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A Fuzzy–GIS Model for the exploration of groundwater potential zones in Tamiraparani sub-basin, Tamil Nadu, India

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Abstract: Groundwater is one of the important natural resource found in earth and it serves as a source for potable drinking water. Due to its ever-increasing demand, this precious resource is depleted unsustainably. To overcome this hurdle, new technological innovations like GIS and remote sensing are widely used for delineating the groundwater potential zones. The present study deals with the evaluation of groundwater potential zones in Tamiraparani sub-basin, south India. Various thematic layers viz. slope, lineament density, drainage density, geology, geomorphology, land-use and rainfall are used to evaluate the potential zones. These thematic layers are extracted from different sources such as Landsat ETM+ image, topographical maps, digital elevation models and other secondary data source repositories. An integrated fuzzy logic and GIS technique has been applied in the study area and it is found that the suitable zones are found near the flood plain areas and cultivable lands. Fuzzy overlay analysis allows combining the fuzzy membership raster data together, based on selected overlay type. The overlay type used here is GAMMA, which is an algebraic product of the fuzzy sum and fuzzy product, both raised to the power of 0.5 (Gamma value). The study reveals that the application of fuzzy based analysis in GIS platform is worthy for mapping the groundwater potential zones.

Keywords: *Groundwater Potential Zones, Fuzzy logic, GIS, Tamiraparani sub-basin, India.*

1. INTRODUCTION

Groundwater is one of the most valuable assets of any nation. It has the capability to sustain life and other developmental activities. In India, groundwater fulfils almost 85% of rural domestic needs and 50% of urban needs [1]. Besides that, it is extensively used for irrigation and industrial purposes. As a result, this precious resource has been exploited unsustainably. The ever-increasing demand of this vital resource can be overcome by sustainable management and by exploring potential groundwater zones. Technology has grown so far in the field of geosciences for the exploration of potential groundwater zones; one such innovative technology is GIS and remote sensing.

These techniques have a number of advantages with reference to spatial, spectral, and temporal availability of data over a large area for assessing, monitoring, and conserving groundwater resources [2]. Application of satellite images has been widely used for the exploration of groundwater resources. This technology is a rapid and cost-effective tool for producing valuable data on geology, geomorphology, lineaments slope, etc. that helps in deciphering the groundwater potential zone [3].

In recent years, many researchers such as, [4 – 14] have used GIS to delineate groundwater potential zone, and it was found that the analyzing factors required for the estimation of groundwater potential zones were different, and hence the results vary accordingly. Besides that, weighted overlay technique is often used by most of the researchers for delineating the groundwater potential zones. The derived result from this technique is found to be satisfactory based on ground truth and the output varies from one region to another because of geo-environmental dissimilarity.

Fuzzy overlay technique is much more advanced than weighted overlay technique in GIS. It is introduced recently in ArcGIS 10. It handles the concept of partial truth (truth values between 1 (completely true) and 0 (completely false)). It has the capability to model vagueness and ambiguity in complex systems [15].

In the present study, an integrated Fuzzy – GIS approach has been taken up for delineating the potential groundwater zones in Tamiraparani sub-basin, south India.

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2. STUDY AREA

The present study has been carried out in Tamiraparani sub-basin, south India. It lies between 8^0 25’ and 8^0 55’ North latitudes and 77^0 9’ and 77^0 48’ East longitude covering a total extent of 2056 sq. km (Fig. 1). The climate of this sub-basin is tropical, semi-arid climatic condition prevails over the eastern part of the study area with the temperature ranges from 30 to 40^0 C. The mean annual rainfall is 900 mm, and 70% of the total rainfall is contributed by south-west retreating monsoon. The rainy season usually starts from mid October and ends in December. The rest of the months remain dry causing serious water scarcity. Tamiraparani River is the only source for drinking and irrigation water supply. Besides that, groundwater also plays a major role in domestic and industrial water needs, as it is accessed from bore wells, and dug wells. Geologically, the underlain rock formations are represented by Charnockite, hornblende biotite gneiss, garnet biotite gneiss, garnet biotite-sillimaanite gneiss, quartizite, calc granulite and limestone. These rocks have feeble porosity and the groundwater movement is restricted to joints, faults, and fractures.

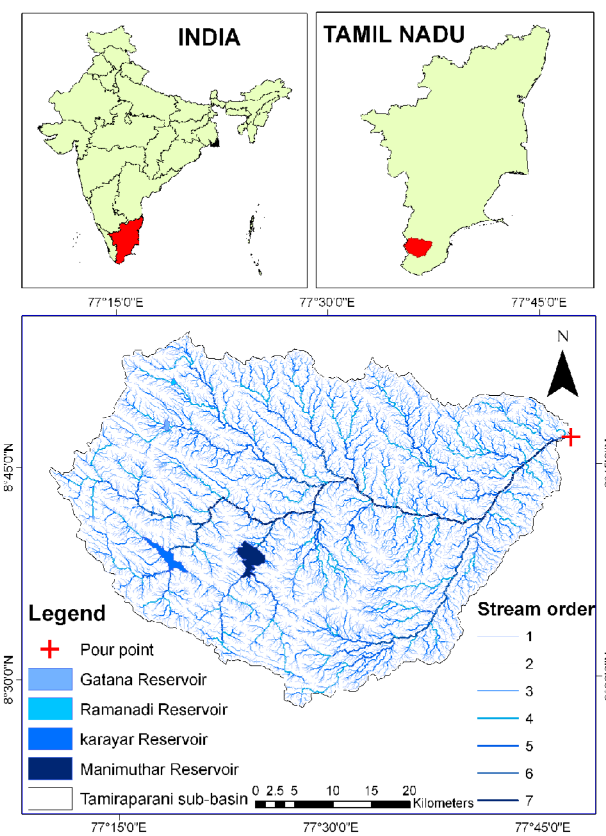

Fig. 1. Location map of the study area

3. MATERIALS AND METHODS

3.1. Generation of Thematic layers

The Tamiraparani sub-basin boundary is extracted from SRTM DEM using the watershed tool in ArcGIS® 10 spatial analyst module. The Shuttle Radar Topographic Mission (SRTM) data (90-meter resolution) provided by The Consultative Group for International Agriculture Research Consortium for Spatial Information (CGIAR-CSI) Geo-portal was used. The thematic layers used in this study includes, geomorphology, geology, landuse, slope, lineament density, drainage density and rainfall. Out of these thematic layers, slope and drainage density are extracted from SRTM DEM using slope and line density tool in ArcGIS® 10. Landuse details were extracted from Landsat ETM imagery using Erdas Imagine 10 software. Supervised classification technique is adopted in which Maximum likelihood method is used for classifying the image. Rainfall layer is created with the help of IMD rain gauge stations data and the station points are interpolated using inverse distance weighted algorithm in GIS. Whereas, remaining layers are digitized from secondary data source like Geological Survey of India, and published geomorphological maps. The flowchart for generating the groundwater potential zones using fuzzy overlay analysis is shown in fig. 2.

3.2. Assignment of ranks for thematic layers

All the thematic layers are converted into raster formats in GIS platform, and these layers are reclassified to a scale of seven using the reclassify tool in ArcGIS® 10. The higher rank (1) represents the most suitable zones, and the lower rank (7) represents the least suitable zone for groundwater occurrence. The ranks are assigned based on expert’s opinion in their relevant field, and each rank allocation is based on the thematic layers ability to contribute towards groundwater occurrence. The rank allocations for various thematic layers are shown in table 1.

3.3. Assigning Fuzzy membership functions

Each thematic layer is assigned a fuzzy membership to a scale of 0 to 1. For the universal X and given the membership degree function $\mu \rightarrow [0, 1]$, the fuzzy set A is defined as $\tilde{A} = \{[x, \mu_A(x)] | x \in X\}$. The membership function $\mu_A(x)$ quantifies the grade of membership of the elements x to the fundamental set. The value 0 means that the member is not included in the given set; 1 describes a fully included member. The values between 0 and 1 characterize fuzzy members [16]. In the present study, the reclassified raster data sets on a scale of 1 to 7 ranks are assigned a membership function between 0 and 1. The membership functions are determined by knowledge acquisition from an expert or group of experts in their relative field.

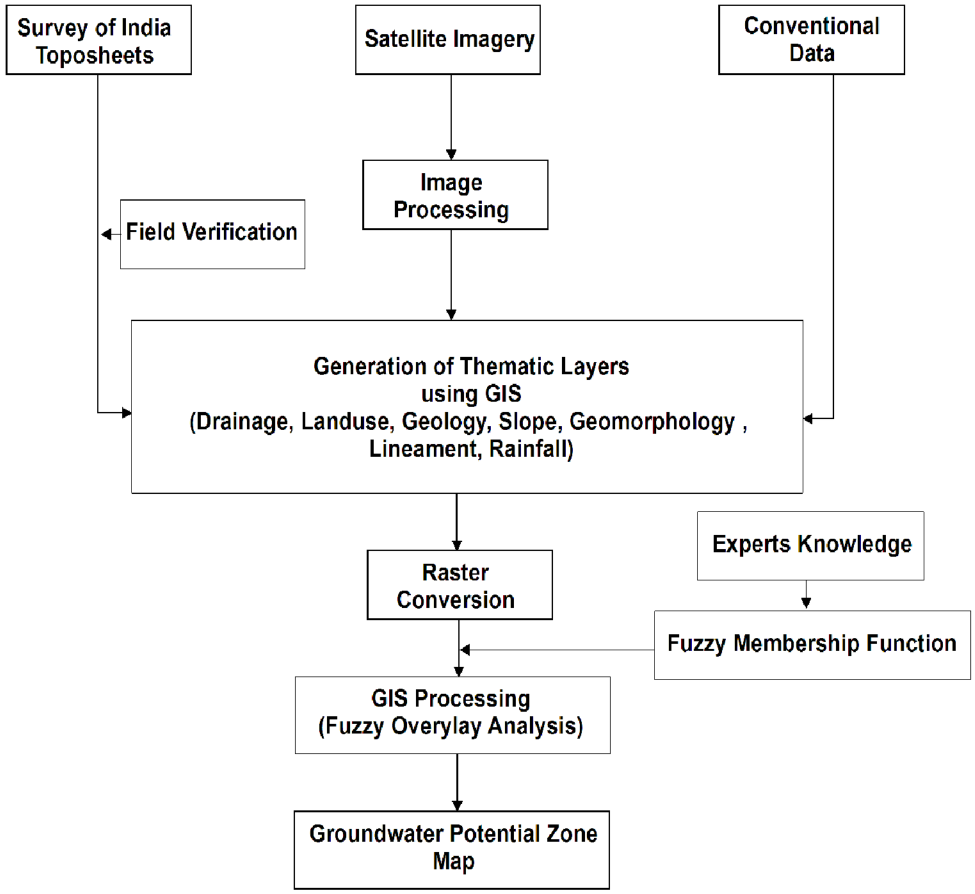

Fig. 2. Flowchart for mapping the groundwater potential zones

This approach is adopted because most of the membership functions like triangular, trapezoidal, piecewise-linear, Gaussian, bell-shaped, etc. are not appropriate as they do not represent accurately the linguistic terms being modeled and so will have to be elicited directly from the expert.

4. RESULTS AND DISCUSSION

4.1. Geomorphology

Geomorphology is one of the important criteria for determining the potential groundwater zones. The study area comprises of seven different geomorphic units namely, basada, denudational hills, structural hills (large and small), residual hills, pediment – Inselberg complex, pediplain – weathered/buried and flood plains. The areal extent of geomophological features are show in table 2. In which, 50.8% of the study area is laid by pediplain followed by structural hills 35.5% in the west part of the study area and 10.5% of pediment – Inselberg complex (Fig. 3). Other features are found to be less than 1 %. The occurrence of pediplain, around 50% of the study area is attributed to moderate groundwater potential zones. Whereas, structural hills in the west have poor groundwater occurrence.

4.2. Geology

The study area is composed of seven types of geological features such as, Charnockite, hornblende biotite gneiss, garnet biotite gneiss, garnet biotite-sillimaanite gneiss, quartizite, calc granulite and limestone (Fig. 4). Aeolian deposits are found in the downstream of Tamiraparani river. This is considered to be an important water-bearing source in the study area. Other geologic features comparably have low infiltration capacity, resulting in poor infiltration. Significant faults and fractures in these geologic types may promote groundwater movement.

TABLE I
RANK ALLOCATION FOR VARIOUS THEMATIC LAYERS

Thematic layer	Features/Values	Ranking
Geomorphology	Basada	3
	Denudational Hills	5
	Structural Hills (Small)	7
	Structural Hills (Large)	7
	Residual Hills	6
	Pediment - Inselberg complex	2
	Pediment - weathered/buried	3
	Flood plain	1
Geology	Hornblede biotite gneiss	6
	Charnockite	7
	Garnet biotite gneiss	6
	Garnet biotite sillimanite gneiss	5
	Calc granulite and limestone	5
	Quartzite	7
	Aeloian	1
Landuse	Settlements	7
	Cultivated lands	2
	Water bodies	1
	Non-cultivated lands	4
	Forest	3
	Barren lands	6
Lineament density	0-0.29	7
	0.29-0.59	6
	0.59-0.89	5
	0.89-1.19	4
	1.19-1.49	3
	1.49-1.79	2
	1.79-2.09	1
Rainfall	572.2-680.8	7
	680.8-789.4	6
	789.4-898.0	5
	898.0-1006.6	4
	1006.6-1115.1	3
	1115.1-1223.7	2
	1223.7-1332.3	1
Slope	0-9.2	1
	9.2-18.4	2
	18.4-27.6	3
	27.6-36.9	4
	36.9-46.1	5
	46.1-55.3	6
	55.3-64.6	7
Drainage density	0.3-1.0	7
	1.0-1.6	6
	1.6-2.3	5
	2.3-3.0	4
	3.0-3.7	3
	3.7-4.4	2
	4.4-5.0	1

TABLE 2
AREA EXTENT OF GEOMORPHOLOGICAL FEATURES

S.No.	Geomorphological Features	Area sq. km	Average
1	Bazada	2.39	0.12
2	Denudational Hills (Large)	13.79	0.67
3	Flood Plain	19.44	0.95
4	Pediment - Inselberg Complex	217.27	10.57
5	Pediplain Weathered/ buried	1045.23	50.85
6	Residual Hill	6.61	0.32
7	Structural Hills (Large)	730.40	35.54
8	Structural Hills (Small)	20.23	0.98
	Total	2055.37	100.00

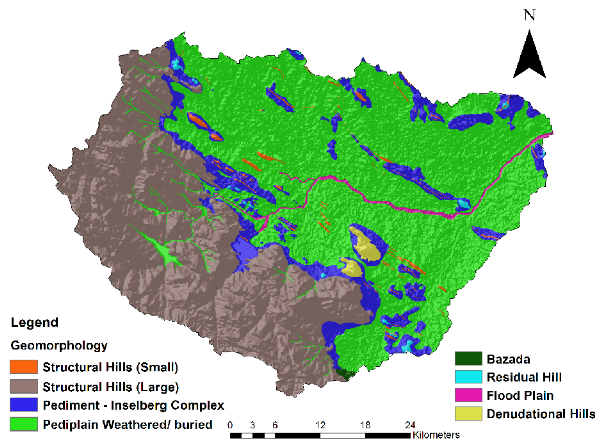

Fig. 3. Geomorphological map of the study area

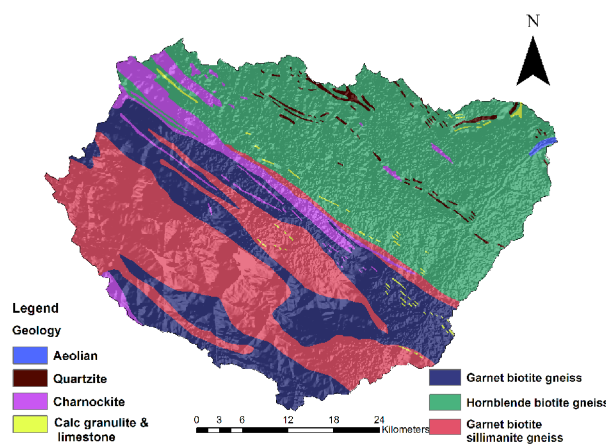

Fig. 4. Geology map of the study area

4.3. Landuse

The landuse map for the study area is prepared using Landsat ETM imagery. Supervised classification technique is adopted to classify different landuse types. The major landuse types in the study area are forest, cultivated lands, non-cultivated lands, barren lands, settlements, and water bodies (Fig. 5). The areal extent of landuse is shown in table 3. Around 25% of the study area is covered by barren lands followed by forest (23%). Cultivated and non-cultivated land equally contributes about 22%. Settlements and water bodies in the study area contributes 5 and 3% respectively. Groundwater potential will be higher in those areas where signatures of water availability are foreseen. This includes areas like water bodies, cultivated land and forests, other areas have feeble signatures of water availability.

4.4. Slope

Slope plays a major role in groundwater occurrence. Slope gradient directly affects the infiltration capacity of rainfall. Steep slopes have meager recharge potential as water flows rapidly over the surface and minimize the retention time of flowing water. The slope gradient in the study area ranges from 0^0 to 65^0. The slope map of the study area is shown in figure 6. The steep slopes are seen in the west part of the study area which is represented by structural hills. Whereas, flat areas are seen towards the eastern part of the sub-basin and these areas have higher infiltration capacity.

4.5. Lineament density

Lineaments are generally referred to the linear features seen in the earth surface. These features are attributed to faults, joints, and fractures evolved from global tectonics. Lineaments are widely used to understand the groundwater movement and storage. Lattman and Parizek were the first to adopt a lineaments map to exploit groundwater [17]. Lineament density refers to closeness of one of more linear features over an area. The lineament density map was prepared using the line density tool in GIS environment. The lineament density in the study area ranges from 0 to 2.09 km/km^2. High density is seen in the north and south part of the study area and it is directly proportional to the groundwater potential zones (Fig. 7).

4.6. Drainage density

The drainage networks are extracted from the SRTM DEM in GIS platform. The drainage pattern in the study area shows dendritic to sub-dendritic in nature which indicates the uniform control of underlying bedrock over the stream flow. Drainage density refers to closeness of drainage channels over space. Higher the drainage density higher will be the water infiltration capacity and hence higher will be the groundwater occurrence. The drainage density map of the study area is shown in figure 8 and it ranges from 0 to 5.09 km/km^2. The map reveals that North West and Southern part of the study area has high drainage density indicating high potential of groundwater occurrence.

TABLE 3
AREA EXTENT OF LANDUSE/LANDCOVER

S.No.	Landuse / Land cover	Area in %
1	Settlements	5
2	Cultivated lands	22
3	Water bodies	3
4	Non Cultivated lands	22
5	Forest	23
6	Barren lands	25
	Total	100

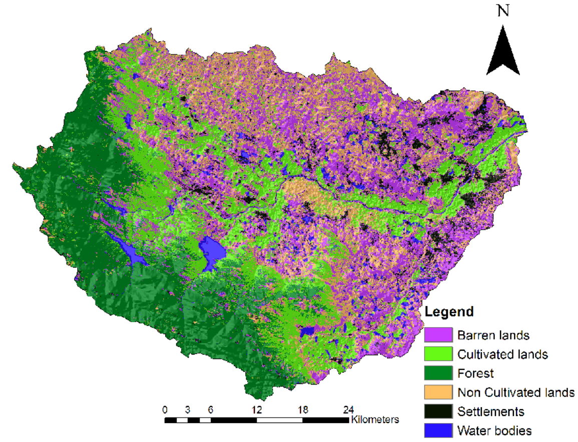

Fig. 5. Landuse map of the study area

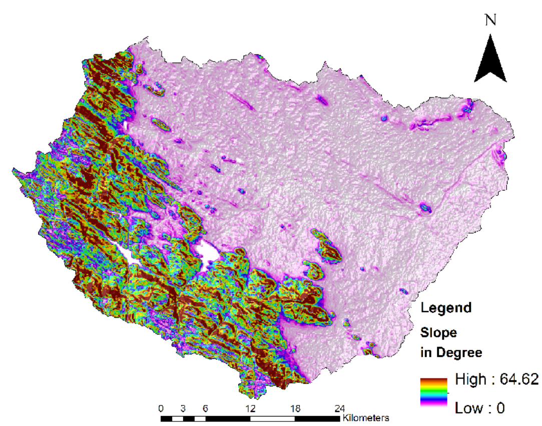

Fig. 6. Slope map of the study area

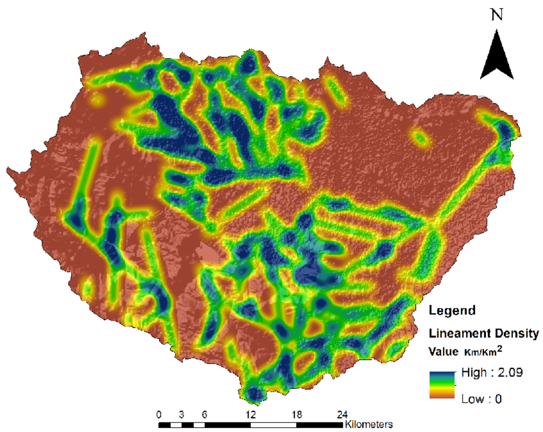

Fig. 7. Lineament density map of the study area

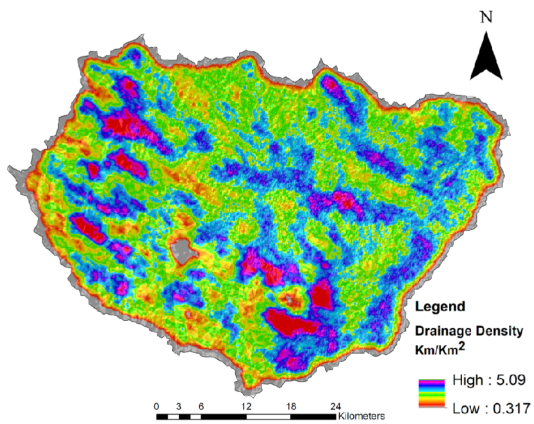

Fig. 8. Drainage density map of the study area

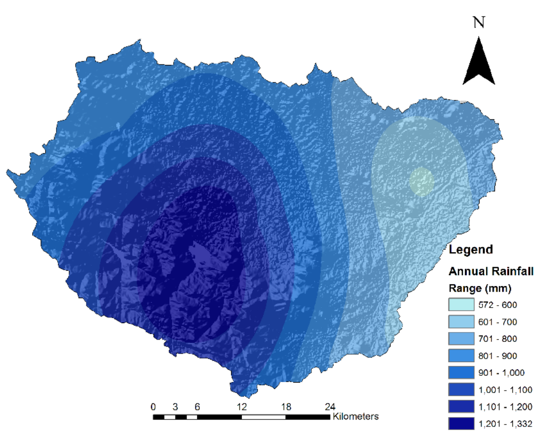

Fig. 9. Rainfall map of the study area

4.7. Rainfall

The spatial distribution of rainfall over the study area was mapped using the inverse distance weighted algorithm in GIS. The Indian meteorological department (IMD) rain gauge stations located in the study area are shown in figure 9. The resulting map was classified into eight major classes <600, 601-700, 701-800, 801-900, 901-1000, 1001-1200, and 1200-1332 mm/year. The generated map reveals that high rainfall intensity is seen at southwest part and low intensity is observed at northeastern part of the study area. The presence of Western Ghats plays a major role in rainfall distribution over the study area.

4.8. Delineation of Groundwater potential zones

The potential groundwater zones in the study area are demarcated by integrating various thematic layers. The ranks assigned for each class of specific thematic layers are based on experts in their relative field. Later, these layers are assigned a membership function in a scale of 0 to 1. These fuzzy membership thematic layers are then subjected to fuzzy overlay analysis in GIS platform. The overlay type used in this analysis is GAMMA, which is an algebraic product of the Fuzzy Sum and Fuzzy Product, both raised to the power of 0.5. The output of this analysis reveals that high potential zones are clustered in those areas where water infiltration is high (Fig. 10). These are areas nearby water bodies, cultivated lands, and flood plains. Field verification has been conducted to assess the output of this technique and the results are found to be satisfactory; in the sense that, groundwater level in the potential zones are found to be within five meters and in non-potential zones it was nearly 20 to 30 meters. Similar results are observed by [14, 18, 19]. This shows that water infiltration rate has a direct relationship with groundwater potential zones.

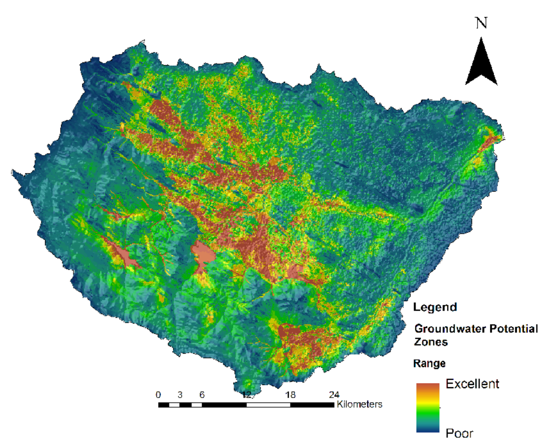

Fig. 10. Groundwater potential zones of the study area

The conventional weighted overlay analysis imposes artificial precision on real world information and it fails to satisfy the way of human thinking about the real world. Integrated fuzzy logic with GIS has the capability to handle the uncertainties present in the real world. This technique can make decisions based on expert's experience in the decision making process and hence, it serves as a reliable technique for mapping and exploring groundwater potential zones.

5. CONCLUSION

Exploration of groundwater potential zones for a vast area is a tedious task and application of frontier technology in the field of remote sensing and GIS is found to be an efficient tool for the management of water resource. In the present study, various thematic layers are analyzed using fuzzy overlay technique in GIS environment for the exploration of groundwater potential zones. These layers are extracted from various sources and each thematic layer has its own importance while delineating the groundwater potential zones. The resulting map reveals that high potential zones are concentrated near areas like water bodies, flood plains and cultivated lands. The applied technique is new in the field of GIS and can be used for implementing various action plans for groundwater management.

REFERENCES

[1]. CGWB, "Manual on artificial recharge of groundwater", Central Groundwater Board, India, 2007.

[2]. T. J. Jackson, "Remote Sensing of soil moisture: implications for groundwater recharge", *Hydrogeol J.*, vol. 10, pp. 40–51, 2002.

[3]. A. Dar, K. Sankar, M. A. Dar, "Deciphering groundwater potential zones in hard rock terrain using geospatial technology", *Environ Monit Assess*., vol. 173, pp. 597 – 610, 2010.

[4]. R. Teeuw, "Groundwater exploration using remote sensing and a low-cost geographic information system", *Hydrogeol J.*, vol. 3, pp. 21–30, 1995.

[5]. J. N. Krishnamurthy, K. Venkatesa, V. Jayaraman, M. Manivel, "An approach to demarcate ground water potential zones through remote sensing and geographical information system", *Int J. Remote Sens.*, vol. 17, pp.1867–1884, 1996.

[6]. S. Nour, "Groundwater potential for irrigation in the EastOweinat area,WesternDesert", *Egypt. Environ Geol.*, vol. 27, pp.143–154, 1996.

[7]. P. Sander, M. Chesley, T. Minor, "Groundwater assessment using remote sensing and GIS in a rural groundwater project in Ghana: lessons learned", *Hydrogeol J.*, vol. 4. pp.78–93, 1996.

[8]. K. S. R. Murthy, "Groundwater potential in a semi-arid region of Andhra Pradesh: A geographical information system approach", *Int J. Remote Sens.*, vol. 21, pp.1867–1884, 2000.

[9]. R. Obi, G. P. Chandra, K. Mouli, S. K. Srivastav, C. V. Srinivas, A. K. Maji, "Evaluation of groundwater potential zones using remote sensing data—a case study of Gaimukh watershed, Bhandara district, Maharashtra", *J. Indian Soc. Remote Sensing.*, vol. 28, pp.19–32, 2000.

[10]. K. Pratap, K.V. Ravindran, B. Prabakaran, "Groundwater prospect zoning using remote sensing and geographical information system: A case study in Dala–Renukoot Area, Sonbhadra District Uttar Pradesh", *J. Indian Soc. Remote Sensing.*, vol. 28, pp. 249–263, 2000.

[11]. M. N. Ravi Shankar, G. Mohan, "Assessment of the groundwater potential and quality in Bhatsa and Kalu river basins of Thane district, western Deccan Volcanic Province of India", *Environ Geol.*, vol. 49, pp. 990–998, 2006.

[12]. S. Ettazarini, "Groundwater potentiality index: a strategically conceived tool for water research in fractured aquifers", *Environ Geol.*, vol. 52, pp. 477–487, 2007.

[13]. Chowdhury, M. K. Jha, V. M. Chowdary, "Delineation of groundwater recharge zones and identification of artificial recharge sites in West Medinipur District, West Bengal using RS, GIS and MCDM techniques", *Environ Earth Sci.*, vol. 59, pp.1209–1222, 2010.

[14]. N. S. Magesh, N. Chandrasekar, John Prince Soundranayagam, "Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques", *Geoscience Frontiers*., vol. 3, pp. 189–196, 2012.

[15]. L. A. Zadeh, "Fuzzy sets", *Inf Control.*, vol. 8, pp. 338–353, 1965.

[16]. L. M. De Campos, M. J. Bolanos, "Representation of fuzzy measures through probabilities", *Fuzzy Sets Syst.*, vol. 31, pp. 23–36, 1989.

[17]. L. H. Lattman, R. R. Parizek, "Relationship between fracture traces and the occurrence of groundwater in carbonate rocks", *J Hydrol.*, vol. 2, pp. 73–91, 1964.

[18]. M. N. R. Shankar, G. Mohan, "Assessment of the groundwater potential and quality in Bhatsa and Kalu river basins of Thane district, western Deccan Volcanic Province of India", *Environ Geol*., vol. 49, pp. 990–998, 2006.

[19]. R. K. Prasad, N. C. Mondal, P. Banerjee, M. V. Nandakumar, V. S. Singh, "Deciphering potential groundwater zone in hard rock through the application of GIS", *Environ Geol.*, vol. 55, pp. 467–475, 2008.