Groundwater Vulnerability Assessment in Pavagada taluk, Tumakuru district, Karnataka, India, using a GIS-based DRASTIC model

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Abstract: - Throughout the world, one of the most accessible resources is groundwater. Groundwater quality is rapidly declining due to anthropogenic and geogenic sources, resulting from over-reliance. Previous research indicates that the concentration of pollutants such as Fluoride, Arsenic, Iron, and Total Dissolved Solids has rapidly increased. This affects crop yield and human health as well as the socioeconomic development of the region. For this reason, identifying areas where groundwater is vulnerable is crucial to reducing pollution in groundwater and maintaining its quality. In this study, groundwater-vulnerable zones in Pavagada Taluk are evaluated using the GIS-based DRASTIC model. The seven DRASTIC parameters are combined with data on land use and land cover to help explain how anthropogenic sources and possible human intervention affect groundwater quality. It is observed that the groundwater samples we collected had high concentrations of Iron, Sulphate, Fluoride, and Nitrate, as per BIS 10500 (2012). The study area's northeastern, southeastern, northern, southern, and southwestern regions are classified as high to moderate risk zones on the final DRASTIC map. The high Fluoride content in groundwater is caused by bore wells situated on rocks such as Granite, Granodiorite, Hornblende-Biotite Gneiss, and Biotite. In order to validate the model, the results of the physicochemical analysis were compared to the final drastic map. This comparison shows that the model is 80.39% valid for the region.

Keywords*: DRASTIC, Fluoride, GIS, Groundwater.*

1. Introduction

Around the world, groundwater is the primary source of freshwater for domestic use, irrigation, and industry (Dangar, Asoka, and Mishra 2021, Li et al. 2022). Its dependability is growing due to its accessibility, low treatment costs, ability to withstand contamination, and ability to function during dry spells. Over 50% of the urban population depends on groundwater, and this percentage is rising quickly due to factors like urbanisation, rising per capita demand, and dwindling perennial sources. In rural areas, over 90% of people rely on groundwater for both basic needs and agricultural activities (Varua et al., 2018). In India, a significant amount of groundwater is used for agriculture due to erratic rainfall and inadequate irrigation infrastructure, such as tanks and canals. (Dalin, 2021). Additionally, groundwater levels are being lowered by the growing groundwater-based agricultural sector and urban areas' reliance on tube wells (Fischer et al., 2022). Increased risk of Fluoride and arsenic contamination in deeper aquifers makes groundwater unfit for human consumption. (Parrone et al., 2020). Other sources of groundwater contamination include runoff from mining operations, spills and leaks from industrial activities, and extreme use of agrochemicals. The primary factors contributing to groundwater contamination in urban areas are surface water pollution and urban runoff. Septic systems, underground petroleum storage tanks, unapproved waste disposal yards, and pollutants carried by runoff are also major contributors (Müller et al., 2020). Accordingly, studies that evaluate groundwater vulnerability are essential for determining the most susceptible areas, which aids legislators in developing practical plans to prevent groundwater contamination (Ram et al., 2021). A number of models have been developed to assess groundwater susceptibility., including SINTACS (Civita et al., 1997), EPIK (Doerfliger 1999; Nekkoub et al., 2020), AVI (Stempvoort et al. 1993), GOD (Foster 1987), and PI (Goldscheider et al., 2000), DRASTIC (Aller et al. 1986), SIGA (Vrba, 1991), FIS (Pathak & Bhandary, 2020), etc. According to Al-Rawabdeh et al. (2013), of the models mentioned above, when evaluating groundwater vulnerability, the DRASTIC model is the most generally used and recognised model. The US Environmental Protection Agency successfully implemented this model for the first time. (Aller et al. 1986, 1987). According to (Ahada and Suthar 2018), the primary benefit of this model is its ability to predict the factors governing the transport of pollutants in groundwater over a wide geographic area. This facilitates a more thorough evaluation of the groundwater's suitability for human use and other industrial processes. The groundwater pollution vulnerability assessment for Pavagada taluk in Tumakuru District has been carried out using the DRASTIC model in conjunction with Remote Sensing (RS) and Geographic Information System (GIS). The model's final validation was determined using the groundwater quality measurements of the samples collected from the study area. Lithologically, the region under study is made up of pink granite (31% of the total area), pink granulite (more than 55% of the western and central sections), Closepet Granite (66% of the territory), and Peninsular gneisses (34% of the area). According to the 2011 census, there are 245194 people living in Pavagada Taluk. With a decadal change of -0.43%, the population density of the Taluk is 159.57 people per square kilometre. The primary source of income for this taluk's maximum standard of living is agriculture. This taluk has 6754 ham of net groundwater available, of which 4626 ham were utilized for irrigation and 574 ham were utilized for residential and commercial purposes, according to CGWB data from 2017. Fluoride concentrations in over 60% of the samples exceeded the permissible limit of 1.5 mg/l with regard to groundwater quality. The DRASTIC model is crucial in this situation because it assists local authorities in determining the groundwater zones that are most susceptible to future groundwater development and water resource management.

2. Materials and methodology

2.1 Geographical overview of the study area

The semi-arid Pavagada taluk, which spans 1360.98 km^2 and is located in the Tumakuru district of Karnataka state, is vulnerable to drought. Situated between latitudes 13º55' N and 14º20' N and longitudes 77º30' E and 78º05' E (Figure 1). Compared to other Tumakuru district taluks, it has a hotter climate, with summertime highs of 40ºC and 560mm of annual rainfall on average. The Non-perennial River and low rainfall in Pavagada taluk make groundwater the most valuable resource for addressing basic needs. Nearly 85% of the workforce is directly employed in agriculture, and in the past few decades, even on tiny plots of land, the number of bore wells has increased.

2.2 Materials used

The following seven parameters were taken into account: Topography (T), Impact of the vadose zone (I), Depth to water level (D), Net recharge (R), Aquifer media (A), Soil media (S), and Hydraulic conductivity (C). All of the data are shown in Table 1, along with their utilities and sources.

2.3 Materials applied

This overlay analysis-based model is widely utilised to evaluate vulnerability. It is well-recognised that overlay analysis depends on several variables. A single output is produced by all parameters that are weighted differently. Among these is the DRASTIC model. The following lists the main procedures involved in calculating the DRASTIC model.

Step one: Compiling all relevant data (Figure 2; Table 1).

Step Two: Table 2 illustrates how each theme layer has been distributed into several sub-classes.

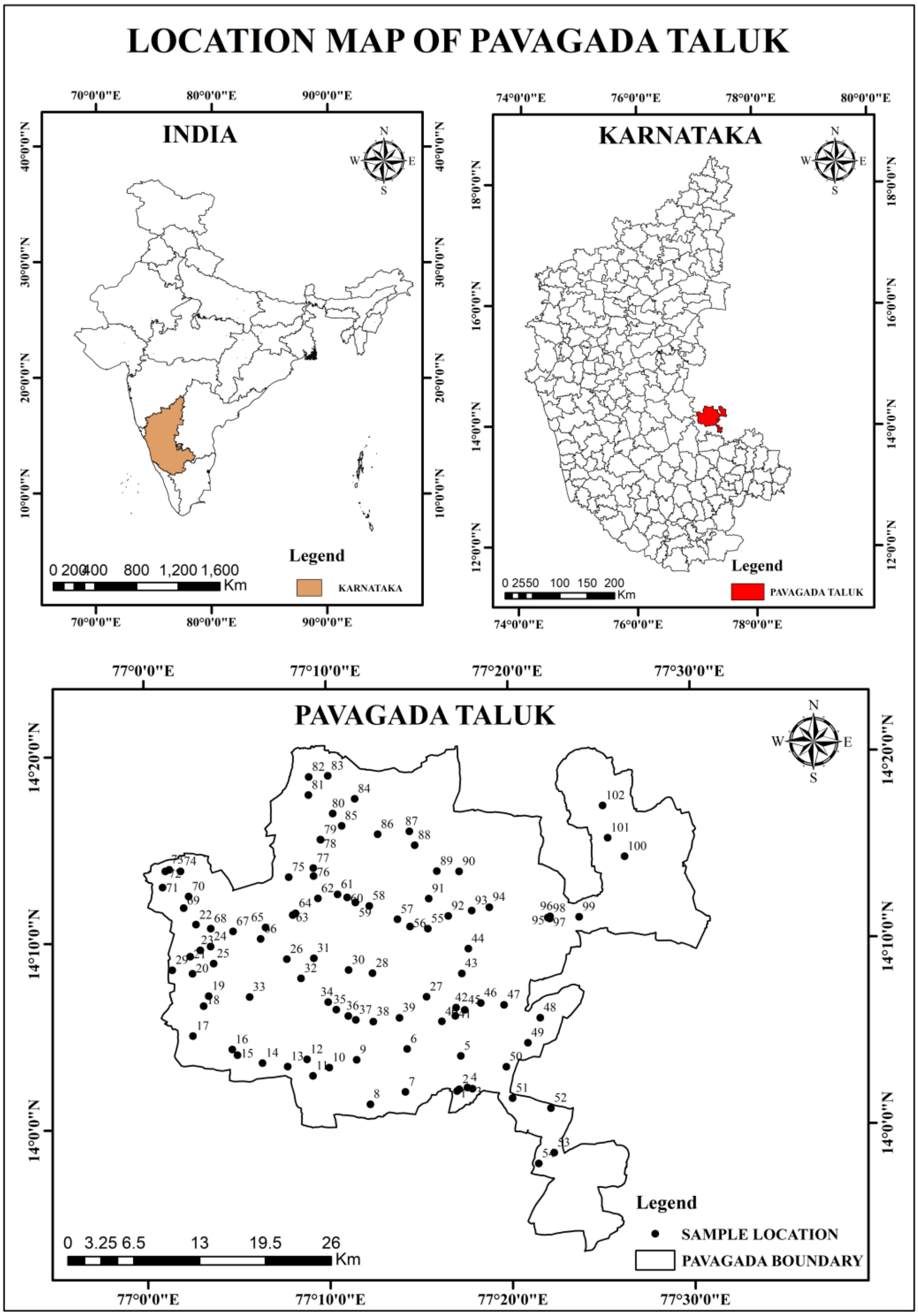


Figure 1 Location map of Pavagada taluk

Step Three: This step is primarily used to compute the weight (W) and rate (R) for each layer's sub-class. There is a rate assigned based on the importance and requirements of this model. Table 2 illustrates that weight is constant for a single layer while rates (R) differ for different subclasses. After the weight (W) and rate (R) have been calculated, to calculate the total weight (R. Ghosh et al., 2021).

$$Total\ weight = Rate * weight$$

Table 1 Type of data and source used in this study

Sl.No.	Data type	Data Source
1	Depth to water level	CGWB
2	Recharge	CGWB
3	Aquifer media	Geological survey of India
4	Soil media	National soil and land use board
5	Topography	SRTM (http://earthexplorer.usgs.gov.)
6	Impact of Vadose zone	CGWB
7	Hydraulic Conductivity	CGWB
8	Land use land cover	IRS-R2 LISS-IV at 5.8m resolution

Table 2 Class, rank and weight for the DRASTIC parameters

Thematic layer	Sub-classes	Assigned rate-r	Assigned weight(w)	Total weight
Depth to Water level, mbgl	7.7-10	9	5	45
	10.1-15	8	5	40
	15.1-20	7	5	35
	20.1-25	5	5	25
	25.1-37.5	3	5	15
Net Rechage, mm/year	0 – 1.5	3	4	12
	1.51 - 2	4	4	16
	2.1 - 2.5	5	4	20
	2.51 - 3	6	4	24
	3.1 - 3.6	7	4	28
Aquifer media	Banded Biotite Gneiss and Hornblend Gneiss	9	3	27
	Granodiorite and Granite	8	3	24
	Hornblende-Biotite Gneiss	9	3	27
	Metabasalt	4	3	12
	Pink and Grey Granite	6	3	18
	Pink Granite	6	3	18
	Pink Granulite	6	3	18
	Quartzite/Quartz-Sericite Schist	4	3	12
Soil media	Fine	3	2	6
	Fine loamy	4	2	8
	Clayey skeletal	3	2	6
	Clayey over sandy	5	2	10
	Loamy	5	2	10
	Loamy Skeletal	6	2	12
	Dyke Ridges	2	2	4
	Rock area	2	2	4

Table 2: continued….

	Habitations	9	2	18
	Water bodies	4	2	8
Topography(slope)	0-1%	10	1	10
	1-3%	9	1	9
	3-5%	8	1	8
	5-10%	5	1	5
	10-15%	3	1	3
	15-35%	2	1	2
	35-50%	1	1	1
Impact of vadose zone	Clayey	2	5	10
	Coarse Sandy Silt	6	5	30
	Granules	6	5	30
	Silt	5	5	25
Hydraulic Conductivity, mm/day	50-100	4	3	12
	100-150	5	3	15
	150-200	6	3	18
	200-250	7	3	21
	250-300	8	3	24
Land use Land cover	Built up	9	5	45
	Agriculture land	8	5	40
	Forest	2	5	10
	Wastelands	2	5	10
	Water bodies	4	5	20

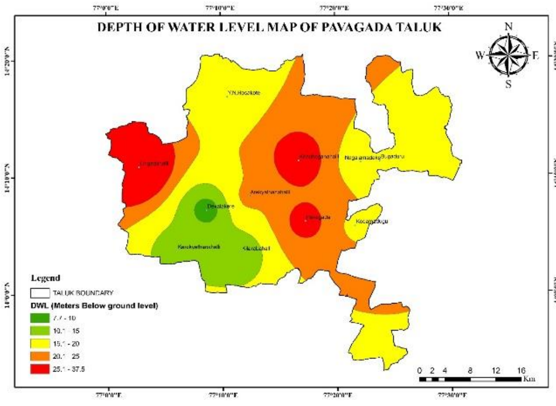
Step Four: Next, Using the reclassify tool in the Arc GIS environment, all thematic layers were reclassified. For every theme layer, an attribute table with the total weight of every pixel was made.

Step Five: The final DRASTIC model map was obtained by a quick calculation using the raster calculator in the Arc GIS programme (R. Ghosh et al., 2021).

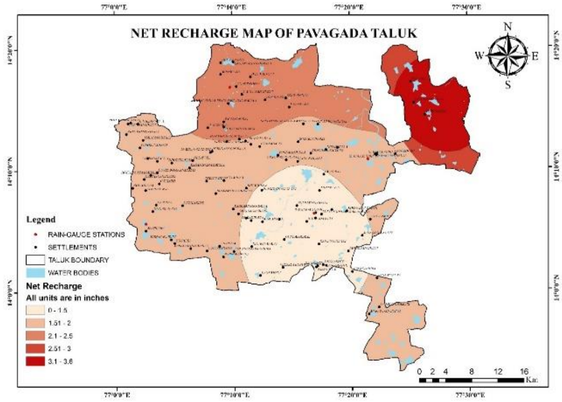
$$\text{DRASTIC Index} = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw$$

Where w is the matching weight factor and r is the associated rating factor. The letters D, R, A, S, T, I, and C stand for Depth to water level, Net recharge, Aquifer media, Soil media, Topography, the Impact of the vadose zone, and Hydraulic conductivity, respectively, and represent the seven parameters.

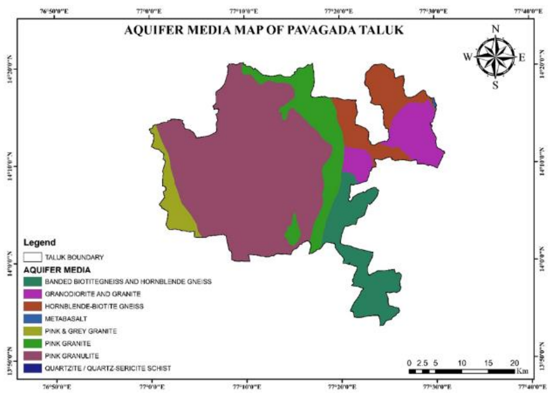
A detailed summary of every theme layer has been provided below to ensure proper understanding of the previously mentioned stages.


DEPTH OF WATER LEVEL MAP OF PAVAGADA TALUK
Legend
TALUK BOUNDARY
DWL (Meters Below ground level)

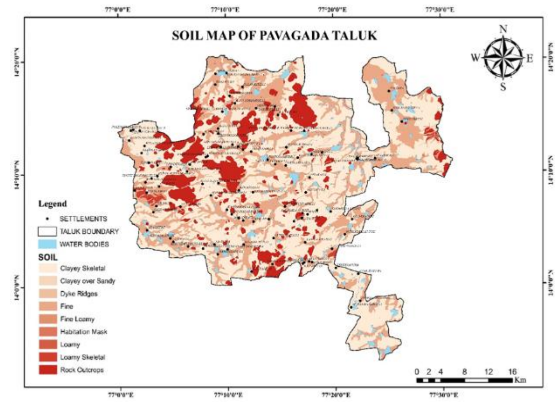
a


NET RECHARGE MAP OF PAVAGADA TALUK
Legend
RAIN-GAUGE STATIONS
SETTLEMENTS
TALUK BOUNDARY
WATER BODIES
Net Recharge
All units are in inches

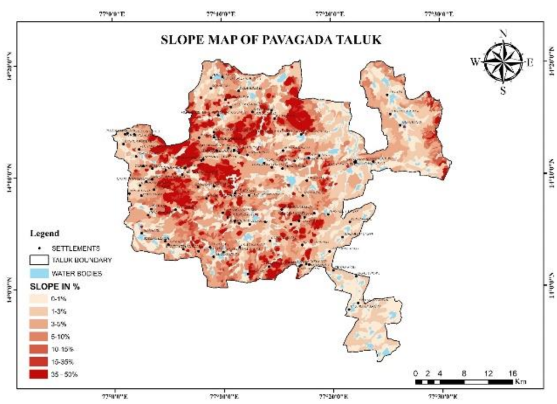
b


AQUIFER MEDIA MAP OF PAVAGADA TALUK
Legend
TALUK BOUNDARY
AQUIFER MEDIA
BANDED BIOTITEGNEISS AND HORNBLENDE GNEISS
GRANODIORITE AND GRANITE
HORNBLENDE-BIOTITE GNEISS
METABASALT
PINK & GREY GRANITE
PINK GRANITE
PINK GRANULITE
QUARTZITE / QUARTZ-SERICITE SCHIST

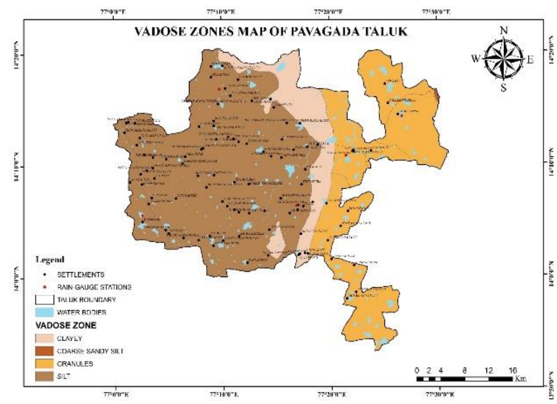
c


SOIL MAP OF PAVAGADA TALUK
Legend
SETTLEMENTS
TALUK BOUNDARY
WATER BODIES
SOIL
Clayey Skeletal
Clayey over Sandy
Dyke Ridges
Fine
Fine Loamy
Habitation Mask
Loamy
Loamy Skeletal
Rock Outcrops

d


SLOPE MAP OF PAVAGADA TALUK
Legend
SETTLEMENTS
TALUK BOUNDARY
WATER BODIES
SLOPE IN %

e


VADOSE ZONES MAP OF PAVAGADA TALUK
Legend
SETTLEMENTS
RAIN GAUGE STATIONS
TALUK BOUNDARY
WATER BODIES
VADOSE ZONE
CLAYEY
COARSE SANDY SILT
GRANULES
SILT

f

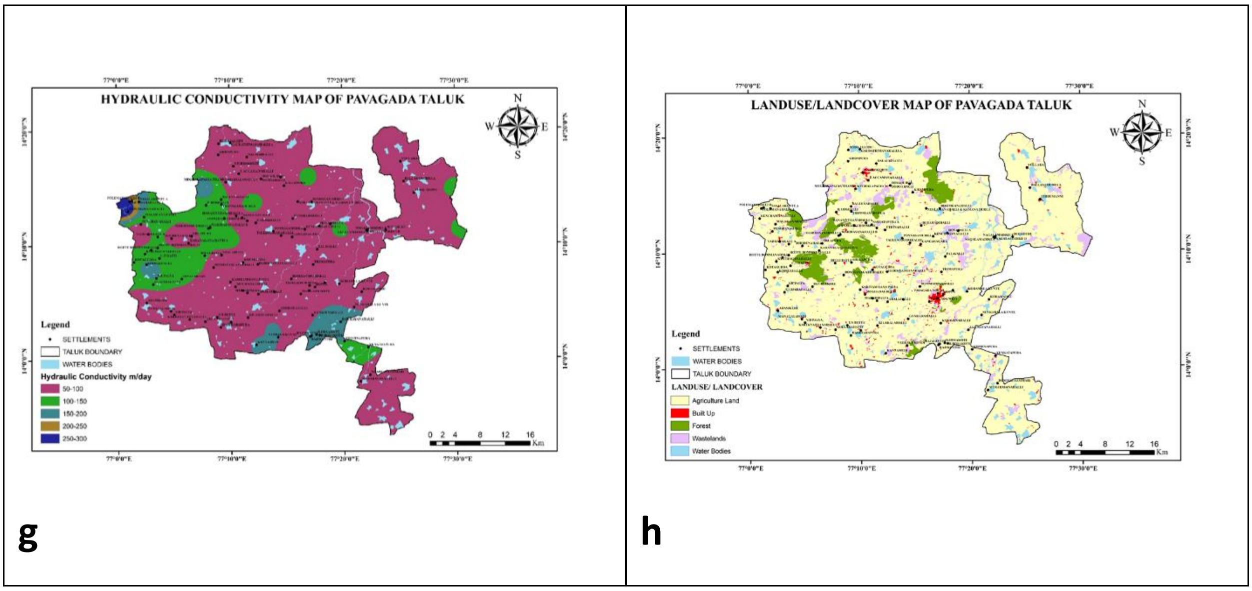


Figure 2 Layer maps of DRASTIC Parameters

The depth to water is the most important factor. Deeper water levels typically result in longer pollutant travel times, which raises the possibility of a decrease (A. Ghosh et al., 2015). Thus, a minimum rating of three has been assigned to higher depth, and a maximum rating of nine to lower depth. (Table 2). There is more chance of groundwater pollution in the southern region of the research area because it has the lowest water table, as indicated by the high scores (9 and 8). In the research region, the northern, eastern, central, and a small portion of the south eastern part have a rating of 7, while the western, north eastern, and south eastern regions have the deeper water table, with ratings of 5 and 3.

The volume of recharge has a direct relationship with the likelihood of aquifer contamination (Barbulescu, 2020) established a minimum rate of 3 for 0-1.5 mm/year and a maximum rate of 7 for 3.1-3.6 mm/year. Due to its high percentage of urban land, lower rainfall than other areas of Pavagada taluk, and generally lower recharge rate, the southernmost portion of the research area is ranked lowest.

The availability of groundwater and aquifer contamination are directly impacted by materials such as sand, limestone, gravel, and other materials (Adnan et al. 2018). The likelihood of contamination is directly correlated with grain size. As grain size gets smaller, the chance of aquifer contamination will go down (Shah et al., 2021). It is mostly made up of Pink Granulite in the research area (more than 55%), Pink Granite (11%) Banded Biotite Gneiss, and Hornblende Gneiss (11%). The remaining twenty-three percent is composed of different aquifer media, including Quartzite/Quartz-Sericite Schist (0.05%), Hornblende-Biotite Gneiss (9%), Metabasalt (0.05%), Pink and Grey Granite (4%), and Granodiorite and Granite (9%).

Soil media affects groundwater recharge, which is one of the primary pathways by which pollutants pass from the surface to the phreatic level (Kirlas et al. 2022). The majority of the study's area is composed of loamy skeletal soil (55%), fine soil (26.66%), rocky areas (12%), water bodies (3.5%), and other types of soil (2.84%).

Slope is one of the key topographic factors affecting the rate of infiltration and water level recharge, according to Saud (2010). The slope angle and the infiltration rate are inversely correlated (Rahmati and Samani 2014). As a result, Table 2 shows that the areas with a lower slope have been assigned a higher rate, while the steeper slope has been assigned a lower rate. A mild slope of (0-1%) with a DRASTIC rating of 10, (1-3%) with a DRASTIC rating of 9, (3-5%) with a DRASTIC rating of 8, (5–10%) with a DRASTIC rating of 5, (10–15%) with a DRASTIC rating of 2, (15–35%) with a DRASTIC rating of 2, and (35–50%) with a DRASTIC rating of 1(Table 2).

The vadose zone is an unsaturated region that stretches from the earth's surface to the uppermost portion of the phreatic zone. Compared to the impermeable layer, the permeable vadose layer has a greater influence on the flow of contaminants. Accordingly, Table 2 shows that the permeable layers received higher ratings than the impermeable layer. Throughout the whole research region, four distinct types of vadose zones have been observed (Figure 2f). This region's maximal area, or roughly 797.06 km^2, is covered in a silt layer. There have also been reports of granules, clayey, coarse, and sandy silt with little water in this area, in addition to these three layers. The regions that these three layers have been covered are 392 km^2, 155.10 km^2, and 1.05 km^2, in that order. For clayey, coarse sandy silt, granules, and silt, the vadose zone has been rated 5, 7, 5, and 1, respectively.

Depending on the kinds of soil in that area, hydraulic conductivity is described as the capacity to transfer fluid via pores and fractured rocks (Zhang et al., 2022). Therefore, a rating of 8 has been given to the zone of 250-300 mm/day hydraulic conductivity, rating of 7 has been given to the zone of 200-250 mm/day, rating of 5 has been given to the zone of 150-200 mm/day, rating of 3 has been given to the zone of 100-150 mm/day, rating of 4 has been allocated to the zone of 50-100 mm/day hydraulic conductivity (Aller et al. 1986) (Table 2).

3 Results and Discussion

This study uses the DRASTIC model to determine which areas are vulnerable to groundwater extraction. Thus, this study prioritises the implementation of models before identifying groundwater pollution zones. Following the model's application, an ultimate vulnerability map for ARC GIS 10.8.2 environments was produced, based on weighting and rating. The model's final output has yielded a range of results in terms of vulnerability (Figure 3). The obtained DRASTIC scores range from 82 to 205. The quantile classification scheme was used to reclassify these values into three classes: low vulnerable zone, moderate vulnerable zone, and high vulnerable zone.

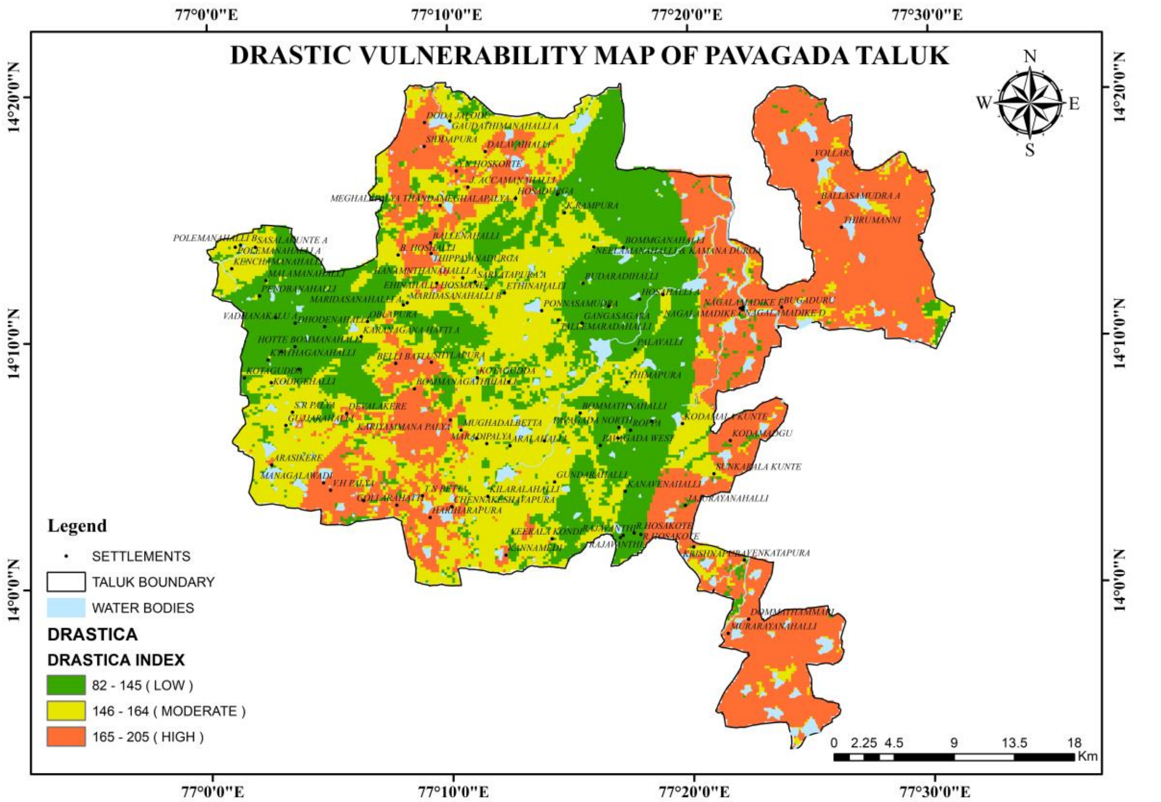


Figure 3 Groundwater vulnerability zones of Pavagada taluk

The model's findings showed that, out of the total 1360.98 km^2, an area of about 411.48 sq km (30.80%) was in a "low" vulnerable zone with a DRASTIC-LULC index ranging between 82 and 145, 460.44 sq km (34.46%) in a "Moderate" vulnerable zone with a DRASTIC-LULC index ranging between 146 and 164, and 464.04 sq km

(34.73%) in a "High" vulnerable zone with a DRASTIC-LULC index ranging from 165 as well. According to this, there was a high to moderate risk of pollution in 69.19% of the Pavagada taluk. The majority of these areas were in Pavagada Taluk's northeastern, southwestern, southern, and eastern regions. The main reason of the high level of vulnerability in the northeast is the high levels of Fluoride and Nitrate in the groundwater, which is found beneath the aquifer media of granite, granodiorite, and hornblende-biotite gneiss. The cause of vulnerability in the southwestern and southeast regions is high Nitrate, Sulphate, and Fluoride levels. The aquifer media in the southeast are known to contain high levels of Fluoride minerals, particularly in the Banded Biotite and Hornblend gneisses. As a result, this region is considered highly vulnerable and a high concentration of Nitrate, Fluoride, Iron, and Sulphate is creating vulnerability in the northwest. Because of the low slope, moderate recharge, and pink granulite rocks found in these areas, the patches of extremely vulnerable zone are found in the northwest.

The western portion of Pavagada taluk has low to very low vulnerable zones, while a small portion is located in the northern, central, and southern regions. It is evident from a comparison of the final DRASTIC map and the LULC map that the entire study area's wasteland and forest areas are covered in a low vulnerability zone. Certain significant parameters, such as Nitrate and Fluoride, are below allowable limits in this zone. Furthermore, the model can be applied to a variety of disciplines and is easily understood. Thus, it is easy to relate the model in this instance to the discussion and outcome.

3.1 Validation of the model

This model needs to be validated before it can be considered justified. Several chemicals that are harmful to health if they are present in excess of the permissible limit were used in the validation of this model. For validation purposes, certain chemicals such as pH, Electrical Conductivity, Iron, Sulphate, Fluoride, and Nitrate are taken here. It is taken that the aforementioned chemical components cause harm if they surpass the allowable limit, health and the environment (Table 3).

Table 3 Effects of different chemicals in groundwater on the environment and human health

Parameter	Standards	Recommended agency	Effects of exceeding a limit on human health
pH	6.5-8.5	BIS	irritation of the skin and eyes, mucous membranes, and worsening of skin conditions
EC	750-2000	BIS	Gastrointestinal issues
HCO_3^-	244	BIS	Respiratory and metabolic acidosis
SO_4^{2-}	200-400	BIS	The possible risk of diarrhea-related dehydration and its laxative effects
F^-	1-1.5	BIS	Skeletal fluorosis, dental fluorosis
Iron	0.3	BIS	Skin problems as well as harm to the pancreas, liver, and heart
Nitrate	45	BIS	Diabetes mellitus, thyroid gland damage, heart problems, and blue baby syndrome.

For validation purposes, from the study area, 102 randomly chosen sample points were chosen. (Figure 1; Table 3). A simple mathematical technique has been used to extract the accuracy from the prepared DRASTIC model(R. Ghosh et al., 2021).

(i) The total quantity of sample points chosen =102

(ii) The quantity of sample points at which the expected and actual values coherently agree =82

(iii) The number of sample points where the actual value and the predicted value differ =20

$$\textbf{The accuracy prediction} = \frac{\textbf{Number of sample points under agreement}}{\textbf{Total number sample}} * \textbf{100}$$

$$= \frac{82}{102} * 100$$

= 80.39%.

4. Conclusion

The swift contamination of groundwater in the current "development" is a major concern for geologists, hydrologists, environmentalists, and other scientific communities. Groundwater pollution zones can be extracted in a variety of methods. Extracting groundwater pollution zones can be done in a variety of ways. When it comes to research ethics, however, the model's application is more trustworthy than that of other qualitative and quantitative techniques since it is capable of demonstrating the real truth. Therefore, in any geographical study, the model-based approach is widely accepted. One popular model is the DRASTIC model. The model provides a very satisfactory explanation of the vulnerable zone at the micro level. The investigation's results show that most vulnerable areas are located in the northeastern and southeast sections of the Pavagada taluk. These regions are home to rocks with high Fluoride content, such as hornblende-biotite gneiss, granodiorite, and granite. Conversely, the higher rate of Fluoride contamination in the water is formed by the Banded Biotite and Hornblend gneisses in the Southeast. High fertilizer application and intensive farming practices may be the cause of the high nitrate content. Given that the Pavagada Taluk in the Tumakuru district is one of the taluks in Karnataka that is contaminated with Fluoride, this kind of vulnerability assessment of groundwater is imperative for the sustainability of healthy groundwater. Therefore, in order to enhance groundwater quality and ensure that the public has access to groundwater devoid of dangerous pollutants, the government should be in charge of specifically monitoring this area.

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