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Identification of groundwater recharge zones and rainwater harvesting sites using geoinformatics:A case study of Karwan watershed in Sagar district of Madhya Pradesh

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Abstract: The primary objective of the study is the optimum management of water resources for drought proofing area on long-term basis through multi-thematic information derived from remote sensing data. An attempt is made to suggest an action plan for sustainable development of the rain harvesting site using Geographic Information System (GIS) and remote sensing techniques. For that purpose, IRS P6 (LISS III) imagery has been used for the preparation of different thematic layers. The geomorphic unit such as lineaments, fractures and pediplain have been identified under structural landforms. The results are validated against existing data on hydrologic networks, reservoir capacities and runoff. Predictions of sites with very good to good recharge prospects rain water storage correlate well with the locations of existing regional dams and farm tanks. Based on the results from testing and validation, it is pointed out that the study can be used to identify potential sites for rain water harvesting and artificial recharge zones in Karwan watershed.

Keyword: Remote sensing, Geographic Information System (GIS), Ground water recharge zone, Artificial recharge

1. Introduction

The assessment of quality and quantity of groundwater is essential for the optimum utilization of the water resource. The occurrence and movement of groundwater in an area is governed by several factors such as topography, lithology, geological structures, secondary porosity, soil, drainage pattern, landforms, land-use/land-cover, climatic conditions and interrelationship between these factor. The interpretation of satellite data in conjunction with sufficient ground truth information makes it possible to identify and outline various features such as geological structure, geomorphic features and their hydraulic characters, that may serve as direct or indirect indicators of the presence of groundwater. However, the quality and quantity of groundwater is controlled by the interaction of topographical and geological features. Moreover, groundwater distribution is not uniform and is subject to wide spatial-temporal variations, depending on the underlying rock formation and structure. Therefore, a detailed hydrogeomorphological mapping is required for identification of groundwater prospect zones and artificial recharge sites. It is obvious that groundwater cannot be seen directly from remotely sensed data; hence, its presence must be inferred from identification of surface features, which act as an indicator of groundwater. Since delineation of groundwater prospect zone and identification of artificial recharge sites are based on the combined role being played by various factors therefore it is necessary to use remote sensing and Geographical Information System (GIS) for better analysis. The present study is an attempt to delineate groundwater prospect zone and identification of artificial recharge sites in Karawan watershed, Sagar district, Madhya Pradesh using remote sensing and GIS.

2. Study area

The watershed area of Karawan river is 275.61 km^2 and is located between 23°44’45”N to 23°58’30”N latitude and 78°35’45”E to 78°46’15”E longitudes. The Karawan river originates from the south-west part of the Sagar town. Location map of the study area is given in fig. 1. The Karawan river is 32.5 km long. The Karawan river flows toward to northeast and meets the river Dhasan near Mehar village in Sagar district. Dhasan river is an important right bank tributary of the Yamuna river. The study area is covered by the Survey of India (SOI) toposheets No. 55I/9, 55I/10 and 55I/13. (Scale-1:50,000)

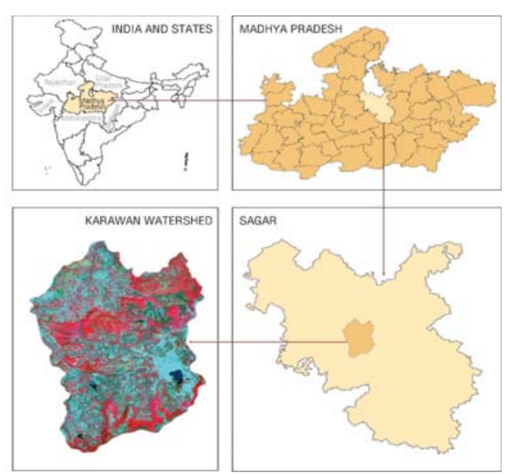

Figure 1: Location map of Karawan watershed

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3. Data and methodology

The primary data has been derived from IRS-P6 (LISS III) satellite images with 23.5m resolution for year 2011 and 2012 (kharif and rabi season) are used for analysis of land cover /use, geomorphology, drainage density, lineament etc. ASTER DEM data are used for slope analysis. Secondary data are collected from Geological Survey of India are modified and used for analysis of lithology. GPS is used during ground truth and for locating rain harvesting sites. The prime objective of the study is to evaluate the surface and subsurface water potential of the region. The methodology adopted in this study is presented schematically in figure 2 and described in the following steps:-

- The various thematic maps such as base map, geology, geomorphology, soil, land-use/cover, lineament, drainage and slope have been generated through conventional field methods using the SOI toposheets and IRS-P6 (LISS-III) imagery and digital data.
- The thematic maps have been converted into the vector format using digitization in Arc-GIS10 and ERDAS software.
- The weightage and ranks have been assigned to the themes and units depending upon their influence over recharge.
- Overlay technique of GIS has been used for assessment of artificial recharge zone and ground water potential zones. It also helpful for demarcation the sites for artificial ground water recharge.

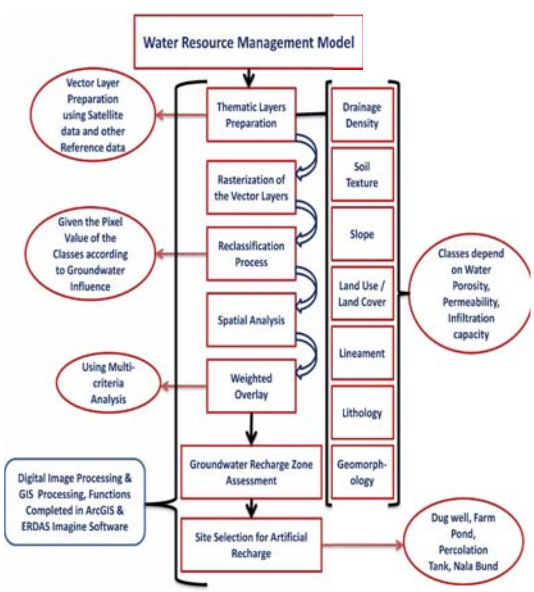

Figure 2: Conceptual model

3.1 Weighted assignment

A number that tells importance a variable for a particular calculation is the weight. The larger the weight assigned, the more influencial is the variable. The outcome of the equation, called the weighted assignment. Weighted assignment has been done on Arc-GIS10 software. A probability weightage approach has been applied during overlay analysis in Arc-GIS environment. The total influence for all raster's is equal to 100 percent. Each feature of a particular theme is ranked on the scale of 1-9 in ascending order according to hydrogeological and hydrogeomorphological significance. The Ground Water Recharge Index (**GWRI**) for an integrated layer is calculated using the following formula;

$$\mathbf{GWRI} = \sum (w*r) / \sum W$$

where, the index 'w' represents the weight of a theme and 'r' the rank of a feature in the theme.

The maps of these parameters have been assigned respective theme weight and their class weights. The individual theme weight has been multiplied by its respective class weight and then all the raster thematic layers have been aggregated in a linear combination equation in Arc Map GIS Raster Calculator module as given here;

$$\mathbf{GWRI} = (L_W*L_r + Gw*G_r + LT_W*LT_r + E_W*E_r + S_W*S_r + DD_W*DD_r + LL_W*LL_r) / \sum W$$

where, the subscript 'w' represents the weight of a theme and 'r' the rank of a feature in the theme.

The final cummulative map is generated by applying the above equation and is shown in fig. 3. The tool has been used for suitability modelling (to locate suitable areas), higher values indicate that a location is more suitable and the vice-versa. This tool has been used to assess groundwater recharge zones. Here, high values indicate higher groundwater recharge potential.

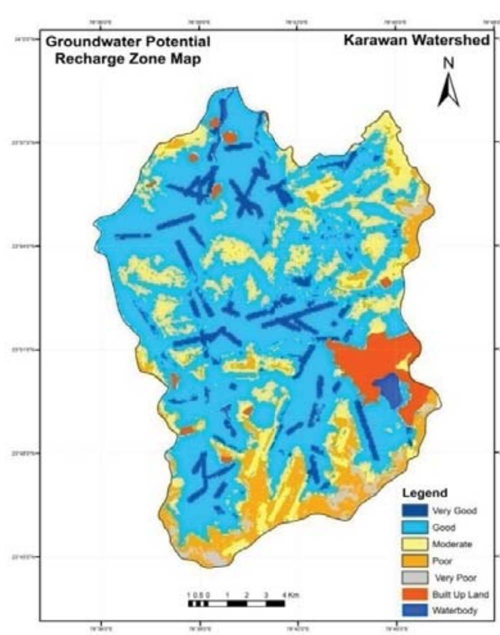

Figure 3: Groundwater recharge zones

4. Results

4.1Thematic layers

4.1.1 Lithology: The general lithology of the area has been mapped by the GSI (Geological Survey of India) which describe geological aspects of the study area. It is mainly composed of compact basalt situated on southern part of the watershed area, vesicular basalt, sandstone, shale have relatively no water potential because of their massive nature and insignificant primary porosity.

4.1.2 Geomorphology: Geomorphological mapping involves the identification and characterization of various landforms and structural features. Many of these features are favourable for the occurrence of groundwater and it is classified in terms of groundwater potentiality. Major geomorphological units found in the study area are structural hill, denudetional hill, residual hill, pediment and pediplain/buried pediplain.

4.1.3 Lineament: Lineament is defined as topography of the underlying linear structural features. Lineaments provide the pathways for ground water movement and are hydro geologically very important. The lineaments intersection is considered as good ground water potential zones. Numerous lineaments have been mapped. The lineaments are trending in the direction of NNW- SSW, NNE SSW and NE-SW direction and the length of the lineaments varying from few km to several km. The lineament present in the hard rock region is very significant for ground water occurrence. In the present study area, it is a function of a fracture - induced secondary permeability and hydraulic conductivity. Maximum lineament in Karawan watershed is along with streams.

4.1.4 Slope: Slope data are generated from the ASTER DEM grid corresponding to the boundary of the watershed. The slope assignment corresponds to the maximum change in elevation 25 between a cell and its eight neighbours, i.e. the steepest downhill gradient for a grid cell on a raster surface. The slope is expressed in degrees ranging from 0 to 90 or percent slope (which is the rise divided by the run, multiplied by 100). In relation to groundwater flat areas where the slope amount is low are capable of holding rainfall water, which in turn facilitates infiltration, whereas in elevated area the slope amount is high, there will be high run-off and low infiltration.The slope (percentage) data is then classified into five categories.

4.1.5 Soil: The infiltration rate of the soil determines the type of structure to be located and the surface run-off potential also depends on the soil texture of the area (Jasrotia et al., 2009). Pore spaces represent the reservoir for holding water called permeability. The textural class of a soil is determined by the percentage of sand, silt and clay. Soil texture attributes were derived based on the dominant soil type map extracted from MPRA (Madhya Pradesh Resource Atlas). The soil class attributes are taken as fine, loamy skeletal, loamy, fine loamy-clayey and clayey skeletal.

4.1.6 Land use/land cover (LU / LC): LU / LC map was prepared using IRS-P6 (LISS III) data. LU / LC classes are classified by help of ERDAS Imagine-11 software. This study depicts that there are ten units of LU / LC patterns in the study area. These are barren rocky, built-up land, dense forest, double crop, fallow land, kharif crop, open uncultivated land, rabi crop, scrub forest and water body.

4.1.7 Drainage density: Drainage density is defined as the length of drainage per unit area. A high drainage density reflects a highly dissected drainage basin with a relatively rapid hydro-logic response to rainfall events, while a low drainage density means a poorly drained basin with a slow hydrologic response (Melton, 1957). The length of drainage streams was measured and divided by the total surface area of the basin.

4.2 Groundwater recharge zones

The potential zones for groundwater recharge zone exploration have been identified and delineated after integrating the information of geology, geomorphology and hydrology along the recharge condition of the study area. In Karwan watershed five groundwater recharge zones have been identified. These are as very good, good, moderate, poor and very poor. In each zone, the prospect of groundwater recharge zone has been described in relation to its geomorphology and hydrological characteristics. The important characteristics of each groundwater recharge prospect zone are –

- Very good groundwater recharge prospect zone:

Spatially, the very good categories are distributed along areas near to lineament and less drainage density. This is spread over 24.56 km^2 (8.9%) area.

- Good groundwater recharge prospect zones:

This zone is dominated by geomorphic units like pediment and buried pediplain. Spacially, it is developed under vesicular basalt with very gentle slope and cover nearly 147.17 km^2 (53.38%) area.

- Moderate groundwater recharge prospect zone:

This is mainly a pediment zone which occupies area about 50.42 km^2 (18.29%).

- Poor groundwater recharge prospect zone:

Pediments with compact basalt and area far from lineaments are grouped under poor groundwater prospect zone, cover about 29.40 km^2 (10.66%).

- Very poor groundwater recharge prospect zones:

The very poor categories of groundwater recharge zones are spatially distributed mainly along ridges where slope class is very high, the lithology is compact or massive and far from lineaments developed under Deccan basalt. Accordingly, these potential unites have been mapped as very poor groundwater recharge zone and cover an area about 7.58 km^2 (2.75%). Because of the above surface characteristics, these areas act mainly as runoff zone and are not suitable for groundwater infiltration and recharge (Fig. 4).

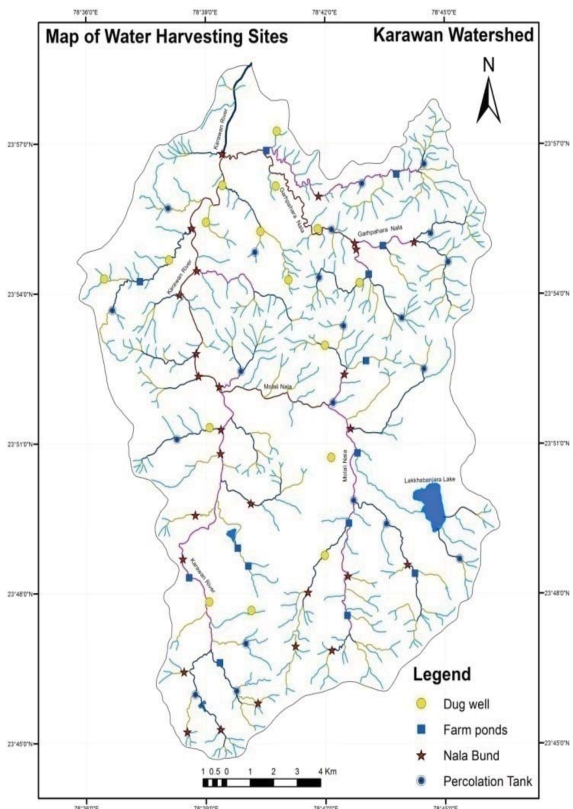

Figure 4: Water harvesting sites in Karwan watershed

4.3 Suitable sites for artificial recharge

For selection of artificial recharge site, the first task is to identify the factors facilitating recharge to take place (Saraf and Choudhury, 1998). The existing artificial recharge system in the area has been studied with respect to its hydrogeology and topography. An attempt has been made for selection of sites for artificial recharge by an integrated analysis through a combination of weighted indexing method in the GIS platform. To find out suitable sites for check dams, nala bunding, dug well, percolation tank, farm pond etc. the following criteria are used:

- **Site selection criteria for nala Bunds**

-The nala bunds should be preferably located in area where contour or graded bounding of lands have been carried out.
- Nala bunds can be constructed across bigger streams of second order in areas having gentle slopes.
- The rainfall in the catchments should be less than 1000 mm annually.
- The soil in downstream of the bund should not be prone to water logging.
- The rock strata exposed in the pond area should be adequately permeable to cause ground water recharge through pond water.

- **Site selection criteria for percolation tank**

- A tank could be located across small streams by creating low elevation.
- Terrain with highly fractured and weathered rock for speedy recharge.
- Rainfall pattern based on long-term evaluation is to be studied so that the percolation tank gets filled- up completely during the monsoon (preferably more than once).
- Soils in the catchment area should preferably be of light sandy kind to avoid silting up of the tank bed.
- The location of the tank should preferably be downstream of run-off zone or in the upper part of the transition zone, with a land slope gradient of 3 to 5%.

- **Site selection criteria for farm ponds**

- In relatively flatter terrain with good soil cover, a farm pond has an earth section with usually 3:1 side slopes on waterside and 2:1 side slopes on the downstream face.
- The drainage area above the pond should be large enough to fill the pond in 2 or 3 spells of good rainfall.
- The pond should be located where it could serve a major purpose: e.g. for irrigation, it should be above the irrigated fields and for sediment control it should intercept the flow from the most erodible parts of the catchment.
- Junction of two drainage channels or large natural depressions should be preferred.
- The land surface should not have excessive seepage losses unless it is meant to serve as a percolation tank for ground water recharge.

- **Site Selection criteria for dug well**

Where land use is crop land or fallow or waste land, slope category 0–3% and where minor lineaments intersect.

5. Conclusion

The above study has the suitability to identify potential sites for rain water harvesting and storage. Furthermore, it can easily update suitability levels and weighted score of decision criteria on which the potential sites for rain water harvesting and storage are based. In addition, the information on identifying potential sites for rain water harvesting and storage has been used for the development and operation of water management programs. The study region is having the contrast ratio of the irrigated land to the no irrigated land. The drainage system in Karwan watershed have dendrite pattern of streams. The basin has the number of suitable sites for percolation tank, Nala bunds construction, farm pond and dug wells which is much suitable for water harvesting. The middle part of the study region is more suitable for artificial recharge of water for ground water development. This study demonstrates the capabilities of using global data sets and Geographic Information Systems (GIS) in spatial-temporal analysis model.

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