International Journal of Civil
Engineering (IJCE)
ISSN(P): 2278-9987; ISSN(E): 2278-9995
Vol. 3, Issue 4, July 2014, 33-46

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

GIS BASED SUITABLE SITES SELECTION FOR ARTIFICIAL GROUNDWATER RECHARGE OF MAHARASHTRA STATE, INDIA

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ABSTRACT

Water has become a scarce resource all over the world and so special attention must been paid to artificial groundwater recharge (AGR) in water resource management. Availability of non-committed runoff, hydro-geologically favourable area for recharges and site specific design of artificial recharge structures are the major requirements of an AGR system. Only two main sources of fresh water in the world are available which are surface water and groundwater. The amount of this water sources are very little and which required storing for future by groundwater recharge which is very important now a days. For AGR suitable site investigation is required. Groundwater is the main source of agriculture and it is also used for domestic purpose. The ultimate objective of this study is to investigate the areas which are very suitable for AGR in upper Bhima River basin in the semi-arid zone of Pune district, Maharashtra, India. In this study weighted values are used in Geographical Information System (GIS) environment and create the thematic layers, the exact type of artificial recharge structure, like Check dam, nallabund, gully plugging, percolation ponds etc are selected for an artificial recharge. The conventional practice in water harvesting takes into consideration the availability of land, suitability of a particular artificial recharge technique depending on local conditions, and the area benefited. Hence, decisions regarding the location and type of recharge structure for water conservation can be made only after extensive ground study. GIS based modelling approach provides excellent tools for identifying recharge zones with suitable structures in stipulated time.

KEYWORDS: Artificial Recharge, Geomorphology, Geoinformatics, Groundwater, GIS, Land Use Land Cover, Remote Sensing, Weighted Overlay Analysis

INTRODUCTION

Groundwater is one of the most valuable natural resources. The total volume of ground water is only 0.65% of the total water availability of the globe. The natural underground water reservoir for storage is very small. It helps to support enormous human health, economic development and ecological diversity (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 semiarid regions, dependence on groundwater resource has increased tremendously in the recent years due to vagaries of monsoon and scarcity of surface water (Kannan et al., 2009). Effective management of 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, a problem compounded by the lack of rainwater harvesting practices (Shankar et al., 2005). Artificial recharge is an effective technique for the augmentation of groundwater resources (Ghayoumian et al., 2007). There are many factors to be considered when determining if a particular site will be receptive to artificial recharge. The stability of terrain should be assessed before constructing any recharge structures to avoid risks of landslide. Hence, selection of suitable recharge-site is an important step in the artificial recharge planning. The application of traditional data processing methods in site selection for artificial groundwater recharge (AGR) is very difficult and time consuming, because the data is massive and usually needs to be integrated. GIS is capable of developing information in different thematic layers and integrating them with sufficient 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 analyse the spatial data objectively using various logical conditions. Modern remote sensing techniques facilitate demarcation of suitable areas for groundwater replenishment by taking into account the diversity of factors that influences groundwater recharge. Geology, geomorphology, structure and climatic condition are the controlling factors of ground water storage, occurrence and movement in hard rock terrain. These features cannot be observed on the surface by bare eyes but can be picked up through satellite remote sensing with reasonable accuracy (Kannan et al., 2009). The aim of the paper is to study for identifying suitable site for artificial Recharge of Groundwater with help of GIS and Remote sensing techniques. Practically it is shown that only by weighted value method we are unable to find the exact and suitable area.

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 Figure 1 in four SOI 1:50000 scale toposheets No. 47 F/14, 47 F/15, 47 J/ 2 and 47 J/3 Figure 2. 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 area is approximately 220 km^2 and perimeter 70 km. The average temperature staying between 24^0 - 40^0C in summer season and in winter goes down to 10^0C. 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.

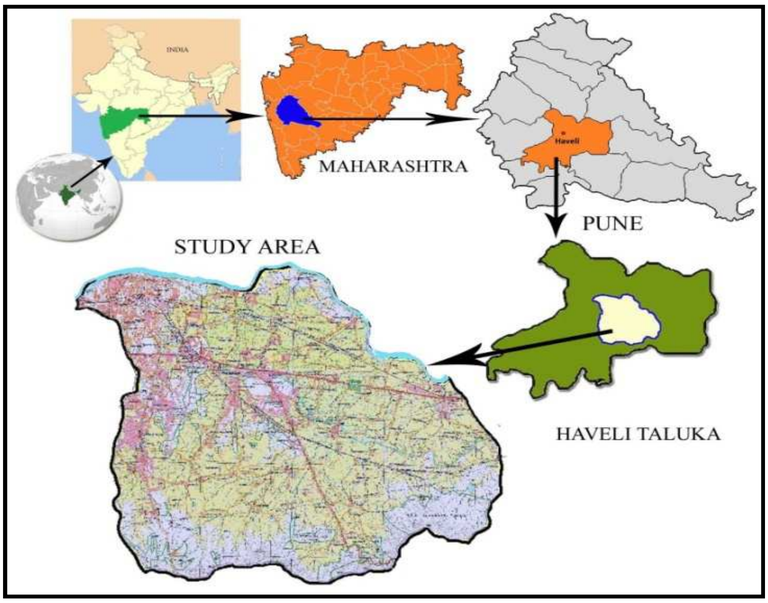

Figure 1: Location Map of the Study Area

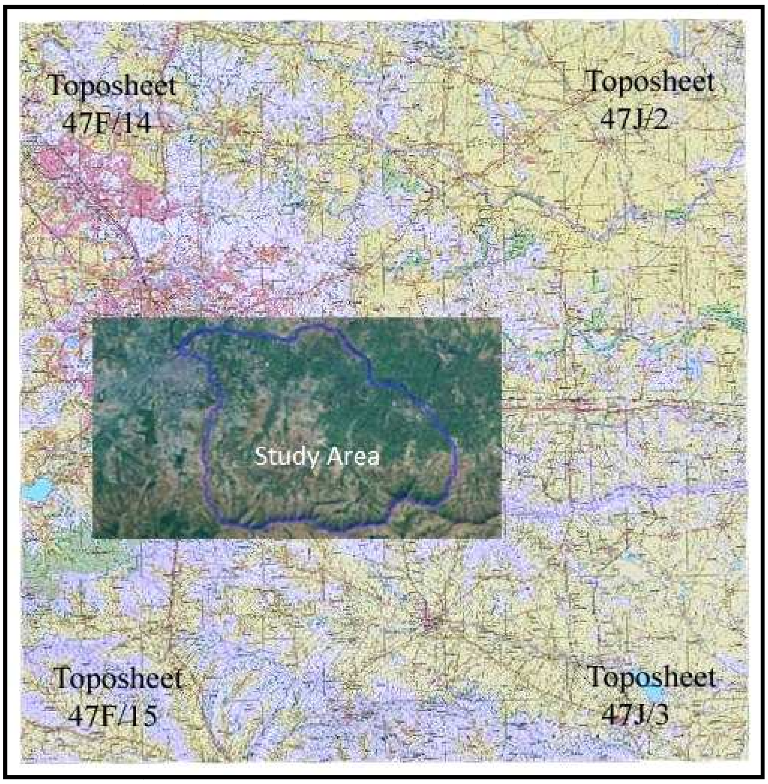

Figure 2: Location of Study Area in SOI Top O Sheets

AIM AND OBJECTIVES

The primary aim and objectives identify the potential sites for locating the groundwater recharge structures using Remote Sensing and GIS techniques. They are as follows:

- Studying the Groundwater recharge structures (check dam, percolation pit/pond, etc.) for recommendation
- Appling weighted overlay rules (by ArcGIS version 10.1 overlay tool).
- Preparation of suitable artificial recharge structures map (check dam, Vented Cross Bars, Gabion Dams, percolation pit/pond, etc.)

MATERIALS AND METHODOLOGY

Data Collection

For the study the following primary and secondary data has been collected:

- Geological Data Satellite: Indian Research Satellite (IRS) LIII Image (march-2012), ASTER GLOBAL DEM (**Coordinates:** 18.5^{0}N, 74.5^{0}E Date:17-Oct-11) (http://earthexplorer.usgs.gov/)
- Survey of India (SOI) topographic data from 47 F/14, 47 F/15, 47 J/ 2 and 47 J/3 on 1: 50,000 scale.
- Water level fluctuation data (2012-13)
- Rainfall Runoff data (2008-2012) of Haveli Taluka, Pune.

Methods

Advanced technologies like Remote Sensing (RS) and Arc 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. The namely 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 occurs due to classification in GIS. By using GIS aspects of ambiguity in linguistic variables can be modelled (Benedikt et al. 2002).

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 Figure 3. The required steps are as follows:

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

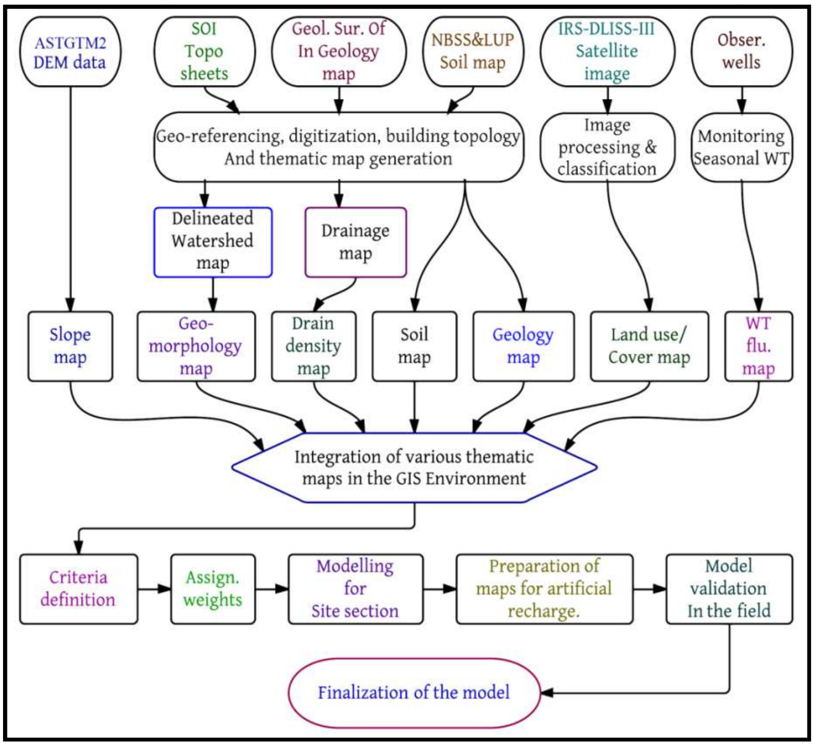

Figure 3: Flowchart of Various Steps Involved in the AGR

RESULTS AND DISCUSSIONS

Digital Elevation Model (DEM)

For percentage slope map, DEM data Figure 4 is required. The DEM was repaired from 'ASTGTM2 N18E073 &74' Aster DEM data in the ArcGIS platform by the mosaic tools. Topographic and the slope maps were generated using the spatial analyst tools of ArcGIS 10.1, then the study area was clipped out according to its known coordinates.

Thematic Maps

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

Slope, Soil, Geomorphology, Land Use Land Cover, Drainage

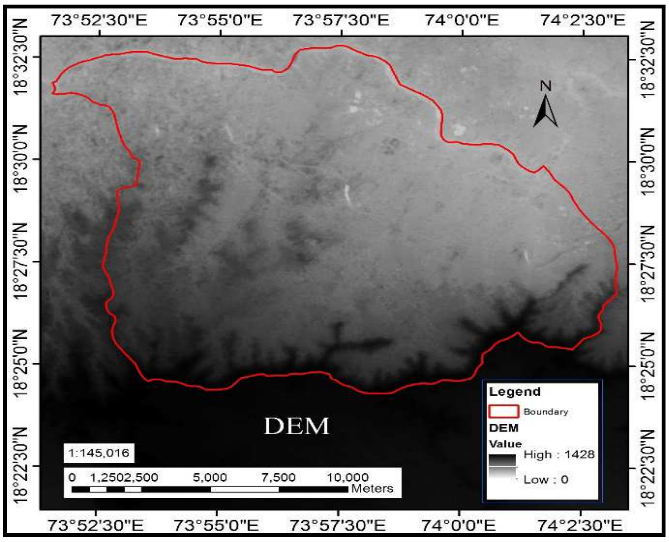

Figure 4: DEM Data Map

Slope

For estimation of slope percentage, DEM map is used in scale of 1:145000. 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, strong and steep Figure 5.

Soil

According to the data we get to know that the study area has three types of soils i.e. alluvium, regur and mountain from north to south respectively Figure 6. Alluvium is very suitable than regur as the infiltration rate of the alluvium soil is more that the other two. On the other hand, mountain soil's infiltration rate is very poor due to mountain and hard rock contents for that it is very poor for groundwater recharge.

Geomorphology

The Geomorphology map Figure 7 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

- **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.

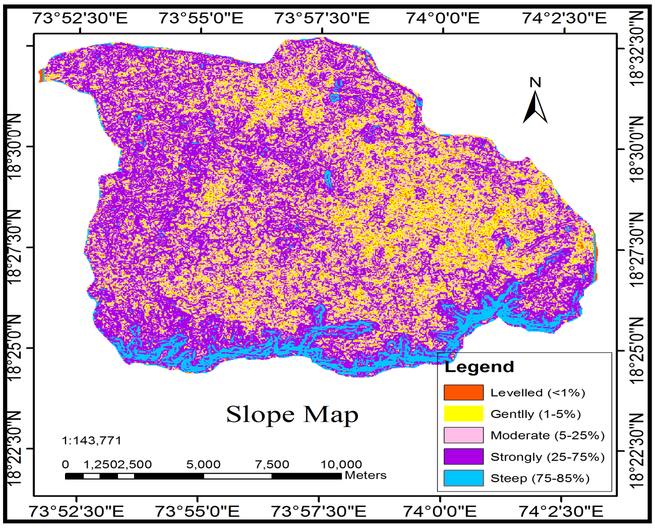

Figure 5: Percentage Slope Map

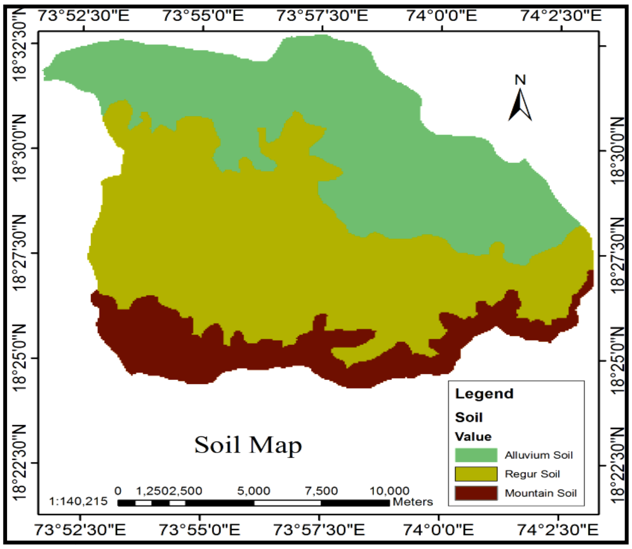

Figure 6: Soil Map with Types of Soil

- **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.

- **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 shows greenish red tone and regular texture in the satellite imagery. It is favourable for vegetation growth.

- **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 5 Km^2 Figure 8.

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 the plane land like agricultural land and the water bodies are most suitable for it. According to the suitability weightage are given to the various land used and covered portion and in GIS environment.

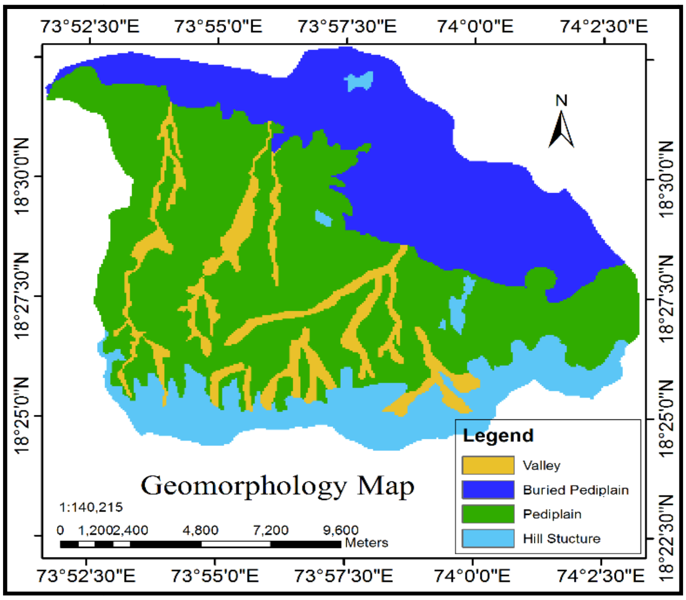

Figure 7: Geomorphology Map

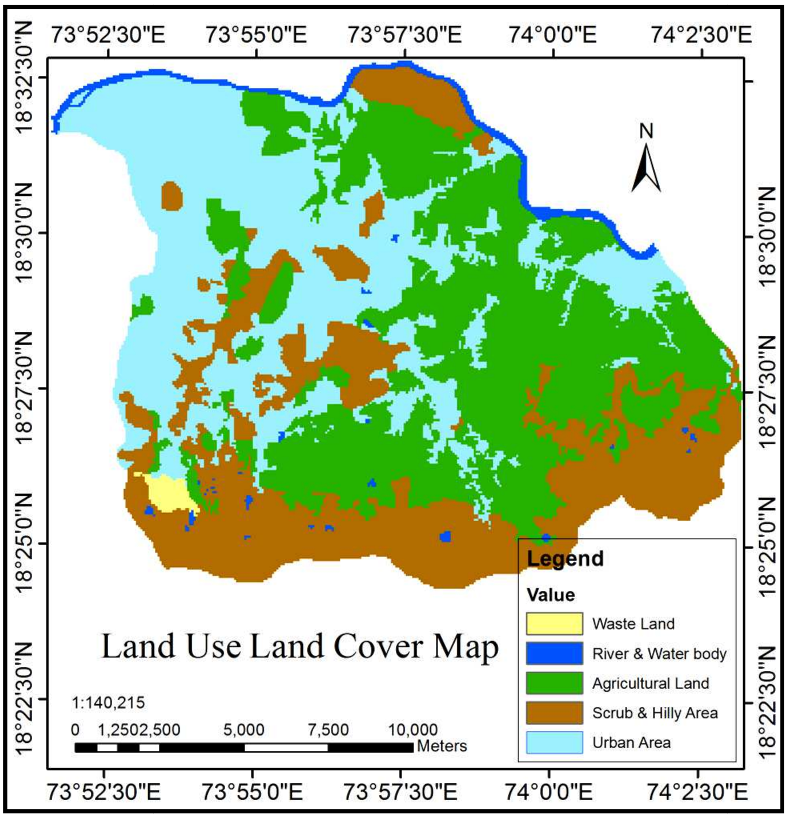

Figure 8: Land Use Land Cover (LuLc) Map

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 Figure 9a. 3rd and 4th order drainage lines carry more runoff water.

In Strahler's System (1952)

- The order of the stream is 1, if a stream has no contributing tributaries.
- 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+1 and if the streams of different order unite the new stream retains the order of the highest order stream Figure 9b.

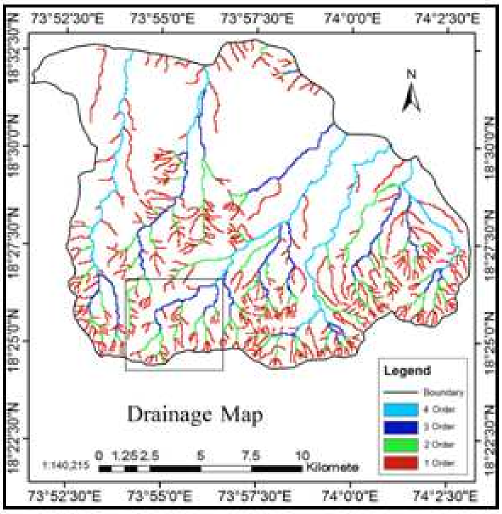

Figure 9a: Drainage Map

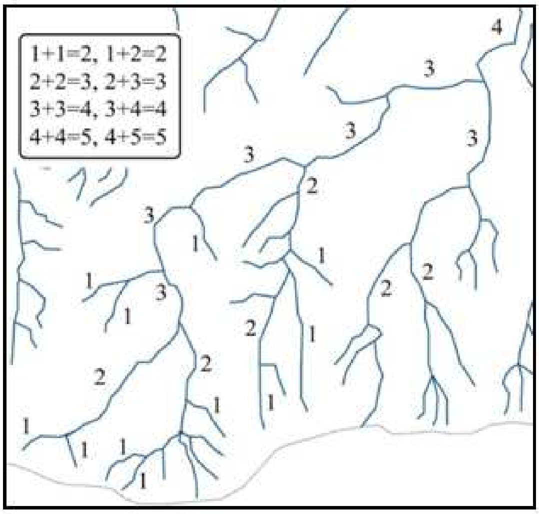

Figure 9b: Strahler's Ordering Scheme in Drainage

Result

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 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: Weighted Index of the Thematic Maps

Maps	Types	Classes	Weighted Value	Area (Km^2)	Area (%)
Slope (%)	Levelled (<1%)	Very suitable	1	95	43.18
	Gently (1-5%)	Suitable	2		
	Moderate (5-25%)	Good	3		
	Strongly (25-75%)	Moderately suitable	4	105	47.72
	Steep Slope (75-85%)	Unsuitable	4	20	9.1
Soil	Alluvium	Suitable	1	84	38.18
	Regur	Moderate	2	105	47.73
	Mountanian	Unsuitable	4	31	14.09
Geomorphology	Valley	Very Suitable	1	20	9.10
	Burried Pediplain	Suitable	2	62	28.16
	Pediplain	Moderate	3	107	48.64
	Structural Hill	Unsuitable	4	31	14.10
Land used Land cover	Water body	Very Suitable	1	6	2.73
	Agricultural land	Suitable	2	78	35.45
	Scrub and hilly land	Moderate	3	68	30.91
	Urban area	Unsuitable	4	66	30
	Waste land	Very poor	4	2	0.91

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. More water level difference means less infiltration and vice versa. From the data analysis we come to know that infiltration rate of Furusungi and the surrounding area have less infiltration capacity as the water level difference is much high than the other four places. So priority of AGR is less than the others. Kondhwa Khurd is very suitable for AGR as the water level difference of pre and post monsoon is less, so infiltration rate of this area is high.

Table 2: Water Level Fluctuation Data (2011-2013)

Village Well	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)	Depth of Well	Post Monsoon Depth (m)	Pre 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

Water Availability

Pune gets rainwater during the five months monsoon which is from Mid of June to October. Out of the 31 dams of Pune district, for 10 dams, (which are in south and south-western region of the study area) five years (*2008-2012*) average monthly 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. Mula-Mutha River is the only main river of the area. Water comes as runoff (average 4419.3 cusec per year) from the all 10 dams by various tributaries.

Table 3: Avg Monthly Rainfall and Runoff Data (2008-2012)

Name of the Dam	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)	Avg Rainfall (mm)	Avg Runoff (Cusec)
Kasarsai	18.618	73.664	961.2	6428.4
Mulshi	18.526	73.511	2837.2	66229.6
Temghar	18.453	73.541	2927.4	15204.2
Varasgaon	18.387	73.613	2062.2	35612.4
Panshet	18.378	73.613	2278.6	44703.8
Khadakwasla	18.442	73.767	786	276601.6
Nira Devdhar	18.108	73. 723	2091	40101
Bhatghar	18.175	73. 871	2226.4	40013.2
Veer	18.123	74. 096	1234.4	41721.6
Nazare	18.303	74.188	632.8	337734.2

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, nalla bunding, 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. The groundwater recharge zone using weightage index is prepared that is Table 1. This table helps for required map preparation. In the Arc GIS version10.1 environments 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. In the final map Figure 10 the yellow portion have weighted value 1 and which is highly suitable for groundwater recharge and it is 9.1% of total area under study Table 4. The dark blue portion (14.1%) is very poor for AGR as the infiltration rate is very low due to hard rock and mountain soil contents. The slope of the hill is very strep for that precipitated rain water flow at high velocity. Due to high velocity infiltration rate decreases which effects in AGR. River is very suitable as water is available throughout the year as runoff by the drainage channels.

Artificial 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.

Table 4: Final Map Data

Classes	Weighted Value	Area (Km^2)	Area (%)
Highly Suitable	1	20	9.1
Moderately Suitable	2	169	76.8
Poorly Suitable	3	31	14.1

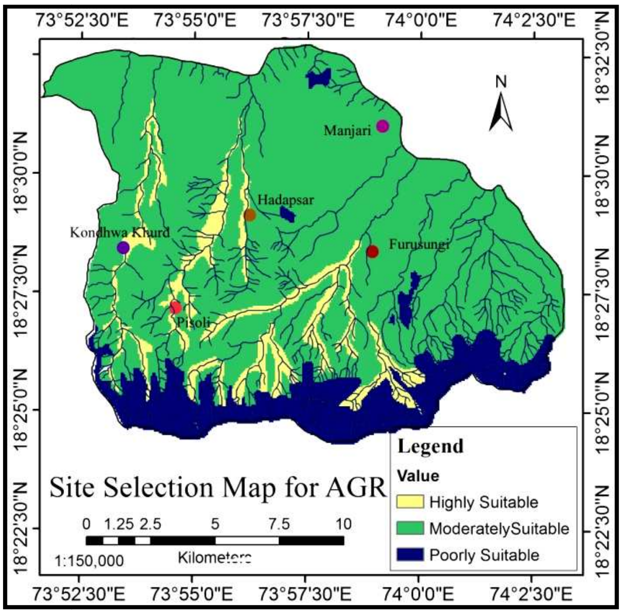

Figure 10: Final Site Selection Map

CONCLUSIONS

Five check dams are already present in this river outside the research area but no such check dam is present in the current study area. So for that studies are being carried out with the satellite image and various parameters like rainfall, runoff, slope, soil, geomorphology the suitable site for recharge to maintain the ground water level also for storage the usable water of agricultural work. Rain water is only source of water in Pune district. For this, there are 31 dams already present to store the rain water which can be used during the rest of the dry months after monsoon. Hence, this research work is more important. In the final study area map near about 23% area is most suitable in where runoff water come into that filed by various drainage line from the hill and mixed into the main rive Mula-Mutha. Natural groundwater recharge is done in catchment area by the precipitation in the monsoon time but the rate is very low and most of the water immediately dispatched over the drainage according to slope and evaporated and evapo transpirated by sun and crops respectively to overcome that, recharge structure is required to reduce the water loss and water can be stored and water levelled is maintained by artificial recharge. Groundwater recharge also depend upon some more physical parameters also like water holding capacity, Potential evapotranspiration and field capacity of soils. The conventional practice in water harvesting takes into consideration with the availability of land, soil structure for capacity of groundwater, potential groundwater zone investigation and the area benefited. The current multiparametric approach using GIS and remote sensing is holistic in nature and will minimize the time and cost especially of identifying suitable site-specific recharge structures on a regional as well as local scale, thus enabling quick decision-making for water management. The weighted algebraic product operator would be an appropriate combination operator, because at each location the combined weighted membership values tend to be very small with this operator, due to the effect of multiplying several numbers less than one.

ACKNOWLEDGEMENTS

Authors would like to acknowledge the Civil Engineering Department of College of Engineering, Pune (CoEP) for giving us the opportunity to carry out this study. Authors wish to thank Dr. S. S. Bhosale, Head, Civil Engineering Department, CoEP for his support and encouragement. Authors are grateful to Mr. Shivaji Patil for shearing soil and geomorphology data.

REFERENCES

1. **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.
2. **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.
3. **Bonham-Carter, G.F.**: Geographic Information Systems for Geosciences, Modeling With GIS. Computer Methods in the Geosciences Vol. 13, Pergamon, Love Printing Service Ltd., 1996; 398.
4. **Elbeih S:** Impact of Groundwater Recharge on the Surrounding Environment, PhD Thesis, Faculty of Engineering- Ain Shams University, Egypt, 2007.
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 30, 2007; 364–374.
6. **Gale, M.I.:** 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.
7. **Kannan S and Dr. 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.
8. **Karanth K R:** Groundwater assessment, development and management, Tata Mcgraw Hill, New Delhi, 1987.
9. **Muralidharan D and Athavale R N:** Artificial-recharge in India. Rajiv Gandhi National drinking water mission, NGRI, Hyderabad, 1998.
10. **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.

11. **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.

12. **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.

13. **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.

14. **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

15. **Sivakumar V, Khare M, Subramanian SK and 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, March, 2013; 203-216.

16. **Sooraj Kannan, and Dr. 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.

17. **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.