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Priya PGL
 School of Water Resources, IIT,
 Kharagpur, West Bengal, India

Krupavathi K
 Dept. of Soil and Water Eng.
 College of Agri. Engg. ANGRAU,
 Andhra Pradesh, India

Rohit Minz
 Dept. of Geoinformatics, IIT
 Bombay, Maharashtra, India

Indexing of ground water vulnerability in Guntur district, Andhra Pradesh using GIS based agricultural drastic model

Priya PGL, Krupavathi K and Rohit Minz

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Abstract

Agricultural activities especially application of fertilizers, pesticides and fumigants have been identified as one of the non-point sources of pollutants which leach various pollutants from agricultural land through the unsaturated zone and groundwater zone gives rise to contamination to groundwater and soil, which poses serious detrimental risk in rural areas. To assess the groundwater vulnerability and analyze the risk, research was carried out in Agricultural areas of Guntur District, Andhra Pradesh. The GIS-based Agricultural vulnerability indexing method (DRASTIC) is selected in this study, which identifies vulnerability zones and is helpful in formulation of strategies to mitigate adverse impact of factors responsible for ground water pollution. Seven DRASTIC layers using parameters such as groundwater influencing parameters were created. Rates and weights were assigned to each parameter layer. By overlapping the layers in ArcGIS, the aquifer vulnerability map was prepared. By multiplying each parameter rate by its weight and adding for all layers Agricultural DRASTIC index number is determined. The results indicated that the Agricultural vulnerability Index in the study area ranged from 72-196 is determined. The developed maps are validated with nitrate concentrations. Different parameters like EC, pH, Ca, Mg, K Na, and NO₃ was estimated and correlated to estimate the degree of association. It was observed from the developed Agricultural vulnerability maps for Guntur District that 10.56% of the study area falls under low vulnerable zone, 39.98% under moderate zone and 49.46% under high vulnerable zone due to agricultural leachates in cropped areas.

Keywords: Ground water, vulnerability, aquifer, GIS, drastic

Introduction

Groundwater is a major natural replenishable water resource of the earth. The over exploitation of groundwater resources beyond the annual replenishment leads to continuous declining of water levels, reduction of well yield, drying up of shallow wells, deterioration of groundwater quality, seawater intrusion in coastal aquifers etc. These indirectly make agriculture uneconomic mainly for small scale farmers. As compared to surface water, the groundwater is safe and reliable source. Though it is not easily polluted, but once it is polluted it's exhaustively expensive, extremely difficult and time consuming to remediate this source of the contaminants from which it has been polluted with and replenishment lost integrity and sometimes it's impossible to restore. One of the important sources of pollution is from agricultural land. By using the excessive use of fertilizer and pesticides on the crop lands, nitrates and metals from fertilizer dissolves in irrigation water then leaches to groundwater, while moving of various pollutants through the unsaturated zone from land surface gives rise to contamination of vadose and saturated zone. Hence, it is important to monitor the ground water all the time from the possible contaminates. For monitoring and taking remedial measures, it is important to identify the zones of vulnerability. Identifying vulnerability zones and preparing the vulnerability zone maps is not only for protection in turn the areas can also be converted into ground water recharge zones and also for environmental management. Vulnerability is described as a transferring capacity of the geological zones from land surface to aquifer under the effect of environmental settings which describes the degree of contamination. To identify the vulnerable zones in the agriculture intensive Guntur district among the several existing methods, a standardized method called DRASTIC approach was used. DRASTIC method takes into account the physical and hydro geological characteristics of the area. The DRASTIC method was developed by United States Environmental Protection Agency (USEPA) (Aller *et al.* 1987) [2].

Corresponding Author:
Krupavathi K
 Dept. of Soil and Water Eng.
 College of Agri. Engg. ANGRAU,
 Andhra Pradesh, India

Guntur district is one of the coastal districts of Andhra Pradesh, India. It comprises of 3 divisions namely Narasaraopet, Guntur and Tenali and 57 mandals with 729 villages and 1036 hamlets. It has a geographical area of 11,328 sq. kms. It lies between North latitudes 15°18' & 16°50' and East longitudes 70°10'00" & 80°55'00". Average elevation of study area is 33 m from MSL. Average rainfall of study area is 853.10 mm. Minimum and maximum temperatures of study area were 33° C and 20° C respectively. Highest & lowest relative humidity is 84% and 30% respectively. Wind speed varies from 15 to 30 km/hr. The Guntur district location of is shown in Fig. 1. DRASTIC approach is a methodology allows to systematically evaluate the pollution potential of any area. The most important hydro geologic factors that control the

groundwater potential are Depth of water, Net recharge, Aquifer media, Soil media, Topography, Impact of Vadose zone and Hydraulic conductivity of the aquifer. For ease of reference, the above factors have been arranged to form DRASTIC. To determine index of vulnerability, a relative weight ranging from 1 to 5 was assigned to each factor. In this the most significant factors have weights of 5 and the least significant factor with a weight of 1. Later, each factor was divided into different ranges, which have an impact on pollution potential. The range varies between 1 for least pollution and 10 for highest pollution (Ahmad, 2009). ARCGIS 10.1 software is used to prepare the thematic layers with a 100 m grid resolution in raster format as described below.

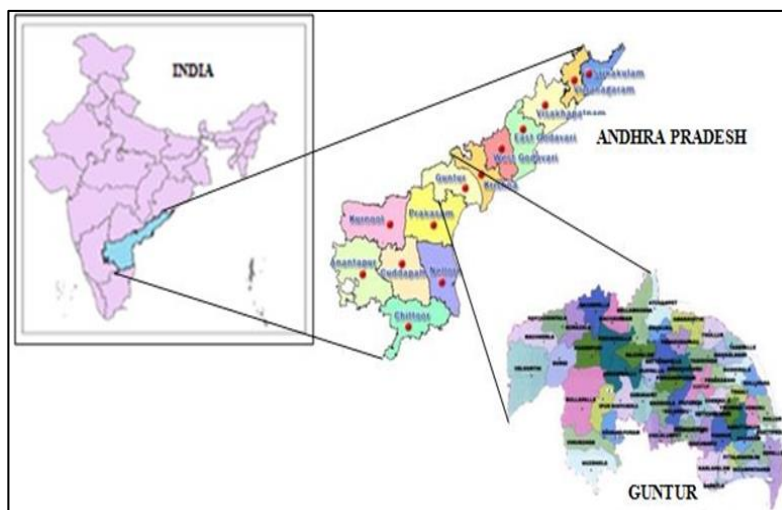


Fig 1: Location of the Guntur District

Depth to water table (D)

The groundwater level data of Guntur district pertaining to 57 mandals information between 2007 and 2016 for pre-monsoon and post monsoon periods were collected from Ground Water Department. By the krigging algorithm, the point data of observation wells are interpolated and generated a 100 × 100 m grid pattern raster map. The map was reclassified by assigning ratings defined by DRASTIC model (Table 1.) and assigned a weight to generate "D" parameter

layer. The groundwater level depth varied between 1.45 m to 6.42 m below ground level (mbgl). The maximum area covered is under the depth range of 1.5 - 4.5 m (rating of 9), occupied 83.62% of the region. Some parts are in the depth range of 1.5 to 4.5 and it is assigned with drastic rating of 10. High depth to water table i.e. depth ranging from 4.5 to 9 m. The area under this depth range is 0.24% of total area of the district (Fig 2).

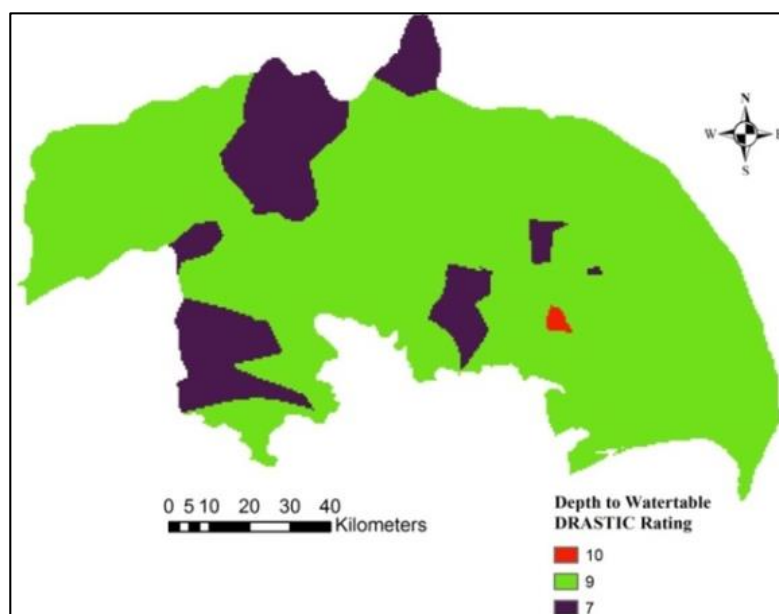


Fig 2: Rated Depth to water table 'D' map of Guntur district

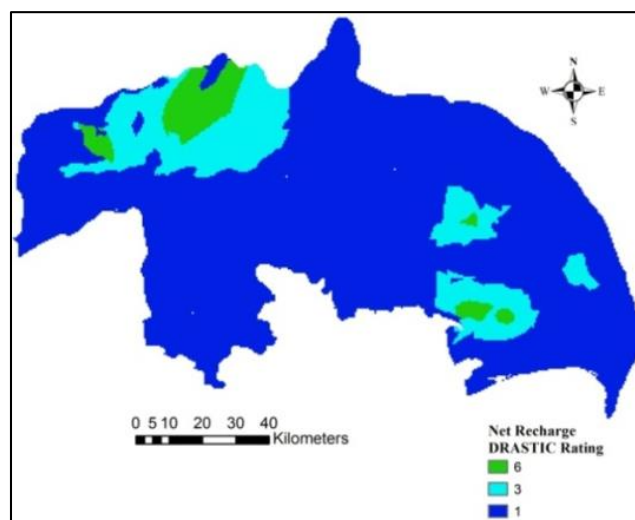
Table 1: DRASTIC ratings to different parameters (Aller *ET AL.*, 1987)

Depth of water table	
Range (m)	Rating
0 - 1.5	10
1.5 - 4.5	9
4.5 - 9	7
Net recharge	
54<	9
178 - 254	8
102 - 178	6
51 - 102	3
0 - 51	1
Aquifer media	
Schist	9
Alluvium	6
Limestone	6
Sandstone	6
Quartzite	5
Gneiss	4
Banded Gneissic Complex	4
Charnockite	4
Khondalite	4
Shale	2
Soil media	
Gravel soils	10
Sandy soils	9
Loam soils	5
Calcareous soils	3
Clay soils	1
Rock / Water	0
Topography	
0-2	10
2-6	9
6-12	5
12-18	3
>18	1
Impact of vadose zone	
SCHIST	9
Limestone	6
Alluvium	6
Sandstone	6
Quartzite	5
Khondalite	4
Banded Gneissic Complex	4
Gneiss	4
Shale	3
Charnockite	2
Hydraulic conductivity	
82<	10
41-82	8
29-41	6
12-29	4
4-12	1
0-4	1

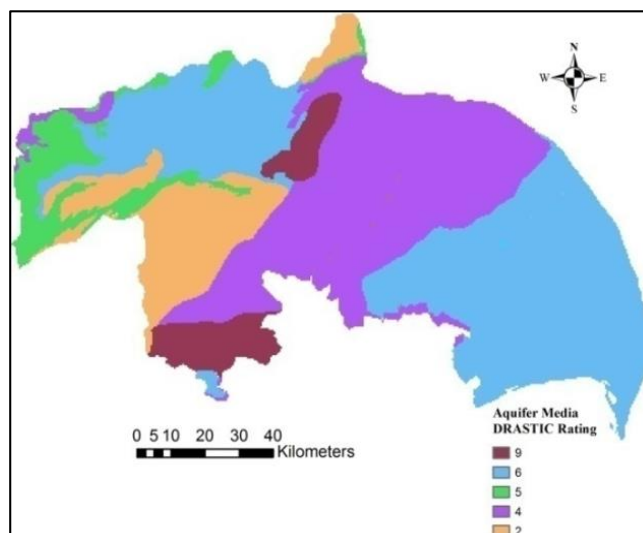
Net recharge (R)

The amount of water infiltrates into the ground and reaches the water table in a unit area that is called as Net Recharge. The Water Table Fluctuation method (WTF) is used to prepare average annual net recharge of the aquifers at Guntur

district. The net recharge has been calculated from the water table data, specific yield of geological formations and ground water draft obtained from Government of Andhra Pradesh Water Resources Department, Guntur, 2016. Post monsoon water table data subtracted from post monsoon water table data. The obtained map was reclassified by assigning rates based on range in DRASTIC (Table 1.) system and has been assigned with rating and weight to generate “R” parameter layer. Net Recharge = ((Ground water head*Specific Yield) + (Ground Water Draft)) ----- (1) From the above formula, generated a 100 × 100 m grid pattern raster map. The net recharge varies from 0.33 to 133 m/year. Most of the area is under 0.33 to 50 m/year recharge in 81.05% area (Fig 3).

**Fig 3:** Rated Net recharge rated map of Guntur district**Aquifer media (A)**

Aquifer is the permeable geologic formation, which contains and transmits water in economic amounts, under ordinary hydraulic gradients, for water supply and has generally sand and gravel (Usul, 2009) [6]. Aquifer map obtained from Ground Water Department, Guntur. The map is digitized and generated a 100 × 100 m grid pattern raster map. The map was reclassified by assigning ratings defined by DRASTIC model (Table 1.) and assigned a weight to generate “A” parameter layer. Aquifer media Alluvium is observed in major part of the study area covering 27.97% of total area (Fig 4).

**Fig 4:** Rated Aquifer media ‘A’ map of Guntur district

Soil media (S)

Soil infiltrates water and contaminants to the water table and has a significant impact on the amount of recharge. The soil map collected from Central Ground water Board (CGWB) and converted in to raster form. Most of the study area covered with calcareous soil the by gravel. Then, the rating as per DRASTIC model to each class of soil media was added to attribute table of soil map and assigned with weight to generate “S” parameter layer. The study area is covered by calcareous soil, clay, sand, gravel and loam soils. Calcareous soils are observed in many parts of the study area covering 39.71% of total area (Fig 5).

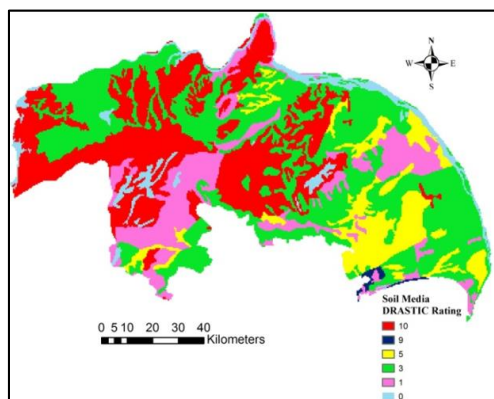


Fig 5: Rated Soil map ‘S’ map of Guntur district

Topography (T)

Topography is the slope of the land surface. Topography controls pollutant runoff. Higher groundwater pollution potential is associates with Flat slopes that provide a more opportunity for contaminants to infiltrate. Percentages of slope were extracted from ASTER DEM. The rating values were added to the Topography map and reclassified according to DRASTIC range and ratings (Table 1) and assigned with weight to generate “T” parameter layer. The slope variability of study area is from 0% to 10%. However, most of area under 6-10% slopes, which contributed to higher vulnerability ratings (Table 2). Slope range of 0 to 2% is observed in the study area covering about 82.56% of total area (Fig 6).

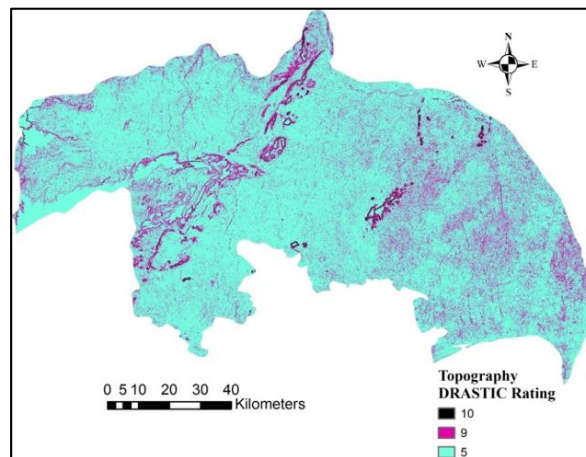


Fig 6: Rated topography ‘T’ map of Guntur district

Impact of vadose zone (I)

Impact of the vadose zone was derived by incorporating soil permeability and depth to water table to assess the contaminant migration. Clay inter beds existence observed in the study area has high impact on vulnerability decrease.

Impact of Vadose Zone = Soil Permeability + Water table..... (2)

The equation gives value for vadose zone as defined by above factors of the study area. The values of vadose zone is grouped by assigning the rating (Table 1) and weight to generate “I” layer. In the study area geological unit containing alluvium has given a rating of 6 existed in an area of 43.28%. The Schist covering 6.12% of area is rated as top i.e. with 9 (Fig 7).

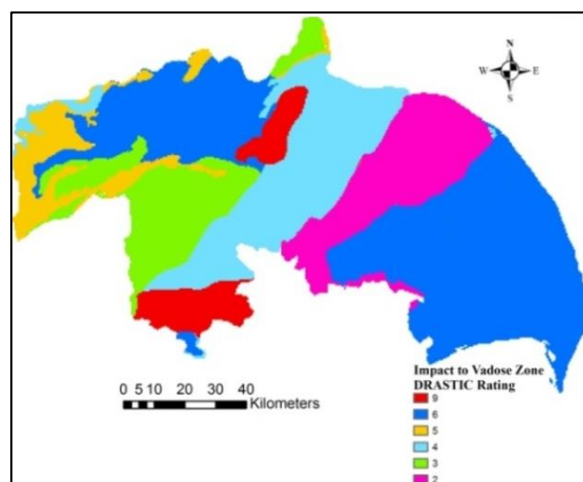


Fig 7: Impact of vadose zone rated map of Guntur district

Table 2: Percentage area covered under different depth, net recharge and geology ranges

Depth to Water Table	Area (sq.km)	Area,%
0-1.5	1829.21	16.15
1.5-4.5	9471.87	83.62
4.5-9	26.9163	0.24
Net recharge, m/year	Area, sq. km	Area,%
0-51	9182.09	81.05
51-102	1655.37	14.61
102-133	490.54	4.33
Geology	Area, Sq. km	Area,%
Gneiss	9.74	0.086
Schist	670.61	5.920
Quartzite	776.08	6.851
Shale	1397.535	12.337
Limestone’s	1508.66	13.318
Banded Gneissic Complex	2065.67	18.235
Charnockite	1559.75	13.769
khondalite	5.67	0.050
Alluvium	3169.46	27.979
Sandstone	164.82	1.455

Hydraulic conductivity (C)

The values of hydraulic conductivity of aquifer media has been taken from literature. The values were attributed to aquifer media map and reclassified according to DRASTIC range and ratings in hydraulic conductivity layer and it has been assigned with weight to generate “C” parameter layer.

Hydraulic conductivity of the aquifer media varied from 0 to 43.3 m/day (Table 3). The hydraulic conductivity map of study area is shown below. The hydraulic conductivity is high near the eastern coastal region where the velocity of ground water flow is more leading to easy transmission of contaminants and also in some central and western regions (Fig 8). After careful preparation of all layers, weights are assigned to DRASTIC parameters between 1 to 5 as per their

relative importance in cropped land. In Agricultural DRASTIC the high rating is given to ‘D’ layer as 5. Next weightage is given to R, S, and I as 4. To A and T the rating assigned as 3. The least weight age is given to ‘H’ as 2. The flow chart of complete methodology is shown in Fig. 9. DRASTIC index number is determined by multiplying each parameter rating by its weight and adding together as computed by the following equation (3) DRASTIC

$$\text{Index} = \text{DRDW} + \text{RRRW} + \text{ARAW} + \text{SRSW} + \text{TRTW} + \text{IRIW} + \text{CR}$$

$$\text{CW} \text{ ----- (3)}$$

Where, R= Rating, W= Weight of respective parameters,

Finally vulnerability map is prepared in ArcGIS by superimposing of the seven layers involved in Agricultural DRASTIC method and reclassifying as shown in Fig 10. The Agricultural DRASTIC Vulnerability Index map for the district and presented in Fig.11. The generated indexes used for determination of zones of vulnerability. The Agricultural DRASTIC vulnerability Index map for cropped areas of the district which is extracted using LULC map of study area. The Agricultural DRASTIC index varied from 72-196. The agricultural drastic index map is divided into 3 classes namely, high, medium and low (Arfin *et al* 2016) [4]. The red, green and yellow colours as shown in the Fig 11 are high, medium and low vulnerable classes respectively. The high medium and low vulnerable classes occupy 49.46%, 39.98, 11.56% respectively (Table 5). The data used for generating the maps were statistically analysed and the following results were obtained. The statistical summary of seven rated parameters of the Agricultural DRASTIC model was presented in Table 6.

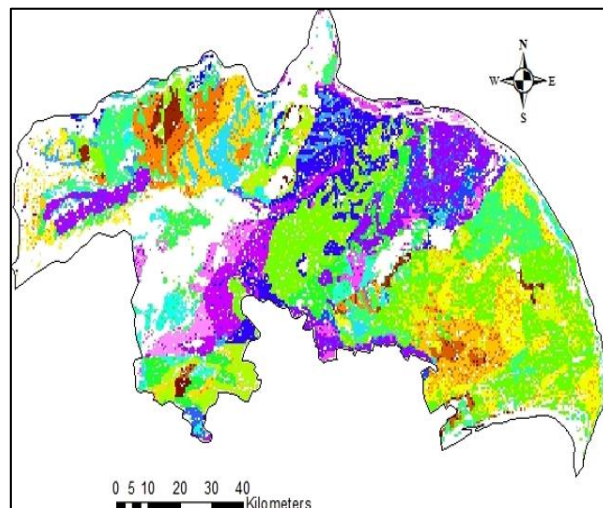


Fig 10: Agricultural DRASTIC Index map of Guntur district

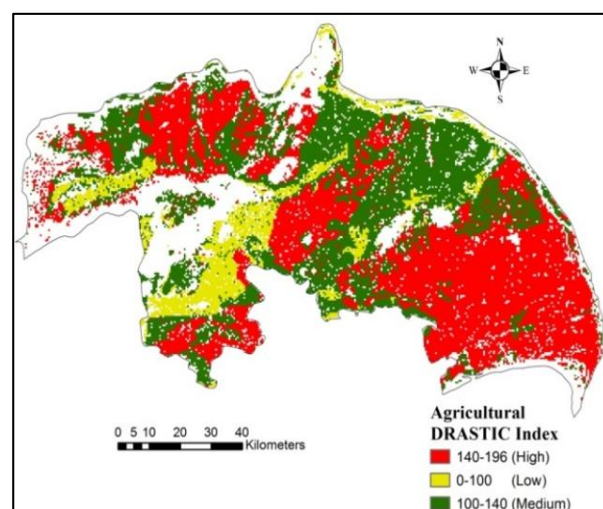


Fig 11: Agricultural Vulnerability classes of Guntur district

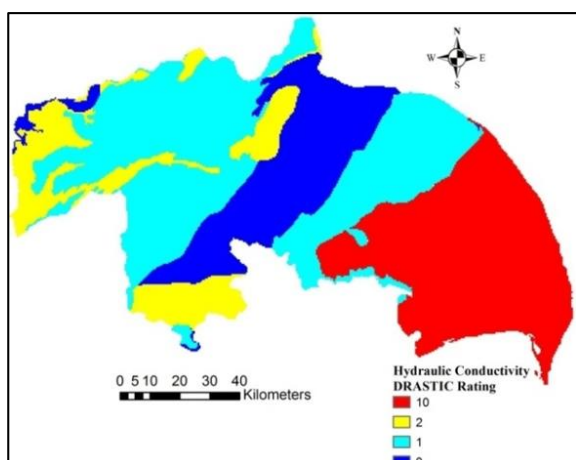


Fig 8: Hydraulic conductivity rated map of Guntur district

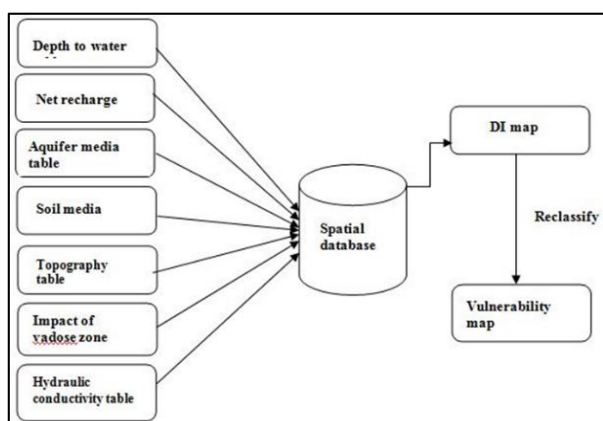


Fig 9: Vulnerability map flowchart with DRASTIC method

Table 3: Percentage area covered under different Soil media, slope, Hydraulic conductivity

Soil media	Area sq.km	% Area
Rock/Water	592.02	5.22
Clay	1611.01	14.22
Calcareous	4499.28	39.71
Loam	1235.60	10.90
Sandy	45.08	0.39
Gravel	3345.01	29.53
% Slope	Area(sq. km)	% Area
0-2	9352.17	82.56
2-6	1895.43	16.73
6-10	80.40	0.70
Hydraulic Conductivity, (m/day)	Area (sq.km)	Area,%
0	2163.97	18.45
0-4	4651.11	39.66
4-12	1501.21	12.80
>82	3411.36	29.09

Table 4: Vulnerability classes and corresponding definition (Foster *et al.*, 2002)

Vulnerability classes	Corresponding definition
Extreme	Vulnerable to most water pollutants with rapid impact in many pollution scenarios.
High	Vulnerable to many pollutants (except those strongly absorbed or readily transformed) in many pollution scenarios.
Moderate	Vulnerable to some pollutants but only when continuously Discharged or leached.
Low	Only vulnerable to conservative pollutants in the long term when continuously and widely discharged or leached.
Negligible	Confining beds present with no significant vertical groundwater flow leakage.

Table 5: Area distribution in Agricultural drastic vulnerability class

Vulnerability Class	Agricultural Drastic Area, Sq. km (%)
High	5602.829(49.46)
Medium	4528.934(39.98)
Low	1196.237(10.56)

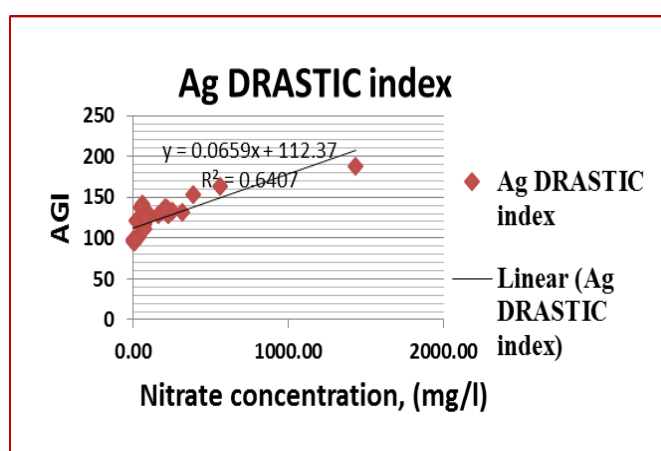
Analysis of chemical properties of water samples

Groundwater samples were collected from different wells of 20 mandals of Guntur district from different hand pumps, bore wells and wells. The samples were analysed using standard procedures mentioned in APHA (2006). The parameters analysed are (i) pH (ii) Electrical Conductivity (EC) (iii) Calcium (Ca⁺²) (iv) Magnesium (Mg⁺²) (v) Sodium (Na) (vi) Potassium (K) (vii) Carbonates (CO₃) (viii) Bicarbonates (HCO₃) (ix) Sulphates. pH and EC were measured by pH meter and EC meter, Ca⁺² and Mg⁺² were analyzed using EDTA method, K and Na were determined by flame photometry. HCO₃ and CO₃ were estimated by titrimetric method.

Validation of vulnerability map

The location of well map was prepared and overlaid on the Agricultural DRASTIC map. The nitrate value is a direct measure of contamination of ground water. The correlation between the vulnerability-risk degree of groundwater and nitrate concentration was used as an indicator of the reliability and accuracy of the applied methods (Sinha *et al.*, 2016) [5].

The positive correlation existed between both Agricultural DRASTIC and nitrate value as shown in Fig. 12. The correlation matrix for different ground water quality variables for Guntur district is depicted in Table 7. High positive correlation coefficient is observed between EC and Mg (0.812), EC and Ca (0.63). Calcium maintained positive correlations with manganese, Sulphates, Carbonates and Bicarbonates. There is a negative correlation of NO₃ with the EC, Sulphates, Carbonates and Bicarbonates. Positive correlation existed between NO₃ and Ca, Mg also matched with Anornu and Kabo-bah2013.

**Fig 12:** Relationship between NO₃ conc. and agricultural drastic**Table 6:** Coefficient of variation for different parameters

Layer	Minimum Rating	Maximum Rating	Mean	Standard Deviation	Coefficient of Variation
Depth to water table	7	10	8.67	1.25	14.39
Net recharge	1	6	3.33	2.05	28.64
Aquifer media	2	9	5.20	1.32	44.52
Soil map	0	10	4.67	1.77	32.81
Topography	5	10	8.00	2.16	27.00
Impact of Vadose Zone	2	9	4.83	2.27	46.90
Hydraulic conductivity	0	10	3.25	1.96	36.87

Table 7: Correlation table for water quality parameters

Para-Meters	pH	EC	Ca	Mg	So ₄	Co ₃ ⁻	Co ₃ ²⁻	K	NO ₃
pH	1								
EC	-0.21	1							
Ca	-0.18	0.63	1						
Mg	-0.09	0.81	0.48	1					
Sulphates	-0.20	0.56	0.24	0.30	1				
Carbonates	-0.05	0.32	0.16	0.02	0.24	1			
Bicarbonates	-0.09	-0.02	0.00	-0.26	-0.06	0.71	1		
K	-0.16	0.30	0.17	0.21	0.22	0.31	0.35	1	
NO ₃	-0.01	-0.33	0.17	0.14	-0.37	-0.28	-0.13	-0.31	1

Conclusions

To study the ground water pollution in agricultural areas, thematic layers were prepared for seven influencing parameters with the help of ARCGIS software. The vulnerability maps are prepared for Agricultural areas of Guntur district by overlying the seven layers. As per the statistical summary of the layers, Vulnerability map is more affected by the parameter depth to water table followed by net recharge. Agricultural vulnerability index ranged from 72-196. The developed Agricultural vulnerability map indicated that the north east mandals of study area are more prone to pollution than interior and North West mandals. Agricultural vulnerability map showed that the high medium and low vulnerable classes occupy 49.46%, 39.98, 11.56% respectively. The coefficient of variation indicates that the high contribution to the variation of vulnerability index is

made by Impact of vadose zone (46.90), aquifer media (44.52) and hydraulic conductivity (36.87) which needs to be considered for sensitivity analysis. The nitrate value is a direct measure of contamination of ground water. Vulnerability zones were validated by correlating with nitrate distribution layer by Pearson correlation coefficient tests. There is a negative correlation of NO₃ with the EC, Sulphates, Carbonates and Bicarbonates. Positive correlation existed between NO₃ and Ca, Mg. The criteria may be used for analysis and development of decision support system for ground water protection planning the model needs to be further calibrated with the ground data by considering land use, rainfall, and coastal area activates, site specific pollutants etc.

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