ACTA SCIENTIFIC AGRICULTURE (ISSN: 2581-365X)

Volume 2 Issue 10 October 2018

Research Article

Characterization of Aquifer Systems and Identification of Potential Groundwater Recharge Zones Using Geospatial Data and GIS

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Received: August 20, 2018; **Published:** September 11, 2018

Abstract

A study was undertaken to characterize the aquifers and identify the potential groundwater recharge zones at the farms of Indian Agricultural Research Institute (IARI) New Delhi. The study area was divided in to five sub-watersheds on the basis of artificial drainage divides. A Digital Terrain Model (DTM) was developed to determine the general drainage pattern of the IARI watershed. Hydrologic characterization involved determination of the various hydraulic properties of the aquifers and surface soils. Potential groundwater recharge zones were identified by integrating various thematic maps pertaining to soil type, DEM, land use and drainage pattern in ArcView GIS. Potential groundwater recharge zones were delineated using structured query language (SQL) available in ArcGIS which was programmed to delineate recharge zones on the basis of suitable combinations of hydraulic properties of soil and aquifer. The study demonstrate potential of GIS in delineating groundwater recharge zones and that the developed methodology will be applicable to other watersheds in India.

Keywords: Groundwater Recharge; Recharge Zones; Aquifer; GIS

Introduction

The planning and design of the groundwater recharge structures requires proper understanding of groundwater recharge processes and their interrelationship with geological, geo-morphological, soil, land use and other parameters. Amount of groundwater recharge depends on the suitability of aquifer and its potential to store the recharged water. Recharge is largely governed by number of processes, like infiltration, percolation and hydraulic conductivities of the subsurface soils and aquifers. It is possible that an area may have good infiltration and percolation but poor hydraulic conductivity of the sub surface soil and aquifer which can limit the groundwater recharge. Therefore, it becomes essential to characterize the aquifer and estimate its groundwater recharge potential before undertaking any groundwater recharge project. Much of the work has been done to identify the groundwater potential zones using remote sensing and GIS [1-4] but very less work has reported on identification of potential groundwater recharge zones considering the aquifer properties.

At IARI farms, declining water table has posed a serious threat to the availability of water. This can be attributed to over drafting of aquifers for agricultural and drinking water needs. In 1974, average water table of IARI was just 2m below ground level [5] and presently the water table in IARI is below 9m from the surface. Some pockets have shown decline in water table even greater than 15m, which in turn has increased the cost of pumping and reduced the well discharge. In IARI huge amount of surface water is available [6] during monsoon season, but due to rolling top topography and large scale concretization combined with good drainage network reduces the time of concentration and leading to small infiltration opportunity time for recharge to take place. This problem can be well circumvented by artificially recharging the surplus runoff generated during monsoon season. In order to utilize surface water for groundwater recharge, it is imperative to have clear information about aquifer properties, which largely govern the groundwater recharge and potential groundwater recharge zones for the implementation of groundwater recharge schemes. Potential groundwater recharge zones are the sites where artificial recharge schemes can effectively recharge the water as compared to rest of the surrounding area. Jyothiprakash., *et al.* [7] reported that the location of the site for construction of the artificial recharge structure plays a primary role in the effectiveness of any recharge structure. The main objective of the present study was to characterize the aquifers and to identify the potential groundwater recharge zones by using various thematic maps pertaining to soil type, land use, contour map and topography prepared using ArcView GIS. Present study aims at developing a methodology to assess the potential groundwater zones using geo-spatial data and GIS capabilities.

Materials and Methods

Study area

IARI has an area of 473 ha comprising mainly of farm area, residential complexes and office buildings. It is a part of greater watershed having an area of approximately 1030 ha. IARI is situated between the latitudes of 28^0 37’ 22” N and 38^0 39’ N and longitudes of 77^0 8’ 45” E and 77^0 10’ 24” E at an average elevation of 230m above mean sea level. Out of 473 ha area, nearly about 290 ha area is under extensive agriculture. Location map of IARI is shown in figure 1. The mean annual temperature is 240C. The mean annual rainfall was 710 mm of which as much as 75% is received during monsoon season (June to September). Most of the irrigation at the IARI farms is being carried out by pumping water through tube wells, storing it into tanks and delivering it through underground pipelines to individual fields. Water shortage becomes a crucial problem during peak demand period of irrigation. In addition to the tube well water, canal water from was also used for irrigation. The annual import of canal water for irrigation has reduced from 150 ha-m to 20 ha-m highlighting the increased dependence of irrigation on groundwater resources of the watershed.

Delineation of sub-watersheds

The study area was divided in to five sub areas on the basis of artificial divides like dykes prepared for roads. As roads are the dominant features of the IARI, the embankments outlining the roads were taken as boundaries of the sub-areas. The area, which falls out-side of the main boundary of the institute, was not considered in the study because no runoff from these areas enters in to the IARI watershed boundary due to presence of boundary wall.

Figure 1: Land use map of IARI farms showing location of tube wells.

Watershed characterization

Delineated sub-watersheds were characterized in terms of soil type, infiltration rates, hydraulic properties of the soils and aquifers, land use, etc. Values of these parameters for various sub-watersheds are presented in table 1. Two main properties of the soil, infiltration rate and hydraulic conductivity have major control over the recharge rate. These properties were adopted from review and some earlier studies conducted at IARI farm.

Aquifer parameters

Aquifer properties govern the rate at which water is recharged to the aquifer and also the quantum of water that can be stored underground. Specific storage and hydraulic conductivity are the two most important hydraulic properties of underground formations. In present study, characterization of aquifer involved determination of various properties of the aquifer formations, like specific yield, hydraulic conductivity, and transmissibility. The pump test data and analysis of well logs was carried out to determine the aquifer properties (Table 1).

Name of Tube well	Hydraulic Conductivity, m/day	Transmissibility m^2/day	Coefficient of storage
GEN 3	3.26	144.24	0.060
GEN 10	1.68	156.72	0.109
MB1	1.69	133.44	0.140
MB2	1.94	146.40	0.147
MB8	1.94	146.40	0.109
MB10	2.26	156.96	0.109
MB14	1.39	107.28	0.069
MB16	3.12	242.40	0.160
Mid B	2.40	176.88	0.150

Table 1: Aquifer parameters at selected locations in IARI farms.

GEN: Genetics Block; MB: Main Block; Mid: Middle Block.

In order to assess the spatial distribution of the water bearing formation, well logs at eight different locations within the IARI were analyzed for the type and thickness of water bearing formations. This was supported by two electrical resistivity surveys covering a large area of IARI conducted by Chandrashekharan (2003). The resistivity surveys used in present analysis were 1. Geo-electric section along IIP-WTC-NRL: A two-dimensional geo-electric section for the traverse of Indo Israel project (IIP)-WTC-NRL obtained by electrical resistivity method (Figure 2) and 2. Geo-electrical investigation for Krishikunj and part of IARI farm: Geoelectrical investigations carried out for the large expanse of IARI covering Krishikunj, Middle Block, part of Main Block, Top Block and for small areas around WTC and hostels figure 3. Thematic maps of soil hydraulic properties, aquifer hydraulic properties and land use land cover were integrated in GIS environment. A SQL based query was generated to delineate the potential groundwater recharge zones within the watershed.

Figure 2: Geo-electric section along the IIP-WTC-NRL.

Figure 3: Fence diagram for Krishikunj and part of IARI.

Results and Discussion

Geology of the area

Indian Agricultural Research Institute is situated between two ridges that form the fork of Arawali hills. The greater part of IARI lies on Alluvium but the small hills and ridges in and around IARI consists of Alwar quartzites of the Delhi system. These quartzites are white pale to gray or pinkish purple in color, thickly bedded and harder than usual Alwar quartzites.

The deposits are composed of dominantly stratified clay minerals called glacial till, but include some stratified beds of silt, sand and gravel. Sand, clay and gravel ranging in thickness from few centimeters to few meters, occur as irregular lenses or layers in the till. In general, because of the complex glacial history, the character of drift varies greatly in vertical as well in horizontal direction. However, considering the basin as a whole, the character of the drift in relation to the occurrence and movement of groundwater is fairly uniform.

Soils

Soils of IARI represent typical alluvium profile of Yamuna origin. The entire farm is covered under several soil series. The soil type ranges from sandy loam in Meharuli series to clay loam in the Jagat series. Digitized soil map with the details of various soil series prepared by Delhi Center of National Bureau of Soil Survey and Land Use Planning is presented in figure 4. The texture up to a depth of about 150 cm appears almost uniform. As per USDA classification, major portion of the area belongs to sandy loam class. There are only minor pockets representing clay and sandy clay texture class. At some places hard kankar calcium layer exist below 150 cm. Porosity in general is about 40% and the soil belongs to a good class with respect to permeability. Major portion of study area is under agricultural land use. However, considerable area is under residential complexes and office buildings. The land use land cover map of the IARI farms is presented in figure 5.

Figure 4: Soil map of IARI.

Figure 5: Land Use map of IARI.

Topography and drainage

The general topography of IARI is classified as moderately rolling to tabletop surface. There is elevation difference of 8 to 9 meters between the South East corner, commonly known as Todapur block, and North West corner and has gentle slope in the same direction. The Todapur area is at much higher elevation as compared to other farm areas in the North West. There are some low-lying areas (Main Block 15, 16 and neighboring area towards the western boundary of IARI farm), which has significant drop as compared to other fields on the farm. IARI has good drainage network. Water from all along its area gets collected in the main drain and leaves IARI at Lohamandi side. Topographic map of IARI is shown in figure 4.

Potential groundwater recharge zones

A two-dimensional geo-electric section for the traverse of Indo Israel project (IIP)-WTC-NRL obtained by electrical resistivity method (Figure 3) showed that compact rock (bottom of aquifer) occurs at an average depth of 70m below ground level (bgl) for whole section with an exception near WTC which has a big inverted cone shaped depression forming a channel consisting of three layers of clay plus sand, sand plus kankar and Kankar plus fractured rock. The top of the channel is at the depth of 40m bgl and apex rests at a depth of 90 m. The survey section reveals that the major part of this channel is filled with the sand, kankar and fractured rock. Due to its porous nature this channel forms a good groundwater reservoir.

Geoelectrical investigations were carried out for the large expanse of IARI covering Krishikunj, Middle Block, part of Main Block, Top Block and for small areas around WTC and hostels figure 2 and figure 3. Analysis of this showed that in Krishikunj areas, good water bearing formations exists between 10 to 20 m below ground surface. Average thickness of kankar plus fractured rock is about 40m. Thickness of this formation decreases and depth from ground surface increases towards the IARI fields in the middle block. Vast spatial expanse of relatively porous and permeable subsurface material underlies in the areas of Middle Block, Main Block 3, 6, whole of the Top Block and areas around WTC and hostels, however, its thickness is much smaller (45 - 50m) in Middle and Main Block as compared to that in Top Block (> 100m). In general whole of this area is suitable for groundwater recharge.

Some sizable area was encountered under clay and sand at an average depth of 10m in the Main Block as well as in the Top Block. Care should be taken while planning recharge structures like recharge shaft or recharge well so that the bottoms of these structures do not lie above this clay pan. A continuous lens of compact sand and clay material was observed beneath the Top Block at very shallower depth of 10 to 12m and is 4 to 6m in thickness. Top Block has good storage capacity but recharge is only possible through deep penetrating structures like recharge shaft and recharge or injection well, surface methods of recharge may be considered as infeasible. In all the above-mentioned areas, compact rock occurs at a depth greater than 110m

Analysis of well logs revealed that almost all the areas are suitable for groundwater recharge through recharge shaft or recharge well. However, depth of these structures should be about 20m. However, there are certain pockets, which are suitable for percolation ponds also. Properties of aquifers and soils of five sub-watersheds have been presented in table 2.

Sub- water-shed	Hydraulic conductivity (m/day)			Depth of aquifer (m)		
	Minimum	Maximum	Average	Minimum	Maximum	Average
SA1	1.40	3.14	2.24	55.23	85.86	76.72
SA2	1.63	3.26	2.13	54.20	92.96	71.55
SA3	2.26	2.60	2.30	61.00	76.34	68.29
SA4	2.05	2.55	2.19	61.81	75.35	72.27
SA5	2.04	2.41	2.17	61.52	75.21	72.33

Table 2: Depth and hydraulic conductivity values of the aquifers in different sub-watersheds.

Potential water bearing formation consisting sand plus kankar and kankar plus fractured rock, ranging in thickness of 25m near NRL and 30m in between NRL and WTC, exists at depths ranging between 12 to 25m. The thickness of this water bearing formation reduces considerably as one move towards Indo Israel Project (IIP) and mixture of sand and clay becomes dominant up to depth of as high as 40m and below which is an impermeable compact rock.

Identification of Potential Groundwater Recharge Zones

Soil map, contour map and drainage maps were used to identify the location of groundwater recharge zones. It was observed that all the sub watersheds have good infiltration rate, sufficiently higher values of unsaturated zone and aquifer hydraulic conductivities and thickness of aquifer. Therefore, it can be said that almost all

Figure 6: Digital elevation model of IARI showing location of percolation ponds.

Sub Water-shed	Basic infiltration rate (mm/hr)	Soil hydraulic conductivity (m/day)	Land use	Soil type	Area (m^2)
SA 1	15	1.74	Agricultural	Loam soil with some patches of sandy loam and clay loam	1433829
SA 2	10 - 20	0.32	Urban and High density urban	Loam soils	965456
SA 3	10 - 20	0.32	Urban	Loam soils	656925
SA 4	25 - 30	1.1	Mixed land use	Sandy loam and loam	651417
SA 5	25 - 30	0.66	Urban and Agricultural	Sandy loam with small patches of loam	1019569

Table 3: Properties of five sub-watersheds.

the sub watersheds are suitable for groundwater recharge. However, the selection of the recharge method would depend on cost involved and capacity to recharge a maximum amount of available surface runoff. As all characteristics are favorable for the recharge, two possible locations of the percolation ponds were identified based on the considerations like convergence of surface flows, availability of space for the construction and other social considerations. The possible location of percolation pond is shown in figure 6.

Conclusions

Analysis of eight well logs and two geophysical surveys covering vast expanse of the study area was done to assess the properties of the aquifers of IARI watershed and delineation of the potential groundwater recharge zones. The potential groundwater recharge zones were identified, by integrating various thematic maps viz., soil type, land use, topography and drainage network. The present study shows that almost all the sub-watersheds are suitable for artificial recharge. Indo-Israel-project area, which is a part of the sub-watershed SA4, limits its use as recharge area due to low storage capacity of the underlying formation. In order to avoid the conveyance of rain water to the recharge sites, existing drainage network was suggested as one of the possible options for the construction of recharge shafts along its bank.

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Volume 2 Issue 10 October 2018
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