A GIS-Based Multi Criteria Decision Making Technique for Groundwater Potential Zones of a Tropical River Basin, Northern Kerala, Southern India

N. P. Jesiya, M. V. Shyamkumar, and Girish Gopinath

Abstract The study encompasses the efficiency of the combination of geospatial and fuzzy-based multi-criteria decision-making (MCDM) techniques for evaluating the groundwater potential zones of Valapattanam River basin, Northern Kerala, India. The availability of groundwater (GW) mainly depends on parameters like geomorphology, geology, slope, lineament density, drainage density, soil texture, and land use land cover of the study area. First of all, the thematic data for each of these parameters was created with the help of various tools of the ArcGIS platform. As the second step, the fuzzy analytic hierarchy processes (FAHPs) were carried out by arranging the influencing parameters and their sub-criteria. Based on the assigned weights, the normalised weight of each parameter and its sub-criteria were identified. Finally, a composite groundwater potential zone (GWPZ) map was generated by weighted sum overlay analysis of thematic layers with normalised weights. According to the findings, the groundwater potential zones of the Valapattanam river basin are very good (5.3%), good (16.8%), moderate (22.5%), poor (34.7%), and very poor (20.5%). The GWPZ map was validated by using the data from India-WRIS and field data. The study also pointed out that the use of the MCDM technique with remote sensing and the GIS method has great significance in groundwater management practices.

Keywords Groundwater potential zone · Fuzzy · GIS · Valapattanam

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1 Introduction

Natural groundwater (GW) resources are the most valuable and finite source of fresh water in semi-arid and urban areas. According to the UN report, there are more than 2 billion people worldwide who depend upon GW as a major source of water for their needs like irrigation, industrial purposes, domestic usage, etc. [1]. However, increasing urbanisation, population growth, and the emergence of new water-consuming industrial sectors all place strain on GW resources. It also causes the water table to decline, springs and wells to dry up, and water chemistry to change negatively, among other effects [2–8]. Due to the lack of freshwater, approximately 0.6 million people in a semi-arid country like India were experiencing high to extremely high water stress. As a result, residents in those places must rely increasingly on groundwater resources to survive. According to a World Bank research, unless suitable efforts are made, India will become a water-stressed region by 2025 and a water-scarce region by 2050.

In view of the high-level threat to groundwater resources, valid evaluation, planning, and management have become critical and necessary phenomena. The use of remote sensing and GIS techniques allows for the rapid and cost-effective assessment of groundwater resources, which would otherwise be a very expensive, time-consuming, and laborious task [9–16]. The introduction and emergence of new technologies, and their benefits of spatial, spectral, and temporal data availability, have been found effective in gaining access to data about the factors that control the occurrence and movement of groundwater [17–19]. The application of GIS-based multi-criteria decision analysis (MCDA) is the ideal alternative for combining, analysing, and managing a wide range of geoenvironmental variables [20].

Geographical information system (GIS) techniques are particularly reliable in identifying GW prospects because they describe all important features within a spatial context and may combine data in a variety of ways [21–23]. Many hydrogeologists have turned to geospatial technology to complete their work because data is readily available and can be processed in a GIS environment to investigate various hydrogeological processes such as groundwater potential zonation, artificial recharge assessments, quality analysis, etc. with high accuracy [24–28].

The multi-criteria decision-making techniques like AHP, AHP/ANP, or fuzzy-based AHP can be used to analyse each of the geoenvironmental parameters, assessing the reliability of the result and so eliminating bias in the decision-making process. [29]. An integrated AHP-fuzzy model is more dependable than other MCDM techniques for calculating groundwater potential and vulnerability studies [8, 30–34]. It allows you to work with a large number of variables since it generates an aggregated index, handles linguistic attributes, and treats draft data without losing the vital parts of the concepts [35–38]. The integrated fuzzy AHP with GIS approach makes it feasible to evaluate the hydrological response of regions with various forms of development by including hydrogeological and anthropogenic data [8]. Furthermore, by supporting water managers in the selection of potential areas, the use of this integrated method can lower the cost of recharge operations and water management studies. The present work attempted to appraise the groundwater potential zones in the Valapattanam River basin, a tropical river basin located in northern Kerala, using the state-of-the-art GIS-based fuzzy AHP method.

2 Study Area

The Valapattanam River, which is located in a tropical monsoon climate, covers 44% of this district. The river originates from the Brahmagiri hills of Western Ghats, Kodagu, with an elevation of 1350 m. By length, Valapattanam River is the 9th longest river of Kerala, and in the case of quantum of water resources it takes 4th position. The basin located between north latitudes of 11º 49′ 30" and 12º 13′ 50″ and east longitudes of 75º 58′ 55″ and 75º 17′ 22″. The main stream has a length about 110 km and catchment area about 1900 km^2. The drainage area of the river in Kerala is 1321 km^2 (Fig. 1).

The major tributaries are Vallithodu, Aralam, Bavali, Iritty, Sreekandapuram, and Katampallipuzha. Valapattanam River is a major source of irrigation in the

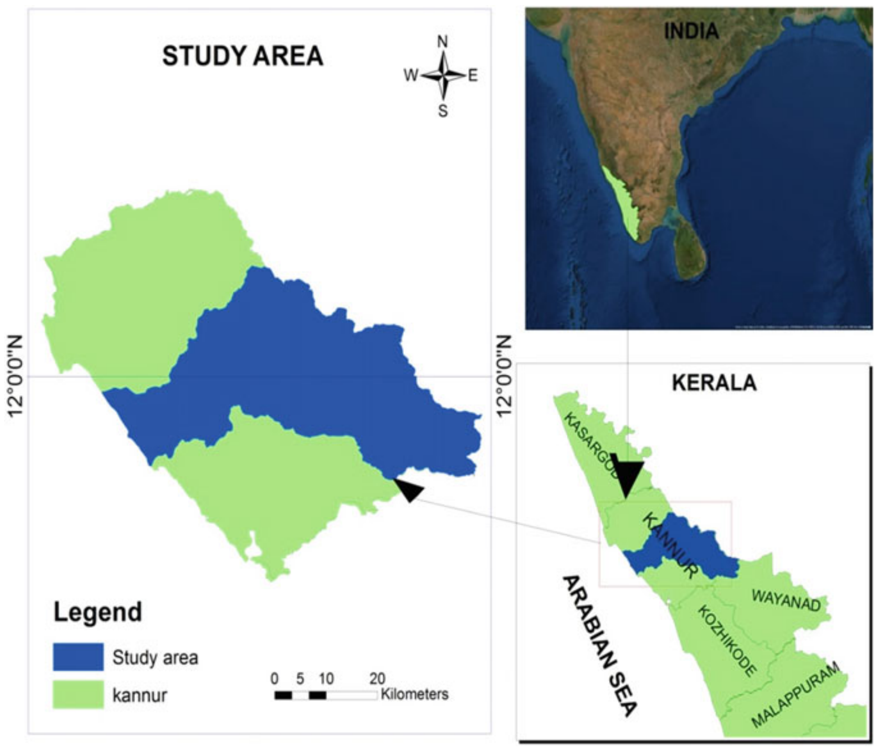

Fig. 1 Study area map of Valapattanam River basin

district (Pazhasi dam), and many wood-based industries are situated in its banks. Average annual stream flow (computed) is 4779 MCM, and average annual rainfall is 3600 mm. Water requirement for three main crops is 240 Mm^3 (ENVIS). As per the ENVIS report, water requirement for domestic use is 82$Mm^3$and that of water requirement for industrial use is 90 Mm^3.

3 Materials and Methods

The study used an integrated method using remote sensing and a GIS-based FAHPs to analyse the groundwater (GW) potential zones. The groundwater potential zonation (GWPZ) was achieved through four successive phases, including data collection, thematic layer preparation using Arc-GIS 10.8, deriving numerical index using FAHP, and the spatial and non-spatial integration of these data using ArcGIS 10.8 (Fig. 2).

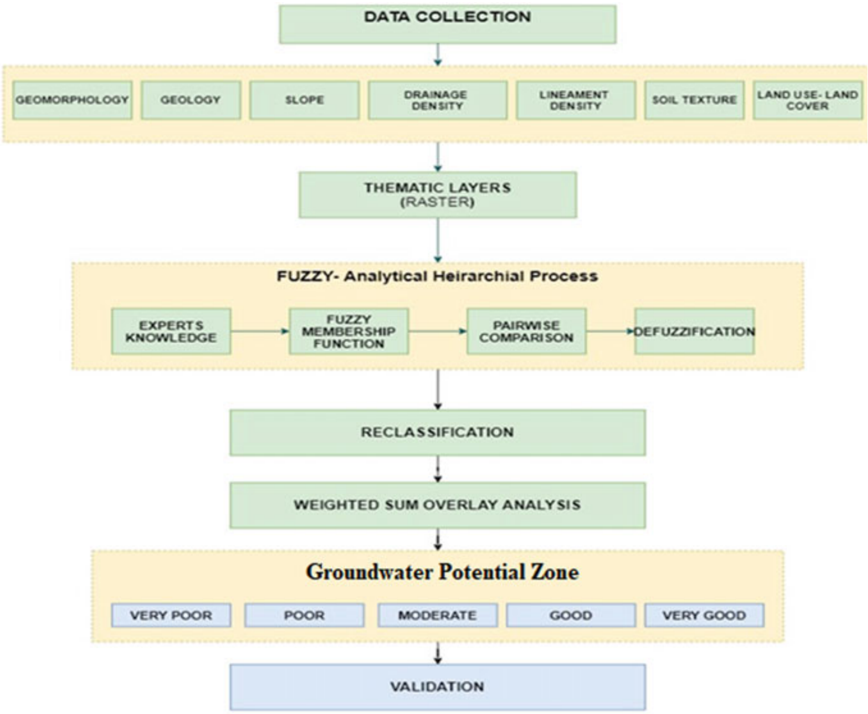

Fig. 2 Flow chart showing the methodology of groundwater potential mapping, using MCDM technique

3.1 Field Investigations and Data Collection

Valapattanam watershed boundary was delineated based on the data obtained from CWRDM-Water atlas [39]. A thorough field visit was conducted to study the environmental and geological aspects of the area. Groundwater inventory was carried out to collect hydrogeological parameters like depth to water table, total depth of well, and other primary information. Further, the collected groundwater data were used for the ground truthing of secondary water level data.

3.2 Preparation of Thematic Maps of Influencing Factors

Thematic data for geology and soil texture were developed in ArcGIS 10.8 utilising various geoprocessing features, including georeferencing, digitisation, and so on. Landuse and land cover classes of the study area were generated from IRS-P6, LISS-III data using the Image Classification tool in ArcGIS 10.8. Drainage patterns were extracted from a 1:50,000 scale survey of India's topographical maps, and lineaments were derived using the Bhuvan web portal's thematic services. In addition, point density analysis was used to generate lineament and drainage density data (Km/Km^2). Slope (in %) analysis was performed with SRTM DEM (30 m) data, which was obtained from Earth Explorer (https://earthexplorer.usgs.gov/dd) and employed surface analysis using the spatial analyst tool.

3.3 Deriving Numerical Index Using Fuzzy AHP Method

The numerical potential index is a dimensionless quantity determined by ratings and weights of influencing factors generated through the fuzzy AHP. As a first phase, each parameter was assigned a subjective score of 1–9 rely on expert opinion and scientific data. Components with the least potential are given a ranking of one, while those with the most potential are given a ranking of nine. A fuzzy AHP pairwise comparison scale is conducted using triangular fuzzy integers, and a fuzzy evaluation matrix is created for this comparison [8]. The comparison thus derived the vectors of weights for the seven major criteria and its sub-criteria. And as the output of the analysis, the normalised weightages of each parameters are displayed in Table 1.

Table 1 Rating and criteria weights evaluated after fuzzy AHP analysis

Criteria	Assigned weight	Normalised weight	Sub-criteria	Score	Normalised weight
Geomorphology	9	0.22			
			Water body	9	0.16
			Marshy	8	0.14
			Floodplain	8	0.14
			Young coastal plain	7	0.12
			Valley	7	0.12
			Pediment zone	5	0.07
			Valley fill	5	0.07
			Lower plateau (Lateritic) Dissected	3	0.05
			Residual hills	2	0.04
			Residual mount (pediment)	2	0.04
			Denudation hills	1	0.03
			Rock exposure	1	0.03
Slope	8	0.18	< 5	9	0.38
			5–10	7	0.26
			10–15	5	0.17
			15–20	3	0.10
			> 20	2	0.09
Drainage density	6	0.12	< 1	9	0.29
			1–2	8	0.24
			2–3	7	0.19
			3–4	6	0.15
			> 4	5	0.13
Lineament density	6	0.12	> 2	9	0.29
			1.5–2	8	0.24
			1–1.5	7	0.19
			0.5–1	6	0.15
			0–0.5	5	0.13
Geology	5	0.10	Fluvial costal alluvium	9	0.38
			Warkali formation	7	0.25

(continued)

Table 1 (continued)

Criteria	Assigned weight	Normalised weight	Sub-criteria	Score	Normalised weight
			Hornblende biotite gneisses	5	0.16
			Charnockite	3	0.11
			Metavolcanoes	3	0.11
Soil texture	4	0.08	Gravelly loam	7	0.49
			Gravelly clay	5	0.31
			Clay	3	0.20
Land use/land cover	3	0.06	Vegetation	9	0.39
			Water body	9	0.39
			Others	4	0.13
			Built-up area	2	0.09

3.4 Integration of Spatial and Non-spatial Data

The thematic maps were combined with non-spatial data (ratings and weights) derived from the fuzzy AHP analysis. Using the conversion tool in ArcGIS, all thematic layers were converted to raster format. Using reclassification and raster editing methods, the weightages derived from fuzzy AHP were added to the thematic layers (raster). Each of the integrated thematic layers was combined using weighted overlay analysis within the GIS platform, resulting in the spatial distribution of GW potential zones (GWPZ) for the study area.

3.5 Validation Analysis

Groundwater data were collected from CGWB for the pre- and post-monsoon seasons in the year 2019, and the groundwater fluctuation in metres was calculated. The calculated GW fluctuation data were combined with the resultant GWPZ data in order to perform validation analysis. The validation analysis was enabled by the spatial relationship between the shape file of GW fluctuation data and the GWPZ raster data.

4 Result and Discussion

The evaluation of groundwater potential in the Valapattanam River basin based on the advanced technologies point outs to the necessity to predict the potential of GW level of the area. The relative influences of geoenvironmental factors of the study area in the potentiality of GW were determined by a potential index modelling with the help of fuzzy AHP analysis. Importance of each criterion in groundwater occurrence and its analysis result was discussed below.

4.1 Groundwater Influencing Factors

4.1.1 Geology

Geology has a vital role in groundwater occurrence and distribution in any terrain. The Valapattanam River basin is underlain by charnockites, pyroxene granulites, garnetiferous gneisses, hornblende biotite gneisses, and schistose rocks, overlain by tertiaries and coastal alluvium along the coast, ranging in age from Archean to Recent [40]. Among the geological formations, the fluvial coastal sediments are assigned the relatively highest units for groundwater occurrence. Consolidated formations, viz. weathered and fractured crystallines, semi-consolidated sediments, and laterite formations and unconsolidated formations such as recent alluvium occurring along the coast are the hydrogeological units in the river basin. The weathered and fractured rocks of the consolidated formation are mostly made of charnockites, hornblende gneisses, schist, and other intrusive and constitute potential phreatic aquifers [40]. Charnockite formations are assigned a relatively low weightage because of its low degree of weathering.

The gneissic rocks are assigned moderate weightage towards groundwater potential due to highly weathered and well-jointed gneissic rocks. These formations characterised by good water potential zones with a well yield of 10–20 m^3/day [40] (Fig. 3a). The porous laterites recharge quickly, and the recharge water leaves as subsurface flow, particularly in wells on topographic highs and steep slopes. As a result, even though these formations constitute a potential aquifer in the midland regions, laterites are assigned the lowest rating. The coastal alluvium, which consists of sand, silt, and clay, has the potential to form phreatic aquifers in the area. Therefore, these geological formations are assigned the highest rating for groundwater potential.

4.1.2 Soil Texture

Soil texture influences the volume of water which can infiltrate into subsurface formations and, as a result, the rate of water infiltration to the ground. The four classes of soil

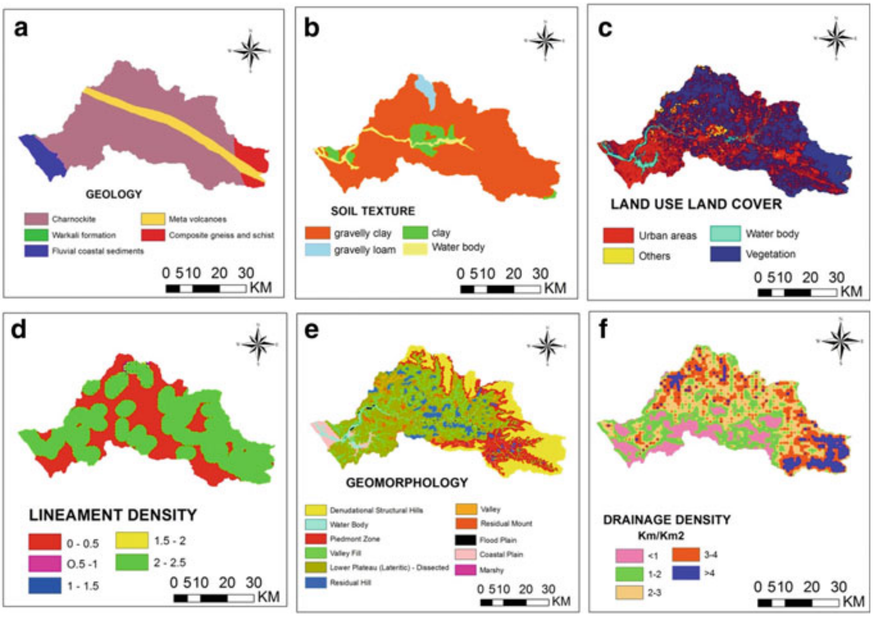

Fig. 3 Spatial distribution of **a** geology, **b** soil texture, **c** landuse/landcover, **d** lineament density, **e** geomorphology, **f** drainage density of Valapattanam River basin

occurred in the area are lateritic soil, coastal and river alluvium, brown hydromorphic soil, and forest loamy soil. The soil texture in the area is found with three kinds of soil texture: clay, gravelly clay, and gravelly loam (Fig. 3b). The predominant soil type in the Valapattanam River basin is lateritic soil, which is a weathered product derived under humid tropical conditions. Soil texture in lateritic soil ranges from sandy loam to red loam. The coastal alluvium observed in the western coastal stretch is made up of recent, mostly marine deposits. It is distinguished by being immature and having a high sand content. River alluvium with surface textures varied from sandy loam to clay is found along river valleys that cut through extensive lateritic soils. The river alluvium is characterised by being fertile, having water holding capacity.

4.1.3 Land Use/land Cover

The majority of the land in the Valapattanam River basin is used for agriculture, with urban areas ranking second [42]. The LU/LC data gives important information on moisture content of soil, infiltration, occurrence of groundwater, etc. The urban land is composed of built-up areas (commercial and residential classes) (Fig. 3c). Built-up and fallow lands inhibit groundwater recharge and are assigned the lowest rating, whereas water bodies were assigned with a highest rating towards groundwater potential.

4.1.4 Lineament Density

Lineaments denote the linear features, developed by tectonic activity. Through this major portion of water flows into the impermeable rocks. Based on the distribution in a single grid of (km/km^2), the density of lineament fractures in the study area can be classified into five classes (Fig. 3d). The intersection of lineaments and lineaments parallel to stream network regions is evidence of groundwater movement and storage. Therefore, delineation and analysis of lineaments in a hydrogeological regime provides information on the groundwater zones of that region. The presence of the intersections in the high lineament density zones favours high groundwater recharge, hence high groundwater potential. The areas with high lineament density are characterised by high groundwater potential, and 63.03% of the study area covered high lineament density zones.

4.1.5 Geomorphology

Geomorphic characteristics can be used as surface indicators to evaluate subsurface hydrologic status [19]. The three physiographic units of the study area are the coastal plains and lowlands in the west, the central undulatory midland terrain, and the high land region in the east [40]. Geomorphically, the area was classified as residual hill, lower plateau, valley fill, piedmont zone, valley, denudational structural hills, marshy areas, denudational hills, coastal plain, floodplain, and water body. The narrow coastal plains composed of alluvial deposits located parallel to the coast, and it covers an area of 2.72% of the study area. In some locations, the midland region adjacent to the east of the coastal strip constitutes a plateau land covered by a thick cover of laterite. The denudation structural hills located in the hilly tract of the eastern part makes highly rugged terrains. The residual hills and denudation hills together impart least influence on groundwater occurrence in the area. Good groundwater potential zones were recognised in valley fills that ran through the lateritic plateau. The valley fills occupied 9.70% of the area. Lateritic terrains with the thickness of ranges from 10 to 20 m were assigned with moderate potential to groundwater (Figs. 3e and 4).

Dinesh Kumar et al. [41] were studied on groundwater potential of Muvattupuzha river basin, Kerala and explained that residual hills are poor in groundwater occurrence. Hence, residual hills were assigned with least rating.

4.1.6 Slope %

Valapattanam River basin classified in to five classes based on the degree of steepness, viz. < 5%, 5–10%, 10–15%, 15–20%, and > 25% classes. Flat-to-gentle slope terrain (i.e. 0–5%) is categorised as a very good groundwater potential zone because slow surface water runoff through the terrain permits more residents time for rainwater to percolate and increases the rate of infiltration. About 11.72% of the area

	Water boady	Marshy	Flood plain	Young coastal plain	Valley	Pedimont zone	Valley fill	Lower plateau(Lateritic) Dissected	Residual hills	Residual mount(pediment)	Denudation hills	Rock exposure
Water boady	1	1/2 1 1.5	1/2 1 1.5	1 1.5 2	1 1.5 2	2 2.5 3	2 2.5 3	3 3.5 4	3.5 4 4.5	3.5 4 4.5	4 4.5 5	4 4.5 5
Marshy	1/1.5 1 2	1	1	1/2 1 1.5	1/2 1 1.5	1.5 2 2.5	1.5 2 2.5	2.5 3 3.5	3 3.5 4	3 3.5 4	3.5 4 4.5	3.5 4 4.5
Flood plain	1/1.5 1 2	1	1	1/2 1 1.5	1/2 1 1.5	1.5 2 2.5	1.5 2 2.5	2.5 3 3.5	3 3.5 4	3 3.5 4	1 1.5 2	1 1.5 2
Young coastal plain	1/2 1/1.5 1	1/1.5 1 2	1/1.5 1 2	1	1	1 1.5 2	1 1.5 2	2 2.5 3	2.5 3 3.5	2.5 3 3.5	3 3.5 4	3 3.5 4
Valley	1/2 1/1.5 1	1/1.5 1 2	1/1.5 1 2	1	1	1 1.5 2	1 1.5 2	2 2.5 3	2.5 3 3.5	2.5 3 3.5	3 3.5 4	3 3.5 4
Pedimont zone	1/3 1/2.5 1/2	1/2.5 1/2 1/1.5	1/2.5 1/2 1/1.5	1/2 1/1.5 1	1/2 1/1.5 1	1	1	1 1.5 2	1.5 2 2.5	1.5 2 2.5	2 2.5 3	2 2.5 3
Valley fill	1/3 1/2.5 1/2	1/2.5 1/2 1/1.5	1/2.5 1/2 1/1.5	1/2 1/1.5 1	1/2 1/1.5 1	1	1	1 1.5 2	1.5 2 2.5	1.5 2 2.5	2 2.5 3	2 2.5 3
Lower plateau(Lateritic) Dissected	1/4 1/3.5 1/3	1/3.5 1/3 1/2.5	1/3.5 1/3 1/2.5	1/3 1/2.5 1/2	1/3 1/2.5 1/2	1/2 1/1.5 1	1/2 1/1.5 1	1	1/2 1 1.5	1/2 1 1.5	1 1.5 2	1 1.5 2
Residual hills	1/4.5 1/4 1/3.5	1/4 1/3.5 1/3	1/4 1/3.5 1/3	1/3.5 1/3 1/2.5	1/3.5 1/3 1/2.5	1/2.5 1/2 1/1.5	1/2.5 1/2 1/1.5	1/1.5 1 2	1	1	1/2 1 1.5	1/2 1 1.5
Residual mount(pediment)	1/4.5 1/4 1/3.5	1/4 1/3.5 1/3	1/4 1/3.5 1/3	1/3.5 1/3 1/2.5	1/3.5 1/3 1/2.5	1/2.5 1/2 1/1.5	1/2.5 1/2 1/1.5	1/1.5 1 2	1	1	1/2 1 1.5	1/2 1 1.5
Denudation hills	1/5 1/4.5 1/4	1/4.5 1/4 1/3.5	1/2 1/1.5 1	1/4 1/3.5 1/3	1/4 1/3.5 1/3	1/3 1/2.5 1/2	1/3 1/2.5 1/2	1/2 1/1.5 1	1/1.5 1 2	1/1.5 1 2	1	1
Rock exposure	1/5 1/4.5 1/4	1/4.5 1/4 1/3.5	1/2 1/1.5 1	1/4 1/3.5 1/3	1/4 1/3.5 1/3	1/3 1/2.5 1/2	1/3 1/2.5 1/2	1/2 1/1.5 1	1/1.5 1 2	1/1.5 1 2	1	1

Fig. 4 Comparison matrix of geomorphology of the study area

is characterised by gentle slope terrain. Rolling lateritic hills and valley fills in the area with 5–15% and 15–25% slope terrain are characterised by a moderate infiltration rate, hence assigned a moderate rating in groundwater potential. The eastern part of the river basin consists of plateau edges and high mountain regions that have steep slopes (> 25%). This steep slope zone is characterised by poor potential for groundwater occurrence due to low infiltration rate and high surface runoff.

4.1.7 Drainage Density

The closeness of spacing of channels is expressed as drainage density, and it is expressed as length of drainage within a square grid of the area in terms of km/km^2. About five classes of drainage density zones are occurred in the Valapattanam River basin (Fig. 3f). The areas with high drainage density (> 4 km/Km^2) not suitable for groundwater potential because of the higher surface runoff. Therefore, the study area with high drainage density is assigned with least rating for groundwater potential and vice versa. In Valapattanam River basin, majority of the areas were characterised with 1–3 km/Km^2 drainage density. The less drainage density zones hinder surface runoff which consequently enhances infiltration and thereby favours groundwater recharge [23]. The intermediate drainage density classes are assigned with moderate ratings towards groundwater recharge.

4.2 Groundwater Potential Zones in Valapattanam River Basin

The GIS-based fuzzy-AHP approach delineated the Valapattanam River basin into five groundwater potential zones: very good, good, moderate, poor, and very poor

(Fig. 5). The very good potential zone mainly occurs in the western part of the study area, which covers 5.3% of the study area. The very good zone is characterised by the gently sloping coastal alluvium with low drainage density. Soil in the coastline and riverine alluvium has a high water retention capacity. Groundwater occurs in phreatic conditions with a depth to the water table of 0.5 to 5 m in the very good potential zone.

The laterite-capped midland region with relatively moderate groundwater influence factors constitutes a moderate groundwater potential zone. It covers 22.5% of the area (Table 2). Open-dug wells, according to C.G.W.B., are suitable groundwater extraction structures where the depth to groundwater is between 5 and 20 m. The eastern part comprises a poor to very poor potential zone. The area covers 55.2% of the Valapattanam River basin and consists of steep terrain, weathered rock, and high drainage density zones. Some terrains, particularly fracture planes in the east, contribute to potential groundwater zones capable of supporting bore wells [40].

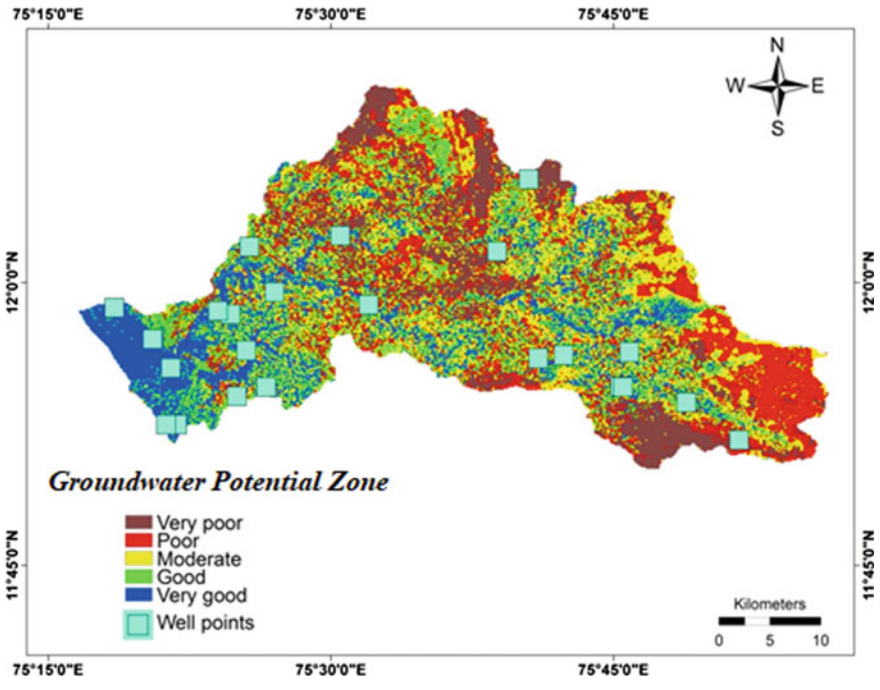

Fig. 5 Spatial distribution of groundwater potential zones in the Valapattanam River basin

Table 2 Groundwater potential zones in the Valapattanam River basin

S. No.	Ground water potential	Area in km^2	Area in %
1	Very poor	269.0	20.5
2	Poor	454.0	34.7
3	Moderate	294.8	22.5
4	Good	220.0	16.8
5	Very good	69.8	5.3

4.3 Validation of GWPZ with Available Well Data as Ground Validation

For the validation analysis, data from 23 dug wells in the Valapattanam River basin were used. The depth to water level varies from 2.6 (along the coastal area) to 22.5 m below ground level (mbgl). The validation of the outcome (GWPZs) from the study with field observation from dug wells in the Valapattanam River basin revealed that very good GWPZs are occupying the coastal area, which has a very good alluvial cover, whereas the eastern part has very little soil cover and is predominately made of hard rocks and occupies poor GWPZs. The GWPZ, derived logically from the fuzzy AHP model, has been validated with water level fluctuation data (in metres). In the validation analysis, the spatial relationship between well points and potential classes revealed that wells in very good potential zones show comparatively less fluctuation (0.7 m), indicating high groundwater yield in the area (Table 3), whereas average water level fluctuations in wells from good and moderate potential zones are 0.3 and 0.67 m, respectively. Moreover, most of the dug wells in the eastern part get dry during the summer, and these aquifers are recharged only during the monsoon. On the other hand, wells in the central and western parts of the country are perennial throughout the year. Average water level fluctuations in wells from poor and very poor potential zones are 1.6 and 1.7 m, respectively.

Table 3 Statistics of validation analysis between GWPZ classes and GW fluctuation data

Potential class	Minimum	Maximum	Average groundwater fluctuation level (m)	Std. Dev
Very good	− 1.6	2.01	0.07	0.9
Good	0.2	5.7	0.3	0.7
Moderate	0.1	1.9	0.67	0.9
Poor	0	1.1	1.6	0.5
Very poor	0	0.07	1.7	0.5

5 Conclusions

Groundwater potential analysis of the Valapattanam River basin, Kerala, with the help of remote sensing and GIS technology combined with the FAHP technique perfectly demonstrated the efficiency and reliability of the MCDM-geospatial techniques in groundwater resource management. The groundwater controlling factors and their sub-criteria were assigned a weight (on a 1–9 scale) based on their importance in hosting groundwater occurrences. The normalised weights were generated by pair-wise comparisons of features and sub features using fuzzy AHP analysis. Besides, fuzzy AHP is an excellent tool that can be used in group decision-making to eliminate ambiguity, imprecision, and uncertainty in the comparison analysis. Fuzzy weigh-tages were integrated with the particular GW controlling features, and the resulting groundwater potential zone map was generated. The Valapattanam River basin is divided into five groundwater potential zones. The very good potential zone, covering 5.3% of the area, mainly occurred in the western part of the study area. The zone is characterised by gently sloping coastal alluvium with low drainage density. The midland region of the study area constitutes a moderate groundwater potential zone, and it covers 22.5% of the area. The zone of poor to very poor potential covers 55.2% of the Valapattanam River basin and consists of steep terrain, weathered rock, and high drainage density zones. The present study proved that the MCDM methodology, geostatistical modelling, and its application in geospatial layer preparation have a great role in getting a precise and reliable picture of the current groundwater condition of the Valapattanam River basin. Furthermore, this analysis will help formulate a long-term sustainable use plan for groundwater conservation.

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References

1. United Nations (2015) World population prospects. Report No. ESA/P/WP.241, United Nations, New York 59
2. Foster SSD, Morris BL, Chilton PJ (1999) Groundwater in urban development-a review Howardof linkages and concerns. In: Proceedings of impacts of urban growth on surface water and groundwater quality, IUGG 99 Symposium HS5, IAHS Publ, Birmingham vol 259, pp 3–12
3. Howard KWF, Gelo KK (2002) Intensive groundwater use in urban areas: the case of megacities. Intensive Groundwater Challenges Opportunities 484
4. Kløve B, AlaAho P, Bertrand G, Gurdak JJ, Kupfersberger H, Kværner J, Muotka T, Mykra H, Preda E, Rossi P, Uvo CB, Velasco E, Pulido- Velazquez M (2014) Climate change impacts on groundwater and dependent ecosystems. J Hydrol 518:250–266
5. Bougharіou E, Allouche N, Jmal I, Mokadem N, Ayed B, Hajji S, Khanfir H, Bouri S (2018) Modeling aquifer behaviour under climate change and high consumption: case study of the Sfax region, southeast Tunisia. J Afr Earth Sci 141:118–129

6. Le Brocque AF, Kath J, Reardon-Smith K (2018) Chronic groundwater decline: a multi-decadal analysis of groundwater trends under extreme climate cycles. J Hydrol 561:976–986
7. Howard K, Gerber R (2018) Impacts of urban areas and urban growth on groundwater in the Great Lakes Basin of North America. J Great Lake Res 44(1):1–13
8. Jesiya NP, Gopinath G (2020) A fuzzy based MCDM–GIS framework to evaluate groundwater potential index for sustainable groundwater management—a case study in an urban-periurban ensemble, southern India. Groundwater Sustain Dev 11
9. Moore ID, Grayson RB, Ladson AR (1991) Digital terrain modelling: a review of hydrological, geomorphological, and biological applications. Hydrol Process 5(1):3–30
10. Krishnamurthy J, Mani A, Jayaraman V, Manivel M (2000) Groundwater resources development in hard rock terrain: an approach using remote sensing and GIS techniques. Int J Appl Earth Obs Geoinf 3(3–4):204–215
11. Jha MK, Chowdary VM, Chowdhury A (2010) Groundwater assessment in Salboni Block, West Bengal (India) using remote sensing, geographical information system and multi-criteria decision analysis techniques. Hydrogeol J 18:1713–1728
12. Arkoprovo B, Adarsa J, Prakash SS (2012) Delineation of ground- water potential zones using satellite remote sensing and geographic information system techniques: a case study from Ganjam district, Orissa India. Res J Recent Sci 1(9):59–66
13. Hammouri NA, El-Naqa A, Barakat M (2012) an integrated approach to groundwater exploration using remote sensing and geographic information system. J Water Resour Prot 4(9):717–724
14. Lee S, Kim YS, Oh HJ (2012) Application of a weights-of-evidence method and GIS to regional groundwater productivity potential mapping. J Environ Manag 96(1):91–105. https://doi.org/10.1016/j.jenvman.2011.09.016
15. Davoodi MD, Rezaei M, Pourghasemi HR, Pourtaghi ZS, Pradhan B (2015) Groundwater spring potential mapping using bivariate statistical model and GIS in the Taleghan watershed Iran. Arab J Geosci 8(2):913–929
16. Thapa R, Gupta S, Guin S, Kaur H (2017) Assessment of groundwater potential zones using multi-influencing factor (MIF) and GIS: a case study from Birbhum district West Bengal. Appl Water Sci 7(7):4117–4131
17. Bobba AG, Bukata RP, Jerome JH (1992) Digitally processed satellite data as a tool in detecting potential groundwater flow systems. J Hydrol 131(1–4):25–62
18. Meijerink AMJ (2000) Groundwater In: Schultz GA, Engman ET (eds) Remote sensing in hydrology and water management. Springer, Berlin, pp 305–325
19. Preeja KR, Joseph S, Thomas J, Vijith H (2011) Identification of groundwater potential zones of a Tropical River Basin (Kerala, India) using remote sensing and GIS techniques. J Indian Soc Remote Sens 39(1):83–94
20. Saidi S, Hosni S, Mannai H, Jelassi F, Bouri S, Anselme B (2017) GIS-based multi-criteria analysis and vulnerability method for the potential groundwater recharge delineation, case study of Manouba phreatic aquifer, NE Tunisia. Environ Earth Sci 76(15)
21. Nair HC, Padmalal D, Joseph A, Vinod PG (2017) Delineation of groundwater potential zones in river basins using geospatial tools—an example from Southern Western Ghats, Kerala, India. J Geovisualization Spat Anal 1:1–2
22. Swetha TV, Gopinath G, Thrivikramji KP, Jesiya NP (2017) Geospatial and MCDM tool mix for identification of potential groundwater prospects in a tropical river basin Kerala. Environ Earth Sci 76(12):1–17
23. Jesiya NP, Gopinath G (2019) A Customized FuzzyAHP - GIS based DRASTIC-L model for intrinsic groundwater vulnerability assessment of urban and Peri urban phreatic aquifer clusters. Groundw Sustain Dev 8:654–666
24. Gumma MK, Pavelic P (2013) Mapping of groundwater potential zones across Ghana using remote sensing, geographic information systems, and spatial modeling. Environ Monit Assess 185(4):3561–3579
25. Murthy KSR (2000) Groundwater potential in a semi-arid region of Andhra Pradesh-a geographical information system approach. Int J Remote Sens 21(9):1867–1884

26. Lone RMM, Ahmed S (2011) Integrating geospatial and ground geophysical information as guidelines for groundwater potential zones in hard rock terrains of south India. Environ Monit Assess 184:4829–4839
27. Senthil Kumar GR, Shankar K (2014) Assessment of groundwater potential zones using GIS. Front Geosci 2(1):1–10
28. Raj BS (2019) Groundwater potential zonation of Delampady Grama Panchayath, Kasaragod, Northern Kerala: a geophysical and GIS approach. Int J Res Appl Sci Eng Technol 7(5):1919–1929
29. Arulbalaji P, Padmalal D, Sreelash K (2019) GIS and AHP Techniques based delineation of groundwater potential zones: a case study from Southern Western Ghats India. Sci Rep 9(1):1–18
30. Kumar A, Krishna AP (2018) Assessment of groundwater potential zones in coal mining impacted hard-rock terrain of India by integrating geospatial and analytic hierarchy process (AHP) approach. Geocarto Int 33(2):105–129
31. Şener E, Şener Ş, Davraz A (2018) Groundwater potential mapping by combining fuzzy-analytic hierarchy process and GIS in Beyşehir Lake Basin, Turkey. Arab J Geosci 11:1–21
32. Chaudhry AK, Kumar K, Alam MA (2019) Mapping of groundwater potential zones using the fuzzy analytic hierarchy process and geospatial technique. Geocarto Int 1–22
33. Rajasekhar M, Raju GS, Sreenivasulu Y, Raju RS (2019) Delineation of groundwater potential zones in semi-arid region of Jilledubanderu river basin, Anantapur district, Andhra Pradesh, India using fuzzy logic, AHP and integrated fuzzy-AHP approaches. Hydro Res 2:97–108
34. Bhadran A, Girishbai D, Jesiya NP, Gopinath G, Krishnan RG, Vijesh, VK (2022) A GIS based fuzzy-AHP for delineating groundwater potential zones in tropical river basin, southern part of India. Geosyst Geoenvironment 100093
35. Seekao C, Pharino C (2016) Assessment of the flood vulnerability of shrimp farms using a multicriteria evaluation and GIS: a case study in the Bangpakong Sub-Basin Thailand. Environ Earth Sci 75:308
36. Rebolledo B, Gil A, Flotas X, Sanchez JA (2016) Assessment of groundwater vulnerability to nitrates from agricultural sources using a GIS-compatible logic multi-criteria model. J Environ Manage 171:70–80
37. Fernandez DS, Lutz MA (2010) Urban flood hazard zoning in Tucuman Province, Argentina, using GIS and multicriteria decision analysis. EngGeol 111:90–98
38. Aydi A (2018) Evaluation of groundwater vulnerability to pollution using a GIS-based multi-criteria decision analysis. Groundw Sustain Dev 7:204–211
39. Water Atlas of Kerala (1995) Centre for water resources development and management
40. Santhana Subramani M (2013) Ground water information booklet of Kannur district, Kerala state technical reports: series 'D'. Cent Ground Water Board, Gov India, Ministry Water Resou 1–30
41. Dinesh Kumar PK, Gopinath G, Seralathan P (2007) Application of remote sensing and GIS for the demarcation of groundwater potential zones of a river basin in Kerala, southwest coast of India. Int J Remote Sens 28(24):5583–5601
42. Jyothirmayi P, Sukumar B (2019) Role of relief and slope in agricultural land use: a case study in Valapattanam River Basin in Kannur district, Kerala using GIS and remote sensing. J Geogr Environ Earth Sci Int 21(2):1–11