Identification of Suitable Sites for Groundwater Recharge

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Abstract

Identification of suitable sites for groundwater artificial recharge is very important, which is necessary to carry out with enough accuracy and in the possible minimum time. The study area is Gavbandi river basin located in Boushehr province, Iran. In this study; among different methods of artificial recharge, two methods of water spreading and artificial basins were selected. For this purpose, four factors of slope, surface infiltration, alluvial thickness and water quality of sediment were investigated. The slope map was prepared from topographic maps. Surface infiltration was estimated from texture of sediment samples. The aquifer thickness was determined by geo-electric method and the point measured thickness of aquifer. The alluvial quality was determined from EC data of the study area. Also the maps of land use and landform units of the study area were extracted from Landsat ETM+ images. The Suitable sites for artificial recharge were identified by overlaying of the slope, surface infiltration, thickness and quality of sediment layers in GIS. To study the relationship between landform units and artificial recharge, two maps of the landform and suitable sites were overlaid. The results show that only 8- 12% of the study area is in suitable class for artificial recharge. The study of relationship between landform units and artificial recharge show that suitable sites for water spreading are chiefly located in the piedmont unit and suitable sites for artificial recharge by basins method are located in the piedmont and fans units.

Keywords: Groundwater, Artificial recharge, GIS, Remote sensing, Iran.

Introduction

Water resources in Iran are very unevenly distributed, both spatially and temporally. The magnitude of flood volume resulting from ephemeral rivers is in the order of 65 billion m^3 out of 127 billion m^3 of the total surface flow from the country which mostly ends up in salt lakes, desert, swamps and the ocean (Sharifi and Ghafouri, 1998). The greater part of Iran is characterized as an arid and semi-arid region. Groundwater is the only water resource in most parts of such regions, thus it is considered as the main constraint on economic and social development. Soil conservation and its proper utilization must be taken into account as a natural resource, in addition to water resources management plans.

A variety of methods have been developed to recharge groundwater, and most use variations or combinations of direct surface, direct sub-surface or indirect recharge techniques. The most widely practiced methods are direct-surface technique, including surface flooding, ditch and furrow systems, basins and stream channel modification. The advantage of these direct-surface techniques lies in the ability to replenish underground water supplies in the vicinity of metropolitan and agricultural areas, where groundwater overdraft is severe; and there is an added benefit of the filtering effect of soils and the transmission of water by the aquifer (Asano, 1985).

There are many factors to be considered when determining if a particular site will be receptive to artificial recharge. The application of traditional data processing methods in site selection for artificial groundwater recharge is very difficult and time consuming, because the data is massive and usually needs to be integrated. GIS is capable of developing information in different thematic layers and integrating them with sufficient accuracy and whithin a short time. Therefore the application of such methods is indispensable for such analysis. Identification of suitable sites for flood spreading as an artificial groundwater recharge techniquse has been practiced in recent years. The success of artificial groundwater recharge via surface infiltration is discussed by Haimerl (2001). Zarkesh (2005) developed a Decision Support System (DSS) for site selection and conceptual design of floodwater spreading schemes in the semi-arid region of Iran.

Each artificial recharge technique has its own characteristics and thus, the method of site determination will differ from other techniques. Recharge basins are created in highly permeable areas and is most suitable in Iran because of its relatively high practicability, efficiency and easy maintenance. In this research, site selection for artificial recharge via recharge basins is considered in a coastal aquifer in the Gavbandi River Basin, Iran.

Materials and methods

The study area is in the Gavbandi River Basin located in the south of Iran, between 52° 35´ and 53° 20´ E longitude and 27° 3´ and 27° 32´ N latitude. Its total area is 1349 km^2; of which 488 km^2 consist of Piedmont Plains and the rest of mountains. The depth of annual rainfall over the region differs from 31 mm in dry years to 506 mm in wet years. The long term average temperature and annual rainfall are 26.5 ºC and 258 mm respectively. The basin is located in the Zagros Fold Belt and the Piedmont Plain is formed on a syncline including Mesozoic and Cenozoic geological formations.

In order to determine the most suitable locations for artificial groundwater recharge, factors such as slope, infiltration rate, depth to groundwater, quality of alluvial sediments, and land use of the Quaternary regions are used. For this purpose different thematic maps were prepared from existing maps and data sets, remotely sensed images, and field investigations. The thematic layers for the above parameters were prepared, classified, weighted and integrated in a GIS environment by the means of Boolean and Fuzzy logics. To find out about the relationships between geomorphological units and appropriate sites for groundwater artificial recharge, land-use and geomorphological maps were extracted from remotely sensed images.

Slope is an important factor in determining the most suitable areas for flood - spreading purposes. Water velocity is directly related to land slope and its depth. On steep slopes, runoff is more erosive, and can more easily remove loose sediments down slope. Topographic maps of the region were used to develop a slope map by the Digital Elevation Model. The slope map was classified into five classes (Saraf and Choudhury. 1988).

Infiltration values were determined based on texture-permeability relationship (FAO, 1979). Thirty five samples were taken from the surface of the plain in order to analyze the texture and develop the infiltration rate map. To verify the texture-permeability relationship some double ring infiltration tests were performed. The infiltration map was classified into four classes (FAO, 1979). Table 1 shows the infiltration classes for the study area.

Table 1. Infiltration rate classes for the study area

Suitability Class	Infiltration Class (mm/h)	Area (Km^2)	Area (%)
Very Suitable	>45	244.9	50.2
Suitable	25-45	130.6	26.7
Moderately Suitable	15-25	33.7	6.9
Unsuitable	0-15	79.2	16.2

Observation well logs and geoelectrical resistance sounding results were used to develop the depth to bed rock and groundwater level in the plain. The map of thickness of sediment to water table was classified into four classes based on the experience in site selection of artificial recharge of aquifers by flood spreading in Iran (Soil Conservation and Watershed Management Research Institute, 1999).

Electrical Conductivity (EC) and Total Dissolved Solids (TDS) variations have similar trends over the area, so EC factor is used as the indicator of water quality criteria. Average electrical conductivity data from observation wells measured over a 10-year period are used to develop the EC map. Raghonath (1987) salinity classification was used to classify electric conductivity into four classes, (Table 2).

Satellite images of Landsat-7 ETM+ in 2000 are used along with field studies to develop land-use and geomorphology maps of the study area. The appropriate band combinations were selected for visual interpretation. ArcView was applied to the mentioned band combinations to develop the relevant maps. The developed land-use map indicates four land types in the basin. The area of each type is shown in Table 3. Based on the geomorphological map developed by remotely sensed images the Gavbandi river basin consists of five geomorphological units.

Table 2. Electrical conductivity classes for the study area

Suitability Class	Electrical conductivity Class (μmhos/cm)	Area (km^2)	Area (%)
Very Suitable	0-1000	3.1	0.6
Suitable	1000-2250	87.3	17.9
Moderately Suitable	2250-4000	102.2	20.9
Unsuitable	>4000	295.7	60.6

Table 3. Land use type of the study area

Land use	Area (ha)	Area (%)
Range land	40348	82.6
Agriculture	7039	14.4
Residential	1394	2.9
Forest	45	0.1

The produced thematic layers were classified, weighted and integrated in a GIS environment considering Boolean and Fuzzy logic. To find out the relationship between geomorphological units and the appropriate sites for artificial recharge, geomorphological and land-use maps were prepared. There are different methods for integrating thematic layers. In this research Boolean logic in which only satisfactory and unsatisfactory conditions are considered (zero and unit values), and fuzzy logic in which a range of zero to one is considered for different satisfactory levels were used.

Results and discussion

According to the different types of land-use, only range lands are always appropriate for artificial recharge. Therefore, the range lands and non-range lands regions are determined on the land-use map and coded as one and zero, respectively. This classification is applied to the map of recharge satisfactory areas, as a filter.

The result of overlaying the maps of the geomorphology and suitability areas for groundwater artificial recharge using fuzzy logic is shown in Table 4. The results indicate that prevailing coastal conditions are the major limitations for artificial groundwater recharge plans. The main limiting factors are: EC and dry alluvial layer thickness. The EC of 60.56 percent of the Quaternary areas is above 4000 μmhos/cm, which makes the artificial recharge difficult. Besides this, 50.2 percent of the Quaternary region has dry alluvium less than 10 meters thick which is not suitable for artificial recharge plans. The main reasons for the existence of these two limiting factors are: closeness of the area to saline ground water resources and shallow groundwater levels.

Table 4 Results of overlaying geomorphological units and artificial recharge maps

Model	Land suitability	Alluvial fans	Fluvial deposits	Eroded Pediment	Marine sediments	Rock outcrops	Total
Boolean	High	4.5	0.8	8.4	0	0	13.7
	Low	11.2	0.6	35.7	38.8	0.2	86.3
Fuzzy	High	4.9	0.8	8.5	0	0	14.2
	Moderate	4.6	0.5	8.2	0.02	0	13.3
	Low	6.2	0.1	27.4	38.7	0.12	72.6

Integrating thematic layers using Boolean and Fuzzy logics indicate that in the Boolean model 12 percent of the area is considered as appropriate for artificial recharge, while in the Fuzzy model 12 and 8 percent of the study area are considered as appropriate and moderately appropriate.

In site selection, the fuzzy algebraic product operator would be an appropriate combination operator, because at each location the combined fuzzy membership values tend to be very small with this operator, due to the effect of multiplying several numbers less than one. Parameters considered in selection of groundwater artificial recharge locations are diverse and complex. Integrated assessment of thematic maps using a fuzzy logic model developed based on GIS techniques was a suitable method for identifying preferred artificial recharge sites. Satellite data has proven to be very useful for surface study, especially in the preparation of current land-use and geomorphological maps.

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