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Integrated Remote Sensing and GIS Approach for Groundwater Exploration using Analytic Hierarchy Process (AHP) Technique.

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ABSTRACT

Since last decade, the value per barrel of potable ground water has outpaced the value of a barrel of oil in many areas of the world. Hence proper assessment of groundwater potential and management practices are the needs of the day. Establishing relationship between Remote Sensing data and hydrologic phenomenon can maximize the efficiency of water resources development projects. Present study focuses on ground water potential assessment in Kandanassery Panchayath of Thrissur District and its field verification. For the same, all thematic layers important from ground water occurrence and movement point of view were digitized and integrated in the GIS environment using Weighted Index Overlay Analysis (WIOA) method. The weights of different parameters/ themes were computed using Analytic Hierarchy process (AHP) Multi-Criteria Evaluation (MCE) technique. Through this integrated GIS analysis, ground water prospects map of the study area was prepared qualitatively. Field verification at observation wells was used to verify identified potential zones and depth of water measured at observation wells. Generated map from weighted overlay using AHP performed very well in predicting the groundwater surface and hence this methodology proves to be a promising tool for future.

Keywords: GIS & Remote Sensing, WIOA, AHP

1. INTRODUCTION

The last decade has seen a phenomenal growth in the use of Remote Sensing and GIS technology in ground water studies as the ground water has become the most sought-after natural resource by the mankind due to tremendous pressure on the ground water system by the ever-increasing population and industrial growth. In this research, Weighted Index Overlay Analysis (WIOA) approach for easy assessment of groundwater potential is adopted for GIS integration of thematic layers developed from base maps and DEM"s [1].

Remote sensing technique integrated with GIS platform through Weighted Index Overlay Analysis (WIOA) is found to be very effective tool for identification of potential zones for groundwater exploration [2]. Also Hydrogeomorphological mapping coupled with hydrogeological investigations and structure/lineaments have been proved to be very effective to locate groundwater potential zones [3]. Identifying a good site for groundwater exploration in a rugged terrain is a challenging task. In hard rocks, groundwater occurs in secondary porosity developed due to weathering, fracturing, faulting, etc., which is highly variable within short distance and contributing to near-surface inhomogeneity. In such situations topographic, hydrogeological and geomorphological features provide useful clues for the selection of suitable sites and hence integration of GIS & Remote Sensing technique [4] through weighted overlay, using Analytic Hierarchy Process (AHP), can be a most promising method.

1.1 Study Area

Selected study area is the Kandanassery Panchayath in Thrissur District of Kerala State. Total aerial extent of study area is 15.21 km2 and total population comes to 21,037 among which 9854 are males and 11183 are females (Source: Census Data 2001). Due to rugged terrain nature of this Panchayath, acute shortage of potable water has been reported. Structural features such as lineaments present in the region have to be identified along with topographical and geological features to understand underlying groundwater potential. Hence in the present study, an attempt is made to link the topographical features to the water prospect zones by employing technique – Weighted Index Overlay Analysis (WIOA), using Analytic Hierarchy Process (AHP).

2. METHODS & MATERIALS

In earlier studies of Weighted Index Overlay Analysis (WIOA), different thematic layers have been assigned weights arbitrarily for ground water potential assessment. Since the weights forms the governing criteria, their variation can affect the accuracy of the map generated. In this research specific weighing scheme has been adopted as Analytic Hierarchy process (AHP) Multi Criteria Evaluation (MCE) technique [5].

Thematic layers identified for weighted overlay analysis were Drainage Density, Lineament Density, Landuse, Elevation, Slope and Soil. Subclasses in every thematic layer were derived through reclassification method which is based on natural breaks in data. Relative importance of each individual class within the same thematic map was compared with each other by pairwise comparison method (using continuous rating scale developed by Satty in 1977). Formulated pairwise comparison files in *.pcf format are used as input in WEIGHT module of IDRISI 32 software, to calculate the weights of subclasses in a thematic layer, with a cross check on acceptable consistency levels. Similarly by pairwise comparison of thematic layers with each other based on their relative importance, weights of individual thematic layers for WIOA were determined.

2.1 Source Data

Data used in current study is Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (Figure 1) along with IRS LISS III image to derive thematic layers for Weighted Index Overlay Analysis (WIOA).

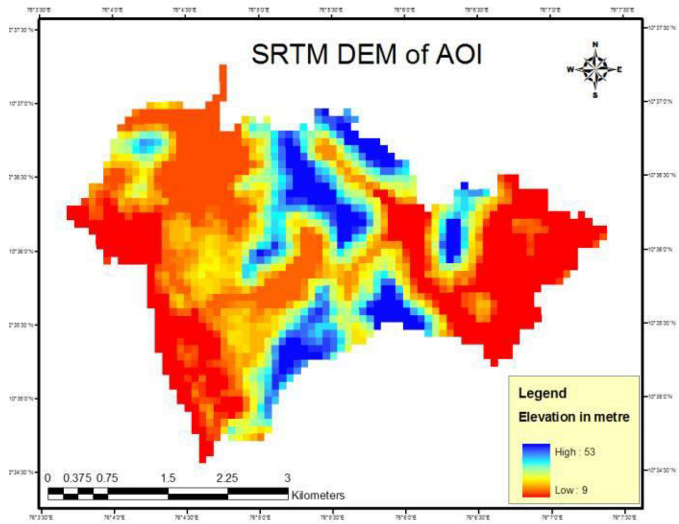


FIGURE 1. DEM OF KANDANASSERY AOI

2.2 Procedure

Stepwise procedure for Weighted Index Overlay Analysis in the adopted methodology is listed below (geo-referencing executed wherever necessary):

1. Derive drainage network from SRTM DEM using Arc Hydro tools and calculate Drainage Density using Line Density tool in Spatial analyst
2. Obtain Lineament Density from Lineament Map.
3. Derive Landuse map by means of supervised classification from LISS –III Imagery (Visual interpretation and field verification).
4. Adopt Elevation map as SRTM digital elevation model itself.
5. Derive Slope map from SRTM DEM.
6. Develop Soil map by visual interpretation and association from google earth imagery and landuse map supplemented by field verification.
7. Project every map into common coordinate system
8. Resample every map to a common cell size and convert to integer format
9. Calculate Individual weightage of subclasses of each map using Saaty's MCE (Multi Criteria Evaluation) AHP (Analytic Hierarchy process).
10. Calculate percentage influence between thematic layers for ground water potential using Saaty's MCE (Multi Criteria Evaluation) AHP (Analytic Hierarchy process) Table.
11. Calculate Weights using WEIGHT Module of IDRISI 32.
12. Execute Weighted Index Overlay Analysis (WIOA) and prepare the final Potential zone Map which categorizes potential zones

Groundwater prospect map derived from WIOA has to be field verified. For the same, sample wells were surveyed and depths of water in wells were measured to develop actual ground water level with sufficient degree of accuracy. Coordinate location of wells were identified using GPS and altitudes were checked with SRTM digital elevation model. For comparison purpose altitudes of wells were adopted from Digital Elevation Model.

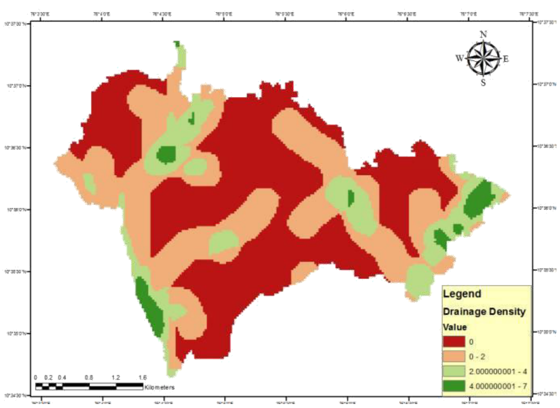
2.3 Softwares Employed

Software‟s used for carrying out the this research work were

1. ArcHydro module for drainage extraction
2. Google Earth Pro for validation of data.
3. ArcGIS 10 for derivation of thematic layers
4. ERDAS Imagine 9.2 for geo-referencing of LISS-III satellite data and for image classification
5. IDRISI 32 for calculation of weights
6. ArcGIS 10 for Weighted Index Overlay Analysis

3. RESULTS & DISCUSSIONS

Six different thematic layers were derived prior to weighted overlay analysis. Drainage density map (Figure 2) was derived from SRTM DEM of AOI using Arc Hydro Tools (version 2.0), an ArcGIS-based system; which is a series of tools built on top of the Arc Hydro database, geared to support water resources applications. In deriving lineament density map (Figure 3), „density tool‟ of spatial analyst extension in ArcGIS is employed for deriving the density of lineament lines.



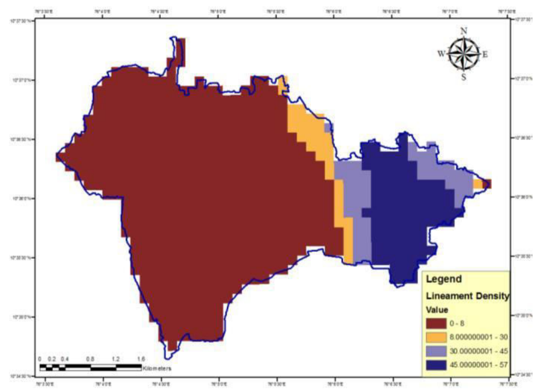


FIGURE 2. DRAINAGE DENSITY MAP

FIGURE 3. LINEAMENT DENSITY MAP

Landuse map (Figure 4) of AOI was derived from LISS-III imagery through supervised classification. Different categories of interpretation were selected from GE Imagery of AOI (Figure 5), based on their relative importance towards ground water potential influence. Finally field verification concluded the landuse map with four categories such as dense vegetation, urban, paddy and crops. Elevation map was directly adopted as digital elevation model values (Figure 6).

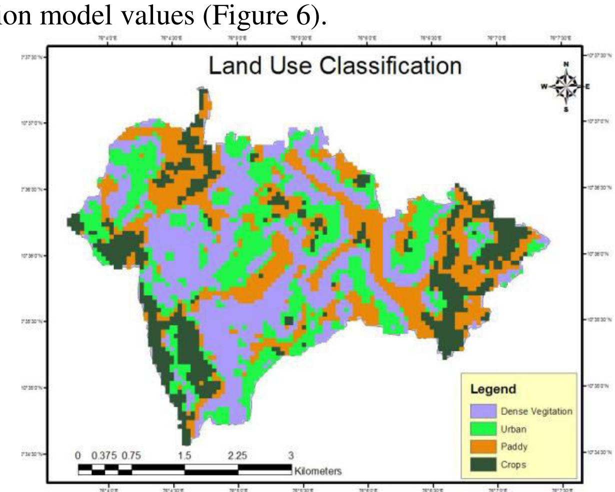


FIGURE 4. LANDUSE MAP

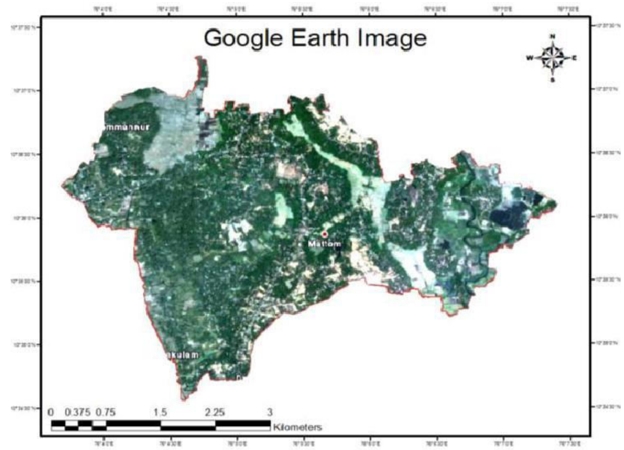


FIGURE 5. GOOGLE EARTH IMAGERY

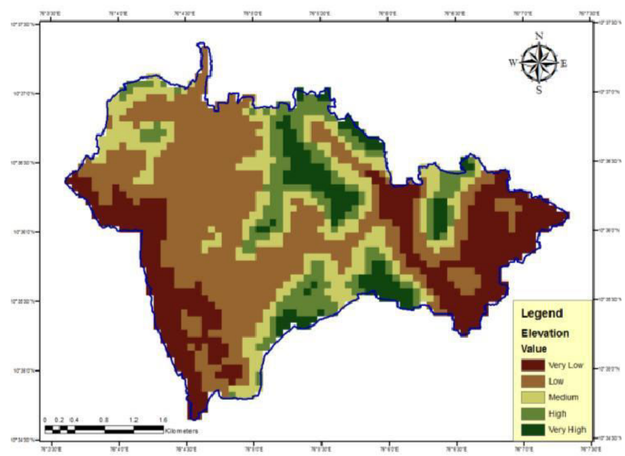


FIGURE 6. ELEVATION MAP

Slope map (Figure 7) as percentage rise was derived from SRTM Digital Elevation Model (DEM). For each cell, the Slope tool calculates the maximum rate of change in value from that cell to its neighbors. Basically, the maximum change in elevation over the distance between the cell and its eight neighbors identifies the steepest downhill descent from the cell. Four subclasses of soil thematic layer were assigned through reclassification method.

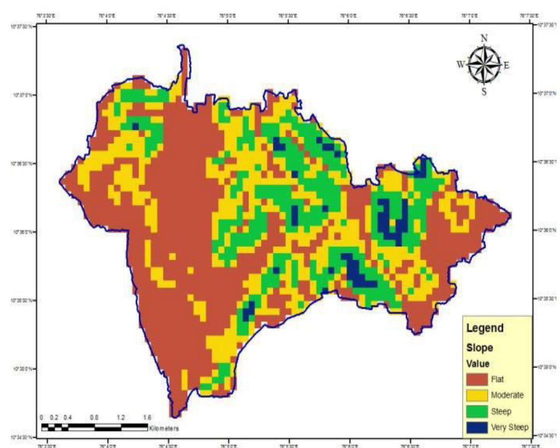


FIGURE 7. SLOPE MAP

TABLE 1. WEIGHTS FOR DRAINAGE DENSITY LAYER

Sl. No	Classes	Raster Value	Weight (Fraction)	Weight (Decimal)	% influence	Relative Weights for WIOA
1	Low	0	1/9	0.11	0.0693	**1**
2	Moderate	0 to 2	1/7	0.14	0.0891	**1**
3	High	2 to 4	1/3	0.33	0.2087	**2**
4	Very High	4 to 7	1	1	0.6329	**6**

TABLE 2. WEIGHTS FOR LINEAMENT DENSITY LAYER

Sl. No	Classes	Raster Value	Weight (Fraction)	Weight (Decimal)	% influence	Relative Weights for WIOA
1	Low	0 to 8	1/9	0.11	0.0687	**1**
2	Moderate	8 to 30	1/6	0.17	0.1038	**1**
3	High	30 to 45	1/3	0.33	0.2069	**2**
4	Very High	45 to 57	1	1	0.6206	**6**

TABLE 3. WEIGHTS FOR LANDUSE LAYER

Sl. No	Classes	Raster Value	Weight (Fraction)	Weight (Decimal)	% influence	Relative Weights for WIOA
1	Dense Vegitation	1	1	1	0.5990	**6**
2	Urban	2	1/3	0.33	0.1975	**2**
3	Paddy	3	1/5	0.20	0.1191	**1**
4	Crops	4	1/7	0.14	0.0844	**1**

TABLE 4. WEIGHTS FOR ELEVATION LAYER

Sl. No	Classes	Raster Value	Weight (Fraction)	Weight (Decimal)	% influence	Relative Weights for WIOA
1	Very Low	2 to 9	1	1	0.5619	**5**
2	Low	9 to 18	1/3	0.33	0.1857	**2**
3	Medium	18 to 27	1/5	0.20	0.1114	**1**
4	High	27 to 37	1/7	0.14	0.0792	**1**
5	Very High	37 to 53	1/9	0.11	0.0618	**1**

TABLE 5. WEIGHTS FOR SLOPE LAYER

Sl. No	Classes	Raster Value	Weight (Fraction)	Weight (Decimal)	% influence	Relative Weights for WIOA
1	Flat	0 to 2	1	1	0.6699	**6**
2	Moderate	2 to 5	1/4	0.25	0.1660	**2**
3	Steep	5 to 9	1/7	0.14	0.0939	**1**
4	Very Steep	9 to 15	1/9	0.11	0.0732	**1**

TABLE 6. WEIGHTS FOR SOIL LAYER

Sl. No	Classes	Raster Value	Weight (Fraction)	Weight (Decimal)	% influence	Relative Weights for WIOA
1	Sand	0	1	1	0.6807	**7**
2	Laterite	2	1/3	0.33	0.2236	**2**
3	Clay	1	1/7	0.14	0.0957	**1**

TABLE 7. WEIGHTS FOR WIOA

Sl. No	Theme	Weight (Fraction)	Weight (Decimal)	% influence	WIOA % contribution
1	Lineament Density	1	1	0.5128	**51**
2	Slope	1/3	0.33	0.1702	**17**
3	Soil	1/5	0.20	0.1022	**10**
4	Drainage Density	1/6	0.17	0.0853	**9**
5	Landuse	1/7	0.14	0.0727	**7**
6	Elevation	1/9	0.11	0.0567	**6**

TABLE 8. POTENTIAL ZONES AND DEPTH OF WATER TABLE

Sl. No	Zone	No of Cells	Area (Km^2)	Depth Range (m)	No of Observation Wells
1	Very Poor	225	4.88	22 to 37	**12**
2	Poor	220	4.77	07 to 18	**13**
3	Fair	172	3.73	01 to 08	**6**
4	Moderately Potential	58	1.26	No Data	**Nil**
5	Potential	34	0.74	No Data	**Nil**

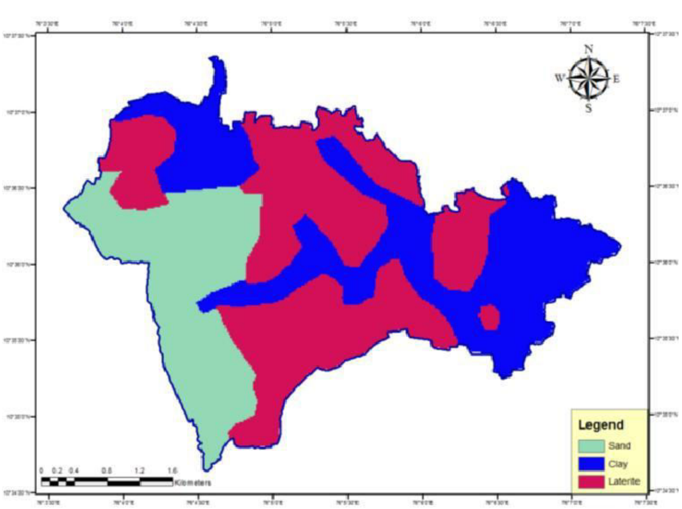


FIGURE 8. SOIL MAP

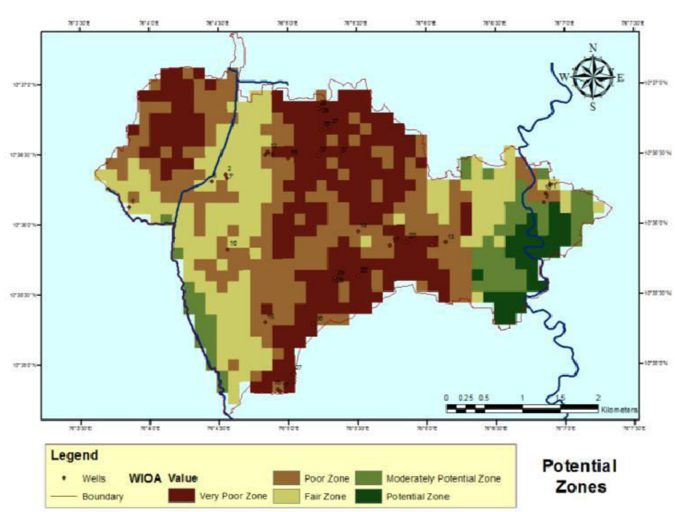


FIGURE 9. GROUNDWATER POTENTIAL MAP

For deriving the soil map (Figure 8) of AOI, visual interpretation and field survey was adopted.

Through visual interpretation of google earth imagery all areas coming as paddy fields were classified as clay. Coastal areas were found to be sandy in nature. For hilly areas laterite was assigned and further investigated through field survey gave clear boundary of soil types.

Weighted overlay operation of six thematic layers with their weight as tabulated in Table 1 to 6 and overall percentage of influence as derived in Table 7 generated Ground Water Potential Zone Map (Figure 9) of Area of Interest (AOI). The delineation of ground water potential zones was carried out by reclassifying into five different groundwater potential zones: Very Poor Zone, Poor Zone, Fair Zone, Moderately Potential Zone and Potential Zone. Total extent falling under each zones were computed. To verify the generated potential zones, field validation through survey of depths in wells were adopted.

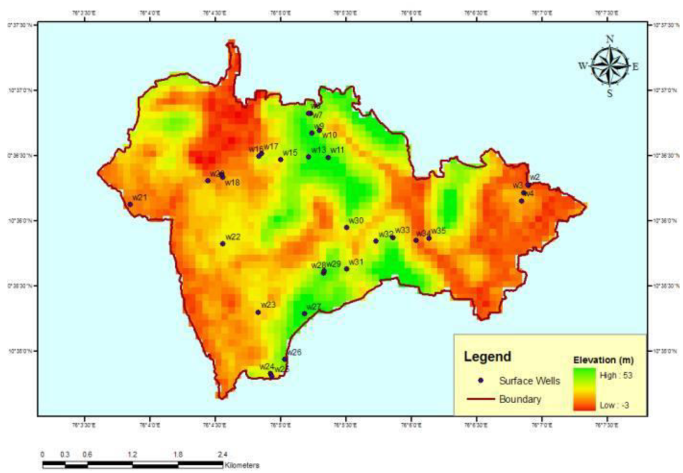


FIGURE 10. OBSERVATION WELLS IN AOI

For verification of resulted map, secondary field data collected as depth of water in 31 observation wells distributed across the AOI is shown in Figure 9. Depths against zones (Table 8) clearly indicate that the qualitative classification of groundwater potential zones through WIOA gave fairly accurate potential zone map. As depth of occurrence of water observed in wells reduces from 22-37m to 07-18m, corresponding classified zone changed from very poor to poor zone. Similarly as depth of water observed in well reduced from 07-18m to 01-08m, the classified zone became fair zone from poor zone. This indicates relationship between qualitatively classified potential zones and depth of water measured at observation wells. Wells were absent in moderately potential and potential zones identified.

Hence for future water scarcity problems the moderately potential zones and potential zones are suggested for prospective open well sites. Since a relationship has been established between potential zones generated through WIOA and depth at which water is available, future research scope lies in modelling the relationship for prediction purpose. Common man is mainly concerned about the depth at which water is available rather than the yield of the aquifer. Hence the identified relationship between potential zones and depth of occurrence of water will enable the common man to predict the depth of occurrence of water before construction of an open well in specific areas.

4. CONCLUSIONS

In this research, Weighted Index Overlay Analysis (WIOA) approach for easy assessment of groundwater potential is adopted for GIS integration of thematic layers developed from base maps and DEM. Adopted thematic layers gave fairly accurate clues about groundwater occurrence from geomorphologial, topographical and structural features. Generated result from WIOA by employing AHP method for weight calculation qualitatively categorized the Area of Interest (AOI) as different zones based on groundwater potential. Secondary field data collected from observation wells were well matching with the prospect zones. Hence this methodology of integrated remote sensing and GIS approach using Analytic Hierarchy Process (AHP) technique is a promising method for groundwater exploration.

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