Seepage Velocity of Different Groundwater Aquifers in Halabja Saidsadiq Basin—NE of Iraq

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Abstract For understanding and prediction of transport in different groundwater aquifers media, the groundwater flow velocity (magnitude and direction) has to be considered. Halabja Saidsadiq Basin is located in the northeast part of Iraq, which covers an area of 1278 square kilometers with population of more than 200,000 inhabitants. The climate of this area is hot in the summers and cold in the winters. Groundwater aquifers in this area provide approximately 90% of whole water requirements. Therefore, it is important to understand some groundwater features in the area such as groundwater flow velocity, to prevent contaminant transport toward the groundwater aquifers. The main aim of this study was to apply geographic information system technique to estimate the magnitude and direction of the groundwater seepage velocity based on several hydrological and hydrogeological data in the region. The results revealed that the seepage velocity magnitude ranged from (0 to 51) m/d, while the flow direction is from the eastern to the western part of the study area.

Keywords Seepage velocity · Magnitude · Aquifer · Groundwater

1 Introduction

Halabja Saidsadiq Basin (HSB) is located in the northeastern part of Iraq (Fig. 1). Hydrologically, this basin is divided into two sub-basins [1]. The whole study area is of about 1278 square kilometers, with a total number of inhabitants of about 190,727

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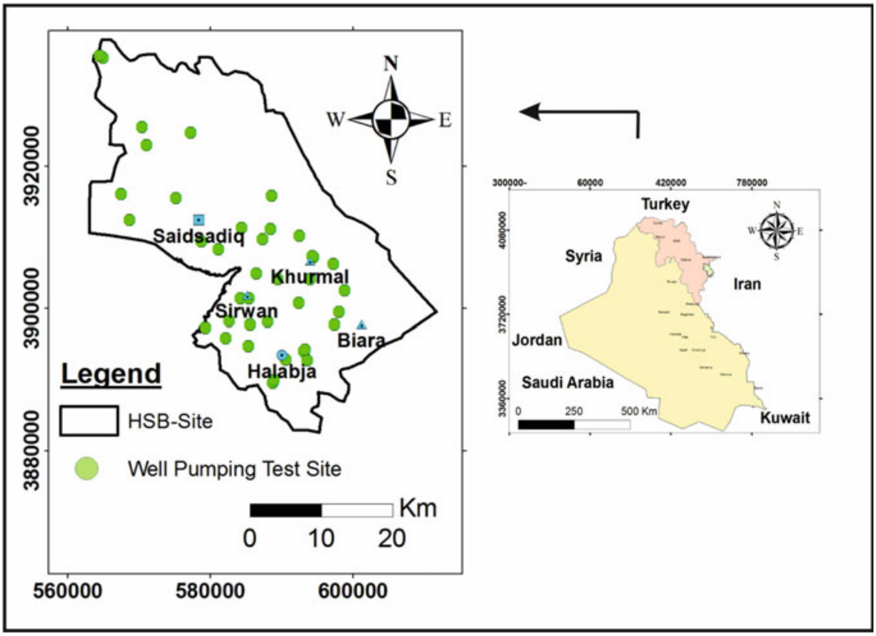

Fig. 1 Site map of the HSB [2]

in 2015 [2]. The study area is characterized by a discrete continental interior climate of about 45–50 °C in the summers and about 0–10 °C in the winters of the Mediterranean type, with the total annual precipitation ranging from 500 to 700 mm. Geologically, several units outcropped in the HSB of different geological time scales ranging from Jurassic to recent. The oldest exposed rocks in the basin are of Jurassic age [2]. Hydrogeologically, alluvial deposits are the most significant units in the HSB. These sediments are deposited as debris flows on the gently sloping plains or as channel deposits or as channel margin deposits and over bank deposits [3]. The thickness of this deposit as recorded in the field is nearly 300 m.

In hydrology, seepage flow refers to the flow of water in permeable media [4]. The fluid fills the pores in the unsaturated bottom layer and moves into the deeper layers as a result of the effect of gravity. The ground media has to be permeable so that the seepage water is not stored [4]. Darcy Law analysis can be applied to calculate the flow field. The flow field is a vector field of groundwater seepage flow velocities and is expressed as two rasters, one for magnitude and the other for direction, [5]. The first step in groundwater flow modeling is to determine the flow velocity and direction at each point in the flow field. Therefore, the main aim of this study was to apply groundwater tool in the GIS technique to calculate and map groundwater seepage velocity both in magnitude and direction. This map can be useful to prevent pollutant spread within the direction of groundwater flow and to know the potential site of groundwater resources quantitatively.

2 Materials and Methods

Seepage velocity (**v_s**) is the actual velocity following through voids or porous media and is always higher than the discharge velocity (v). The seepage velocity can be calculated using the following equation [5]:

$$v_s = v/n \tag{1}$$

where v_s is the seepage velocity in (m/day), v is the Darcy's velocity in (m/day), and n is the effective porosity [6]. Darcy's Law states that the Darcy velocity v in a porous medium is calculated from the head gradient (the change in the head per unit length in the flow direction in an isotropic aquifer) and hydraulic conductivity k, [5] as

$$v = k\nabla h \tag{2}$$

where k is the hydraulic conductivity (m/d), ∇h¿is the head gradient (the change in the hydraulic head per unit length in the direction of the flow in an isotopic aquifer).

The hydraulic conductivity (k) can also be calculated from the transmissivity T and thickness b as $k = T/b$.

Here k = hydraulic conductivity is the rate of flow under a unit hydraulic gradient through a unit cross-sectional area (A) of aquifer and T = transmissivity which is the rate of flow under a unit hydraulic gradient through a unit width (b) of an aquifer. Transmissivity was estimated form 39 well pumping tests which covered all the studied area (Fig. 1).

The Darcy Flow function calculates the groundwater volume balance residual, flow direction, and magnitude grids. It assumes a steady-state flow within the modeled aquifer. The inputs for this tool are a set of rasters (all rasters have to have the same extent and cell size), including groundwater elevation head, effective formation porosity, aquifer saturated thickness, and aquifer transmissivity.

The groundwater elevation head and the aquifer saturated thickness were interpolated from a set of the wells using Inverse Distance Weight (IDW). Transmissivity of the aquifer is calculated from pumping well test analysis using AQTESOLV for Windows software and then interpolated using an interpolation tool. Porosity of each aquifer has been estimated from [4] as explained in Table 1.

Table 1 Representative value of porosity, after [4]

Aquifer materials	Porosity in percent
Dolomitic limestone	26
Limestone	>26–30
Mixture of clay, sand, and gravel	>30–34
Sandstone and marly limestone	>34–37

3 Results

Darcy velocity map for the HSB was generated with the aid of groundwater command in a spatial analysis tool in GIS/ArcMap software 10.3 using IDW method for interpolation. From the groundwater head elevation above sea level in meter, the shallowest water table was found toward the southwestern part of the HSB. This means that the ground water is flowing from the northeastern toward southwestern parts. The study area was characterized by different groundwater aquifers of different lithological materials. The effective porosity of these materials was estimated from recommended representative porosity which was in the range (26–37%) as shown in Table 1.

The saturated thicknesses of each formation in the HSB has been interpolated. This thickness varies in the area of HSB due to difference in hydrogeological properties, in general, it decreases toward the northeastern part. However, the transmissivity in the area decreases toward the southwestern part within the range of (0.28–2431) m^2/d.

Seepage velocity direction and magnitude maps were constructed from Darcy Velocity command in the ArcMap software, (Fig. 2). The seepage velocity magnitude ranged from 0 to 51 m/d. The flow direction is generally from the eastern part (higher velocity magnitude) to the western part (lower velocity magnitude) of the HSB. The factor controlling the flow direction in the HSB refers to the direction of dipping strata of the geological formation, the high elevation head of groundwater in the eastern part, and low transmissivity in the western part.

4 Conclusions

- Hydrogeologically, Halabja Saidsadiq Basin has been considered as one of the most important basins in the Iraqi territory in terms of groundwater quantity and quality.
- The water demand is mainly provided from groundwater resources. Therefore, the study of groundwater flow velocity magnitude and direction is of high importance, in order to introduce the groundwater movement to prevent pollutant release gravitationally.
- The results indicated that the groundwater flows from the eastern to the western part of the HSB, in general, toward the Darbandikhan Lake in the southwestern part. This is related to the direction of the dipping strata of the geological formation, transmissivity, and the groundwater head elevation.
- The seepage velocity magnitude ranged from 0 to 51 m/d because of the different hydrogeological parameters of each groundwater aquifer, namely, groundwater elevation head, effective porosity, saturated aquifer thickness, and aquifer transmissivity.

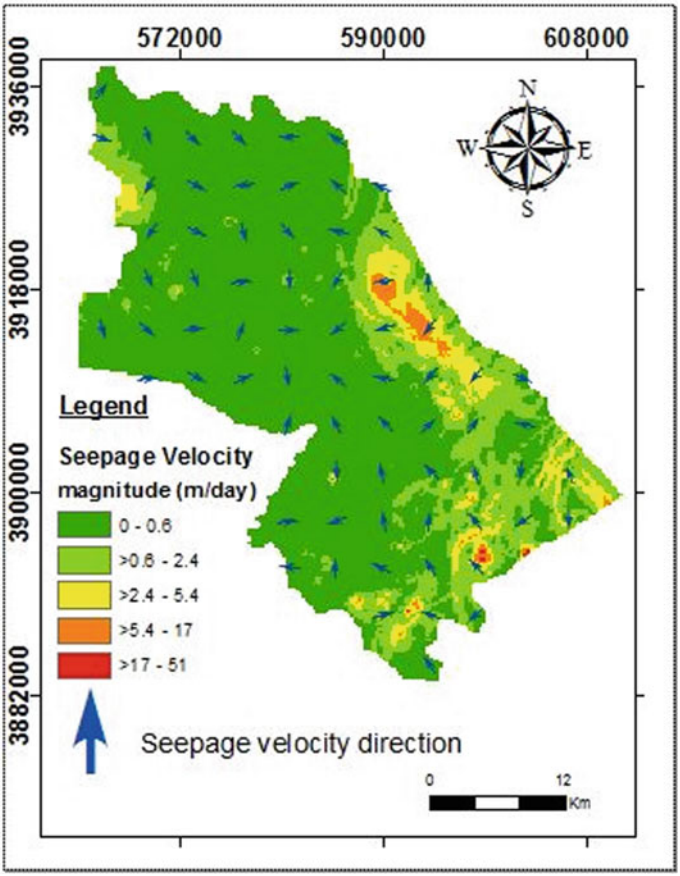

Fig. 2 Seepage velocity magnitude and direction of the groundwater in the HSB

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