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Delineation of Groundwater Potential zone using Frequency Ratio method and GIS

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Abstract— Groundwater is one of the most vital natural resources that vary spatially in quality and quantity. Groundwater potential mapping and its sustainable development are an important aspect for areas such as Aromatic and Medicinal Plant Research Station (AMPRS), Odakkali that faces an inadequacy in water resources for various research activities. In the present study, the groundwater potential zones were delineated by adopting Frequency Ratio (FR) model in GIS platform. Geology, geomorphology, landuse / landcover, elevation, soil texture, lineament density and stream density were the thematic factors considered for groundwater potential zone mapping. Data from 55 well were collected in the study area, out of which 45 wells that were categorized as good yielding wells were considered in the FR model. The final groundwater potential map was classified into 4 zones as very high, high, moderate and low.The final map also matches the ground truth data, which indicates the validity of the model. The result of this study is therefore highly reliable and can serve as a guideline for planning and future identification of groundwater resources in the study area.

Index Terms— Frequency ratio, GIS, ground truth, Groundwater potential mapping, Inadequacy, validity.

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1 Introduction

Water is the most important natural resource essential for the subsistence of life and is a basic human need. The occurrence and movement of groundwater is controlled by several factors such as geology, geomorphology, landuse/ landcover, elevation, soil texture, lineament density, stream density etc. These factors independently as well as collectively influence the functioning of the total water system. In India, development of groundwater in different parts of the country has not been uniform. Highly intensive development of groundwater in certain areas in the country has resulted in over exploitation leading to decline of groundwater levels and subsequently the sea water intrusion into the coastal aquifers.

In many arid, semi-arid and drought prone areas of the country, groundwater development has exceeded the annual replenishment. So, an assessment for this groundwater resource is extremely significant for the sustainable management of groundwater systems. It has become crucial not only for targeting of groundwater potential zones, but also monitoring and conserving this important resource.

GIS and remote sensing tools are widely used for the management of various natural resources [1, 3, 4 and 7]. Identifying the potential groundwater zones using remote sensing and GIS is an effective tool. In recent years, extensive use of satellite data along with conventional maps and rectified ground truth data has made it easier to establish the base line information for groundwater potential zones.Weightage determination of thematic map can be determined by MIF technique [2, 5, 6 and 10] .The number of thematic layers created and the method for calculating GoundWater Potential Index (GWPI) are different in different studies [8 and 9]. Also validation is also not in many studies.Here FR method is used for calculating GWPI and validation is done with the waterlevels in the open wells in the study area.

2 Materials and Methods

2.1 Study Area

The Aromatic and Medicinal Plant Research Centre (AMPRS), Odakkali in the Ernakulum district of Kerala, which is the study area, faces inadequacy of water for its research and development activities. Suggestion of an appropriate water management technique by delineating groundwater potential zones in watersheds named 14P143b, 14P140c and 13M38b provides a solution to the above-mentioned problem. It also helps in agricultural extension and transfer of technology. The study area of 62.0918 sq.km, lies between10^{0} 2′ 32.704″N to 10^{0} 9′ 4.671″ N latitude and 76^{0} 31′ 16.772″ E to 76^{0} 38′ 13.525″ E longitude. The average temperature of the study area is 28^{0}C, humidity 83%, annual average rainfall of 2900 mm and wind velocity 0.41 m/sec towards South. Fig 1 shows the study area.

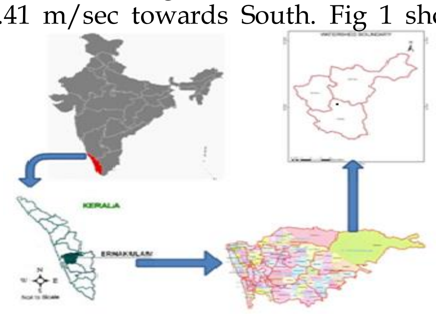

Fig 1. Study area.

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2.2 Source of Data

The various data inputs required and their methods of collection are depicted in the following Table: 1

Table : 1. Source of data

SL.No	Data	Source	Objective / work done
1.	Watershed Boundary	KSLUB Thrissur	Digitalizing the boundary, Estimate the study area
2.	Parameters 1. Geology 2. Geomorphology 3. Soil type 4. Drainage density 5. Landuse/ landcover	KSLUB Thiruvananthapuram	Vector data are converted to raster data and data are projected to UTM 1984
	6. Lineament density	Bhuvan	Creating thematic map and rasterization
	7. DEM	ASTER DEM	Generating slope (in raster)
	8. Rainfall data	AMPRS	Validation
	9. Soil thickness	Field survey	Validation and comparative study
3.	Ground water data	Field survey	Validation

2.2 Pre processing Data Using ArcGIS

The collected data was projected using project (data management) tool in ArcGIS 10.2.2 version. SRTM DEM (earthexplorer.usgs.gov) has been used as elevation data source. Stream density/drainage density and lineament density was prepared by using line density tool in the spatial analyst extension of ArcGIS. Land use /land cover of year 2019 was prepared and demarcated into five categories such as Builtup/Fallow land, Waste land, Plantation/ Forest, Paddy Converted/Crop land/Paddy and Waterbodies by visual interpretation in ArcGIS.

The geomorphological features were interpreted into 3 classes of features such as residual hill, pedi plain and plateau. Similarly lithology and soil type were also interpreted into various categories based on the data obtained as shown in Table 2.

Well inventory survey was conducted on the study area centering AMPRS, Odakkali. Depth of wells, depth of water table, diameter of wells, overburden thickness (the depth up to crystalline rocks) and water table of wells were collected. GraminEtrax 20x GPS was used to find latitude and longitude coordinates and elevation of different positions. The GPS has shown accuracy up to 3.0 m.

2.3 Frequency Ratio Method

Frequency ratio approach is based on the observed relationships between distribution of potential wells and each well-related factor, revealing the correlation between well locations and the causative factors in the study area. The frequency is calculated from analysis of the relation between wells and the attributing factors. If the value is greater than 1, it means a higher correlation, and value lower than 1 means lower correlation (Pradhan, 2010)

The frequency ratios of each factors class or type were calculated by dividing the well occurrence ratio by area ratio of those classes to produce weighed thematic maps. Using GIS software, the grids were overlaid with the geographic coverage for the study area. Groundwater prone zone is calculated by raster calculator tool in Arc GIS software. The GWPI represents the relative value of groundwater occurrence. The larger the value is, the higher to groundwater proneness.

$$\text{Frequency ratio} = \frac{\text{Well Occurance ratio}}{\text{Area ratio}}$$

$$\text{Well Occurrence ratio} = \frac{\text{No.of wells in each class}}{\text{Total number of wells}} \times 100$$

$$\text{Area ratio} = \frac{\text{No.of pixels in each class}}{\text{Total no.of pixels in whole layer}} \times 100$$

$$\text{Groundwater Potential Index} = EV_{FR} + GM_{FR} + GL_{FR} + SD_{FR} + LD_{FR} + LC_{FR} + ST_{FR}$$

Here EV_{FR} is frequency ratio of elevation; GM_{FR} is frequency ratio of geomorphology; GL_{FR} is frequency ratio of Geology; SD_{FR} is frequency ratio of stream density; LD_{FR} is frequency ratio of lineament density; LC_{FR} is frequency ratio of LU/LC; ST_{FR} is frequency ratio of soil texture.

3 RESULTS AND DISCUSSION

The data for 55 wells were collected out of which 10 wells have a lower capacity for recharging and 45 wells had an immense potential for recharging.

FR values were estimated from each thematic layer as shown in Table 2. The groundwater potential zone map of the study area prepared by considering the following factors: geology, geomorphology, land use/land cover, drainage density, slope, lineament density and soil type were classified into low, moderate, high and very high potential zones (Figure 1) and each class occupied 3.85%, 39.075%, 48.05% and 9.022% of total study area respectively (Table 3).

Table 2. Frequency ratio value of different thematic attributes for groundwater potential mapping.

Sl. No	Theme	Class	No. of good wells	Well ratio	No. of pixel	Area ratio	Frequency ratio
1	GEOLOGY	Basic rocks	9	20	49079	7.904	2.530
		Charnockite	36	80	536157	86.349	0.9264
		Migmatite	0	0	35682	5.746	0
2	GEOMORPHOLOGY	Residual Hill	0	0	8240	1.327	0
		Pediplain	6	13.333	120574	19.418	0.686
		Plateau	39	86.666	492118	79.254	1.093
3	LULC (2019)	Builtup land/ Fallow	18	40	108592	17.488	2.2872
		Waste land	0	0	407	32.358	0
		Plantation/ Forest	3	6.666	200926	49.3662	0.135
		Paddy Converted/ Crop land/Paddy	24	53.333	306531	49.366	1.080
		Waterbodies	0	0	4476	0.720	0
4	ELEVATION (degree)	8 – 45.8	21	46.666	41996	63.261	0.737
		45.8 – 83.6	24	53.333	21204	31.940	1.669
		83.6 – 121.4	0	0	2644	3.982	0
		121.4 – 159.2	0	0	469	0.706	0
		159.2 – 197	0	0	72	0.108	0
5	SOIL TEXTURE	Sandy loam	0	0	18973	3.055	0
		Sandy clay	28	62.222	385199	62.035	1.003
		Sandy clay loam	6	13.333	39334	6.334	2.104
		Clay	11	24.444	177426	28.574	0.855
6	LINEAMNET DENSITY (m/km²)	0 – 1.020	44	97.777	260606	90.370	1.081
		1.020 – 2.040	0	0	4172	1.446	0
		2.040 – 3.061	0	0	8202	2.844	0
		3.061 – 4.081	0	0	9410	3.263	0
		4.081 – 5.102	1	2.222	5985	2.075	1.070
7	STREAM DENSITY (m/km²)	0 - 1.703801	40	88.888	393930	64.557	1.376
		1.703 - 3.407	2	4.444k	92776	15.204	0.292
		3.407 - 5.111	3	6.666	86047	14.101	0.472
		5.111 - 6.815	0	0	29133	4.774	0
		6.815 - 8.519	0	0	8314	1.362	0

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Table : 3. GWP area under classifications.

Sl. No	Classes	Area (km^2)	Area (%)
1	Low	2.4167	3.850425
2	Moderate	24.5253	39.07511
3	High	30.1601	48.0528
4	Very high	5.6624	9.02166

3.3 Validation

The Frequency Ratio Method was used for the 45 good well data and resulted in over 90 percent of the good wells considered falling to high and very high and no wells in low potential classification. This gives good agreement to the verification of the ground truth data and confirms the reliability of the method used. (Figure 2)

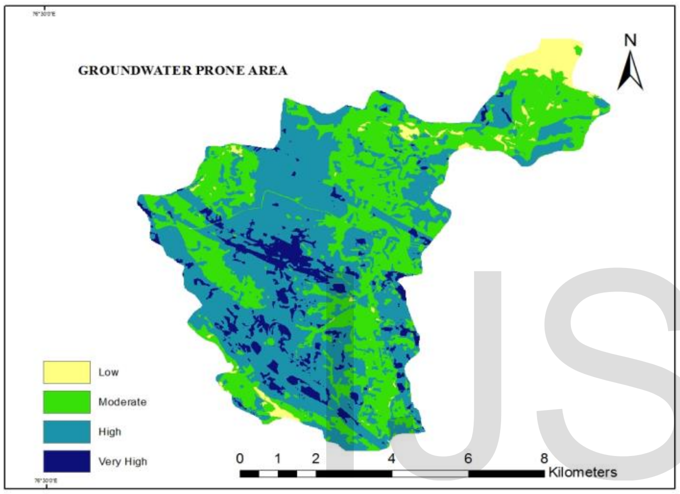

Fig 2. Groundwater potential area.

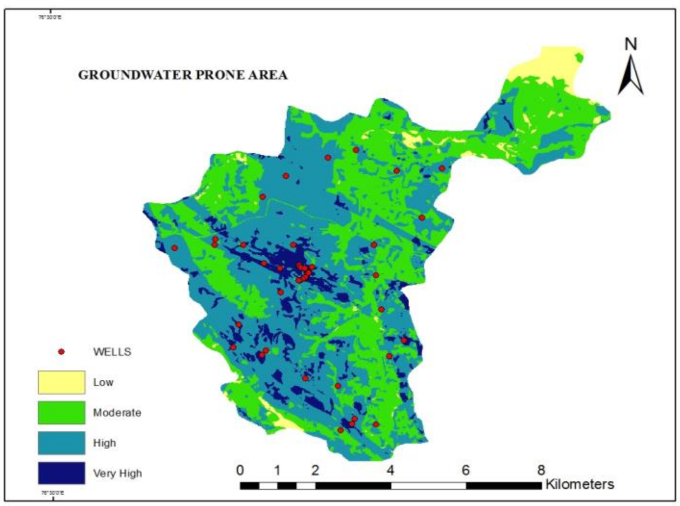

Fig 2. Validation Map

4 CONCLUSION

The groundwater potential map for Aromatic And Medicinal Plant Research Station (AMPRS), Odakkali was developed using the Frequency Ratio method and it is clear from the groundwater potential map that a large portion of the area falls within the high potential zone. The scarcity of water in the area can therefore be overcome by the proper extraction of groundwater. The final map also matches the ground truth data, which indicates the validity of the model. The result of this study is therefore highly reliable and can serve as a guideline for planning and future identification of resources in the study area.

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