GIS BASED FUZZY MODELLING APPROACH TO IDENTIFY THE SUITABLE SITES FOR ARTIFICIAL RECHARGE OF GROUNDWATER

Prasenjit Bhowmick[1] , Sivakumar V[2]
[1]Department of Civil Engineering, College of Engineering, Pune-411005, India , email: prasenjit.bhowmick88@gmail.com
[2]Centre for Development of Advanced Computing (C-DAC), Pune-411007, India, email: v.sivakumars@gmail.com

ABSTRACT

Water has become a scarce resource all over the world and so special attention must be paid to ground water resource management. Only two main sources of fresh water in the world are available which are surface water and groundwater. The amount of water in these sources is very little and is required for future storing by groundwater recharge which is very important. Groundwater is the main source of water mainly for agriculture and domestic purposes. Artificial Groundwater Recharge (AGR) method is best Availability of non-committed runoff, hydro-geologically favourable area for recharges and site-specific design of recharge structures are the major requirements. The aim of this study is to investigate the suitable areas for AGR structures in upper Bhima River basin in the semi-arid zone of Pune district, Maharashtra, India. In this study, knowledge based weightage values are assigned for each thematic layer and these thematic maps were integrated to fuzzy tool to determine membership values. Membership values were derived respective thematic map's each class, then fuzzy overlay analysis was carried out. The entire area has been classified as very suitable, suitable, moderate and unsuitable for AGR. Artificial recharge structure, like Check dam, nallabund, gully plugging, percolation ponds etc. are suggested to increase groundwater level. The conventional practice in water harvesting takes into consideration the availability of land, suitability of a particular artificial recharge techniques based 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 on a local scale.

Keywords: Artificial recharge, Fuzzy Logic, Groundwater, GIS, Remote Sensing.

INTRODUCTION

Groundwater is one of the most valuable natural resources. The total volume of ground water being only 0.65% of the total water availability of the globe, the natural underground water reservoir for storage is very small. Yet, it helps to support an enormous number of human lives, economic development and ecological diversity (eg., Sivakumar, et al., 2013).

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 (Kannan et al., 2009). Effective management for aquifer recharge is becoming an increasingly important aspect of water resource management strategies (Glae, 2005). A large amount of rain water is lost through runoff, in addition to the problem compounded by the lack of rainwater harvesting practices (eg., Shankar et al., 2005). Accordingly, artificial recharge is an effective technique for the augmentation of groundwater resources (Ghayoumian et al., 2007).

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 of the site of Artificial Groundwater Recharge (AGR) 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 (Ghayoumian et al., 2007). GIS provides the facility to analyze the spatial data objectively using various logical conditions. In addition to this, 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 (Kannan et al., 2009). Practically it is shown that using only the weighted value method, we are unable to find the exact and suitable area. But on the other hand fuzzy logic based values help us to find the precise region and site to build artificial recharge structure for groundwater recharge as the values come in the range of 0 to 1.

STUDY AREA

The area under study is the upper Bhima river basin which is located in Haveli Taluka of Pune district of Maharashtra, India and lies between latitude 18^0 39’ to 18^0 55’ N and longitude $73^0$31’ to $73^0$40’ E (Fig.1) in four SOI 1:50000 scale toposheets No. 47 F/14, 47 F/15, 47 J/ 2 and 47 J/3. The topography of watershed is undulating with highest elevation of 1005 m and lowest elevation of 520 m above the mean sea level. The area of the study zone is approximately 220 km^2 and the perimeter is 70 km. The average temperature ranges between 24^0 - 40^0C in summer season and goes down to 10^0Cin winter. The maximum relative humidity is 70% to 80% in rainy season, and 30% in summers. The average annual rainfall ranges from 400 to 600 mm by south west monsoon.

From the geological point of view the basin’s content is alluvial soil (38.18%), regur soil (47.73%) and mountain soil (14.09%). The Northern part of the study area is bounded by Mula-Mutha River, Southern part by hills, North Western and South Western part by suburbs of Pune city and eastern part by villages of Haveli Taluka.

AIM AND OBJECTIVES

The primary aim and objective is to identify the potential sites for locating the groundwater recharge structures using Remote Sensing and GIS techniques. Objectives are as follows:

1. To prepare thematic maps such as geology, geomorphology, drainage, land use land cover, etc.
2. To analysis knowledge base weightage for each thematic maps and thematic derivation fuzzy membership values.
3. To integrate all thematic maps (fuzzy membership) in GIS environment.
4. To prepare suitable groundwater recharge zone map through GIS analysis.
5. To study the groundwater recharge structures (check dam, percolation pit/pond, etc.) for recommendation.
6. Appling Fuzzy rules (by ArcGIS software tools)

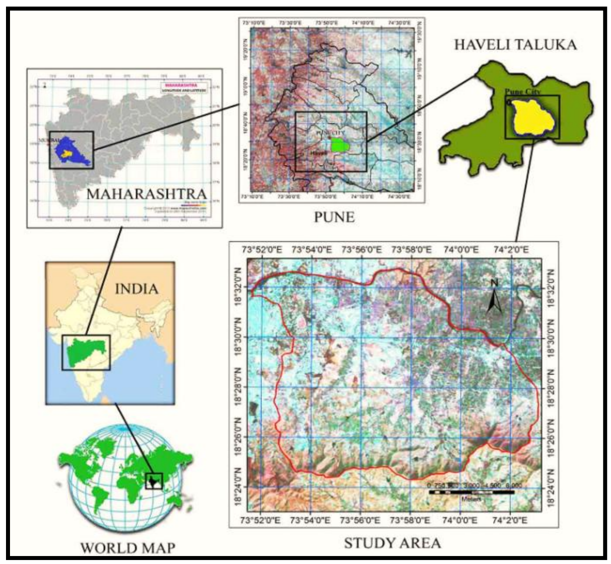

Fig. 1: Location map of the study area.

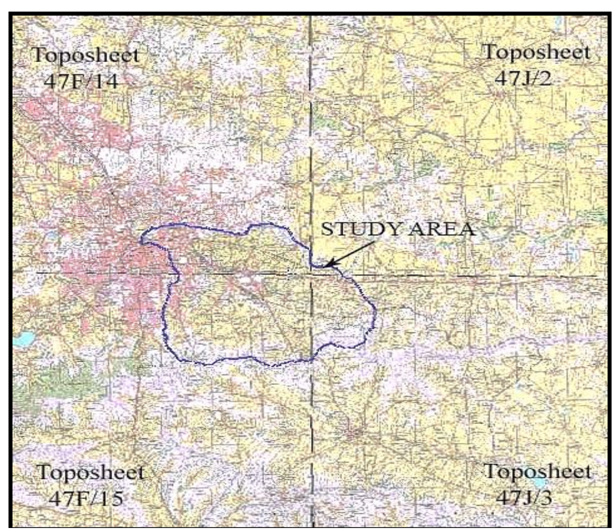

Fig. 2: Location of study area in SOI toposheets

MATERIALS & METHODOLOGY

DATA COLLECTION

Following primary and secondary data has been collected:

a) Survey of India (SOI) topographic data(47 F/14, 47 F/15, 47 J/ 2 and 47 J/3) on 1: 50,000 scale.
b) Satellite Data: IRS LIII Image (March-2012) (Source: www.bhuvan.nrsc.gov.in), ASTER GLOBAL DEM (**Coordinates:** 18.5^{0}N, 74.5^{0}c (Date: 17-Oct-11) Source: http://earthexplorer.usgs.gov/)
c) Rainfall Runoff data (2008-2012) of Haveli Taluka, Pune.
d) Water level fluctuation data (2012-13)

METHODS

Advanced technologies like Remote Sensing (RS) and GIS are very useful for groundwater studies. In the main task of the current study, the primary and secondary data are assembled together in GIS platform and different "thematic" maps were generated using data sources like satellite and topographic data. Thematic maps contain information about a single object or theme to make the thematic data easy to understand. The spatial data are assembled in digital format and properly registered to take the spatial component referenced. Namely, the sensed data provides more reliable information on different themes. Hence, in the present study various thematic maps were prepared by visual interpretation of satellite imagery, SOI Top sheet. All the thematic maps are prepared on the scale of 1:140,000 to 1:150,000.

GIS BASED MODELLING METHODS

The volume of geographic data is high and the analyses are very complex and time-demanding. To reduce the uncertainties that occur due to classification in GIS, Fuzzy Logic can be applied. By using Fuzzy Logic in GIS, aspects of ambiguity in linguistic variables can be modelled (Benedikt et al. 2002).

FUZZY LOGIC MODEL

Fuzzy Logic can be used as an overlay analysis technique to solve traditional overlay analysis applications such as site selection and suitability models.

Site selection can also be done by Weighted Overlay and Weighted Sum method but this are based on crisp sets, where each cell is either in a class or not. Fuzzy Logic specifically addresses situations when the boundaries between classes are not clear. Unlike crisp sets, Fuzzy Logic is not a matter of in or out of the class; it defines how likely it is that the phenomenon is a member of a set (or class). Fuzzy Logic is based on set theory and form of many-valued logic; therefore, we define possibilities, not probabilities.

Fuzzy Logic deals with reasoning that is approximate rather than fixed and exact, it is generally based on two principles:

1) Classifying maps compared together and based on importance.
2) Weighting classes in every map basedbetween 0 and 1(Ghayoumian, 2007).

Compared to traditional binary sets (where variables may take on true or false values) Fuzzy Logic variables may have a truth value that ranges in 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 is 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 (Bonham-Carter, 1996).

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. The following equation is selected and applied for this process:

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

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

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

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.

For example, we are exploring the relationship of the different heights of people within a group, short, medium, and tall.

A short person may be 5 feet (1.524 meters) or under, a tall person may be 6 feet (1.829 meters) and over and a person of medium height is between 5 and 6 feet. If a person is 6 feet tall, they will be placed in the tall class. If a person is 5' 11", they will be classified as medium. With a difference of only 1 inch (0.025 meters) between the two people's height, they are placed in two separate classes. This same difference relationship would be depicted if another group member is 5' 1" and the second is 6' 5". Due to the coarseness of the classifications, the full relationships between the heights cannot be captured.

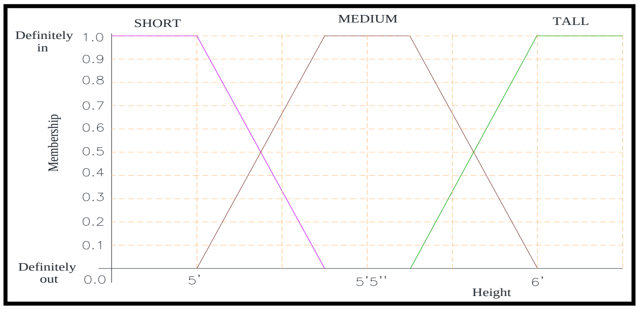

Fig.3: Fuzzy Logic in Height Scale

In the height application above, if we stay with our three heights classes-short, medium, and tall-the three classes in fuzzy logic can overlap.

In the above image, full membership into each class is

- Short: < 5 feet
- Medium: 5' $2\frac{1}{2}$" to 5' $8\frac{1}{2}$"
- Tall: > 6

For the short classes, anyone 5 feet or below is definitely within the small class and is assigned as fuzzy membership1.

Any height greater than 5 feet and less than 5'$2\frac{1}{2}$" is between the small and medium classes. For heights between 5 feet and 5'$1\frac{3}{4}$", the heights are more likely to be in the short class. Heights greater than 5'$1\frac{3}{4}$" and less than or equal to 5'$3\frac{1}{2}$" are possibly in the short class but have a greater possibility of being part of the medium class.

FUZZY OVERLAY

For the site selection of AGR five thematic maps were generated in GIS environment which are: (i) Geomorphology, (ii) Soil, (iii) Land Use and Land Cover,(iv) Slope and (v) Drainage density. To analyze the relationships and interaction between all these thematic layers for the multiple criteria in the overlay model, Fuzzy membership and overlay techniques are used. The membership data was combined based on Fuzzy Logic (Fig.4) to generate intersecting polygons, in a paired combination according to weightage. The available Fuzzy set overlay techniques which are found to be useful for combining exploration datasets are Fuzzy AND, Fuzzy OR, Fuzzy Algebraic Product, Fuzzy Algebraic Sum and Fuzzy Gamma operator.

- Fuzzy **AND:** The minimum of the Fuzzy memberships from the input fuzzy rasters.
- Fuzzy **OR:** The maximum of the fuzzy memberships from the input rasters.

- Fuzzy **Algebraic Product:** It is a decreasive function and it is used when the combination of multiple evidence is less important or smaller than any of the inputs alone.
- Fuzzy **Algebraic Sum:** It is an increasive function and it is used when the combination of multiple evidence is more important or larger than any of the inputs alone.
- Fuzzy **Gamma:** The algebraic product of the Fuzzy Sum and Fuzzy Product, both raised to the power of gamma.

Fuzzy algebraic product is defined as:

$$u_{Combination} = \prod_{i=1}^{n} u_i \text{-------(4)}$$

Where, u_i is the fuzzy membership values of i^{th} map and $i=1,2,3\ldots\ldots n$. In fuzzy algebraic product operator as a t-norm, the weight of compositional layer in the multi- layer intersection section is equal to their products and for other sections is zero.Using this overlay analysis a new composite map is generated which is integration of various features from these thematic maps and this is the final composite map for artificial groundwater recharge zones (Fig.5). The required steps are as follows:

- Spatial database building
- Spatial database analysis
- Data integration through GIS

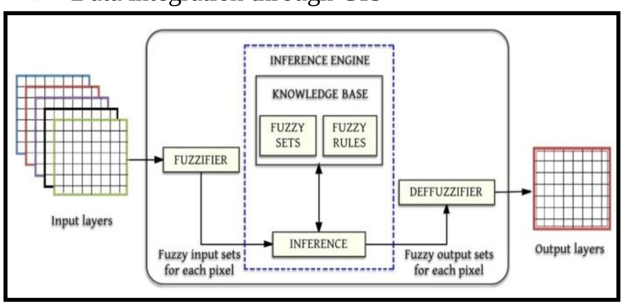

Fig.4: Structure of the proposed fuzzy overlay method

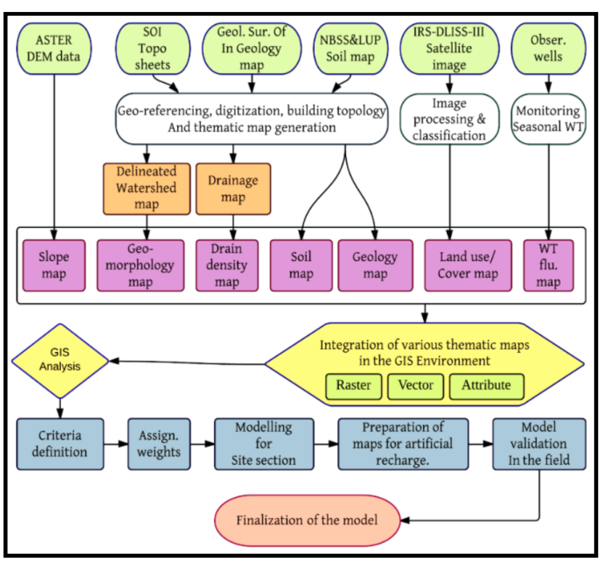

Fig.5: Flowchart of various steps involved in the AGR

RESULT AND DISCUSSION

DIGITAL ELEVATION MODEL (DEM)

The DEM was used for preparing percentage slope map. The DEM mosaic was prepared from 'ASTGTM2 N18E073 &74' ASTER DEM data in the ArcGIS platform by the mosaic tools (Fig.6). Topographic and the slope maps were generated using the spatial analyst tools of ArcGIS 10.0, then the study area was clipped out according to its known coordinates.

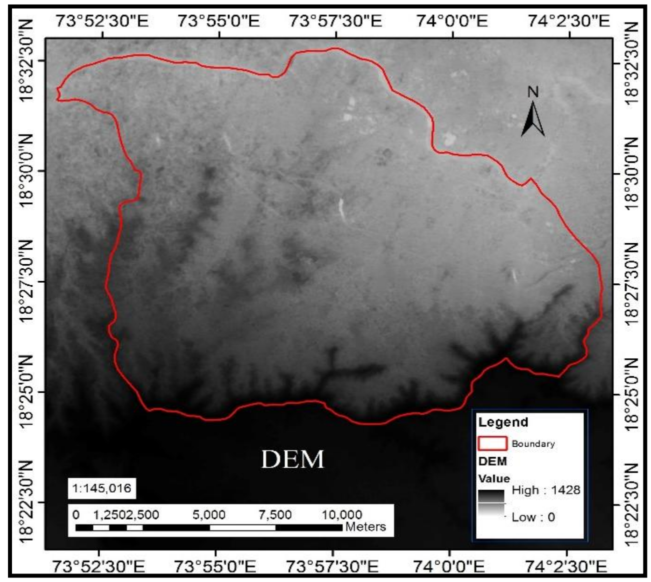

Fig.6: DEM data map

THEMATIC MAPS ANALYSIS

All the thematic maps were changed into raster format and superimposed by weighted overlay method (weightage wise thematic maps) for AGR zoning.

1. Slope ; 2. Soil; 3. Geomorphology;

4. Land use Land Cover; 5.Drainage.

SLOPE

For estimation of slope percentage, DEM map was used. According to the recharge priority of groundwater, weightage value is assigned to different slopes. Steeper the slope, lower will be the potential of ground water recharge. Very high degree of slope is given highest weightage value (0 to 4). Five types of slope are found which are: nearly levelled, gentle, moderate, steep and very steep (Fig.7).

The weightage giving map is reanalysed and reclassified into three zones by the Fuzzy Membership in ArcGIS environment (Fig.8).

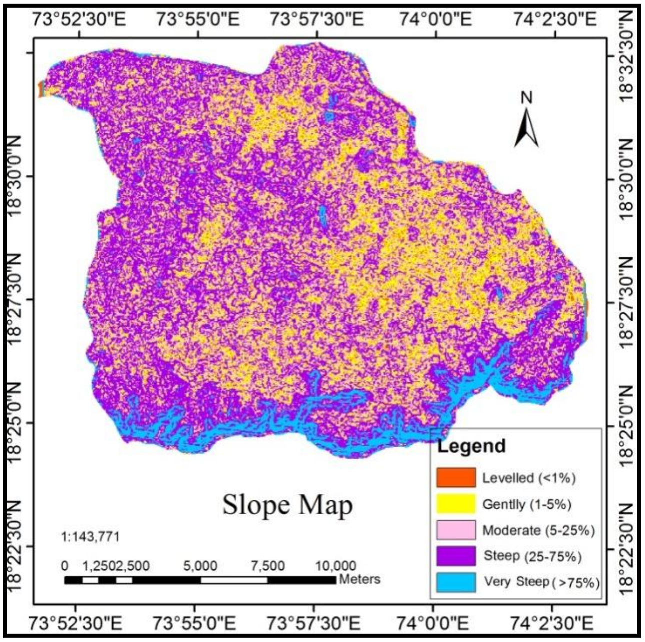

Fig.7: Percentage Slope map

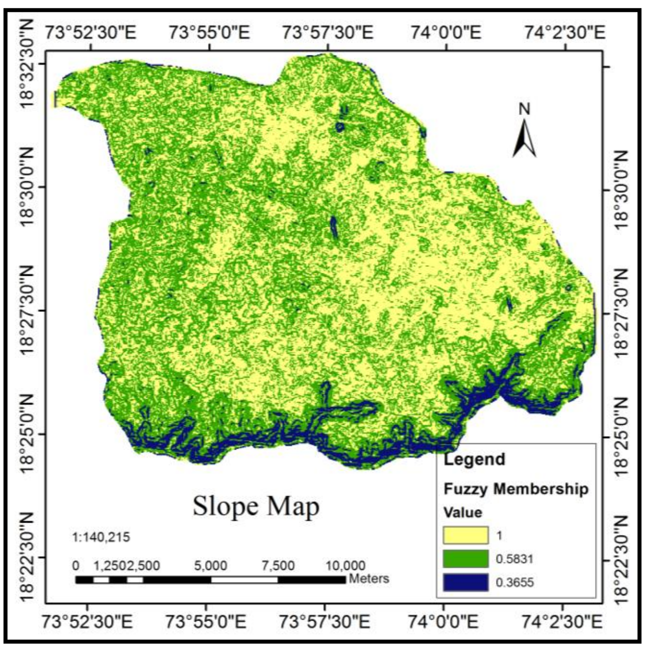

Fig.8: Slope map with Fuzzy Membership

SOIL

According to the data we get to know that the study area has three types of soils i.e. **alluvial soil, regur soil** and **mountain soil** from north to south respectively. The infiltration rate of alluvial is more than regur soil. On the other hand, mountain soil contents hard rock which is responsible for low infiltration so it is poor for groundwater recharge. According to the suitability, fuzzy membership is calculated with respect to the weightage values (Fig.9).

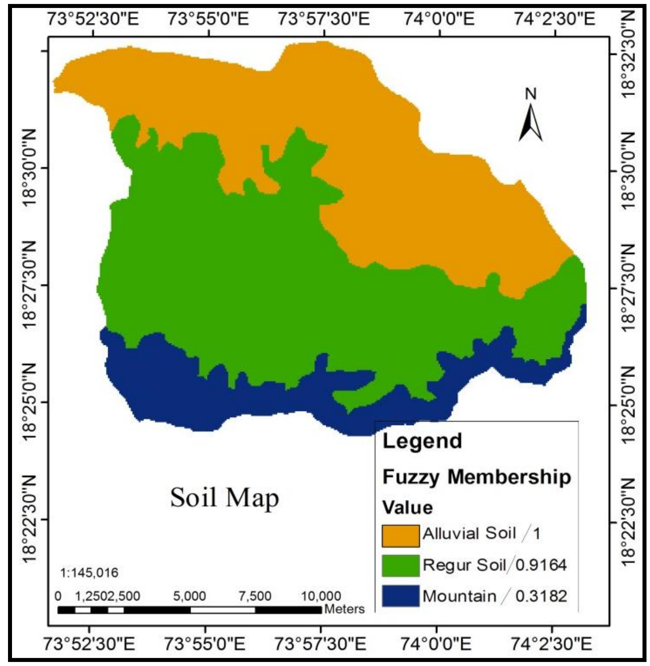

Fig.9: Soil map with Fuzzy Membership

GEOMORPHOLOGY

The Geomorphology map (Fig.10) was prepared from IRS LIII (March-2012) data using image interpretation elements with limited field validation. The Geomorphological units are highly helpful for selecting the artificial recharge sites (Ghayoumian, 2007). In the present investigation, various landforms based on geomorphology are classified as such:

(a) Valley, (b) Pediplain, (c) Buried Pediplain, (d) Hill structure.

According to groundwater recharge priority the various landforms are reclassified by four weightage values and transformed into three groups by fuzzy membership (Fig.11) with the help of ArcGIS.

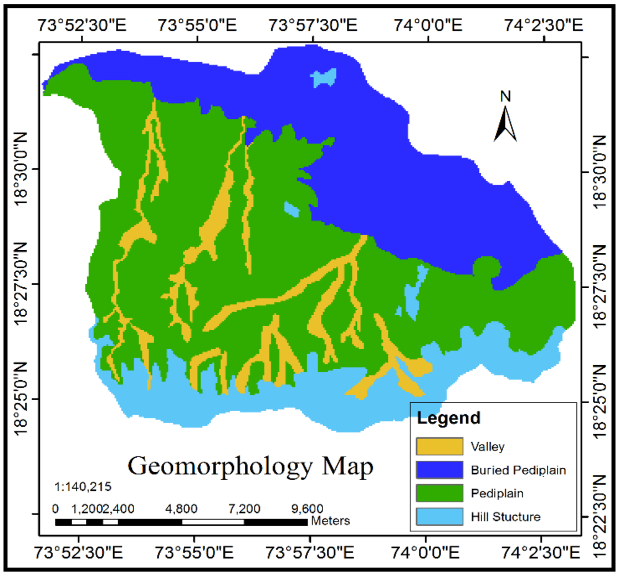

Fig.10: Geomorphology map

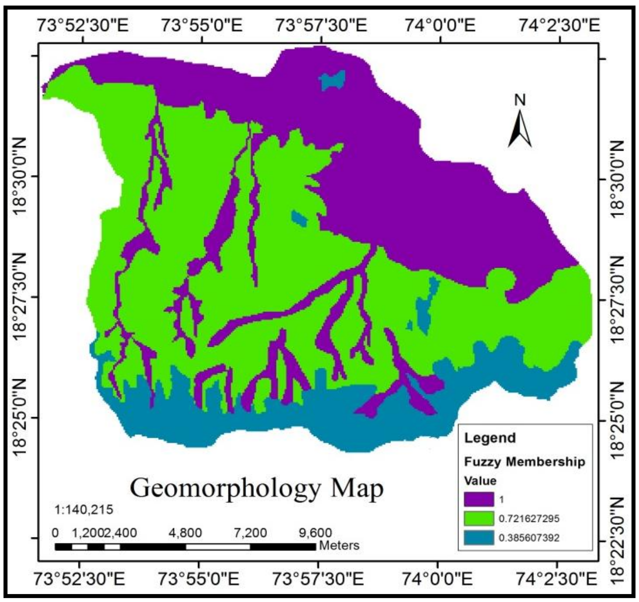

Fig.11: Geomorphology map with Fuzzy Membership

(a) VALLEY

Normally the valleys found in denude structural hill provinces will neither be having a preferred shape nor shape less architecture. However, the valleys act as active basin or trough to receive the eroded sediments, diving down the slope such as the valley fill having the unconsolidated materials, which can store more water and support lot of vegetation. In the satellite images, valleys are found all along the foothill and reddish tone due to the presence of vegetation in an irregular pattern. The stream which originates from the hill ranges, on reaching valleys narrows down because of the sudden obstruction caused by the valleys. It dumps the sediments in valleys and thus causes the formation of colluvial fills. Colluvial fills are found all along the hill ranges.

(b) PEDIPLAIN

The extensive slightly inclined denudation plain, which is formed under the conditions of arid and semiarid climate on the spot, is earlier than the existed mountain or hilly relief by the parallel retreat of slopes from the axis of valleys and connection of the separate settlement sections is called pediplan.

(c) BURIED PEDIPLAIN

The surface of the pediplain which normally supports vegetation no fracture present will support to content more water deposition. The pediment content with no rock cut materials on the plain surface is called Buried Pediplain. This portion showsgreenish red tone and regular texture in the satellite imagery. It is favourable for vegetation growth.

(d) STRUCTURAL HILLS

The structural hills controlled with complex folding, faulting, crisscrossed by numerous joints / fractures, which facilitate some infiltration and mostly act as runoff zones. The southern part of the study area is occupied by intricately folded charnockites, gneiss and fringes of the area have developed conspicuous slopes encircling them.

LAND USE LAND COVER

The study area is basically covered by agricultural land (78Km^2), scrub and hilly land (68Km^2), urban area (66Km^2) and very small waste land (2Km^2). Some water bodies also present mainly in south portion of study area. Main river, Mula-Mutha is present covering northern part of the study area with 5Km^2(Fig.12).

Other areas of the watershed are mostly altered by extension cultivation land and settlements and different road ways and railway tracks. On the basis of the alteration of land cover areas, some urban centres have been coming up on the margin of road ways and railway track of the watershed.

The urban area, the hilly portion and the wasteland are unsuitable for artificial groundwater recharge. But plain land, such as agricultural land, and the water bodies are most suitable for it. According to the suitability weightage were given to the various land used and covered portion and in GIS environment it was analysed and fuzzy membership was calculated with four groups (Fig.13).

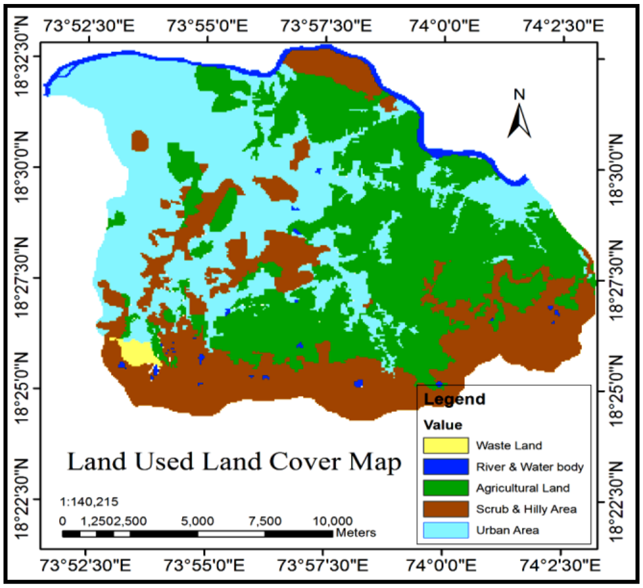

Fig.12: Land used Land cover (LULC) map

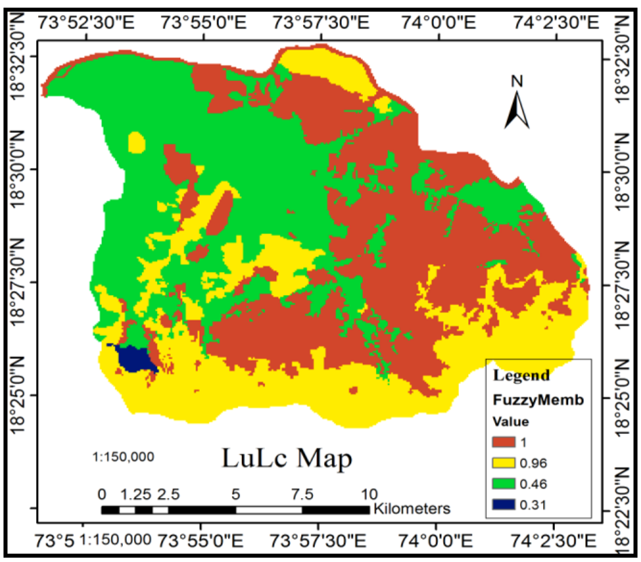

Fig.13: LULC map with fuzzy membership

DRAINAGE

The watershed region is extensively drained to Mula-Mutha River by many streams form source to mouth by a number of 1st order, 2nd order, 3rd order and 4th order according to Strahler's method (Fig.14a).

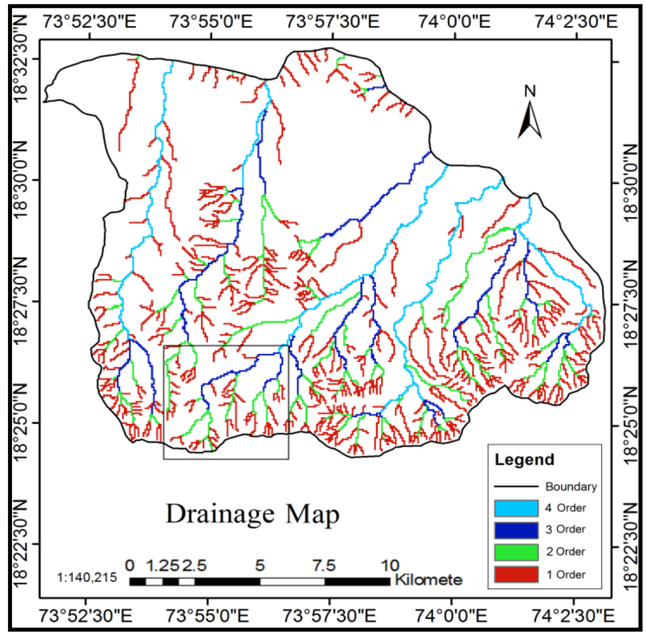

Fig.14a: Drainage density

- **IN STRAHLER'S SYSTEM (1952)**

i) The order of the stream is 1, if a stream has no contributing tributaries.

ii) If there have more than one tributaries, in *i* and *j* orders then

- If $i = j$ then the order of the resulting stream will be i+1 or j+1
- Else if $i<j$ then the order of the resulting stream will be j
- Else if $i>j$ then the order of the resulting stream will be i.

Two streams with same order i unite to give a stream of order i+1and if the streams of different order unite the new stream retains the order of the highest order stream (Fig. 14b).

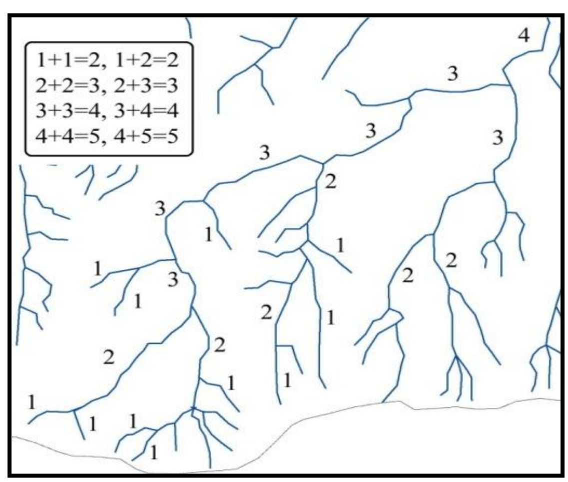

Fig.14b: Strahler's ordering scheme in Drainage line

Rainwater is available due to south west monsoon from June to October and the average annual rainfall ranges from 400 to 600 mm. (according to the India Meteorological Department (IMD), Pune). By the availability of the water as runoff and the groundwater level fluctuation in between pre and post monsoon season, the suitable site for the AGR was selected over the final overlay map.

WEIGHTED INDEXING TABLE

Each raster is converted into the shape files and given the knowledge base weightage values (Table 1) and again converted into raster. According to the giving weightage, percentage of the areas was calculated. The weights in the present study were given upon the experience of other specialists from previous studies and upon the economic point of view (Elbeih, 2007).

Table 1: Fuzzy Membership of the thematic maps

Maps	Types	Classes	Weight age	Fuzzy membership	Area (Km^2)	Area (%)
Slope (%)	Levelled (<1%)	very suitable	1	1	95	43.18
	Gently (1-5%)	suitable	2	1		
	Moderate (5-25%)	good	3	1		
	Steep (25-75%)	moderate	4	0.58	105	47.72
	Very Steep (>75%)	Unsuitable	4	0.37	20	9.1
Soil	Alluvial	Suitable	1	1	84	38.18
	Regur	Moderate	2	0.92	105	47.73
	Mountanian	Unsuitable	4	0.32	31	14.09
Geo-morphology	Valley	Very Suitable	1	1	20	9.1
	Burried Pediplain	Suitable	2	1	62	28.18
	Pediplain	Moderate	3	0.72	107	48.64
	Structural Hill	Unsuitable	4	0.39	31	14.10
Land use Land cover	Water body	Very Suitable	1	1	6	2.73
	Agricultural land	Suitable	2	1	78	35.45
	Scrub and hilly land	Moderate	3	0.96	68	30.91
	Urban area	Unsuitable	4	0.46	66	30
	Waste land	Very poor	4	0.31	2	0.91
Drainage lines	1 Order	Poor	4	0.58		
	2 Order	Moderate	3	1		
	3 Order	Good	2	1		
	4 Order	Very Suitable	1	1		
	5 Order	Suitable	1	1		

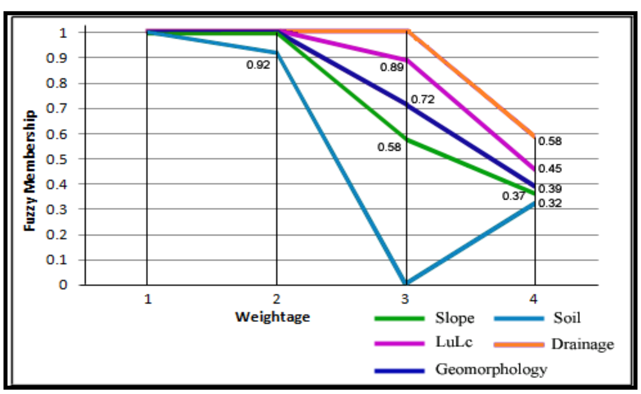

Fig.15: Fuzzy Membership vs. Weightage graph

In the Figure 15, the relative Fuzzy Membership vs. Weightage graph of the all thematic maps is shown. From this chart, we can see that more than 0.5 fuzzy membership values are suitable for AGR whereas the lower ones are unsuitable.

WATER LEVEL

It is very important to know about the water level of the underground water for selection of suitable artificial groundwater recharge sites or zones. The water table is fluctuating for ground water use by human beings and by the monsoon rainfall infiltration. There were total nineteen villages in the study area but during the survey we took five villages' pre-monsoon and post-monsoon water level data (Table 2) from the village well and approximately three wells per village were considered for taking well readings.

The water level data is used to understand the water level difference in pre and post monsoon season in the region. These data provide clues to prioritizing the AGR in the area. If water level (water table) difference is high that area may be consider first priority for AGR, than the area which comes under less difference.

Table 2: Water level fluctuation data (2012-2013)

Village well	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)	Depth of well (m)	Pre monsoon depth (m)	Post monsoon depth (m)	Water level difference (m)
Kondhwa Khurd	18.4736	73.8897	8.80	2.71	1.46	**1.25**
Pisoli	18.4518	73.9091	23.13	8.73	5.54	3.19
Furusungi	18.4732	73.9826	13.30	11.28	3.46	**7.82**
Manjari	18.5182	73.9862	10.91	9.40	5.32	4.08
Hadapsar	18.4856	73.9370	9.85	6.33	2.48	3.85

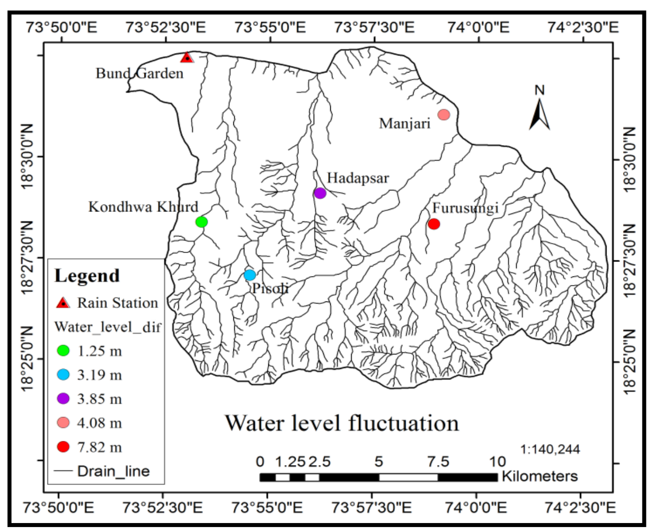

Fig.16: Water level difference map

WATER AVAILABILITY

Pune gets rain water during the five months monsoon which is from mid of June to October. Out of the 31 dams of Pune district, for 9 dams, (which are mainly in west and north-western region of the study area) five years (2008-2012) average annual rainfall and runoff data was collected from the Department of Irrigation, Pune (Table 3). By this data, water available throughout the year is known and according to that the recharge by the recharge structure can be done. The origin of Mutha River is from Varasgaon, Panshet and Khadakwasla dam and the other hand Mutha River from Mulshi dam. Before entering into Pune city it joint together and become Mula-Mutha River which is the only main river of the area. Water comes into this river as runoff (average 1782.75 cumec per year) from the all 9 dams by various tributaries. From that point of view the amount of runoff from the dams throughout the year is very important for this research work.

Table 3: Five years average annual rainfall and runoff data (2008-2012):

Name of the Dam	Latitude (in decimal degrees)	Longitude (in decimal degrees)	Avg. rainfall (in mm)	Avg. Runoff (in cumec)
Kasarsai	18.618	73.664	961.2	182.032
Mulshi	18.526	73.511	2837.2	1875.41
Temghar	18.453	73.541	2927.4	430.54
Varasgaon	18.387	73.613	2062.2	1008.43
Panshet	18.378	73.613	2278.6	1265.87
Khadakwasla	18.442	73.767	786	7832.5
Nira Devdhar	18.108	73. 723	2091	1135.53
Bhatghar	18.175	73. 871	2226.4	1133.05
Veer	18.123	74. 096	1234.4	1181.42

ARTIFICIAL RECHARGE SITE SELECTION

Artificial recharge is the process of augmenting the natural movement of surface water into underground formations by several artificial recharge methods like percolation ponding, recharge pitting, en echelon damming, flooding, induced recharging, and construction of a battery of wells are being practiced successfully all over the world (Karanth 1987; Muralidharan and Athavale 1998). They have various other types of soils and water conservation methods which are also commonly adopted including contour trenching; terracing, nallabunding, and inter-basin transfer (Troch *et al* 1980). Selection of suitable sites for application of appropriate artificial-recharge techniques is critical for effective recharge and is dependent upon several parameters which are to be analyzed together in a GIS environment. Recharge potential of a terrain highly depends on the infiltration capacity of the unsaturated zone above the aquifer, geologic and hydrogeomorphologic parameters, terrain slopes, land use land cover and drainage density.

In the ArcGIS environment, all thematic layers and table of weights which were needed for the weighted model, were built and run to come up with the most favourable sites selection map using the previously mentioned criteria and overlay process.

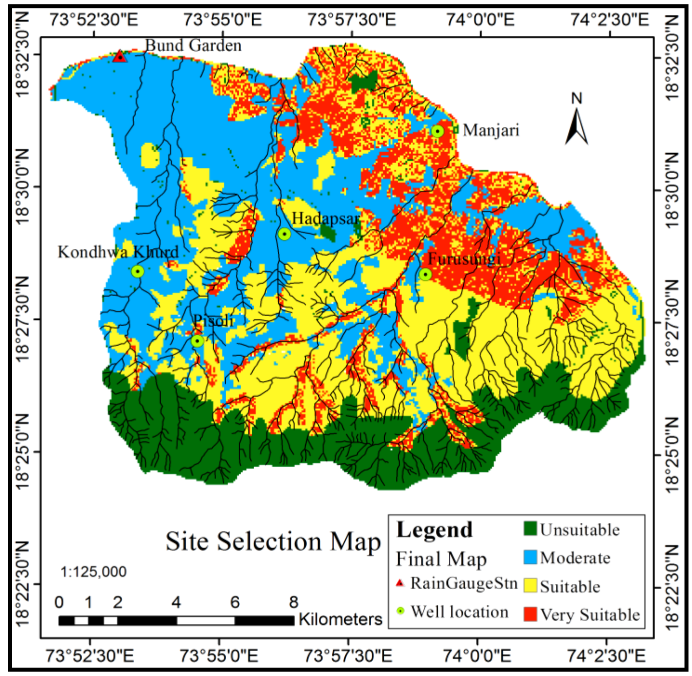

Fig.17: Final Site Selection zones map for Artificial Groundwater Recharge

In the final map (Fig.17) the red colour shows the fuzzy value is in between 1-0.722 (Table 4) which indicates very suitable for AGR and it is 22.82% of total area, Yellow portion (25.59%) is less suitable as fuzzy value come in between 0.722-0.451. The dark green portion (17.32%) of the final map is very poor for AGR as the infiltration rate is very low due to hard rock structure and steep slope. The urbanization area given below in light blue colour (34.27%), this zone is not possible for the artificial recharge structure construction but river and water bodies are very suitable as water is available throughout the year as runoff by the drainage channels.

Table 4: Final result of site selection for AGR:

Classes	Fuzzy value	Area (Km^2)	Area (%)
Most Suitable	1-0.722	50.2	22.82
Suitable	0.722-0.451	56.3	25.59
Moderate	0.451-0.386	75.4	34.27
Unsuitable	0.386-0.318	38.1	17.32

RECHARGE STRUCTURES

PERCOLATION POND

Percolation or Infiltration ponds are large open water ponds that are either excavated or in an area of land surrounded by a bank, and normally will not exceed 15,000 m^3. They store rainwater but with the main aim of infiltrating the water to aquifers where it can be extracted using boreholes, hand-dug wells, or nearby springs. They are constructed in areas where the base of the pond is permeable and where the aquifer to be recharged is at or near the surface. In the suitable sites where the low-potential zones with medium-to-high water table fluctuations happen this is suitable for such structure.

CHECK DAM

A **check dam** is a small dam, which can be either temporary or permanent, built across a minor channel, swale and drainage ditch in order to prevent runoff and detain the water to enhance infiltration into the subsurface. Check dams are recommended at 6 locations across the 3nd and 4rd order streams in the runoff recharge zones, with low to moderate slope.

EN ECHELON DAMS

En echelon dams constructed to reduce the velocity of river flow, and thereby promote infiltration across streams obstruct drainage. For quick flow of water by the long linear stretches of the river, gets little time for infiltration. In such cases, the most suitable recharge technique would be the construction of a series of en echelon dams to control the water flow by a controlled velocity.

CONTOUR TRENCHING

Contour trenching is an agricultural technique that can be easily applied in arid sub-Sahara areas to allow for water, and soil conservation and minimise soil erosion. A trench about 10 feet long, one foot wide and one foot deep is very effective. Try to stagger them on the hillside so that water is slowed evenly across the entire slope. This technique should only be used where the trenches will not complicate the use of the field.

CONCLUSION

The integrated remote sensing, GIS and Fuzzy logic methods are useful for identifying AGR structures. GIS and remote sensing minimize the time and cost especially for identifying suitable site for AGR. Fuzzy logic provides a framework for processing linguistic knowledge and its corresponding data through membership functions for AGR site selection. In this study shows that the north-east portion is very suitable zone (total about 23% area) for AGR, 26% area is suitable, and 51% area is not suitable for AGR. The study suggested that the 4th and 5th order drainage and valleys are highly suitable for check dams; alluvial soil area is suitable for percolation tank and recharge pit; and gentle slope areas are suitable for contour trench and percolation tank. However, further studies such as soil sampling, subsurface geological mapping and environmental impact assessment are recommended before constructing the artificial recharge structures.

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REFERENCES

[1] Bahram M, 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.

[2] Balachandar D, Alaguraja P, Sundaraj P, Rutharvelmurthy K, Kumaraswamy K;Application of Remote Sensing and GIS for Artificial Recharge Zone in Sivaganga District, Tamilnadu, India. International journal of Geomatics and Geosciences volume 1, no 1, 2010, 84-97.

[3] Benedikt J, Reinberg S, Riedl L; A GIS application to enhance cell-based information modeling. Inform Sci142 (1–4); 2002, 151–160. Doi: 10.1016/s0020-0255(02)00163-9.

[4] 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.

[5] Elbeih S; Impact of Groundwater Recharge on the Surrounding Environment, PhD Thesis, Faculty of Engineering- Ain Shams University, Egypt, 2007.

[6] 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 30 no.2, 2007; 364–374.

[7] Gale MI; Techniques for management of aquifer recharge in arid and semi-arid regions. Proc. RegionalWorkshop on Management of Aquifer Recharge and WaterHarvesting in Arid and Semi-arid Regions of Asia, Yazd, Iran, 2005.

[8] 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.

[9] Karanth K R; Groundwater assessment, developmentand management, Tata Mcgraw Hill, New Delhi, 1987.

[10] 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.

[11] Muralidharan D and Athavale R N;Artificial-recharge in India. Rajiv Gandhi National drinking water mission, NGRI, Hyderabad, 1998.

[12] Murugiah M, Venkatraman P;Role of Remote Sensing and GIS in artificial recharge of the ground water aquifer in Ottapidaram taluk, Tuticorin district, South India. International journal of geomatics and geosciences volume 3, no 3, 2013; 405-415.

[13] Pradhan MP, Ghose MK, Kharka YR;Automatic Association of Strahler's Order and Attributes with the Drainage System. International Journal of Advanced Computer Science and Applications, Vol. 3, No.8, 2012; p. 30-34.

[14] RaviShankar MN and 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.114 No. 5, Oct 2005; 505–514.

[15] 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, Vol.4, Issue 1, 2011; 24-35.

[16] Saravi MM, Malekian A, and Nouri B; Identification of Suitable Sites for Groundwater Recharge. The 2nd International Conf. on Water Resources & Arid Environment, 2006; 1-5.

[17] Şener B, Süzen M, Doyuran V; (2006) Landfill site selection by using geographic information systems. Environ Geol 49 (3); 2006, 376–388. Doi: 10.1007/s00254-005-0075-2

[18] Sivakumar, V., Khare, M., & Seshadri, K; Geo-spatial technology based study on climate change impact and stewardship for rural India: A pragmatic approach for comprehensive groundwater resource mapping and management.International Journal of Water Resources and Environmental Engineering, 5(4), March, 2013; 203-216.

[19] Sooraj Kannan, Mathew; GIS and Remote Sensing for artificial recharge study in a degraded Western Ghat terrain.Journal of Centre of Studies in Resources Engineering, IITB; 2008, 1-15.

[20] Troch F R, Hoopa J A and Donahue R L; Soil and water conservation for productivity and environmental protection. Prentice-Hall, New Jersey, 1980, p. 718.