Journal of African Earth Sciences 134 (2017) 241–248

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

Annual safe groundwater yield in a semiarid basin using combination of water balance equation and water table fluctuation

Abolfazl Rezaei [a, b, *], Zargham Mohammadi [c]

[a] Faculty of Earth Sciences, Institute for Advanced Studies in Basic Sciences (IASBS), Zanjan 45137-66731, Iran
[b] Center for Research in Climate Change and Global Warming (CRCC), Institute for Advanced Studies in Basic Sciences (IASBS), Zanjan 45137-66731, Iran
[c] Department of Earth Sciences, Shiraz University, Shiraz, Iran

ARTICLE INFO

Article history:
Received 4 February 2017
Received in revised form
25 June 2017
Accepted 30 June 2017
Available online 4 July 2017

Keywords:
(Semi-)arid areas
Unconfined aquifer
Annual safe yield
Water balance equation
Water table fluctuation

ABSTRACT

The safe groundwater yield plays a major role in the appropriate management of groundwater systems, particularly in (semi-)arid areas like Iran. This study incorporates both the water balance equation and the water table fluctuation to estimate the annual safe yield of the unconfined aquifer in the eastern part of the Kaftar Lake, an Iranian semiarid region. Firstly, the water balance year 2002–03, owing same water table elevation at the beginning and year-end, was chosen from the monthly representative groundwater hydrograph of the aquifer to be taken into account as a basic water year for determining the safe yield. Then the ratio of the total groundwater pumping to the annual groundwater recharge in the selected water balance year together with the quantity of total recharge occurred in the wet period (October to May) of the year of interest were applied to evaluate the annual safe yield at the initiation of the dry period (June to September) of the year of interest. Knowing the annual safe groundwater withdrawal rate at the initiation of each dry period could be helpful to decision makers in managing groundwater resources conservation. Analysis results indicate that to develop a safe management strategy in the aquifer; the ratio of the annual groundwater withdrawal to the annually recharged volume should not exceed 0.69. In the water year 2003–04 where the ratio is equal to 0.52, the water table raised up (about 0.48 m) while the groundwater level significantly declined (about 1.54 m) over the water year 2007–08 where the ratio of the annual groundwater withdrawal to the annually recharged volume (i.e., 2.76) is larger than 0.69.

1. Introduction

The overexploitations of surface water and groundwater together with climate change (drought condition) have imposed serious challenges in (semi-)arid areas like Iran. At the present time, groundwater covers about 55% of the total water demand in Iran (Madani, 2014). In the most recent decades, the groundwater overexploitation has led to a sever groundwater depletion, water level decline, drying up of most Qanats (a gently sloping underground channel to drain groundwater to the surface) and springs as well as the degradation of groundwater quality (Ehsani and Khaledi, 2011; Gleeson et al., 2012; Home and Sale, 2011; Joodaki et al., 2014; Khodapanah et al., 2011; Madani, 2014; Voss et al., 2013). For instance, the number of production wells (primarily for agricultural activities) have increased from 47000 in 1971 to781000 in 2014 (Iran Water Resources Management Company, 2016). The groundwater depletion is also exacerbated by the recent drought condition in Iran (Abarghouei et al., 2011; Ghaleni and Ebrahimi, 2015; Golian et al., 2015; Morid et al., 2006; Nikbakht et al., 2013; Raziei et al., 2009). However, at the present time, 277 aquifers around the country are in a critical condition and the significant declines in the groundwater level (Forootan et al., 2014; Joodaki et al., 2014) has led to a significant land subsidence in many aquifers such as Tehran (the capital of Iran), Mashhad, Yazd and Kashmar (Dehghani et al., 2009, 2013; Mahmoudpour et al., 2016; Motagh et al., 2007, 2008; Mousavi et al., 2001). The water crisis in Iran comes from the long-term mismanagement and lack of planning (Lehane, 2014; Madani, 2014). The ongoing groundwater depletion, especially in eastern and southern parts of Iran, will cause a forced migration in the near future. Therefore, safe management of groundwater resources is indispensable in Iran to

* Corresponding author. Faculty of Earth Sciences, Institute for Advanced Studies in Basic Sciences (IASBS), Zanjan 45137-66731, Iran.
E-mail addresses: arezaei@iasbs.ac.ir (A. Rezaei), zmohammadi@shirazu.ac.ir (Z. Mohammadi).

http://dx.doi.org/10.1016/j.jafrearsci.2017.06.029
1464-343X/

restore the groundwater depletion happened over the three past decades around the country (Madani, 2014; Zektser and Everett, 2000).

The safe yield and sustainable yield are the most common concepts have been used to safely manage the groundwater development over the most recent decades (De Vries and Simmers, 2002; Domenico, 1972; Heath and Spruill, 2003; Hugman et al., 2013; Jacobs and Holway, 2004; Kalf and Woolley, 2005; Lee, 1915; Sakiyan and Yazicigil, 2004; Sophocleous, 2000; Theis, 1940; Todd and Mays, 2005; Zhou, 2009). The safe yield is commonly defined as a long-term balance between the annual rates of recharge and discharge (Sophocleous, 1997, 2000; Sophocleous and Sawin, 1997) or as the largest quantity of water can be extracted from an aquifer without causing an undesirable effect (Dottridge and Jaber, 1999; Heath and Spruill, 2003). The exact determination of the safe yield is not a simple task; thereby the safe policy in many countries is simply proceeding as a fraction of the recharge rate or even there is no any defined policy in many other countries like those in the Middle East (Chatterjee and Ray, 2014). However, the safe yield policy can be an appropriate hypothesis to stop the severe declining trend of groundwater level and to restore the depleted aquifers in the critical water condition like Iran. The basic issue in the safe yield is the groundwater budget; therefore, analysis of water balance has been commonly conducted to address the safe yield of the aquifers. For example, Heath and Spruill (2003) analyzed the safe yield of Cretaceous aquifers in the central Coastal Plain area of North Carolina using the water balance equation only based on historical data available. Voudouris (2006) used the water balance equation to determine the safe yield of a coastal aquifer in Greece considering the safe yield as a sum of the long-term annual average recharge rate keeping the condition of greatest groundwater use, domestic use in rainy season, artificial recharge and lateral groundwater input. Chen et al. (2010) delineated the safe yield equal to 0.33 natural recharge at an alluvial fan in Taiwan by conducting a linear programing based on the water-well level, the natural recharge and the water budget together with sustaining the minimum groundwater level requires for prevention saline water intrusion into the aquifer.

The purpose of this study is to estimate the annual safe yield in the unconfined aquifer to the eastern part of the Kaftar Lake, Iran, using the combination of the water balance equation and the water table fluctuation under conditions of lacking data in (semi-)arid areas like Iran. In fact, we applied the method presented by Marechal et al. (2006) in the innovative way to estimate not only the specific yield and direct recharge but also the safe yield of the aquifer. The proposed straightforward approach enables decision makers to calculate the annual safe yield before initiation of the dry period of the year of interest in order to conduct the safe management. Moving towards the safe management is essential to prevent more depletion of groundwater in Iran since such a resource often is a key to economic development in the country (Madani, 2014).

2. Materials and methods

2.1. Study area

The unconfined aquifer in the eastern part of the Kaftar Lake, 76 km^2 in the area, is located 200 km north of Shiraz City (Fig. 1). The region is characterized by a semi-arid climate with about 500 mm average annual precipitation, falling mostly in the wet period (October to May). The aquifer is bounded by the Dehbid Watershed to the southeast (Fars Regional Water Authority, 2007), and the shale and clayey limestone formation (Kazhdomi Formation), having a very low permeability, to the northeast (Fig. 1). The southwest boundary was chosen perpendicular to the equipotential lines (Fig. 2). The only groundwater-passing boundary is the northwest boundary (Fig. 2). The average thickness of the alluvial sediments at the study area is about 60 m (Fars Regional Water Authority, 1995). The aquifer consists of unconsolidated heterogeneous sediments including gravel, sand, and clay since the abundance of clay content increases towards the Kaftar Lake (Fars Regional Water Authority, 1997). There is no any spring, Qanat or stream in the study area. A water channel (Domdarya Channel in Fig. 1) which is branched from the eastern end of the Kaftar Lake plays an important role in recharge to the aquifer. The average depth of the water table is about 25 m (range from about 20 m in the eastern parts to about 29 m in the western parts). The groundwater generally flows from the southeast towards the northwest, having a slope of about 0.0026 (Fig. 2). The monthly representative groundwater hydrograph from 2002–03 to 2007–08 (Fig. 4) was prepared using Thiessen Polygon method based on the observed water level at 6 piezometers within the aquifer. While the water table fluctuation is approximately sharp (Fig. 4), then the method of water table fluctuation can reasonably be used to estimate the recharge rate in the aquifer. The sharp water table fluctuation may result from the relatively shallow depth of water table, the low value of the specific yield and existing separate wet and dry periods. In fact, the most quantity of recharge occurs in the wet season mainly as a result of precipitation whereas the groundwater commonly withdrawals in the dry season dominantly by the production wells. This issue caused the water table in the wet period becomes greatly higher than that of the dry period. The dry-period recharge from precipitation is approximately equal to zero, in part due to very small precipitation, high temperature, and very dry condition. Note that the pumping commonly occurs from late June to December in the area. However, the groundwater level may raise up from August to October due to (1) the irrigation return flow resulted from the intensive pumping over June and July percolates into the aquifer by the time-lag of about 2 or 3 months and (2) the harvesting time in which the pumping rate significantly decreases, happens commonly in September.

The data used in the study (water level, precipitation, well discharge, etc.) were acquired from the Fars Regional Water Authority archive. The water level has been measured in the piezometers by the Fars Regional Water Authority since Oct-1996. We only considered the climatological data were taken in pluviometer Kaftar Station since (1) it is located close to the study area (Fig. 2); (2) its topography elevation (2319 m) is approximately the same as

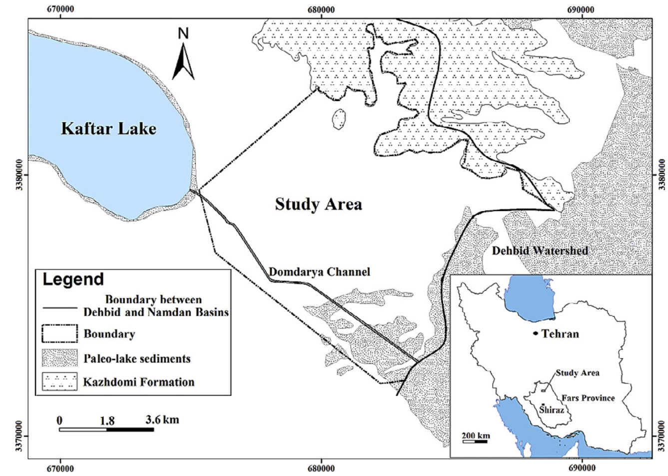

Fig. 1. The hydrogeology map and the boundary of the unconfined aquifer in the eastern part of the Kaftar Lake.