The Indian Geographical Journal
Volume 96 (2) December - 2021, pp 20-33
ISSN 0019-4824

IDENTIFICATION OF GROUNDWATER VULNERABLE ZONES THROUGH GEOGRAPHICAL INFORMATION SYSTEM (GIS) IN NOYYAL RIVER BASIN, TAMIL NADU

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Abstract

The Noyyal basin is one of the active industrial regions in Tamil Nadu facing a critical groundwater contamination. The vulnerability zones of the basin are delineated by combining the physical factors (depth to the groundwater level, net recharge, aquifer media, soil texture, topography, impact of the vadose zone, hydraulic conductivity, lineament density, proximity from the river) and environmental factors (land use/land cover, population density, and source of contamination). All the selected factors and their sub-classes are weighted and ranked based on their tendency to contaminate the groundwater resources. Using these factors geospatial layers are generated which in turn integrated through Geographical Information System (GIS) to generate groundwater vulnerability zones (at village level). The result shows that 18 percent of the area is highly vulnerable, and 31 percent is moderately vulnerable to contamination. The spatial result is explicit that the villages present adjoining the main river are under moderate to high-vulnerability than other areas.

Keywords: Groundwater Vulnerablity, Physical Factors, Environmental Factors, DRASTIC, Geographical Information System

Introduction

Groundwater is contaminated when the polluted water infiltrates through the soil and rocks, and eventually reaches the aquifer. Vulnerability assessment is one of the basic steps for monitoring and managing groundwater resources, and the factors of groundwater contamination can be identified from the source, pathway, receptor, and consequence (Zhang et al., 2013). The source of contamination is generally of both natural and anthropogenic origins. The transmission pathway of contaminants to the aquifer is on its aquifer medium, soil, fractures, etc. The people and environment are the receptors of contaminants. Consequences of the groundwater contamination are human health related issues, degradation of groundwater quality, agricultural productivity, soil infertility, etc.

Groundwater vulnerability is defined as the tendency of the aquifer for getting contaminated, and the zones of contamination can be delineated with vulnerability map

(Ducci,1999). The physically vulnerable regions can be delineated from the hydro-geological factors of the basin that controls the groundwater contamination. Index-based methods are commonly used for vulnerability zone delineation, such as SINTACS DRASTIC, DRIST, GOD, SEEPAGE, etc. to assess the intrinsic vulnerability of the groundwater (Al-Amoush et al., 2010; Muruganandam, 2015; Lathamani et al., 2015; Vaezihir and Tabarmayeh, 2015; Sakala et al., 2019). The DRASTIC model by Aller et al. (1987) is a relatively more reliable method to delineate the intrinsic groundwater vulnerability using the Geographical Information System (GIS). The model considers the factors such as Depth to the water level, net Recharge, Aquifer media, Soil, Topography, vadose zone Impact, and hydraulic Conductivity. Later, several modified DRASTIC models were adapted by the researchers to study the specific vulnerabilities by adding appropriate parameters. The pesticide DRASTIC model is used to study pollutant-based contamination (Meenakshi and Ganesh, 2019). Differences in vulnerability with distance from pollution sources such as industrial plants (Aylin et al., 2001) or landfill sites (Elliott et al., 2001) are important factors in environmental studies. The Geographical Information System (GIS) is an excellent tool for water resource management studies, and the integration of layers not only aids the visualisation but also makes the overall analysis more sound, objective, and simple (Simsek and Gunduz, 2007). Delineating the vulnerability zones using GIS is very much needed for the Noyyal River basin as it is an active industrial region.

Noyyal basin is located in the western part of Tamil Nadu state, originates from Velliangiri hills in the Western Ghats, and flows through four districts- Coimbatore, Tiruppur, Erode, and Karur. Noyyal is the right bank tributary that drains a total area of 3,500 km^2 and runs 180 km long to drain into the River Cauvery at Noyyal village, Karur District. The Noyyal basin lies between 10º54’ N to 11º19’ N latitudes and 76º39’ E to 77º55’ E longitudes. The basin takes over a fern leaf-like structure with a broad central part and narrow edges (Figure 1). The climate of the region is dry and warm, the natural flow of the Noyyal is seasonal and occurs only during the north-east monsoon months, but the river exhibits perennial flows in a few stretches because of the sewage from the urban and industrial centres, and returns the flow from Lower Bhavani Project. The lithology of the area comprises hard rock and unconsolidated formations. Hard consolidated rocks cover a significant part of the basin, mainly as weathered and fractured granite gneisses, granites, and charnockites. Red sandy and red loamy are the dominant types of soil. The basin is highly urbanised with a population density of 120 people/km^2 in the rural settlements and 1000 people/km^2 in urban centres. The basin is the cotton belt of Tamil Nadu, with favourable geographic and climatic conditions that shelter the hosiery industries. Urban centres-Coimbatore and Tirupur are the industrial hubs with most textile industries. Land use shrinks from agriculture to industrial and urban, with rural to urban migration showing the changing nature of the occupation. Assessing groundwater vulnerability is important, because the region is a promising source of groundwater for agriculture and human consumption. Therefore, classifying the basin into different categories based on its degree of contamination is a powerful tool for conservation of groundwater.

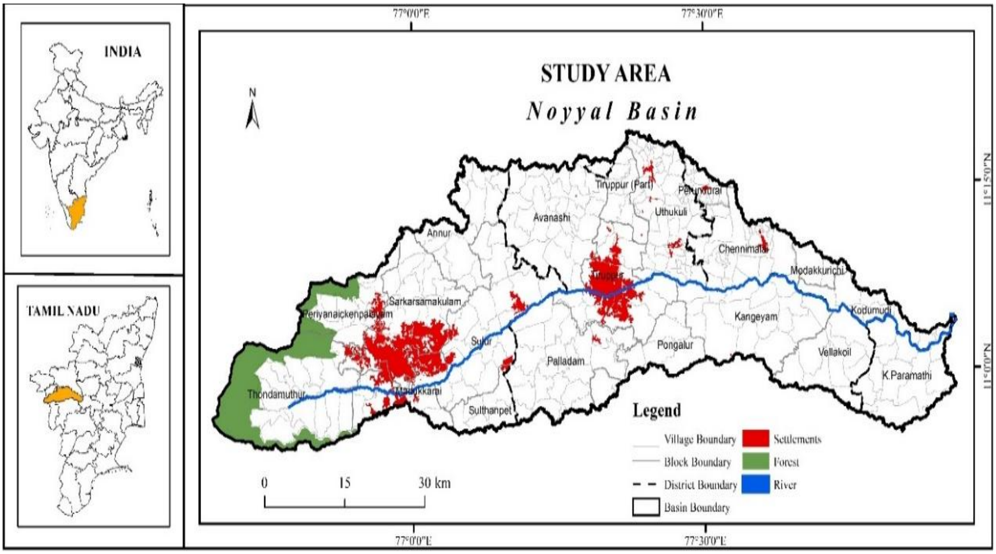

Figure 1: Location of the study area

Data and Methods

The study assesses the physical and environmental factors to prepare a groundwater vulnerability zone map for the Noyyal basin. Different data sources are used, and all the factors implemented are given in Table 1 below.

Table 1. Data sources and the type of data used for all the parameters

Factors	Data Used	Source
Depth to the Water and Net Recharge	Water Level and Rainfall (1987 - 2018)	State Ground and Surface Water Resources Data Centre (SG&SWRDC), Taramani, Chennai.
Aquifer Media	Geology	Geological Survey of India (GSI)
Soil Texture	Soil Data	Tamil Nadu Agricultural University (TNAU), Coimbatore
Topography	Aster 30m DEM	United States Geological Survey (USGS) - Earth Explorer
Impact of Vadose Zone and Hydraulic Conductivity	Vadose Zone and Conductivity	Central Ground Water Board (CGWB), Chennai
Lineament Density	Lineament	Web Map Service of Bhuvan, National Remote Sensing Centre (NRSC)
River Proximity and Land Use / Land Cover	Landsat 8 ETM+ 30m Resolution Imageries	USGS - Earth Explorer
Population Density	Demography	District Census Handbook, 2011

Physical Factors

DRASTIC

DRASTIC is a seven parameters model, i.e., Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone, and hydraulic Conductivity. It is widely used because the input information is either readily available or from governmental agencies. The model is more suitable in the plain and coastal regions than in hard rock zones. Noyyal basin is the hard rock region that would not aid aquifer interactions. Therefore, a modified DRASTIC model was attempted. The weights given to all the seven parameters range from 1 to 5, based on the relative importance.

Depth to the Water Level

Water travels for a certain distance to reach the saturation zone; this distance gives the time taken by the pollutant to travel and the extent of the contamination. The shallow aquifers are more easily susceptible to contaminants than deep aquifers. The depth level data was collected from SG & SWRDC, and the basin is classified into three depth categories - <10m, 10-20m, and >20m. Regions with greater distance are less vulnerable to contamination, therefore, the greater the distance smaller the rating value.

Net Recharge

The net recharge is the total water infiltrates from the surface to the aquifer. The greater the recharge of the aquifer, the higher the transmission of contaminants. The recharge of the basin is mainly due to rainfall. The rainfall data from 1980 - 2018 was collected from SG & SWRDC. The rainfall values vary from <500 mm to >900 mm, and the ratings were assigned from 2 – 10.

Aquifer Media

The geological formation of the basin has both consolidated and unconsolidated materials that yield sufficient water for an aquifer. It controls the route and path length of a contaminant, which in turn determines the attenuation and purification capacity. The unconsolidated material enables to penetrate water into the aquifer than the hard rock. Aquifer media data was obtained from the Geological Survey of India, and a wide range of aquifer media are present in the basin, out of which fluvial and alluvium are given the highest rating of 10.

Soil Texture

Soil is the topmost layer of the vadose zone, and it has its potential influence on groundwater contamination (Saidi, 2011). Soil texture has a strong connection with permeability and porosity. Soil with a coarse texture can transmit contaminants more rapidly than a fine texture. Soil texture data was collected from TNAU, and the rating was based on whether the soil texture was coarse or fine.

Topography

The topography represents the slope or land surface of the basin, and it was derived from the ASTER 30m DEM data. The topography indicates the possibilities of pollutant infiltration or run off, and here in the study area, the slope of the basin varies from $<1\%$ to $>15\%$.

Impact of Vadose Zone

The vadose zone is the unsaturated or partially saturated zone that is present below the ground surface and above the aquifer. The vadose zone can control the water movement and the attenuation capacity (Meenakshi and Ganesh, 2019). Vadose zone data was collected from Central Ground Water Board. The thickness of the vadose zone influences the percolation of contaminants into the water table. The thicker the vadose zone, the time taken by the contaminants to reach the aquifer is also high. The basin is prominently covered by metamorphic and igneous hard rock having a low vadose zone impact, and a moderate impact zone has sand and gravel mixed with silt and clay.

Hydraulic Conductivity

Hydraulic conductivity is one of the important factors that control the groundwater flow within the aquifers. It is defined as the rate at which the groundwater will flow under a given hydraulic gradient. The rate of groundwater movement is directly proportional to the rate of contaminant transmission. Aquifer with high hydraulic conductivity leads to high transmission of contaminants. Hydraulic conductivity of the basin is calculated as follows,

$$K = T / h$$

Where, K is the Hydraulic conductivity in m/day;
T is the Transmissivity in m^2 per day and
h is thickness in metre.

Conductivity data was collected from Central Ground Water Board, and the hydraulic conductivity values of the basin range from <100 m/day to >700 m/day are categorised into four classes (<100m, 100-300m, 300-700m and >700m).

Other Physical Factors

Lineament Density

The interaction of aquifers within the study area is very low due to the hard rock formation. The lineaments provide the secondary porosity for water percolation. It acts as a conduit and enables groundwater interaction in the hard rock region. The higher intensity of lineaments would increase the chance of contaminant movement towards groundwater (Abdullah, 2015). Lineament data was obtained from the Web Map Service of Bhuvan, National Remote Sensing Centre. Lineament density values range from <0.5 km/km^2 to >0.9 km/km^2.

River Proximity

Proximity from the river is one of the important factors considered for the delineation of the vulnerability zones in the Noyyal basin. The interaction of groundwater within the basin is very low because the majority of the region is of hard rock. However, the exchange happens through the sedimentary deposits found along the main river. Several industrial and bleaching units, CETPs (Common Effluent Treatment Plants), and STPs (Sewage Treatment Plants) are present on the bank of the river. Therefore, the proximity to the main river is an important factor that governs groundwater contamination. The groundwater wells that are present close to the main river are more prone to contamination than the farther wells, and the proximity values range from <1 km to >6 km, are ranked accordingly.

Environmental Factors

Source of Contamination

Point and non-point are the sources of pollutants. A point source is a discharge from a structure specially designed for the disposal of effluents, and on the other hand, a non-point source of contamination has widely distributed sources. Therefore, it is difficult to address the treatment of pollutants. In the basin, wastewater from the electroplating industries, bleaching and dyeing units, effluent treatment plants, sewage treatment plants, municipal dumping sites, and sewage are considered as point sources. The non-point source of contamination is mainly the agricultural land due to the use of fertilisers and pesticides, and these pollutants enter the riverine system through return flow. The intensity of contamination is high in the point source contamination. Hence, a high rating is given and a low rating to the non-point source of contamination.

Land Use / Land Cover

Land use/ land cover is a salient factor that could be utilised for the identification of the source of contaminants. Residential and agricultural land are the two-prime land-use types that supply pollutants to the groundwater (Sener, 2012). Sewage disposal, garbage dumping, and industrial wastewater are the sources of contaminants that are aggregated from the built-up land and contaminants like fertiliser and pesticides are from agricultural land use. The classes are rated depending on their pollutant intensity.

Population Density

In an urban environment, population density is one of the prominent factors used for evaluating pollutant load (Nurroh et al., 2020). The region is vulnerable to contamination when the population density is high. Urban areas with high population density are the contributors of pollutants, such as municipal waste, sewage disposal, industrial wastewater, etc. (Vaezihir and Tabarmayeh, 2015).

Groundwater Vulnerability Index

Each of the above listed parameters are mapped in GIS by overlaying their appropriate factors. Weights and rating for all the parameters were assigned on the basis of level of vulnerability. The linear combination of the generated thematic layers and the assemblage of the weights leads to the creation of groundwater vulnerability zones (Kourgialas and Karatzas, 2015). Each factor is multiplied by its weight and ranked. Then all the factors were summed to produce the final resultant layer.

$$\mathbf{GVI} = \sum_{\mathbf{i=1}}^{\mathbf{n}} \mathbf{w_i x_i}$$

Where, GVI is the resultant layer, i is the appropriate factors for a particular index, n is the number of factors and x_i is the rank of factor i. The weightage and ratings of the factors are tabulated in Table 2.

Results

Groundwater Contamination

All the seven parameters of the DRASTIC model vary within the basin are as follows. Depth to water, the basin has a shallow aquifer in the eastern part, moderate in the central region, and deep aquifers in the western part. The Western Ghats is located in the western part of the basin, and the region receives more rainfall than the rest. Therefore, net recharge is substantial in this region. The geology of the study area is highly characterised by old crystalline, and metamorphic rocks belonging to the Archaean group, and the basin is entirely underlain by gneiss. The unconsolidated alluvial deposit is found under the foothill of the Western Ghats and could also be seen along the course of the river bed. Hydraulic conductivity is high along the river course. The coarser soil textures like sandy, loamy sand, and sandy loam are highly present in the eastern portion of the basin having a high tendency to transmit contaminants. The western part of the basin has a steep slope, and high vadose zone impact that is filled with pervious sand and gravel material. The spatial results reveal that the vulnerability of the region is high along the course of the main river than the peripheral parts. Figure 2 portrays modified DRASTIC layers with vulnerable zones.

Other Controlling Factors

The industrial cluster of the basin (3km buffer zone from the major source of pollutants) is considered as a point source of contamination, and the rest of the region is considered to be non-point source of contamination. Therefore, the region present within the one km buffer zone from the main river is highly vulnerable to groundwater contamination. Coimbatore and Tiruppur corporations are regions with high population densities and are the sources of potential pollutants. Figure 3 show the source of contamination, land use/land cover, and population density vulnerable zones.

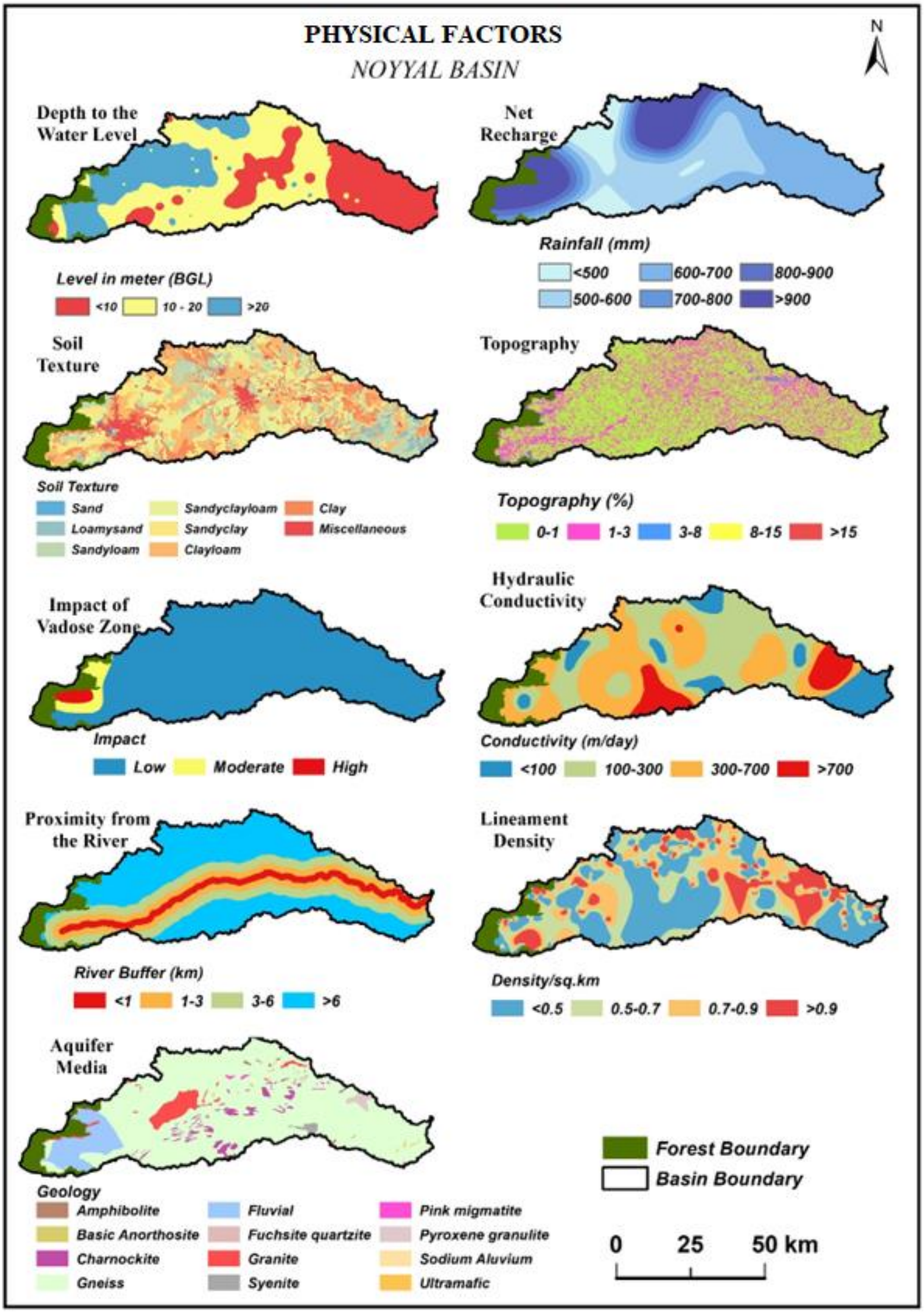

Figure 2: Physical factors - Depth to the water level, Net Recharge, Soil Texture, Topography, Impact of Vadose Zone, Hydraulic Conductivity, Proximity from the River, Lineament Density, Aquifer Media of the Noyyal Basin

Table 2. Weights and rating for all the parameters

Factors	Parameters	Sub-classes	Weightage (w)	Ratings (x)
DRASTIC	Depth to the Water Level (m)	<10	5	10
		10 - 20		6
		>20		2
	Net Recharge (mm)	<500	4	2
		500-600		2
		600-700		4
		700-800		6
		800-900		8
		>900		10
	Aquifer Media	Fluvial, Sodium Alluvium	3	10
		Gneiss		8
		Pyroxene granulite, Fuchsite Quartzite		6
		Amphibolite, Charnockite		4
		Anorthosite, Granite, Syenite, Pink migmatite and Ultramafic		2
	Soil Media	Miscellaneous	2	0
		Clay, Clay Loam		2
		Sandy clay		4
		Sandy clay loam		6
		Loamy sand, Sandy Loam		8
		Sand		10
	Topography (%)	<1	1	10
		1-3		8
		3 - 8		6
		8 - 15		4
		>15		2
	Impact of Vadose Zone	Metamorphic & Igneous	5	2
		Sand & Gravel with Significant Silt & Clay		6
		Sand & Gravel		10
	Hydraulic Conductivity (m/day)	<100	3	2
		100 - 300		6
		300 - 700		8
		> 700		10
Other Physical Factors	Lineament Density (km/km^2)	<0.5	5	2
		0.5 – 0.7		6
		0.7 – 0.9		8
		>0.9		10
	Proximity from the Main River (km)	<1	5	10
		1-3		8
		3 - 6		4
		>6		2
Environmental Factors	Source of Contamination	Point Source Contamination	5	10
		Non-Point Source Contamination		2
	Land Use / Land Cover	Built-up	4	10
		Agriculture Land		8
		Waterbody		6
		Wasteland, Scrubland		4
		Forest Land		2
	Population Density	<1500	3	2
		1500-3000		6
		3000-4500		8
		>4500		10

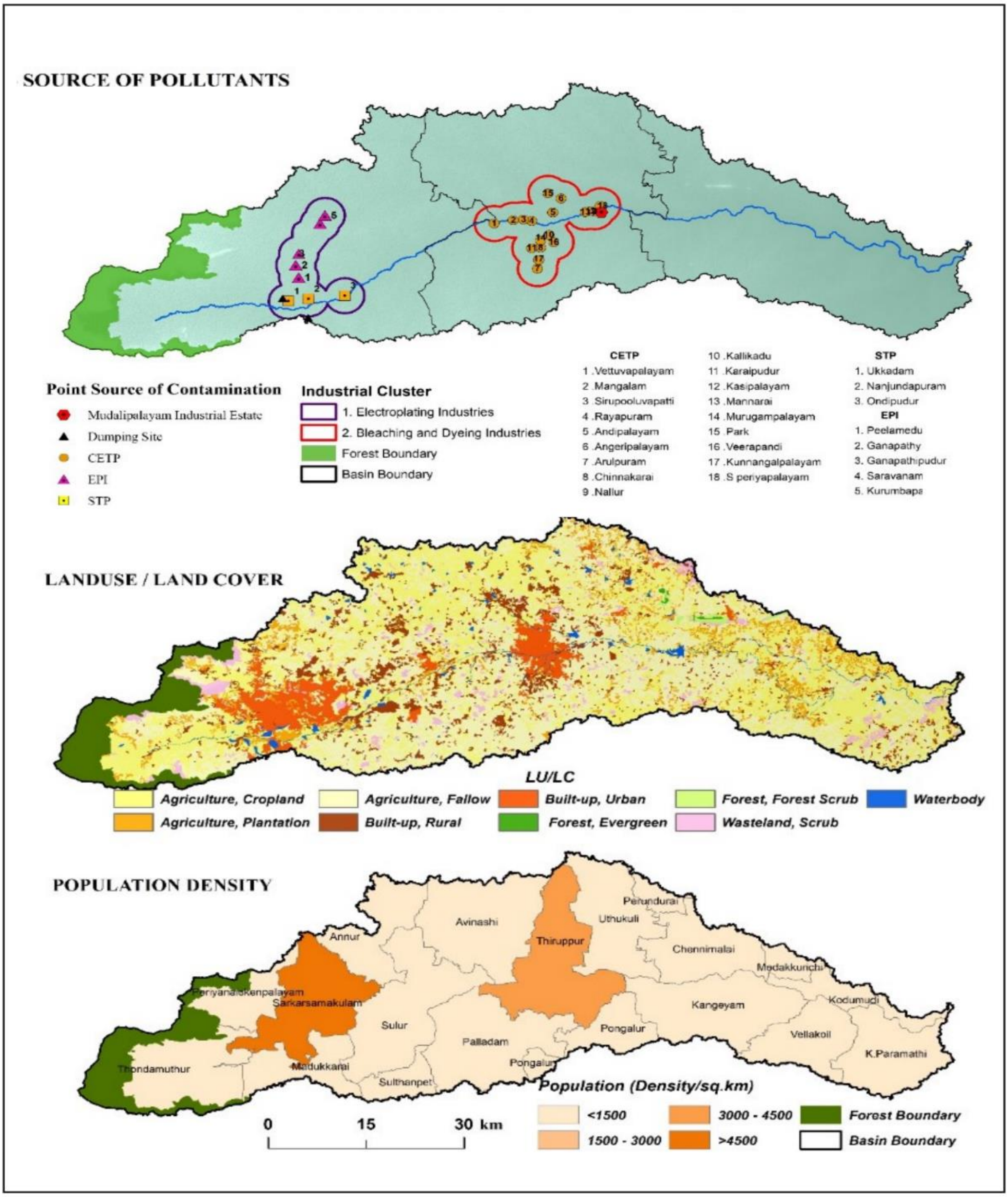

Figure 3: Environmental Factors - Point Source of Contamination, Land Use / Land Cover and Population Density of the Noyyal Basin

Groundwater Vulnerability Index

The groundwater vulnerability zones were delineated by overlaying all the physical and environmental layers (Figure 4). The result shows that 18 percent is highly vulnerable, 31 percent is moderately vulnerable and 51 percent is low vulnerable, of the total area. After generalising the result, it is pinpointed that among 285 villages, 18 villages are under the highly vulnerable zone, 105 villages are in the moderate zone, and the rest 162 villages are in the less-vulnerable zone. The Tiruppur corporation and the southern portion of the Coimbatore corporation are highly vulnerable. The spatial result shows that the villages adjacent to the main river are moderately to highly vulnerable to contamination due to the sedimentary deposits. The northern and southern portions of the basin are vulnerable to contamination because of the hard rock structure.

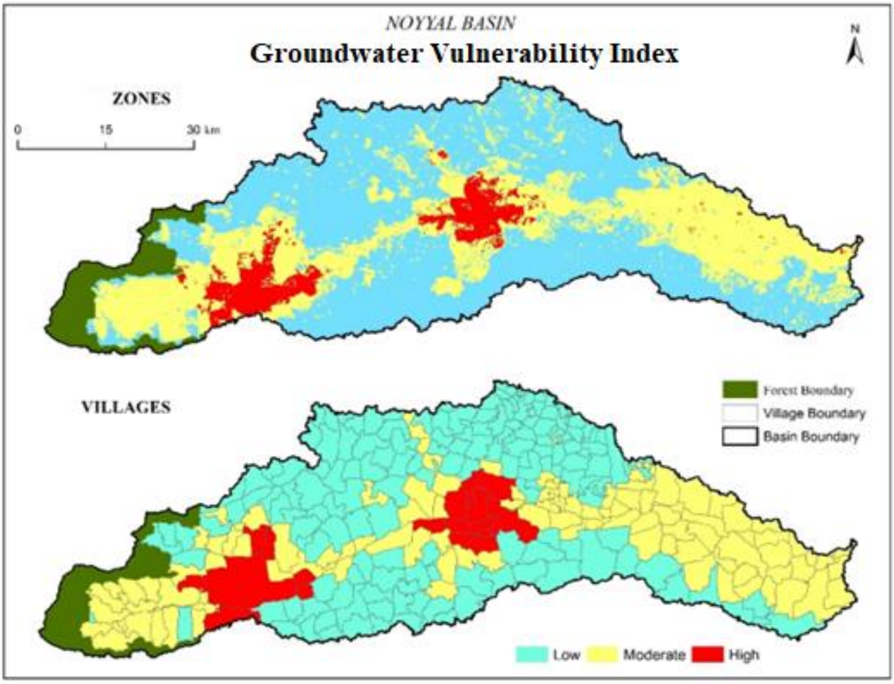

Figure 4: Groundwater Vulnerability Zones and Vulnerable Villages in the Noyyal Basin

Discussion

Groundwater quality analysis of the Noyyal basin has shown that the water from most parts of the area is unhealthy for human consumption and irrigation purposes. The reasons are anthropogenic and geological, i.e., less recharge, longer duration of contact, chemical weathering of rock-forming minerals (Selvarani and Shivakumar, 2020, Duraisamy et al., 2019). Here in the study, the western-most basin is under the foothills of the Western Ghats with uncontaminated freshwater, and the water quality index constitutes good in quality for drinking and irrigation purposes. However, the region tends to be highly vulnerable to groundwater contamination due to the presence of unconsolidated formation, high vadose zone impact, and recharge region. In parallel, the easternmost part is also highly vulnerable because of a very porous soil texture (sand and sandy loam), shallow aquifer, and high lineament density.

The northern and southern peripheries of the basin remain less vulnerable. Due to the hard rock formation, these areas remain undisturbed by the contaminants. The central and the downstream area of the basin are at high vulnerability where agriculture is the main occupation of the people. The region within the buffer of one km is at high vulnerability, and the periphery is low to moderate vulnerability because of the hard rock formation with less lineament density, low hydraulic conductivity, and distant from the river. The villages adjoining the main river are at moderate to high vulnerability for trace element contamination. A high vulnerability to contamination is assessed in the southern portion of the Coimbatore corporation due to contamination from the hazardous dumping sites and sewage treatment plants. Shallow water table, gentle topography, sandy loamy soil, thinner vadose zone, and underlying geologic formations with well-developed fissures and fractures are the causes of high vulnerability in the Noyyal basin as suggested by (Saranya et al., 2021), and the outcome of the study is in congruence with it.

Conclusion

In the study, groundwater vulnerability assessment is implemented to find the potentially vulnerable zones of the basin. The modified DRASTIC model that includes the lineament density, proximity from the river, source of contamination, population density, and land use/land cover factors was employed to delineate the specific groundwater vulnerability zones. Contamination zones were depicted from the point source contamination of industrial clusters (hotspot for contamination) and water quality indices. All the layers were weighted and integrated into the GIS environment. The northern and southern portion of the basin remains at low vulnerability. Due to the bedrock formation, these areas remain undisturbed by the contaminants. The basin exhibits a higher vulnerability in 18 villages near the Coimbatore and Tiruppur corporations. The aquifers of these regions are more vulnerable to contaminants. The quality of the contaminated aquifers could be improved by the injection of harvested rainwater, along with suitable artificial recharge structures. Therefore, the vulnerable regions need proper management strategies.

Acknowledgment: The first author wishes to thank the University Grants Commission (UGC) for providing Basic Scientific Research Fellowship and the second author wishes to thank the Indian Council of Social Science Research (ICSSR) for providing Senior Fellowship to carry out the research in the Department of Geography, Bharathidasan University, Tiruchirappalli. The authors would also like to thank Defence Research & Development Organisation, Ministry of Defence, Government of India and Department of Environmental Sciences, Bharathiar University, Coimbatore for providing IC-PMS facility for groundwater element analysis.

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