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Identification of potential locations for groundwater pumping and recharge to minimize the impact of floods and droughts in the Ganges basin

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Abstract: Floods and droughts are very frequent in the Ganges basin that flows across four countries namely Nepal, India, Bangladesh and Bhutan. In the monsoon season, floods are causing damage to huge property, agriculture and loss for many lives. On the other hand in the non-monsoon season, downstream areas mostly in Bangladesh and Indian territories are facing acute water shortage for agriculture and navigation. During the last four decades, many studies were conducted by various researchers to understand the impact of groundwater pumping and recharge on floods and droughts. The results indicated that creating subsurface storage during the non-monsoon season by extracting groundwater and storing flood water during the rainy season can reduce the impact of both floods and droughts in the basin. Identification of such locations is very critical and detailed information is not available. In the present study, attempts were made to identify potential locations in Ramganga sub-basin of the Ganges for pumping, recharge and both pumping-recharge by integrating pertinent hydrological and hydrogeological information using Arc GIS. The analysis results revealed that in the Ramganga sub-basin, 14,515 km^2 area is suitable for groundwater pumping in the non-monsoon with simultaneous recharge in monsoon and 8,419 km^2 area is highly potential for immediate groundwater recharge. The implementation of the technique can increase the basin ecosystem service by increasing groundwater availability and river flows while reducing impacts of floods and droughts with huge potential to implement elsewhere in the similar kind of river basins.

Key words: Ganges basin, Ramganga, recharge, floods, groundwater pumping, Arc GIS

1. INTRODUCTION

River Ganges and its tributaries formed a large flat and fertile lands in India and Bangladesh. It flows mainly through Nepal, India, Bangladesh and Tibet (China) that covers 1,086,000 km^2 (http://india-wris.nrsc.gov.in/). The lands are very fertile with abundant water resources and suitable climate that creates developed agriculture based civilization. On the other hand, monsoonal floods are causing loss of life, property, crops, infrastructure, etc. However, in the nonmonsoon season surface water flows are not sufficient to meet minimal water requirement for navigation and irrigation mostly in the downstream parts of Ganges those are Bangladesh and India between Haridwar and Allahabad during December to May. On an average Ganga basin receives 1 million cubic meters (MCM)/km^2. Of this, 30% is evaporation, 20% seepage to sub-surface and remaining 50% is available as surface runoff. In all tributaries of Ganges has flooding characteristics with 0.5-2 km width of river banks. This active flood plain floods every year (http://nmcg.nic.in /hydrology.aspx).

Therefore, Revelle and Lakshminarayana (1975) have suggested pumping groundwater near rivers in non-monsoon to create subsurface storage that can fill during monsoon by natural infiltration and river seepage. He also suggested that in the non-monsoon season the stored water can seep towards the rivers that can increase dry season flows. During last four decades, a lot of water resource development has taken place. Now the scenario has been changed and it is required to implement distributed recharge with pumping that can minimize the impact of floods (Surinaidu et al. 2016). In the present study, an effort has been made to identify the potential locations for recharge and groundwater pumping by considering high resolution hydrogeological data base for the Ramgana sub-basin basin that methodology can be up scaled to the basin scale.

2. GEOLOGY AND HYDROGEOLOGY

Ramganga is the first major tributary that joins the Ganges River, which is having a catchment area of 25,086 km^2 (Figure 1). The topographic elevation of the Ramganga sub-basin varies from 1,000 to 3,071 m above mean sea level (amsl) in the northern part. The river falls to an elevation less than 360 m amsl after entering the alluvial Ganga Plains. In the plains, the topography ranges from 360 m in Bijnor District to 124 m in Hardoi District in the south. The river flows through the states of Uttarakhand (formerly Uttaranchal) and Uttar Pradesh and has a total length of 595 km. (Water Resources Information System of India [http://www.india-wris.nrsc.gov.in]). The average annual rainfall from 1996 to 2010 in the Ramganga Sub-basin was 923 mm, with a minimum of 506 mm in 1997 to a maximum of 1,221 mm in 1998. The basin receives 90% of the rainfall during the monsoon period from July to September (Surinaidu et al. 2016).

The geology of Ramganga basin consists of a variety of lithologies such as inner lesser Himalaya comprises of bedrocks belonging Damtha and Tejam groups and Berinag Formation. The upper parts of the basin (Almora, Garhwal, and Nainital) is Crystallines defined by a variety of schists, micaceous quartzites and gneisses. The lower parts below foothills (Bijnor to Hardoi) filled by Holocene, Quaternary and the Precambrian age alluvium. The detailed geology of the Ramganga sub-basin has explained by Asthana et al. 2015. The subsurface lithology in the Ramganga was indicated clay with silt and sand on the surface and it is underlaid by sand with gravel and boulders with varying proportion (Surinaidu et al. 2016).

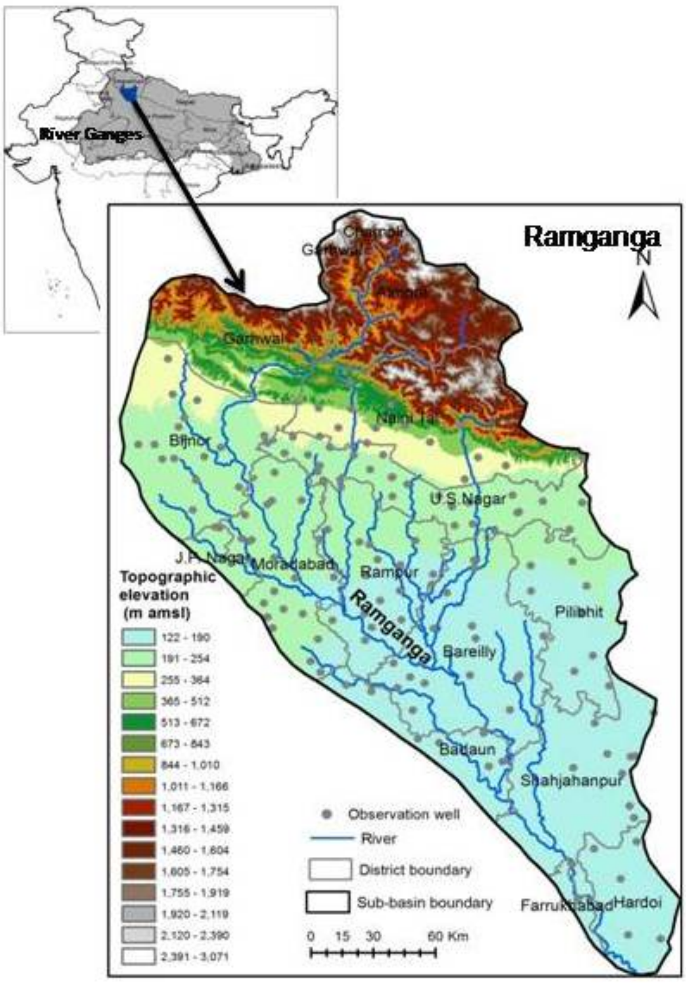

Figure 1. Location of the Ramganga sub-basin and streams with stream order

3. DATA AND METHODOLOGY

GIS techniques have been used by many researchers to identify potential groundwater zones in different river basins (Daiman and Gupta, 2015). The data has been collected from a different organization such as district groundwater boards and web based information. In the present study, integrated GIS technology has been used to generate various thematic maps viz., geology, lineaments, slope, drainage, land use-land cover, soils, annual rainfall and groundwater level. The maps were converted into raster format using the spatial analysis tools and then all thematic layers were reclassified (Figures 2 and 3). Subsequently, the weighted overlay analysis method was used to assign suitable weights (ranking system) on their hierarchy of importance and integrated all thematic layers in the process of identification of groundwater recharge areas, and to facilitate the demarcation of potential zones for groundwater recharge and groundwater pumping. The weights assigned to the different layers have considered, according to Raymond et al. (2009). The final product shows very poor to very good locations for groundwater recharge (Fig. 4). On the other hand, poor zones for groundwater recharge is highly potential for groundwater pumping.

4. RESULTS

The collected information has been analyzed and reclassified using Arc GIS. The weights and ranks have been assigned based on their importance for groundwater recharge. The following layers have been considered in the integrated analysis.

4.1 Land use and land cover

In the present area land use and the land cover map is extracted from IWMI global land use maps (http://waterdata.iwmi.org/Applications/GIAM2000/). The distribution of different land use patterns in the area is shown in Figure 2a. The major land use pattern in the Ramganga basin is agriculture lands followed by forest lands. In the analysis of recharge locations, urban lands and existing water bodies were given low priority and forest and agriculture lands were given high priority (Figure 2a and Table 1).

4.2 Soil Type

The Ramganga sub-basin is occupied by alluvial soils that can have good recharge and water retention capacity. Distribution of different soil types are presented in Figure 2b. Ustifluvents, typichaplaquepts and fluent soils are given greater priority for recharge and other soils less priority in the analysis.

4.3 Topography and Slope

Slope index was derived from the DEM (ASTER 30m resolution) to find the ratings for recharge, it was reclassified and given priority for more recharge for less slopes and less or nil priority for greater slopes. The spatially distributed slope map was presented in Figure 2c. The generated slope ranges from 1-2% in the plains and whereas in uplands it is >6% (Figure 2c and Table 1). Since there are no major variations in slope in the plains, the slope has been neglected in the analysis.

4.4 Rainfall

Rainfall is the principle source of all groundwater aquifers. Rain fall distribution is attempted by taking 12 stations data distributed across the area from 2000-2010. The average rainfall varies from 575 mm to >1400 m. The high rainfall high priority and low rainfall low priority was given in the area (Figure 2d and Table 1). However, rainfall recharge depends on several other factors such as topography and hydrogeological conditions.

Lineaments:

Lineaments are preferential pathways for infiltration and retention of more water. Hence, major lineaments are extracted from (http://www.india-wris.nrsc.gov.in) and prepared lineament density map. The high density facilitates more recharge and good potential for groundwater, so that, greater preference for high dense lineaments and low preference for low density lineaments. The spatially distributed lineament map is presented in (Figure 3a and Table 1).

Table 1. Range of different thematic layers and its ranking based on priority in the Ramganga R-Ranking

Drainage density ($/km^2$)		**Groundwater level in m (bgl)**		**Lineament $/Km^2$**		**LULC**		**Rainfall (mm)**		**Slope**	
Range	R	Range	R	Range	R	Range	R	Range	R	Range	R
0.0-0.2	9	2.13-3	1	0-0.01	1	Urban	0	575-600	2	0-1	6
0.2-0.4	8	3-4	2	0.01-0.03	2	Forest Evergreen	0	600-750	6	1-2	5
0.4-0.6	7	4-5	3	0.03-0.05	3	Forest Deciduous	1	750-900	7	2-3	4
0.6-0.8	6	5-6	4	0.05-0.1	4	Forest Mixed	1	900-1050	7	3-4	3
0.8-1	5	6-7	5	0.1-0.15	5	Pasture	7	1050-1200	8	4-6	2
1-1.2	4	7-8	6	0.15-0.25	6	Range Grasses	7	1200-1300	8	>6	1
1.2-1.4	3	8-10	7	0.25-0.35	7	Range Brush	7	1300-1400	8		
1.4-1.6	2	10-15	8	0.35-0.45	8	Water	0	>1400	9		
1.6-1.98	1	>15	9	0.45-0.7	9	Snow	0				
						Agricultural Land Generic	9				

4.5 Groundwater

In the groundwater analysis, observation records of 150 wells for 10 years (2000-2010) were considered. Then, the average pre-monsoon water level map is prepared. In the study area, groundwater level fluctuations are varying from <3 m to > 15 m in pre-monsoon. The greater groundwater depths have given high priority for groundwater recharge and whereas areas having less groundwater depths are considered for potential locations for groundwater pumping (Figure 3b and Table 1).

4.6 Geology

Geology plays a greater role in occurrence and movement of groundwater and recharge capacity with different well yields. Hence geology layer is integrated for identification of both pumping and managed aquifer recharge locations. The geology map indicated that the Ramganga sub-basin filled by alluvial sediments and the uplands are covered by crystalline rock formations (Figure 3c).

4.7 Drainage

The drainage of the study is derived from the analysis of ASTER 30 m resolution DEM data. The drainage density map was prepared using the spatial analysis tool in Arc GIS. The drainage density values thus obtained were reclassified to prepare a drainage density map of the study area. In general, drainage represents geological and lithological characteristics of the area, more drainage represents hard rocks and more runoff with poor recharge and low drainage density is good to recharge and low runoff. The high ranks for less drainage density and low ranks for high drainage density are considered in the study. The spatial distribution of drainage density map is presented in (Figure 3d and Table 1)

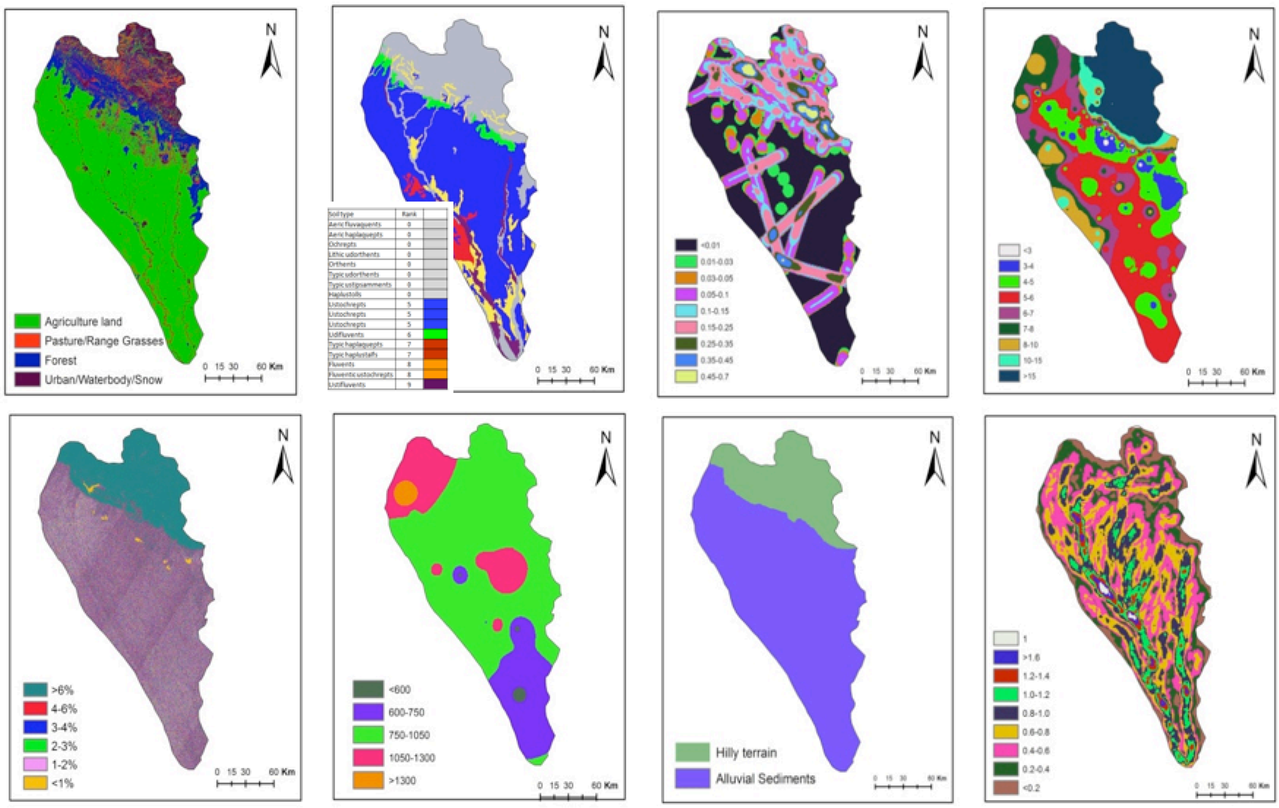

Figure 2. Reclassified thematic layers of Ramganga for identification of recharge and pumping

5. DISCUSSION

The potential unmet water demand in the Ramganga sub-basin is estimated under two scenarios by Amarasinghe et al. (2016). The first scenario assumed that irrigation will be provided to all irrigable area in the Rabi season (November to March) and hot-weather season (March to June). The second scenario assumes that irrigation will be provided to all cropped areas in the Rabi and hot-weather season. The estimated potential unmet demand under the two scenarios ranges from 2.5 to 3.3 Bm^3. However, due to water supply constraints, the potentially reliable unmet water demand in the Ramganga sub-basin is about 2.5 Bm^3. Muthawatte et al. (2015) have estimated runoff from the Ramganga sub-basin 10.1 Bm^3 (75% dependable flows), and approximately 83% of this runoff is occurring during the rainy season. It contributes to 7% of the total inflow from the upstream areas to the regularly flood-stricken Bihar, which is located in the middle part of the Gangas River Basin (Muthuwatta et al. 2015). However, to meet the maximum unmet agricultural water demand in the Ramganga sub-basin only require capturing 33% of the monsoon flows. Surinaidu et al. (2016) have suggested that 4 m subsurface storage could be created by pumping of 0.25 Bm^3/yr by the year 2020. If the flood waters stored in sub-surface that can minimize the flood impact on downstream and increase the dry season flows. The high hydraulic conductivities of aquifers in the Ganga basin can increase the base flows to the rivers in the dry season after storing the water in the monsoon. In order to store flood waters, there should be storage in the aquifers. For this, aquifer should be explored for groundwater pumping. However, in some places of the basin storage space is already available. Hence, identification of locations for both recharge and pumping is the trivial task.

The groundwater recharge depends on several factors such as soils, geology, hydrogeology and rainfall. It is essential to integrate all of these thematic layers to identify potential locations for both groundwater recharge and pumping. In the present study the integration of various thematic layers has been carried out using Arc GIS. The weights and ranks with a total score of each thematic layer are presented in Table 2. The slope will have great importance in groundwater recharge and hence highest weight 20 was given. But in the Ramganga slope variations in the plains are almost negligible that varies from 1-2% so that it has given low rank 1. Geology, groundwater depths, and rainfall are major driving factors in the basin for recharge, so that these layers are assigned highest weight of 15 then drainage density was given 10. The highest rank was given layers based on their importance for recharge viz., LULC, geology, groundwater levels, rainfall, soil, drainage density and lineament density.

The final integrated map for identifying recharge and pumping is obtained by multiplying of the ranks and weights of the layers then the summing of all pixel values of the different classes. The final product for identifying potential recharge and pumping locations are presented in Figure 4 which indicated that 7526.8 km^2 and 1192.7 km^2 area in the Ramganga is having good to very potential groundwater recharge. The recharge structures can be selected based on local hydrogeological conditions. However, the poor recharge areas mean the areas having shallow groundwater tables in the Ramganga and these locations can be potential zones for further groundwater pumping. In the Ramganga 1852 km^2 area is highly suitable for groundwater pumping. In addition 14515 km^2 area is also suitable for groundwater pumping but this needs to be filled up by means of artificial recharge during the monsoon season (Figure 4). The additional pumped out water can bring the additional area under irrigation or can increase the intensity of the irrigation. The subsurface storage can be filled with monsoon rains/flood water that minimizes floods in the downstream and increases water accessibility in the basin.

Table 2. Integration of different thematic layers and overall ranking and weight

Thematic layer	Weight	Rank	Total Score
LULC	15	9	135
Soil	5	5	25
Slope	20	1	1
Rainfall	15	7	105
Lineament density	5	2	10
Groundwater levels	15	8	120
Geology	15	9	135
Drainage density	10	4	40
Total	100		571

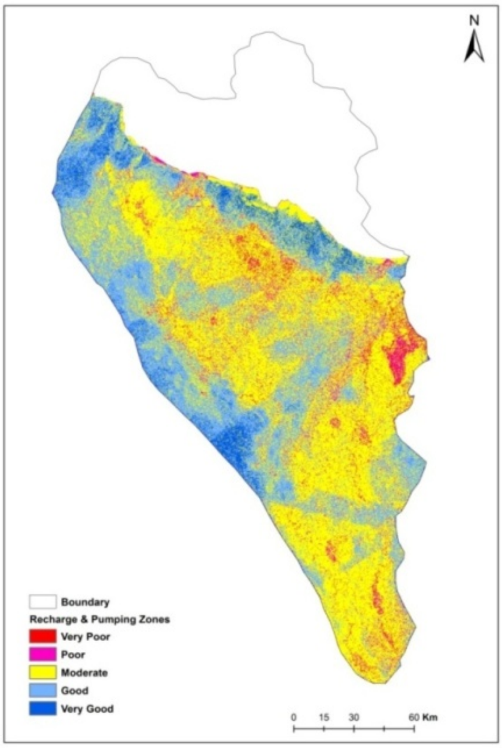

Figure 4. Hot spot locations for both pumping and recharge in the Ramganga (Very poor - 273.2 km^2, Poor-1579 km^2, Moderate -14515 km^2, Good - 7526.8 km^2, Very good - 1192.7 km^2)

Notes:

- Hilly portion was excluded in the analysis
  Immediate pumping can be implemented in very poor to poor regions that covers 1852 km^2
  Start with groundwater pumping than recharge in an area of 14515 km^2 (Moderate)
- Area should start with recharge first and highly potential for immediate recharge is 8719 km^2 (Good to very good)

6. CONCLUSIONS

The Ramganga sub-basin receives an average annual rainfall of 930 mm/year. The most upstream parts of the basin are highly elevated >2000 m amsl. The downstream areas are low elevated <190 m amsl and flat terrain. The Ramganga plains have very less slope with 1-2% with Gangetic alluvial deposits with a lot of scope for groundwater recharge. Most of the basin is covered by agricultural and then forest lands. The well managed conjunctive utilization of land and water resources can create ample scope for creating additional subsurface water storage that can bring additional land under irrigation. In the Ramganga basin, 1852 km^2 is available for additional groundwater pumping, in addition, 14,515 km^2 is also available for groundwater pumping but groundwater recharge should also be initiated after creating sub-subsurface storage by pumping. The groundwater recharge should be implemented and 8719 km^2 of land is highly potential for immediate groundwater recharge.

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