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Groundwater Vulnerability Assessment using SINTACS Model and GIS in Raipur and Naya Raipur, Chhattisgarh, India

Shweta Kumari[1*], Ramakar Jha[1], Vivekanand Singh[1], Klaus Baier[2] and M. K. Sinha[2]

[1]Department of Civil Engineering, NIT, Patna - 800005, Bihar, India;
shwetasingh7892@gmail.com, rjha43@gmail.com, vsingh@nitp.ac.in
[2]Department of Engineering Geology and Hydrogeology, RWTH Aachen University, Germany;
baier@lih.rwth-aachen.de,manishsinha200389@gmail.com

Abstract

Objectives: This study aims at the vulnerability assessment of groundwater in Raipur and Naya Raipur, Chhattisgarh, India, and to identify areas where vulnerability of groundwater to contamination is the most. **Methods:** A vulnerability map has been developed using SINTACS model in order to identify areas where vulnerability of groundwater to contamination is the most. In this analysis, vulnerability index is calculated by considering different hydrogeological parameters such as water table depth, net recharge, unsaturated conditions, soil media, aquifer media, hydraulic conductivity and topographic slope. All the parameters used in this study have been prepared, classified, weighted and integrated in a Geographic Information System (GIS) environment. **Findings:** The value of vulnerability index estimated lies between 121 to 176.Further, result shows that out of total area, 0.26% of the area indicates very low vulnerability 11.58% indicates low vulnerability 81.35% indicates moderate vulnerability and 6.81% of area indicates high vulnerability. It means majority of the study area exhibit moderate vulnerability. The study produces an effective tool for local authorities who manage and monitor the ground water resources. **Novelty:** This paper deals with a new approach towards vulnerability assessment. Instead of the conventional statistical methods, this work uses the SINTACS method which is a much improved method and hence provides much more probable values of vulnerability indices than those obtained from DRASTIC methods.

Keywords: GIS, Groundwater, SINTACS Model, Vulnerability

1. Introduction

About one-fifth of the total fresh water supply available in the world is found as groundwater. This fact makes it a valuable resource as it can act as a natural storage, buffering against shortages of surface water, asintimes of drought. It is not unlimited source and hence has to be managed against excessive exploitation and contamination. Raipur and Naya-Raipur both are the highly populated and urbanized areas of Chhattisgarh. India has been facing the severe problem of water pollution as about 70% of resources of surface water and a considerably large number of reserves of GW have already been contaminated by organic, inorganic, and biologicalpollutants[1]. Ground water is preferred to surface water due to its lesser vulnerability to contamination. Groundwater vulnerability is the tendency of, or probability for, contaminants to reach a given position in the system of ground water after introduction at some place above the upper most aquifer[2]. Due to the rapid degradation of ground water quality it has become important for us to protect it from contamination and maintain its quality. The objective of the study is to develop a groundwater vulnerability map integrating SINTACS model into GIS and to locate the areas having different degrees of groundwater vulnerability to contamination.

** Author for correspondence*

Using the hydrogeological parameters, a groundwater vulnerability map has been produced for the Raipur and Naya Raipur areas of the Chhattisgarh state.

2. Study area

Geographically, Raipur city is situated at 21.25 degrees North latitude and 81.63 degrees East longitude having a height of about 298 meters above Mean Sea Level. The average annual precipitation is about 1330 mm. Raipur city has a flat topography with a few elevated places of land having general slope towards northwest. The total geographical area of the study measures 739 km^2.

It has a tropical wet and dry climate. In summer it is very hot and dry winds blow and in winter temperature falls to very low. Alluvium deposits are lying all along the flood plains nearly 2 km extending on either side. Alluvium consists mostly gravels, coarse to medium sand and silt. Its thickness is 10 to 20 m along Kharun River. The aquifers found in our study area are porous and permeable in nature. The aquifers of the area that provide ground water are confined and semi confined in nature[3,4].

3. Methodology

Last few decades have witnessed development of many techniques to assess groundwater vulnerability which include index, rating, hybrid, statistical and simulation methods[5]. Of all these models SINTACS model is used in this study. It was developed by Civita and De Maio in1997[6]. This model is derived from DRASTIC model. This method assesses ground water pollution vulnerability by using seven Hydro-Geological parameters. The seven parameters of SINTACS model are S - water table depth, I - net recharge, N - unsaturated conditions (Vadose zone), T – soil media, A – aquifer media, C – hydraulic conductivity and S – topographic slope[6]. This way is valuable and adequate from scientific point of view to assess a potential contamination of a CSC (Contamination Spreading Centre) in areas of small spread, is quiet impracticable where the aim is to assess aquifer vulnerability of large area or when it is done to prevent contamination in aquifer protection planning[6].

Each parameter has been assigned a rating that ranges between0 to 10, depending upon the contribution of the parameter in defining the degree of vulnerability. Ratings are obtained from the standard rating chart[7]. These parameters are assigned a weight also depending upon the environmental and anthropogenic condition of the area. The intrinsic vulnerability index (In) can be calculated by adding up the products of ratings and the respective weights of the different parameters.

$$\mathrm{In} = \sum_{i=1}^{7} \mathrm{Si} \cdot \mathrm{Wi} \qquad (1)$$

Where Si = rating of parameters, and Wi = weights of parameters.

4. SINTACS Parameter Map Preparation Method

4.1 Hydrogeological Factors

4.1.1 Depth to Water Table (S-Parameter)

Depth of water table (meters) is calculated by the difference between surface elevation and water table elevation. The surface elevation data was taken from Digital Elevation Model (DEM) and the water level map was obtained by interpolating well data by the method of IDW (Inverse Distance Weighted) [Figure1][Table 1]. The pre- monsoon well data is taken for interpolation.

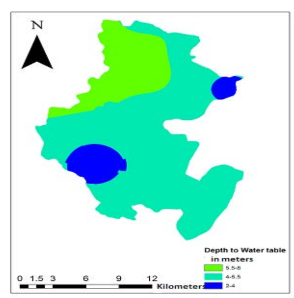

Figure 1. Depth to water table map of the study.

Table 1. Depth to groundwater (m), weight: 5

Range	Rating	Index
2-4	8	43
4-5.5	7	35
5.5-8	6	30

4.1.2 NetRecharge (I-parameter)

Precipitation is the primary source of recharge. More recharge leads to greater probability for the contaminants to reach the water table. Net recharge is calculated by using the Water Table Fluctuation Method (WTF) [Figure 2] [Table 2].

WTF formula, $R = \Delta L \cdot \frac{Sy}{\Delta t}$ (2)

where, ΔL = change in water table height, Sy = Specific Yield and Δt = Time interval.

The change in water table height was obtained from well data. The net recharge obtained for the study area ranges between100-400 (mm/yr) [Figure 2].

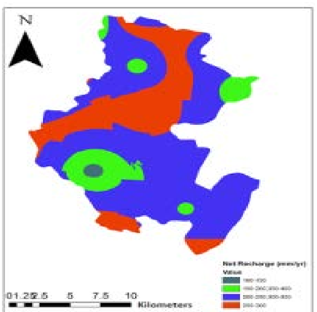

Figure 2. Net recharge map of the study area.

Table 2. Net recharge, weight: 4

Range(mm/year)	Rating	Index
100-150	6	24
350-400, 150-200	7	28
300-350,200-250	8	32
250-300	9	36

4.1.3 Impact of Vadose Zone (N-parameter)

Vadose zone, the unsaturated zone is the layer lying above the saturated zone and is responsible for the attenuation and passage of the contaminant to the saturated zone. It depends on the porosity of the media. In our rating system alluvium has the highest rating. The information about Vadose zone is obtained, from the geological map of the area[Figure 3]. Alluvium, Stromatolitic sandstone and, Shale are found, in the study, area [Table 3].

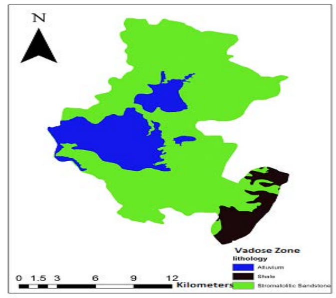

Figure 3. Impact of Vadose zone map of the study area.

Table 3. Impact of Vadose zone, weight: 5

Range	Rating	Index
Alluvium	7	35
Stromatolitic Sandsatone	6	30
Shale	4	20

4.1.4 Soil Media (T-parameter)

Soil is found on the upper most portion of the unsaturated layer. It goes down from the top surface to about 6ft below. The soil characteristics determine the infiltration rate [Figure 4][Table 4]. The permeability depends on the texture of soil. Soil acts as a passage for the downward vertical motion of the contaminated materials to reach ground water and affects the vulnerability.

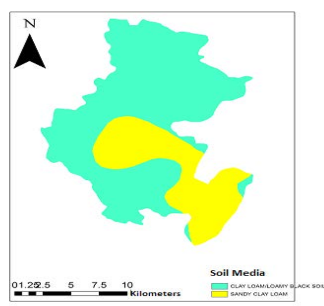

Figure 4. Soil media map of the study area.

Table 4. Soil Media, weight: 4

Soil Type	Rating	Index
Sandy Clay Loam Soil	5	20
Clay Loam ,Loamy Black Soil	3	12

4.1.5 Aquifer Media (A-Parameter)

Aquifer is defined as a layer lying under the ground, consist of water-bearing rocks of permeable nature, rock fractures or unconsolidated materials from which groundwater can be obtained using water well[7]. Aquifers are found here in confined to semi-confined conditions given in [3] [Figure 5][Table 5]. The aquifer media provide pathway for the mobility of the contaminants through it.

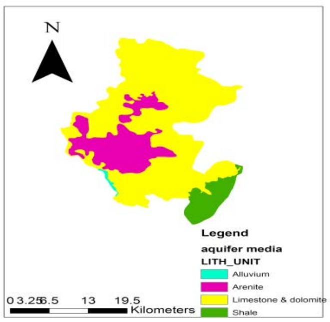

Figure 5. Aquifer media map of the study area.

Table 5. Aquifer Media, weight: 3

Aquifer	Rating	Index
Alluvium	9	27
Arenite	8	24
Limestone	6	18
Shale	3	9

4.1.6 Hydraulic Conductivity (C-Parameter)

Hydraulic conductivity represents the capacity of the aquifer materials to transmit water enabling to control the rate at which ground water will flow under a specified hydraulic gradient[8]. With increment in hydraulic conductivity, groundwater velocity along with the speed at which pollutants are transported also increases resulting in the rise in aquifer vulnerability. Pumping test data is used for obtaining hydraulic conductivity [Figure 6] [Table 6]. Its value ranges between (3.97-63.9)cm/day.

Table 6. Hydraulic conductivity, weight: 3

Range(cm/day)	Rating	Index
31.9-63.9	3	9
15.984-31.96	2	6
7.94-15.984, 3.97-7.94	1	3

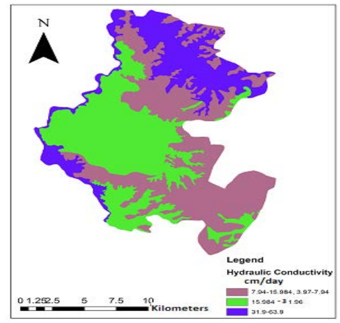

Figure 6. Hydraulic Conductivity map of the study area.

4.1.7 Topographic Slope (% slope) (S-parameter)

Slope can be defined as the measure of steepness of an area. The area having low slope leads to storage of water that gives more time to water to percolate as compared to areas having large slope. The areas of low slope have greater potential for contamination and are more vulnerable to groundwater pollution. The slope is obtained from DEM (Digital Elevation Model) (http://dwtkns.com/srtm.) data of the area using Arc GIS tool [Figure 7] [Table 7].

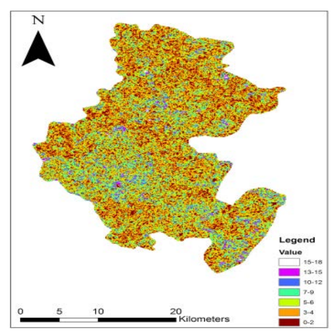

Figure 7. Topographic Slope map of the study area.

Table 7. Topography, weight: 2

Range (%)	Rating	Index
0-2	10	20
3-4	9	18
5-6	8	16
7-9	7	14
10-12	6	12
13-15	5	10
16-18	4	8

To calculate the SINTACS vulnerability all the parameter's maps are summed together. By the use of Raster calculator all the raster maps of the seven parameters are multiplied to their respective weights and summed up then the SINTACS Vulnerability index (In) is obtained.

$$\mathrm{SINTACS(In)} = 5 \cdot \mathrm{S} + 4 \cdot \mathrm{I} + 5 \cdot \mathrm{N} + 4 \cdot \mathrm{T} + 3 \cdot \mathrm{A} + 3 \cdot \mathrm{C} + 2 \cdot \mathrm{S} \quad (3)$$

5. Result and Discussions

The water table depth values obtained in our study ranges between 2-8 meters and it has been further classified into three classes:(i) 2-4 m, (ii) 4-5.5 m and (iii) 5.5-8 m having rating values of 8, 7 and 6 respectively. The areas having low water table depth is highly vulnerable to contamination. More recharge leads to greater chance for the contaminants to reach the water table. The annual net recharge of the study area ranges between 100mm to 400mm.The ratings assigned to the net recharge values vary from 6 to 9 with index values ranging from 24 to 36.The unsaturated conditions comprise of Alluvium, Shale and Stromatolitic Sandstone having the rating values of 7, 4 and 6 respectively with the index values of 35, 20 and 30 respectively. The types of soil that cover the study area are Clay Loam, Loamy Black Soil and Sandy Clay Loam and have been assigned a rating of 3, 3 and 5 respectively. The index value of clay loam as well as loamy black soil is 12 and that of sandy clay loam is 20. For the aquifer media, Alluvium has been assigned the rating of 9 which is the highest. Arenite has been assigned the second highest value of rating of 8 and the lowest rating of 3 has been assigned to Shale. In general, with increment in the grain-size and the number of fractures or openings within the aquifers, the permeability increases and the attenuation capacity becomes lower resulting in higher pollution potential[9]. So coarser (saturated or unsaturated) media is assigned a higher rating value as compared to finer media. Raipur has a flat topography having general slope. Its topographic slope obtained ranges from 2-18%. The area having high vulnerability possess low slope. Hydraulic Conductivity is calculated using the pumping test data. The values of Hydraulic Conductivity obtained range from 8 to 64cm/day. The aquifers having high hydraulic conductivity value are more susceptible to contamination as the plume of contamination can easily make its way through theaquifers[10].

The vulnerability map obtained shows the different levels of vulnerability of the aquifers towards contamination [Figure 8]. The resulting Vulnerability Index values obtained based on SINTACS index values range between121 to 176.The result obtained is normalized and further classified into four classes. The classes based on SINTACS index values are termed as Very low (In=100-122), Low (In=122-144), Moderate (In=144-166) and High vulnerable (In=166-187) [Table 8]. The result shows that out of total area, 0.26% of the area indicates very low vulnerability 11.58% indicates low vulnerability 81.35% indicates moderate vulnerability and 6.81% of area indicates high vulnerability. It means majority of the study area exhibits moderate vulnerability (Table 3). The 50.272 km^2 area showing high vulnerability to contamination is mainly the old parts of the study area like Raipur. This area is mainly in the central part of the study area where the physical factors like gentle slope and high water table are supporting the probability of shallow aquifer water getting polluted. The annual net recharge of the high vulnerability area was 250-300 mm with the rating of 9 and index value 36. Loamy Black soil and Sandy Clay Loam soil are found in the area of high vulnerability. Under the aquifer media, arenite and limestone cover the high vulnerable zone having the rating of 8 and 6 respectively and index value of 24 and 18 respectively. Alluvium and Stromatolitic Sandstone represent the Vadose zone of the high vulnerability area having the rating of 7 and 6 respectively. Hydraulic Conductivity of the area ranges between 8 and 15 (cm/day). The depth to water table in the high vulnerability zone is found to be 2-5.5metres having the rating of 8 and 7 with the index value of 40 and 35. The high vulnerability area is having slope between 5-12%.

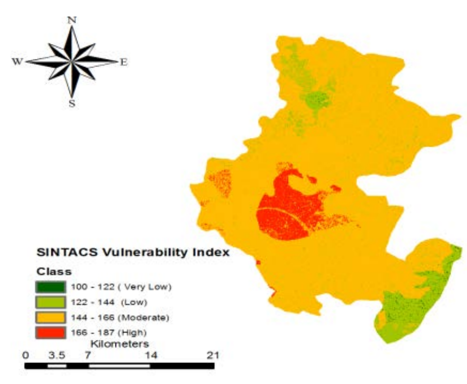

Figure 8. SINTACS Index map of the study area.

Table 8. Vulnerability index class

Vulnerability SINTACS Class			
Range	**Class**	**Area (%)**	**Area(sq.km)**
100-122	Very low	0.265	1.96
122-144	Low	11.58	85.418
144-166	Moderate	81.3	599.63
166-187	High	6.81	50.272
			Total= 737.28

6. Conclusion

The combined use of SINTACS and GIS proves to be highly reliable method in assessing the ground water vulnerability for contamination. The SINTACS index values for the study area recorded lies between 121 to 176. From the resulting SINTACS Index map of the study area it can be observed that out of the total area, majority of the total area (81.3%) (599.63km^2) lies in the Moderate Vulnerability zone. The lower central area is highly populated and urbanized and is in High Vulnerability zone i.e. 6.81% (50.272km^2) of the total area. The main reason for very high vulnerability is the high annual net recharge (250+mm) and majority of the area has 5%-6% slope ranges, which allowed the water to percolate more easily into the soil. The lower part and some upper parts of the study area show Low vulnerability i.e. 11.58% (85.418km^2) of the total area. The study produces an effective tool to assist the local authorities who manage and monitor the ground water resources.

7. Acknowledgement

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8. References

1. Rao SM, Mamatha P. Water quality in sustainable water management. Current Science. 2015; 87(7): 942–7.
2. Vrba J, Zoporozec A. Guidebook on mapping groundwater vulnerability. International Contributions to Hydrogeology (IAH), Heise, Hannover. 1994; 16:131.
3. CGWB. Ground water brochure of Raipur district, Chhattisgarh 2008-2009. Central Ground Water Board Ministry of Water Resources Government of India; 2009.
4. CGWB. Status report on review of ground water resources estimation methodology New Delhi, India; 2009.
5. Voudouris K. Assessing groundwater pollution risk in Sarigkiol basin, NW Greece. In Gallo M, Herrari M, editors, River Pollution Research Progress, Nova Science Publishers Inc.; 2009.p. 265–81.
6. Civita MV. The combined approach when assessing and mapping groundwater vulnerability to contamination. Journal of Water Resource and Protection. 2010;2:14–28.
7. Subramanya K. Engineering hydrology. Fourth Edition. McGraw Hill Education (India) Private Limited; 2013.
8. Al Kuisi M, El-Naqa A, Hammouri N. Vulnerability mapping of shallow groundwater aquifer using SINTACS model in the Jordan Valley area, Jordan. Environmental Geology. 2006; 50:645–50.
9. Anwar M, Prem CC, Rao VB. Evaluation of groundwater potential of Musi River catchment using DRASTIC index model. Proceedings of the International Conference, Hyderabad; 2002.p. 399–409.
10. Sinha MK, Verma MK, Ahmad I, Baier K, Jha R, Azzam R. Assessment of groundwater vulnerability using modified DRASTIC model in Kharun Basin, Chhattisgarh, India. Arabian Journal of Geosciences. 2016Feb;9:98.