Scholars Journal of Engineering and Technology (SJET) **ISSN 2321-435X (Online)**
Sch. J. Eng. Tech., 2014; 2(3A):316-319 **ISSN 2347-9523 (Print)**

(An International Publisher for Academic and Scientific Resources)
www.saspublisher.com

Review Article

A review on GIS based Fuzzy and Boolean logic modelling approach to identify the suitable sites for Artificial Recharge of Groundwater

Prasenjit Bhowmick[1*], S. Mukhopadhyay[1], V. Sivakumar[2]
[1]Department of Civil Engineering, College of Engineering, Pune-411005, India
[2]Centre for Development of Advanced Computing (C-DAC), Pune-411007, India

***Corresponding author**
Prasenjit Bhowmick
Email: prasenjit.bhowmick88@gmail.com

Abstract: This paper critically reviewed fuzzy and Boolean logic based studies for identifying sites for groundwater artificial recharge which is very important and necessary to implement with high accuracy and in the possible minimum time. Using weighted values from Geographical Information System (GIS) environment and with the means of Fuzzy Logic and Boolean Logic on the thematic layers. The exact type of artificial recharge structure, like Check dam, nallabund, gully plugging and percolation ponds are selected for an artificial recharge. The conventional practice in water harvesting takes into consideration of availability of land, suitability of a particular artificial recharge technique depending on local conditions, and the area benefited. Hence, decisions regarding to the location and type of recharge structure for water conservation can be made only after extensive geological and hydrogeological studies for regional scale. This leads investing an enormous amount of time and money in identification of sites suitable for artificial-recharge. The aim of the paper is to review fuzzy and Boolean logic based study for identifying suitable site for artificial Recharge of Groundwater with help of GIS and Remote sensing techniques. In this paper, GIS based on fuzzy and Boolean based modelling approach providing powerful tools for identifying and classifying recharge zones with suitable structures by values ranging between 0 to 1.
Keywords: Groundwater, Artificial recharge, GIS; Fuzzy Logic, Boolean Logic

INTRODUCTION

Groundwater is one of the most valuable natural resources due to its limited existence, which helps to support the enormous human health, economic development and ecological diversity [1]. The total volume of ground water is only 0.65% of the total water availability of the globe. The depletion of groundwater levels is not a new story in India due to rapid and accelerated urbanisation and industrialisation. In many parts of India, especially in arid and semi arid regions, dependence on groundwater resource has increased tremendously since the last few decades due to vagaries of monsoon and scarcity of surface water [2]. Effective management for aquifer recharge is becoming an increasingly important aspect of water resource management strategies [3]. A large amount of rain water is lost through runoff, in addition to the problem compounded by the lack of rainwater harvesting practices [4]. Accordingly, artificial recharge is an effective technique for the augmentation of groundwater resources [5]. There are many factors to be considered for determining if a particular site will be receptive to artificial recharge.

The stability of terrain should be assessed before deciding to construct any recharge structures to avoid risks of landslide and other environmental effects. Hence, selection of suitable recharge-site and its types are important steps in the artificial recharge planning. The compilation of traditional data processing methods for selection the site of artificial groundwater recharge is so sophisticated and consumes much time because the data is massive and usually needs to be integrated.

Accordingly, GIS is capable of developing information in different and superimposed thematic layers and integrating them with high accuracy and within a short period of time. The application of these methods is indispensable for such analyses [5]. GIS provides the facility to analyze the spatial data objectively using various logical conditions. In addition to modern remote sensing techniques facilitate demarcation of suitable areas for groundwater replenishment by taking into account the diversity of factors that influences groundwater recharge: 1) geological and geomorphological structure; 2) groundwater recharge and abstraction; 3) water levels and their movement; 4) land use and 5) climatic condition. These factors control ground water potentiality (quantity and quality of groundwater with time and place), occurrence and movement in hard rock terrain. These features cannot be observed on the surface by bare eyes but can be obtained through satellite remote sensing historical data and monitoring network for water levels and their quality for proposed area with reasonable accuracy, short time and less cost [2]. Practically it is shown that by only weighted value method we unable to find the exact and suitable area but in other hand fuzzy and Boolean based value help us to find particular suitable region and site to build artificial recharge structure for groundwater recharge as the values come in 0 to 1 range.

GIS BASED MODELLING METHODS FOR ARTIFICIAL GROUNDWATER RECHARGE

FUZZY LOGIC

Fuzzy Logic is a form of many-valued logic; it deals with reasoning that is approximate rather than fixed and exact. Compared to traditional binary sets (where variables may take on true or false values) Fuzzy Logic variables may have a truth value ranging to degree between 0 (does not occur) and 1 (definitely occur). Fuzzy Logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false. As additional data gathered, many Fuzzy Logic systems are able to adjust the probability values assigned to different parameters. Because some such systems appear able to learn from their mistakes, they are often considered a crude form of artificial intelligence. Furthermore, when linguistic variables are used, these degrees may be managed by specific functions.

In the current study, after analysis of various thematic maps which have been implemented by GIS based we obtain data classified into good, moderate, low, very low, gentle etc. Accordingly, we weighted it 0 to 10, but this is not pacified the exact probability. In contrast to Boolean logic, no certainty exists in Fuzzy Logic. This leads that there is no unit area indefinitely satisfactory or unsatisfactory for artificial recharge. The individual classes for each map might be defined relevant to their degrees of membership. The classification for any map can be associated with fuzzy membership values in an attribute table. Fuzzy membership values must lie in the range (0, 1), but there are no practical constraints on the choice of Fuzzy membership values [6].

The method can be outlined in the following steps:

Step I: By the following equation the relative weight of each layer is identified and normalized**:**

$$W_j' = \frac{W_j}{\sum_{j=1}^{n} W_j} \qquad \text{---------- (1)}$$

Where: W_j' is the normalized weight and W_j is the raw weight for the j-th attribute.

Step II: The input thematic layers are classified and scored in a GIS environment in different scales such that they should be normalized to a common dimension less unit [7]. The following equation is selected and applied for this process:

$$a_{ij}' = \frac{a_{ij}}{a_j^{max}} \quad j = 1,....,n; \quad i = 1,....,m \qquad \text{---------- (2)}$$

Where: a_{ij}' is the normalized score and a_{ij} is the raw score for the j-th thematic layer (attribute) and i-th class (alternative) n, m: represent the number of attributes and alternatives, respectively.

Step III:

$$A_i = \sum_{j=1}^{n} W_j' \, a_{ij}' \quad j = 1,...,n; i = 1,..,m \qquad \text{---------- (3)}$$

Eq. 3 is used for Integration of the weighted thematic layers in the raster environment of the ArcGIS.

Where: A_i is the value of suitability for i-th alternative (pixel), W_j' is the normalized weight for the j-th attribute, and a_{ij}' is the normalized score for the i-th alternative and j-th attribute. Each pixel in this thematic layer has a value (from 0 to 1) that indicates its suitability for Management of Artificial Recharge.

Step IV: The output of the thematic layer from step III is classified into categories such as unsuitable, moderately suitable and suitable.

Step V:, All possible arrangements of the 'if' part (antecedent) of the 'if-then' rules are identified, based on the defined membership functions in the inputs layers.

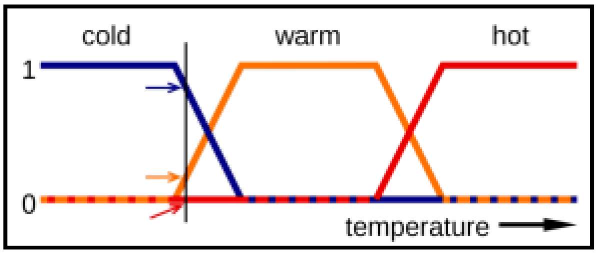

Fig: 1 Fuzzy logic in temperature scale [13]

In the figure 1, a temperature scale is discussed by fuzzy logic modelling and functions mapping with the meanings of the expressions *cold*, *warm*, and *hot*. A point on that scale has three "truth values"—one for each of the three functions. The vertical line in the image represents a particular temperature that the three arrows (truth values) gauge. Since the red arrow points to zero, this temperature may be interpreted as "not hot". The orange arrow (pointing at 0.2) may describe it as "slightly warm" and the blue arrow (pointing at 0.8) "fairly cold".

BOOLEAN LOGIC

One of alternative methods to find out the suitable locations for artificial recharge is Boolean Logic (rather than creating a suitability map) to query the required data. Once all the needed datasets (the thematic layers) have been created, such a query would be finding all the suitable locations. Probably the simplest and best-known type of GIS model is based on Boolean operations. Robinov (1989) introduced the use of Boolean operations for reasoning with geological maps.

In fact, Boolean modelling involves the logical combination of binary maps resulting from the application of conditional operators [6]. Only one or zero values are assigned to each unit area, specifying whether it is satisfactory or unsatisfactory, respectively Boolean Logic generally applies a binary condition to the inputs and evaluates to a binary condition for the output. The binary condition can be expressed in several ways: "1" and "0", "True" and "False", "yes" and "no", "on" and "off", and so forth. The False condition is represented with a value of 0, and the True condition as any value other than 0. The operators AND, OR, XOR, and NOR are Boolean operators (Table 1).

Table-1: Shows various types of Boolean operators

Boolean **AND**	Performs a Boolean And operation on the cell values of two input rasters. If both input values are true (non-zero), the output value is 1. If one or both inputs are false (zero), the output is 0.
Boolean **NOT**	Performs a Boolean Not (complement) operation on the cell values of the input raster. If the input values are true (non-zero), the output value is 1. If the input values are false (zero), the output is 0.
Boolean **OR**	Performs a Boolean Or operation on the cell values of two input rasters. If one or both input values are true (non-zero), the output value is 1. If both input values are false (zero), the output is 0.
Boolean **XOR**	Performs a Boolean exclusive Or operation on the binary values of two input rasters. If one input value is true (non-zero) and the other false (zero), the output is 1. If both input values are true and both are false, the output is 0.

REVIEWS

Saravi et al., identified suitable sites for artificial groundwater recharge using Fuzzy logic base approach in the Gavbandi river basin located in Boushehr province [12], Iran. In this study they used four factors of slope, surface infiltration; alluvial thickness and water quality of sediment were investigated. They build the slope map from topographic maps, infiltration from texture of sediment samples; the aquifer thickness was determined by geo-electric method, alluvial quality from EC data of the study area and the maps of land use and landform from Landsat ETM+ images by using the ArcGIS software.

Riad et al., analysed various thematic maps using ArcGIS overlay weighted models and Fuzzy logic to locate the suitable Groundwater Artificial Recharge zone in arid and semi-arid regions in the western Nile delta in Egypt [8]. They applied Fuzzy logic to give more accurate suggestions by giving another classification inside each area of priority. Numbers of points from different locations in each priority zone in the suitability map were selected by them to be manipulated by fuzzy logic in Matlab.

Mahdavi et al., used GIS and Fuzzy logic by collected including slope, infiltration rate, thickness of unsaturated zone, surface water EC, landuse and stream network for identification of groundwater artificial recharge sites in the Shahrekord plain of Iran [11]. He classified and weighted in ArcView 3.2a and ArcGIS 9.3 software and was integrated using multiplying operator in Fuzzy model.

Bonham et al., used multi-criteria decision making, GIS, and a fuzzy inference system to manage aquifer recharge in Shemil-Ashkara plain in the southern part of Iran for data classification by slope, geology, groundwater depth, potential for runoff, land use [6]. Groundwater electrical conductivity has been considered as site-selection factors. By comparing the results with the traditional simple additive weighted method they want to show that the proposed method yields were more precise results and Fuzzy-set theory can be an effective method to overcome associated uncertainties in classification of geographic information data.

Ghayoumian et al., proposed Fuzzy and Boolean logic based approach for determining the areas are most suitable for groundwater recharge in a coastal aquifer in arid and semi-arid regions [5]. They prepared thematic layers, classified, weighted and integrated in a GIS environment by the means of Boolean and Fuzzy logic with the help of slope, infiltration rate and depth to groundwater, quality of alluvial sediments and land use. They derived the relationship that between geomorphology and appropriate areas for groundwater recharge indicates that the majority of these areas are located on alluvial fans and pediment units.

Riad et al., presented two ways to go about performing analysis; creating a map and another way is querying the created data sets to obtain a Boolean result of true or false map to find suitable location for groundwater recharge [9]. These techniques have been applied on Sadat Industrial City in the western desert of The Nile delta, Egypt. He prepared some parameters for thematic layers from some maps and satellite images and they have been classified, weighted and integrated in ArcGIS environment. By the means of the overlay weighted model in ArcGIS he obtained a suitability map, which was classified into number of priority zones and it was compared with the obtained true-false map of Boolean logic which gave more accurate suitability map in wider ranges of areas.

CONCLUSION

Various methodologies that had been used earlier in different terrain and various expanses have been identified. Various thematic maps were analyse and compare the traditional weighted overlay value with the Fuzzy overlay tools based on Fuzzy logic model to select the most suitable Artificial Groundwater Recharge site with the help of spatial and non-spatial data, such as toposheets, satellite image, etc. The fuzzy algebraic product operator would be an appropriate combination operator, because at each location the combined fuzzy membership values tend to be very small with this operator, due to the effect of multiplying several numbers less than one. Parameters considered in selection of groundwater artificial recharge locations are diverse and complex. Integrated assessment of thematic maps using a fuzzy logic model developed based on GIS techniques was a suitable method for identifying preferred artificial recharge sites. Boolean logic is easy and not time consuming, so it can be used as first estimations for the best locations [6, 8]. Fuzzy based approach is most suitable for Groundwater Management than Boolean logics which can give more accurate suggestion for selection of suitable site for artificial groundwater recharge over the location map. Further scope of the study may be micro watershed level analysis and validating fuzzy and Boolean logic model outputs with ground truth.

Acknowledgement

I would like to acknowledgment the Civil Engineering Department, College of Engineering, Pune (CoEP) for giving me the opportunity to carry out this study. I wish to thank Dr. S. S. Bhosale, Head, Civil Engineering Department, CoEP for support and encouragement.

REFERENCES

1. Sivakumar V, Khare1 M, Subramanian SK, Seshadri K; Geo-spatial technology based study on climate change impact and tewardship for rural India: A pragmatic approach for comprehensive groundwater resource mapping and management. International Journal of Water Resources and Environmental Engineering, 2013; 203-216.
2. Kannan S, Mathew; GIS and Remote Sensing for artificial recharge study in a degraded Western Ghat terrain. Journal of Centre of Studies In Resources Engineering, 2008, 1-15.
3. Gale MI; Techniques for management of aquifer recharge in arid and semi-arid regions. Proc. Regional Workshop on Management of Aquifer Recharge and Water Harvesting in Arid and Semi-arid Regions of Asia, Yazd, Iran, 2005.
4. Shankar R MN, Mohan G; A GIS based hydrogeomorphic approach for identification of site-specific artificial-recharge techniques in the Deccan Volcanic Province (DVP). Journal of Earth System Science, 2005; 114(5):505–514.
5. Ghayoumian J, Mohseni SM, Feiznia S, Nouri B, Malekian A; Application of GIS techniques to determine areas most suitable for artificial groundwater recharge in a coastal aquifer in southern Iran. Journal of Asian Earth Sciences, 2007; 30:364–374.
6. Bonham-Carter GF; Geographic Information Systems for Geosciences, Modeling With GIS. Computer Methods in the Geosciences Vol. 13, Pergamon, Love Printing Service Ltd., 1996; 398.
7. Şener B, Süzen M, Doyuran V; Landfill site selection by using geographic information systems. Environ Geol, 2006; 49 (3):376–388.
8. Riad PH, Max H. Billib, Ahmed AH, Maha AS, Mohamed NED; Application of the overlay weighted model and Boolean logic to determine the best locations for artificial recharge of groundwater", journal of urban and environmental engineering, 2011;5(2): 57-66.
9. Riad PH, Max H. Billib, Ahmed AH, Maha AS, Omar; Overlay Weighted Model and Fuzzy Logic to Determine the Best Locations for Artificial Recharge of Groundwater in a Semi-Arid Area in Egypt. Nile Basin Water Science & Engineering Journal, 2011; 4(1):24-35.
10. Majid RM, Hamid RJ; Site selection for managed aquifer recharge using fuzzy rules: integrating geographical information system (GIS) tools and multi-criteria decision making. Hydrogeology Journal, 2012, 20: 1393–1405.
11. Mahdavi A, Tabatabaei SH, Nouri M and Mahdavi R; Identification of groundwater artificial recharge sites using Fuzzy logic: A case study of Shahrekord plain, Iran. International magazine of geo-science publication, 2012; 1-14.
12. Saravi MM, Malekian A, Nouri B; Identification of Suitable Sites for Groundwater Recharge. The 2nd International Conf. on Water Resources & Arid Environment, 2006; 1-5.
13. Available online at http://en.wikipedia.org/wiki/File:Fuzzy_logic_temperature_en.svg