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Assessment of groundwater vulnerability using the GIS approach-based GOD method in Surat district of Gujarat state, India

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ABSTRACT

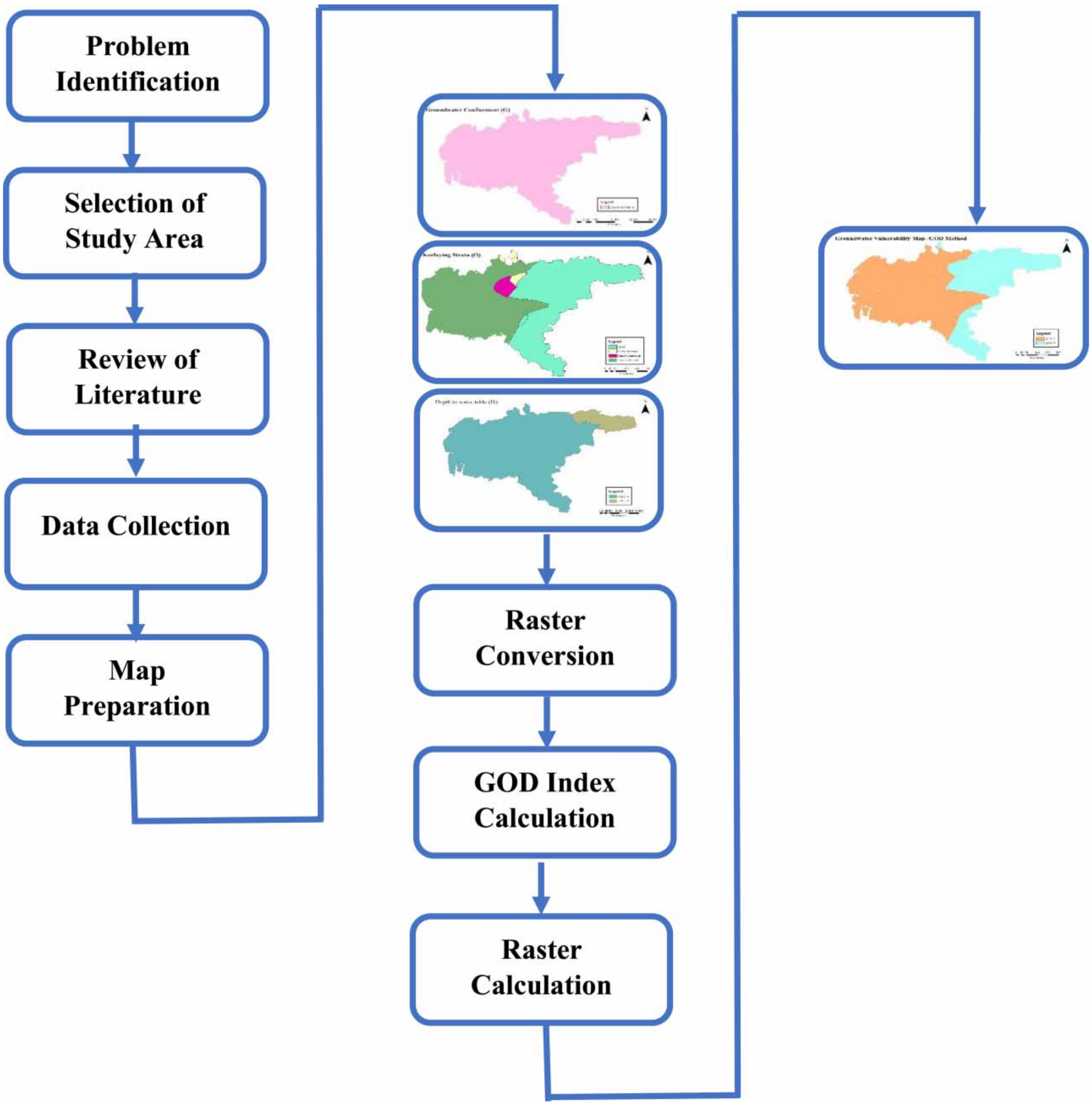
There are different sources of groundwater pollution among them industrial water disposal, seawater ingress, usage of pesticides and fertilizers in agricultural fields, and municipal and residential wastewater disposal. The aim of the study is to assess groundwater vulnerability in terms of quality using the GOD method using the Geographical Investigation System approach for Surat and its surroundings. Groundwater confinement, overlying strata and depth to water table are the three parameters that are used in the assessment of groundwater vulnerability. In this study, all three parameters are given by the conventional weights which are suggested by Foster 1987. Based on the study Mahuva, Mandvi, Umarpada and some parts of the Bardoli talukas lie in very high-vulnerability zones whereas another part of the study area lies in a high-vulnerability zone. Almost 35.98% of the area of the district lies in the higher-vulnerability zone. Depth to the water table and the overlying strata are very important parameters that effectively cause groundwater vulnerability. This study may help in groundwater quality management, and watershed management as well as it is very much useful for the policymakers and local authorities as well as the government.

Key words: GOD, groundwater contamination, groundwater management, vulnerability

HIGHLIGHTS

- To assess the groundwater vulnerability in Surat district, the GIS approach-based GOD method is effectively used.
- This study helps to improve the quality of the groundwater in the study area.
- This study helps to improve groundwater management policies.
- Effective and authentic data provided by the government bodies are used for the assessment.
- From this study, we can achieve sustainable water use management.

GRAPHICAL ABSTRACT



INTRODUCTION

Precipitation is a very important and major source of water and water is very important for all living organisms. Groundwater is an important source of water and it provides about half of all drinking water on the planet, as well as 43% of all irrigation water used in agriculture (Patel *et al.* 2022). Also, groundwater is comparatively safe in terms of quality and reliability compared to all-surface water sources (Kaddour *et al.* 2018). Groundwater is the water that exists below the ground surface. Groundwater systems are extremely dynamic and they are more compatible with pollution because water is constantly moving downward (Vijayakumar *et al.* 2021; Patel *et al.* 2022). Groundwater sources are our current and future water demand reserves and they differ from other water sources in that they perform a critical function in terms of cleanliness and accessibility that cannot be replaced (Shirazi *et al.* 2013). Industrial activities, agricultural activities such as the use of fertilizers and pesticides and soil pollution play a major role in groundwater pollution. Groundwater is easily contaminated but it is difficult to remediate so in today's time it is very important to manage the quality of the groundwater (Khodabakhshi *et al.* 2015). Pollution control and removal of contaminants from the groundwater is a very costly and challenging task (Khodabakhshi *et al.* 2015; Rukmana *et al.* 2020). So, a proper and effective quality management technique is very much required for groundwater (Chowdary *et al.* 2005).

The vulnerability of groundwater is defined as 'the tendency or possibility of contaminants reaching a specified position in the groundwater system after introduction at some location above the uppermost aquifer' (National Research Council 1993; Foster *et al.* 2002). The concept of groundwater vulnerability assessment is that the aquifer does not have the same characteristics in all locations and that some geographical areas are more vulnerable to deterioration in terms of quantity and quality (Gogu *et al.* 2003). Groundwater vulnerability assessment is a crucial process in determining how vulnerable a certain region is to a specific threat, whether natural or man-made (Mendoza & Barmen 2006). Vulnerability of assessment is very much helpful to know about the quality of the groundwater in the area and ultimately it is helpful in the management of groundwater as well as the environment (Piscopo 2001; Mendoza & Barmen 2006; Rukmana *et al.* 2020). Also, the groundwater levels are decreasing, demanding long-term planning to safeguard these vital resources (Narendra & Rao 2006).

There are different types of groundwater vulnerability assessment methods, among them overlay and index methods are very effective and easy methods to find pollution-prone areas of the groundwater (Sener 2021; Patel *et al.* 2022). In overlay and index methods, parameter maps are prepared and then overlay methods with respect to some effective weights are given by the different authors as well as researchers (Sener 2021; Patel *et al.* 2022). There are many overlay and index methods among them DRASTIC (Aller 1985), SINTACS (Civita & De Maio 1997), GOD (Foster 1987), AVI (Stempvoort *et al.* 1993) and PI (Golds cheider *et al.* 2000) are the commonly used and known methods. The GOD method gives good results in the areas where groundwater quality is to some extent too good as well as where the groundwater pollution is more affected by the aquifer as well as the depth to the water table (Foster 1987). For checking the primary risk or for the smaller-scale vulnerability assessment, the GOD method gives an effective result (Kaddour *et al.* 2018). GOD is a well-known system for determining the aquifer's pollution vulnerability promptly (Maria 2018). The GOD method is effectively applied in India as well as in the other countries for groundwater vulnerability assessment. At small–moderate scales, the GOD approach may be sufficient for vulnerability mapping in aquifers (Maria 2018). The GOD method is very easy and effective for designing a large area for land management (Maria 2018). The GOD method gives the best result compared with all other methods in the small urban-type aquifers, so it is more helpful in small urban areas to assess the groundwater quality vulnerability as a primary risk factor (Maria 2018). The study area is affected by industrial activities, agricultural activities and solid waste management so the groundwater of the study area may be polluted by these sources. In this study, the GOD method is used for the assessment of groundwater vulnerability. Basically, in the GOD method three parameters are considered, groundwater confinement, overlaying strata and depth to water table as an important parameter are responsible for groundwater pollution. This GOD method shows the vulnerable areas, so this method helps in improving the groundwater management policies as well as water resources management.

STUDY AREA

Surat district is in the western area of India, in the state of Gujarat. Due to immigration from within the state and other Indian states, it is one of India's most active districts, with one of the fastest growth rates. Surat is a very important state of Gujarat with a population of 7.7 million. Surat is the ninth most populated city in India. 'The City Chairman Establishment, a global research organization' focusing on urban issues, ranks Surat fourth in a global survey of the fastest-growing cities. Surat is situated on the banks of the Tapi River, with the Arabian Sea to the west, between latitudes 21°06° N and 21°15° N, and longitudes 72°45° E and 72°54° E. It is 13 meters above sea level. It is a densely populated district of Gujarat state. It is 306 km far away from the Gujarat state capital, Gandhinagar. It is connected on the west by the Arabian Sea, on the north by Bharuch, on the south by the Valsad district, on the southeast by the Dang district and on the east by the Tapi district. Surat district is divided into nine groups of villages, basically we call it a taluka, i.e., Bardoli, Choryasi, Kamrej, Mahuva, Mandvi, Mangrol, Olpad, Palsana and Umarpada, it covers an area of about 4,418 sq. km.

The study area, which includes a seashore plain with a profound, fine, salt-influenced soil area, is located on the Tapi riverbank and the Dumas coastal belt, Arabian sea (Figure 1). Some talukas in the district, such as Bardoli, Umarpada, Choryasi and Mandvi, are covered by agricultural land and their groundwater may be contaminated by fertilizers and pesticides. Furthermore, because some talukas, such as Palsana and Kamrej, are located along the district's industrial corridor, their groundwater may be impacted by industrial activity and huge sugarcane mills. Industrial waste is also a source of groundwater pollution. Release of industrial waste through the

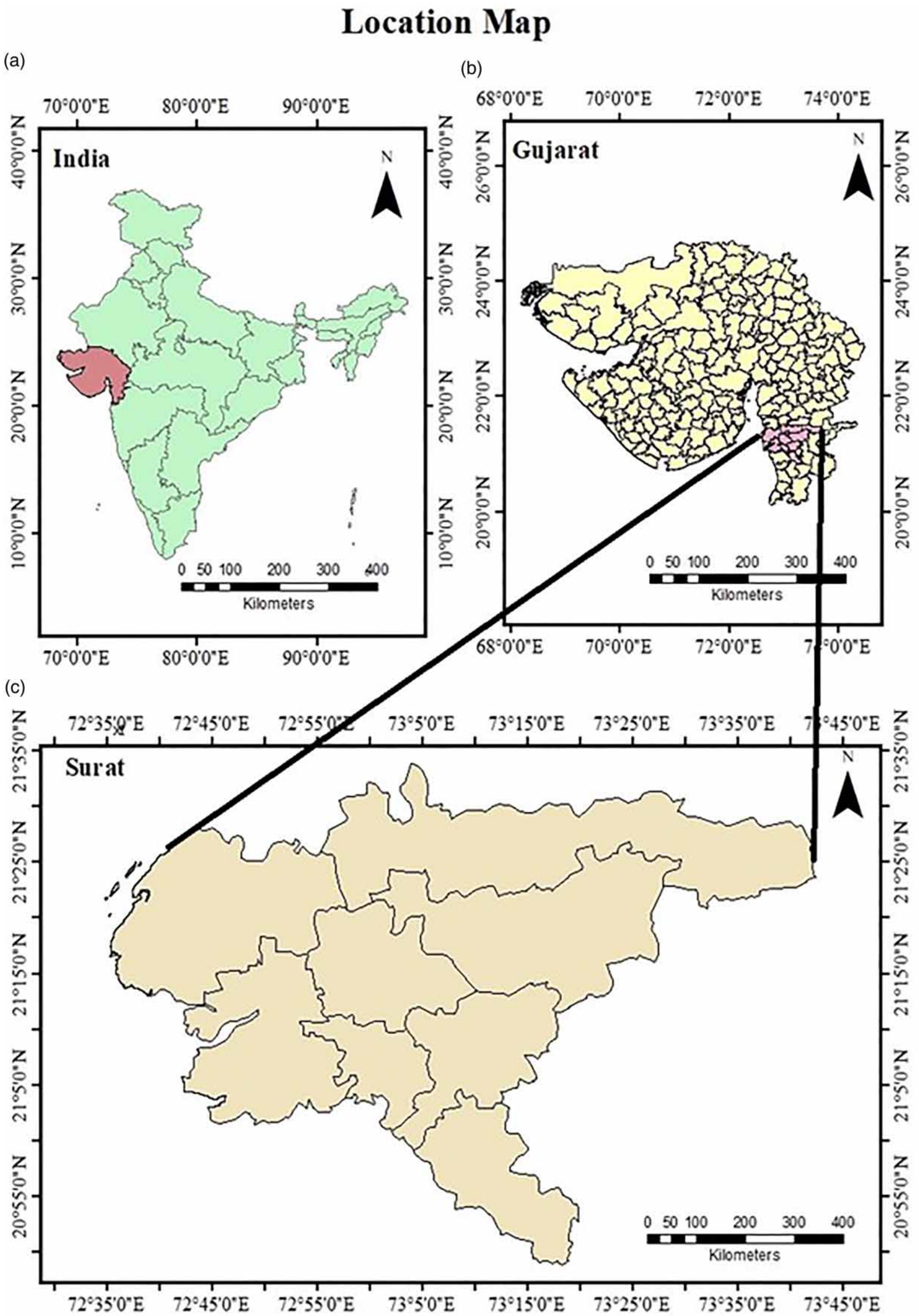


Figure 1 | Location map of the study area.

cracks and pores of the earth, groundwater may get polluted. River pollution and toxins from water sediments as well as pesticides and fertilizers enter the groundwater through fractures in the surface of the earth. In the coastal part, seawater ingress may very much affect the groundwater quality. People who live there have a major source of groundwater for drinking and domestic use, which is why we chose this zone as our research area. The location is near the southwestern coastlands of the Deccan promontory. Although the theoretical Sahyadri scarp lies outside the region's eastward bounds, it determines the region's course. There are two types of sedimentary fields: shorefront fields and sand dunes.

In the district's middle sections, the Tapi river passes over alluvial fields (CGWB 2013). Tapi features a reasonably wide meandering canal with terraces built into it. The area's topography is mostly level, with the exception of a minor slope in the west. The area's lowest point is 45 meters above sea level. The elevations are frequently under 60 meters above sea level.

The groundwater is largely unconfined and most likely caused by the presence of clay objects.

DATA COLLECTION

All the parameters of the GOD method are collected and collated to create a layer for each parameter in the ArcGIS (Aeronautical Reconnaissance Coverage Geographic Information system) software. All the data related to the parameter are collected from the different governmental organizations and government bodies' research data, which are mentioned in Table 1.

Table 1 | Data sources of different parameters

Parameter	Data source
Groundwater confinement (G)	Collected from the Central Ground Water Board Report for the Surat district.
Overlaying strata (O)	Collected from the website of the Commission of Geology and Mining by the industries and Mines Department of the Government of Gujarat.
Depth to water table (D)	Collected from the Water Resources Information System portal for the last year.

METHODOLOGY

Overview of the GOD method

The GOD method is an important overlay and index method to assess groundwater vulnerability (Patel *et al.* 2022). The GOD method was developed by Foster (1987) and Foster & Hirata (1993). GOD is a vulnerability assessment method developed in Great Britain (Ghazavi & Ebrahimi 2015). The GOD method includes basically three parameters groundwater confinement (G), overlaying lithology (O) and depth to water table (D). For evaluating GOD vulnerability, each composing parameter is given a value between 0 and 1, with 0 representing the least vulnerable and 1 representing the most vulnerable (Kaddour *et al.* 2018). After preparing the parameter maps, the GOD index is calculated based on the ratings and ranges of the parameter. With the use of the GOD index, the vulnerability map is prepared so that vulnerable areas can easily be identified as well as classified into different classes of vulnerability. The GOD index is calculated by multiplying the influence of the three elements using Equation (1) to evaluate and map the aquifer vulnerability induced by pollution.

$$\text{GOD Index} = C_a * C_l * C_d \ \ldots \tag{1}$$

where C_a is the type of aquifer; C_l is the overlaying lithology of the zone and C_d is the depth to the aquifer.

Groundwater confinement (*G*)

This parameter includes the confinement or the occurrence of the groundwater. Generally, there are unconfined as well as confined types of aquifers which may store the groundwater. So, this parameter shows the occurrence of groundwater.

Overlaying strata (*O*)

This parameter shows the aquifer geology type which considerably lies in the respective study areas. There are different types of aquifers and their geology is different. Geology is the main concern for groundwater occurrence and storage.

Depth to water table (*D*)

This parameter is one of the most important parameters for groundwater quality. It includes the depth of the water table. If the depth of the water table is very less, then the contaminants can easily reach the groundwater and if the depth is more, it is not easily reached. So, it is directly dependent on the quality of the groundwater.

After applying the rates according to Table 2, and after preparation of the vulnerability map prepared and based on the vulnerability map, the study area is divided into the different vulnerability classes which are included in Table 3. Supplementary Annexure 1 includes the data collection and steps for creating the parameter map.

Table 2 | Standard GOD parameters

Layer	Range/Type	Rating
Groundwater occurrence (G)	Confined aquifer	0.2
	Semi-confined aquifer	0.4
	Unconfined aquifer	0.6
Overlaying strata (O)	Basalt	1.0
	Karst limestone	0.9
	Massive sandstone	0.7
	Sand and gravel	0.8
Depth to water table (D)	0–2.0 m	1.0
	2.0–5.0 m	0.9
	5.0–20.0 m	0.8
	20.0–50.0 m	0.7
	>50 m	0.6

Table 3 | Vulnerability class for the GOD method

Vulnerability class	Index value
Negligible	0–0.1
Low	0.1–0.3
Moderate	0.3–0.5
High	0.5–0.7
Very high	0.7–1.0

RESULTS AND DISCUSSION

Groundwater is occurring in the saturation zone below the earth's surface. There are two types of aquifers that may hold the groundwater, one is an unconfined aquifer and the other is a confined aquifer. Based on the geological condition of the whole study area, groundwater only occurs in the unconfined aquifer that is mentioned in Figure 2. An unconfined aquifer is more vulnerable than a confined aquifer or semi-confined aquifer. So, on the basis of the methodology, higher ratings are given to the unconfined aquifer type.

Overlaying strata are basically the strata that are made up of the type of aquifer. Generally, the type of overlaying strata is influencing the groundwater quality. If the overlaying strata are of smaller grain size, they are more vulnerable to groundwater quality. This is another crucial parameter that affects groundwater quality. Figure 3 shows that the study area consists mostly of basalt as well as sand and gravel type of strata. So, we can say that it is more vulnerable to groundwater quality. On the basis of the methodology, basalt type of the strata is given higher ratings. So, the area which is having the basalt type of strata is more vulnerable.

The depth of the water table is defined as the distance between the groundwater surface and the water table. So, depth to the water table influences the contaminant contact and surface materials with the groundwater. So, it directly degrades the groundwater quality. The depth of the water table is the most influential parameter of the water table. If the water table depth is more, then the aquifer is less vulnerable to pollution. Figure 4 shows the depth of the water table of the study area and it is indicated that the whole part of the study area has a depth in the range of 0–2 m and only Umarpada taluka of the district has a depth in the range of 2–5 m. So,

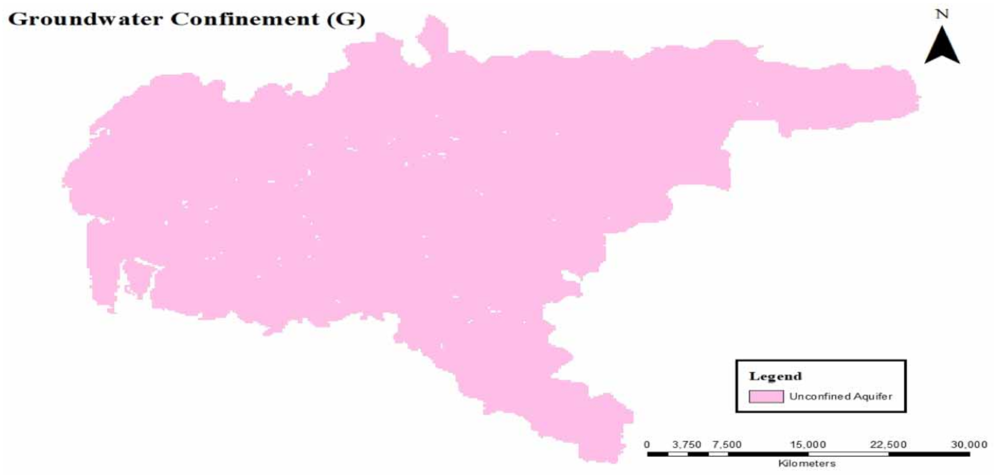


Figure 2 | Groundwater confinement map.

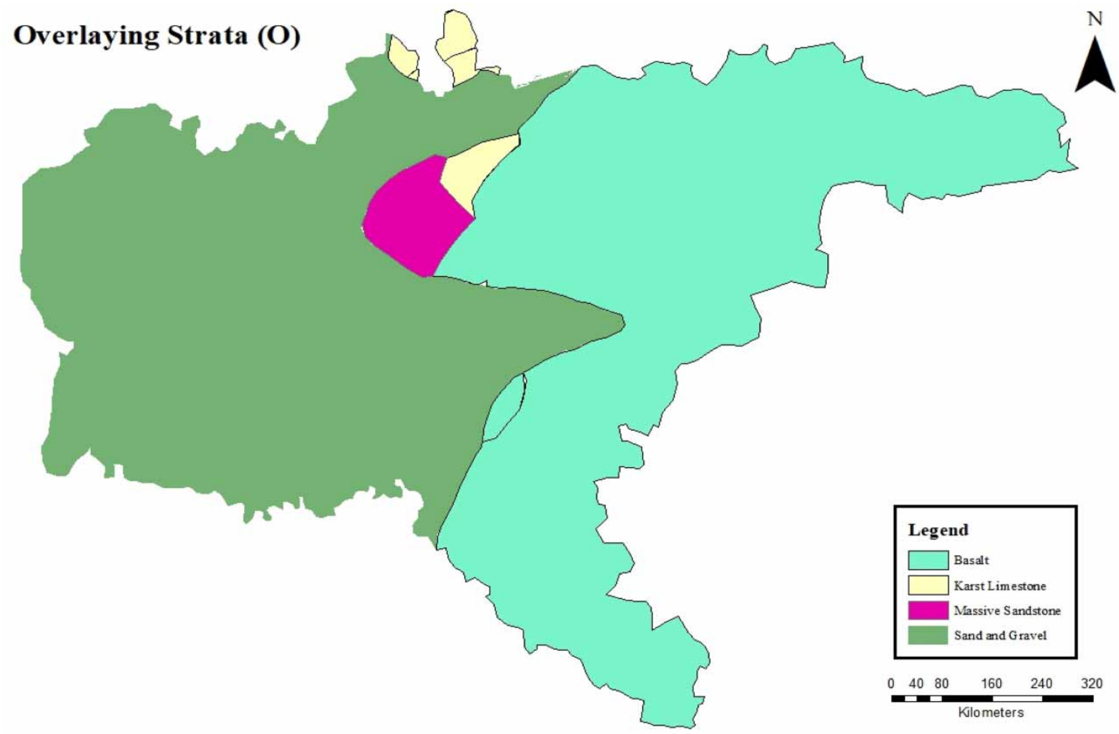


Figure 3 | Overlaying strata map.

from the map, we show that Umarpada taluka of the study area is less vulnerable to pollution compared to the other talukas. On the basis of the methodology and based on Figure 4, higher ratings are given to the depth in the range of 0–2 m which is more vulnerable.

Figure 5 shows the vulnerability map of the study area. Based on the vulnerability map and methodology, the study area is divided into two parts which are moderate vulnerability and high vulnerability. Umarpada, Bardoli, Mahuva and Mandvi talukas are considered a higher vulnerability zone while another part of the study area is considered as moderate vulnerability. The higher vulnerability may be due to the shallow depth of the water table as well as the more vulnerable overlaying strata. So, depth to the water table and overlaying strata are the important parameters that may affect the groundwater vulnerability of a particular area.

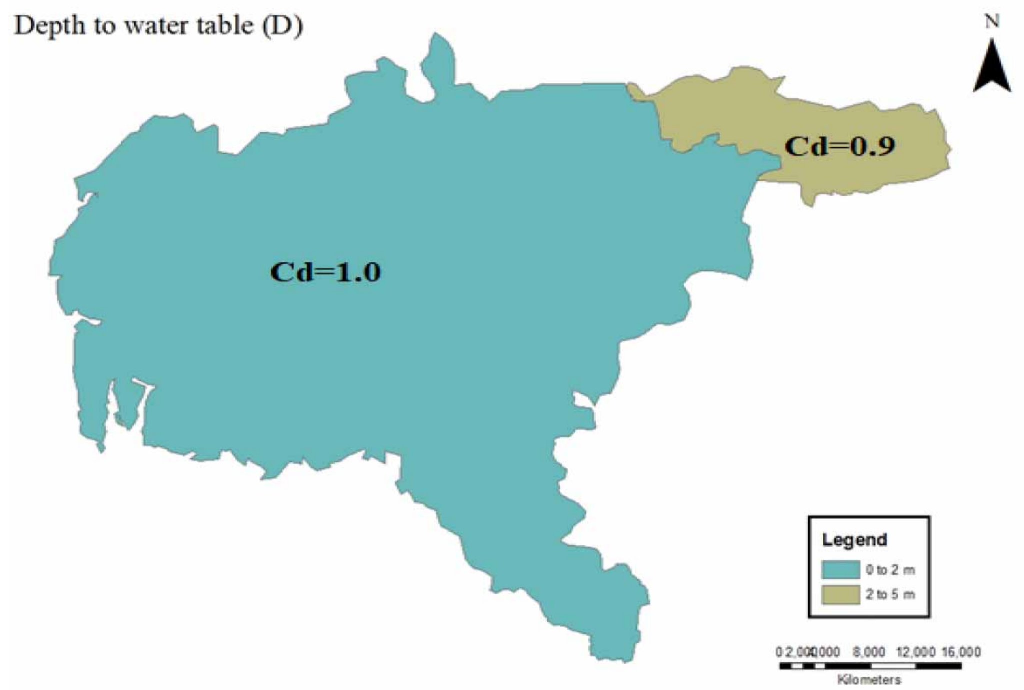


Figure 4 | Depth to water table map.

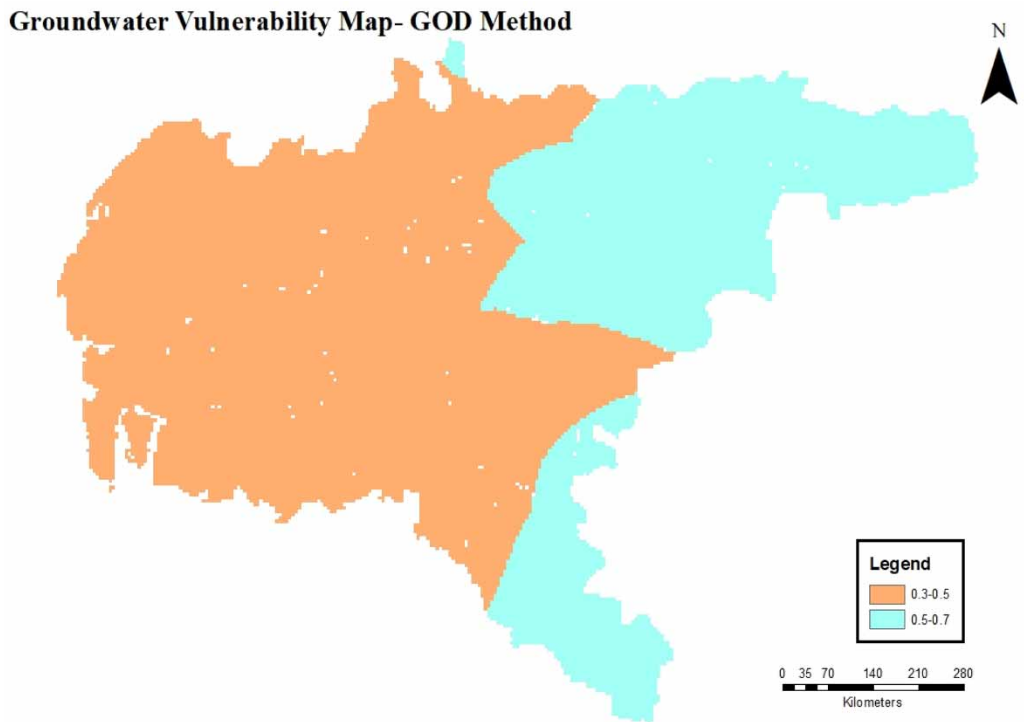


Figure 5 | Groundwater vulnerability map.

CONCLUSION

In this paper, the GOD method is effectively used with the geoinformatics approach for groundwater vulnerability assessment. Based on the above study, it is observed that almost 36% of the total study area is under the higher vulnerability zone and other parts of the area are under the moderate vulnerability zone. It is also observed that Umarpada and some parts of the Bardoli, Mandvi and Mahuva talukas are under the higher vulnerability zone. This may be due to the shallow depth of the water table as well as the type of overlaying strata being basalt type. So, based on the above study, depth to the water table and the overlaying strata are the important parameters that mostly affect groundwater vulnerability. This GOD method is an effective and valuable method for the assessment of groundwater vulnerability using the geoinformatics approach. Primary-level treatment of industrial waste can prevent groundwater pollution before it is released into the environment. Reducing pumping rates, relocating pumping wells, using physical surface or subsurface barriers, using natural or artificial recharge (pressure or positive barriers), pumping saline water along the seashore (abstraction or negative barriers) and combining techniques can all help reduce seawater ingress (mixed barriers). Thus, it ultimately improves the quality of groundwater. This study can identify the groundwater vulnerable areas so that effective management policies can be applied in vulnerable areas. So, this result may be useful in the management of groundwater policies as well as in monitoring and maintaining the groundwater quality of a particular area.

FUNDING

This research received no external funding.

DATA AVAILABILITY STATEMENT

All relevant data are available from an online repository at https://indiawris.gov.in/wris/.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Aller, L. 1985 *DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings*. Robert S. Kerr Environmental Research Laboratory, Office of Research and Development, US Environmental Protection Agency.

CGWB 2013 *Groundwater Year Book*. Central Ground Water Board and Ministry of Water Resources, Government of India.

Chowdary, V. M., Rao, N. H. & Sarma, P. B. S. 2005 Decision support framework for assessment of non-point-source pollution of groundwater in large irrigation projects. *Agricultural Water Management* **75**(3), 194–225.

Civita, M. & De Maio, M. 1997 SINTACS Un sistema parametrico per la valutazione e la cartografia per la valutazione della vulnerabilita degli acquiferi all'inquinamento. Metodologia e automazione, Pitagora Ed., Bologna, 199.

Foster, S. 1987 Fundamental concept in aquifer vulnerability pollution risk and protection strategy. In: *Proc. Intl. Conf. Vulnerability of Soil and Groundwater Pollution*, April, The Netherlands.

Foster, S. & Hirata, R. 1993 *Determinação do risco de contaminação das águas subterrâneas: um método baseado em dados existentes*. Instituto Geológico, São Paulo.

Foster, S., Hirata, R., Gomes, D., D'Elia, M. & Paris, M. 2002 *Groundwater Quality Protection*. The World Bank, Washington, DC.

Ghazavi, R. & Ebrahimi, Z. 2015 Assessing groundwater vulnerability to contamination in an arid environment using DRASTIC and GOD models. *International Journal of Environmental Science and Technology* **12**(9), 2909–2918.

Gogu, R. C., Hallet, V. & Dassargues, A. 2003 Comparison of aquifer vulnerability assessment techniques. Application to the Néblon River basin (Belgium). *Environmental Geology* **44**, 881–892.

Golds cheider, N. I. C. O., Klute, M. A. R. K. U. S., Sturm, S. & Hötzl, H. 2000 The PI method – a GIS-based approach to mapping groundwater vulnerability with special consideration of karst aquifers. *Z AngewGeol* **46**(3), 157–166.

Kaddour, K., El Hacen, B., Hlima, D. & Yasmina, D. 2018 Groundwater vulnerability assessment using GOD method in Boulimat coastal District of Bejaia area North east Algeria. *Journal of Biodiversity and Environmental Sciences* **13**(3), 109–116.

Khodabakhshi, N., Asadollahfardi, G. & Heidarzadeh, N. 2015 Application of a GIS-based DRASTIC model and groundwater quality index method for evaluation of groundwater vulnerability: a case study, Sefid-Dasht. *Water Science and Technology: Water Supply* **15**(4), 784–792.

Maria, R. 2018 Comparative studies of groundwater vulnerability assessment. In: *IOP Conference Series: Earth and Environmental Science*, Vol. 118, No. 1, p. 012018. IOP Publishing.

Mendoza, J. A. & Barmen, G. 2006 Assessment of groundwater vulnerability in the Río Artiguas basin, Nicaragua. *Environmental Geology* **50**(4), 569–580.

Narendra, K. & Rao, K. N. 2006 Morphometry of the Meghadrigedda watershed, Visakhapatnam district, Andhra Pradesh using GIS and Resourcesat data. *Journal of the Indian Society of Remote Sensing* **34**(2), 101–110.

National Research Council 1993 *Ground Water Vulnerability Assessment: Predicting Relative Contamination Potential Under Conditions of Uncertainty*. National Academies Press, Rome, Italy.

Patel, P., Mehta, D. & Sharma, N. 2022 A review on the application of the DRASTIC method in the assessment of groundwater vulnerability. *Water Supply* **22**(5), 5190–5205. https://doi.org/10.2166/ws.2022.126.

Piscopo, G. 2001 *Groundwater Vulnerability Map Explanatory Notes Castlereagh Catchment*. Centre for Natural Resources, NSW Department of Land and Water Conservation, Parramatta.

Rukmana, B. T. S., Bargawa, W. S. & Cahyadi, T. A. 2020 Assessment of groundwater vulnerability using GOD method. In: *IOP Conference Series: Earth and Environmental Science*, Vol. 477, No. 1, p. 012020. IOP Publishing.

Şener, E. 2021 Intrinsic groundwater vulnerability assessment, comparison of different methodologies and validation. *Arabian Journal of Geosciences* **14**(19), 1–17.

Shirazi, S. M., Imran, H. M., Akib, S., Yusop, Z. & Harun, Z. B. 2013 Groundwater vulnerability assessment in the Melaka State of Malaysia using DRASTIC and GIS techniques. *Environmental Earth Sciences* **70**(5), 2293–2304.

Stempvoort, D. V., Ewert, L. & Wassenaar, L. 1993 Aquifer vulnerability index: a GIS-compatible method for groundwater vulnerability mapping. *Canadian Water Resources Journal* **18**(1), 25–37.

Vijayakumar, C. R., Balasubramani, D. P. & Azamathulla, H. M. 2021 Assessment of groundwater quality and human health risk associated with chromium exposure in the industrial area of Ranipet, Tamil Nadu, India. *Journal of Water, Sanitation and Hygiene for Development* **12**(1), 58–67.

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