Seepage Velocity Mapping Using ArcMap/GIS Software

Qais Al-Madhlom, Nadhir Al-Ansari, Hussain Musa Hussain, and Jan Laue

Abstract Groundwater flows from high to low hydraulic head regions. This flow is controlled by Darcy velocity equation. Darcy velocity represents the flow velocity within the cross-sectional area of the soil. Actually, however, groundwater flows at a higher velocity than that of Darcy's, called seepage velocity. Seepage velocity considers the real area (pores area) that is available for groundwater flow in calculations. There are many applications which are affected by the seepage/Darcy velocity, e.g., underground thermal energy storage systems and contaminants transfer in soil. In spite of the importance of Darcy/seepage velocity in many applications, there is no specific method to depict these velocities on a large-scale map. This paper proposed a tool that can be used to depict the seepage velocity on a large scale. The considered tool is offered by ArcMap/GIS software. To explain how this tool works, Babylon (Iraq) was considered as a study area.

Keywords Darcy velocity · Seepage velocity · ArcMap/GIS software

1 Introduction

In reality, groundwater is rarely in static conditions [1, 2]. It flows from high to low hydraulic head regions [3, 4]. This flow is controlled by the Darcy velocity equation:

$$v = ki = -\mathrm{k}\frac{\Delta h}{\Delta s} \tag{1}$$

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where v is Darcy velocity, k is the hydraulic gradient, Δh is the head difference, and Δs is the distance [2, 5]. Actually, groundwater flows in a smaller area which consists of the pores area within the soil matrix. The velocity of the groundwater within the soil pores is referred to as seepage velocity, average linear velocity, or average pore velocity [3, 6]. Seepage velocity can be estimated by dividing Darcy velocity by the effective porosity:

$$v_{seep} = \frac{v}{n_{eff}} \tag{2}$$

where v_{seep} is the seepage velocity, v is Darcy velocity, and n_{eff} is the effective porosity [3, 6]. There are many applications that are effected by the Darcy velocity and seepage velocity. These applications can be categorized under two mains titles/heads:

1. Heat transfer applications [7, 8]. 2. Mass transfer applications [6]. Examples of these applications are advection losses within Underground Thermal Energy storage (UTES) systems [7, 9], and transporting the dissolved solids (contaminants) [4, 6, 10]. There is no a specific method that can be used to depict the values of these velocities (direction and magnitude) for a specific region on large-scale map. This paper forwarded a facility within ArcMap/GIS software that can be used to produce large-scale maps (magnitude and direction) for seepage velocity within a specific region.

2 Study area

Babylon Province (Iraq) was considered as a study area (Fig. 1). Babylon Province stretches over 5135 km^2, and has a population of 2 million inhabitants. The soil is alluvial silty clayey soil loam [11].

3 Methodology

According to Eqs. 1 and 2, the seepage velocity can be written as follows:

$$v_{seep} = -\frac{k}{n_{eff}} \frac{\Delta h}{\Delta s} \tag{3}$$

Since transmissivity = hydraulic conductivity * saturated thickness (= kb) [1]. Then, Eq. 3 can be written as follows:

$$v_{seep} = -\frac{T}{bn_{eff}} \frac{\Delta h}{\Delta s} \tag{4}$$

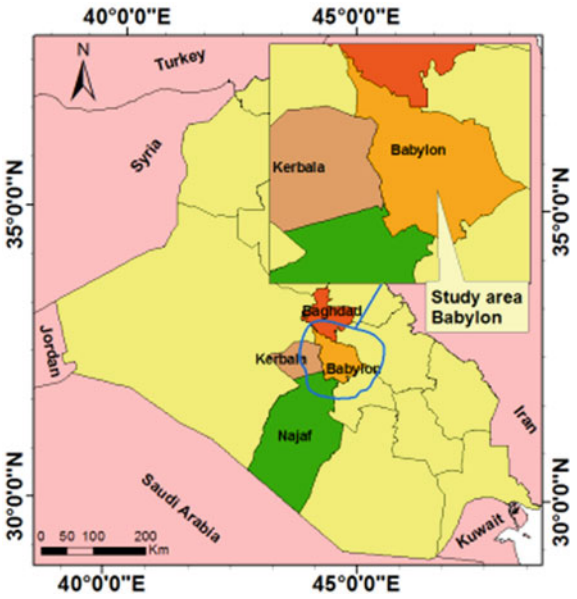

Fig. 1 Study area

To produce the seepage velocity maps, according to Eq. 4, four raster maps should be available (groundwater elevation head, aquifer effective porosity, aquifer saturated thickness, aquifer transmissivity). All these raster maps should have the same cell size and should be dimensionally homogeneous [12]. ArcMap GIS offers a tool (Darcy velocity) within Groundwater set/Spatial Analysis Tool box that is able to produce the seepage velocity maps. The results include two separate maps: magnitude and direction, which can be merged together in one map.

4 Results

The data from the well logs were used to produce the hydraulic head, porosity, transmissivity, and saturated thickness maps (Figs. 2, 3, 4, and 5). These maps are used to produce seepage velocity maps (Fig. 6).

The groundwater level rates from 38.27 m above sea level (masl) in the northern parts of the province to about 20 masl in the southern parts (Fig. 2). Since the soil is silty clayey [11], porosity is considered to be equal to 44% [1]. Transmissivity changes from 52 to 157 m^2/days (Fig. 4). The aquifer saturated thickness changes from 8.82 to 32.51 m (Fig. 5). The resultant seepage velocity map is presented in Fig. 6. The seepage velocity ranges between 1.34×10^{-6} and 0.11 m/day.

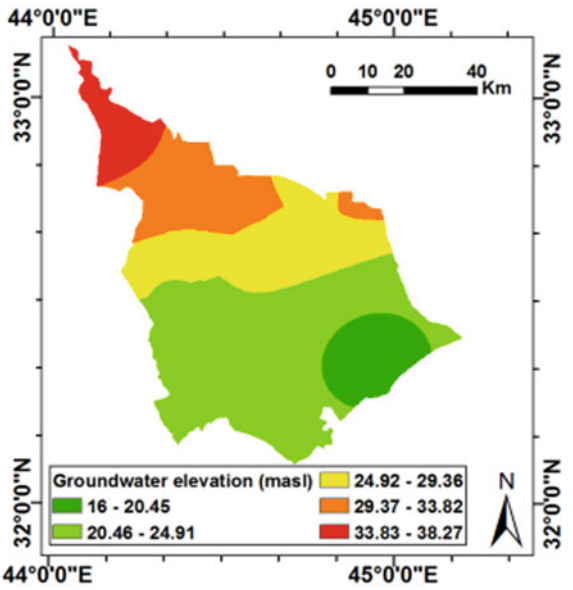

Fig. 2 Groundwater elevation map

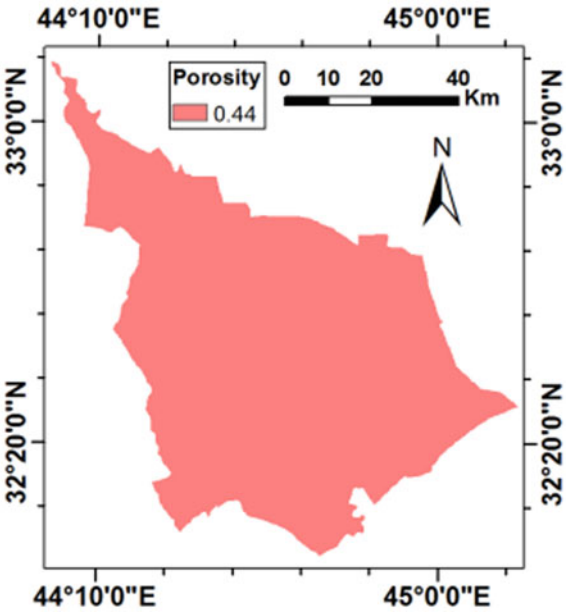

Fig. 3 Porosity map

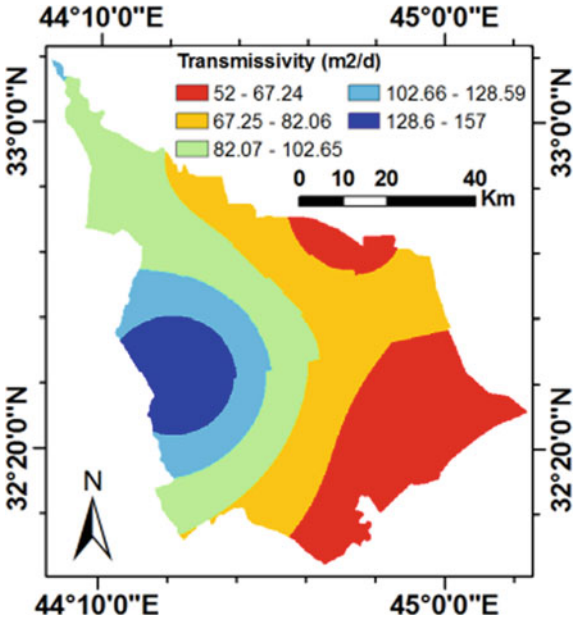

Fig. 4 Transmissivity map

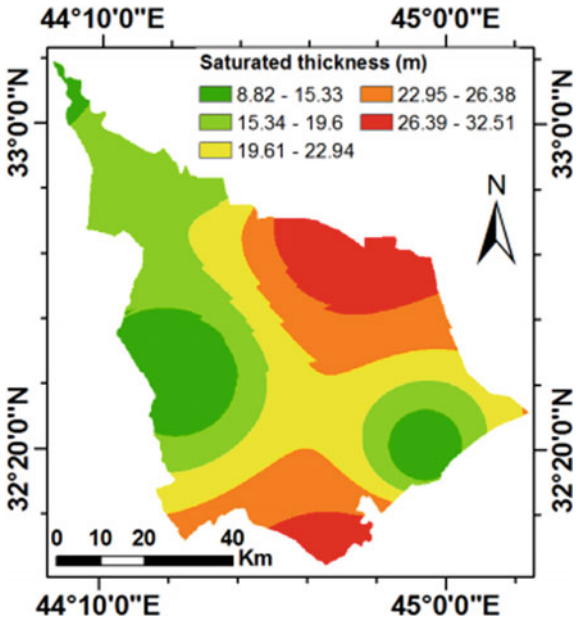

Fig. 5 Saturated thickness map

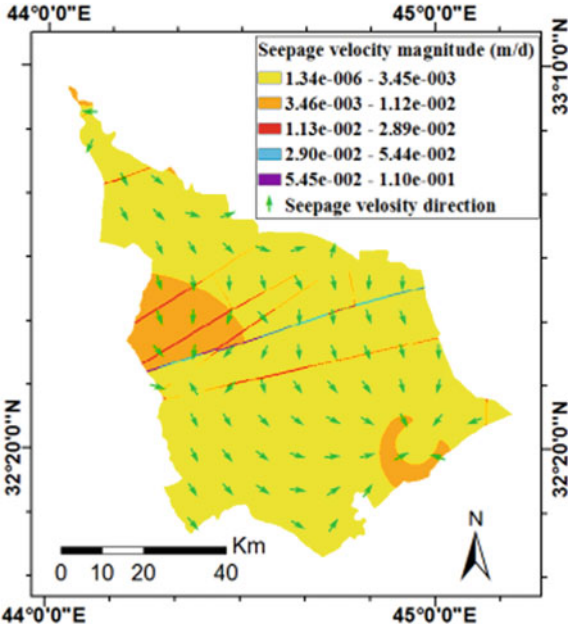

Fig. 6 Seepage velocity map for Babylon groundwater

5 Discussion

The groundwater elevation in Babylon Province decreases from 38.27 masl in the northern parts to 16 masl in the southern parts. Due to that tip, the groundwater flows from the northern parts toward the southern parts. The seepage velocity in any location is approximately twice the Darcy velocity, due to the porosity value (0.44).

6 Conclusion

Arc Map/GIS provide a suitable tool (Darcy velocity) to determine the seepage velocity and depicts the results as maps. The resultant seepage velocity maps' accuracy depends on the accuracy of the four maps: groundwater elevation head, transmissivity, saturated thickness, and porosity. Groundwater within Babylon Province flows from the north/west north direction toward south/east south direction. The seepage velocity direction is affected by the groundwater gradient. The seepage velocity within Babylon Province is limited to 0.11 m/days.

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