AHP-GIS Based DRASTIC Model for Groundwater Vulnerability to Pollution Assessment: A Case Study of Hazaribag District, Jharkhand, India

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Abstract- **Groundwater pollution due to anthropogenic activities is one of the most serious environmental problems in urban/industrial areas. Groundwater is one of the main sources of drinking water in Hazaribag District and hence its vulnerability assessment to delineate areas that are more susceptible to contamination is very important. The present study aims to demonstrate AHP-GIS based DRASTIC model to estimate the relative probability of contamination of the groundwater resources in the selected study area.**

The study result reveals that the vulnerability index varying from 4.53 to 9.47 (Scale: Minimum possible Index- 1.00 and Maximum possible index- 9.84). The range of the vulnerability index has been classified into five classes (low, moderately low, moderate, moderately high, and high) and accordingly the whole study area is classified into five types of zones on the basis of vulnerability index. The study results delineate areas that are more susceptible to contamination due to the existing hydro-geologic factors and show areas of greatest potential for groundwater contamination.

Keywords- AHP; Groundwater Vulnerability Assessment; DRASTIC; GIS; Hazaribag District

I. INTRODUCTION

Groundwater is the most important water resource on earth [1]. The quality of groundwater is generally under a considerable potential of contamination especially in agriculture-dominated areas with intense activities that involve the use of fertilizers and pesticides [2-6]. The issue of protection of groundwater against pollution is of crucial significance [7]. The concept of groundwater vulnerability is a cornerstone in the evaluation of the risk of groundwater contamination and in the development of management options to preserve the quality of groundwater [8-10].

Groundwater vulnerability studies are based on the idea that specific land areas are more vulnerable to groundwater contamination than others [11]. Hence, groundwater vulnerability assessment delineates areas that are more susceptible to contamination due to the hydrogeologic factors and anthropogenic sources and shows areas of greatest potential for groundwater contamination. In general, this connotes the estimation of the potential for contaminants to migrate from the land surface through the unsaturated zone (characterised by pore spaces that are incompletely filled with water) until reaching the areas of interest [12]. As such, the concept of groundwater vulnerability is important for a rational management of groundwater resources and subsequent land use planning [12-14]. Groundwater vulnerability maps provide useful information to protect groundwater resources and evaluate the potential for water quality improvement with changes in agricultural practices and land use applications [12-15].

The use of groundwater vulnerability assessment in planning, policy analysis, and decision making varies and reflects different aspects including (but not limited to): (i) advising decision makers of the need for adopting specific management options to mitigate the quality of groundwater resources; (ii) elucidating the implications and consequences of their decisions; (iii) providing direction for allotting water resources; (iv) enlightening decisions about land use practices and activities; and (v) educating the general public about the potential for groundwater contamination throughout public awareness campaigns [16].

The concept of aquifer vulnerability to external pollution was introduced in 1960s by Margat, 1968 [17], with several systems of aquifer vulnerability assessment developed in the following years (Aller et. al., 1987 [18]; Civita, 1994 [19]; Vrba & Zaporozec, 1994 [20]; Sinan & Razack, 2009 [21]; Polemio et. al., 2009 [22]; Foster, 1987 [23]). They found that the reason behind the different vulnerability is the different hydro-geological settings. Many approaches have been developed to evaluate aquifer vulnerability. These include process based methods, statistical methods, and overlay/index methods [24, 25]. The process based methods use simulation models to estimate the contaminant migration [26]. Statistical methods use statistics to determine associations between the spatial variables and the actual occurrence of pollutants in the groundwater. While the overlay/index methods use location specific vulnerability indices based on the factors controlling movement of pollutants from the ground surface to the water bearing strata. Of these major approaches, the overlay/index method has been the most widely adopted approach for large scale aquifer sensitivity and groundwater vulnerability assessments. Scientists started to give predictions of groundwater pollution potential based on hydro-geological settings [22, 27-38]. In this paper, AHP-GIS based

DRASTIC model is demonstrated for the study. The main objective of this paper is to assess groundwater vulnerability to pollution of the aquifer situated in the study area using the AHP-GIS based DRASTIC model in combination.

II. STUDY AREA

Hazaribag District as shown in Fig. 1 was taken up for this study. It is a medium-size fast growing urban centre Jharkhand State in India. The study area is situated in 23.98˚ N and 85.35˚ E. It covers approximately 4500 km^2 of area. The district comprises of 11 blocks, namely Hazaribagh, Chauparan, Barhi, Padma, Ichak, Barkatha, Bishungarh, Katkamsandi, Keredari, Barkagaon and Churchu as shown in Fig. 1.

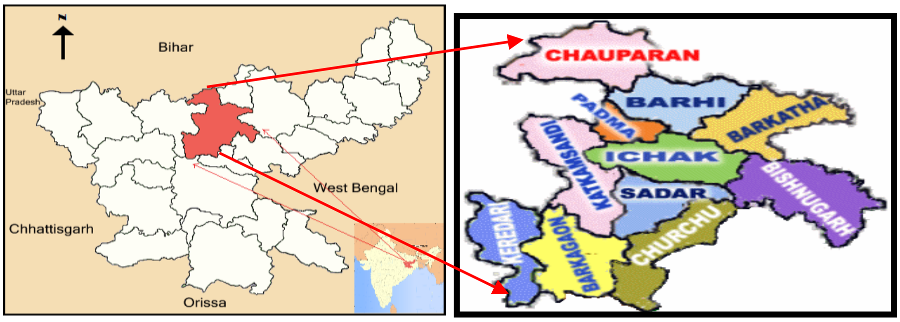

Fig. 1 Study area map

The average annual rainfall is 1347 mm. The maximum temperature during peak summer goes up to 46^0C and minimum during peak winter drops down to 4^0C. The average elevation of Hazaribagh District varies from 150-200 m from mean sea level.

Geologically the area is underlain by Chotanagpur granite gneiss, phyllite mica-schist**.** It is uniformly overlain by lower Gondwana formations consisting of sandstone, shales and coal seams. Granite rocks showed maximum thickness of weathered mantle in favourable topographic and drainage condition.

Two types of aquifers (unconfined and confined) are mainly observed in both Granite-gneiss and Gondwana rocks. Unconfined aquifer (an aquifer underlain by an impermeable stratum, but the top of the aquifer consists of soil layers that are permeable enough to provide easy passage of water) is observed in weathered formations whereas semi-confined (an aquifer underlain by an impermeable stratum and bounded at the top by soil layers of relatively low permeability) to confined aquifers (an aquifer bounded both at the bottom and at the top by an impermeable stratum and fully filled with water which is usually under pressure) are in deeper fractures. Water levels in unconfined aquifers vary between 3-10 mbgl. Piezometric head in Granite-gneiss varies between 2-9 mbgl. In Gondwana rocks it varies between 18-20 mbgl in Bhurkunda area and 6-9 mbgl in Ghato, Banji area.

III. MATERIALS AND METHODOLOGY

Groundwater vulnerability of the study area was evaluated using hydrogeologic parameters that can affect the contaminants transport through the vadose zone to the water table using DRASTIC method [18]. Each of the seven DRASTIC hydro-geological parameters (Depth to water table, Net recharge, Aquifer media, Soil media, Topography, Impact of vadose zone and Hydraulic conductivity) is mapped and classified either into ranges or into significant media types, which have an impact on pollution potential. Each factor or parameter is assigned a subjective rating. Weight multipliers are then used for each factor to balance and enhance its importance. The final vulnerability map is based on the DRASTIC Index (DI) which is computed as the weighted sum overlay of the seven layers using the following equation:

$$DI = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w \quad (1)$$

Where, *D*, *R*, *A*, *S*, *T*, *I*, and *C* represents the seven parameters, *r* is the rating value, and *w* the weight assigned to each parameter.

Where;

D_r = Ratings to the depth to water table

D_w = Weights assigned to the depth to water table

R_r = Ratings for ranges of aquifer recharge

R_w = Weights for the aquifer recharge

A_r = Ratings assigned to aquifer media

A_w = Weights assigned to aquifer media

S_r = Ratings for the soil media

S_w = Weights for soil media

T_r = Ratings for topography (slope)

T_w = Weights assigned to topography

I_r = Ratings assigned to vadose zone

I_w = Weights assigned to vadose zone

C_r = Ratings for rates of hydraulic conductivity

C_w = Weights given to hydraulic conductivity

The flow chart in Fig. 2 shows the general overview of the working methodology.

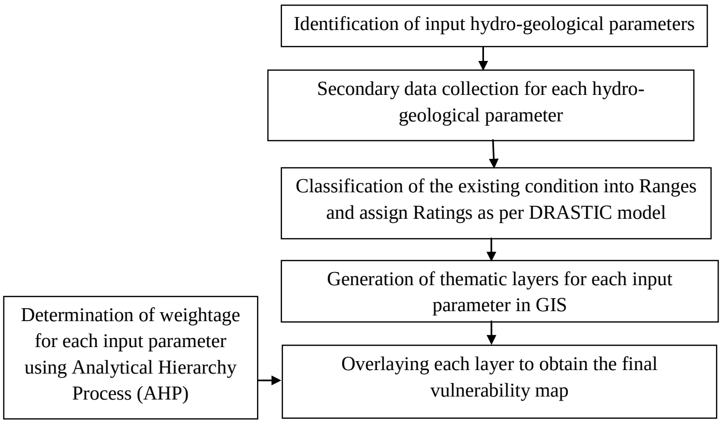

Fig. 2 Flow chart of the working methodology

IV. ASSESSMENT OF AQUIFER VULNERABILITY TO POLLUTION

The work has been completed with the following steps:

A. Page Layout

The data has been generated from various published reports/maps of CGWB, JSAC and satellite data, etc. Various data types and their sources to generate the thematic layers of different hydrogeological parameters are shown in Table 1.

TABLE 1 DATA TYPES AND ITS SOURCES FOR CREATION OF OUTPUT LAYERS

Sl. No.	Data Type	Source	Output Layer
1	Well data	CGWB, Ranchi	Depth to water
2	Average annual rainfall	CGWB, Ranchi	Net recharge
3	Geologic map	JSAC	Aquifer media
4	Soil map	JSAC	Soil media
5	SRTM data	USGS GLOVIS visualisation viewer	Topography
6	Soil map	JSAC	Impact of vadose zone
7	Geologic map	JSAC	Hydraulic conductivity

B. Assigning Ranges and Ratings

The ranges and ratings for each parameter have been assigned similarly to the standardized DRASTIC system given by [18] for evaluating groundwater pollution potential using different hydrogeologic settings.

Each DRASTIC factor has been divided into either ranges or significant media types that affect groundwater vulnerability. The media types such as aquifer material, soil type and impact of vadose zone, cannot be measured numerically. Each range of each DRASTIC parameter has been evaluated with respect to the others to determine its relative significance to pollution potential, and has been assigned a rating of 1 to 10. The most vulnerable range is given the rating 10, and the least vulnerable the rating 1.

Every parameter in the model has a fixed weight indicating the relative influence of the parameter in transporting contaminants to the groundwater. The DRASTIC parameters *D*, *R*, *A*, *S*, *T*, *I* and *C* have been assigned one value each range or a typical value. Ratings of each parameter are shown in Table 2, which vary from 1 to 10, with higher values describing greater pollution potential. The numerical ratings, which were established using the Delphi technique [18], are well defined and have been used worldwide [14, 39-42]. The ratings for each parameter are listed in Table 2 for all the ranges and types.

TABLE 2 RANGES AND RATINGS FOR VARIOUS HYDRO-GEOLOGICAL SETTINGS [18]

Depth to Groundwater			**Net Recharge**		
Ranges (m)	**Ratings (D_r)**	**Sub-Index (D_r*D_w)**	**Ranges (cm)**	**Ratings (R_r)**	**Sub-Index (R_r*R_w)**
0-1.52	10	50	0-5.08	1	4
1.52-4.57	9	45	5.08-10.16	3	12
4.57- 9.14	7	35	10.16- 17.78	6	24
9.14- 15.24	5	25	17.78- 25.4	8	32
15.24-22.86	3	15	25.4+	9	36
22.86- 30.48	2	10			
30.48+	1	5			
Weight (D_w)	**5**		**Weight (R_w)**	**4**	
Aquifer Type			**Soil type**		
Type	**Ratings (A_r)**	**Sub-Index (A_r*A_w)**	**Type**	**Ratings (S_r)**	**Sub-Index (S_r*S_w)**
Massive Shale	2	6	Thin or absent	10	20
Metamorphic/ Igneous	3	9	Gravel	10	10
Weathered Metamorphic/ Igneous	4	12	Sand	9	18
Glacial Till	5	15	Peat	8	16
Bedded sandstone, Limestone and Shale sequences	6	18	Shrinking and/or Aggregated Clay	7	14
Massive Sandstone	6	18	Sandy Loam	6	12
Massive Limestone	6	18	Loam	5	10
Sand and Gravel	8	24	Silty Loam	4	08
Basalt	9	27	Clay loam	3	06
Karst Limestone	10	30	Muck	2	04
Weight (A_w)	**3**		Non-shrinking and Non-aggregated Clay	1	02
Topography or slope			**Weight (S_w)**	**2**	
Ranges (in Percent)	**Ratings (T_r)**	**Sub-Index (T_r*T_w)**	**Impact of Vadose Zone**		
0-2	10	10	**Type**	**Ratings (I_r)**	**Sub-Index (I_r*I_w)**
2-6	9	9	Confining layer	1	5
6-12	5	5	Silt/ Clay	3	15
12-18	3	3	Shale	3	15
18+	1	1	Limestone	6	30
Weight (T_w)	**1**		Sandstone	6	30
Hydraulic Conductivity			Bedded Limestone, Sandstone, Shale	6	30
Range (m/d)	**Ratings (C_r)**	**Sub-Index (C_w*C_r)**	Sand and Gravel with significant Silt and Clay	6	30
0.06- 6.71	1	3	Metamorphic/ Igneous	4	20
6.71- 20.15	2	06	Sand and Gravel	8	40
20.15- 47.02	4	12	Basalt	9	45
47.02- 67.18	6	18	Karst Limestone	10	50
67.18 - 134.36	8	24			
134.36+	10	30			
Weight (C_w)	**3**		**Weight (I_w)**	**5**	

1) Determination of Weightage for Each Parameter:

Analytical Hierarchical Process (AHP) is an approach to decision making that involves structuring multiple choice criteria onto a hierarchy, assessing the relative importance of these criteria, comparing alternatives for each criterion and determining an overall ranking of the alternatives. The foundation of the Analytic Hierarchy Process (AHP) is a set of axioms that carefully delimits the scope of the problem environment [43]. It is based on the well-defined mathematical structure of consistent matrices and their associated right eigenvector's ability to generate true or approximate weights, [44-46]. The AHP methodology compares criteria, or alternatives with respect to a criterion, in a natural, pair wise mode. To do so, the AHP uses a fundamental scale of absolute numbers that have been proven in practice and validated by physical and decision problem experiments. The fundamental scale has been shown to be a scale that captures individual preferences with respect to quantitative and qualitative attributes just as well or better than other scales [45, 46]. It converts individual preferences into ratio scale weights that can be combined into a linear additive weight w(a) for each alternative a. The resultant w(a) can be used to compare and rank the alternatives, and hence assist the decision maker in making a choice. Given that the three basic steps are reasonable descriptors of how an individual comes naturally to resolve a multi-criteria decision problem, then the AHP can be considered to be both a descriptive and prescriptive model of decision making. The AHP is perhaps the most widely used decision making approach in the world today. Its validity is based on the many hundreds (now thousands) of actual applications in which the AHP results were accepted and used by the cognizant decision makers (DMs) [46].

Each input parameter has a predetermined, fixed and relative weight that reflects its relative importance of groundwater vulnerability to pollution. The most significant factors have a higher weight and vice-versa. The pollutant's weights have been determined using AHP. The detailed methodology is explained below to determine the relative weightage of each pollutant.

The weightage of individual pollutants can be found out using AHP. AHP is a systematic method for comparing a list of objectives or alternatives. This method forms a pair-wise comparison matrix 'A' as shown below, where the number in the i^{th} row and j^{th} column gives the relative importance of individual parameter P_i as compared with Pj.

The comparison matrix generated by author's expertise using Saaty's scale [45] is shown below in matrix A. The relative weightage can be improved by taking the experts views.

$$A = \begin{bmatrix} & T & S & C & A & R & I & D \\ T & 1 & 1/2 & 1/3 & 1/3 & 1/4 & 1/5 & 1/5 \\ S & 2 & 1 & 1/2 & 1/2 & 1/3 & 1/3 & 1/3 \\ C & 3 & 2 & 1 & 1 & 1/2 & 1/2 & 1/2 \\ A & 3 & 2 & 1 & 1 & 1 & 1/2 & 1/2 \\ R & 4 & 3 & 2 & 1 & 1 & 1/2 & 1/2 \\ I & 5 & 3 & 2 & 2 & 2 & 1 & 1 \\ D & 5 & 3 & 2 & 2 & 2 & 1 & 1 \end{bmatrix}$$

The sum of each column and then division of each column by the corresponding sum are computed to obtain the normalize weights, the normalized matrix N, thus obtained is represented in matrix N as given below.

$$N = \begin{bmatrix} & T & S & C & A & R & I & D \\ T & 0.043 & 0.034 & 0.037 & 0.042 & 0.035 & 0.05 & 0.05 \\ S & 0.086 & 0.068 & 0.056 & 0.063 & 0.047 & 0.083 & 0.083 \\ C & 0.130 & 0.137 & 0.113 & 0.127 & 0.071 & 0.125 & 0.125 \\ A & 0.130 & 0.137 & 0.113 & 0.127 & 0.142 & 0.125 & 0.125 \\ R & 0.173 & 0.206 & 0.226 & 0.127 & 0.142 & 0.125 & 0.125 \\ I & 0.217 & 0.206 & 0.226 & 0.225 & 0.285 & 0.25 & 0.25 \\ D & 0.217 & 0.206 & 0.226 & 0.255 & 0.285 & 0.25 & 0.25 \end{bmatrix}$$

The relative weight vector W for the pollutants is given by the average of the row elements in matrix N as

$$W = \begin{bmatrix} w_T \\ w_S \\ w_C \\ w_A \\ w_R \\ w_I \\ w_D \end{bmatrix} = \begin{bmatrix} 0.041 \\ 0.070 \\ 0.118 \\ 0.128 \\ 0.161 \\ 0.241 \\ 0.241 \end{bmatrix}$$

Thus, the sum of the weightage of the pollutants obtained as $\sum_{i=1}^{7} W_i = 1$. The consistency ration of the matrix can be checked by

$$CR = \frac{CI}{RI} = \frac{0.021}{1.414} = 0.014$$

where,

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} = \frac{\left(\sum A\bar{w} - n\right)}{(n-1)} = \frac{(7.130 - 7)}{7-1} = 0.021$$

$$RI = \frac{1.98(n-2)}{n} = \frac{1.98(7-2)}{7} = 1.41$$

Since, CR < 0.1, the judgements are acceptable.

2) Generation of Thematic Layers for Each Drastic Parameter:

Thema tic layers for each hydrogeological parameter were generated using Arc GIS software. Different sources of raw data (mentioned above) have been used for the generation of individual thematic layer. The flow chart for the generation of layers is shown in Fig. 3.

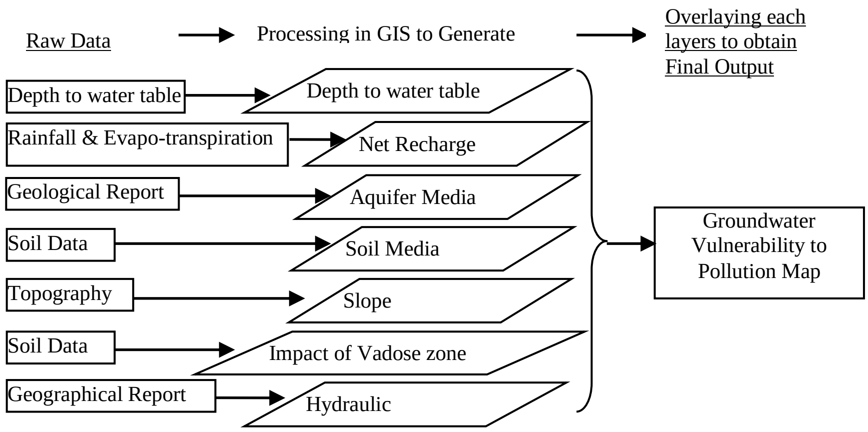

Fig. 3 Flow chart for generation of layers for input parameters using Arc GIS

The detailed methodology for generation of thematic layers is given below:

Depth to Water Table: The depth-to-water table parameter was derived from water level data collected from Central Ground Water Board (CGWB), Ranchi. The depth-to-water table is shallow and has a range of 1.14-8.45 mbgl. The well data was then used to generate the map for depth to water table contoured by interpolating using Inverse Distance Weighted method.

The study area was extracted using the district boundary as a mask. The map thus obtained was reclassified into three ranges that fit the DRASTIC model. The three reclassification ranges and their assigned ratings are shown in Table 3. The map thus generated for depth to water is shown in Fig. 4.

TABLE 3 RANGES AND RATINGS FOR VARIOUS HYDRO-GEOLOGICAL SETTINGS USING DRASTIC DATA FOR THE STUDY AREA

Depth to Groundwater			**Net Recharge**		
Ranges (m)	**Ratings (D_r)**	**Sub-Index (D_r*D_w)**	**Ranges (cm)**	**Ratings (R_r)**	**Sub-Index (R_r*R_w)**
0-1.52	10	2.41	25.4+	9	1.449
1.52-4.57	9	2.169			
4.57- 9.14	7	1.687			
Weight (D_w)	**0.241**		**Weight (R_w)**	**0.161**	
Aquifer Media			**Soil Media**		
Type	**Ratings (A_r)**	**Sub-Index (A_r*A_w)**	**Type**	**Ratings (S_r)**	**Sub-Index (S_r*S_w)**
Metamorphic /igneous	3	0.384	Coarse Loamy	6	0.42
Weathered metamorphic igneous	4	0.512	Loamy & loamy skeletal	5	0.35
Bedded sandstone, shale sequences & massive sandstone	6	0.768	Fine & fine loamy	2	0.14
Sand & Gravel	8	1.024			
Basalt	9	1.152			
Weight (A_w)	**0.128**		**Weight (S_w)**	**0.070**	
Topography or slope					
Ranges (in Percent)	**Ratings (T_r)**	**Sub-Index (T_r*T_w)**	**Impact of Vadose Zone**		
0-2	10	0.41	**Type**	**Ratings (I_r)**	**Sub-Index (I_r*I_w)**
2-6	9	0.369			
6-12	5	0.205	Fine & fine loamy	3	0.723
12-18	3	0.123	Loamy	4	0.964
18+	1	0.041	Loamy skeletal & coarse loamy	6	1.446
Weight (T_w)	**0.041**				
Hydraulic Conductivity					
Range (m/d)	**Ratings (C_r)**	**Sub-Index (C_w*C_r)**			
0.06- 6.71	1	0.118			
47.02- 67.18	6	0.708			
134.36+	10	1.18			
Weight (C_w)	**0.118**		**Weight (I_w)**	**0.241**	

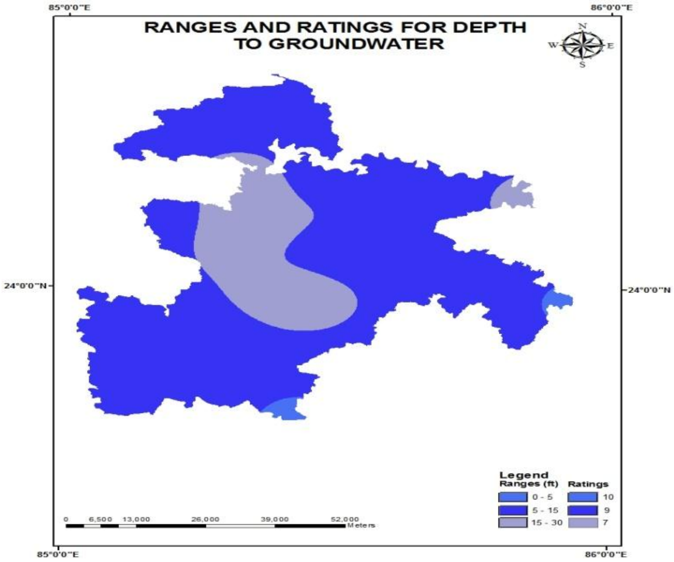

Fig. 4 Depth to water table

Net Recharge: The map for precipitation was generated using the rainfall data collected from CGWB, Ranchi. The evapotranspiration map was prepared considering evapotranspiration as 5% of the precipitation (value taken from a report of Birsa Agricultural University (BAU) for rainfall and evapotranspiration relationship in Jharkhand State). The runoff coefficient ranges from 0-1 depending on the land use type. Due to lack of data the runoff coefficient for this study has been considered as 0.5. Then the map for net recharge was generated using raster calculator by the formula of net recharge as the amount of precipitation minus evapotranspiration and runoff. The reclassification was done according to the ranges and corresponding ratings. Due to homogeneity in net recharge for the entire district has single range (25.4+) with rating (9) as in Table 2 and the subindex of the same is reported in Table 3. The map thus generated for net recharge is shown in Fig. 5.

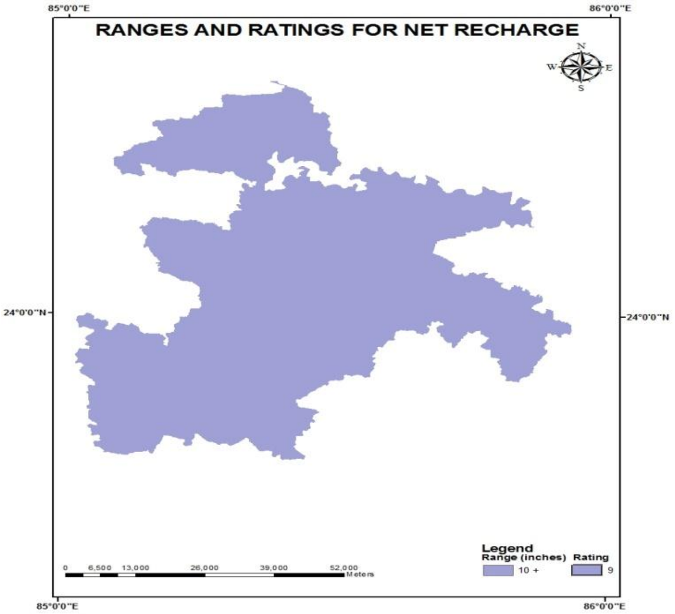

Fig. 5 Net recharge

Aquifer Media: Aquifer media map was prepared from the geologic map of Jharkhand. The study area consists of different types of aquifer media which were reclassified into five types and their corresponding rating was assigned for each aquifer media as given in Table 3. The map thus generated is shown in Fig. 6.

Soil Media: Soil media map was prepared from the soil map of Jharkhand. The study area consists of fine to coarse loamy type soil. The soil type existing in the study area was classified into three types and their corresponding ratings were assigned for each type of soil media as given in Table 3. The map generated for soil media is shown in Fig. 7.

Topography: The topography map was prepared using the Shuttle Radar Topography Mission (SRTM) data. The percentage slope raster file was created from Digital Elevation Model (DEM) using Spatial Analyst. The slope in the study area varies from 0-18 percent. Reclassification was done for the percent slope raster in the ranges of 0 to 18% into five classes and assigned their corresponding ratings as given in Table 3. The map of topography is shown in Fig. 8.

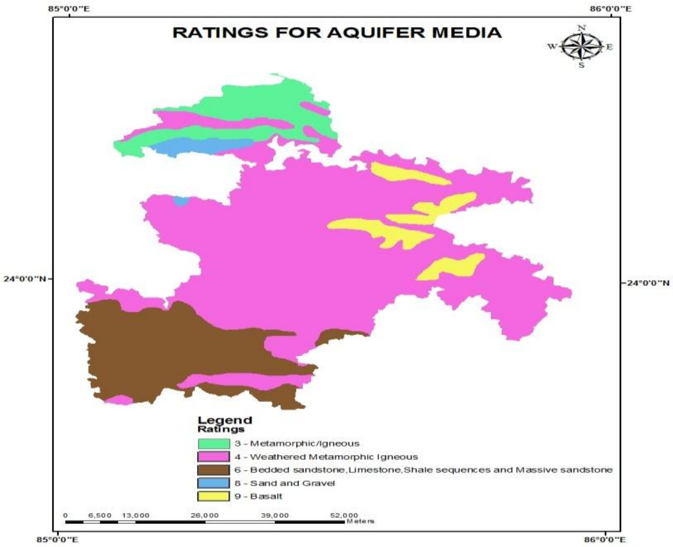

Fig. 6 Aquifer media

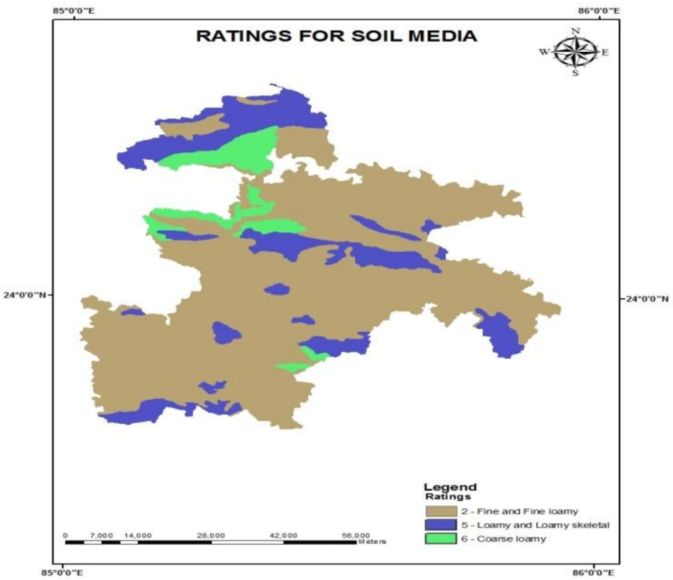

Fig. 7 Soil media

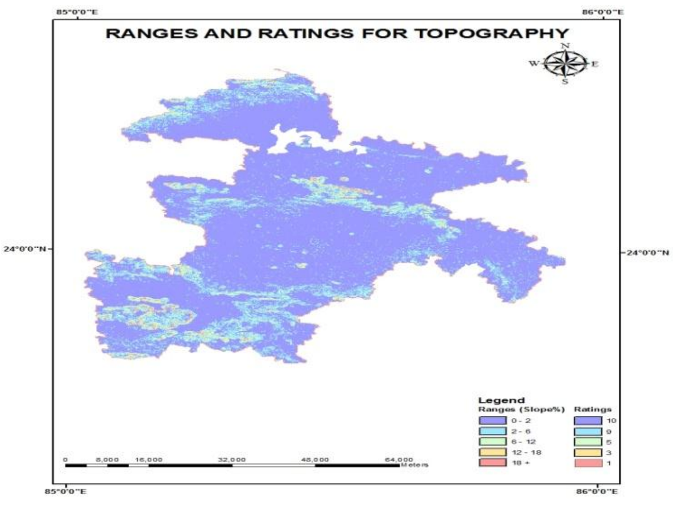

Fig. 8 Slope map

Impact of vadose zone: Due to unavailability of Vadose Zone data in the study area, information of the soil media was used to derive the approximate ratings for Vadose zone. The map was converted to a raster data by defining ratings for the vadose zone media (using soil media data) (Table 3 & Fig. 7). The map of impact of vadose zone is shown in Fig. 9.

Hydraulic Conductivity: Due to unavailability of hydraulic conductivity data in the study area, information of the aquifer media was used to derive the approximate ratings for hydraulic conductivity. It was converted to a raster data according to the defined ratings. The ratings of the hydraulic conductivity were assigned (using aquifer media data instead here) in Table 3. The map of hydraulic conductivity is shown in Fig. 10.

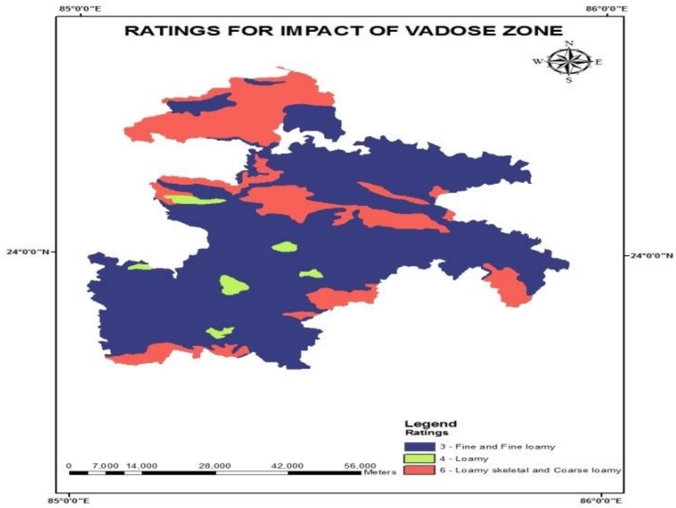

Fig. 9 Impact of Vadoze zone

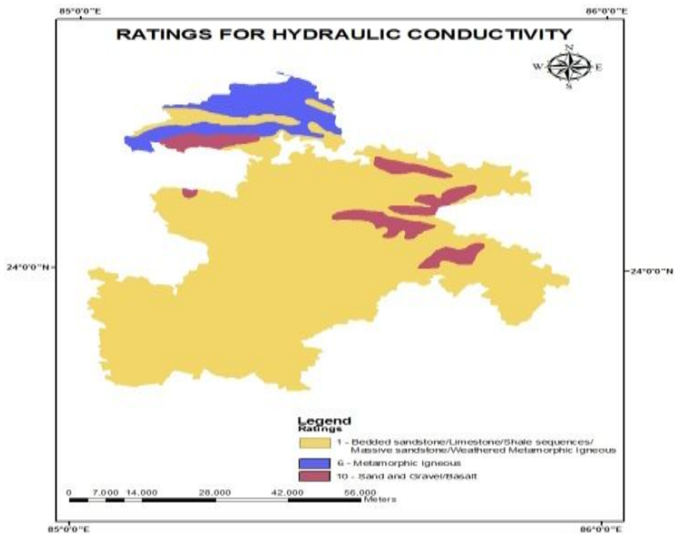

Fig. 10 Hydraulic conductivity

V. RESULTS AND DISCUSSION

The hydrogeological settings of Hazaribag District with their ranges and ratings are listed in Table 3. The final vulnerability map was obtained by running the model in the ArcGIS 9.2 environment by using the seven hydro-geological data layers. The map thus obtained is shown in Fig. 11. The vulnerability index was reclassified into five classes that describe the relative probability of contamination of the groundwater resources. These five classes are: low, moderately low, moderate, moderately high, and high. A regional scale has been used for comparing the relative vulnerability of groundwater resources. The vulnerability index class for final vulnerability map is given below in Table 4.

The result of groundwater vulnerability to pollution assessment shows index values which vary from 4.53 to 8.47. The possible vulnerability indices vary from 1 to 9.84, if calculated from Table 2. The maximum and minimum vulnerability indices are calculated by sum of the product of maximum and minimum ratings for all the parameters with its corresponding weightage respectively. The results of the groundwater vulnerability assessment show that the study area has been divided into five zones of relative vulnerability: low groundwater vulnerability risk zone (index: <5.36); moderately low vulnerability risk zone (index: 5.36-6.00), moderate vulnerability zone (index: 6.00-6.76), moderately high vulnerability zone (index: 6.76-7.46), and high vulnerability zone (index: >7.46) which is shown in Table 4.

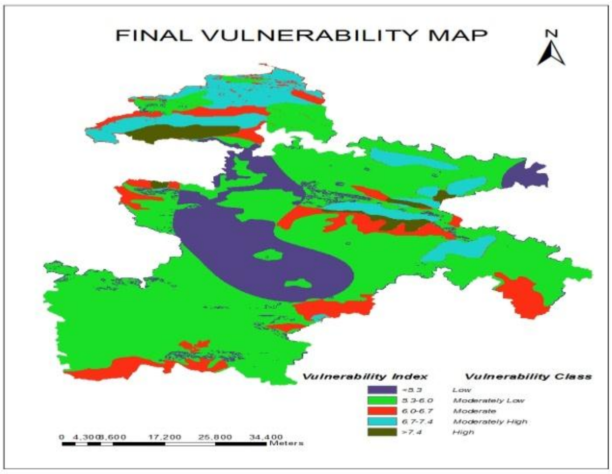

Fig. 11 Relative potential of groundwater vulnerability to pollution map

TABLE 3 RANGES, RATINGS AND WEIGHTAGE OF DRASTIC PARAMETERS

$$\textbf{Maximum Vulnerability Index} = \sum_{i=1}^{7} Rating_i * Weightage_i = \sum_{i=1}^{7} Max\ Sub\ Index_i$$

$$= 2.4 + 1.44 + 1.17 + 0.42 + 0.40 + 1.44 + 1.2 = 8.47$$

$$\textbf{Minimum Vulnerability Index} = \sum_{i=1}^{7} Rating_i * Weightage_i = \sum_{i=1}^{7} Min\ Sub\ Index_i$$

$$= 1.68 + 1.44 + 0.39 + 0.14 + 0.04 + 0.72 + 0.12 = 4.53$$

TABLE 4 VULNERABILITY INDEX, CLASS AND CORRESPONDING AREA

Vulnerability Class	DRASTIC Index	Area in km^2	Percentage of area
Low	<5.36	807.84	18.0
Moderately Low	5.36-6.00	2603.47	57.9
Moderate	6.00-6.76	492.78	11.0
Moderately High	6.76-7.46	464.98	10.3
High	7.46	125.36	2.80
Total Area		4494	100

It is very difficult to say the role of particular parameter on the spatial changes in the vulnerability index. But the vulnerability map clearly reveals that the depth to groundwater has significant role in spatial changes in vulnerability index. It is clear from the map that the higher the groundwater depth (15-30 ft), the lower the vulnerability class. Since, the net recharge factor is constant throughout the study area and thus does not have any influence on the spatial changes in the vulnerability index. The higher class of vulnerability index is more or less influenced by soil media and aquifer media.

The total area under different vulnerability classes and their corresponding percentages is reported in Table 4. The results revel that the percentages of area (total area) under different vulnerability class are 18% (807.84 km^2), 57.9% (2607.47 km^2), 11% (492.78 km^2), 10.3% (464.98 km^2), and 2.8% (125.36 km^2) for low, moderately low, moderate, moderately high and high respectively. The high vulnerability zones are mainly lie in the blocks of Ichak, Katkamsandi, and Sadar.

VI. CONCLUSION

Groundwater plays an important role in drinking water supply in Hazaribag District. This study utilized DRASTIC model and GIS technique to assess the aquifer vulnerability in the study area. Seven environmental parameters which include depth to water, net recharge, aquifer media, soil media, topography, impact of vadose zone, and hydraulic conductivity were used to represent the hydro geological setting of the study area. The result of groundwater vulnerability to pollution assessment shows index values which vary from 4.53 to 8.47 (Scale: Min- 1 and Max- 8.16). According to the results of the groundwater vulnerability assessment, the study area has been divided into five zones of relative vulnerability: low, moderately low, moderate, moderately high and high vulnerability zone. The maximum area has fallen under moderately low vulnerable zone, accounting for 57.9% (2607.47 km^2).

The study suggests that the DRASTIC model can be used for prioritization of vulnerable areas in order to prevent the further pollution to already more polluted areas. There is a need to develop a system that can be used to identify areas where attention or protection effort is required. There should be a detailed and frequent monitoring in high and moderately high vulnerable zones in order to monitor the changing level of pollutants. The above study also helps for screening the site selection for waste dumping. The measurement of relative ground-water vulnerability to pollution may be one of many criteria used in siting decisions, but should not be the sole criteria.

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