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Remote sensing and GIS tool – An aid in site delineation for hydrological structure(s)

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Abstract: Water scarcity and its degrading quality is one of the prime global issues in the field of hydrological science. In this paper the integrated approach of GIS (Geographic Information System) and Remote Sensing is used to delineate suitable sites for recharge structures over an area ~ 200km^2 in order to replenish and sustain the groundwater aquifer. Further to validate the delineated sites, a sub-watershed basin of 2km^2 was selected for detailed recharge assessment and site feasibility studies through geophysical and tracer tests. Some of the sites selected for appropriate construction of recharge structures were investigated for site efficacy. The impact of the study over groundwater quality was astounding; overall groundwater fluoride concentration of > 3.5 mg/l was brought down to < 1.5 mg/l. Similar endemic hydrological problems can be resolved through proper understanding of site geomorphology/lithology and integrating the same with GIS and remote sensing.

Index Terms*:* GIS, Artificial Recharge, GIS, Remote Sening.

1. INTRODUCTION

In the past few decades, remote sensing has become a powerful source of spatial data as an input for GIS through which a detailed map can be generated. Remote sensing data outputs have been widely used in water resource management studies, especially in citing various artificial rainwater recharge structures through the preparation of thematic maps on the land use land cover, geomorphology, surface water bodies etc.

After setting up of the Rajiv Gandhi National Drinking Water Mission in 1986, there has been tremendous progress in rural water supply infrastructure. Still the goal to provide safe drinking water to all is still to be achieved (Sharma S.K., 2003). Groundwater with excess fluoride is a perennial problem in most of the semi-arid hard rock provinces of Indian sub-continent. Also mostly every remote rural area in India is dependent on groundwater source as potable drinking water supply.

Continuous decline of groundwater is another serious threat to the local population of the semiarid provinces of India. Andhra Pradesh, India in particular has more than 7000 habitations engulfed with high groundwater fluoride and the worst affected districts in the state are Nalgonda, Ananthapur, Guntur, Prakasam and Kurnool, where fluoride concentration in groundwater ranges between 2 to 11 ppm. (Rolland, 2012). In this paper the area of study is within Nalgonda district (Telangana State presently) where there are no fluoride based industries or active volcanoes and also the rain water analysis for fluoride has shown only a trace amount of 0.03mg/l (Rama Mohana Rao N.V. 1982). Occurrence of groundwater in crystalline rocks, especially alkaline granites (deficient in calcium) are susceptible to release of fluoride ion relatively more into the natural cycle (Pradeep Raj,2000).

In this manuscript the author tries to highlight the application of GIS and remote sensing, mainly to prepare different maps, which were used as an input parameter in AHP (Analytic Hierarchy Process) for delineating suitable sites for constructing artificial recharge structures like check dams and percolation ponds in the study area.II.

2. STUDY AREA

The study area is located in Nalgonda district of presently Telangana State, India with a spatial extent of ~200 km^2. It is situated at a distance of about 75 kms ESE of Hyderabad city.

The area under study forms the part of Krishna river catchment having an average elevation, ranging from 635m in the NW to 128m in the SE, depicting highly rugged terrain with hills and plains. The average annual rainfall in the area is approximately 500 mm.

The rocks in general belong to the Precambrian granite complexwith numerous fractures and joints. The study areacomprises a number of second and third order streams having a drainage pattern of the nature parallel to sub parallel in western part and sub-dendritic to dendritic in eastern part (Rolland Andrade, Ph.D Thesis, 2009).

The area comprises a number of lineaments and structures like dykes, trending NS and EW in direction inferred from satellite imageries and Aerial photos. The entire watershed has been sub-divided into 31 sub-watersheds based on DEM (Digital Elevation Model) analysis using Arc SWAT [**S**oil and Water Assessment **T**ool] in GIS. Several maps like lineament/drainage, soil-

Type, Land use land cover (LULC) and Elevation map of the watershed was deduced based on the integrated application of GIS and remote sensing data as shown in

Figure. 1. These maps were used as input parameter in AHP for identifying suitable recharge sites as explained under the methodology

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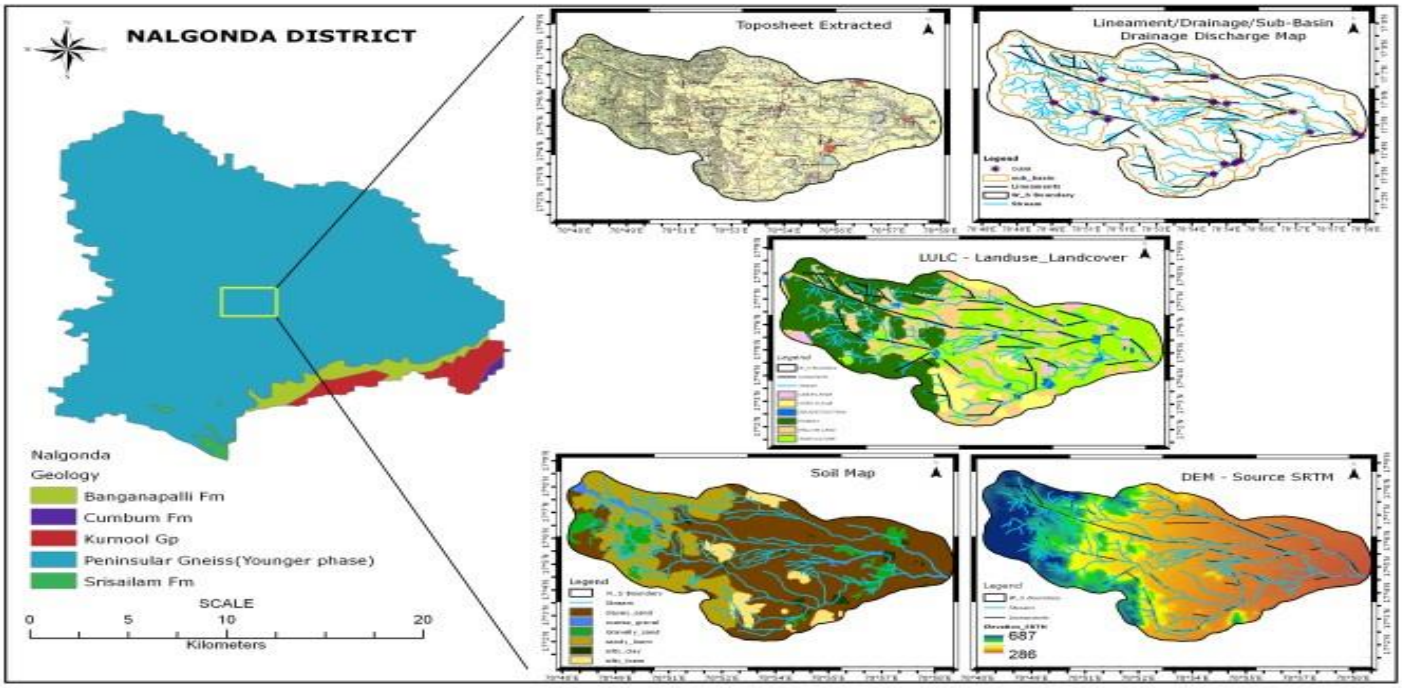

Fig. 1 Location of Watershed area with different physiographical parameters

Groundwater samples (hand pump and borewell) were collected and analyzed for Fluoride (mg/l), pH and conductivity (µmhos) from all the villages within the study area. It was very clear from the water sample analysis data that fluoride enrichment had taken place in the study area mainly due to over exploitation of groundwater for drinking and agriculture usage, followed by poor rainfall. Hence it resulted in lowering of water level and quality deterioration (enrichment of fluoride) in many province of the watershed area. The fluoride concentration in the watershed area is shown in figure.2.

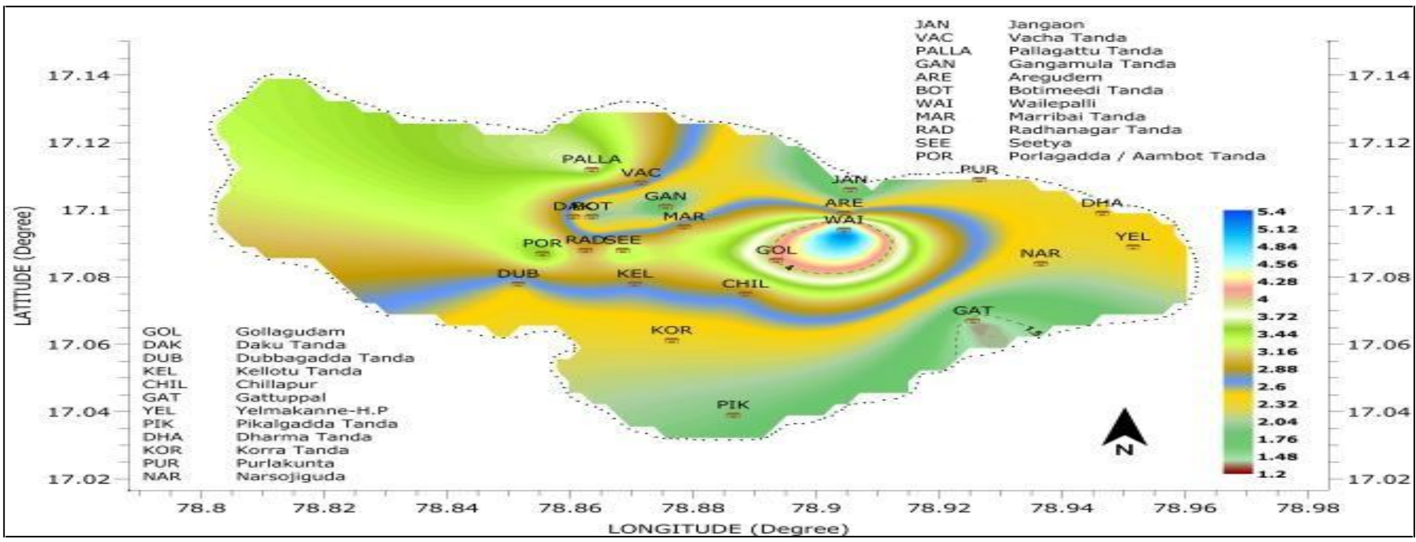

Fig. 2. Groundwater Fluoride scenario in the study area.

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3. METHODOLOGY

Computation of suitable site selection for water harvesting structures*:*

Satellite imageries of LANDSAT-7, ETM with the file name ELP143R048_7T20011022 Path – 143 Row – 48, geo referenced TOPOSHEET (SOI) 56K/16 and SRTM (http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp) for 90m spatial resolution were used to extract the area encompassing the entire watershed basin (Rolland, 2012). Soil map and LULC (Land Use Land Cover) map was prepared in ERDAS software, wherein supervised classification method was adopted and later imported to Arc GIS for calculation of HSG (Hydrological Soil Group) as per SCS curve method (Chow et.al, 2002) depicted in equation 1 and 2 is shown as individual map in Figure.1.

$$CN_{(I)} = \frac{4.2 * CN_{(II)}}{10 - (0.058 * CN_{(II)})} \quad \text{.........................(1)}$$

$$CN_{(III)} = \frac{23 * CN_{(II)}}{10 + (0.13 * CN_{(II)})} \quad \text{.........................(2)}$$

Where CN *(II) is* the curve number for normal condition, *CN (I)* is the curve number for dry condition, and *CN (III)* is the curve number for wet condition. The Soil Conservation Service (SCS) model developed by United States Department of Agriculture (USDA) computes direct surface runoff through an empirical equation that requires the rainfall and a watershed coefficient as inputs. The watershed coefficient is called the curve number (CN), which represents the runoff potential of the land cover soil complex.

Using Arc-SWAT tool, the entire watershed area was classified into different sub-watershed. Rainfall data for five Successive years 2002 to 2006 was analyzed and the discharge calculation for individual sub-watershed basins was done using the formula as mentioned in equation (3) And (4).

$$Q = (P - I_a)^2 / (P - I_a + S) \quad \text{............... (3)}$$

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad P \geq 0.2S \quad \text{............................... (4)}$$

Where Q implies surface runoff, P is the precipitation (rainfall), I_a is initial abstraction and S is the saturation index.**A**nalytic **H**ierarchy **P**rocess AHP (decision making method) was adopted for the calculation of suitable site delineation for recharge structures using the specification as given by Rama krishnan et.al, (2008). Depending upon the geomorphology of the study area, individual rank and overall weightage in percentage was assigned to three major parameters namely slope (53.09%), soil type (HSG) (29.21%) and LULC (Land use Land cover) (17.70%) respectively. Further these parameters were subdivided into sub-categories with individual weightage.

Using raster calculator in GIS, site suitable maps pertaining to the above mentioned criteria and weightage were prepared. The probable sites selected for engineering (artificial recharge) structures viz. Percolation Tank and check dam based on the suitable criteria was found to be sparsely distributed all over the entire watershed area. In order to delineate most suitable site among the probable locations, drainage and lineament map were taken under consideration. As mentioned earlier the area comprises second order streams controlled by lineaments. Applying appropriate query in raster calculator in GIS, most suitable sites were marked, which resulted in 8 check dams and 9 percolation pond sites falling along the stream course as shown in figure.3.

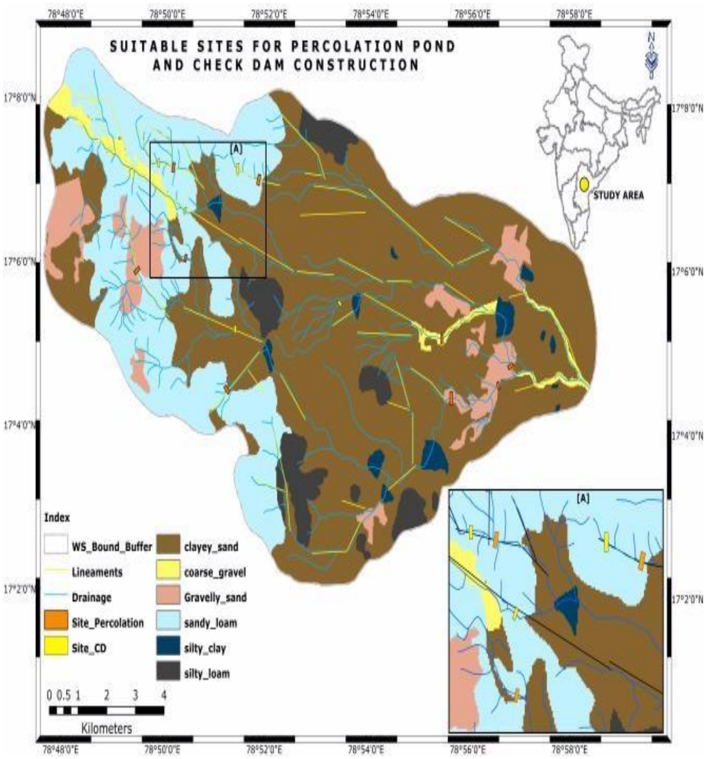

Fig. 3. Site delineation using GIS and AHP; Inset [A]sites delineated in*Pallagattu Tanda*.

4. RESULTS AND DISCUSSION

Site suitability studies*:*

Sites selected for artificial recharge structures based on AHP and GIS integration, were subjected for validation and their efficacy. A small area of 2 sqkm within the watershed was selected for executing different studies for validification. Conventional and resistivity imaging survey was carried out along the stream course at closer station and spatial interval in order to map the sub-surface geology of the area. Few shallow bore wells (25 – 30 mts) were drilled along the stream course recommended on the basis of resistivity survey results. The bore wells were cased using PVC (polymerizing vinyl chloride) pipes upto a depth of 6 m, in the weathered and semi-weathered zone to protect them from collapsing. Based on integrated result analysis of the geophysical studies, cadastral survey and drilling results, the subsurface lithological section corrected to mean sea level (M.S.L) along the stream course was mapped and showninfigure.4.

Also in order to decipher the aquifer continuity and estimate the groundwater flow velocity, dye tracer (color dye) was injected in one of the bore hole (OB-1) on the upstream near to the recommended check dam site and monitored in OB-2 located downstream near to the recommended percolation tank site. The movement of tracer between bore wells through the fractured granite is conceptualized as a model and is shown in inset [A] of figure.4.

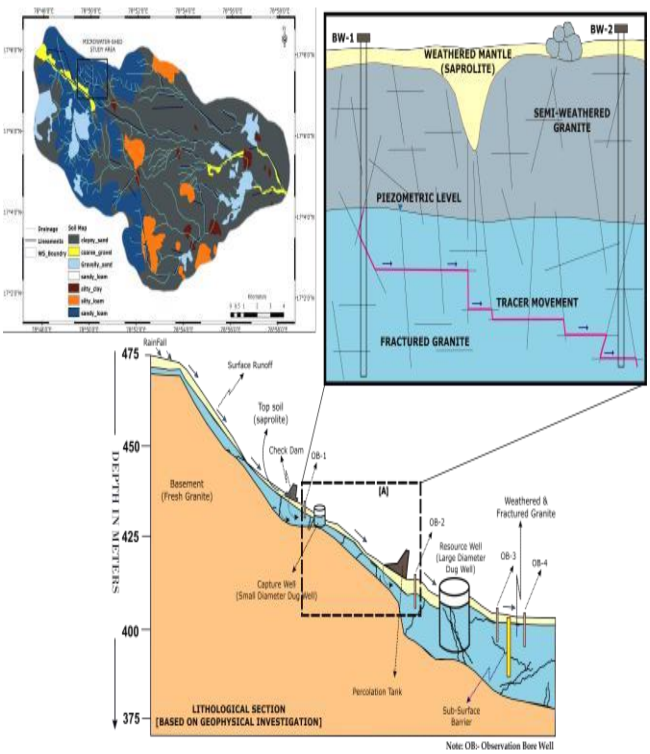

Fig.4. Geological section with recharge structures and conceptual model of tracer movement through fractures

Numerous other investigations like double ring infiltration test, water level monitoring, pumping test etc were carried out to at GIS recommended suitable sites for artificial recharge structures.
This detailed investigations carried over a small micro-watershed area was to validate the recharge sites (check dam and percolation tank) demarcated based on GIS and AHPMethod over an entire watershed near in Nalgonda district. Resistivity investigation showed that there is sufficient thickness of weathered formation below the proposed Structures to accommodate the impounding water. TheExistence of interconnectivity through the fractures in the aquifer was revealed through tracer test. Finally the infiltration test results and permeability measurements suffice that the sites proposed by remote sensing and GIS tool are suitable for engineering interventions.

5 .CONCLUSION

A set of specific criteria was involved to locate suitable sites for water harvesting structures like check dams and percolation ponds using the basin discharge calculation and spatial decision support system methodology. The sites delineated for check dam and percolation pond using the above methodology were reoccupied on ground for geophysical and tracer investigation to ascertain its site suitability in practice. Most of the sites investigated were feasible for construction of artificial recharge structures. After implementation of recharge structures, groundwater quality analysis was carried out with rainfall depicted the improvement in groundwater standards of the area. From the above results it was proved that the criteria chosen were comprehensive and sensitive. Application of GIS and AHP as a tool is very useful in integrating various information and deciphering suitable sites for recharge structures to harvest the rainwater and enhance the aquifer performance.

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