JOURNAL GEOLOGICAL SOCIETY OF INDIA
Vol.93, March 2019, pp.293-304

Assessment of Groundwater Pollution Vulnerability Using GIS Based Modified DRASTIC Model in Raipur City, Chhattisgarh

Rubia Khan* and D. C. Jhariya[!]

Department of Applied Geology, National Institute of Technology, Raipur, GE Road, Raipur – 492 010, India.
E-mail: *geology.rubia@gmail.com*; dcjhariya.geo@nitrr.ac.in[!]*

ABSTRACT

In the present study DRASTIC model was used to assess the groundwater vulnerable zone for Raipur city. In this study DRASTIC model is modified into four ways i.e. DRASTIC, Modified DRASTIC-Lu, DRASTIC AHP and Modified DRASTIC-Lu AHP. To modify the DRASTIC model, LULC parameter was added in the real DRASTIC model and also AHP technique applied to determine the rating and weight. In this study, it is observed that 2.83%, 7.57%, 32.03%, 47.78% and 9.8% areas are respectively falling under very low, low, moderate, high and very high vulnerable DRASTIC index, 2.56%, 10.96%, 30.10%, 47.47% and 8.9% areas are respectively falling under very low, low, moderate, high and very high vulnerable modified DRASTIC-Lu index, 3.27%, 16.63%, 47.14%, 74.44% and 9.96% area are respectively falling under very low, low, moderate, high and very high vulnerable DRASTIC-AHP index classes and 2.74%, 12.27%, 38.16%, 41.5% and 5.3% area are respectively falling under very low, low, moderate, high and very high vulnerable modified DRASTIC-Lu AHP index. To determine the accuracy of the DRASTIC models, total 50 groundwater samples of nitrate concentration were used for pre-monsoon and post-monsoon seasons and it was observed that Modified DRASTIC-Lu AHP model is most accurate and suitable for present study area.

INTRODUCTION

Groundwater vulnerability evaluation portrays territories that are more defenseless to pollution due to the hydrogeological factors and anthropogenic sources and shows regions of most prominent potential for groundwater contamination (Almsari, 2008; Tirkey et al., 2013). To assess the groundwater vulnerability, various methods are proposed such as process-based simulation models, statistical methods and overlay index methods (National Research Council, 1993; Tesoriero et al., 1998, Harbaugh et al., 2000; Dixon, 2004; Huan et al., 2012; Neshat et al., 2014, Sinha et al., 2015). DRASTIC model is worldwide applied in various countries to assess groundwater vulnerability, it first developed by United State Environmental Protection Agency (US EPA) (Evans and Mayers, 1990; Fritch et al., 2000; Knox et al., 1993; Piscopo, 2001; Rundquist et al., 1991; Secunda et al., 1998; Aller et al., 1987; Nawafleh, 2007; Huan et al., 2012; Neshat et al., 2014; Kaliraj et al., 2015). DRASTIC vulnerability method is mainly based on hydrogeological setting of the area, it includes mainly seven parameter such as depth to water level, net recharge, aquifer type, soil properties, topography, impact of the vadose zone and the hydraulic conductivity (Navulur and Engel, 1998; Wen et al., 2009; Shekhar et al., 2015; Kumar et al., 2015; Almasri, 2008; Al-Adamat et al., 2003). At present scenario, groundwater is highly influenced by anthropogenic activities (Neshat et al., 2014). Hence, researchers have modified DRASTIC model by adding others parameter like LULC, lineaments etc. (Neshat et al., 2014).

Now a day's several researchers have continued to enhance the model with different methods such as by incorporating a multi-criteria decision analysis technique. Analytical hierarchy process (AHP) is one of the most commonly utilized multi-criteria decision methods (Awasthi and Satyaveer, 2011). Multi-criteria decision methods involve the assessment of a given alternatives by a group of decision makers based on a selected set of criteria. AHP is a decision support model that requires the summation of certain weights on a given level of the decision (Beynon et al., 2000). AHP involves the construction of a series of pair-wise comparison matrices, which compare the criteria to one another. Comparison is performed to estimate a rating or weight for each criteria; this rating describes the extent of the contribution of each criteria to the overall objective. Saaty's scale of 1 to 9 plays a key role in the implementation of AHP (Saaty and Vargas, 1991). The scale is coupled with the experience and knowledge of experts or users to determine the factors or criteria affecting the decision process (HO, 2008; Dweiri and Al-Oqla, 2006).

AHP is capable of capturing both subjective and objective evaluation measures and providing a useful mechanism to check the consistency of the evaluation measures and alternatives suggested by experts or decision makers, thereby reducing bias in decision making (Ariff et al., 2008). In present study, Groundwater pollution vulnerability assessment was carried out using modified DRASTIC model and analytical hierarchy process (AHP) techniques in Raipur City, Chhattisgarh, India.

STUDY AREA

Raipur is divisional, and district headquarter, and it is culturally, educationally and economically forward town in the state of Chhattisgarh. Raipur city is situated in western part of Raipur district, Chhattisgarh, India. Study area is confined between longitude 81°35' to 81°40' and latitudes 21°10' to 21°20' under Survey of India (SOI) toposheet no. 64 G/11 and 64G/12 encompassing approximately 151.41 km^2 geographical area. Location map of the study area is shown in Fig. 1. Raipur has a tropical wet and dry climate, temperatures remain moderate throughout the year, except from March to June, which can be extremely hot. The temperature in April to May reaches up to 48 °C and temperature lower down up to 10°C during winters last from November to January.

MATERIAL AND METHODOLOGY

In this study to evaluate the DRASTIC model various data were used, which are given in Table 1. A systematic methodology adopted to carry out present study as shown in Fig.2.

DRASTIC model is based on numerical system, which contains weights, ranges and ratings. A detail of method adopted is explained below.

Weights and Ratings

Seven layers involved in DRASTIC model in which weight and rating were assigned to each parameter according to their importance

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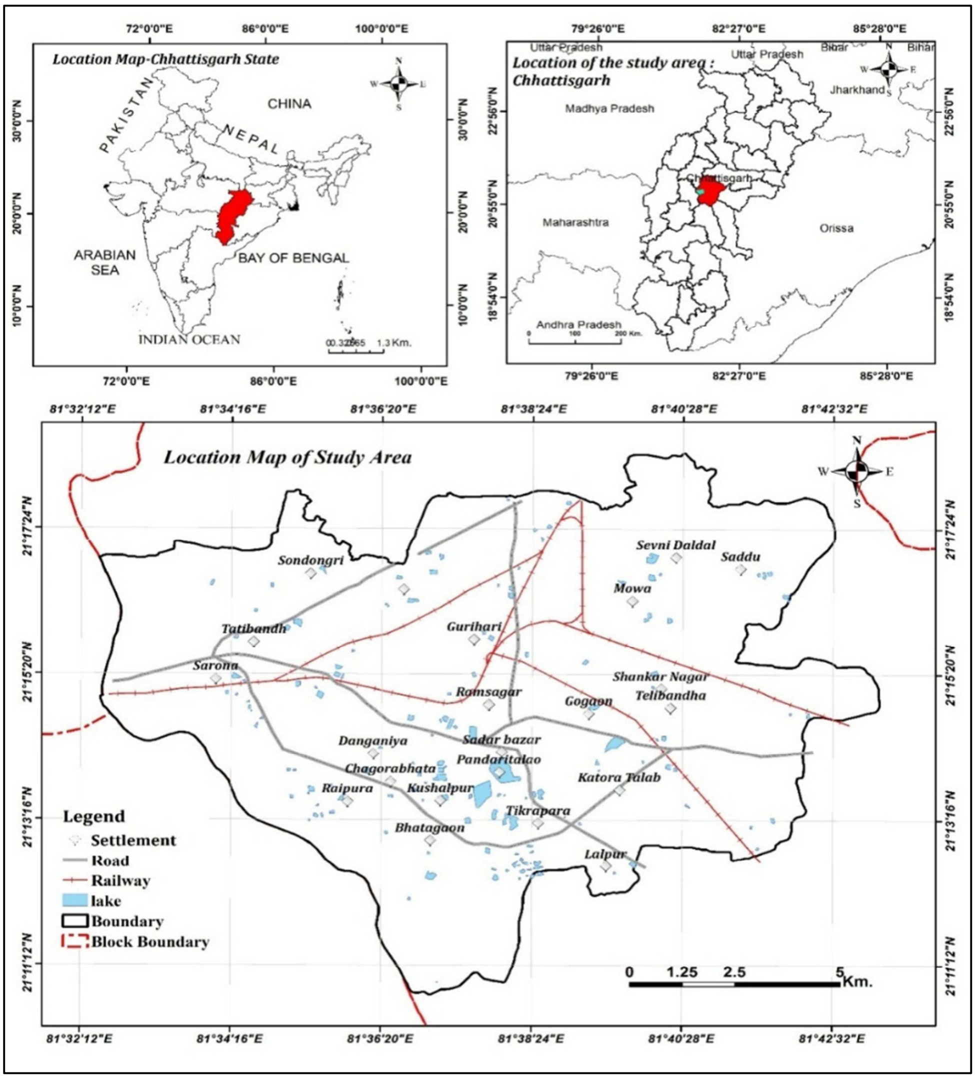


Fig.1. Location map of the study area.

(Sener and Davrez, 2013). In this study each parameter has been classified into ranges and rated 1 to 10 scales according to their relative importance (Sener and Davrez, 2013; Wu et al., 2014; Eskandari et al., 2016). After, that each layers has been assigned weight 1 to 5 on the basis of their importance in determining the groundwater vulnerability (Sener and Davrez, 2013; Fortin et al., 1997; Hammouri et al., 2014).

Table 1. Utilized data and their source.

S. No.	Data	Source
1.	Toposheet no. 64G/11 and G/12 on scale of 1:50,000.	Survey of India (SOI), Government of India.
2.	Geological Data (Published geological map on 1:50.000 scale)	Geological Survey of India (GSI), Raipur Chhattisgarh, Government of India.
3.	Hydrogeological Data	Central Ground Water Board (CGWB), NCCR, Raipur, Government of India.
4.	Cartosat-1-Digital Elevation Model (DEM) with spatial resolution 30m.	Downloaded from Bhuvan website (http:/bhuvan.nrsc.gov.in), NRSC, Government of India.
5.	Soil data	Chhattisgarh Infotech Promotion Society (CHIPS), Raipur, Government of Chhattisgarh.
6.	Satellite (LANDSAT 8 OLI/TIRS C1 Level 2 satellite image with spatial resolution 15m. panchromatic and 30m. multispectral resolution)	Downloaded from USGS website (www.earthexplorer.com).
7.	Rainfall Data	India Meteorological Department (IMD), Government of India.

The DRASTIC vulnerability index was calculated by adding the products of weights and rating using following equation (Eq. 1):

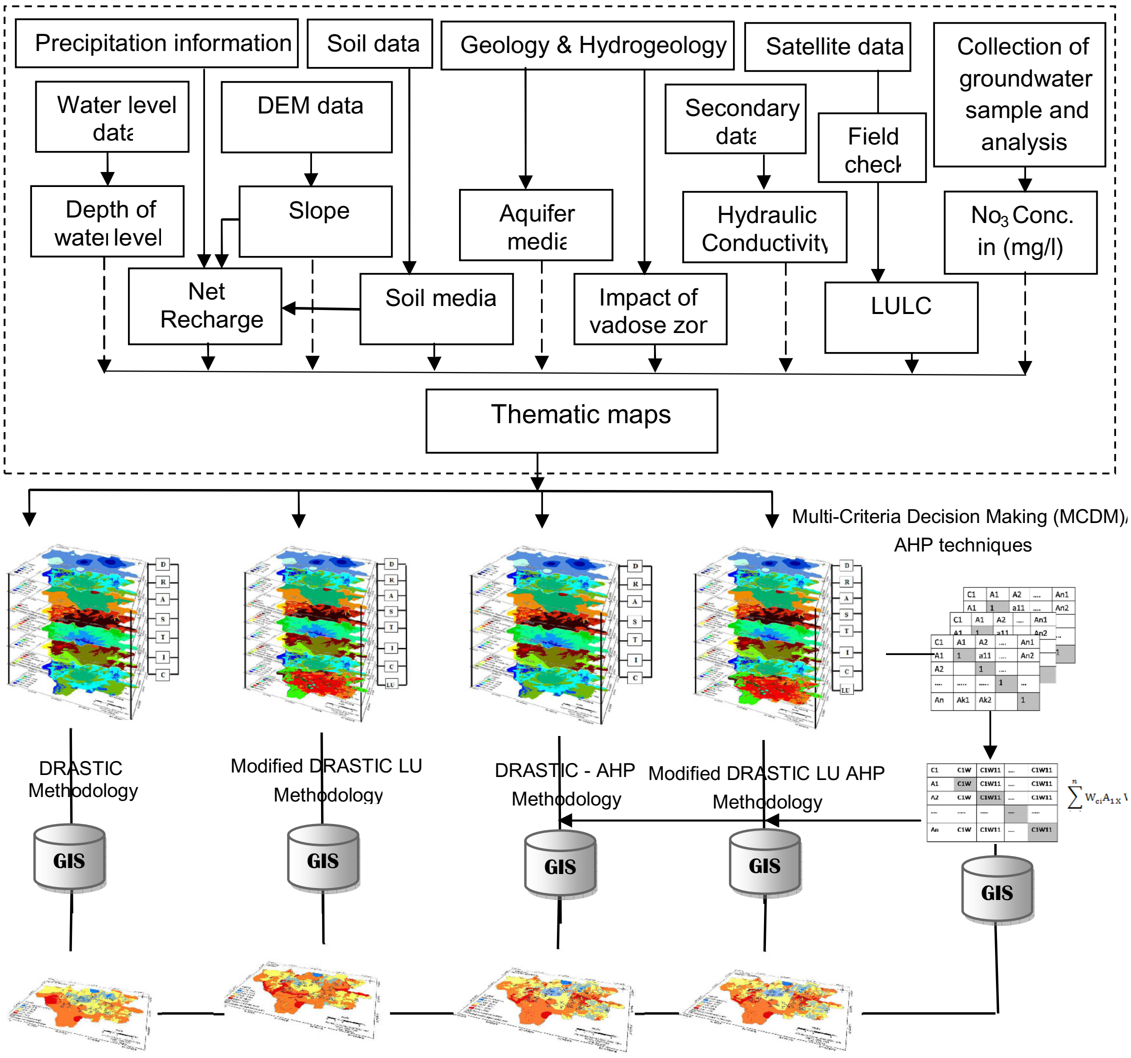
$$DVI= DrDw+RrRw+ArAw+SrSw+TrTw+IrIw+CrCw \quad (1)$$

Where 'D' is depth to water level, 'R' is net recharge, 'A' is aquifer media, 'S' is soil, 'T' is topography, 'I' is impact of vadose zone and 'C' is hydraulic conductivity. And subscripts '*r*' and '*w*' stand for ratings and weights (Sener and Davrez, 2013).

After that land use land cover (LULC) parameter was added to modify the DRASTIC model as Modified DRATIC-Lu model. And, accordingly rating and weight assign to LULC as per its importance.

In present study, analytical hierarchy process (AHP) technique was also used to determine the weight and rating. AHP technique is a powerful tool to determine the rating and weight (Sener et al., 2010). In this method pairwise- comparison matrix was developed and this makes the decision makers to evaluate the objective independently, to simplify the decision making process (Sener and Davrez, 2013; Eskandri et al., 2016). The consistency of the matrix of order 'n' was then evaluated, if this not reached to a threshold level, then the comparisons were re-examine (Dengiz et al., 2015). The consistency index, CI, was calculated using equation as given below (Eq. 2):

$$CI = \lambda_{max} - n/n-1 \quad (2)$$



Correlation and Validation of the vulnerability of Groundwater Nitrate Concentrations.

Fig.2. Methodology flow-chart adopted to carry out present study.

Where CI is the consistency index, 1 max is the largest or principal Eigen value of the matrix, and n is the order of the matrix (Sener et al., 2010; Sener and Davrez, 2013). This CI compared with random matrix (RI) to get the ratio of CI/ RI, is the consistency ratio, CR. As a rule, CR≤0.1 should be maintained for the matrix to be consistent (Sener and Davrez, 2013). In the present study, consistency ratio for DRASTIC-AHP model is 0.025 and for Modified DRASTIC-Lu AHP model is 0.027, which means matrix maintained consistent.

In this way four model were prepared such as DRASTIC, DRASTIC-AHP, Modified DRASTIC-Lu and Modified DRASTIC-Lu AHP. The vulnerability maps were prepared in ArcGIS software using overlay analysis and also validated and compared accuracy using Nitrate concentration of 50 bore wells.

RESULT AND DISCUSSION

In this study to determine the groundwater pollution vulnerability, different parameters were used which are discussed below:

Depth to water level: Depth of water level is the distance from the ground surface to the saturation zone which influences the movement of contaminates towards aquifer. In the present study groundwater data of May 2016 was collected from CGWB and groundwater level map prepared using ArcGIS software. In this study, it is found that in the study area depth of groundwater level ranges between 3-41 m. bgl. (Fig. 3).

Net recharge: Net recharge represent the quantity of water that infiltrate from the ground surface and reaches to the zone of saturation. To prepare this map different data are required like slope, rainfall and soil permeability (Al-Rawabdeh, 2007), with the help of these data net recharge map was prepared in GIS environment using tool overlay analysis as shown in Fig. 4.

Recharge value = Slope%+ Rainfall + Soil permeability

Aquifer media: Aquifer has an ability to transmit and yield sufficient amount of water to well/spring. Geogenic contamination is mainly depend on the type of aquifer media. Now a day's aquifers are also affected by anthropogenic activity (Srinivasamoorthy et al., 2011; Anane et al., 2013). Aquifer media map was prepared using data collected from CGWB, Raipur in ArcGIS software as shown is Fig.5.

Soil Media: Soil is one of the important parameter for determining the groundwater contamination (Shekar et al., 2015). In the present study, soil map has been prepared by soil data collected from Chhattisgarh Promotion Infotech Society (CHIPS), Raipur using ArcGIS software (Fig.6.).

Topography: Topography is variation in slope (Nasher, 2007). If slope is less then chances of groundwater contamination is high. Slope map of the study area (Fig.7) is derived from digital elevation

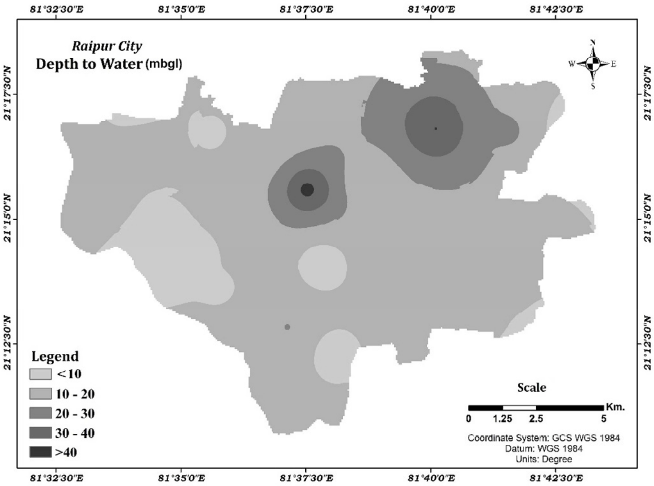


Fig.3. Depth to water level map.

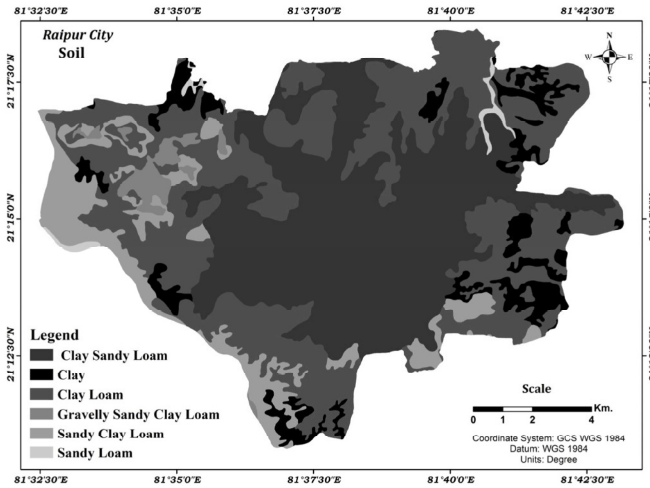


Fig.6. Soil media map.

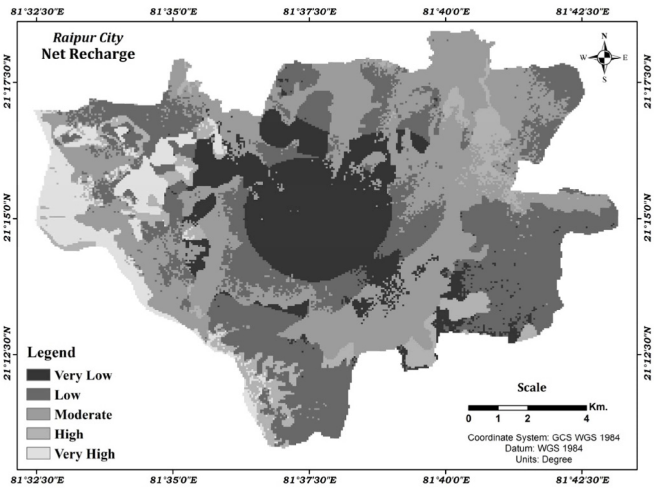


Fig.4. Net recharge map.

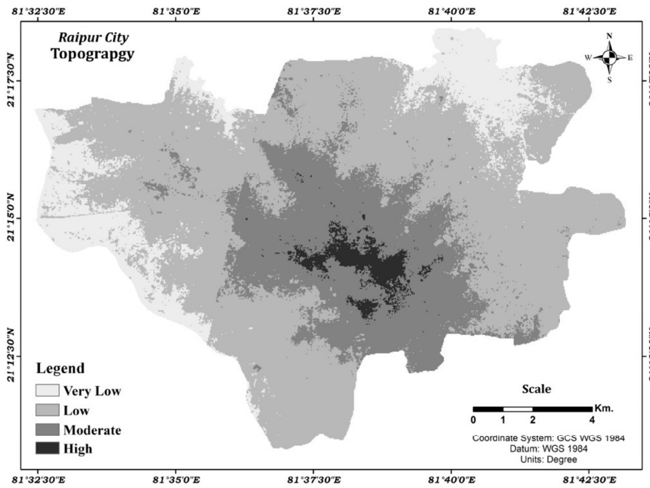


Fig.7. Topography.

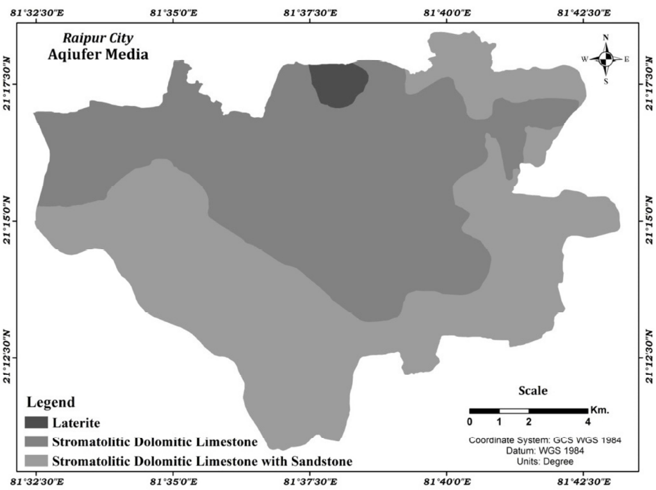


Fig.5. Aquifer media map.

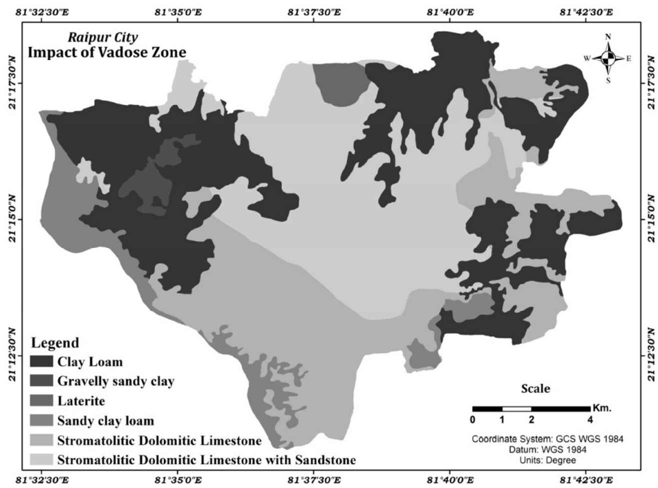


Fig.8. Impact of vadose zone map.

model (DEM) (Anane et al., 2013). Major part of the study area, has low slope, indicating more chances of groundwater contamination (Krishnaraj et al., 2010).

Impact of Vadose Zone: Water which recharges the aquifer first percolates from vadose zone. Hence, vadose zone plays an important role in the quantity and quality of groundwater. In the present study the impact of vadose zone map was prepared using borehole data collected from GSI and CGWB using ArcGIS software (Fig.8).

Hydraulic Conductivity: Hydraulic conductivity is the measures of the flow rate of fluid (Ahmed, 2009; Das et al., 2017). It also controls the rate of contamination (Shirazi et al., 2013). Hydraulic conductivity map of the study area was prepared using data collected from the CGWB with the help of ArcGIS software (Fig.9).

Land Use Land Cover (LULC): To prepare LULC map of Raipur city, satellite image of year 2016 visually interpreted in ArcGIS software. In this study different image interpretation elements like

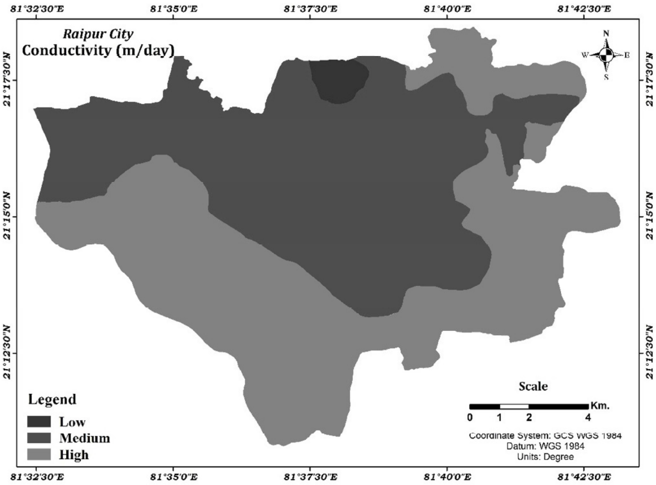


Fig.9. Hydraulic conductivity map.

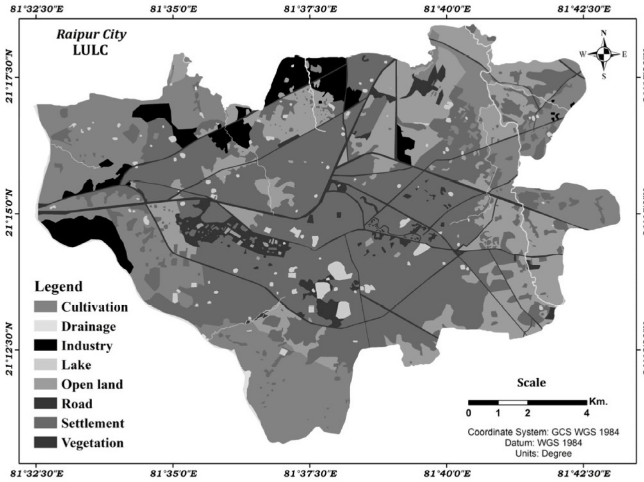


Fig.10. Land Use Land Cover (LULC) map.

tone, texture, size and pattern were used and interpreted image verified with field check. The LULC map is classified into eight classes such as settlement, road, cultivation, industry, drainage, lake, open land and vegetation (Fig.10).

After, preparing all thematic layers, ratings and weights were assigned to each parameter according to the guidelines given by US EPA for DRASTIC model, and also considering the hydrogeological condition of the study area. In this study to determine the groundwater vulnerable index, AHP method was also used to determine the rating coefûcients of each parameter of DRASTIC AHP model and Modiûed DRASTIC-Lu AHP model. This method was used to compute the ratings and weight of all parameters used in the models in order to change the initial weight factors participating in assessing the vulnerability equation. The weights of speciûc criteria were established by ranking their importance and suitability (Sener et al., 2010).

The rating and weights to each parameter of DRASTIC, Modified DRASTIC-Lu, DRASTIC AHP and Modified DRASTIC-Lu AHP model for groundwater vulnerability index was given in Table 2.

Classification of DRASTIC Vulnerability Index Classes

To classify the different DRASTIC classes, the vulnerability indexes were presented based on the classification scheme introduced by Al-Adamat et al., 2003. In this method, the GIS coverage (Figs. 3-10) are in raster format and values for each layer were summed in ArcView GIS using overlay tool according to the pixel value that resulted from multiplying the ratings with its appropriate DRASTIC weight (Table 2).

Since that the minimum possible DRASTIC index using these parameters is 86 and the maximum is 212, for DRASTIC-AHP minimum possible index is 16.27 and maximum is 37.04, for Modified DRASTIC-Lu minimum possible index is 10 and maximum is 257 and for Modified DRASTIC-Lu AHP model minimum possible index is 16.27 and maximum is 37.04. These classes were divided into five equal classes using equal interval tool in ArcGIS software and classify into five classes such as Very low, low, moderate, high and very high as shown in Figs. 11-14.

Assessment of Groundwater Vulnerability using DRASTIC Model

In real DRASTIC method, seven hydrogeological parameter such as depth to water level, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity were considered to determine groundwater vulnerability index (Sener and Davraz, 2013).

The rating and weight of each parameter are given in Table 1. DRASTIC vulnerability map was prepared using overlay analysis of seven hydrogeological parameter maps as discussed above (Fig.11). The DRASTIC vulnerability index was calculated according to equation 1 and found it is ranging between 86 to 212. According to the result of the groundwater vulnerability map DRASTIC map is classified into five classes i.e. very low, low, moderate, high and very

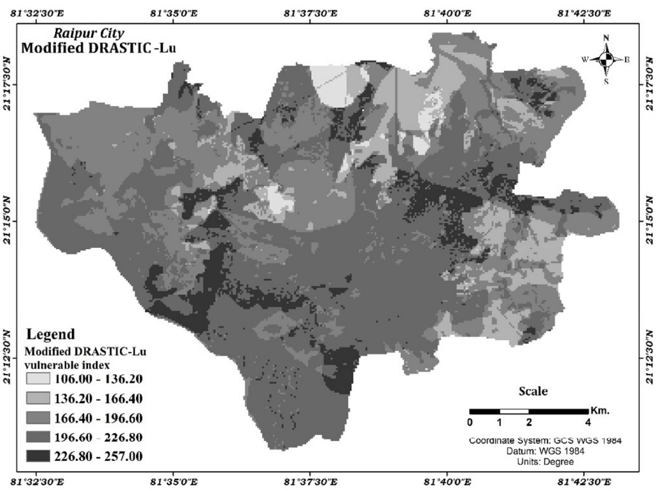


Fig.11. DRASTIC groundwater vulnerable map.

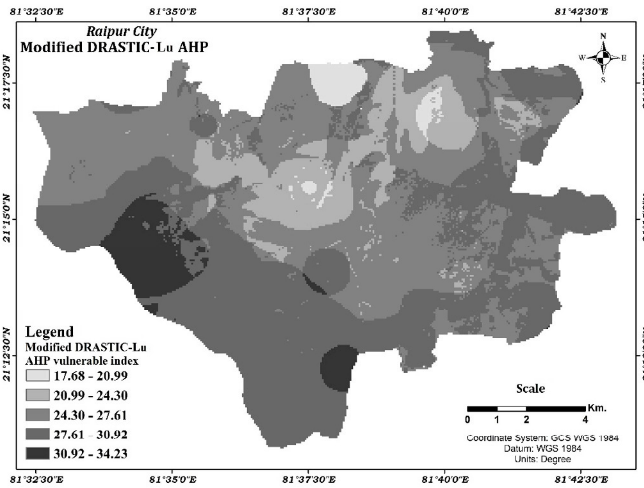


Fig.12. DRASTIC-AHP groundwater vulnerable map.

Table 2. Rating and weights of each parameter of DRASTIC, Modified DRASTIC-Lu, DRASTIC AHP and Modified DRASTIC-Lu AHP models for groundwater vulnerability index.

S. No.	Parameters	Sub-Parameter	DRASTIC		DRASTIC -AHP		Modified DRASTIC-Lu		Modified DRASTIC-Lu AHP	
			Rating	Weight	Rating	Weight	Rating	Weight	Rating	Weight
1	Groundwater depth (m)	0 - <10	10	5	0.502	0.218	10	5	0.502	0.191
		10 - <20	7		0.335		7		0.335	
		20 - <30	5		0.239		5		0.239	
		30 - <40	3		0.101		3		0.101	
		>40	1		0.033		1		0.033	
2	Net recharge	Very High	10	4	0.255	0.2	10	4	0.255	0.143
		High	9		0.235		9		0.235	
		Medium	8		0.23		8		0.23	
		Low	6		0.181		6		0.181	
		Very low	2		0.081		2		0.081	
3	Aquifer media	Stromatolitic Dolomitic Limestone with Sandstone	10	3	0.562	0.159	10	3	0.562	0.103
		Stromatolitic Dolomitic Limestone	9		0.421		9		0.421	
		Laterite	1		0.019		1		0.019	
4	Soil media	Sandy loam	4	3	0.313	0.0552	4	3	0.313	0.083
		Gravelly sandy clay loam	3		0.15		3		0.143	
		Sandy clay loam	2		0.143		2		0.15	
		clay sandy loam	2		0.125		2		0.125	
		Clay loam	2		0.121		2		0.121	
		clay	1		0.108		1		0.108	
5	Topography	very low	10	1	0.328	0.0507	10	1	0.328	0.074
		Low	9		0.287		9		0.287	
		Moderate	8		0.267		8		0.267	
		High	7		0.121		7		0.121	
6	Impact of Vadose	Stromatolitic Dolomitic Limestone with Sandstone	9	5	0.209	0.214	9	5	0.209	0.163
		Stromatolitic Dolomitic Limestone	8		0.197		8		0.197	
		Gravelly sandy clay loam	3		0.17		3		0.17	
		Sandy clay loam	3		0.137		3		0.137	
		Laterite	2		0.124		2		0.124	
		Clay loam	1		0.122		1		0.122	
7	Hydraulic conductivity (m/day)	0.80 m/day	9	4	0.565	0.102	9	4	0.565	0.081
		0.60 m/day	8		0.39		8		0.39	
		0.000864 m/day	1		0.045		1		0.045	
8	LULC	Settlement					9	5	0.162	0.266
		Road					8		0.153	
		Cultivation					7		0.146	
		Industry					6		0.144	
		Lake					5		0.146	
		Drainage					4		0.137	
		Open land					3		0.131	
		Vegetation					2		0.126	

high and it is observed that 2.83%, 7.57%, 32.03%, 47.78% and 9.8% areas are respectively falling under Very low, low, moderate, high and very high groundwater vulnerable DRASTIC index classes as shown in Table 3.

Assessment of Groundwater Vulnerability using DRASTIC-AHP Model

To determine the rating and weight of each DRASTIC parameter AHP techniques was used. In this method the pairwise comparison matrix was prepared for the seven parameter. The determined rating and weight are given in Table 1. DRASTIC-AHP vulnerability map was prepared using overlay analysis in GIS environment (Fig.12). The obtained vulnerability index value is ranging between 16.27 to 37.04. DRASTIC-AHP vulnerability map, 3.27%, 16.63%, 47.14%, 74.44% and 9.96% area are respectively falling under very low, low, moderate, high and very high vulnerable DRASTIC-AHP index classes as shown in Table 3.

Assessment of Groundwater Vulnerability using Modified-DRASTIC-Lu Model

In this study, LULC added to modify the original DRASTIC to develop Modified DRASTIC-Lu model. Where Lu stand for LULC. Modified-DRASTIC-Lu map was prepared using ArcGIS software by overlay analysis technique (Fig.13) and it is observed that vulnerability index value is ranging between 106 to 257. According, to the modified-DRASTIC-Lu vulnerability map, 2.56%, 10.96%, 30.10%, 47.47% and 8.9% areas are respectively falling under very low, low, moderate, high and very high vulnerable Modified DRASTIC-Lu index classes as shown in Table 3.

Assessment of Groundwater vulnerability using Modified-DRASTIC-AHP model

In this method to modified-DRASTIC-Lu model AHP method was used to determine rating and weights to each parameter. In this method the pairwise comparison matrix was prepared for the eight parameter.

Table 3. Groundwater vulnerable calculated area for different DRASTIC models.

S. No.	DRASTIC Vulnerable Index	DRASTIC			DRASTIC - AHP			Modified DRASTIC LU			Modified DRASTIC LU - AHP		
		DRASTIC Index	Area (sq.km)	Area (%)	DRASTIC Index	Area (sq.km)	Area (%)	DRASTIC Index	Area (sq.km)	Area (%)	DRASTIC Index	Area (sq.km)	Area (%)
1	Very Low	86 - 111.2	4.29	2.83	16.27 - 20.42	3.27	2.16	106 - 136.2	3.88	2.56	17.68 - 20.99	4.16	2.75
2	Low	111.2 - 136.4	11.46	7.57	20.42 - 24.57	16.63	10.98	136.2 - 166.4	16.6	10.96	20.99 - 24.30	18.59	12.28
3	Moderate	136.4 - 161.6	48.5	32.03	24.57 - 28.73	47.14	31.13	166.4 - 196.6	45.58	30.10	24.30 - 27.61	57.79	38.17
4	High	161.6 - 186.8	72.35	47.78	28.73 - 32.88	74.44	49.16	196.6 - 226.8	71.88	47.47	27.61 - 30.92	62.84	41.50
5	Very High	186.8 - 212	14.86	9.83	32.88 - 37.04	9.96	6.58	226.8 - 257	13.59	8.98	30.92 - 34.23	8.07	5.33

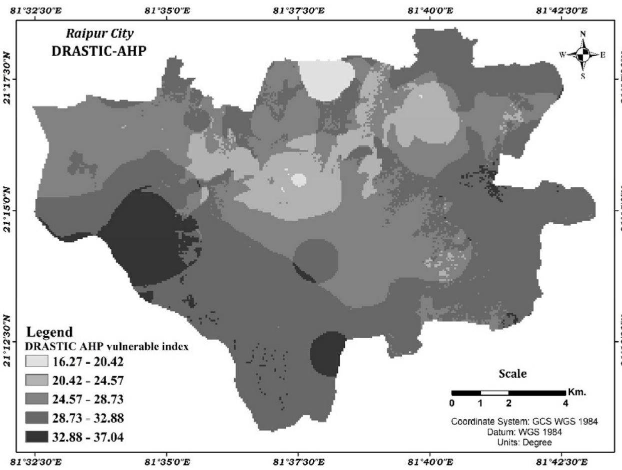


Fig.13. Modified DRASTIC- Lu groundwater vulnerable map.

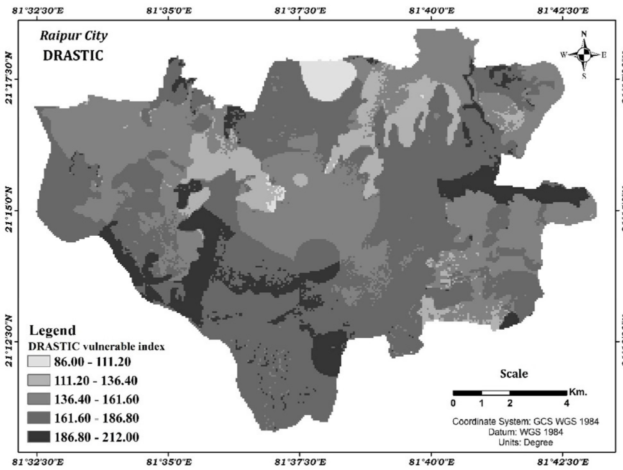


Fig.14. Modified DRASTIC- Lu AHP groundwater vulnerable map.

The rating and weight are given in Table 2. This Modified DRASTIC-Lu AHP vulnerability map was prepared by overlay analysis using ArcGIS software (Fig.14). The obtained vulnerability index value is ranges between 16.27 to 37.04. DRASTIC-AHP vulnerability map, 2.74%, 12.27%, 38.16 %, 41.5% and 5.3% area is fall under Very low, low, moderate, high and very high vulnerable Modified DRASTIC- Lu AHP DRASTIC index classes as shown in Table 3.

Accuracy Assessment of the Developed DRASTIC Models

To determine the accuracy of the adopted methods nitrate concentration of pre-monsoon (May, 2016) and post-monsoon (Nov, 2016) of 50 wells were used. In present study nitrate concentration in pre-monsoon season is ranges from 10.2 mg/l. to 124.2 mg/l. and in post-monsoon seasons it ranges from 5.3 mg/l. to 72.2 mg/l. To assess accuracy of the developed DRASTIC

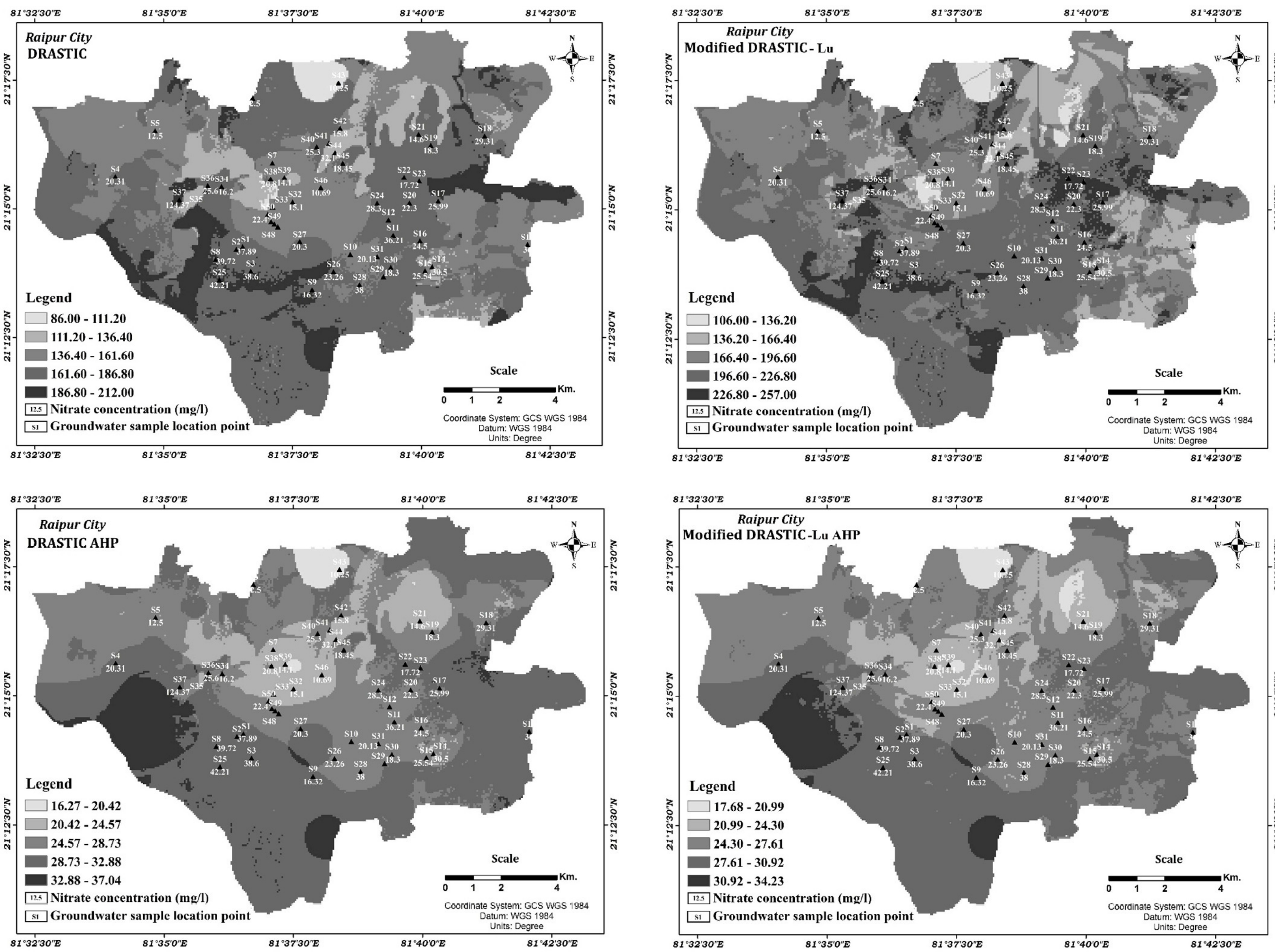


Fig.15. . Accuracy assessment of **(a)** DRASTIC, **(b)**Modified DRASTIC-Lu, **(c)** DRASTIC AHP and **(d)** Modified DRASTIC-Lu AHP vulnerable index map using pre-monsoon season Nitrate concentration.

Table 4. Accuracy assessment for DRASTIC, Modified DRASTIC-Lu, DRASTIC AHP and Modified DRASTIC-Lu AHP methods using pre-monsoon season Nitrate concentration.

S. No.	Coordinates		Sample number	Assessed Nitrate conc.(mg/l)	Expected DRASTIC vulnerable index from developed map	DRASTIC		DRASTIC-AHP		Modified DRASTIC-Lu		Modified DRASTIC-Lu AHP	
	X	Y				Obtained DRASTIC vulnerable index from developed map	Agreement between expected and obtained value	Obtained DRASTIC vulnerable index from developed map	Agreement between expected and obtained value	Obtained DRASTIC vulnerable index from developed map	Agreement between expected and obtained value	Obtained DRASTIC vulnerable index from developed map	Agreement between expected and obtained value
1	81.6089	21.23767	S1	27.18	moderate	high	Disagree	High	Disagree	Moderate	Agree	High	Disagree
2	81.60682	21.23678	S2	37.89	high	High	Agree	High	Agree	High	agree	High	Agree
3	81.61152	21.22981	S3	38.60	high	High	Agree	High	Agree	High	agree	High	Agree
4	81.56769	21.26044	S4	20.31	moderate	high	Disagree	High	Disagree	Moderate	Agree	High	Disagree
5	81.58054	21.27525	S5	12.50	Low	low	Agree	Moderate	Disagree	Moderate	Agree	Moderate	Disagree
6	81.61212	21.28586	S6	12.50	Low	high	Disagree	High	Disagree	High	Agree	Moderate	Disagree
7	81.6185	21.26484	S7	31.53	moderate	low	Disagree	Low	Disagree	Moderate	Agree	Low	Agree
8	81.60015	21.23362	S8	39.72	high	high	Agree	High	Agree	High	Agree	High	Agree
9	81.63136	21.22388	S9	16.32	moderate	high	Disagree	High	Disagree	Moderate	Agree	High	Disagree
10	81.64369	21.23522	S10	20.86	moderate	high	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
11	81.65606	21.24643	S11	18.26	moderate	high	Disagree	Moderate	Agree	Moderate	Agree	Moderate	Agree
12	81.70107	21.23842	S12	36.00	high	moderate	Disagree	High	Agree	Moderate	Disagree	High	Agree
13	81.67021	21.23128	S13	30.50	moderate	moderate	Agree	Moderate	Agree	High	Disagree	Moderate	Agree
14	81.66793	21.22994	S14	25.54	moderate	moderate	Agree	Moderate	Agree	High	Disagree	Moderate	Agree
15	81.66626	21.23958	S15	24.50	moderate	high	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
16	81.67215	21.25243	S16	25.99	moderate	moderate	agree	Moderate	Agree	Moderate	Agree	Moderate	Agree
17	81.6872	21.27352	S17	29.31	moderate	high	Disagree	Moderate	Agree	Moderate	Agree	Moderate	Agree
18	81.66977	21.27054	S18	18.30	moderate	high	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
19	81.66285	21.25187	S19	22.30	moderate	high	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
20	81.66581	21.27413	S20	14.60	Low	high	Disagree	Low	Agree	High	Disagree	Low	Agree
21	81.66114	21.26012	S21	28.31	moderate	high	Disagree	High	Disagree	Moderate	Agree	Moderate	Agree
22	81.66603	21.25894	S22	17.72	moderate	high	Disagree	Moderate	Agree	Very high	Disagree	Moderate	Agree
23	81.65241	21.25175	S23	28.30	moderate	high	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
24	81.60135	21.22706	S24	42.21	high	very high	Disagree	High	Agree	Very high	Disagree	High	Agree
25	81.63828	21.22967	S25	23.26	moderate	high	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
26	81.62732	21.23932	S26	20.30	moderate	high	Disagree	High	Disagree	High	Disagree	Moderate	Agree
27	81.64669	21.2255	S27	38.00	high	high	agree	Moderate	Disagree	High	Agree	Moderate	Disagree
28	81.65122	21.2264	S28	30.69	moderate	high	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
29	81.65446	21.22808	S29	23.66	moderate	moderate	agree	Moderate	Agree	High	Disagree	Moderate	Agree
30	81.65681	21.23105	S30	18.30	moderate	high	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
31	81.65245	21.23452	S31	20.13	moderate	moderate	Agree	Moderate	Agree	High	Disagree	Moderate	Agree
32	81.62504	21.25217	S32	15.10	moderate	moderate	Agree	Low	Disagree	Moderate	Agree	Low	Disagree
33	81.61864	21.25045	S33	10.20	Low	low	Agree	Low	Agree	moderate	Disagree	Low	Agree
34	81.60205	21.25709	S34	16.20	moderate	high	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
35	81.59858	21.25666	S35	51.03	very high	high	Disagree	High	Disagree	Very high	Agree	High	Disagree
36	81.59759	21.25741	S36	25.60	moderate	high	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
37	81.58837	21.25285	S37	124.37	Very high	very high	Agree	High	Disagree	Very high	Agree	High	Disagree
38	81.61815	21.25956	S38	20.80	moderate	moderate	Agree	Low	Disagree	low	Disagree	Low	Disagree
39	81.62241	21.26008	S39	14.10	Low	moderate	Disagree	Low	Agree	Moderate	Disagree	Low	Agree
40	81.63286	21.27004	S40	25.30	moderate	high	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
41	81.63677	21.2712	S41	18.16	moderate	high	Disagree	Moderate	Agree	High	Disagree	Moderate	agree
42	81.64043	21.27617	S42	15.80	moderate	moderate	Agree	Moderate	Agree	Moderate	Agree	Moderate	Agree
43	81.63991	21.29076	S43	10.25	Low	very low	Agree	very low	Disagree	very low	Disagree	very low	Disagree
44	81.63877	21.26813	S44	32.10	moderate	low	Disagree	Low	Disagree	Moderate	Agree	Low	Disagree
45	81.64129	21.26472	S45	18.45	moderate	high	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
46	81.63419	21.25674	S46	10.69	Low	moderate	Disagree	Low	Agree	Moderate	Disagree	Low	Agree
47	81.61808	21.24582	S47	30.20	moderate	moderate	Agree	Moderate	Agree	High	Disagree	Moderate	Agree
48	81.61895	21.24429	S48	20.11	moderate	moderate	Agree	Moderate	Agree	High	Disagree	Moderate	Agree
49	81.61857	21.2454	S49	15.04	moderate	moderate	Agree	Moderate	Agree	High	Disagree	Moderate	Agree
50	81.61759	21.24875	S50	22.40	moderate	moderate	Agree	Low	Disagree	Moderate	Agree	Low	Disagree

Table 5. Accuracy assessment for DRASTIC, Modified DRASTIC-Lu, DRASTIC AHP and Modified DRASTIC-Lu AHP methods using post-monsoon season Nitrate concentration.

S. No.	Coordinates		Sample number	Assessed Nitrate conc.(mg/l)	Expected DRASTIC vulnerable index from developed map	DRASTIC		DRASTIC-AHP		Modified DRASTIC-Lu		Modified DRASTIC-Lu AHP	
	X	Y				Obtained DRASTIC vulnerable index from developed map	Agreement between expected and obtained value	Obtained DRASTIC vulnerable index from developed map	Agreement between expected and obtained value	Obtained DRASTIC vulnerable index from developed map	Agreement between expected and obtained value	Obtained DRASTIC vulnerable index from developed map	Agreement between expected and obtained value
1	81.6089	21.23767	S1	39.72	High	High	Agree	High	Agree	High	Agree	High	Agree
2	81.6068	21.23678	S2	36.74	High	High	Agree	High	Agree	High	Agree	High	Agree
3	81.6115	21.22981	S3	42.15	High	High	Agree	High	Agree	High	Agree	High	Agree
10	81.5676	21.26044	S4	20.43	moderate	High	Disagree	High	Disagree	High	Agree	High	Disagree
11	81.5805	21.27525	S5	16.50	moderate	Moderate	Agree	Moderate	Agree	Low	Agree	Moderate	Agree
12	81.6121	21.28586	S6	25.06	moderate	High	Disagree	Moderate	Agree	High	Agree	Moderate	Agree
14	81.6185	21.26484	S7	31.32	moderate	Moderate	Agree	Low	Disagree	Moderate	Agree	Low	Disagree
17	81.6001	21.23362	S8	20.90	moderate	High	Disagree	High	Disagree	High	Disagree	High	Disagree
20	81.6313	21.22388	S9	18.20	moderate	High	Disagree	Moderate	Agree	High	Disagree	High	Disagree
28	81.6436	21.23522	S10	20.14	moderate	Moderate	Agree	Moderate	Agree	High	Disagree	Moderate	Agree
30	81.6560	21.24643	S11	18.54	Moderate	high	Disagree	Moderate	Agree	Moderate	Agree	Moderate	Agree
34	81.7010	21.23842	S12	40.12	High	Moderate	Disagree	High	Agree	Moderate	Disagree	High	Agree
36	81.6702	21.23128	S13	26.5	moderate	Moderate	Agree	Moderate	Agree	High	Disagree	Moderate	Agree
37	81.6679	21.22994	S14	43.72	High	Moderate	Disagree	Moderate	Disagree	High	Agree	Moderate	Disagree
41	81.6662	21.23958	S15	36.50	High	High	Agree	Moderate	Disagree	High	Agree	Moderate	Disagree
43	81.6721	21.25243	S16	16.76	moderate	Moderate	Agree	Moderate	Agree	Moderate	Agree	Moderate	Agree
44	81.6872	21.27352	S17	21.50	moderate	High	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
45	81.6697	21.27054	S18	23.05	moderate	High	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
46	81.6628	21.25187	S19	27.69	moderate	High	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
47	81.6658	21.27413	S20	13.39	low	High	Disagree	Low	Agree	High	Disagree	Low	Agree
48	81.6611	21.26012	S21	25.32	Moderate	High	Disagree	Moderate	Agree	Moderate	Agree	Moderate	Agree
49	81.6660	21.25894	S22	20.26	moderate	High	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
51	81.6524	21.25175	S23	20.00	moderate	High	Disagree	Moderate	Agree	High	Disagree	moderate	Agree
53	81.6013	21.22706	S24	35.65	High	Very high	Disagree	High	Agree	Very high	Disagree	High	Agree
57	81.6382	21.22967	S25	28.55	moderate	High	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
65	81.6273	21.23932	S26	21.30	moderate	High	Disagree	High	Disagree	High	Disagree	High	Disagree
66	81.6466	21.2255	S27	42.77	High	High	Agree	Moderate	Disagree	High	Agree	Moderate	Disagree
67	81.6512	21.2264	S28	40.65	High	High	Agree	Moderate	Disagree	High	Agree	Moderate	Disagree
68	81.6544	21.22808	S29	28.87	moderate	Moderate	Agree	Moderate	Agree	High	Disagree	Moderate	Agree
69	81.6568	21.23105	S30	21.09	moderate	High	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
71	81.6524	21.23452	S31	29.90	moderate	Moderate	Agree	Moderate	Agree	High	Disagree	Moderate	Agree
72	81.6250	21.25217	S32	40.28	High	Moderate	Disagree	Low	Disagree	Moderate	Disagree	Low	Disagree
73	81.6186	21.25045	S33	15.20	moderate	Moderate	Agree	Low	Disagree	Moderate	Agree	Low	Disagree
76	81.6020	21.25709	S34	28.27	moderate	High	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
77	81.5985	21.25666	S35	15.12	moderate	High	Disagree	High	Disagree	Very high	Disagree	Moderate	Agree
78	81.5975	21.25741	S36	16.38	moderate	High	Disagree	Moderate	Agree	Moderate	Agree	Moderate	Agree
79	81.5883	21.25285	S37	72.21	Very high	Very high	Agree	High	Disagree	Very high	Agree	High	Disagree
83	81.6181	21.25956	S38	24.80	moderate	Moderate	Agree	Low	Disagree	Moderate	Agree	Low	Disagree
84	81.6224	21.26008	S39	22.30	moderate	Moderate	Agree	Low	Disagree	Moderate	Agree	Low	Disagree
86	81.6328	21.27004	S40	29.35	moderate	High	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
89	81.6367	21.2712	S41	20.53	moderate	High	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
90	81.6404	21.27617	S42	36.34	High	Moderate	Disagree	Moderate	Agree	High	Agree	Moderate	Agree
91	81.6399	21.29076	S43	18.30	moderate	Very low	Disagree	very Low	Disagree	Low	Disagree	Very low	Disagree
93	81.6387	21.26813	S44	38.02	High	Low	Disagree	Low	Disagree	Moderate	Disagree	Low	Disagree
94	81.6412	21.26472	S45	25.26	moderate	High	Disagree	Moderate	Agree	High	Disagree	Moderate	Agree
95	81.6341	21.25674	S46	11.20	low	Moderate	Disagree	Low	Disagree	Moderate	Disagree	Low	Disagree
96	81.6180	21.24582	S47	12.40	low	Moderate	Disagree	Moderate	Disagree	High	Disagree	Moderate	Agree
97	81.6189	21.24429	S48	20.92	Moderate	Moderate	Agree	Moderate	Agree	Moderate	Agree	Moderate	Agree
98	81.6185	21.2454	S49	25.13	moderate	Moderate	Agree	Moderate	Agree	High	Disagree	Moderate	Agree
99	81.6175	21.24875	S50	25.61	moderate	Moderate	Agree	Moderate	Agree	High	Disagree	Moderate	Agree

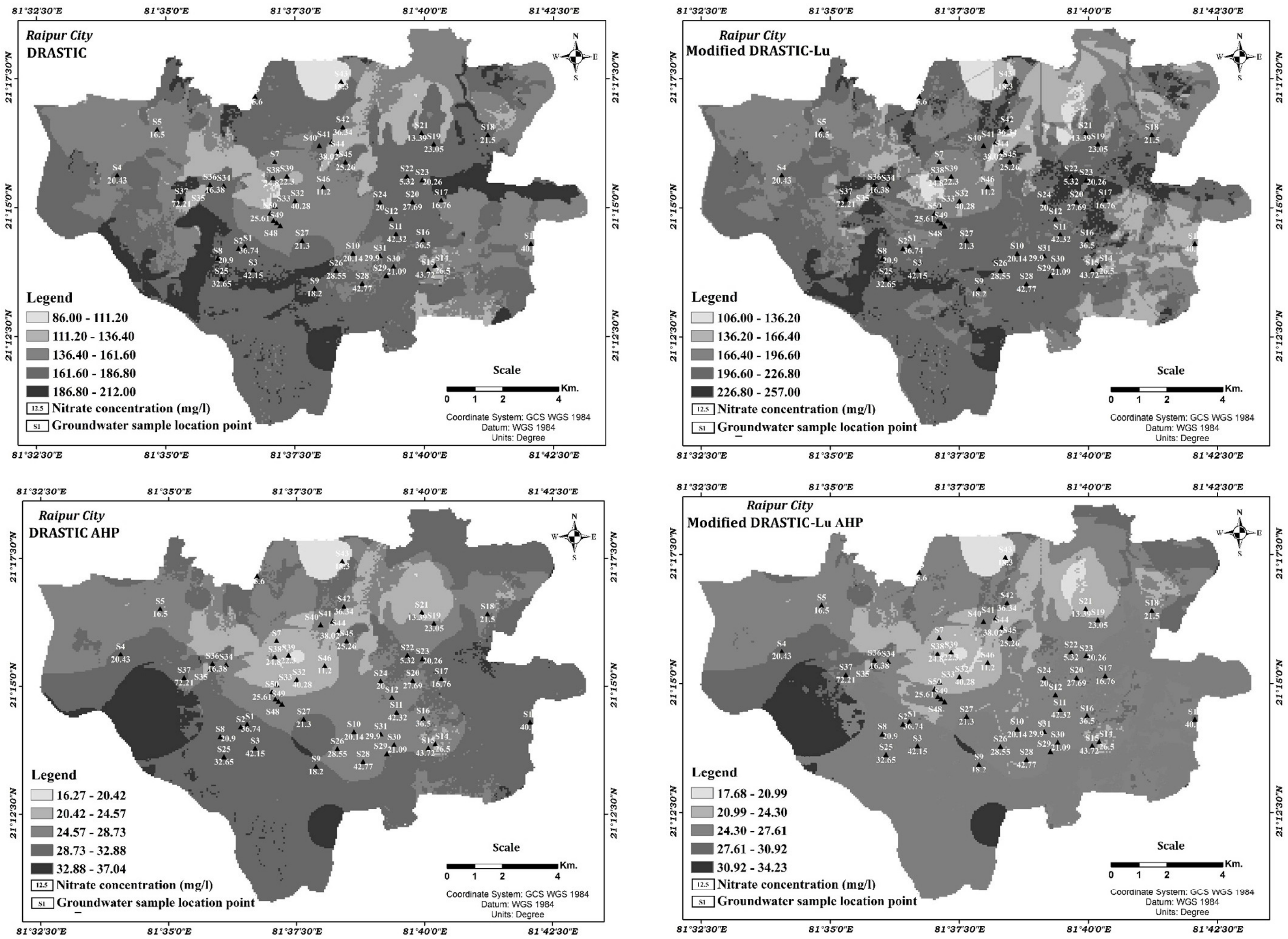


Fig.16. Accuracy assessment of **(a).** DRASTIC, **(b).** Modified DRASTIC-Lu, **(c).** DRASTIC AHP and **(d).** Modified DRASTIC-Lu AHP vulnerable index map using post-monsoon season Nitrate concentration.

models. Nitrate concentration of the study area classified into different classes such as very low (<10 mg/l.), low (10 mg/l. to 15 mg/l.), moderate (15 mg/l. to 40 mg/l.), high (40 mg/l. to 50 mg/l.) and very high (>50 mg/l.).

In this study both seasons nitrate concentrations of different wells were overlay on DRASTIC, Modified DRASTIC-Lu, DRASTIC AHP and Modified DRASTIC-Lu AHP vulnerable index map as shown in Fig.15 (a, b, c and d) and Fig. 16 (a, b, c and d) to see the accuracy. After that, agreement between expected vulnerable index of developed maps and actual nitrate concentration calculated as shown in Table 4 and Table 5.

In this study it is found that, as the DRASTIC models was modified its accuracy is also increases and on applying AHP technique for determining the rating and weights of each parameter the result was improved and accuracy was also increased (Table 6).

CONCLUSION

In present study it is observed that in the Raipur city different areas like Sarona, Tatibandh, Mowa, Deen Dayal Upadhyay Nagar, Dagniya, Sundar Nagar, Changourabhatta, Kankali Para, Brahman Para, Ashwini Nagar, Purani Basti, Kushalpur, Mathpara, Tikrapara, Bhatagaon, Sanjay Nagra, Pachpedi Naka, Lalpur, Amlidih, Shankar Nagar, Anupam Nagar, Gondwara and Rajeev Nagar. In which Sarona, Mathpurena and Kankali para are coming under highly vulnerable areas. During field works it is also observed that in Sarona village, solid waste is being dumping improperly which is near to Kharun river which need to stop. Other Areas which also needed attentions are such as Katora talab, Byron Bazar, Raipura, Siddharth Chowk, Pacpedi naka, Telibandha, Samta colony, Choubey colony. In this study it is found that WRS colony, Daldal Seoni, Ramnagar, Amanaka, Gudhiyari Srinagar are safe areas. This study reflecting that

Table 6. Predicted accuracy of different DRASTIC models.

S. No.	Adopted Models	Pre-monsoon period			Post-monsoon period		
		Agreement between expected and obtained value of DRASTIC vulnerable index map with Nitrate concentration	Disagreement between expected and obtained value of DRASTIC vulnerable index map with Nitrate concentration	Predicted accuracy (%)	Agreement between expected and obtained value of DRASTIC vulnerable index map with Nitrate concentration	Disagreement between expected and obtained value of DRASTIC vulnerable index map with Nitrate concentration	Predicted accuracy (%)
1	DRASTIC	20	30	40	20	30	40
2	Modified DRASTIC-Lu	21	29	42	21	29	42
3	DRASTIC-AHP	34	16	68	32	18	64
4	Modified DRASTIC -Lu AHP	37	13	74	33	28	66

anthropogenic activities are the main cause of groundwater pollution in the study area.

Acknowledgement: The authors are thankful to the Central Ground Water Board, Raipur, Chhattisgarh and Geological Survey of India (GSI), Raipur for providing valuable data to pursue present study. Authors are also grateful to the Chhattisgarh Council of Science and Technology (CGCOST), Raipur, Chhattisgarh for their laboratory facility to carried-out the chemical analysis of groundwater samples.

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(Received: 29 November 2017; Revised form accepted: 17 April 2018)