GROUNDWATER ASSESSMENT AND ANALYSIS USING GEO-SPATIAL TECHNIQUES

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Abstract : With the advent of information and technology and continuously increasing demand of groundwater, remote sensing and GIS techniques has been widely used over the conventional methods. This study has been undertaken for the assessment and analysis of groundwater using remote sensing and GIS techniques. In the present study, an attempt has been made for delineating groundwater potential zones and artificial recharge zones using remote sensing and GIS in the study area. These weights are applied in a linear combination to obtain five different groundwater potential zones, namely, 'poor', 'moderate', 'good', 'very good' and 'excellent'. The groundwater potential zone map was finally verified using the well yield data of 37 pumping wells, and the result was found satisfactory. Rainfall-runoff modeling has been done using SCS curve-number-runoff method. Finally, an attempt of fluoride concentration mapping has been also made. The results indicated that about 67% area is found to lie between suitable to most suitable for runoff storage to recharge the groundwater. The GIS based output maps could be used for water harvesting and conservation plans in the area.

Keywords: Groundwater, SCS curve-number-runoff method, Remote sensing, GIS

I. INTRODUCTION

Groundwater is one of the most valuable natural resources, which supports human health, economic development and ecological diversity. About 71% of Earth's surface is covered by water, out of which only 0.63% is groundwater. India is a large country which supports about 1/6th of the world's population, 1/50th of the world's land and 1/25th of world's water resources (Water management forum, 2003). Groundwater is an important fresh water resource that is held in aquifer. India now suffers severe water shortages in many of its states. It averages about 120cm/yr of precipitation, which is more than any other country of comparable size, but the rain is unevenly distributed (Kumar, 2005; Rodell, 2009).

Groundwater is an important source of irrigation, which caters to more than 45% of the total irrigation in the country. People's lives and livelihoods depend on water. Demand for clean water increases continuously with world population growth. Many areas of the world lack the fresh, drinkable water essential to survival of mankind (Anderson, 1992). It has now become evident in many countries of the world that groundwater is one of the most valuable natural resources, which supports human health, economic development and ecological diversity. According to the estimates adopted by NCIWRD (1999), by the year 2025, the population is expected to be 1,333 million in the high growth scenario and 1,286 million in the low growth scenario. For the year 2050, high rate of population growth is likely to result in about 1,581 million people, while the low growth projections place the number at nearly 1,346 million. Keeping in view the rapidly rising population and increasing agricultural, industrial and other requirements, the freshwater demand for 2025 would be 843 km^3 (high demand scenario) and 784 km^3 (low demand scenario). The requirement for 2050 would be 1180 km^3 (high demand scenario) and 973 km^3 (low demand scenario) (Remesan, 2008).

Rapid economic and social changes that are taking place throughout the world increase the demand of water. Growing pressure in many regions of the world, especially developing countries with arid and semi-arid climates, featuring dynamic population growth, the advent of water shortage has been heralded. Water use for irrigation and human activities in watersheds, such as deforestation, have resulted in substantial reductions in river flows and water shortages in urban areas, flow regimes, water level reductions of many lakes, and lowering of water tables. Decreasing water table and environmental pollution are critical problems in effective groundwater management. Groundwater become polluted or contaminated from leaky underground tanks that store gasoline, leaky landfills, or when too much fertilizer or pesticides are applied on the fields or lawns.

In recent years, the increasing threat to groundwater quality due to human activities has become a matter of great concern. The quality of groundwater depends on a large number of individual hydrological, physical, chemical and biological factors. Generally, higher proportions of dissolved constituents are found in groundwater than in surface water because of greater interaction of groundwater with various materials in geologic strata (CPCB, 2007).

Contamination of groundwater reduces the supply of safe drinking water which affects the public health. GIS which is a computer based system designed tool applied to geographical data for integration, collection, storing, retrieving, transforming and displaying spatial data, can be used for spatial representation of groundwater as associated parameters (Remesan, 2008).

II. STUDY AREA

Unnao district is a part of Central Ganga Plain in Uttar Pradesh, consisting of geographical area of 4558 km^2 which is about 0.1 % of total land in India. It lies between latitudes 26º06′ to 26º55′ North and longitudes 80º03′ to 81º03′ East (Figure 1). The maximum temperature is 45^0C in summer and minimum 3^0C in winter. The district receives a normal annual rainfall of 837.80 mm with rainy days experience sub-tropical climate. The district is mainly drained by perennial rivers Ganga and its tributaries Kalyani, Khar, Loni and Morahi in the western part and by Sai river in the eastern part. The district has 16 administrative blocks for which water quality data was collected.

The occurrence and movement of groundwater in the area is governed by several factors, such as topography, lithology, geomorphology, structure, land use and interrelationship between these factors (Jaiswal *et al.*, 2003). Geologically, the district forms a part of the vast Indo-Gangetic alluvial plain. The alluvium formation of the district comprises of sand, silt & clay with occasional gravel. The older alluvium called bhangar, forms slightly elevated terraces usually above the flood levels. The area is underlain by quaternary alluvium consisting of clays, occasional kankar, sand of various grades and gravels in different proportions.

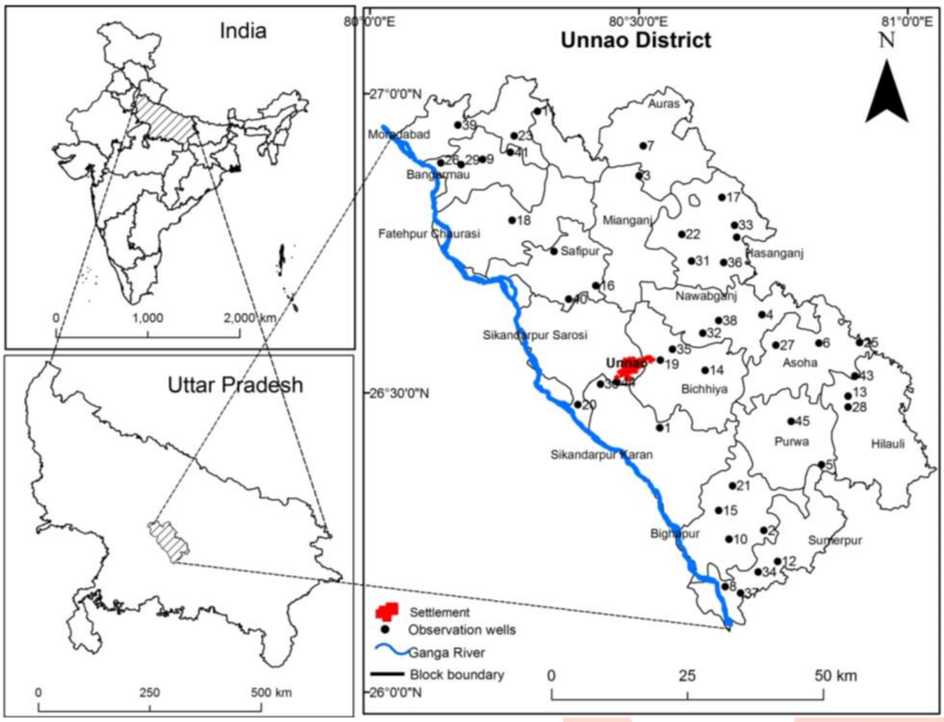

Figure 1. Location of Study Area

III. Utility Of Geo-Spatial Tools For Groundwater Assessment

Geo-spatial tools e.g. remote sensing and Geographical Information System (GIS) methods permit rapid and cost-effective natural resource survey and management. Moreover, remotely sensed data serve as vital tool in groundwater prospecting. Remote sensing data help in fairly accurate identification, delineation of land features and analysis of hydro-geomorphological features. With sufficient ground data, hydrological characteristics of geomorphological features can be deciphered using satellite images. Groundwater occurrence being subsurface phenomenon, its identification and location is based on indirect analysis of some directly observed terrain features, like geological and geomorphic features and their hydrologic characters. Satellite remote sensing provides an opportunity for better observations and more systematic analysis of various geomorphic units, lineament features, following the integration with the help of GIS to demarcate the groundwater potential zones.

With the advent of powerful and high speed computers, efficient techniques for ground water management have evolved, of which remote sensing & GIS are of great significant (Chowdhury et al., 2009). Integration of Remote Sensing & GIS has proven to be an efficient technique in groundwater studies (Krishnamurthy et al., 1996). GIS is a powerful set of tool for collecting, storing, retrieving, managing and displaying spatial data into simplified form. Remote sensing data, which offer synoptic view of large area, help in understanding and mapping the lineaments both at regional and local scale. The lineament analysis of the area from remotely sensed data provides important information on sub-surface fractures that may control the movement and storage of groundwater. The main advantages of using remote sensing techniques for groundwater exploration include; quick and economic way of getting information on the occurrence of groundwater, aids to select promising areas for further groundwater exploration thus reducing the field work, and provides information on recharge sites. GIS, which provides spatial data integration and tools for natural resource management, have enabled integrating the data in an environment which has proved to be an efficient and useful tool for groundwater studies. The efficiency of using GIS technology for different decision-making processes is that it is able to combine various spatial and non-spatial datasets (e.g., geochemical, geophysical, geological, remotely sensed imagery and other textual data) of different standards and uses integrated approaches for interpretation and analysis.

Remote sensing and GIS techniques are regarded as powerful tools for presentation and analysis of data and information. Remote sensing images provide important information related to the soil type, land use, orientation and intensity of fractures, identification of recharge and discharge areas, outcropping areas, coordinates of pumping and observation wells, and others. Depending on the soil texture, microwave images can also provide useful information about the subsurface formation. Topographic (contour) maps can thus be developed and exported directly as shape files or others to groundwater simulation packages. On the other hand, all data including remote sensing images can be organized and stored in different layers using GIS system. Contour maps for groundwater levels, aquifer bottom, and thicknesses of the different layers, hydraulic parameters (porosity, permeability, transmissivity, storativity, and others), water quality, and other types of analyses can be done effectively using GIS.

IV. Data And Methodology

The flowchart of the methodology is shown in Figure 2, while the data used is shown in Table 1. In order to demarcate the groundwater recharge zone in the study area, a multi-parametric dataset comprising satellite data and conventional maps including Survey of India (SOI) topographic sheets was used. All the 20 toposheets covering the study area were scanned, rectified and geometrically corrected. These images were then mosaicked to form a single image and transferred into Arc Info software to prepare layers, namely, drainage, settlement, canal etc., and further updated using satellite images. The thematic layers of geology, geomorphology and lineament were prepared from the existing maps. The soil layer was prepared by digitizing the soil map, and further categorized into hydrological soil group (HSG) on the basis of soil texture and soil properties. Slope map of the area is derived from the SRTM-DEM using in-built Inverse Distance Weighted (IDW) interpolation technique in ERDAS imagine software. Using Theissen polygon method, which divides the study area into four rainfall zones, developed thematic layer of rainfall. Groundwater quality map containing fluoride is prepared using IDW (Inverse Distance weighted) interpolation technique.

Table 1. Data Used

Data Type	Data	Data Source	Scale
Toposheets	54M/16, 63A/4, 8, 63B/1, 2, 5, 6, 7, 9, 10,11,12,15,16 & 63F/3	Survey of India	1:50,000
Satellite images	Landsat ETM+ (2006) SRTM (Elevation data)	GLCF GLCF	30m Pixel Size 90m Pixel Size
Thematic maps	Geology & Geomorphology Soil map	GSI (Kolkata) NBSS-LUP Nagpur	1:2,50,000 1:10,00,000
Field data	Rainfall data Groundwater quality data	IMD Pune UPPCB, Jal Nigam	

All the above layers were spatially organized in the GIS environment with the same resolution and coordinate system. The checking of these spatial maps was done with respect to other database layers by the overlaying technique, and refined mutually as part of standardization of the database. The errors due to digitization and mis-mapping were removed in this process.

4.1. Geology

Geologically, the area has been divided into various classes i.e., Channel Alluvium, Terrance Alluvium, Lacustrine Deposits and Varanasi Alluvium. Channel Alluvium is micaceous, fine to grained medium consists of gravel, loose sand, slit and clay and has better productivity due to presence of water in sand and gravel beds, so it is given higher weights in determining the groundwater potential.

4.2. Geomorphology

Geomorphology is one of the most important features in evaluating the groundwater potential and prospect, as it reflects various landform and structural features. The landform plays a vital role for the occurrence and distribution of groundwater. Four types of geomorphic units are identified in the study area. Active flood plain has higher water level surface, and hence it is the best landform for high groundwater potential.

4.3. Land use

Remote sensing data and techniques provide reliable, accurate baseline information for land use mapping and play vital role in determining land use pattern and changes therein. Landsat ETM+ image having 30m spatial resolution was classified using ERDAS Imagine digital image processing software. Initially, the satellite image was geo-referenced with the SOI toposheets with the help of identifiable features, such as crossing of roads, railways, canals, bridges, etc., on both the toposheets and satellite images. The Universal Traverse Mercator projection with the WGS 84 spheroid and datum was used. Efforts were made to ensure that the ground control points are uniformly distributed on the image. A second order polynomial model was used and due care was taken to keep the rms error (RMSE) less than a half pixel.

Various types of land use pattern are identified in the study area which includes vegetation, dry river, forest, land with scrubs, wasteland, water bodies and urban. Lands with vegetation are excellent sites for groundwater exploration, and hence given the highest rank. Forest and scrubs are considered to have good groundwater prospects, while the water bodies and road fall have poor groundwater potential.

4.4. Drainage density

Drainage pattern of any terrain reflects the characteristics of surface as well as subsurface formations. The drainage pattern, in general is sub-dendritic. Drainage density (expressed in terms of km/sq.km) indicates closeness of spacing of channels. More the drainage density, higher would be runoff. Thus, the drainage density characterizes the runoff in the area or in other words, the quantum of rainwater that could have infiltrated. Hence lesser the drainage density, higher is the probability of recharge or potential groundwater zone. Drainage density is an inverse function of permeability, and therefore it is an important parameter in evaluating the groundwater zones. Unnao district is mainly drained by Ganga and their tributaries Kalyani, Morahi & Loni and Sai river. High drainage density values are favorable for runoff, and hence indicates low groundwater potential zone. High ranks are assigning to low drainage density area and vice versa.

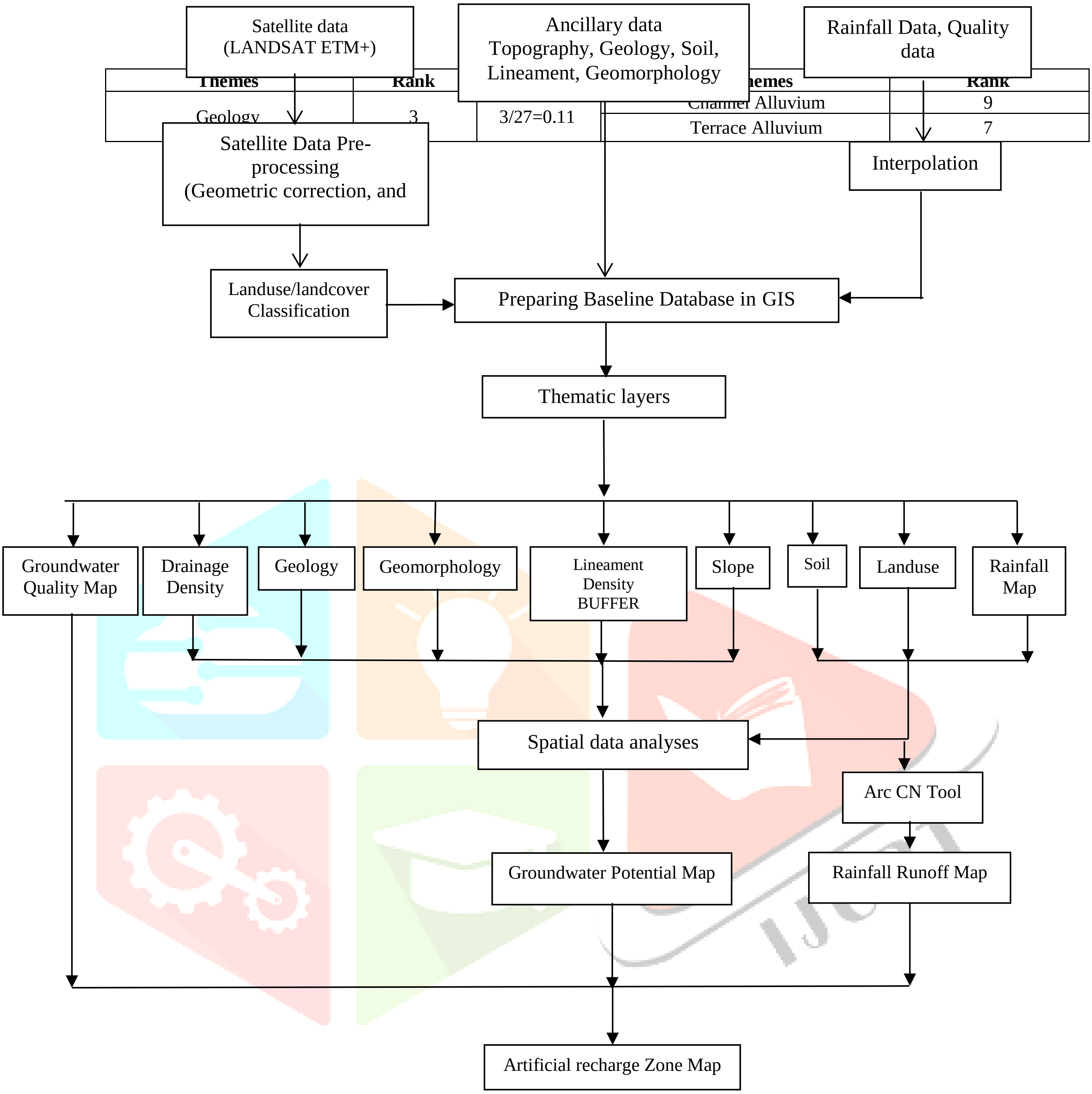

Figure 1.3: Flowchart of Methodology

4.5. Slope

The slope affects the runoff, recharge and movement of surface water, and is considered one of the important parameters for site selection of rainwater harvesting structures. Slope of any terrain is one of the factors controlling the infiltration of groundwater into subsurface, hence it is also an indicator for the suitability for groundwater prospects. The slopes have been classified into five categories, such as nearly level (0–1%), very gentle (1–3%), gentle (3–5%), moderate (5–10%) and strong (>10%), as per IMSD (1995) guidelines.

4.6. Soil

The soils for the study area reveals six main categories; namely sand, loam, sandy loam, silt loam, silt clay loam and clay loam. Ranking/weightage of a soil type has been assigned on the basis of their infiltration rate. For example, sandy soil has high infiltration rate, hence given the higher weights, while the clayey soil has least infiltration rate hence assigned the low weights. This soil map was later used for creating a Hydrological Soil Group (HSG) map.

Table 2. Ranks and weights to various themes and sub-themes

			Varanasi Alluvium	5
			Lacustrine Deposits	3
			River	1
Geomorphology	5	0.19	Active Flood Plain	9
			Older Flood Plain	7
			Varanasi Plain	5
			Lacustrine Plain	3
Lineament	4	0.15	10-7	9
			7-5	7
			5-3	5
			3-1	3
			Less Than 1	1
Landuse	2	0.07	Vegetation	9
			Sand	7
			Scrubs	5
			Fallow Land	3
			Water Bodies	3
			Wasteland	1
			Urban	1
Drainage Density (Km/Km^2)	3	0.11	Very Low	9
			Low	7
			Medium	5
			High	3
			Very High	1
Slope (In Degrees)	5	0.19	0-1	9
			1-3	7
			3-5	5
			5-10	3
			Above 10	1
Soil	2	0.07	Sand	9
			Sandy Loam	7
			Sandy Loam & Loam	7
			Silt Loam	5
			Silt Loam & Loam	5
			Silt Clay Loam & Clay Loam	3
			River	1
Rainfall (cm/yr)	3	0.11	Less Than 50	9
			50-65	7
			65-80	5
			Above 80	3

4.7. Rainfall

Rainfall in the study area varies upto 90 cm annually, and it's divided into four zones: (1) <50 cm/year, (2) 50–65 cm/year, (3) 65–80 cm/year and (4) >80 cm/year. Major portion of the study area has a mean annual rainfall of 50–65 cm/year. High rainfall is favorable for high ground water potential hence higher rank is given to high rainfall.

4.8. Lineament

Structures are the rock failure and deformation created by the changes in stress with time. Lineaments, faults and fractures are the important linear structures for increasing the permeability of the bed rock. Geologically, core area is subdivided by straight long fractures, called lineament. Lineament is an important factor in determining the groundwater potential as it indirectly provides the information about the movement and storage of groundwater. High lineament density is favorable for high groundwater potential hence its gives higher rank.

V. Results And Discussions

5.1. Groundwater Potential Modeling

The thematic layers of geology, geomorphology, soil, slope, rainfall, drainage density, lineament density and land use/land cover were used for the delineation of groundwater potential zones in the study area. To demarcate potential zones, all these layers were integrated using Arc Info GIS software. The weights of different themes were assigned based on their influence on groundwater potential. Different sub-themes of each theme were assigned ranks at a scale of 1 to 9 according to their relative influence on groundwater potential as shown in Table 2. The weights were finalized considering the weights suggested by various experts and those used in earlier studies as well as local experience. To demarcate groundwater potential zones, all the eight thematic layers after assigning weights were integrated (overlaid) step-by-step using Arc Info software. The groundwater potential map is shown in Figure 3(a).

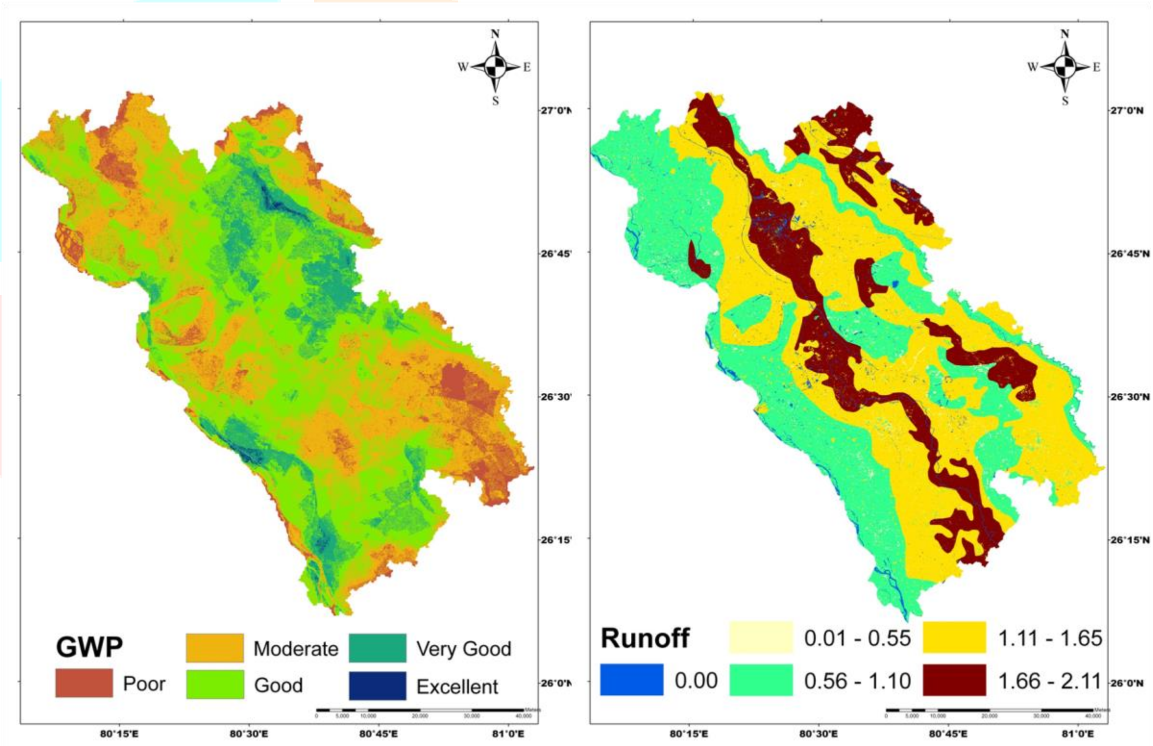

Figure 3. (a) Groundwater Potential Map of the study area (b) Runoff Map of the study area

5.2. Rainfall Runoff Modeling

Arc CN tool was used here, as it considers land use types, HSG map and rainfall data. The runoff is calculated based on the SCS curve-number-runoff method. The SCS curve-number method assumes that, for a rainfall storm event, the ratio of actual retention of soil after runoff begins to the potential maximum retention of soil is equal to the ratio of direct runoff to rainfall. This simplified assumption (Ponce and Hawkins, 1996) results in the following runoff equation where the curve number ($0 \leq CN \leq 100$) represents a convenient representation of the potential maximum soil retention (S). Since the study area mostly comprises of nearly level and very gentle slope (85% of the total area), the adjustment of CN values with respect to slope category has not been carried out.

$$Runoff = \frac{(rainfall - 0.2S)^2}{(rainfall + 0.8S)} \qquad if\ rainfall > 0.2S \qquad \ldots(1)$$

$$Runoff = 0 \qquad if\ rainfall \leq 0.2S$$

Where $S = \frac{25400}{CN} - 254$ in mm.

The average annual precipitation from 1993 to 2007 in Unnao District is 32.98 inch (837.80 mm). In the model, average monthly value is calculated and used. It can be interpreted as the averaged monthly value or a single rainfall event by assuming there are about 12 relative large rainfalls annually. The runoff map is shown in Figure 3(b).

5.3. Fluoride Concentration Mapping

Groundwater quality data about fluoride concentration were collected from Central Pollution Control Board, Unnao. These values were available as point data for 97 villages. ArcGIS software was used for interpolation of data for entire Unnao district, and shown in Figure 4(a). Miaganj, Sumerpur, Bichhiya and Asoha blocks are found to be very critical & Ganjmuradabad, Auras, Hasanganj, Nawabganj and Sikandarpur Karan areas are found to be critical as they contain high excess of fluoride. According to the study carried out by Central Pollution Control Board, the amount of fluoride in Darogakhera, Badlukhera, Pathakpur and Hindunagar villages of Bichhiya blocks varies from 4.5 - 6.2 mg/l. Also the Gurbakhshkhera, Bilaurah and Jabraila villages of Asoha block contains 3.5-4 mg/l of fluoride. There are only few blocks in the area where fluoride concentration is within the prescribed limit. The data about other water quality parameters in all the 16 administrative blocks of the study area were also collected from various government agencies to analyse the quality and suitability of groundwater for drinking and agriculture purpose. Table 3 presents a summary of water quality parameters values.

Table 3. Blockwise water quality parameters of the study area (1. Sikandarpur Sirosi, 2. Nawabganj, 3. Ganj Muradabad, 4. Auras, 5. Fatehpur84, 6. Safipur, 7. Asoha, 8. Hilauli, 9. Bangarmau, 10. Hasanganj, 11. Miyaganj, 12. Purwa, 13. Bichhiya, 14. Sumerpur, 15. Bighapur and 16. Sikandarpur Karan)

Parameter/Block	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Desirable	Permissible
EC (Micro hz)	490	770	440	720	840	960	900	550	410	350	430	710	560	940	450	730	750	2250
pH	8.26	8.2	7.92	8.5	8.1	8.4	8.3	8.4	7.85	8.5	8	8.2	8.6	8.5	7.66	8.6	6.5	8.5
TDS	1840	1066	1260	982	1280	1360	2060	2160	1426	1428	1366	1750	1708	2596	2260	2680	500	2000
Chloride	300	184	156	162	268	220	225	510	258	258	260	258	326	694	468	540	250	1000
Carbonate	19	29	19	29	29	19	29	19	10	10	10	19	19	29	10	19		
Bi-Carbonate	98	293	195	283	293	312	303	234	185	156	273	264	234	303	195	293	244	732
Sulphate	30	60	20	50	65	70	70	40	20	10	20	50	30	70	30	50	150	400
Fluoride	0.2	2.6	2.2	2.5	1.7	1.6	4.2	3	2.4	2.1	3	1.7	6.2	2.25	2.4	2.9	1	1.5
Nitrate (mg/l)	35	22	20	15	30	55	40	30	18	25	16	35	26	32	30	35	45	100
Silicon	Nil	3	Nil	Nil	2	3	2	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	2		
Iron (mg/l)	0.23	0.2	0.22	0.21	0.18	0.24	0.22	0.26	0.22	Nil	0.16	0.22	0.36	0.31	0.24	0.3	0.3	1
Calcium	12	30	10	38	32	36	22	22	18	16	26	24	10	34	23	29	75	200
Magnesium	17	25	16	34	27	27	23	19	14	13	23	20	19	29	18	32	30	100
Boron	0.11	0.14	0.12	0.24	0.22	0.24	0.24	0.12	0.12	0.12	0.12	0.14	0.24	0.22	0.2	0.18	1	5
Sodium	18	55	29	34	62	75	71	33	23	23	22	50	46	71	29	46		
Potassium	0.78	1.17	0.78	1.17	1.17	1.17	0.78	0.78	0.78	0.78	0.39	1.17	0.78	1.17	0.78	0.78		
SAR	0.8	1.79	1.32	0.97	1.94	2.28	2.52	1.25	0.99	1.02	0.76	1.79	1.98	2.18	1.09	1.42	18	26
Salt Index	22.66	18.98	21.63	21.10	18.34	17.03	17.37	21.17	22.20	22.25	22.30	19.56	19.90	17.37	21.66	19.90		

5.4. Modeling for Artificial Recharge Zones

The groundwater potential, runoff, settlement, canal and fluoride level are used to delineate the artificial recharge zones. All the thematic maps and their classes are assigned weights on the basis of their relative contribution towards the output. Weighted indexing method has been used, and output is classified into five classes; namely 'not suitable', 'poorly suitable', 'moderately suitable', 'suitable' and 'most suitable' locations (Figure 4(b)). This map could be used for selecting suitable sites for planning rainwater harvesting structures. The statistics of output map will be shown in Table 4.

VI. CONCLUSION

Unnao district has been experiencing shortage of groundwater particularly during summers. In addition the fluoride concentration is found to be higher than the permissible limit accepted by Indian Standards for drinking water. Reasons for high fluoride concentration could be the presence of tannery industries in the district as well as higher use of pesticides in the agriculture field. Remote sensing images has been found to be very useful for identification and mapping of drainage pattern and land use types in the area. GIS has been found to be extremely useful tool for integrating several thematic layers together to derive groundwater potential, rainfall-runoff modeling. The main advantage of using GIS in this study was to assign different ranks and weights to various themes and sub-themes and devise criteria to integrate the themes for groundwater modeling and artificial recharge zones mapping. These datasets were used to identify potential artificial recharge zones in the district. About 67% area is found to lie between suitable to most suitable for runoff storage to recharge the groundwater. The GIS based output maps could be used for water harvesting and conservation plans in the area.

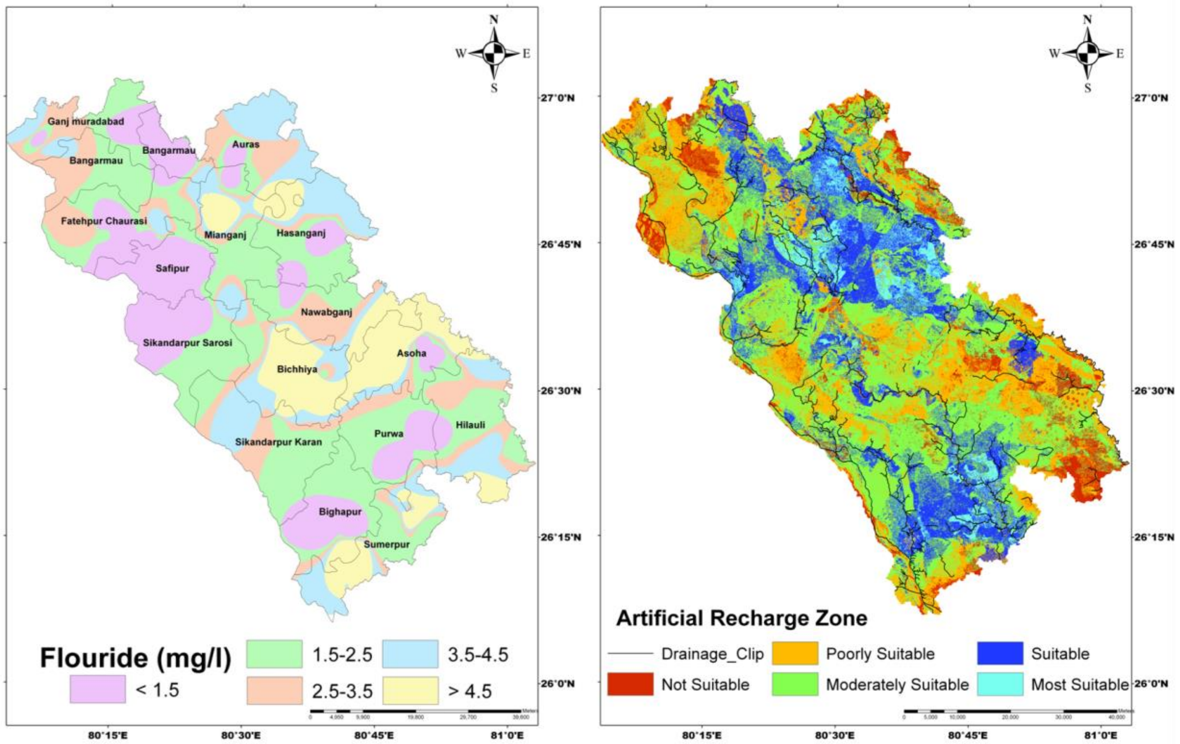

Figure 4. (a) Fluoride concentration Map of the study area (b) Artificial recharge zones of the study area

Table 4. Statistics of Artificial Recharge Zone

S.No.	Rank	Area (Km^2)	% of Area
1	Not Suitable	383.3316	8.47
2	Poorly Suitable	1127.588	24.93
3	Moderately Suitable	1851.684	40.95
4	Suitable	925.0038	20.45
5	Most Suitable	235.3032	5.20

VII. Acknowledgement

The author express their sincere thanks to Geological Survey of India, Indian Meteorological Department, Pune, UPPCB Jal Nigam and the United States Geological Survey (USGS) for providing the toposheet, satellite images and the required data which is very useful in analysis of the study area.

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