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Spatial Distribution of Groundwater Quantity and Quality in Neeva basin, Chittoor District, India

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***Abstract** - The present study is to use Geographic Information System (GIS) for determining the best areas having groundwater quantity and quality in Neeva basin. Themes such as slope, rainfall, groundwater level and land use/land cover was developed in GIS. Thematic layers were weighed and groundwater potential zones map was developed through weighted overlay analysis. Results indicated that 80.26 (61.27 %), 26.07 (19.9%) and 24.67 (18.83%) sq.km. of area has good, moderate and poor groundwater potential. On the other hand, National Sanitation Foundation method was applied for evaluating water quality index in the basin at 43 observation wells and samples were tested for physico-chemical analysis for eight parameters and study revealed that 20.93%, 74.42% and 4.65% of area has good, moderate and poor quality of groundwater. Based on the obtained results, some suggestions for groundwater management in general and for the basin in specific were made.*

Keywords: Groundwater Potential, Groundwater Quality, GIS, landuse, Water Policy

1. Introduction

Water has been, is, and will be one of the most important resources for the survival of mankind. Most of the cities and towns are built on the banks of rivers or some water bodies (Ahmad et. al, 2005). Water is required for drinking, irrigation, industrial and commercial purposes. Sustainable Development Goal no 6 aims to "Ensure availability and sustainable management of water and sanitation for all" (UN Resolution). Rapid increase in population and use of natural resources are hampering our efforts to achieve this goal. A multitude of factors have caused surface water a less commonly used source of water, especially in India (GEC, 1997; GEC, 2015). Throughout the arid and dry regions of the country, the people depend on the groundwater resource to meet their water requirements because groundwater is relatively purer with respect to surface water and easier to obtain in these parts of the country. This makes groundwater is an important, finite resource and is an essential part of the hydrological cycle. Hence, it becomes very imperative for everyone in general and administrators in specific to understand the hydrological cycles manage the diminishing resource of groundwater (Anu et. al. 2012; Rehman et. al., 2024). It is necessary to understand the dynamics of groundwater so that they could be properly monitored and managed. Quantification of groundwater resources if very critical and no single comprehensive technique not yet identified for estimating accurate groundwater assessment (Sutradhar et. al., 2022). The main reason behind this is that accurate estimation needs a multidisciplinary approach to the problem. Various physical, geological, morphological and hydrological properties of the surface determine the groundwater environment (Maitre et. al., 1999). The first order indicators such as recharge or discharge zones, moisture content of soil and vegetation are directly related to the groundwater system (Atar Singh et. al., 2024). The second order indicators are rock types, soil, structures, fractures, landforms, drainage and anthropogenic activities on surface (Magesh et. al., 2012). These are a fair number of surface indicators, which can provide information for groundwater (Tariq et. al., 2023; Naik and Awasthi, 2003).

2. Material and Methods

2.1 Study Area

Andhra Pradesh is a predominantly agrarian state located in the Eastern coast of the country. Three major rivers namely Godavari, Krishna and Pennar run across the state. A major part of the area is underlined by gneissic complex, sedimentary and alluvial formations. The alluvial formations are confined mainly in the delta region where the tube wells yield from 15-60 cu.m./hr. Rainfall in the state varies from 561 mm in Rayalaseema Region to about 1113 mm in the north-eastern part of the state. This study was carried out in Neeva River, Chittoor District which lies in between $12^0 37'$ - $14^0 00'$ North longitudes and $78^0 03'$ - $79^0 55'$ East latitudes with an aerial extent of 15151-sq.km. The district is having population of 41.74 lakhs (Census, 2011) of which urban population is 12.31 lakhs and rural population is 29.43 lakhs. Neeva River is one of the major tributaries of the Ponnai River that flows through the district. It starts near Bhumireddipalle village and flows and carried a length of 16.3km around Chittoor town and joins Ponnai River at the junction of Mukundrajanipeta village and Kotturu village. Neeva River is the life-line of the district headquarters, Chittoor town with catchment area of 131 sq.km (around 10% of total 1300 sq.km catchment of Ponnai river). River flows through most part of the town and is very important for recharging groundwater aquifers in and around the town. Neeva Watershed (Figure 1) is taken as the study area as it would also encompass the effects of built up nature in urban area, commercial and domestic usage in Chittoor town and the agricultural usage in the surrounding mandals using GIS.

The district is (85%) underlain by Archean granites and granite gneisses mainly followed by Cuddapah formation i.e., Quartzites, Shales and Sandstones of upper Gondwana and recent alluvium in the stream courses. The district has an attitude of 300 to 900m above MSL and average annual rainfall of the district is 934 mm. The district is drained by major rivers viz., Cheyyeru, Papagni, Swarnamukhi, Araniyar, Palar, Koratliar, Kalyani and Ponnair besides number of tributaries with dendritic to sub dendritic drainage pattern.

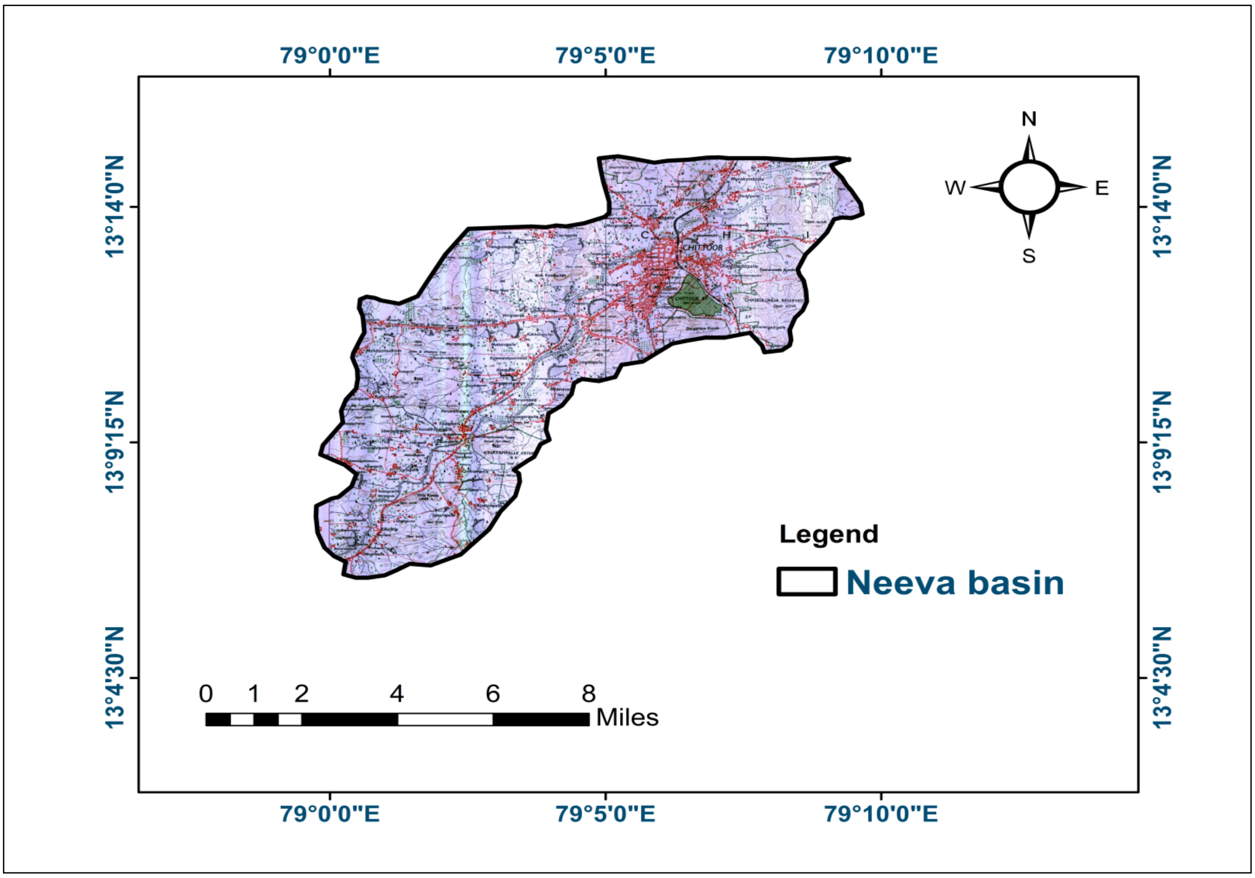

Figure 1: Location of the study area

It experiences semiarid climate conditions with temperatures ranging from 43^{0}c in May to 20^{0}c in December. The major crops cultivated are Paddy, Sugarcane, Pulses, Mulberry, Mango and other Horticulture crops. Since there is no perennial source of water for either irrigation or drinking water purposes, the majority of district is dependent on rainfall, minor irrigation tanks and groundwater for all purposes. Rainfall has been very erratic in the past decade five years were drought declared. This has made people to resort more to groundwater sources. The strain on groundwater aquifers mostly in upland areas is increasing alarmingly.

2.2 Estimation of Groundwater Potential Zones (GWPZ)

Geospatial techniques provide a rapid and cost effective tool for generating valuable geo-data both directly and indirectly, which is used in deciphering groundwater potential zones in hard-rock terrain (Dar et al. 2011). Evaluation of groundwater potential zones in the study area was done by preparing and integrating various thematic layers using GIS. The Indian Remote sensing Satellite (IRS), linear image self-scanning (LISS) III digital data on a 1:50 000 scale, were used in the present study. The IRS LISS III of the area are used for the land use classifications and compared using georeferenced open series map of SOI 57 O/4 (1:50 000 scale). Rainfall data, groundwater level data were also collected to validate the results for final groundwater potential map. Thematic layers pertaining to drainage density and slope were extracted using Digital Elevation Model (DEM) together with the Survey of India (SOI) maps. All the data were integrated in a GIS domain and analyzed to assess the effect of groundwater controlling features. Finally groundwater potential map was generated using overlay technique. Overlay analyses was done using spatial analyst extension tools of ArcGIS 10.2.2, using weighted linear combination technique.

2.3 Estimation of Groundwater Quality Index (GWQI)

GWQI, a mathematical tool to evaluate all the physico-chemical parameters into single parameter. It is one of the aggregate indices that have been accepted as a rating that reflects the composite influence on the overall quality effectively (APHA, 2012). GWQI is computed as follows.

Relative weight (Wi) of each quality parameter is computed using:

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}$$

where, Wi is the relative weight, w_i is the weight of each parameter and n is the number of parameters. Quality rating scale (q_i) of each parameter is determined by dividing its concentration in each water sample by its respective standard. As per Bureau of Indian Standards (BIS, 2012), the values of q_i are computed,

$$q_i = (C_i / S_i) * 100$$

where q_i is the quality rating, C_i is the concentration of each quality parameter in each water sample in mg/l and S_i is the Indian Standard for drinking water of that quality parameter in mg/l. S_i value for each parameter is computed using

$$S_i = W_i * q_i$$

Finally, GWQI for each quality parameter is computed as

$$GWQI = \sum S_i$$

Based on the value of GWQI, the water may be good (GWQI > 100), moderate (100 > GWQI > 200) or poor (GWQI > 200) in quality.

3. Results and Discussion

3.1 Quantitative analysis of groundwater

For sustainable development of water resources, it is imperative to make quantitative estimation of available water resources. Integrated remote sensing and GIS based approach is a tool for assessing groundwater potential zones based on which suitable locations for groundwater withdrawals are located easily.

3.1.1 Slope Map

Slope is a significant terrain characteristic, which expresses the steepness of the ground surface. Slope gives essential information on the nature of the geologic and geodynamic processes operating at regional scale (Riley S.J et al. 1999).

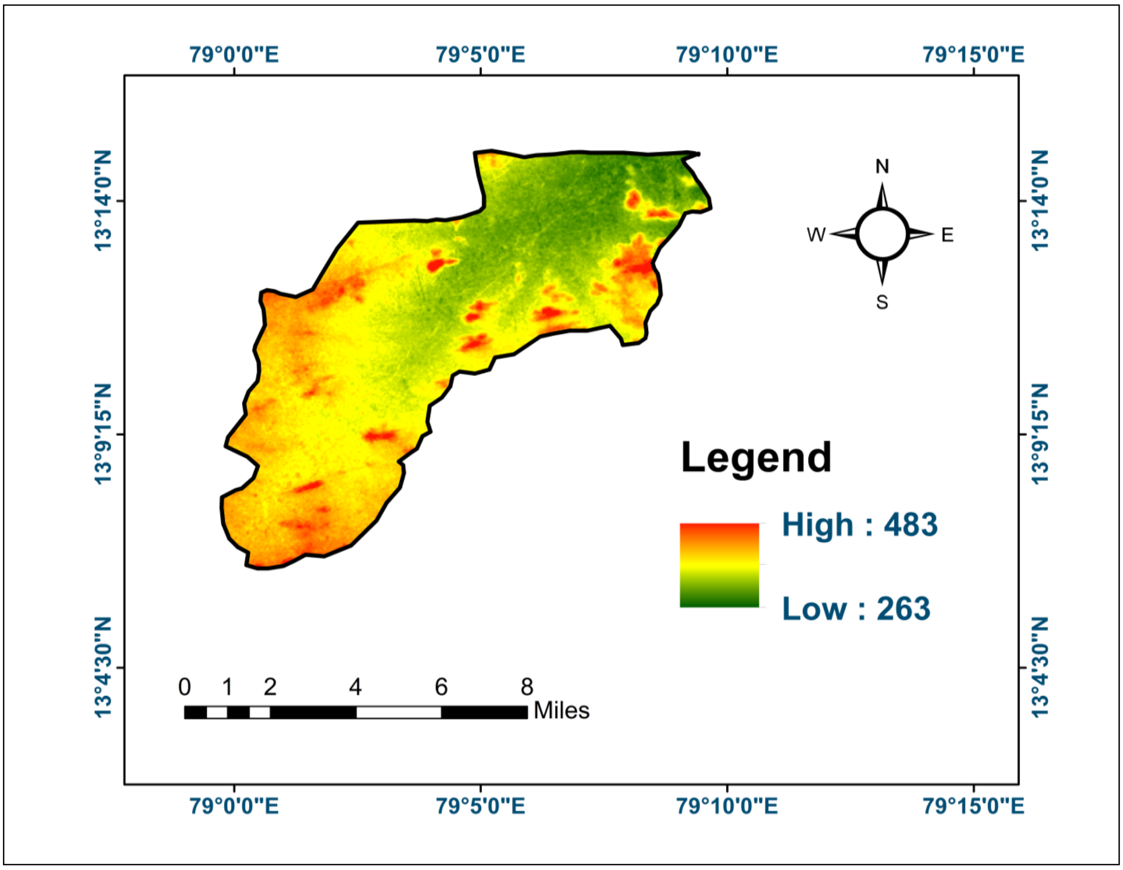

Figure 2: Digital Elevation Model of the study area

Class having less value is assigned higher rank due to almost flat terrain while the class having maximum value is categorized as lower rank due to relatively high run-off. Table 1 represents the Slope of the basin varied from 1 to 128 and values are reclassified in to four categories. Figure 3 presents slope depicted from Digital Elevation Model (DEM) (Figure 2).

Table 1: Details of Slope map

Slope (%)	Area		Groundwater potential	Score	Weights (%)
	Sq. km	%			
1 – 8 (Gentle)	55.19	42.13	Good	3	56.25
32 – 64 (Mild)	45.22	34.52	Moderate	2	20.12
64 – 128 (Steep)	30.59	23.35	Poor	1	23.63

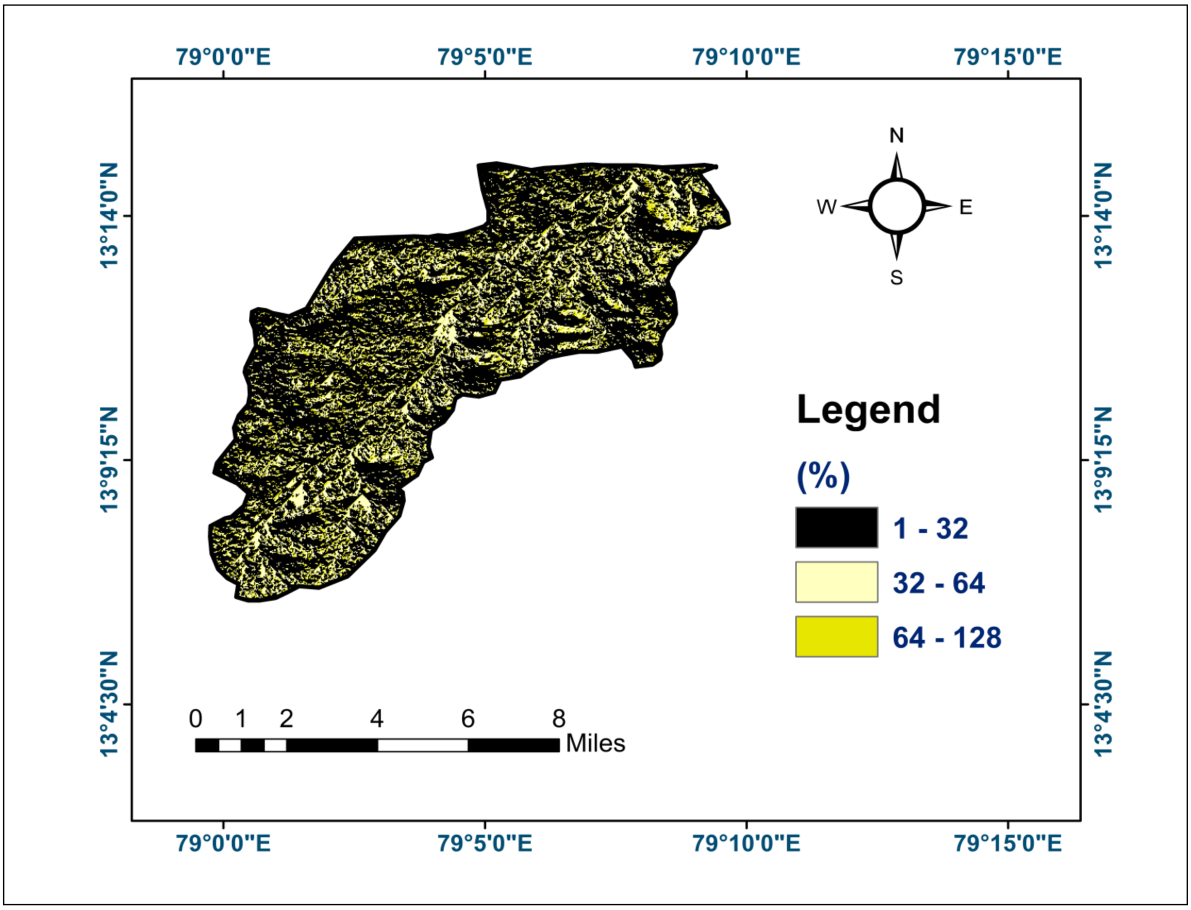

Figure 3: Slope map in Neeva River basin

3.1.2 Rainfall Map

Rainfall is the major source of recharge. It determines the amount of water that would be available to percolate into the groundwater system. Rainfall in the study area grouped into four classes based on annual rainfall in the study area as listed in Table 2. Rainfall data depicts that Northern and Eastern parts of the area receive maximum rainfall. High rainfall is favorable for high groundwater potential, hence assigned higher priority. The data was interpolated and spatial distribution map of rainfall was created using IDW technique as shown in Figure 4. Rainfall values categorized as poor, good and excellent. Accordingly, observed that 77.91% of the study area falls in poor rainfall area (60-220mm), 16.04% in good rainfall areas and only 6.05% of the area falls into excellent rainfall area.

Table 2 : Extent of poor, good and excellent rainfall areas in Neeva river basin

Rainfall Range (mm)	Area		Groundwater potential	Score
	Sq. km	%		
60-220	102.06	77.91	Poor	1
220 - 370	21.01	16.04	Good	2
>370	7.93	6.05	Excellent	3

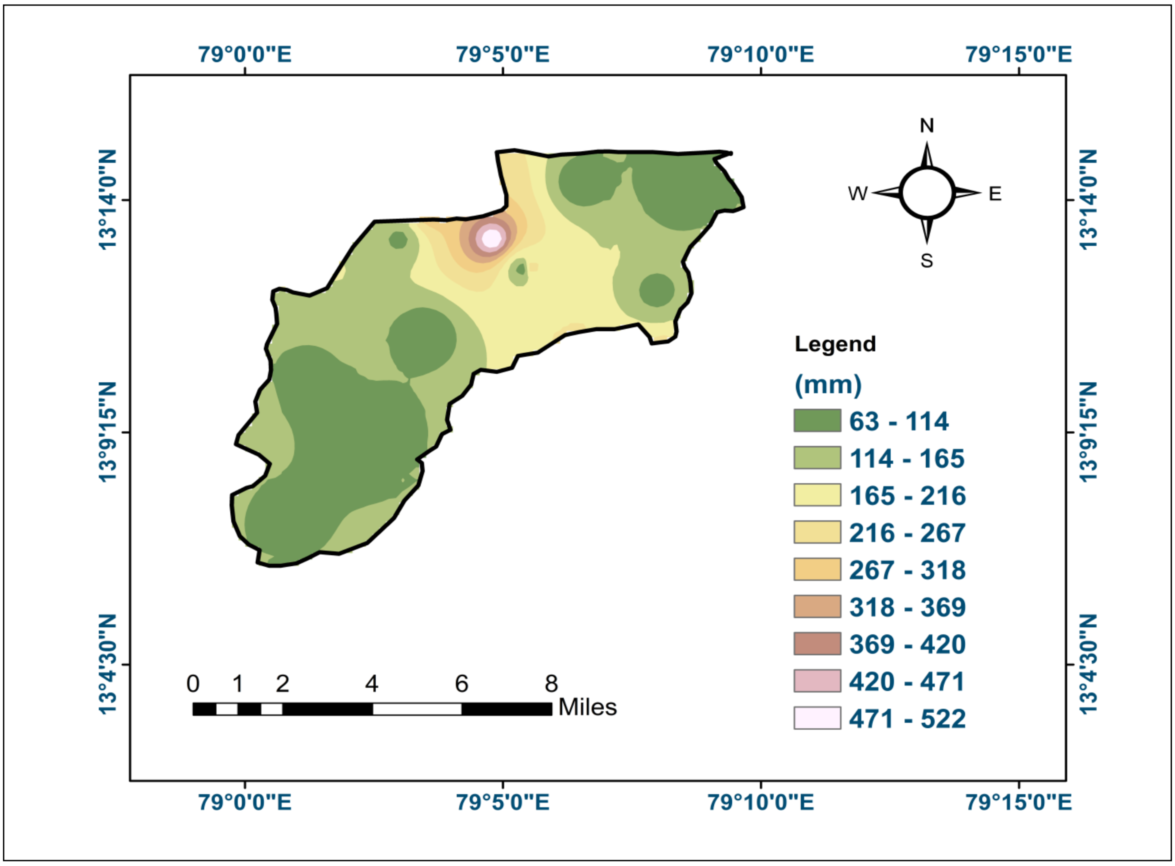

Figure 4: Rainfall map in Neeva River basin

3.1.3 Landuse and Land Cover Map

LULC gives the essential information on infiltration, soil moisture, groundwater, surface water, in addition to providing information on groundwater requirements. Landuse is interpretable by satellite images. Various types of landuse pattern were identified in the study area which includes water bodies, forest, agricultural land, and built-up area (Table 3). Vegetation and river course are excellent sites for groundwater exploration, and hence given the highest rank, paved surfaces ranks very low as it has runoff at maximum. Figure 5 presents the distribution of LULC in the basin.

Table 3: Extent of Land use/land cover classes in the study area

Land use/ land cover	Area		Groundwater potential	Score
	Sq. km	%		
Water bodies	11.79	9	Excellent	6
Vegetation	46.38.	35.4	Very good	5
Open scrubs	42.96	32.8	Good	4
Built-up land	10.06	7.68	Poor	2
Agricultural land	19.81	15.12	Moderate	3

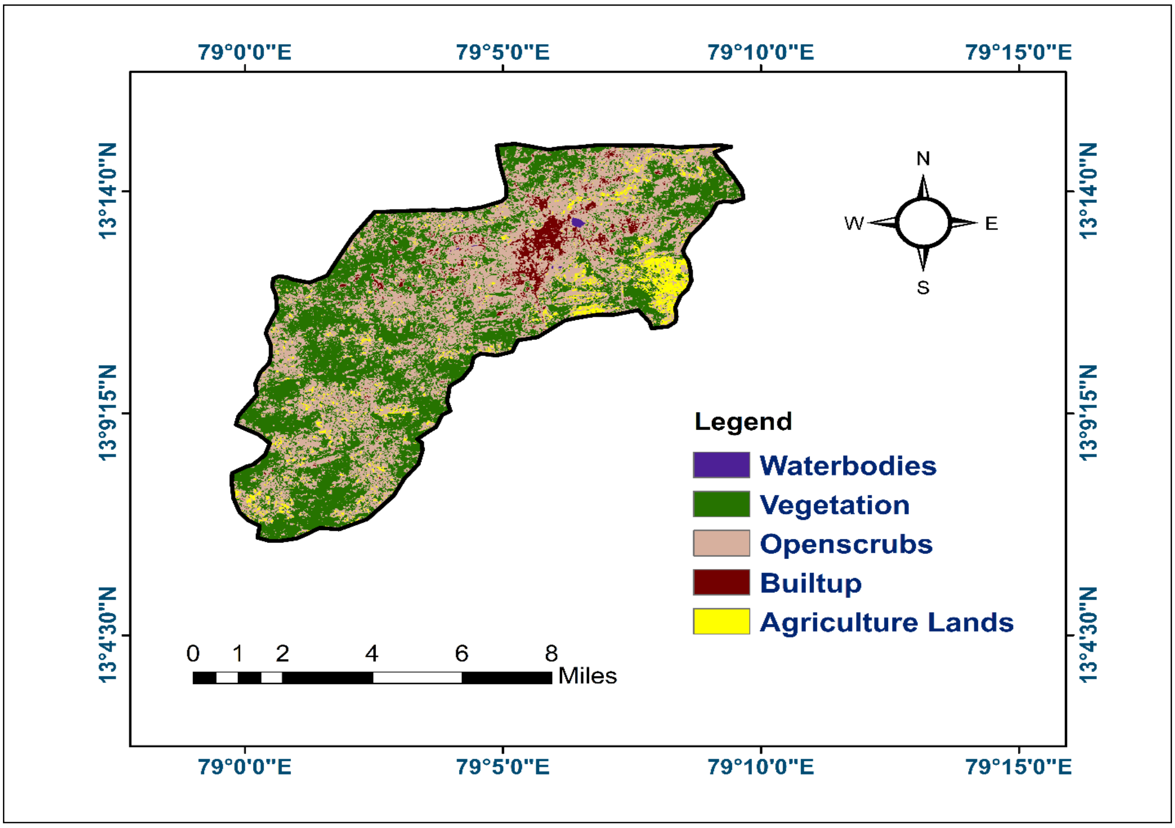

Figure 5 : Landuse/Land Cover pattern in Neeva River basin

3.1.4 Groundwater level Map

Piezometric levels of groundwater tables in the post-monsoon season data collected from Groundwater Department of Andhra Pradesh, to determine direction and movement of groundwater to ascertain the flow accumulation in the aquifers.

Table 4: Piezometric levels of groundwater in the study area

Groundwater Level (m below bgl)	Area		Groundwater potential	Score
	Sq. km	%		
<10	88.21	67.34	Good	5
10 - 30	27.77	21.20	Moderate	4
30 - 50	15.02	11.46	Poor	3

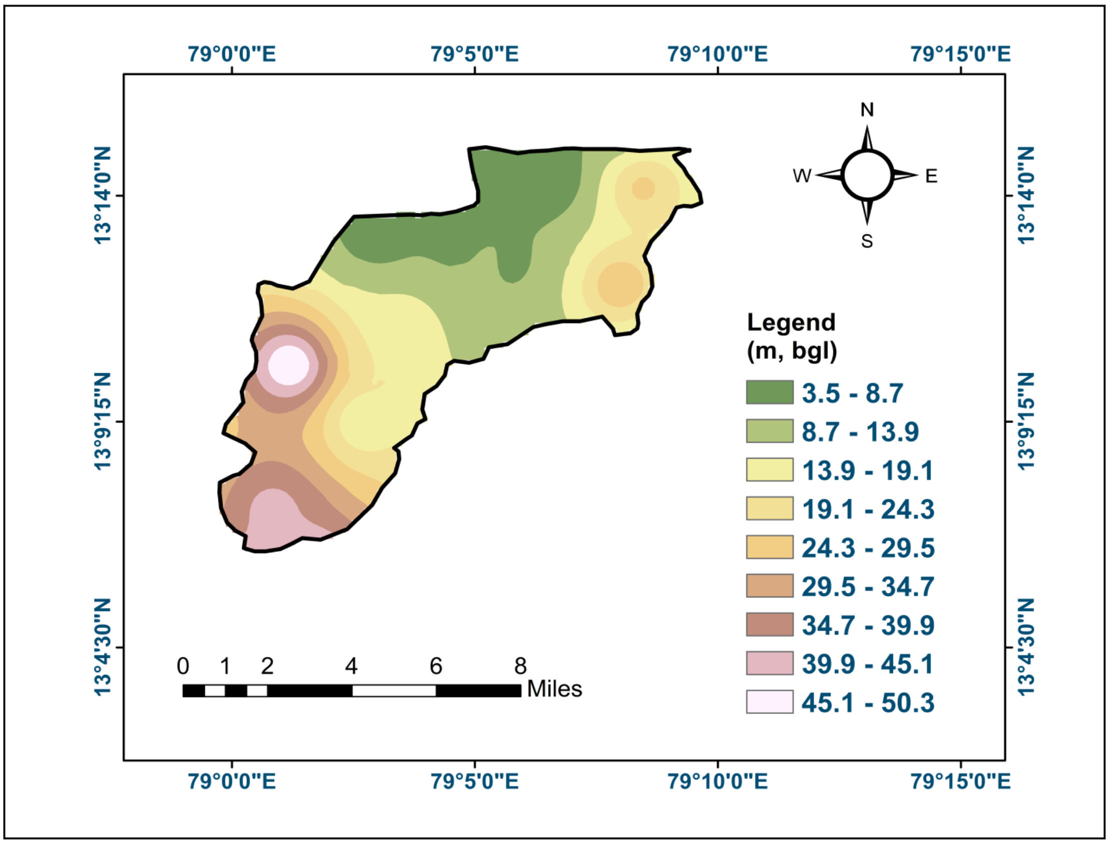

Figure 6 : Depth to Groundwater Level map in Neeva River Basin

In Post- monsoon season, groundwater level with major portion of the area having 10 m depth. In the Southern part of the area, groundwater depth was greater than 50 m. Groundwater level in northern part varies from 10 to 30 m, with a of the study area of 27.77 Sq.km (Table 4). Spatial map is prepared using Inverse Distance Weighted (IDW) tool as shown in Figure 6.

3.1.5 Groundwater potential Zones Map

Groundwater is a replenishable resource, but due to various kinds of anthropogenic activities and skewed developments, recharge of this sustaining resource reduced significantly in the past few decades (Kumar et. al. 2018). The groundwater availability is not uniform in space and time and therefore, an assessment of the Groundwater Potential Zones (GWPZ) map is prepared using weighted overlay technique in the GIS environment with the selected parameters viz., slope, rainfall, land use/land cover and groundwater level.

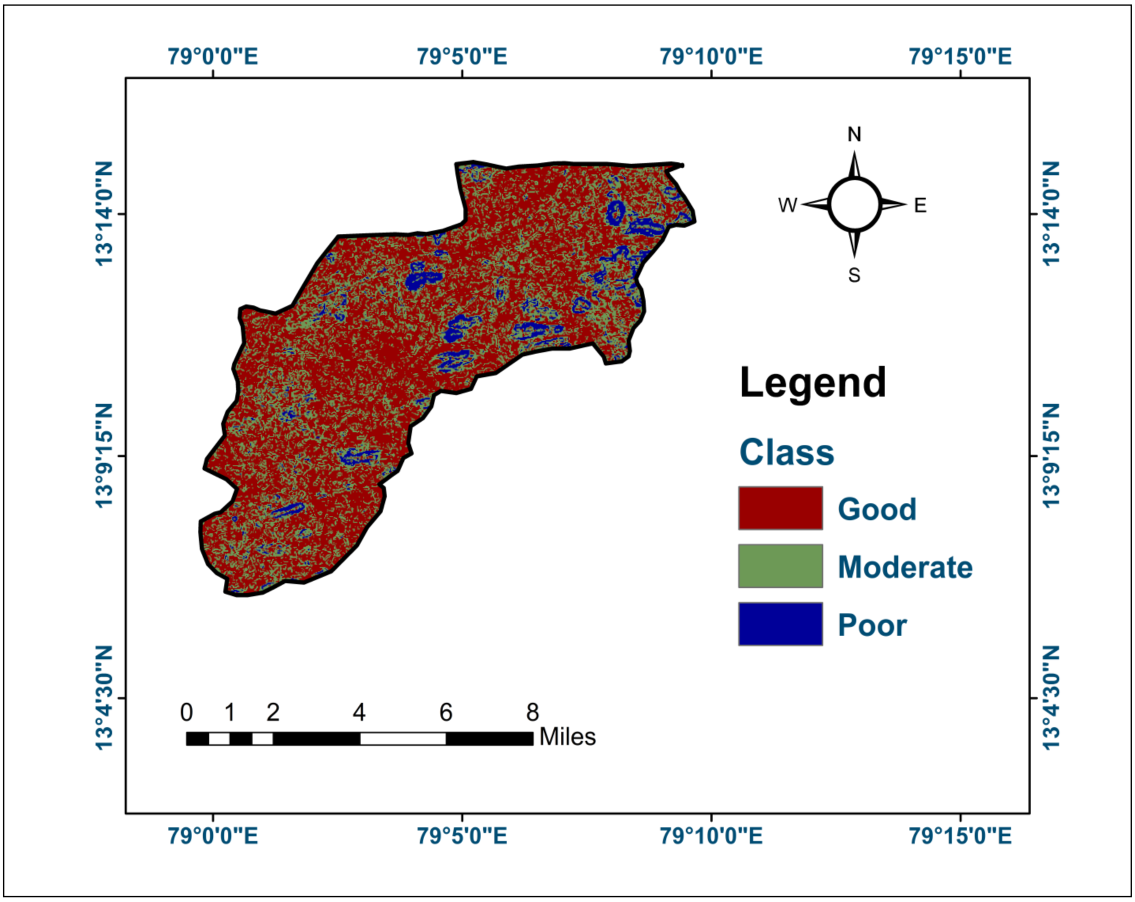

Figure 7: Map showing the Groundwater Potential Zones in Neeva River basin

The results revealed that 80.26 sq.km. (61.27 %) of area has good groundwater potential, 26.07 sq.km (19.9%) of area has moderate groundwater potential and 24.67 sq.km (18.83 %) area is with poor groundwater potential as illustrated in below Figure 7. The figure also depicts, good groundwater potential zones occur predominantly in midland and lowland regions. Good groundwater potential zones confined generally to high rainfall regions, which in turn have high infiltration runoffs.

3.2 Qualitative Assessment of Ground Water

Physico-chemical analyses carried out for all the groundwater samples from forty-three well locations collected during Post-monsoon period. Samples collected as per BIS standards and procedures prescribed by American Public Health Association (APHA, 2012) followed to attain relative weights based on National Sanitation Foundation (NSF) Method (Aragaw and Gnanachandraswamy 2021; Atta et. al. 2022) as shown in Table 5. Each of the groundwater samples was analyzed for Eight parameters viz., pH, Chlorides (Cl^-), Fluorides (F^-), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sulphates (SO_4^{2-}), Total Hardness (TH) and Total Dissolved Solids (TDS). Using these values, Groundwater Quality Index (GWQI) map developed using Inverse Distance Weighted (IDW) tool in GIS environment to study the overall effect and individual quality status over the basin shown in Figure 8. Details of the well locations and GWQI obtained using NSF method shown in Table 6.

Table 5 : Relative Weightages for physico-chemical parameters

S.No.	Chemical Parameters	BIS Standards	Weight(w_i)	Relative Weight (W_i) ($w_i/\sum w_i$)
1	pH	7.0-8.5 (8.5)	3	0.094
2	Chlorides (mg/l)	250 (mg/l)	5	0.156
3	Fluorides (mg/l)	1.5 (mg/l)	2	0.063
4	Calcium (mg/l)	75 (mg/l)	4	0.125
5	Magnesium (mg/l)	30 (mg/l)	4	0.125
6	Sulphate (mg/l)	200 (mg/l)	4	0.125
7	Total Hardness (mg/l)	200 (mg/l)	5	0.156
8	Total Dissolved solids (mg/l)	500 (mg/l)	5	0.156
		Total	32	1.000

Table 6: GWQI data at various locations in the study area

S.No	Longitude	Latitude	Location	GWQI	Quality rating
1	79.09	13.21	Chittoor	**255.11**	Poor
2	79.13	13.10	Gudipala	**187.74**	Moderate
3	79.09	13.36	Puthalapattu	**42.98**	Good
4	79.21	13.50	Panapakam	**117.24**	Moderate
5	79.04	13.60	Pulicherla	**90.89**	Good
6	78.57	13.37	Punganur	**256.86**	Poor
7	79.20	13.17	BNR peta	**105.21**	Moderate
8	79.11	13.45	Pakala	**170.16**	Moderate
9	79.05	13.22	Cherlopallii (Bramhanacheruvu)	**132.95**	Moderate
10	79.17	13.17	Chithalagunta (Gundlavanicheruvu)	**150.14**	Moderate
11	79.08	13.24	Mangasamudram (Mangasamudram Tank)	**166.91**	Moderate
12	79.06	13.23	Mittapalli (Kondamnaiducheruvu)	**120.21**	Moderate
13	79.06	13.23	Mittapalli (Mittapalli Kunta)	**122.79**	Moderate
14	79.12	13.15	Nagiripalli (Papireddycheruvu)	**126.80**	Moderate
15	79.16	13.17	N V palli (N V GaripalliCheruvu)	**135.06**	Moderate
16	79.15	13.16	Perumallakandireega (Rudrappanaidu Tank)	**176.55**	Moderate
17	79.08	13.22	Tenebanda (Kogillacheruvu)	**149.98**	Moderate
18	78.91	13.19	170 gollapalli (Verapunanunicheruvu)	**104.49**	Moderate
19	78.95	13.21	Jambhuvaripalli (Raganna Tank)	**107.40**	Moderate
20	78.95	13.21	Jambhuvaripalli (Kama chengannacheruvu)	**100.29**	Moderate
21	78.94	13.22	Jambhuvaripalli (Diguvakitchannacheruvu)	**116.89**	Moderate

22	79.09	13.21	Collectrate	**132.06**	Moderate
23	79.20	13.12	Al Puram (AddmmaCheruv)	**109.80**	Moderate
24	79.14	13.13	Mogaralapalli (AvathotaCheruvu)	**97.19**	Good
25	79.13	13.12	Muthukurupalli (CircarPapanayuniCheruvu)	**106.61**	Moderate
26	79.18	13.06	Nagamangalam (Nagamangalamcheruvu)	**94.71**	Good
27	79.21	13.13	Naraganti (Naraganti Tank)	**62.14**	Good
28	79.10	13.08	Papasamudram (Rami Reddy Cheruvu)	**153.47**	Moderate
29	79.13	13.10	Vasanthaputam (Bangarakacheruvu)	**156.80**	Moderate
30	79.20	13.12	Vengamambhapuram	**92.61**	Good
31	79.014	13.124	Chittoor Municipality OBS-1	**116.15**	Moderate
32	79.045	13.154	Chittoor Municipality OBS-2	**112.81**	Moderate
33	79.02	13.174	Chittoor Municipality OBS-3	**169.51**	Moderate
34	79.059	13.188	Chittoor Municipality OBS-4	**106.28**	Moderate
35	79.133	13.202	Chittoor Municipality OBS-5	**104.58**	Moderate
36	79.141	13.236	Chittoor Municipality OBS-6	**109.43**	Moderate
37	79.108	13.239	Chittoor Municipality OBS-7	**141.77**	Moderate
38	79.136	13.264	Chittoor Municipality OBS-8	**107.35**	Moderate
39	79.192	13.246	Chittoor Municipality OBS-9	**99.94**	Good
40	79.022	13.09	Chittoor Municipality OBS-10	**144.33**	Moderate
41	78.959	13.12	Chittoor Municipality OBS-11	**89.87**	Good
42	78.967	13.164	Chittoor Municipality OBS-12	**93.58**	Good
43	79.045	13.272	Chittoor Municipality OBS-13	**184.94**	Moderate

Table 7: Study Area classified based on GWQI value

GWQI value	Class	Water quality	Groundwater wells covered (%)
<100	I	Good	20.93
100-200	II	Moderate	74.42
>200	III	Poor	04.65

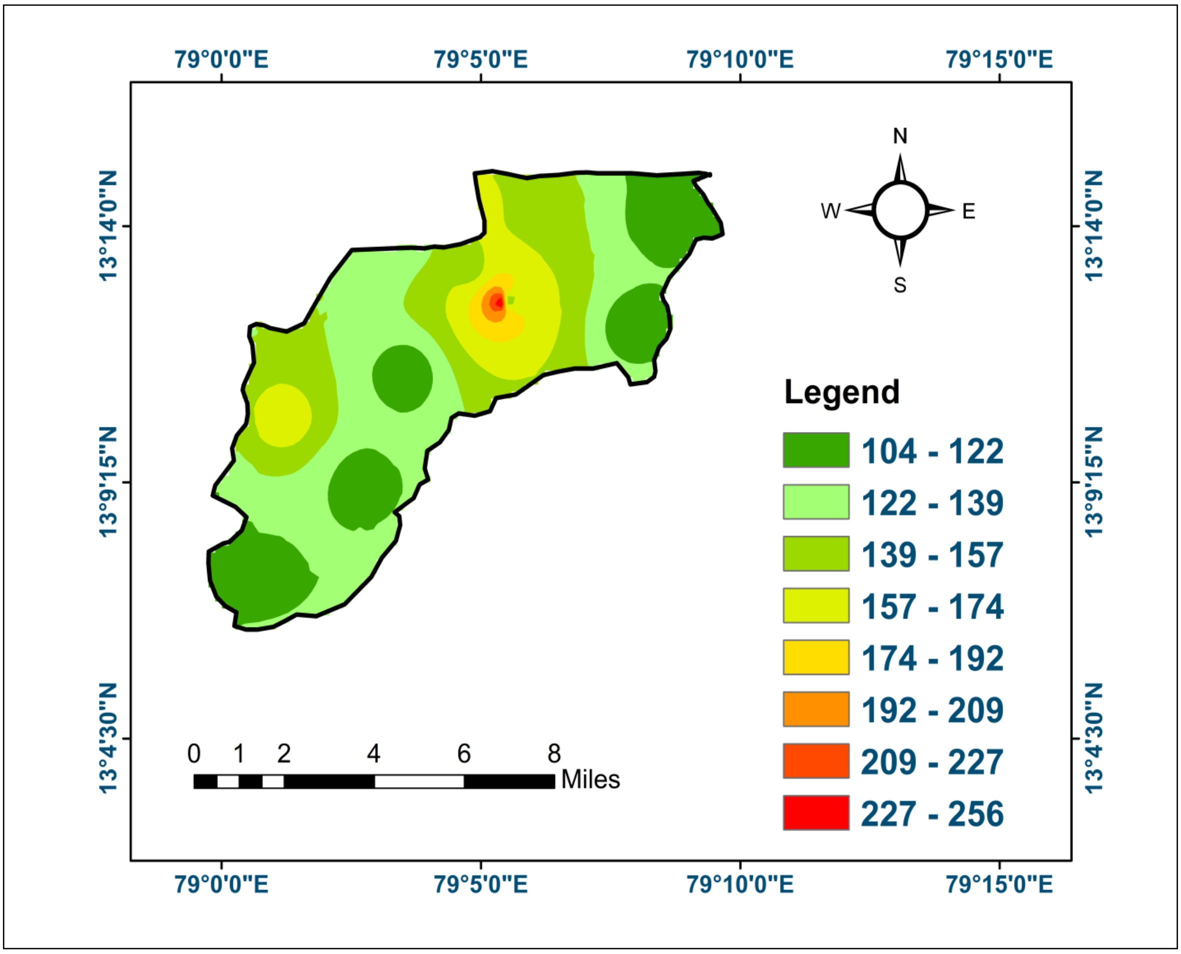

Figure 8: Groundwater quality map in Neeva River basin

GWQI in the present study emphasizes that majority of the samples (Table 7) falls under moderate category, this is due to various factors such as waste and wastewater disposal methods adopted in the study area are the probable reasons for deterioration of quality of groundwater. Spatial distribution map generated using physico-chemical parameters will help in identifying quality status across the study area. GWQI map developed using NSF method, often provides information for better groundwater treatment procedures. Remedial measures such as artificial recharge and control measures for contaminant transport in the porous medium must be priority to improve quality of groundwater.

3.3 Implications for Policy

In the present study, groundwater is the only source to meet the domestic needs of the Chittoor district in addition to the available surface water resources. The intensive groundwater draft leading to critical situation and the problem will manifest itself in the form of declining groundwater levels and shortage in supply (Sekar and Randhir, 2007). In addition to all the remedial measures discussed, water conservation regulations provided below: Andhra Pradesh Water, Land and Trees Act, 2002 (APWALTA, 2002) is a comprehensive act covering surface and groundwater resources. The act aims to promote water conservation, enhance tree cover and regulate the exploitation and use of ground and surface water.

Frequent monitoring of groundwater levels, water quality and the amount of water abstracted will provide an early warning system for efficient groundwater management (Theesfeld, 2010; Sasane and Patil, 2013; Pino-Vargas et. al. 2023). It assumes greater significance with competing demands for water in the area. The state government can institute legislations to protect the drinking sources. Wherever there is a gap between demand and the resource augmentation of the groundwater by way of constructing percolation tanks, check dams and water harvesting structures (Moench, 1996; IDSA, 2010; Foster, 2020). Watershed management programmes also help in improving the groundwater recharge thereby increasing its augmentation.

3.4 Conclusion

The objectives of present study attained by understanding various methods of estimating groundwater potential zones through a mix of theoretical and practical approaches. The parameters that affect the groundwater potential selected through detailed study of similar earlier works in other regions. Results indicated that 80.26 (61.27 %), 26.07 (19.9%) and 24.67 (18.83%) sq.km. of area has good, moderate and poor groundwater potential. Groundwater potential zones map developed will be helpful for groundwater management in the study area. On the other hand, groundwater quality in the study area revealed that 20.93%, 74.42% and 4.65% of area has good, moderate and poor quality of groundwater respectively. This study also encompasses the results of quality of groundwater with moderate class in the majority of the portion. However, the quality of groundwater around the CMC and its surroundings fell under poor groundwater quality due to presence of multiple contamination sources in the urban area. The current policy framework discussed above with implications for better groundwater management in the study area.

Declarations

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Conflict of Interest
The authors do not have any conflict of interest.

Data availability statement
Supporting data is made available with the corresponding author upon reasonable request.

References

1. Ahmad M., Wim G.M. Bastiaanssenand Reinder A. Feddes, “A new technique to estimate net groundwater use across large irrigated areas by combing remote sensing and water balance approaches, Rechna Doab, Pakistan”, Hydrogeology Journal, Vol.13,2005, p 653-664.

2. ANDHRA PRADESH WATER, LAND AND TREES ACT – 2002 (APWALTA – 2002), https://forests.telangana.gov.in/pages/Acts_Rules/WALTA%202002%20(AP).pdf (Accessed 02/04/2024)

3. Anu Varughese, Abdul Suhail, Chitra M.G, Jiji P.S, Deepthy C, Raneesh, K. Y. “Identification of shallow groundwater potential zones using GIS – A case study” International Journal of Advanced Engineering Applications, Vol.1, 2012, pp.65-70.

4. APHA, “Standard Methods for the Examination of Water and Wastewater”, 2012, 22nd edition, American Public Health Association, Washington DC.

5. Aragaw, T.T., Gnanachandrasamy, G. Evaluation of groundwater quality for drinking and irrigation purposes using GIS-based water quality index in urban area of Abaya-Chemo sub-basin of Great Rift Valley, Ethiopia. *Appl Water Sci* 11, 148 (2021). https://doi.org/10.1007/s13201-021-01482-6

6. Atar Singh, Rajesh Kumar, Ramesh Kumar, Prity Singh Pippal, Payal Sharma, Tanuja, Abhilasha Sharma, “Delineation of groundwater potential zone using geospatial tools and analytical hierarchy process (AHP) in the state of Uttarakhand, India”, Advances in Space Research, Volume 73, Issue 6, 2024, Pages 2939-2954, ISSN 0273-1177, https://doi.org/10.1016/j.asr.2023.12.041.

7. Atta, H.S., Omar, M.AS. & Tawfik, A.M. Water quality index for assessment of drinking groundwater purpose case study: area surrounding Ismailia Canal, Egypt. *J. Eng. Appl. Sci.* 69, 83 (2022). https://doi.org/10.1186/s44147-022-00138-9

8. BIS, “Standard Specifications for Potable Water”, Bureau of Indian Standards (BIS-10500-2012), May 2012.

9. Dar, I.A., Sankar, K., and Dar, M.A., 2011. Deciphering groundwater potential zones in hard rock terrain using geospatial technology. Environmental Monitoring and Assessment, 173 (1), 597–610.

10. Foster S. Global Policy Overview of Groundwater in Urban Development—A Tale of 10 Cities! Water. 2020; 12(2):456. https://doi.org/10.3390/w12020456

11. GEC. (1997). "Groundwater Resource Estimation Methodology", 1997, Report of the Groundwater Resource Estimation Committee, Central Ground Water Board, Ministry of Water Resources, Government of India.

12. GEC (2015) Report of the Groundwater Resource Estimation Committee; Central Ground Water Board, Ministry of Water Resources, Government of India, New Delhi.

13. IDSA (2010) Water security for India; The External Dynamics, Institute for Defence Studies and Analyses.

14. Kumar, S.; Bhattacharya, P.; Singh, R.; Mukherjee, S. Groundwater level decline and aquifer vulnerability assessment in the Ghaggar River Basin, North-West India. *J. Hydrol.* 2018, *563*, 674–685.

15. Magesh N.S., Chandrasekar N. and John Prince Soundranayagam"Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques" Journal of Geoscience, Vol 3(2), 2012, p 189-196.

16. Maitre, D.C.L., Scott, D.F., and Colvin, C.,A review of information on interactions between vegetation and groundwater, South Africa Water Research Commission, 1999.

17. Moench, M. 1996. Groundwater policy: Issues and alternatives in India. Colombo, Sri Lank. International Irrigation Management Institute. x, 61p. (IIMI Country Paper, India No. 2)

18. Naik P.K. andAwasthi A.K., "Groundwater resources assessment of the Koyna River basin, India", Hydrogeology Journal, Vol. 11, 2003, p 582-594.

19. Pino-Vargas E, Espinoza-Molina J, Chávarri-Velarde E, Quille-Mamani J, Ingol-Blanco E. Impacts of Groundwater Management Policies in the Caplina Aquifer, Atacama Desert. Water. 2023; 15(14):2610. https://doi.org/10.3390/w15142610

20. Rehman, A., Islam, F., Tariq, A., Ul Islam, I., Brian J, D., Bibi, T., … Al-Ahmadi, S. (2024). Groundwater potential zone mapping using GIS and Remote Sensing based models for sustainable groundwater management. *Geocarto International*, *39*(1). https://doi.org/10.1080/10106049.2024.2306275

21. Riley, S. J. (1999). Index that quantifies topographic heterogeneity. Intermt. J. Sci.5, 23-27.

22. Sasane V. V. and Patil V. M. (2013) Assessment of Ground Water Quality Status Using NSFWQI Method in Selected Rural Area of Kopargaon, Ahmednagar, Maharashtra, International Journal of Advanced Technology in Civil Engineering, Volume-2, Issue-1, 5-10.

23. Sekar, I., & Randhir, T. O. (2007). Policies for sustaining groundwater resources in India. *Water International*, *32*(sup1), 697–709. https://doi.org/10.1080/02508060.2007.9671991

24. Sutradhar S, Sarkar D, Bhuimali A, Mondal P. 2022. Integration of different geospatial factors to delineate groundwater potential zones using multi-influencing factors under remote sensing and GIS environment: a study on Dakshin Dinajpur district, West Bengal, India. Sustain Water Resour Manag. 8(1):37. doi: 10.1007/s40899-022-00630-3.

25. Tariq A, Hashemi Beni L, Ali S, Adnan S, Hatamleh WA. 2023. An effective geospatial-based flash flood susceptibility assessment with hydrogeomorphic responses on groundwater recharge. Groundw Sustain Dev. 23(8):100998. doi: 10.1016/j.gsd.2023.100998.

26. Theesfeld, I. 2010. Institutional challenges for national groundwater governance: Policies and issues. Ground Water 48: 131-142.

27. World Health Organization. (2017). Guidelines for drinking-water quality - incorporating the first addendum.