION OF GROUNDWATER RECHARGE ZONES IN VAIPPAR BASIN OF TAMILNADU USING REMOTE SENSING AND GIS TECHNIQUE

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2015-2017

PREFACE

Groundwater recharge refers to the entry of water from the unsaturated zone below the water table surface, together with the associated flow from the water table within the saturated zone. Groundwater recharge occurs when water flows past the groundwater level and infiltrates into the saturated zone. Field investigations help to explain the process of groundwater recharge and evaluate the spatial-temporal difference in the study area. However, these field investigations often focus on a single affecting factor or an indirect site-specific detail for groundwater recharge, reducing the reliability of the investigations. In recent times remote sensing and geographic information system technique is proved to be a cost effective and time saving tool to produce valuable data on geomorphology, geology, land use land cover, slope, lineament density, drainage density, etc. which helps to decipher groundwater recharge potential zones. Many researchers have used the approach of remote sensing and GIS for identification of groundwater recharge zones and exploration of groundwater with locating the artificial recharge sites. To provide scientifically, appropriate locations for constructing artificial recharge structures, each hydro-geomorphic unit has to be evaluated for its recharge potential and suitably a map showing such groundwater recharge potential zones for appropriate recharge has to be prepared. Using remote sensing and geographic information system (GIS) it is possible to take number of different thematic maps of the same area and overlay them on top of one another to form a new integrated layer. This study was aimed to identify the groundwater recharge potential zones, to be used for better and improved groundwater resources. The thematic layers considered in this study are geomorphology, soil, land use land cover, slope (%), drainage density and lineament density, which are prepared using satellite imagery and other conventional data.

This study is aimed to develop and apply integrated method for combining the information obtained by analysing multi-source remotely sensed data in a GIS environment for better understanding the groundwater resource of Vaippar basin in Tamilnadu. This study was carried out by V.S.Jeyakanthan, Scientist-E, J.V.Tygai, Scientist-G and R.Venkataramana, Scientist-D of this institute.

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ABSTARCT

Satellite images are increasingly used to categorize various earth surface features, which may directly or indirectly serve to identify the presence of groundwater. Hydro-geomorphological mapping using remote sensing data has been used quit long time for delineating ground water prospectus zones in many parts of our country. The intricate relationship among the various terrain parameters controlling ground water regime is difficult to evaluate if the terrain features are highly complex. In these circumstances the Geographic Information System (GIS) has emerged as a powerful tool in analysing and quantifying such multivariate aspects of groundwater occurrence.

The proposed methodology of study involved various activities such as base map preparation, LULC map preparation, Digitization and image processing using ERDAS, ARCGIS software and interpretation of the outputs. First stage includes development of spatial data base by using survey of India (SOI) topo-sheet and satellite data on a 1: 50000 scale. The parameters sunch as hydro-geomorphology, geology, drainage density, lineament, landuse/lancover, slope and soil controls the Ground Water Recharge potential of a basin. The input parameters Landuse/landcover map and lineament has been prepared using Landsat8 satellite data. Slope map have been obtained using the digital elevation model (DEM) with the help of SRTM data. Soil map of the study area was prepared using NBSS&LUP maps. Likewise various themaptic maps such as lineament density, drainage density, slope, soil, geomorphology and wasteland has been prepared and used in the study. The various thematic layers are assigned proper weightage through MIF technique and then integrated in the GIS environment to prepare the groundwater recharge zones map of the study area. According to the groundwater recharge zones map, Vaippar basin is categorized into four different zones, namely ‘good’, ‘moderate’, ‘poor’, and ‘very poor’.

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FIGURES **Page No.**

CHAPTER – 1

INTRODUCTION

Groundwater is a vital natural resource for the reliable and economic provision of potable water supply in both urban and rural environment. Hence it plays a fundamental role in human well-beings, as well as that of some aquatic and terrestrial ecosystems. At present, groundwater contributes around 34% of the total annual water supply and is an important fresh water resource. So, an assessment for this resource is extremely significant for the sustainable management of groundwater systems. GIS and remote sensing tools are widely used for the management of various natural resources (Dar et al., 2010; Krishna Kumar et al., 2011; Magesh et al., 2011a and Magesh et al., 2011b). Delineating the potential groundwater recharge zones using remote sensing and GIS is an effective tool. In recent years, extensive use of satellite data along with conventional maps and rectified ground truth data, has made it easier to establish the base line information for groundwater recharge zones (Tiwari and Rai, 1996; Das et al., 1997;Thomas et al., 1999; Harinarayana et al., 2000; Muralidhar et al., 2000; Chowdhury et al., 2010). Remote sensing not only provides a wide-range scale of the space-time distribution of observations, but also saves time and money (Murthy, 2000; Leblanc et al., 2003; Tweed et al., 2007). In addition it is widely used to characterize the earth surface (such as lineaments, drainage patterns and lithology) as well as to examine the groundwater recharge zones (Sener et al., 2005).

Applications of remote sensing and GIS for the exploration of groundwater potential zones are carried out by a number of researchers around the world, and it was found that the involved factors in determining the groundwater potential zones were different, and hence the results vary accordingly. Teeuw (1995) relied only on the lineaments for groundwater exploration and others merged different factors apart from lineaments like drainage density, geomorphology, geology, slope, land-use, rainfall intensity and soil texture (Sander et al., 1996; Das, 2000; Sener et al., 2005; Ganapuram et al., 2008). The derived results are found to be satisfactory based on field survey and it varies from one region to another because of varied geo-environmental conditions. Development of groundwater in the study area is through construction of dug wells, dug-cum-bore wells and bore wells. However, recharging those groundwater sources is curtailed by frequent dry seasons and failure of monsoons. The minimum depth of the water table in the study area is 5 m in favorable localities adjoining rivers, canal system and abutting tanks, whereas the water table in remote areas is found very deeper up to 50–60 m resulting in acute water shortage. Exploitation of groundwater resources has increased in the past decades, leading to the over-consumption of groundwater, which eventually causes ecological problems such as decreased groundwater levels, water exhaustion, water pollution and deterioration of water quality.

Integration of remote sensing with GIS for preparing various thematic layers, such as lithology, drainage density, lineament density, rainfall, slope, soil, and land-use with assigned weightage in a spatial domain will support the identification of groundwater recharge zones. Therefore, the present study focuses on the identification of groundwater recharge zones in Vaippar basin, Tamil Nadu using remote sensing and geographic information system.

CHAPTER - 2

STUDY AREA

2.1. The Basin and its sub-basins

The Vaippar river basin (Fig. 2.1) is located in the southernmost part of South India and situated between latitudes 8°59′N to 9°49′ N and longitudes 77°15′E to 78°23′E covering a total catchment area of 5423 km^2. It is an intrastate river, i.e., the whole catchment area lies within Tamilnadu State. The Vaippar River is known as Nichabanadhi in the upper reaches. Only after the confluence of Deviar with Nichabanadhi, the river in called the Vaippar. The Nichabanadhi originates in Vasudevanallur reserve forest on the eastern slope of Western Ghats from Neduntheri Mottai in Sivagiri taluk of Tirunelveli district at an attitude of 1650 m above M.S.L.

The basin is bounded by the Vaigai basin and the Western Ghats on the western side, the Thambaraparani and Kallar river basins on the southern side and the Gundaru river basin on the northern side. The basin area lies in Srivilliputhur, Rajapalayam, Sathur, Aruppukottai and Virudhunagar taluks of Kamarajar district, Thirumangalam and Usilampatti taluks of Madurai district, Sankarankoil and Sivagiri taluks of Tirunelveli – Kattabomman districts and Kovilpatti and Vilathikulam taluks of Thuthukudi district. The general direction of drainage is from NW to SE. The total catchment area is 5423 km^2 out of which 671 km^2 area lies in hilly terrain.

The total length of the Vaippar river from its origin in Western Ghat to its outfall in the Bay of Bengal is 112 km. This out-fall is near Vaippar village. Below the confluence of the Kayalkudiyar with the Vaippar, the river has got a well-defined course. No meandering / shifting of the river course is found.

Physiographically, the catchment area of the basin can be divided into two units:

(i) Western hill and valley complex region where the ground slope is steeper making the drainage flow faster
(ii) Eastern plain region having flatter slope yielding extended drainage flow.
(iii)

There are 12 tributaries of the Vaippar river. They are: 1.Nichabanadhi 2.Kalingalar 3.Deviar 4.Nagariyar, 5.Sevalperiyar Mudangiar 6.Arjunanadhi 7.Kousiganadhi 8.Sindapalli Uppodai 9.Uppathur 10.Sinkottaiyar 11.Kayalkudiyar 12.Vallampatti Odai.

There are six reservoirs in the basin. They are (i) Periyar across Periyar river; (ii) Kovilar across Kovilar river; (iii) Anaikuttam at the confluence of Arjunanadhi and Thiruthangal Odai; (iv) Kullursandai across Koushiba Nadhi; (v) Gowarpatti at the confluence of Arjunanadhi and Koushiba Nadhi and (vi) Venbakottai at the confluence of

Nichabanadhi, Sevalaperiar and Kayalkudiyar. One more reservoir is under construction at Irukkankudi at the confluence point of Arjunanadhi with Vaippar.

There are two anicuts in operation across the Vaippar river: Sanakaranatham below the Vembakottai reservoir and at Athankarai just upstream of Vilathikulam. Any flow which crosses this anicut is considered to be a waste to the sea since there is very little scope of using on the downstream of Athankarai.

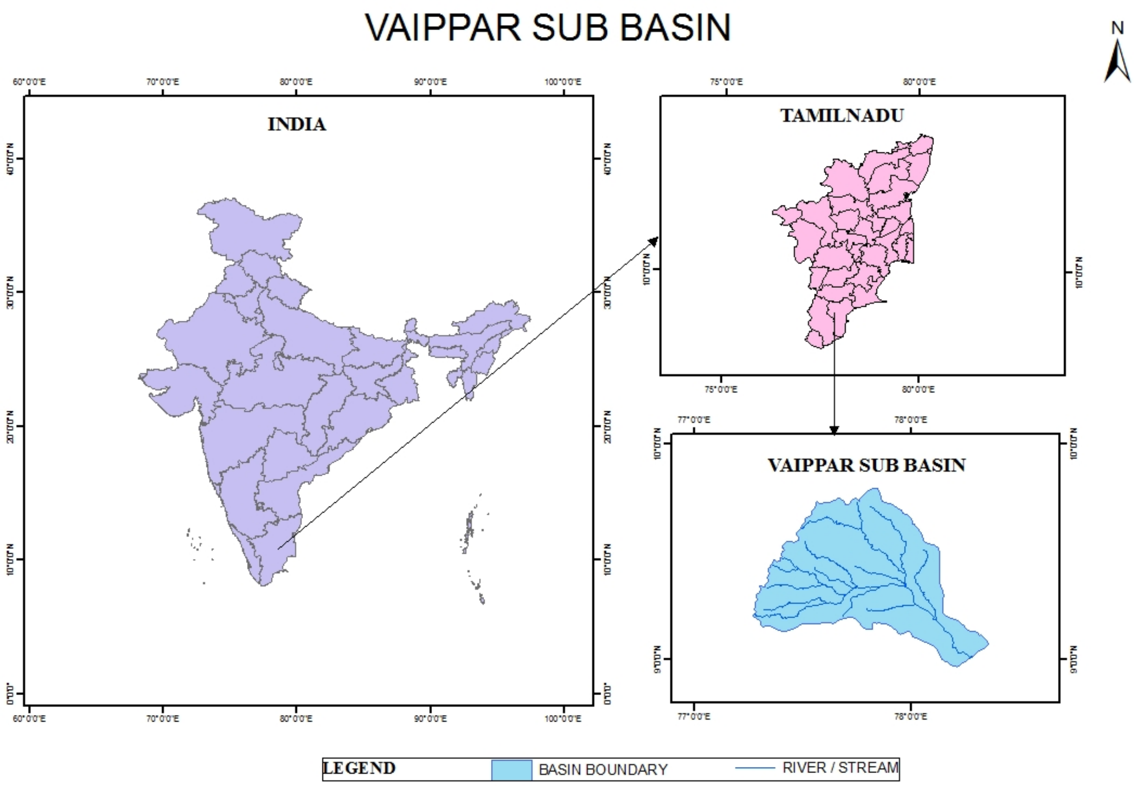

Fig.2.1. Study Area Map (Vaippar Sub-basin)

CHAPTER-3

METHODOLOGY

Groundwater recharge refers to the entry of water from the unsaturated zone into the saturated zone below the water table surface, together with the associated flow away from the water table within the saturated zone (Freeze R.A and Cherry J.A, 1979). Recharge occurs when water flows past the groundwater level and infiltrates into the satu- rated zone. It is an extremely important water component of the circulation cycle in nature. There are several methods such as geological, hydrogeological, geophysical and remote sensing (RS) techniques, which can be applied to determine groundwater recharge potential zone (Mukherjee S., 1996). Many factors affect the occurrence and movement of groundwater in a region, including topography, lithology, geological structures, depth of weathering, extent of fractures, primary porosity, secondary porosity, slope, drainage patterns, landform, land use/land cover, and climate (Jaiswal et.al., 2003, Jha M.K., et.al., 2007). In- site hydrogeology experiments and geophysics surveys help explain the groundwater recharge process and evaluate the spatial-temporal differences in study regions. However, these surveys often focus on a single affecting factor or an indirect site-specific experiment for groundwater recharge, reducing the reliability of the explanation. Recently, RS has been increasingly employed to replace on-site exploration or experiments. RS techniques enable improved characterization of the land surface, which are applicable to an increasing number of hydrogeological studies. RS not only provides a wide-range scale of the space- time distribution of observations, but also saves time and money. RS technology, such as aerial photos, was used in the present study to identify the geological features, topography, and distri- bution of the rivers in the region under consideration. Additionally, the land utilization survey database, geologic maps, and on-site investigation were adopted to quantitatively and qualitatively describe the hydro-geological conditions of the area. The different polygons in the thematic maps were labeled separately. The influ- ence of the factors of groundwater recharge and the interaction between the factors were examined. Weighting values were assigned according to the on-site situation. The distribution of the groundwater recharge potential zone was determined by coordi- nating it with the space integrating function of the GIS. The groundwater recharge potential zone has been assessed in various methods in many countries. In this study, the weights of different factors for potential groundwater recharge and the scores obtained under various characteristics were referred the study methods of Shaban et al. and Yeh et al.

The methodology adopted for the present study is shown in Fig.3.1. The base map of Vaippar basin was prepared based on Survey of India topographic maps on a 1:50,000 scale. The Survey of India (SOI) topo-sheets were scanned and the drainage network of the study area were digitized using ArcGIS platform. The slope map was prepared from SRTM DEM data in ArcGIS Spatial Analyst module. The rainfall maps were prepared using the data obtained from the Indian Meteorological Department (IMD) raingauge stations. These data were then spatially interpolated using Inverse Distance Weighted (IDW) method to obtain the rainfall distribution

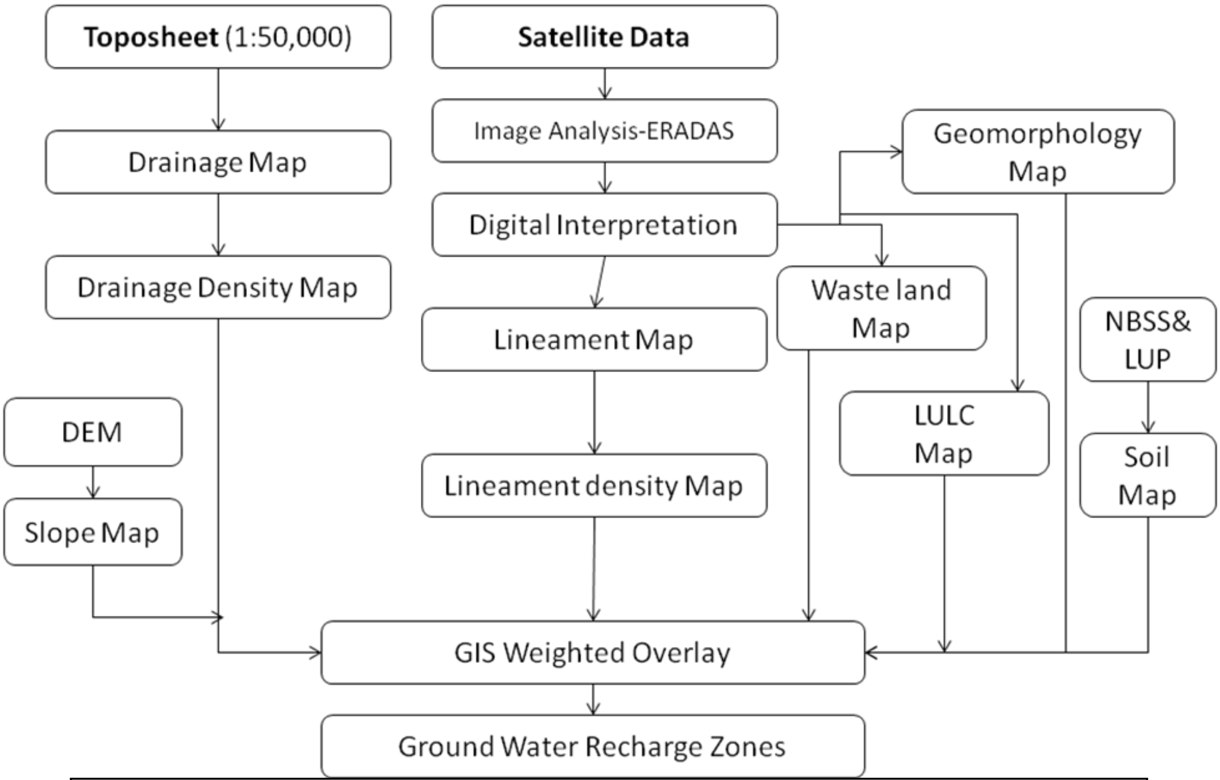

Fig.3.1. Flow chart for identifying groundwater recharge zones

map. This interpolation method combines the concepts of proximity to follow Thiessen polygons with gradual change of the trend surface. The drainage density and lineament density maps were prepared using the line density analysis tool in the ArcGIS software. Satellite images from LANDSAT8 - OLI (Operational Land Imager) sensor, on a scale of 1:50,000 (geo-coded, with UTM projection, spheroid and datum WGS 84, Zone 44 North) have been used for delineation of thematic layers such as land-use, and lineament. The soil map was prepared with the help of

NBSS&LUP maps. These thematic layers were converted into raster format and then the GIS analysis was carried out using the spatial analysis tool in the ArcGIS platform. During the weighted overlay analysis, the ranking was given for each individual parameter of each thematic map, and weights were assigned according to the multi influencing factor (MIF) of that particular feature on the hydro-geological environment of the study area (Shaban et al., 2006).

3.1. Establishing potentially related groundwater recharge factors

Land use/cover: Land use/cover is an important factor in groundwater recharge. It includes the type of soil deposits, the distribution of residential areas, and vegetation cover. These are interpretable from satellite image and land use/cover maps. Knowledge of land use and land cover is necessary to help quantify the water budget. Land use and land cover affect evapotranspiration, runoff, and recharge of the groundwater system. Leduc et al., estimated the difference in the amount of groundwater recharge due to changes of land utilization and vegetation from changes in the groundwater level. Land use/cover is included in this study as an important factor affecting the groundwater recharge process.

Lineaments: A lineament is a linear feature in a landscape which is an expression of an underlying geological structure such as a fault. Lineaments are generally referred to in the analysis of RS of fractures or structures. Lineament photos from satellites and aerial photos have similar characteristics, but the results of the explanation in situ may be different. O'Leary et al., defined lineaments as the simple and complex linear properties of geological structures, such as faults, cleavages, fractures, and various surfaces of discontinuity, that are arranged in a straight line or a slight curve, as detected by RS. Many non-geological structures, such as roads and channels, cause errors in the analysis of lineaments. Therefore, geologic maps and on-site investigations must be used to eliminate possible errors. Lineaments may be used to infer groundwater movement and storage. Lattman and Parizek were the first to adopt a lineaments map to explore groundwater.

Drainage: Drainage density is the total length of all the rivers in a drainage basin divided by the total area of the drainage basin. The structural analysis of a drainage network helps assess the characteristics of a groundwater recharge zone. The quality of a drainage network depends on lithology, which provides an important index of the percolation rate. The drainage-length density, as defined by Greenbaum indicates the total drainage-length in a unit area. Many studies have integrated lineaments and drainage maps to infer apotential groundwater recharge zone .

Slope: In many studies related to groundwater flow and storage, the slope is often ignored; especially in areas with less mountainous terrain. Rainfall is the main source of groundwater recharge in both tropic and subtropic regions. The slope gradient directly in- fluences the infiltration of rainfall. Larger slopes produce a smaller recharge because water flows rapidly down a steep slope during rainfall, so it does not have sufficient time to infiltrate the surface and recharge the saturated zone. The slope analysis function in the GIS is used to assess the variation of slope in the study basin using data from the Digital Terrain Model (DTM) database in Taiwan.

3.2. Multi-influencing factors for identifying groundwater recharge zones

Seven influencing factors, such as landuse-landcover, slope, lineament, drainage, soil, geomorphology and wasteland have been identified to delineate the groundwater recharge zones. Each relationship is weighted according to its strength. The representative weight of a factor of the potential zone is the sum of all weights from each factor. A factor with a higher weight value shows a larger impact and a factor with a lower weight value shows a smaller impact on groundwater potential zones. Integration of these factors with their potential weights is computed through weighted overlay analysis using ArcGIS.

CHAPTER-4

RESULTS & DISCUSSION

4.1. Drainage density

Drainage density depicts the closeness of spacing of stream channels in the study area. It is a measure of the total length of the stream segment of all orders per unit area. The drainage density is an inverse function of permeability. The less permeable a land surface, the less is the infiltration of the rainfall, which conversely tends to be concentrated in surface runoff. Drainage density of the study area is calculated using line density analysis tool in ArcGIS software. The study area has been grouped into four classes. These classes have been assigned to 'Good', 'Moderate', 'poor' and 'very poor' respectively (Fig.4.1a & 4.1b). Moderate drainage density is prevailing in most part of the study area. The highest drainage density value in the study area is 1.51 km/km^2. The suitability of groundwater potential zones is indirectly related to drainage density because of its relation with surface runoff and permeability.

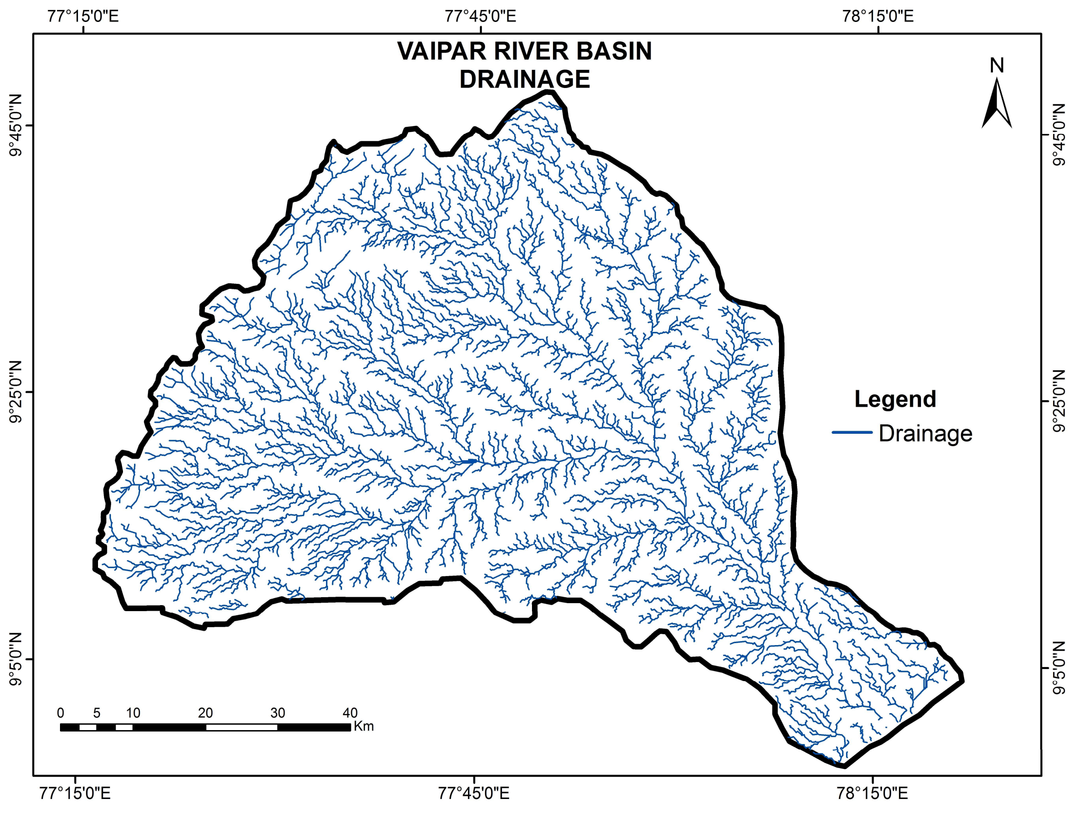

Fig.4.1(a) Drainage Map of Vaippar Basin

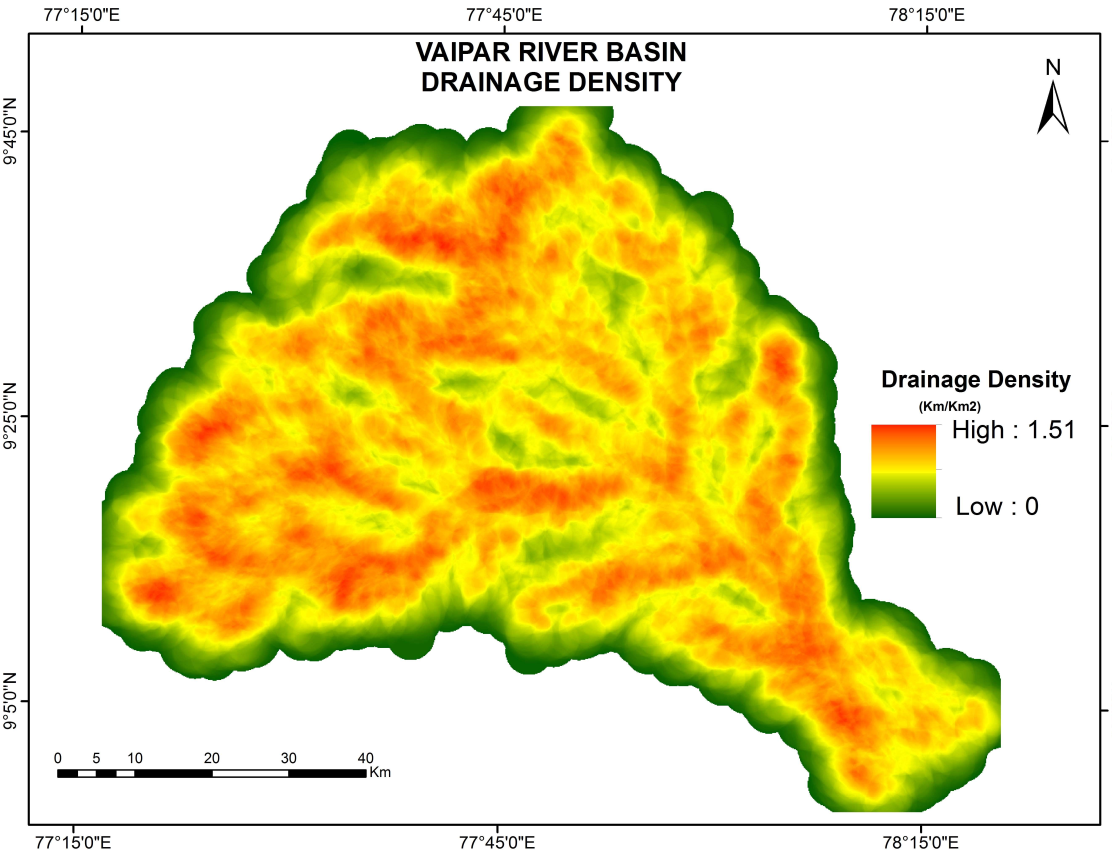

Fig.4.1(b). Drainage Density Map of Vaippar Basin

4.2. Lineament density

Lineaments are structurally controlled linear or curvilinear features, which are identified from the satellite imagery by their relatively linear alignments. These features express the surface topography of the underlying structural features. Lineaments represent the zones of faulting and fracturing resulting in increased secondary porosity and permeability. These factors are hydro-geologically influence the groundwater movement. Lineament density of an area can indirectly reveal the groundwater potential, since the presence of lineaments usually denotes a permeable zone. Areas with high lineament density are good for groundwater recharge zones (Haridas et al., 1998). The lineament density map of the study area is shown in Fig. 4.2, and it reveals that high lineament density is observed in the center and south central portion of the study area with a value ranging from 0 to 2.51 km/km^2.

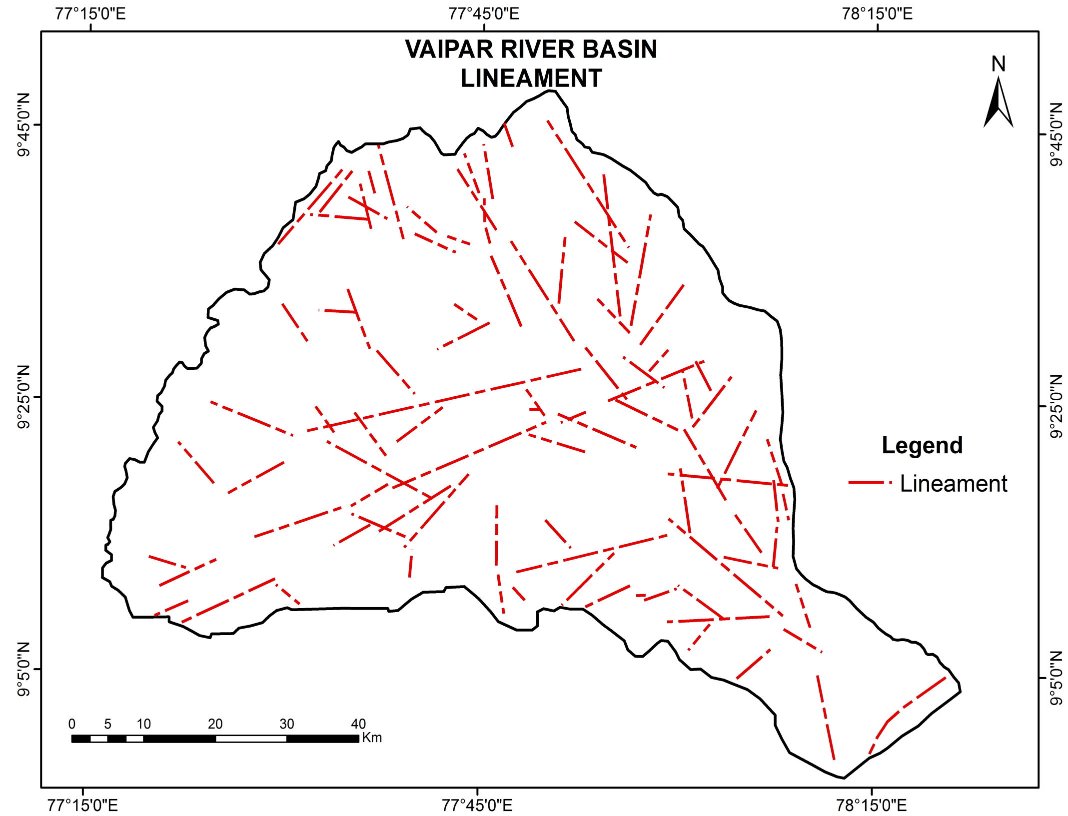

Fig 4.2. Lineament map of Vaippar basin.

4.3. Land-use/land-co

The major land-use type in the study area are barren land, intensively & sparsely irrigated area, and hills, forest and settlement. These land-use classes are delineated from LANSAT8 – OLI (Land Imager) satellite data (Fig.4.3). Around 60% of the total area is under barren land. remaining 40% is occupied by irrigated area, hills and forest.

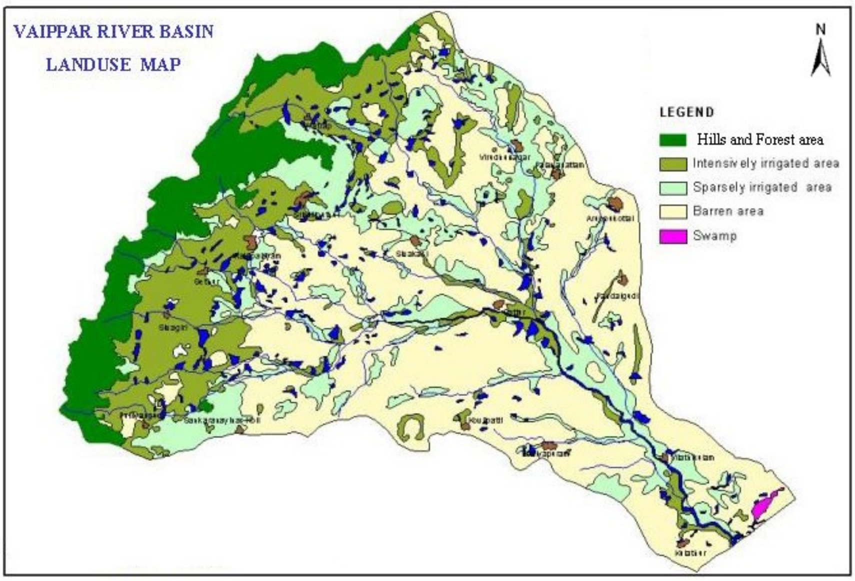

Fig.4.3 Landuse/Landcover Map of Vaippar Basin

4.4 Geomorphology

The identification and characterization of various landforms and structural features in the study area is important from recharge study point of view. Many of these features are favourable for occurrence and recharge of groundwater and are classified in terms of groundwater recharge potentiality. Geomorphologic units were delineated based on the image characteristics such as tone, texture, shape, colour and associations. By overlapping the base map over the geocoded FCC image, the geomorphologic units and landforms, the structural information and structural trend lines are incorporated. Structural hills are observed on northern part of the study area, which are the linear or acute hills exhibiting definite trend lines and mostly act as runoff zones due to its sloping topography. This shows poor potentiality for groundwater occurrence and recharge. Valley fills are low lying depressions formed longitudinally along the streams or amongst the ridge portions, which shows excellent potential for groundwater occurrence and recharge. Burried pediplain are flat and smooth surface with shallow overburden and are usually crisscrossed by fractures / lineaments, faults, etc. and are considered to be good for groundwater occurrence and recharge. By extraction of various classes of geomorphology, a thematic map for geomorphology is generated as per figure 4.4 below. The ranks were assigned to the individual landform, according to its respective influence of groundwater occurrence, holding and recharge.

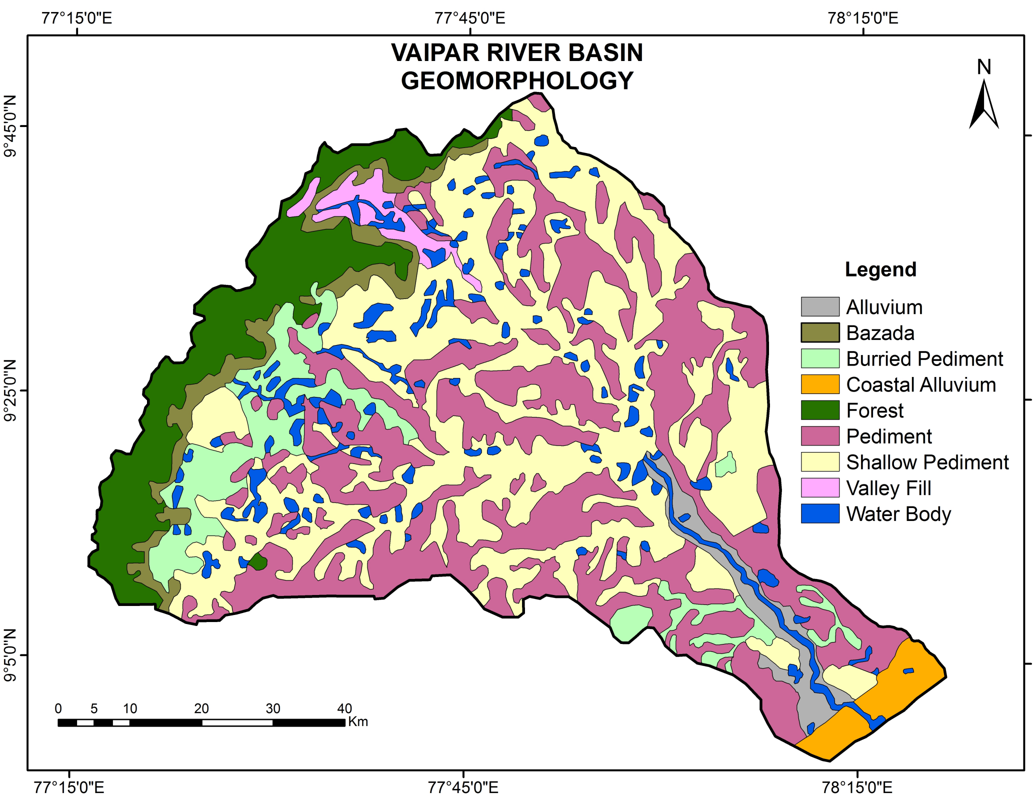

Fig.4.4 Geomorphology Map of Vaippar Basin

4.5 Wasteland

The wasteland map of the study area was prepared using the satellite data. The identified wasteland in the Vaippar basin are land affected by salinity/ alkanity, barren land (covered by black cotton soil), barren land rocky with or without scrub, area covered by scrubs/ shrubs. The mapped units are shown in Fig.4.5. These units have been given appropriate rankling and used in the GIS analysis.

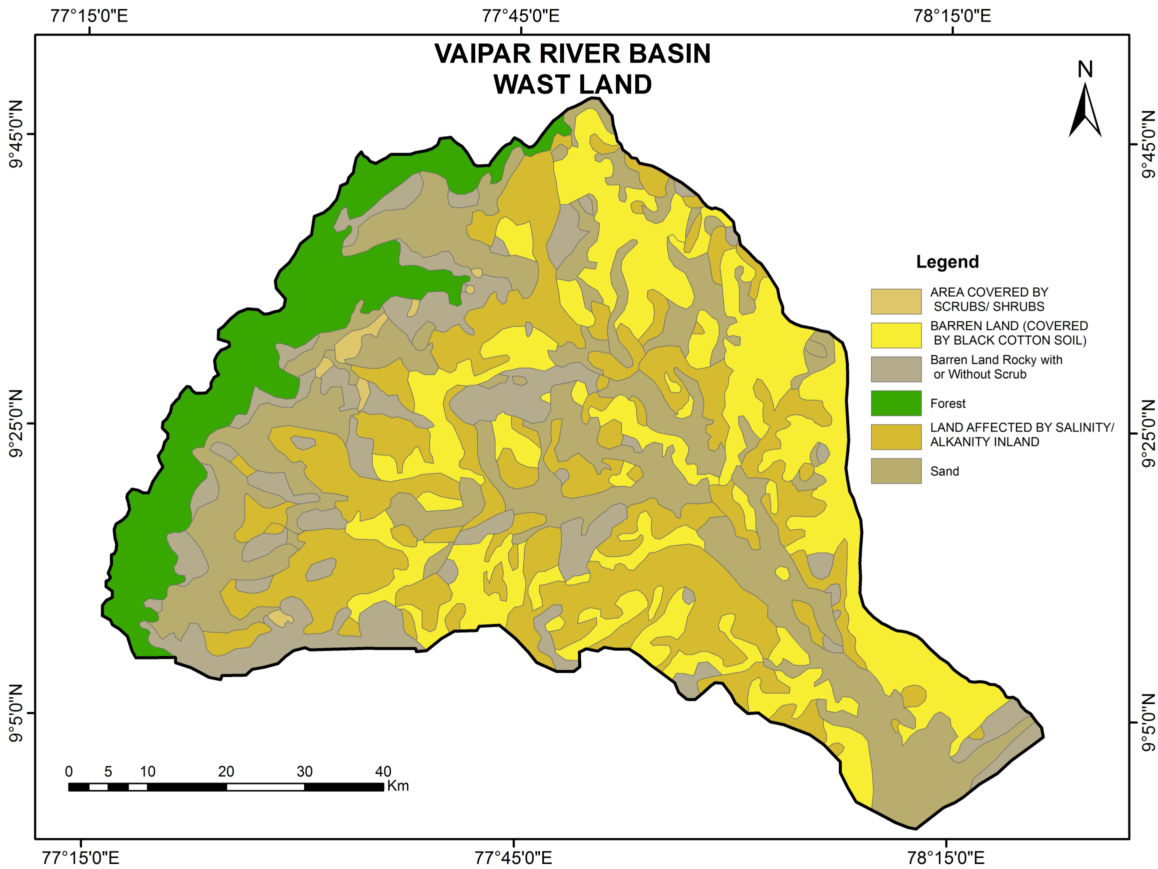

Fig.4.5 Wasteland Map of Vaippar Basin

4.6 Soils

Soil is an important factor to delineate the groundwater recharge zones of any study area. Alluvium soil is loose, unconsolidated soil or sediments, which has been eroded, reshaped by water in some form. These soils are considered as good for groundwater occurrence, holding and recharge potential. Regur soils are black in colour and are also known as black cotton soils. They are well-known for their ability to retain moisture. These soils have moderate effect as a controlling factor for groundwater occurrence and recharge potential for this study area. Mountain soils are mainly found in hill slopes. These are mostly less prone to infiltration and subsequently causing poor in groundwater occurrence and recharge potential. By extraction of various classes of soil types, a thematic map for soil was generated as per Fig. 4.6. The ranks were assigned to the individual soil type, according to its respective influence of groundwater occurrence, holding and recharge potential.

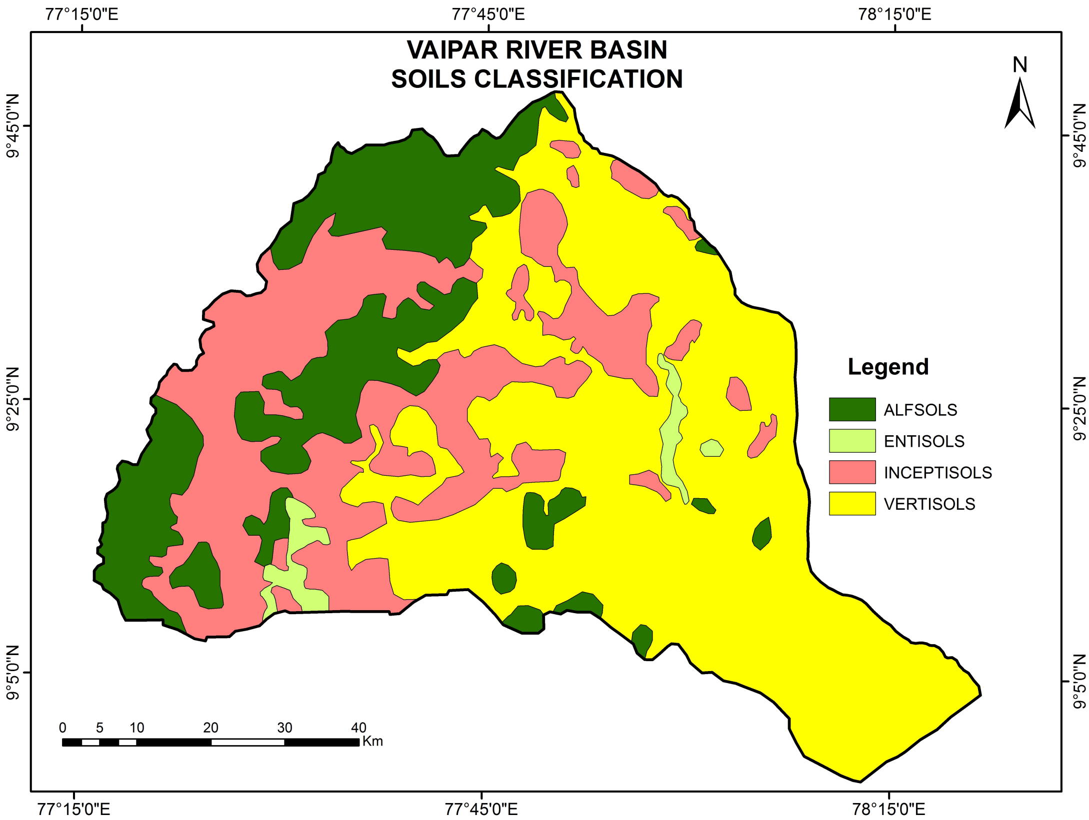

Fig.4.6 Soil Map of Vaippar Basin

4.7. Slope

Slope is an important factor for the identification of groundwater recharge zones. Higher degree of slope results in rapid runoff and increased erosion rate with feeble recharge potential (Magesh et al., 2011a,b). The slope map of the study area was prepared based on SRTM data using the spatial analysis tool in ArcGIS. Slope grid is identified as "the maximum rate of change in value from each cell to its neighbors" (Burrough, 1986). Based on the slope, the study area were divided into four slope classes. The areas having slope 0 to 5 fall into the 'Good' category because of the nearly flat terrain and relatively high infiltration rate. The areas with 6 to 10 slope are considered as 'Moderate' for groundwater storage due to slightly undulating topography with some runoff. The areas having a slope of 11 to 25 cause relatively high runoff and low infiltration, and hence are categorized as 'poor' and the areas having a slope >25 are considered as 'very poor' due to higher slope and runoff. Fig. 4.7 illustrates the slope map of the study area.

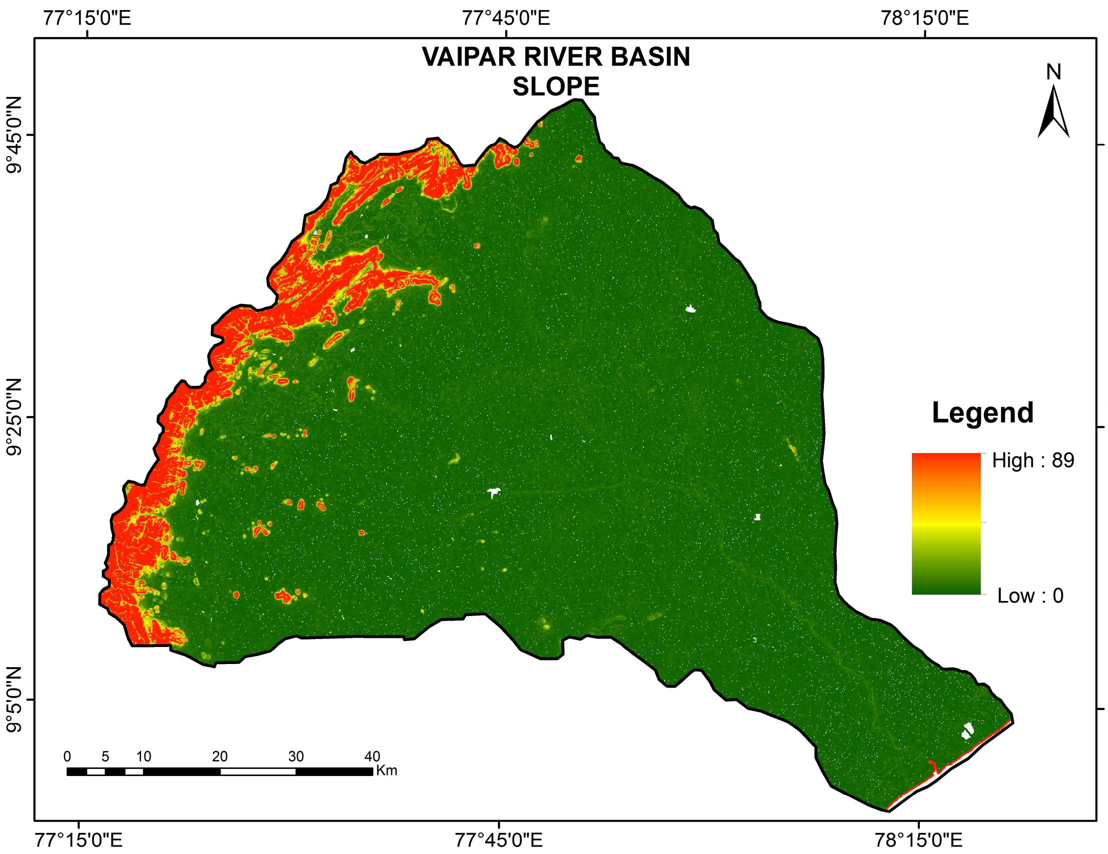

Fig.4.7 Slope Map of Vaippar Basin

4.8. Delineating the groundwater potential zone

The groundwater potential zones for the study area were generated through the integration of various thematic maps viz., drainage, slope, soil, lineament, geomorphology, wasteland and land-use using remote sensing and GIS techniques. The demarcation of groundwater recharge zones for the Vaippar basin were made by grouping the interpreted layers through weighted multi influencing factor and finally assigned different potential zones. The groundwater recharge zone of this study area can be divided into four grades, namely Good, Moderate, Poor, and Very Poor. The identified groundwater recharge zones (Fig.4.8) demonstrates that the potential zone is concentrated in the central and south-eastern region of the study area, due to the distribution of alluvial plains and irrigated land with high infiltration ability. This indicates that, soil type and slope plays a vital role in groundwater augmentation. Moreover, the concentration of drainage density and lineament density also helps the infiltration ability of the groundwater system. About 12.50% of the total area falls under the ‘very poor’ zone, 44.3% falls under ‘poor’ zone, 38.2% falls under ‘moderate’ groundwater potential zone, and 5.0% of the study area fall under ‘good’ zone. Finally, the cumulative effect of the weighted multi influencing factors through overlay analysis using GIS platform revealed the mapping of potential groundwater recharge zones of Vaippar basin.

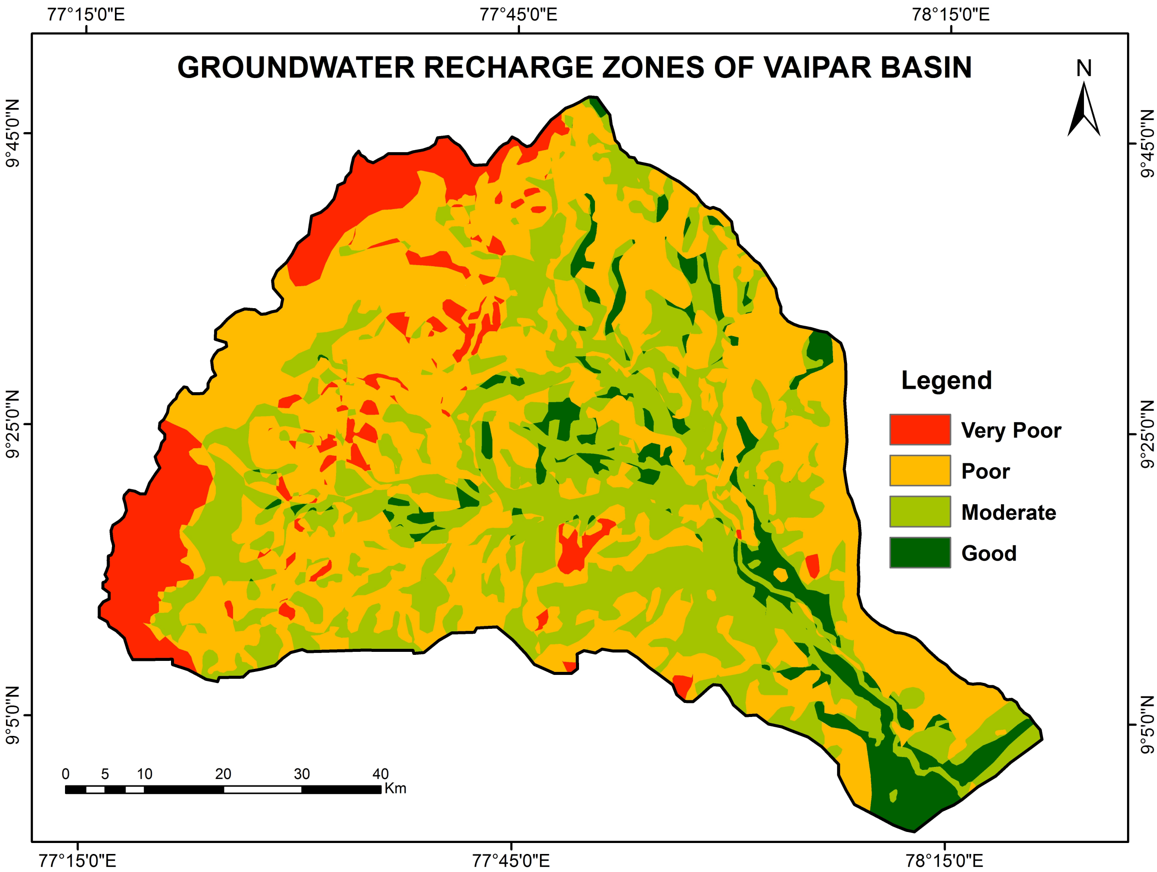

Fig.4.8 Groundwater recharge zones map of Vaippar Basin

CHAPTER - 5

CONCLUSIONS

Delineating the groundwater groundwater recharge zones in Vaippar basin of Tamil Nadu using remote sensing, GIS and MIF techniques is found efficient to minimize the time, labor and money and thereby enables quick decision-making for sustainable water resources management. Satellite imageries, topographic maps and conventional data were used to prepare the thematic layers of lineament density, drainage density, slope, soil, land-use, geomorphology and wasteland. The various thematic layers are assigned proper weightage through MIF technique and then integrated in the GIS environment to prepare the groundwater recharge zones map of the study area. According to the groundwater recharge zones map, Vaippar basin is categorized into four different zones, namely 'good', 'moderate', 'poor', and 'very poor'. The results of the present study can serve as guidelines for planning future artificial recharge projects in the study area in order to ensure sustainable groundwater utilization. This is an empirical method for the exploration of groundwater recharge zones using remote sensing and GIS, and it succeeds in proposing potential sites for groundwater zones. This method can be widely applied to a vast area with rugged topography for the exploration of suitable water management sites.

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