Groundwater Potential Zone Mapping using AHP technique: A case study of Bankura district, West Bengal

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Abstract— **Over-exploitation of groundwater and abrupt changes in climate over the years have imposed immense pressure on the global groundwater resources. In the recent years, the studies related to prospects of groundwater and its replenishment have gained much prominence and Geographic Information System (GIS) has been found to be an essential tool in this context. The present study has been undertaken with an objective to delineate the groundwater potential zone of a drought-prone district Bankura located in the state of West Bengal in India using a combination of GIS and Analytic Hierarchy Process (AHP) technique. Four thematic layers such as Geology, Soil, Rainfall and Slope have been utilised for groundwater potential zone demarcation. Weights assigned to each class in all the thematic maps are based on their characteristics and water potential capacity through AHP technique. The groundwater potential zone map thus obtained was categorized into four classes-very poor, poor, moderate and good. The study reveals that about 75.94% of the study area is covered under moderate groundwater potential zone. The poor groundwater potential zones are observed in 22.79% of area.**

Keywords— ground water potential zone, AHP, GIS

I. Introduction

Groundwater is one of the most important and vital natural resource which is stored in the subsurface geological formations in the critical zone of the earth's crust. It serves as a source of water for domestic, industrial and agricultural uses and other developmental initiatives. The ever-increasing demand of water for meeting human requirements and developments has imposed immense pressure on this limited freshwater resource. The occurrence and distribution of groundwater depends on the various natural and anthropogenic factors. The groundwater related problems are severe in most parts of the tropical and subtropical regions that have high population density and economic developments. In a semi-arid country like India, surface water is not available round the year for meeting different purposes and hence people in such areas have to depend more on groundwater resources for their survival. Millions of people in India are facing high to extremely high water stress due to inadequate availability of fresh water. Further, about three-fourth of the households in the country do not have access to portable water at their premises. According to a World

Bank report, if adequate measures are not taken, India will become a water stress zone by the year 2025 and a water scarce zone by the year 2050. All these reiterate the need for better understanding of all the available freshwater resources of the country with special reference to groundwater resource, as it constitutes a major share of India's freshwater resources.

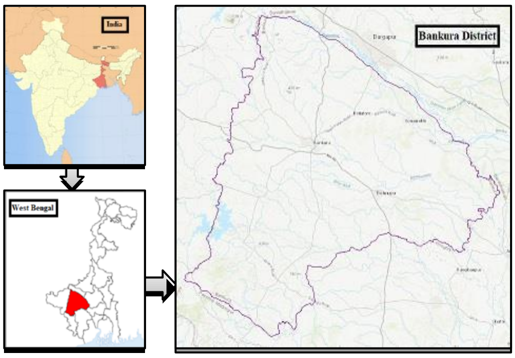


Fig. 1. Study Area

The traditional approaches used to identify, delineate and map the groundwater potential zones are mainly based on ground surveys using geophysical, geological and hydrogeological tools which are generally expensive and time consuming. Geospatial tools, on the other hand, are rapid and cost-effective in producing and modelling valuable data in various geoscience fields. Remote sensing and GIS study with its advantages of spatial, spectral and temporal availability of data converging large and inaccessible areas within a short span of time has become a powerful tool in assessing, monitoring and conserving groundwater resources.

II. STUDY AREA

The entire Bankura district of West Bengal is taken as the study area of the present research work. The entire study area lies between 22038' and 23038' north latitude and 86036' and 87047' east longitude. Water scarcity is a regular threat for the people of Bankura district which has a great negative impact on the socio-economic development of Bankura. Surface water bodies dries up in most of the year during the summer season, people depend on groundwater for domestic, irrigation and other various purposes during this time, but excessive use of groundwater has worsened the situation. Therefore, proper evaluation, planning, and management of groundwater are essential for this region.

III. METHODOLOGY

In the present work slope, rainfall, geology and soil have been considered as major parameters that influence the availability of groundwater at different locations. After the generation of all the thematic maps, the AHP technique was applied to assign the weight of each themes and normalized weight of each layer was obtained. Then a weighted overlay analysis has been performed in a GIS platform to integrate the effects of all the parameters which were considered here. As a resulted overlay map groundwater prospects of different sites has been identified and the model was validated using groundwater prospects map.

IV. RESULT AND DISCUSSION

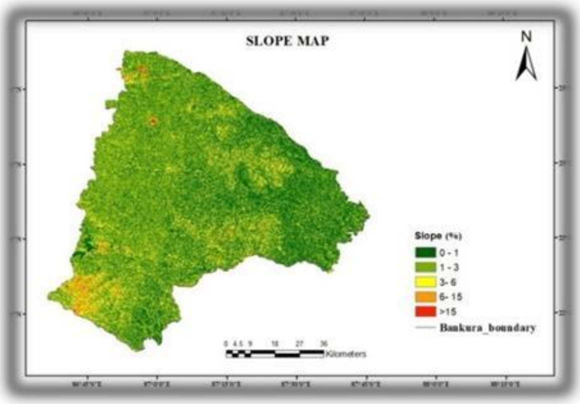
GIS model has been used to demarcate the groundwater potential zones in different geographical areas using few thematic layers and validate the result with real data. However, the entire analysis and its accuracy depend on the assigned weights to different factors. In the present study four parameters (Geology, Soil, Slope, Rainfall) were considered as more important for occurrence of groundwater. These layers had been integrated in a GIS environment and different weights had been assigned using AHP (Analytic Hierarchy Process).

A. Slope

Slope is an important parameter of groundwater potential at a location. The amount of groundwater recharge is inversely proportional to the degree of slope. If the slope is high, the rate of drainage is also high and simultaneously the chance of percolation of groundwater through surface gets reduced, so the availability of groundwater at that places also less.

B. Rainfall

The groundwater recharge is directly proportional to the rate of rainfall at a particular location. The rainfall distribution map was prepared by Inverse Distance Weighted (IDW) method by giving the gridded rainfall shape file as an input.



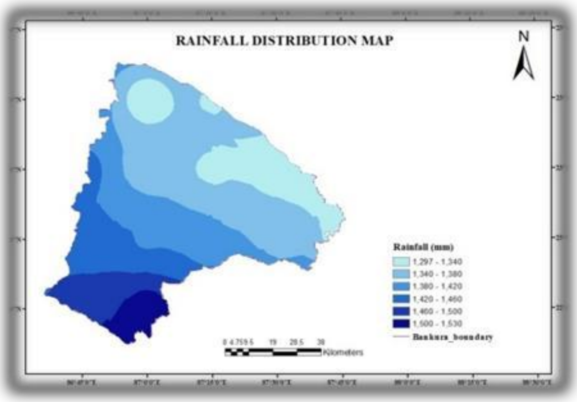
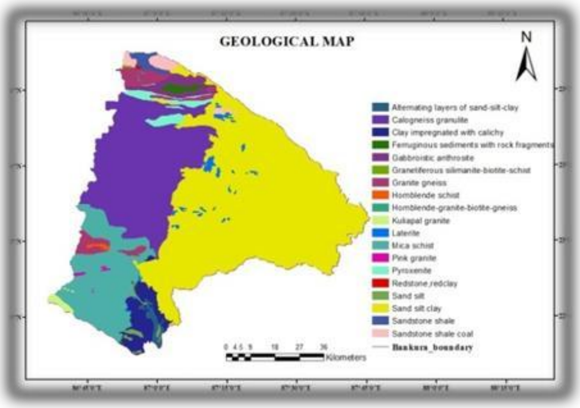


Fig. 2. Slope Map

Fig. 3. Rainfall Map

C. Geology

The word 'Geology' is directly related to the rock formation of the Earth-strata. There are different types of rock structure and each structure has different storage capacity depending on their porosity. So, it can be easily said that geology plays a vital role on the presence of



groundwater at each and every location depending on the storage capacity and rate of transmission.

Fig. 4. Geological Map

Deep water, shallow water and water bodies are the excellent sites for groundwater prospect and higher weightage will be given to them. The vegetation areas are considered to have good groundwater potential where settlement areas have least probability of groundwater occurrence.

D. Soil

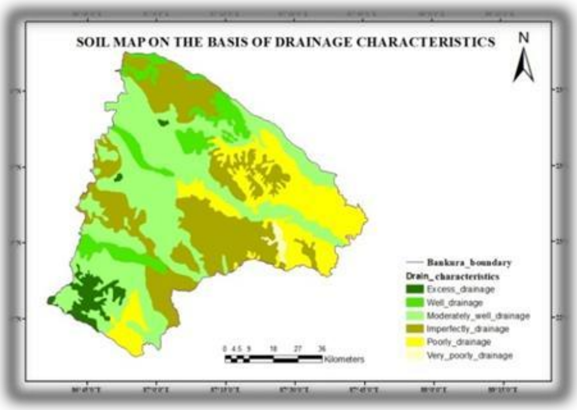


Fig. 5. `Soil Map

The type of soil is an important factor for the availability of groundwater at a location depending on the porosity, permeability and soil-structure. If the interconnectivity of soil-pores is high, the chance of occurrence of groundwater is high at that place. Drainage characteristics of soil are the major parameter for the occurrence of groundwater in a particular site. The rate of drainage of surface water through the soil pores is considered as the main driving factor for the presence of groundwater on a place and on the basis of drainage characteristics Soil of the entire study area was classified in six zones.

E. Weighted Overlay Analysis

The weighted overlay analysis is built into ArcTool in the ArcMap 10.4.1 for the integration of different thematic layers. The accuracy of the method lies into the perfection of the weightage analysis of the different themes. Here the concept of normalized weights and rating was applied. Normalized weights represents the relative importance of the different data layers and rating represents the relative weightage of different categories considered in each and every layers.

In the present study, AHP (Analytic Hierarchy Process) proposed by Saaty, 1990 had been used to obtain the normalized weights of the different parameters which has been considered in mapping of groundwater potential zones. The following steps are followed to apply AHP in this study:

- Creating Pairwise Comparison Matrix;
- Calculating normalized weights of different themes
- Checking the consistency

The relative importance values are determined with Saaty's 1-9 scale, where a score of 1 represents equal importance between the two themes, and a score of 9 indicates the extreme importance of one layer compared to another layer. The pairwise comparison matrix which has been prepared on the basis of Saaty'snine point important scale between the various thematic layers, is shown below (Table I).

All the eigen values for the pairwise comparison matrix (Table I) were obtained. Maximum eigen value is 4.07 and corresponding to this value the eigen vector was generated. The normalized weights were calculated of each thematic layer (Table II).

The term '**consistency ratio (C.R)**' was introduced by Saaty to check the errors in judgment of parameter weights.

$$C.R = \frac{C.I}{R.I}$$

TABLE I. PAIRWISE COMPARISON MATRIX

Thematic Layers	Slope	Rainfall	Geology	Soil
Slope	1.00	0.50	0.25	0.33
Rainfall	2.00	1.00	0.20	0.50
Geology	4.00	5.00	1.00	2.00
Soil	3.00	2.00	0.50	1.00

TABLE II. NORMALIZED WEIGHTS OF DIFFERENT THEMATIC LAYERS

Thematic Layer	Eigen Vector Value	Normalized Weights
Slope	0.3513	0.0918
Rainfall	0.5191	0.1357
Geology	1.9549	0.5111
Soil	1	0.2614

C.I represents for Consistency Index, calculated by the following formula

$$C.I = \frac{\lambda max - n}{n - 1}$$

Where, '**λmax**' is the maximum eigen value and 'n' is the number of parameters used.

According to this research work, the value of **λmax** was 4.07 and 'n' was 4.

R.I stands for Ratio Index, the value of which is specified by Saaty using a composite of two different experiments performed by him at the University of Pennsylvania.

If the C.R value is less than or equal to 0.1, then it is accepted. If the value of C.R is greater than 10%, it requires reconsideration of judgment of pairwise comparison matrix.

The value of consistency index and consistency ratio obtained as per my study was 0.023 and 0.026 respectively. Hence the pairwise comparison matrix did not violate the rule of Saaty's AHP technique as the consistency ratio was less than 10%.

The individual rating of each categories of each thematic layers had been given on the basis of their influences on the chance of occurrence of groundwater in a place. The groundwater potential zone map was developed by reclassifying each and every thematic layers and overlaying them by putting their AHP weightage with category rating of each layer in ArcMap. The individual weight of each layer and the category rating were blended and overlay analysis was carried out based on the following equation given below.

$$GWPI = \sum_{i=1}^{n} \sum_{j=1}^{m} [\alpha_i \beta_{ij}]$$

'GWPI' is Groundwater potential index, β_{ij} is rating of the j^th class of the i^th theme, α_i is the weight of the i^th theme.

The output overlay map has been reclassified into four categories ('Very Poor', 'Poor', 'Moderate' and 'Good') to classify the study area in different zones in terms of suitability of groundwater prospect. The major parts i.e. about 75.94% of the study area is falling under moderate potential zone. About 22.79% areas have poor groundwater potential. There are very few sites in where the groundwater prospects are good (1.08%) and very poor (0.19%).

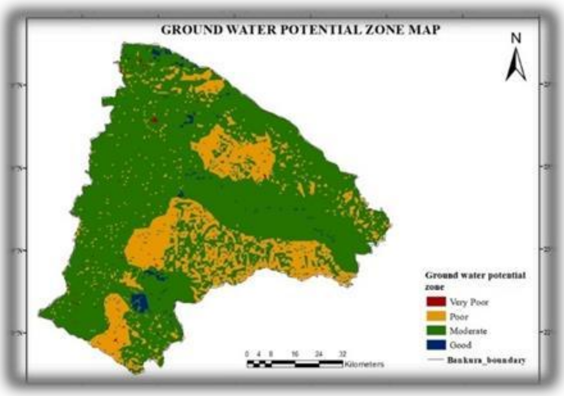


Fig. 6. Ground Water Potential Map

V. CONCLUSION

In this research work, different parameters have been considered as the major driving factors in occurrence of groundwater in a location. An AHP model was developed successfully to assign the weightage of each thematic layer based on these parameters and a weighted overlay analysis has been performed in a GIS environment to get groundwater potential map of the desired study area. It can be easily illustrated from the resulted potential map that most of the sites i.e. 75.94% of area of Bankura district have moderate groundwater prospect. 22.79% zone of study area is of poor potential of groundwater. There are very few locations in where occurrence of groundwater is high. Finally, it is concluded that the groundwater potential in Bankura district is moderate to poor.

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