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Application of GIS techniques to determine areas most suitable for artificial groundwater recharge in a coastal aquifer in southern Iran

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Abstract

Special attention has been paid to artificial groundwater recharge in water resource management in arid and semi-arid regions. Parameters considered in the selection of groundwater artificial recharge locations are diverse and complex. In this study factors such as: slope, infiltration rate, depth to groundwater, quality of alluvial sediments and land use are considered, to determine the areas most suitable for groundwater recharge in a coastal aquifer in the Gavbandi Drainage Basin in the southern part of Iran. Thematic layers for the above parameters were prepared, classified, weighted and integrated in a GIS environment by the means of Boolean and Fuzzy logic. To determine the relationships between geomorphological units and the appropriate sites for groundwater artificial recharge, land-use and geomorphological maps were developed from satellite images. The results of the study indicate that about 12% of the study area is considered as appropriate and 8% moderately appropriate sites for artificial groundwater recharge. The relationship between geomorphology and appropriate areas for groundwater recharge indicate that the majority of these areas are located on alluvial fans and pediment units. At the reconnaissance stage these geomorphological units can be considered as appropriate sites for artificial recharge in regions with similar characteristics.

Keywords: Groundwater; Artificial recharge; GIS; Fuzzy logic; Geomorphology; Gavbandi Basin

1. Introduction

Effective management of aquifer recharge is becoming an increasingly important aspect of water resource management strategies (Gale, 2005). The greater part of Iran is characterized as an arid and semi-arid region. In most parts of such regions groundwater is the only water resource, and is a major constraint on economic and social development. Conservation of soil and its proper utilization must also be taken into account as a natural resource, in water resource management plans.

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, most of which ends up in salt lakes, deserts, swamps and the ocean (Sharifi and Ghafouri, 1998). Artificial recharge is an effective technique for the augmentation of groundwater resources. 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 techniques, 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 the groundwater overdraft is severe; and there is an added benefit from the filtering effect of soils and the transmission of water through the aquifer (Asano, 1985).

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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 within a short period of time. The application of these methods is indispensable for such analyses.

Several studies have been carried out for the determination of areas most suitable for artificial recharge (Krishnamurthy and Srinivas, 1995; Krishnamurthy et al., 1996; Saraf and Choudhury, 1998; Han, 2003). In addition, the identification of suitable sites for flood spreading as an artificial groundwater recharge technique have been practiced in recent years (e.g. Ghayoumian et al., 2002, 2005; Zehtabian et al., 2001; Nouri, 2003). An overview of artificial recharge is given by Bouwer (2002), who points out the major factors to be considered. The success of artificial groundwater recharge via surface infiltration is discussed by Fennemore et al. (2001) and Haimerl (2001). Kheirkhak Zarkesh (2005) developed a Decision Support System (DSS) for floodwater spreading site selection and the conceptual design of floodwater spreading schemes in the semi-arid regions of Iran.

Each artificial recharge technique has its own characteristics and the method of site determination will differ for each techniques. Recharge basins are created in highly permeable areas, and this method 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 in the southern part of Iran.

2. Study area

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 (Fig. 1). The Gavbandi River Basin is a strip 73 km long with an average width of 18 km. Its total area is 1349 km^2, of which 488 km^2 consist of Piedmont Plains and the rest of mountains. The amount of annual rainfall over the region varies from 31 mm in dry years to 506 mm in wet years; long-term average temperature is 26.5 °C and average annual rainfall is 258 mm. The long-term average evaporation over the region is 133.4 mm, which is about 52% of the annual rainfall.

From the geological point of view the basin is located in the Zagros Fold Belt which has a main NW–SE trend. The Piedmont Plain is formed on a syncline composed of Mesozoic and Cenozoic formations (Fig. 2). The mountains to the north are formed mainly of resistant formations of the Asmari-Jahrom and Bangestan groups, and to the south of the Aghajari and Bakhtiari formations. The lithological features of the formations in the basin are presented in Table 1. Unconsolidated deposits in the northern part of the Piedmont Plain are coarse grained materials including pebble gravel and coarse sand, while toward the south and west the deposits are fine silt and clay.

3. Materials and methods

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, remote-sensing images, and field investigations. Thematic layers for these parameters were prepared, classified, weighted and integrated in a GIS environment by the means of Boolean and Fuzzy logic.

To determine the relationships between geomorphological units and appropriate sites for groundwater artificial recharge, land-use and geomorphological maps were developed from remote-sensing images.

Slope is one of the main factors in the selection of flood-spreading areas. Water velocity is directly related to angle of slope and depth. On steep slopes, runoff is more erosive, and can more easily transport loose sediments down slope. Topographic maps of the Gavbandi Piedmont Plain at the scale 1:25,000 were used to develop a slope map by the means of a Digital Elevation Model (DEM). On the slope map, slopes are classified into five classes (Saraf and Choudhury, 1998; Ghayoumian et al., 2005) (Table 2, Fig. 3).

Infiltration values were determined based on texture-permeability relationships established by the Food and Agriculture Organization (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. Table 3 gives the texture and determined infiltration values for the samples. To verify the texture-permeability relationship a few ring infiltrometer tests were performed. The results of these tests allowed the area to be classified into four infiltration classes (FAO, 1979) (Table 4, Fig. 4).

Observation well logs and geoelectrical resistivity sounding results along several profiles in the plain were used to determine the depth to bedrock and to groundwater level (Fig. 5). The area was classified into four classes based on experience in site selection of artificial recharge of aquifers by flood-spreading in Iran (Soil Conservation and Watershed Management Research Institute, 1999) (Table 5, Fig. 6).

Electrical Conductivity (EC) and Total Dissolved Solids (TDS) variations have similar trends over the area, so the EC factor is used as an indicator of water quality. Raghonath's (1987) salinity classification was used to divide the area into four classes on the basis of electric conductivity (Table 6). Average electrical conductivity data from observation wells, measured over a 10-year period, were used to develop the EC map (Fig. 7).