GIS BASED PRIORITIZATION OF ARTIFICIAL RECHARGE ZONE

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ABSTRACT

Artificial recharge is the process by which infiltration of the surface water into the groundwater storage is enhanced by artificial mean. In the present study open source GIS software has been used for identification of suitable artificial recharge zones in Bina river watershed. The weighted index overlay model has been developed for selection of suitable zones for artificial recharge. Six themes namely, geology, soils, topography, soil erosion, groundwater fluctuation and water table rise due to rainfall have been considered. The prioritization map for taking up the artificial recharge activities in the watershed has been prepared and classified in different priority categories. About 10% of the total geographical area of the watershed has been identified as high to very high priority zones and 21% area with moderate priority for artificial recharge. It is also found that around 69 % of the total geographic area of the Bina river basin fall under low priority for artificial recharge.

1. INTRODUCTION

Artificial recharge of ground water basin may be defined as the augmentation of the natural infiltration of precipitation or surface water into underground formations by appropriate methods. A variety of methods have been developed, including water spreading, recharging through pits and wells, and pumping to induce recharge from surface water. Often groundwater is the only source of water in arid and semi-arid regions. Natural recharge to groundwater by rainfall is not significant especially in view of the fact that for most of the year the rainfall is relatively less as compared to the potential evaporation. During the days when the rainfall exceeds evaporation and the storm intensity is sufficient to cause surface runoff, the potential water for recharge moves to locations downstream where it either gets lost by evaporation or joins the sea.

1.1. Problem Identification

In Bina river basin, the ground water is the main source of water supply for villages, small industries and agricultural purposes. With the increase in population, urbanization, industrialization and need of more water for irrigation, the water demand is on a constantly increasing trend which has resulted in over pumpage of groundwater in the region. At many places in the basin the water table is declining regularly because of over pumpage of groundwater. In some areas, where underlying lithounits do not have sufficient porosity and permeability, the groundwater draft exceeds groundwater recharge hence; groundwater cannot suffice the requirement for agriculture or drinking water. This situation can be tackled by artificially recharging of groundwater using various recharging methods.

1.2. Literature Review

Bowen (1980) has reported that first infiltration basin for recharge was constructed at Goteborg, Sweden in 1897 and subsequently several basins were developed. In Germany, first artificial recharge units composed of sand filled infiltration canal and periodically flooded field has started operation. The first recharge tank in the Ruhr area in Germany was built in Essen-Steel in 1902. Shelef (1979) has reported that in Israel over 95 percent of the conventional surface and ground water resources are already in full utilization and hence artificial recharge of ground water by treated effluents acquires a special significance. Bear (1979) has reported that economy of artificial recharge by surface spreading techniques depends to a large extent upon the maintenance of high infiltration rates.

Pathak (1985) has reported that in India, the ground water resources are declining in certain places due to its overexploitation in uncontrolled manner. These places are mainly in the states of Gujarat, Tamilnadu, Maharashtra, Andhra Pradesh, Punjab, Rajasthan and Harayana. Studies have been taken up at these places by Central / State Govt. Organizations. A pilot project on artificial recharge in Mehsana area and coastal Saurashtra in Gujarat State started in April 1980. In the Ghaggar river basin in Harayana, artificial recharge studies were carried out during the period 1976-78. Lohani et al. (1985) summarised various developments in the field of artificial recharge of groundwater at national and international levels. Various artificial recharge methods have been discussed in detail with reference to their design criteria, application, economic feasibility etc.

Mishra et al. (1988) suggested the methods to assess the water recharged from a basin or through an injection well. The methods of assessment are based on monitoring of the water table rise consequent to recharge. Shobha Ram et al (1998) gave the reviewed summery of various development in the field of artificial recharge of groundwater at national and international levels. Saraf et al. (1998) used integrated remote sensing and GIS technique for groundwater exploration and identification of artificial recharge sites in Sironj area of Vidisha district of Madhya Pradesh. The study exhibits reservoir induced artificial groundwater recharge downstream of surface water reservoirs. Bhatacharya (2010) discussed various issues involved in the artificial recharge of groundwater in India. Spandre, has discussed about all aspects of artificial groundwater recharge in his volume. Thilagavathi et al. (2014) analyzed the percent contribution of rainfall in groundwater recharge during various monsoon periods of the year in Salem Chalk Hills area, Tamil Nadu, India.

1.3. Objective

In the present study open source GIS (ILWIS) software has been used for identification of suitable zones for artificial recharge in Bina river watershed. GIS provides efficient tool for data input, storage and retrieval of selected data for further processing. The software can analyze the retrieved data in order to generate desired information in specific form. A GIS based method is found to be very useful in suitability analysis for artificial recharge sites in the hard rock terrain.

2. STUDY AREA

Bina river is a major tributary of River Betwa in Bundelkhand region of Madhya Pradesh, which originate from Begumganj block of Raisen district and enters Sagar district at Rahatgarh block and traverse through Khurai and Bina tehsil before confluence with river Betwa near Basoda town in Vidisha district. Presently, domestic water supplies to Rahatgarh, Khurai and Bina town; railways requirement at Bina Railway Junction and industrial supplies for Bina Refinery and proposed JP power project is met from this river beside limited irrigation from the river by direct pumping. “Bina Complex- Irrigation and Multipurpose

Project" has been proposed. Under this project, four dams are proposed, the Madia dam and Chakarpur dam-cum-pickup weir on Bina river and one each on Dehra and Dhasan rivers, which are the tributaries of river Betwa. The Index map showing the Bina river watershed upto the confluence with Betwa river is shown in Fig.1. The watershed under consideration falls between 23º18' to 24º15' N latitudes and 78º03' to 78º32' E longitudes having total geographical area of 2817 sq.km. The southern part of the watershed is dominated with hills and undulating topography with forest cover, whereas the northern part of the watershed has gentle slopping and plains with fertile agricultural lands.

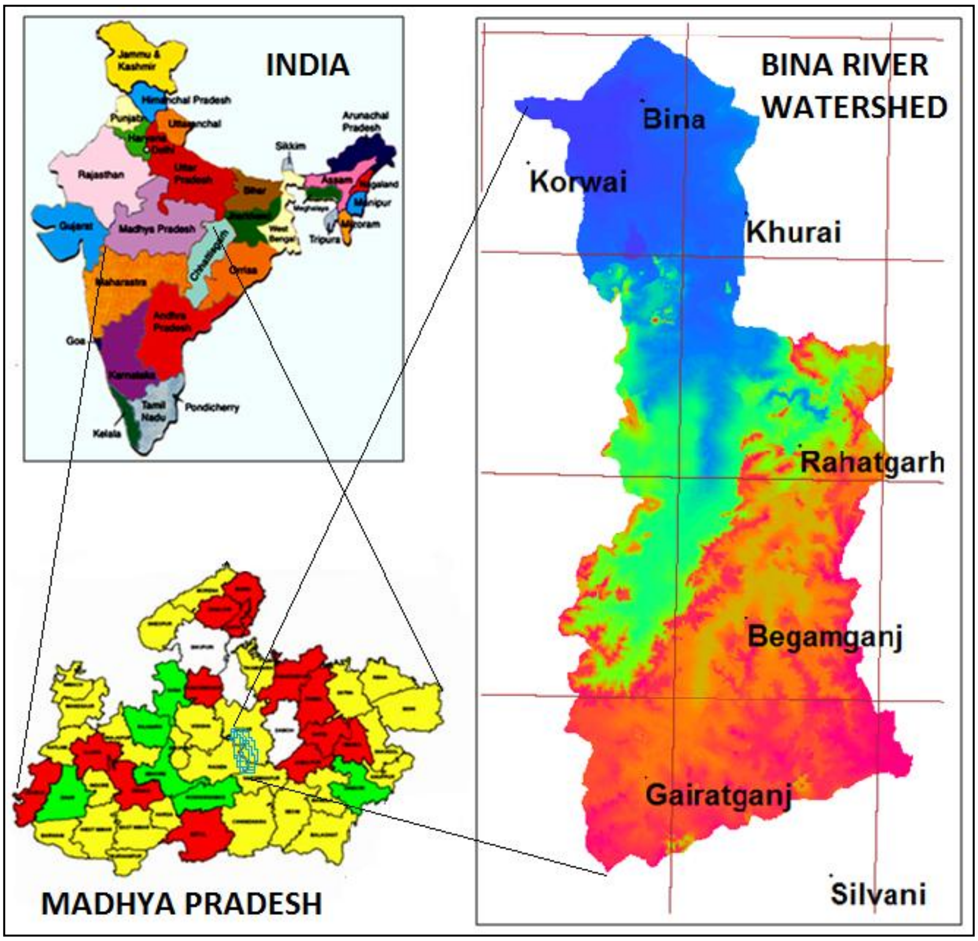

Figure 1: Index map showing Bina river watershed

2.1 Climate

The average normal annual rainfall of the area is 1329.56 mm and average 28 rainy days in a year. About 90% of the annual rainfall takes place during the southwest monsoon period i.e. June to October only 5.5% of annual rainfall takes place during winter and about 4.5% of rainfall occurs during the summer season. The maximum monthly rainfall occurs during the month of July followed by August. The climate of study area can be classified mainly into three seasons: Winter season starting from middle of November to end of February; March to May constitutes the summer season whereas the monsoon season starts from second week of June to end of September. During winter season the January is the coldest month with the average minimum temperature of 11.5˚C whereas the hottest month is May with average maximum temperature up to 40.9˚C.

2.2 Physiography

The study area falls under Bundelkhand plateau as per broad physiographical classification. The topography of the area is rolling to undulating. The land slope is characterized by flat topped hillocks. This topography is a result of the variation in hardness of different types of water flows. The valley land is moderately to poorly drain. The uplands having dendrite drainage pattern have limited natural drains and very low drainage density. The district has fairly extensive network of rivers which are mostly seasonal. Bundelkhand region has network of rivers like Dhasan, Bebas, Bina, Bamner and Sonar etc.

2.3 Geology

The study area falls under the Vindhyan region, important rock found namely in this area are sand stone, Quartizitic sand stone, lime stone and Deccan traps, called basalt. Basalt rocks overlie the Vindhyan sand stone. Lower Vindhyan is represented by quartizitic sand stone and shale where as upper Vindhyan consists of sand stone and shale with subordinate limestone. Lameta lime stone is also found in lower ridge area.

2.4 Soil and Crop

The major types of soils of the region are black, alluvial and red soils. Black soil is popularly called black cotton soil because of its chemical association and suitability for cotton. This clayey soil has a distinct chemical composition and very high moisture retentive capacity. On getting wet the soil becomes extremely sticky and expands greatly due to high absorption of water, on drying up the soil contracts again and develops cracks on the surface. However, it has very high fertility status. The main crop grown in Kharif season Soyabeen, Urad and paddy and main crop grown in Rabi season are wheat, red gram. Other staple crops like linseed, chickpeas, sorghum, oilseeds and grown are also grown in the study area.

3. METHODOLOGY

In the first step, analogue maps of Bina watershed, geology and soils were collected from different sources and converted into digital format by digitization. The digital maps thus generated were stored in raster format and are shown in Fig. 1, Fig. 2 and Fig. 3 respectively. In the second step, an elevation contour map has been digitized from SOI toposheets at 20 m counter intervals and interpolation of the contour map has led to the generation of a digital elevation model (DEM) in raster format. Finally, the classified slope map given in Fig. 4 has been generated. The groundwater data of 120 observation wells have been used for point interpolation using Krigging method to generate the groundwater fluctuation and water table rise maps. The pre monsoon ground water table data of the year 1995 and 2010 have been used to obtain water table fluctuation map as shown in Fig. 5. The pre and post monsoon ground water table data from the year 1995 to 2010 has been used to obtain water table rise due to rainfall in the basin. The average water table rise due to rainfall is shown in Fig. 6.

All the thematic maps have been geo-referenced with the base map generated from SOI toposheet at 1:50,000 scale. Appropriate weights were decided for each class on the basis of its relative importance, and the best suitable conditions have been derived. The weighted maps of all the six themes have been integrated and resultant image has been generated showing the suitable zones for artificial recharge in the Bina river basin.

4. DATA ANALYSIS

GIS is found very useful in suitability analysis for identification of artificial recharge zones in the area. Weighted overlay analysis is the simple method for a combined analysis of multi-class maps. The suitability analysis has been carried out using six thematic information layers namely geology, soils, topography, soil erosion, water table fluctuation and water table rise due to rainfall. In order to achieve better interpretability, the topographic map, water table fluctuation map and water table rise map has been classified into different classes depending upon their range. On the basis of relative importance of the individual classes within each parameter have been given appropriate weight such that the higher value indicates better groundwater prospect. Determination of weight for each class is the most crucial in integrated analysis, as the output is largely dependent on the assignment of appropriate weightages.

4.1 Geology

The alluvium deposits have been given the highest priority considering its primary porosity and permeability. Similarly Basaltic lava flows and Unclassified lava flows have been given higher priority due to their good water holding capacity. Granite and Sandstone are having secondary porosity and permeability, which makes them poor receptacles of groundwater hence are given less priority. The geology of Bina river basin is given at Fig.2.

4.2 Soils

The soils having more infiltration rate and permeability have been given more weight for recharge. Coarse and fine sandy loam types of soils due to their high infiltration rate and permeability provides favorable conditions for ground water recharge, hence such areas are considered most suitable for artificial recharge. On the other side the areas having clay type of soil are considered poor from ground water recharge point of view and hence are given less weight. Fig.3 shows the distribution of soils in the Bina watershed.

4.3 Topography

Gentle slope serves to build up the hydraulic gradient and are thus considered as the most suitable. The areas having higher slopes are considered unfavorable because these may not provide better recharge condition and such areas are generally having high surface runoff condition. The classified slope map of Bina river basin is shown at Fig.4.

4.4 Soil Erosion

The soil erosion map has been prepared using the most popular model, the Universal Soil Loss Equation (USLE) considering the six parameters, the rainfall erosivity index (R), the soil erodibility index (K), slope length factor (L), slope steepness factor (S), cropping factor (C), and management practices actor (P). The USLE model quantify the soil erosion in terms of tons/ha/year, which can be classified in different zones with soil erosion intensity varying from low to very severe. Fig.5 shows various categories of soil erosion in the study area. The severe erosion prone area have been assigned more weight than the low erosion prone area considering that the groundwater recharge will lead to rise in water table and increase the soil moisture content.

4.5 Water Table Fluctuation

The areas showing higher groundwater fluctuation over a period of time are given more priority to enhance the ground water potential of that area. Such areas of high fluctuation are given top priority because of existing favorable conditions. High groundwater fluctuation in that area may be due to some new demand generated, excessive irrigation or some other reason and that demand can be fulfilled by enhancing groundwater potential of that region using artificial recharge method. The areas showing less groundwater fluctuation are given less priority. The fluctuations in the groundwater table between the year 1995 and 2010 is shown at Fig.6.

4.6 Water Table Rise Due to Rainfall

Some areas of alluvium, sand stone and lameta types of geological formation having clay loam to gravelly sandy loam type of soil with gentle land slopes are showing good water table rise due to rainfall. These areas showing high degree of recharge potential and hence are given higher weights for delineating of artificial recharge zones and other areas are given weights accordingly. The average water table rise between premonsoon and postmonsoon periods is given at Fig.7.

The spatial distribution and weights assigned to each class of different parameters have been given in the following Table 1.

Table 1: Weights Assigned for Suitability Analysis

Sl. No.	Parameter	Class	Total Area Sq.Km.	% of Total Area	Weight assigned
1	Geology	Alluvium	93.47	3.33	5
		Basaltic Lava flow	1696.69	60.42	4
		Unclassified Lava flow	37.04	1.32	3
		Granite	951.85	33.90	2
		Upper and Lower Rewa Sandstone	29.03	1.03	1
2	Soils	Sand	24.02	0.86	5
		Loamy fine sand	389.43	13.87	5
		Coarse sandy loam	14.49	0.52	5
		Sandy loam	21.85	0.78	4
		Fine sandy loam	17.04	0.61	4
		Silty loam	366.02	13.03	4
		Sandy clay loam	395.43	14.08	3
		Silty clay loam	491.00	17.49	3
		Clay loam	291.89	10.39	2
		Silty clay	580.64	20.68	2
		Clay	216.27	7.70	1
3	Topography	0.0 - 2.0 %	2069.81	73.71	1
		2.0 - 5.0 %	481.01	17.13	2
		5.0 - 10.0 %	128.77	4.59	3
		10.0 - 20.0 %	86.89	3.09	4
		> 20.0 %	41.60	1.48	5

Table 1: Weights Assigned for Suitability Analysis (continue)

Sl. No.	Parameter	Class	Total Area Sq.Km.	% of Total Area	Weight assigned
4	Soil Erosion	Very Low (0 - 5 t/ha/yr)	2085.05	74.25	1
		Low (5 - 10)	325.02	11.57	1
		Moderate (10 - 20)	181.13	6.45	2
		High (20 - 40)	87.67	3.12	3
		Very High (40 - 80)	67.65	2.41	4
		Severe (80 - 140)	29.53	1.05	5
		Very Severe (> 140)	32.03	1.14	5
5	Water Table Fluctuation	> 1.0 m Fall	254.55	9.06	5
		0 m - 1.0 m Fall	1019.32	36.30	4
		0.0 m - 1.0 m Rise	1384.85	49.32	3
		1.0 m - 2.0 m Rise	139.29	4.96	2
		> 2.0 m Rise	10.07	0.36	1
6	Water Table Rise due to rainfall	1.0 m - 2.0 m	0.49	0.02	1
		2.0 m - 3.0 m	287.72	10.25	2
		3.0 m - 5.0 m	1727.00	61.50	3
		5.0 m - 7.5 m	752.64	26.80	4
		> 7.5 m	40.24	1.43	5

5. RESULTS AND DISCUSSION

All the six weighted thematic maps of information have been multiplied togather in GIS platform. The resultant raster map has been generated showing suitable zones for artificial recharge based on the weights assigned to each class of the six different themes as discussed in the previous section. The resultant map has been further classified into five categories namely, low, moderate, high, very high and extremely suitable zones as shown in Fig. 8. The geographical area under different priority zones is given in Table 2. From the resultant image it is observed that only 2.0 % of total geographical area has been identified as extremely suitable for artificial recharge, 2.88 % as very high and 4.91 % as highly suitable category. Remaining, 20.89 % as moderate and 69.32 % of the total geographical area was found least suitable for artificial recharge. The major part of most suitable area falls in undulating topography of hilly terrain in Gairatganj, Begumganj and Rahatgarh blocks of Raisen and Sagar districts. In these areas the method of contour bunding, contour trenching, check dam, percolation tanks etc. for artificial recharge of groundwater.

Table 2: Distribution of Suitable Zone for Groundwater Recharge

Sl. No.	Priority Class	Area in Sq.Km.	Percent of Total Area
1	Low	1946.68	69.32
2	Moderate	586.52	20.89
3	High	137.91	4.91
4	Very high	80.75	2.88
5	Extremely	56.23	2.00

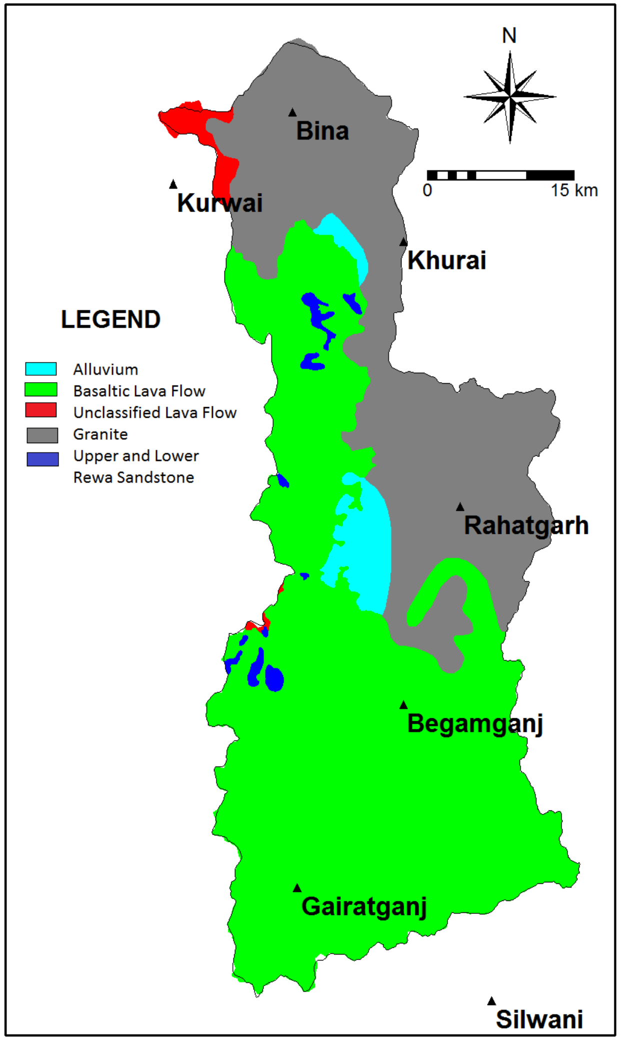

Fig. 2: Geology map of Bina river basin

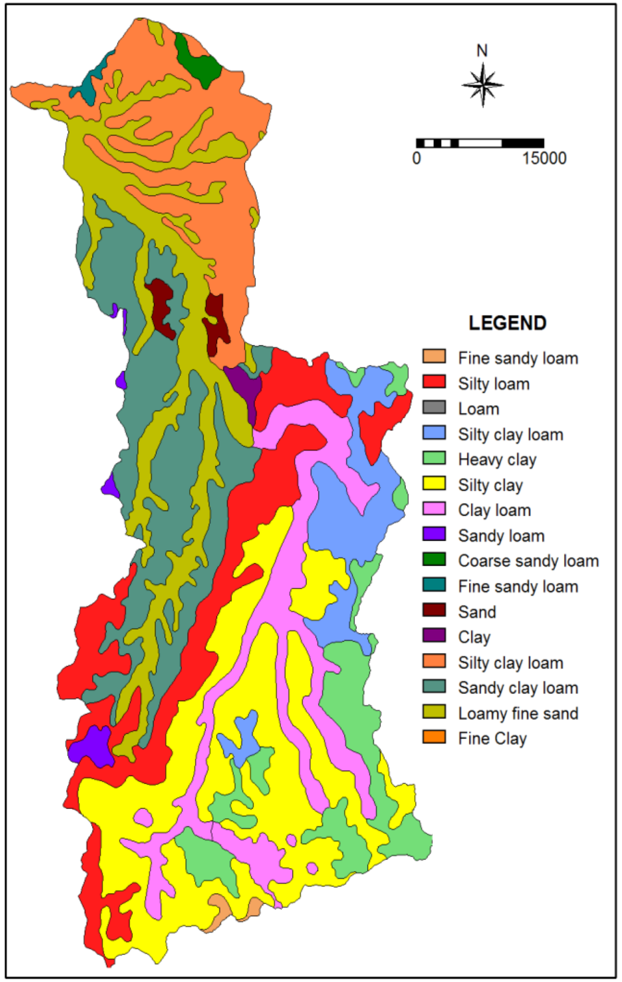

Fig. 3: Soil map of Bina river basin

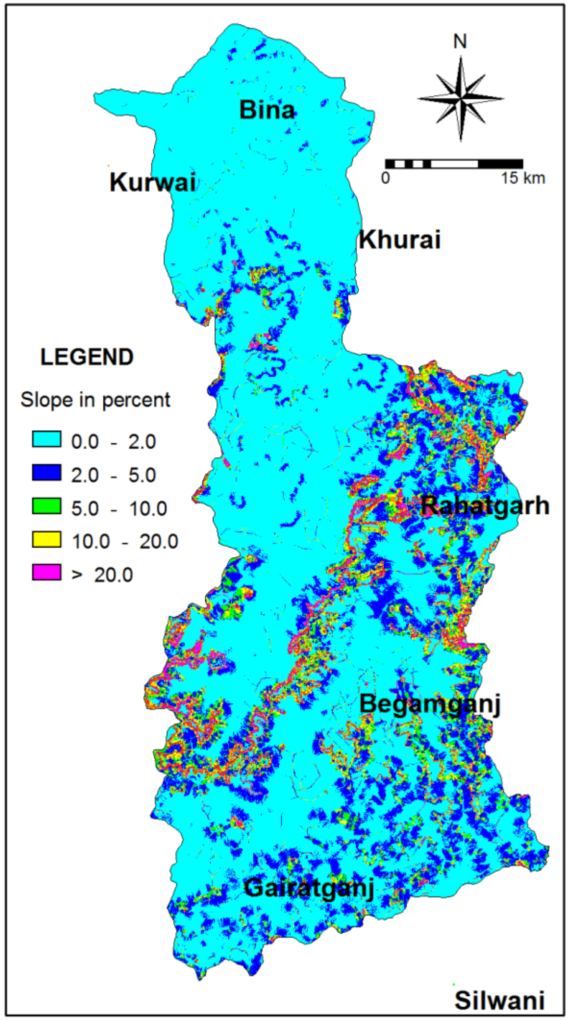

Fig. 4: Slope map of Bina river basin

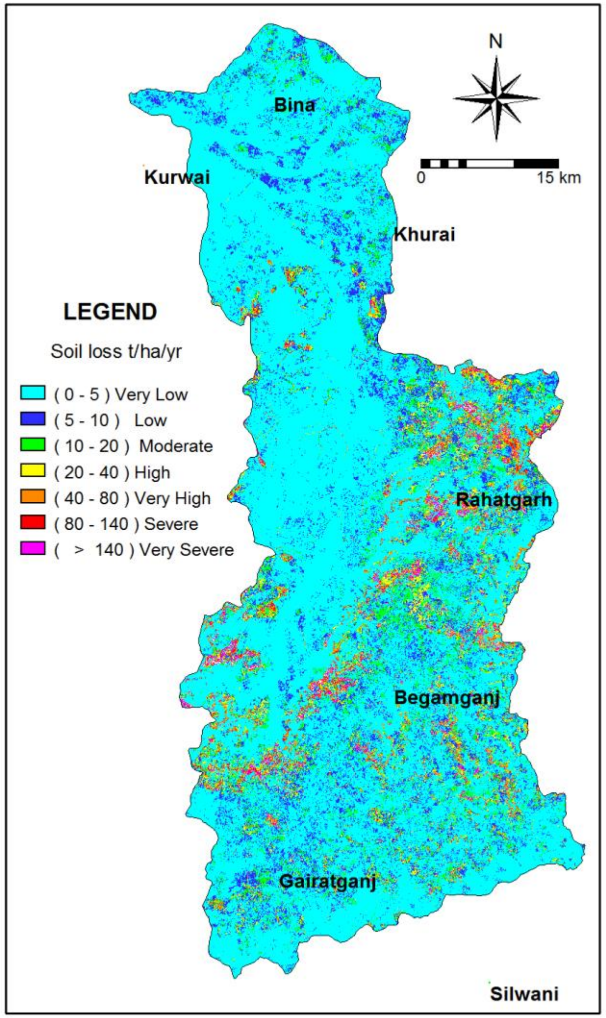

Fig. 5: Soil erosion map

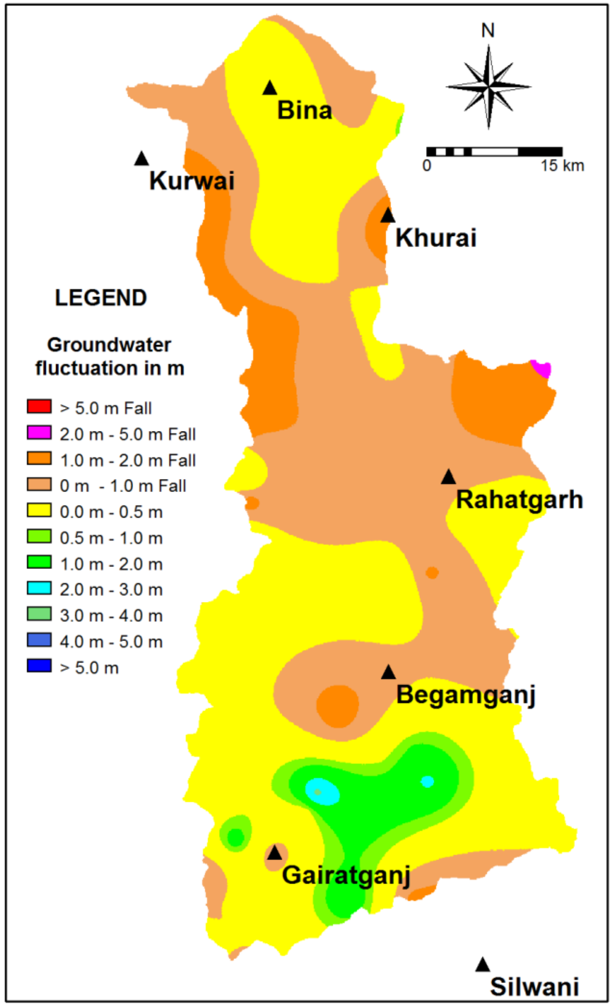

Fig. 6: GW Table fluctuation map

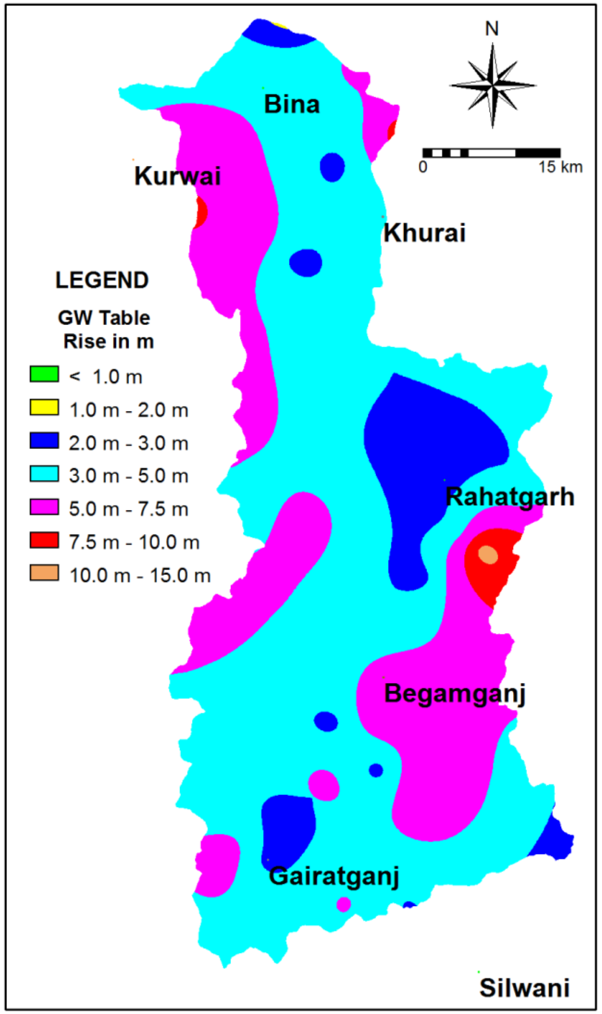

Fig. 7: GW Table rise map

6. CONCLUSIONS

Groundwater is a precious resource of limited extent in hard rock zones. Artificial recharge of groundwater is the effective water management technique, which enables to conserve water for further use. In this study open source GIS (ILWIS) has been used for suitability analysis of artificial recharge in Bina river basin. This study may be found helpful in planning of groundwater management projects in the study area, which will not only help in controlling the declining trend of groundwater but will also ensure its effective utilization.

In the Bina river basin about 27,500 hectare (10 % of the total geographic area) has been identified as most suitable for artificial recharge. As per the Govt. of India Integrated Watershed Mission Program (IWMP) norms, an amount of Rs.15,000/= per ha has been fixed for watershed development (soil and water conservation) activities. Thus, by investing an amount of about Rs.41.25 cr., the Bina river watershed may be developed to control the soil erosion, declining water table and fulfill the water requirements of more than 200 villages in the basin. Further more intensive studies may be carried out for developing specific methods of artificial recharge of groundwater in the area. Use of remote sensing data and consideration of water quality aspects would definitely improve the results.

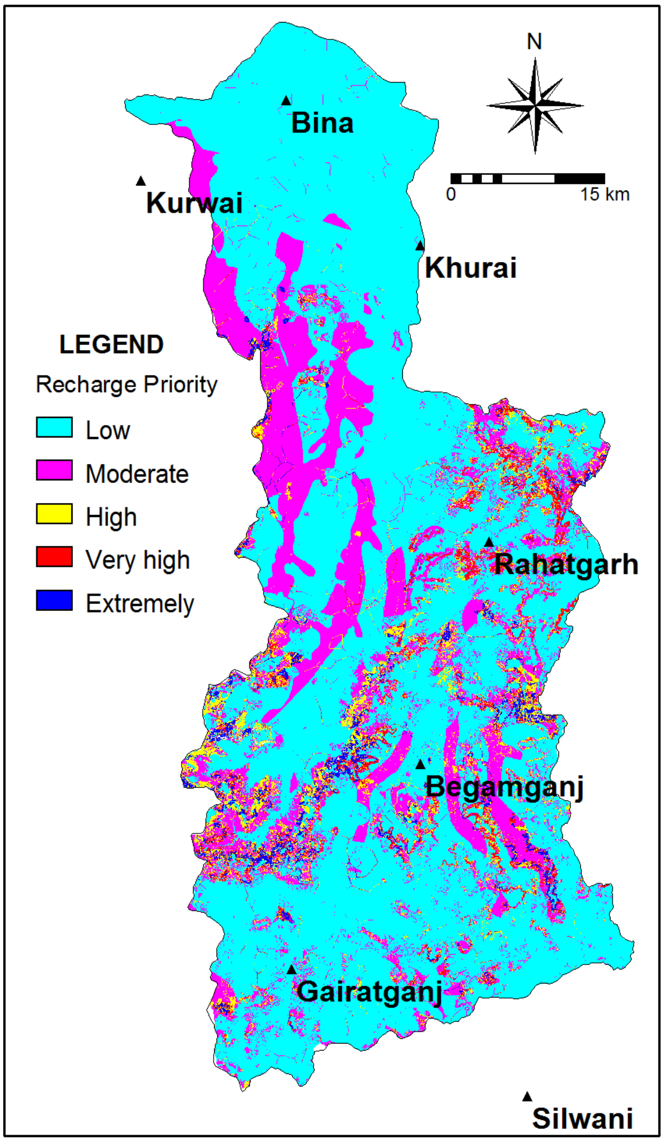

Fig. 8: Priority map for Groundwater Recharge

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