Groundwater vulnerability Assessment by DRASTIC method using GIS

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ABSTRACT

In our day-to-day life, water plays an important role in serving our daily needs. As compared to past days there is a great depletion of surface as well as ground water. The objective of our study is to achieve vulnerability assessment of groundwater by using DRASTIC Method which was developed by United States Environmental Protection Agency (USEPA). It is most commonly used overlay and index method all over the world. Evaluation of groundwater vulnerability would be performed by using computer programs which are based on Geographical Information System (GIS) in order to facilitate data management and spatial analysis.

The term vulnerability, that is used in this study is defined as a degree of capacity of the geological settings which are above water table, as joining of contaminants to groundwater where imposed by environmental factors. All the groundwater has some degree of protection under natural condition. It is an important initial step to identify degree of vulnerability by an index which is provided by superimposition of the environmental and geological properties that are explained in DRASTIC Method.

At the end of the study by using a computer program together with DRASTIC method a vulnerability map will be obtained. The vulnerability map is an informative tool from different aspects such as it is an initial step for taking an attention of risk of groundwater could be getting polluted in some areas. In addition, surface activities could be limited by focusing on groundwater protection strategies which are considering degree of vulnerability of areas that are delineated by DRASTIC vulnerability index.

Key Words: Ground water, DRASTIC index, vulnerability, GIS Map.

I. INTRODUCTION

Definitely water is described as the origin of life. For example, space journeys aim to search for water in other worlds to find out living organisms. In this manner if water could be found, then there should be a life near there. As a result, starting point of the life is water which is one of the vital substances that all living things need from birth till to the end of their life.

The problems that are faced depending on water could be examined in the aspects of quality and quantity. If it is necessary to give an example of water quantity sourced problem, the answer is the people who are suffering from water in arid zones. Quality of water could be determined by measuring the amounts of substances, which are dissolved in water. These harmful materials should be under limits in order to preserve humans' health. It is much more important to know how to reach water in required quantity and quality. The key that will open the door of reaching water sources is hidden in the management of water stocks of our world. In this study the passage of water from surface to underground will be assessed through the window of quality.

Groundwater vulnerability refers to intrinsic characteristics that determine the sensitivity of the water to be adversely affected by an imposed contaminant load. The anthropogenic and agricultural activities are responsible for deterioration of groundwater level and increasing vulnerability. Due to the deterioration of groundwater level, sustainable development plans are needed to protect these resources. Groundwater has a major contribution to agricultural, industrial, drinking, and other municipal uses, particularly in the region where other sources of water are lacking. To get continuous supply of water and mitigate adverse effects, it is urgent to define definite strategies and guidelines for quality control, monitoring and management of groundwater. An assessment of groundwater vulnerability is the most feasible step regarding these purposes. The main concept of groundwater vulnerability assessment is the areas which are more vulnerable to pollution than others.

II. STUDY AREA

East Godavari is one of the districts of Andhra Pradesh and is known for its historical importance. The district enjoys a unique place and is known as "*rice bowel*" of Andhra Pradesh. The district forms part of the Godavari delta region and is endowed by a vast potential of surface water resources.

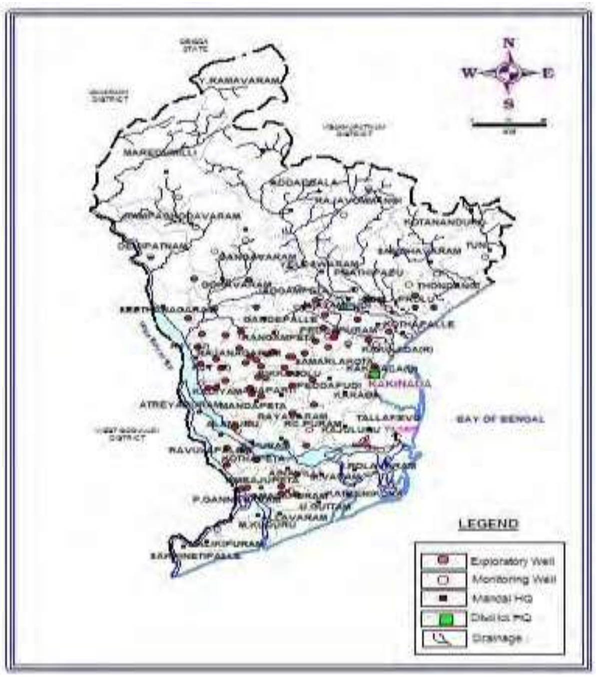

Fig.1 Villages and well location Map

The district lies between north latitude 16°30' and 18°00' and east longitude 81°30' and 82°30' spreading over an area of 10,807Sq.km. The district is bounded in the North by Visakhapatnam district and Orissa state in the East and South by Bay of Bengal and west by West Godavari district.

The major types of the soils in the district are coastal alluvium, clay loams, black cotton and red soils. The alluvial types of soils are found predominantly in Godavari delta area, the tail end portions of which have sandy clay soils. Red loam is of common occurrence in upland areas and agency areas. The black cotton soils are also found in these parts of the district.

III. METHODOLOGY

Ground water vulnerability assessment methods:

Comprehensive reviews of groundwater vulnerability assessment methods are presented in reports by the General Accounting Office (GAO, 1992) and the National Research Council (NRC, 1993). Both reports divide groundwater vulnerability assessment methods into three categories:

(1) Overlay and index methods,
(2) Mathematical models, and
(3) Statistical models.

Overlay and Index Methods:

Overlay and index methods (the GAO report calls these "parameter weighting" methods), combine maps of parameters considered to be influential in contaminant transport. Each parameter has a range of possible values, indicating the degree to which that parameter protects or leaves vulnerable the groundwater in a region. Depth to the groundwater, for example, appears in many such systems, with shallow water considered more vulnerable than deep. The simplest overlay systems identify areas where parameters indicating vulnerability coincide, e.g. shallow groundwater and sandy soils. More sophisticated systems assign numerical scores based on several parameters. The most popular of these methods, DRASTIC (Aller, et al. 1987) uses a scoring system based on seven hydro geologic characteristics of a region.

Mathematical Models:

Process-based mathematical models such as PRZM, GLEAMS, and LEACHM can predict the fate and transport of contaminants from known sources with remarkable accuracy in a localized area by applying fundamental physical principals to predict the flow of water in porous media and the behavior of chemical constituents carried by that water. In the hands of knowledgeable analysts with the appropriate site-specific information, such models allow threats to the safety of ground water supplies to be recognized and can play an important role in planning remediation efforts. Unlike other groundwater quality prediction methods, mathematical models predict variations of water quality both in space and in time. Although process models offer the most sophisticated, and potentially most accurate predictions of water quality, they are not widely used for regional groundwater vulnerability analysis. Reporting on the vulnerability assessment methods used by state agencies, the GAO found that none used mathematical process models (GAO, 1992).

Statistical Methods:

Empirical or statistical methods are the least common vulnerability assessment methods in the literature. Although statistical studies are used as tests for other methods, and geo-statistical methods are frequently used to describe the distribution of water quality parameters, very few vulnerability assessment methods are directly based on statistical methods.

The aquifer properties are affected by several factors such as soil properties, properties of contaminants, hydraulic loading on the soil and crop management (Huddleson, 1994). Understanding the groundwater flow system will enable a better assessment of potentially important factors controlling the intrinsic susceptibility and vulnerability of the groundwater resource. This review focuses on soils and their role in attenuating contaminants before they reach the groundwater table.

Depending on the data accessibility this method is very useful in the concept of defining the pollution vulnerability assessment.

DRASTIC Method:

The name DRASTIC is taken from the initial letters of the seven parameters used to evaluate the intrinsic vulnerability of aquifer systems. The following symbols are used in the computation of DRASTIC vulnerability index.

$\mathbf{D_r}$ = ratings to the depth to water table,
$\mathbf{D_w}$ = weights assigned to the depth to water table,
$\mathbf{R_r}$ = ratings for ranges of aquifer recharge,
$\mathbf{R_w}$ = weights for aquifer recharge,
$\mathbf{A_r}$ = ratings assigned to aquifer media,
$\mathbf{A_w}$ = weights assigned to aquifer media,
$\mathbf{S_r}$ = ratings for the soil media,
$\mathbf{S_w}$ = weights for the soil media,
$\mathbf{T_r}$ = ratings for topography (slope),
$\mathbf{T_w}$ = weights assigned to topography,
$\mathbf{I_r}$ = ratings assigned to vadose zone,
$\mathbf{I_w}$ = weights assigned to vadose zone,
Cr = ratings for rates of hydraulic conductivity, and
Cw = weights given to hydraulic conductivity.

Determination of the DRASTIC index number is done by multiplying each parameter rating by its weight and adding together. Each parameter is rated on a scale from 1 to 10, a rating of 10 indicating a high pollution potential of the parameter. The DRASTIC Index is then computed by applying a linear combination of all factors according to the following equation:

DRASTIC Index= DrDw + RrRw + ArAw + SrSw+ TrTw + IrIw + CrCw

Where D, R, A, S, T, I, and C are the seven parameters and the subscripts **r** and **w** are corresponding to ratings and weights, respectively.

The DRASTIC index can be further divided into four categories: low, moderate, high, and very high. Each category reflects an aquifer's inherent capacity to become contaminated. The higher DRASTIC index number shows the greater relative pollution potential risk to one another. DRASTIC index is relative and dimensionless that depends on the geological and hydro geological characteristics of an aquifer. Each of DRASTIC parameters has been expressed as thematic layer using ArcGIS .All generated maps were used to assess intrinsic groundwater vulnerability to pollution.

Table.1: Relative Weights

IV. RESULTS AND DISCUSSIONS

Depth to groundwater (D)

The value of the variable D (Depth of water table) was obtained using pumping test data. The depth of water in the study area varies between 3 m to10 m below the ground surface. In general, the deeper the water levels are, the longer the pollutant takes to reach the groundwater table [7]. The rating scores ranges between 1 and 3 on the basis of DRASTIC classification. The ratings assigned in the study area were presented in Table 2 and the spatial variation is shown in Fig.2 respectively.

Table. 2 Depth to water Table Rating Table

Range (feet)	**Rating**
5	10
5-15	9
15-30	7
30-50	5
50-75	3
75-100	2
>100	1

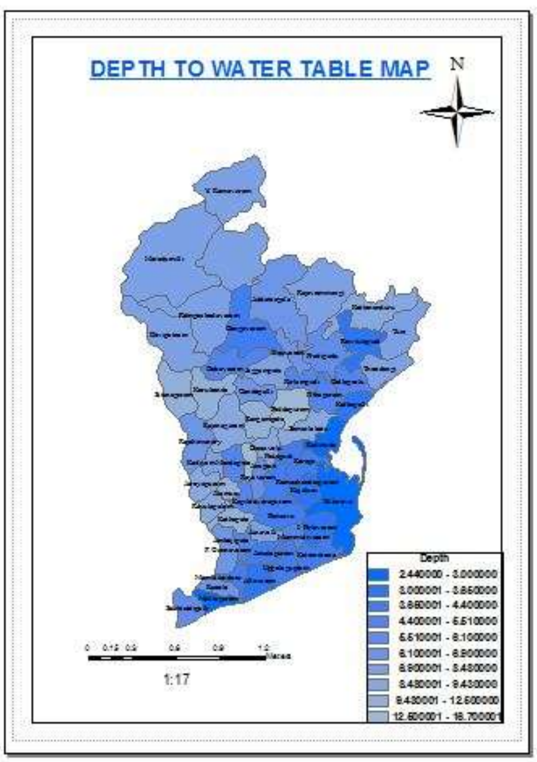

Fig.2 Depth to water table rating map

Net Recharge (R)

Net recharge represents the amount of water that infiltrates into the ground and reaches the water table. The map incorporates available features like slope, soil permeability and rainfall, which are important for the calculation of recharge component. Soil permeability was calculated from soil type, average rainfall of the study area was used as a recharge index and the finalized recharge value was calculated

Factor	**Description**	**Relative Weight**
Depth to water	Represents the depth from the ground surface to the water table, deeper water table levels imply lesser chance for contamination to occur.	5
Net recharge	Represents the amount of water that penetrates the ground surface and reaches the water table, recharge water represents the vehicle for transporting pollutants.	4
Aquifer media	Refers to the saturated zone material properties, it controls the pollutant attenuation processes.	3
Soil media	Represents the uppermost weathered portion of the unsaturated zone and controls the amount of recharge that can infiltrate downward.	2
Topography	Refers to the slope of the land surface, it dictates whether the runoff will remain on the surface to allow contaminant percolation to the saturated zone.	1
Impact of vadose zone	Is defined as the unsaturated zone material, it controls the passage and attenuation of the contaminated material to the saturated zone.	5
Hydraulic conductivity	Indicates the ability of the aquifer to transmit water, hence determines the rate of flow of contaminant material within the groundwater system.	3

and the ratings were assigned as presented in Table 3 and the spatial distribution of net recharge rating shown in Fig.3

Table. 3 Net Recharge Rating Table

Range (inches)	**Rating**
0-2	1
2-4	3
4-7	6
7-10	8
>10	9

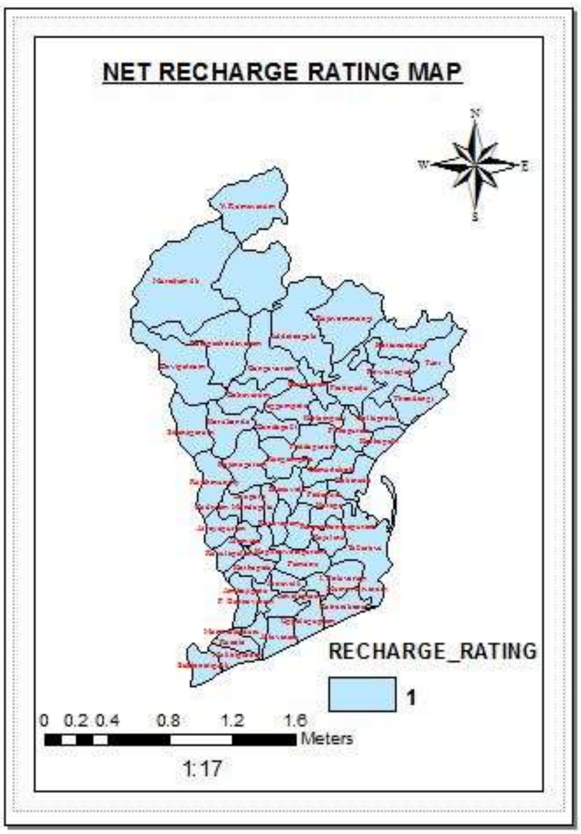

Fig.3 Net Recharge rating map

Aquifer media (A)

Movement of groundwater in the aquifer medium is important in determining the time for attenuation processes, such as sorption, reactivity and dispersion to occur along with the amount of effective surface area of materials with which the contaminant may come in contact within the aquifer. The migration of contaminants is strongly influenced by fracturing, porosity, or by interconnected series of openings. Based on the geological description of the study area, the aquifer media was classified as alluvium, porous sediments, igneous/ metamorphic and meta sediments, which has a rating of 1 to 10. The ratings assigned in the study area were presented in Table 4

Formation	**Aquifer Media Rating**
Terrace	10
Gravel-Sand-Clay	9
Gravel-Sand-Clay	8
Basalt	7
Conglomarate-Sandstone-Limestone-Claystone	6
Granit	5
Serpantin-Radiolorit-Limestone	4
Marble	2

and the spatial distribution of aquifer media is shown in Fig.4 respectively.

Table 4 Aquifer Media Rating Table

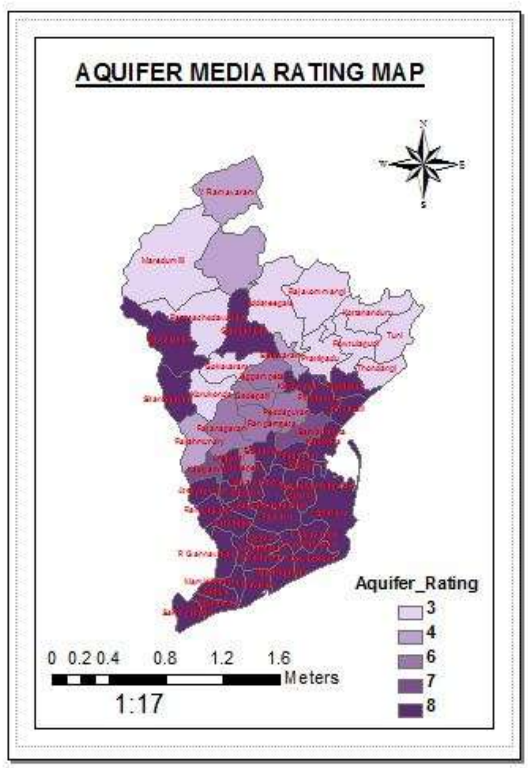

Fig.4: Aquifer media rating map.

Soil Media (S)

Soil is commonly considered the upper weathered zone of the earth which average 1.8 m or less. Soil has a significant impact on the amount of recharge allowing infiltration to the water table and hence contaminant movement. The study area is characterized by clay, sand, gravel and thin, which corresponds to ratings of 1, 8, 9 and 10 respectively as presented in Table 5. The spatial variation of soil media in the study area is shown in Fig. 5.

Table .5 Soil Media Rating Table

Type Of Soil	**Soil media Rating**
Thin or absent	10
Gravel	10
Sand	9
Peat	8
Shrinking and/or	7
Aggregated Clay	6
Sandy Loam	5
Loam	4
Silty Loam	3
Clay Loam	2
Muck	1
Non shrinking and non aggregated clay	

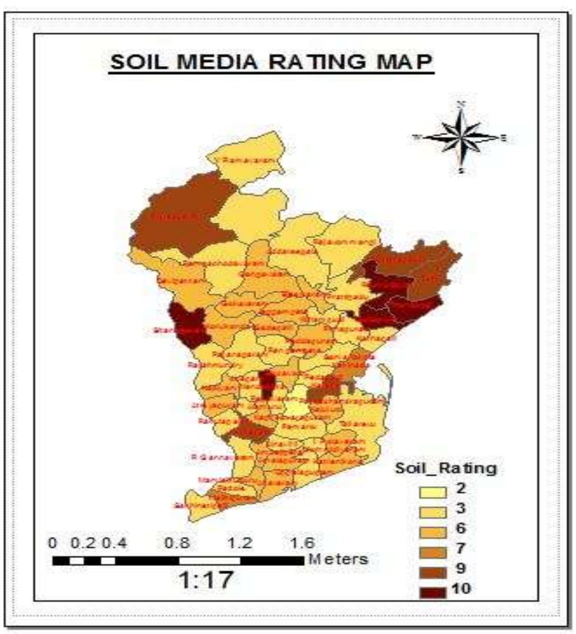

Fig.5 Soil media rating map

Topography (T)

Topography is considered as the slope and slope variability of the land surface. Topography helps to control pollutants runoff or retention on the surface. Slopes that provide a greater opportunity for contaminants to infiltrate will be associated with higher groundwater pollution potential. The ratings assigned in the study area and spatial distributions of slope were presented in Table 6 and Fig. 6 respectively.

Table .6 Topography Ratings

Slope (%)	**Rating**
0-2	10
2-6	9
6-12	5
12-18	3
>18	1

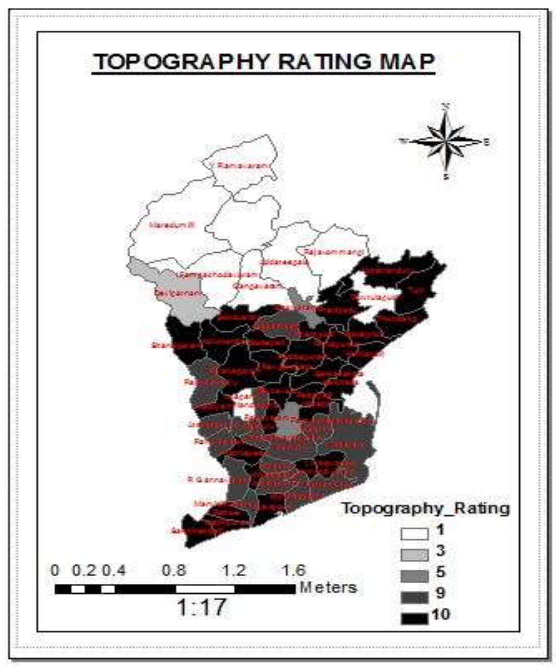

Fig. 6 Topography rating map.

Impact of Vadose Zone (I)

The vadose zone refers to the zone above the water table, which is unsaturated and its type determines the attenuation characteristics of the material including the typical soil horizon and rock above the water table gravel, gravel-sand, clay-sand and clay

Formation	Rating
Terrace	10
Gravel-Sand-Clay	9
Gravel-Sand-Clay	8
Basalt	7
Conglomarate-Sandstone-Limestone-	6
Claystone	5
Granite	4
Serpantin-Radiolorit-Limestone	2
Marble	

are considered the vadose zone of the study area. According to the DRASTIC ratings the value for impact of vadose zone is shown in Table 7 and spatial variations were presented in Fig.7.

Table .7 Impact of Vadose Zone Rating Table

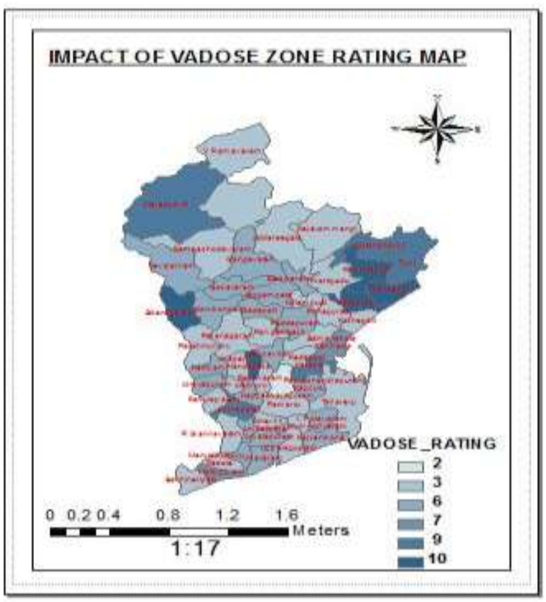

Fig.7 Impact of vadose zone rating map

Hydraulic Conductivity

Hydraulic conductivity is defined as the ability of aquifer materials to transmit water and it is controlled by the amount and interconnection of void spaces within the aquifer that may occur as a consequence of inter-granular porosity, fracturing and/or bedding planes. For the purposes of the present study, hydraulic conductivity has been calculated from the pumping test data and spatial hydraulic conductivity map obtained from geological survey of India. The hydraulic conductivity ranges between 2.16 m/day to 8 m/day in the study area. The ratings based on hydraulic conductivity are shown in table 8. The spatial distribution is shown in Fig.8.

Table 8.Conductivity Rating Table

Formation	Rating
Terrace	10
Gravel-Sand-Clay	9
Gravel-Sand-Clay	8
Basalt	7
Conglomarate-Sandstone-Limestone-	6
Claystone	5
Granite	4
Serpantin-Radiolorit-Limestone	2
Marble	

Fig. 8 Hydraulic conductivity rating map

DRASTIC Index

The DRASTIC index, a measure of the pollution potential, is computed by summation of the products of rating and weights of all seven parameters as discussed above. From the computed DRASTIC index it is possible to identify areas which are more likely to be pollution potential. The vulnerability index ranges from 64 to 150 and is classified into three groups i.e. 64-80, 80 to 120 and 120 to 150 corresponding to low, medium and high vulnerability zones respectively. Using this classification a groundwater vulnerability potential map (Fig.9) was generated which shows that 25.93% area falls in low vulnerability zone and 51.85% falls in medium vulnerability zone. About 22.22% of the study area falls in high vulnerability zones. The vulnerability map thus generated helps in identifying areas which are more likely to be susceptible to groundwater contamination relative to one another.

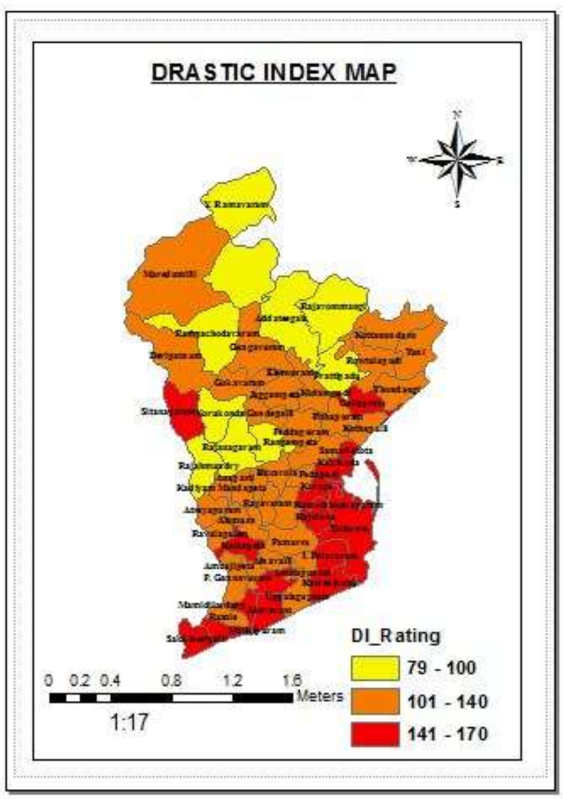

Fig.9 DRASTIC INDEX MAP

The results shows that vulnerability index ranges from 79 to 170 and is classified into three classes i.e., 79-100, 100 to 140 and 140 to 170 corresponding to low, medium and high vulnerability zones respectively. Along the Stretch of the coastal area we can observe more vulnerability. As the area is nearer to sea, the depth to water table is minimum, soil present is of alluvial which is more permeable and having topography with moderate slope which leads more infiltration. We can observe more vulnerable zones in mandals namely Gangavaram, Sitanagaram, Kadiyam, Anaparthi, Kapilesapuram, Kothapeta, Ambajipeta. The reasons may be at Gangavaram, kadiam, kapilesapuram, kothapeta, ambajipeta, amalapuram having aquifer media more conductivity hence conductivity may also high.

V. CONCLUSION

An attempt has been made to assess the aquifer vulnerability of East Godavari district of Andhra Pradesh employing the empirical index DRASTIC model of the U.S. Environmental Protection Agency (EPA). Seven environmental parameters were used to represent the natural hydrogeological settings of the aquifer, Depth to groundwater, Net recharge, Aquifer media, Soil media, Topography, Impact of vadose zone and Hydraulic conductivity. The results shows that vulnerability index ranges from 79 to 170 and is classified into three classes i.e., 79-100, 100 to 140 and 140 to 170 corresponding to low, medium and high vulnerability zones respectively. The groundwater vulnerability potential map shows that the majority of eastern part and some areas along coast fall under high vulnerability followed by medium vulnerability in the central and western regions of the study area. The vulnerability map thus generated helps in identifying areas which are more likely to be susceptible to groundwater contamination relative to one another.

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