Assessment of Ground Water Hazard Vulnerability of Jamnagar Area, Gujarat, India, using DRASTIC Method and GIS Techniques

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Abstract— Jamnagar district is a coastal district of Gujarat. Groundwater hazards identified in the area are inherent salinity of rocks, sea water ingression and chemical pollution of groundwater. Four talukas namely Lalpur, khambhaliya, Bhanvad and kalyanpur of the Jamnagar district have been selected for the ground water vulnerability study using Remote Sensing and GIS techniques. DRASTIC method that is Depth to water table, Net recharge, Aquifer media, Soil media, Topography, Impact of Vadose zone and Hydraulic conductivity (DRASTIC) have been considered and evaluated for assessing ground water hazard vulnerable zones of the study area. Various thematic maps have been prepared and integrated with the geohydrological data in the DRASTIC model for the development of Ground water vulnerability Index Map in GIS environment. Based on Drastic Index, study area has been divided into three ground water vulnerability zones that is Low (<100), Medium (100-140) and High (>140). It indicate that 85.31% area is highly vulnerable, 11.25% medium and 3% low. These classes represent the relative potential of contamination of ground water within the study area. Ground water vulnerability map will help the planner in decision making for the prevention of contamination and development of systematic groundwater management plan.

Keywords: Aquifer Vulnerability, DRASTIC method, GIS, Jamnagar district

I. INTRODUCTION

Jamnagar district is bounded by Gulf of Katchh in the north and Arabian Sea in the west and southwest[1]. The precipitation in the area is low and climate is semi-arid. Rivers flowing in the area are ephemeral. Major central part of the area is occupied by Deccan basalt, western part by marine Tertiary rocks, northern and western coastal area by Quaternary sediments [1]. Average annual rainfall varies from 310 to 586 mm and increases gradually from west (Dwarka) to east (Kalavad), respectively. The temperature in the area varies between 15°C (winter) to 40°C (summer). Diurnal temperature variation is fairly high (up to 20°C in the inland areas).Ground water in the area occurs in unconfined and semi-confined state. About 181 villages of the district are affected by high TDS, 39 villages by high Fluoride and 2 villages both by high TDS and Fluoride. [1] The principal factors which control the distribution of polluted ground water are the porosity and permeability of the country-rocks/ soil, climatic conditions, topography of the terrain, location and type of industries, and location of fresh water and sea water interface in coastal area[1].

Ground water hazards are dependent on the vulnerability of the ground water to contamination in the area and thus affect ground water potential. In the study area groundwater potential it is low due to poor storage capacity of Deccan basalt and saline nature of Tertiary and Quaternary sediments. Unplanned exploitation of ground water for the agriculture and industrial use without considering actual geohydrological condition has resulted in the contamination of groundwater from the sea side as well as from inland. Therefore, attempt has been made to study the vulnerability of ground water in part of the Jamnagar district by using DRASTIC method of Aller et al (1987) in GIS environment. This method involves detailed study of various geological and geohydrological parameters such as Depth to water level, Net recharge, Aquifer media, Soil media, Topography, Impact of vadose zone and Hydraulic conductivity for the assessment and demarcation of vulnerable zones which are likely to be contaminated from natural and anthropogenic causes/ activities.

II. BACKGROUND

There have been many method developed for the evaluation of ground water hazards. The choice of the technique depends on the available data for the evaluation of ground water hazards the method is classify into three main procedure based simulation method and statistical method.

A. Overlay/Index Method

In the overlay index method are based on combining maps of various physiographic attributes by assigning an index or score to each attribute. Thus Overlay/index based ground water vulnerability mapping models essentially integrate rating and attribute of important factors are DRASTIC index, GOD index, The SINTACS method ,PI, ISIS method, GLA, The IRISH perspective RISKE, the German method and EPIK. [3] These method are very popular because they are easy to implement, inexpensive to produce, use readily available data [5]

B. Statistical Method

Statistical method are response variable such as the frequency of contamination occurrence or contamination probability .These methods are based on the concept of uncertainty which is describe in terms of probability distribution for the variable of interest, Statistical method to vulnerability assessment is to identify variable that can be used to design the probability of ground water contamination.[3]These method are generally based on probability theory and required extensive field data. Thence derive the response variable such as contaminant probability, occurrence or non occurrence of a contaminant in the area of interest. [4]

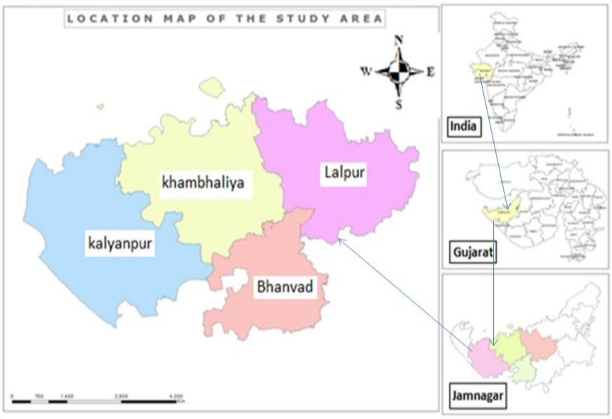
C. Process Based Simulation Method

These method are more complex and constitute and explicit and required larger data. These are complex models and it varies from simple to complex 3-D simulation Models [4]. These methods are more complex and constitute and explicit and require large data. These are complex models and it varies from simple to complex 3-D simulation models.

Behavior Assessment Model, and Attenuation Factor is analytical solution of advection dispersion equation are used to measure groundwater vulnerability. Meeks and Dean (1990) used a one-dimensional advection-dispersion transport model to develop a leaching potential index, which simulates vertical movement through a soil to the water table. Soutter and Pannatier (1996) used cumulative pesticide flux reaching mean water table depth and the total quantity of pesticide applied and expressed the groundwater vulnerability as the ratio of the above two. Neukam C. and Azzam R. (2009) used numerical simulation model of water flow and solute transport with transient boundary and links them to unsaturated strata and hydrologic & hydro geologic characteristic and uses transit time t50. Meta models have also been used for vulnerability assessment of the aquifer. Meta Model is the “model of a model” based on multiple regression analysis, Kriging, Artificial Neural Network (ANN) etc. The difficulty in the examination of process based method is required much more detailed data, time of travel and etc [5].

III. STUDY AREA

Study area in Jamnagar district is located between Longitude 67°46’48”E and 69°57’10”E; and Latitude 21°50’27”N and 22°12’26”N covering four talukas namely Lalpur, khambhaliya, kalyanpur and Bhanvad. The Precipitation in the area is low and climate is semi arid. Average annual rainfall varies from 310 to 586 mm and increases gradually from west (Dwarka) to east (Kalavad), respectively. The temperature in the area varies between 15°C (winter) to 40°C (summer). Diurnal temperature variation is fairly high (up to 20°C in the inland areas). Hot ground water (36° to 46°C) has been encountered in the Lalpur area along linear trend parallel and adjacent to NNW-SSE trending fault. In general ground water temperature varies between 25° and 32°C.



(Source: Bhaskarachary Institute for space Application and Geo -informatics)
Fig. 1: Location Map of Study area

A. Geomorphology [1]

Geomorphic units in the area pediplain, dissected upland and denuded hills, tidal flats, beach and flood plain. Pediplain area is developed on the horizontal to sub horizontal basalt flows (Deccan trap) and on the Tertiary sedimentary rocks having gentle slopes (1-2%) mainly towards NW. Drainage in the central part of the area is dendritic and in the western part radial. Drainage in the tidal flat area is of dendritic, trellis and parallel type. The older tidal flat area is dominated by distributary channels. Trellis and parallel type of drainage is confined to deltaic areas of Aji and Sasoi rivers reflecting tectonic control. Geology and drainage are controlling geomorphology of the area.

B. Geology [1]

Deccan basalt of Cretaceous Eocene age, Tertiary and Quaternary sediments are exposed in the area. Laterite of Bhatiya Formation (Eocene age), occurring as isolated patches underlain by Deccan basalt, forms low lying ridges in the western part of the district. Tertiary sediments comprising Gaj and Dwarka formations are also exposed in the western part. Clay dominated layers contain intercalated sand lenses. Milliolite Formation of Pleistocene age comprising limestone and calcareous sandstone of Pleistocene age occurs in the western coastal tract. It also occurs as isolated patches along the slopes of the denuded hills and dissected upland.

C. Drainage [1]

The drainage in the central part of the area is dendritic and in the western part radial. Drainage in the tidal flat area is of dendritic, trellis and parallel type. The older tidal flat area is dominated by distributaries channel. Trellis and parallel type of drainage is confined to deltaic area of Aji and Sasoi River reflecting tectonic control.

D. Soil [1]

In the study area clayey loam soil is developed over the pediplain and dissected upland underlain by basaltic rock. The soil developed over basaltic rocks is generally insitu soil. High drainage density over the basaltic country rock may be ascribed to the least permeable clayey loam soil (montmorillonite rich) developed over them. Thickness of soil varies from 15 to 45 cm over pediplain and 5 to 15 cm over dissected upland. The basaltic terrain has thin soil followed by thin weathered rock zone. The soil over basaltic rocks is dominated with montmorillonite clay showing high swelling indices (50 to 80%) and very low permeability.

IV. MATERIAL AND METHODOLOGY

Various thematic layers such as topographical, drainage, geological, geohydrological, soil and landuse have been developed using Arc GIS for developing DRASTIC model. Seven parameters have been used in the model which is depth to water, soil media, Aquifer media, soil media, Topography media, Impact of vadose zone and hydraulic conductivity. This yields a numerical index that is derived from rating and weight assigned to the seven model parameters. Each parameter represents the range from 1 to 10 based on their relative effect on the aquifer vulnerability. Seven parameter have been assigned weight ranging from 1 to 5depending on importance of the parameter to assess ground water vulnerability. The DRASTIC Index is then calculated by applying following equation of Aller et al (1987). Thematic and vulnerability maps of the areas have been prepared considering hydrological and geological properties. Accordingly, vulnerable areas were delineated as of high, medium, and low vulnerability using GIS.

(1.1) DRASTIC INDEX= DrDw+RrRw+SrSw+ArAw+TrTw+IrIw+CrCw

Where,

- Dr =Rating for the depth to water table
- Dw =Weight assigned to the depth to water table
- Rr =Rating for aquifer recharge
- Rw = Weight for aquifer recharge
- Ar =Rating assigned to aquifer media
- Aw =Weight assigned to aquifer media
- Sr =Rating for the soil media
- Sw =Weight for the soil media
- Tr =Rating for topography (slope)
- Tw = Weight assigned to topography
- Ir = Rating assigned to impact of vadose zone
- Iw =Weight assigned to impact of vadose zone
- Cr =Rating for rates of hydraulic conductivity
- Cw =Weight given to hydraulic conductivity

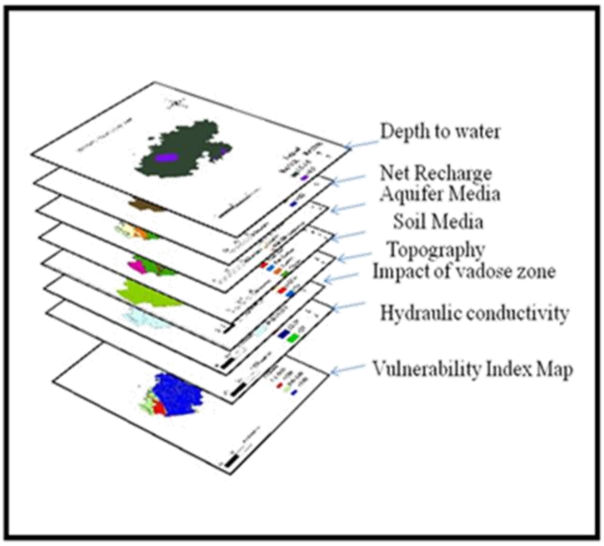


Fig. 2: DRASTIC Method flow chart

SR NO	DATA TYPE	SOURCES	FORMAT	OUTPUT LAYER
1	WATER LEVEL DATA	GWRDC, RAJKOT	TABLE	DEPTH TO WATER TABLE(D)
2	RECHARGE DATA	CGWB	TABLE	NET RECHARGE(R)
3	GEOLOGICAL MAP	BISAG	MAP	AQUIFER MEDIA(A)
4	SOIL MAP	BISAG	MAP	SOIL MEDIA(S)
5	SLOPE MAP	BISAG	MAP	TOPOGRAPHY(T)
6	GEOLOGICAL MAP	BISAG	MAP	IMPACT OF VADOSE ZONE(I)
7	HYDRULIC CONDUCTIVITY	GWRDC, RAJKOT	TABLE	HYDRULIC CONDUCTIVITY

Table 1: Data Used For The Hydro-Geological Parameters For Drastic Model

DRASTIC PARAMETER	RANGE	RATING	DRASTIC WEIGHT	TOTAL WEIGHT
Depth to water (m)	1.5-4.5 >4.5	9 7	5	45 35
Net recharge (mm/year)	51-102 >102	3 6	4	12 24
Aquifer media	W.Basalt Milliolite- limestone Gravel, sand and silt mixed Jointed- Rhyolite Jointed- Felsite Silt/Clay/-LST(Gaj) Laterite	9 6 7 8 8 7 6	3	27 18 21 24 24 21 24
Soil media	Clay Loamy Fine (sand) Fine Loamy Thin soil	1 5 9 6 10	2	2 10 18 12 20
Topography	0-1% 2-6% 6-12% 12-18% >18	10 9 5 3 1	1	10 9 5 3 1
Impact of vadose zone	Weathered Basalt	9	5	45

Hydraulic conductivity (m/day)	4-12 12-29 >29	8 6 4	3	24 18 12

Table 2: DRASTIC parameter used in study

V. RESULT

A. Depth to water (D)

Depth to water (D): Depth to water (D): Depth to water is defined as the distance from the ground surface to the water table. In the present study post monsoon -2013 ground water data to create ground water contour map. The data has been interpolated using the Inverse Distance Weight (IDW) in the Arc GIS. The depth to the groundwater level varies between 2.20 m and 6.30 m. It indicated that in the major part of the area ground water is occurring at shallow depth.

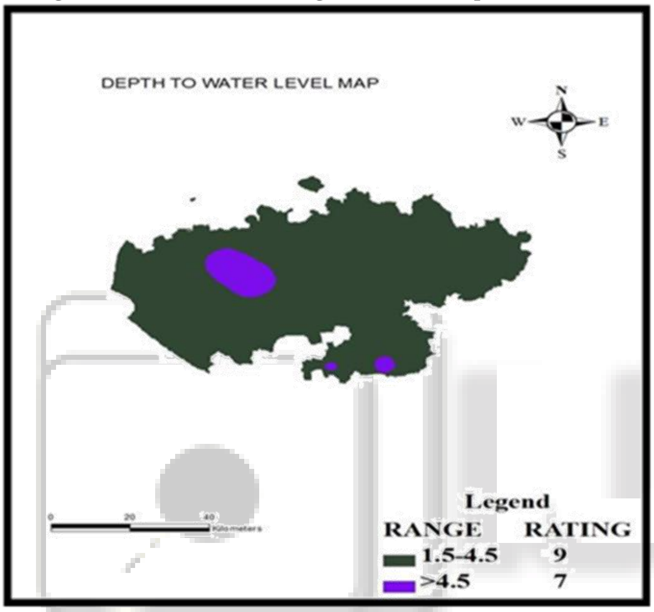


Fig.3: map of depth to water

B. Net recharge

Net recharge represents the amount of water per unit area of land which penetrates the ground surface and reaches the water table. Recharge of ground water depends on the drainage basin area, Precipitation and infiltration rate. Infiltration rate depends on the Geology, Topography and Drainage characteristics. In the study area rate of Recharge varies from 52 to 131.5 mm/year as per year 2011 data. It gave recharge index from 12 to 24. The map of Aquifer media is shown in fig.2

C. Aquifer media (A)

Aquifer media refers to nature of permeable rock or soil which forms aquifer. In the study area the aquifer is present in un-confined, semi confined and confined state. Major part of the area is covered by Basalt rock. In general, it is a poor ground water aquifer but at places due to secondary permeability it forms good ground water potential zones especially when it is highly jointed and or weathered. It has been observed that on the surface 85.33% study area basalt is jointed and weathered and thus its permeability is high. The map of Aquifer media is shown in fig.3

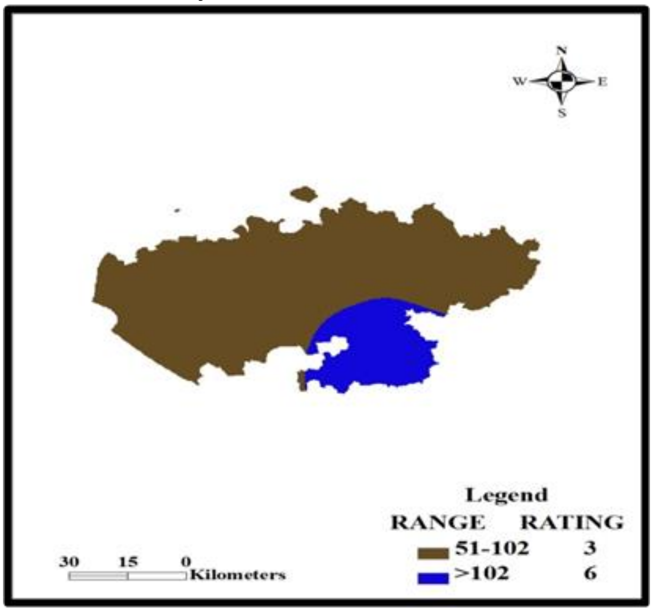


Fig. 4: Map of Net Recharge

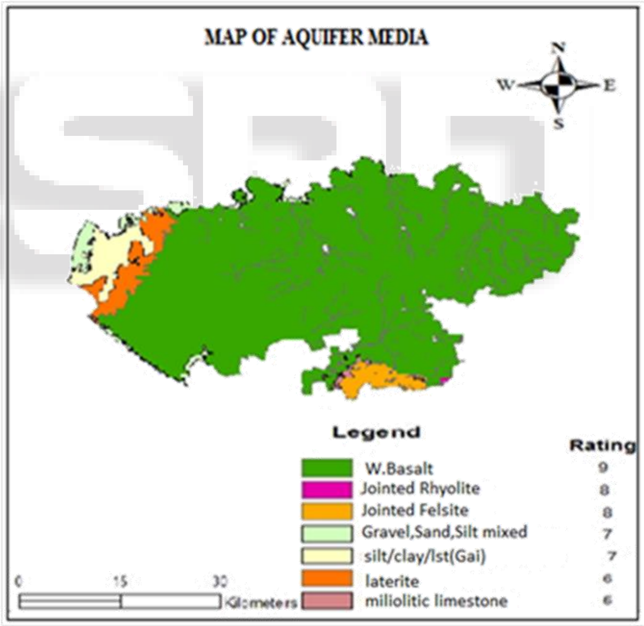


Fig. 5: Map of Aquifer Media

D. Soil media

Soil media refers to the uppermost portion of the vadose zone characterized by significant biological activity.[2] Soil plays a significant role in the amount of recharge which can infiltrate into the ground. Soil media in the study area was determined using soil map. The study area is covered by In the study area clay is 45.78%, Fine loamy 0.20%, Fine sand is 31.21%, Loam is 15.86%, Thin soil is 6.7% .

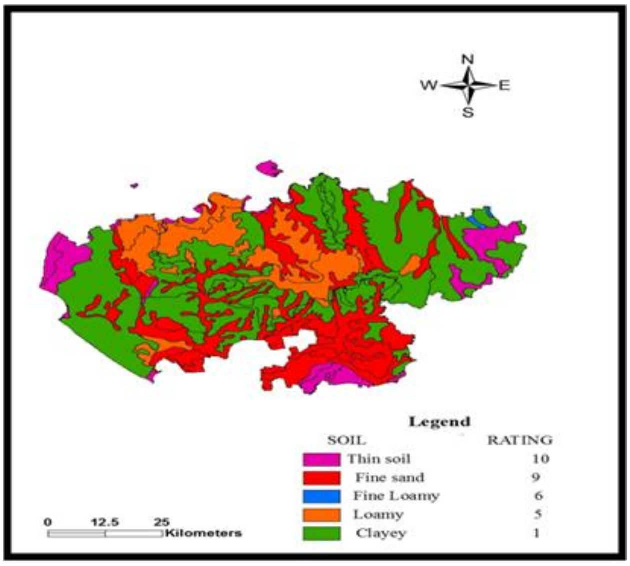


Fig. 6: Map of Soil Media

E. Topography

Slope of the area determines extent of runoff. Run off in the flat area is less thus sufficient time is available for pollutant to infiltrate in sub soil. Slope map of the study area indicated that 90% area is flat having0-1% slope. Therefore, major part of the area is more vulnerable to pollution. The map of Topography is shown in fig.7

F. Impact of vadose zone

The Vadose zone is an unsaturated zone above water table. It acts as a conduit of pollution from surface to saturated zone depending on the porosity and permeability of the material forming vadose zone. In the study area major part of the vadose zone is covered by weathered basalt which is highly permeable. The map of vadose zone impact is shown in fig.8

G. Hydraulic conductivity

Hydraulic conductivity is important because it controls the rate of ground water movement in the saturated zone, thereby controlling the degree and fate of contaminants. Hydraulic conductivity values used in this study were derived from pumping test data. Hydraulic conductivity varied from 3.20 to 33.10 m/day. The map of hydraulic conductivity is shown in fig.9

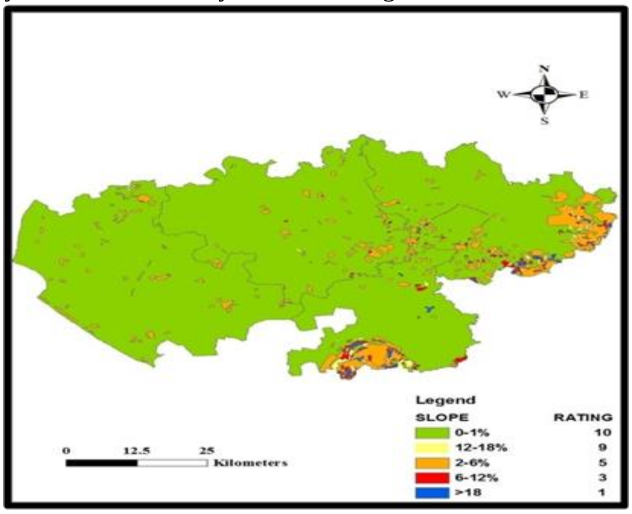


Fig. 7: Map of Topography

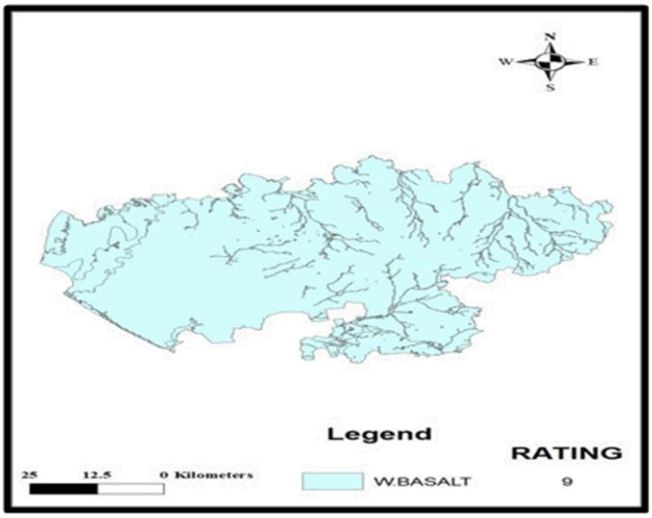


Fig. 8: Map of Impact of vadose zone

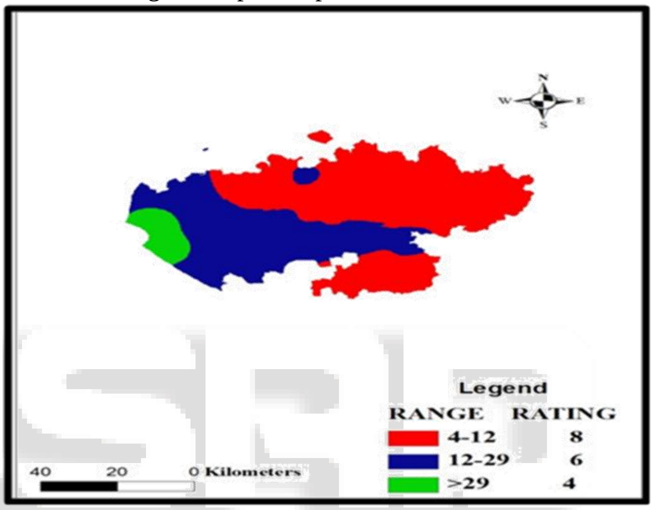


Fig. 9: Map of Hydraulic conductivity

H. The aquifer vulnerability map

Final DRASTIC Index score in the study area varies from 57-181.Accordingly the area has been classified in three zones of vulnerability as below:

1. Low vulnerability (<100),
2. Medium vulnerability (100-140),
3. High vulnerability (>140).

Major part of the area (85.31%) is highly vulnerable to contamination, the medium vulnerable zone is 11.25% and Low vulnerable zone covered 3%area.

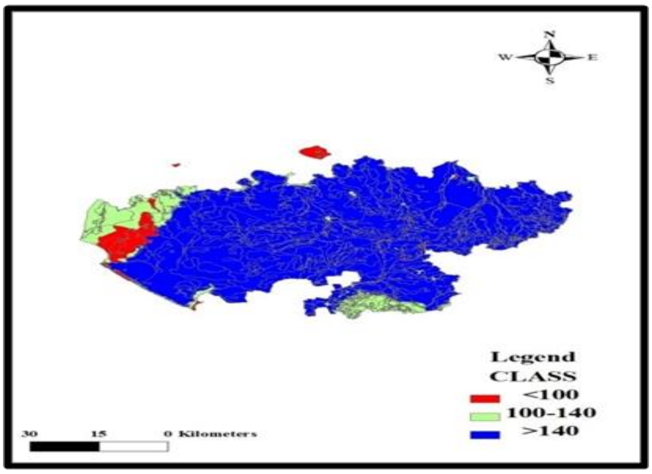


Fig. 10: Map of Vulnerability of study area

VI. CONCLUSION

Ground water hazards in the study area are related with natural causes and anthropogenic activities. The Depth to water table, Net recharge, Aquifer media, Soil media, Topography, Impact of vadose zone and Hydraulic conductivity (DRASTIC) has been considered and evaluated for assessing ground water vulnerability to contamination and for the development of vulnerability index map. Major part of the area is highly vulnerable (>140 vulnerability index) to pollution from the sea side as well as from inland industries and agriculture activity. The present study of ground water hazard vulnerability assessment and mapping will help in proper ground water management.

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