Modelling a complicated hydrogeological system: The case study of Wadi Zerka Ma'in - north east of Dead Sea

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Wadi Zerka Ma'in catchment area is a complicated study area from geomorphologically, hydrologically and hydrogeologically point of view. The conceptual system of that complicated system could be clarified by an advanced integrated approach of remote sensing, Geographic Information Systems (GIS) and numerical modelling. However, in such a complicated arid system understanding the disciplines between the groundwater and hydrology and geomorphology is a must in order to achieve a sustainable water resources management. In Wadi Zerka Ma'in catchment area, we estimated the groundwater recharge and understood the influence of the geomorphological units on the spatial distributions of the groundwater recharge. This was according to a powerful hydroinformatic system that was generated by integrated approach of remote sensing and GIS. Furthermore, a three dimensions geological model for the aquifers of the Wadi was generated and modeled in order to understand the influence of geomorphological units on the spatial distribution of aquifer conductivity.

Keywords: Groundwtaer flow, Geographic Information Systems, Hydrogeological system, Modelling

Introduction

Groundwater is the most important source of drinkable water in the arid and semi arid regions (Seiler and Gat 2007). Jordan has mostly aa arid climate and is considered as one of the nine water poorest countries in the world. The capita water supply is only about 170 cubic meters per year and most of its water demands are supplied by direct groundwater mining (Salameh & Bannayan 1993).

The Wadi Zerka Ma'in catchment area is one of the north-eastern side of the Dead Sea catchment areas and with an area of 272 km² (Fig. 1). It is the smallest catchment area and has the largest city, so-called Madaba, at the eastern side of the Dead Sea. Madaba has about 149500 inhabitants and its water demands are supplied by local groundwater (Department of Statistics 2009).

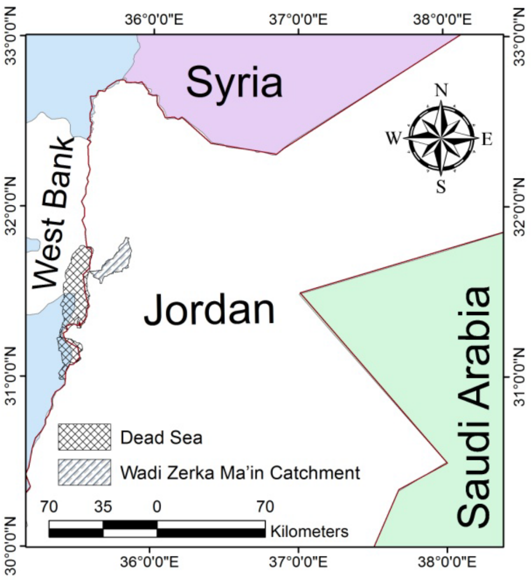

Figure 1: Location of study area. Wadi Zerka Main is at the North East of Dead Sea.

That local groundwater is in complicated hydrogeological system of unconfined limestone aquifer. The This aquifer has a groundwater salinity of about 900 µS/cm (Salameh & Bannayan 1993). However, the faulting systems of Wadi Zerka Ma'in have different directions and types (Odeh et al. 2013). However, faulting has a process that is called brecciation which is fragmenting the rock matrix. The objective of this research is to evaluate the effect of Wadi Zerka Ma'in faulting system, with its different fault types, on the limestone aquifer.

Methodology

A three-dimensional (3D) geological model is essential for generating a 3D hydrogeological model. It visualizes the geometry of the aquifers aquicludes and aquitards that have the exact geometry of the rock units (Zhang et al. 1997). The borehole data in studied area is not enough for 3D geological model. Therefore, the 3D geological model was created by constructive interpolation of geological cross sections, by using the GMS 6.5 software. Topographical cross sections were created from digital elevation model of 30 m resolution by ArcGIS 10.3 using spatial analyst extension. However, boreholes data were generated from the geological cross sections and inserted in the GMS 6.5 software to creat the cross sections and make the constructive interpolations (Fig. 2). The rock units of of the 3D

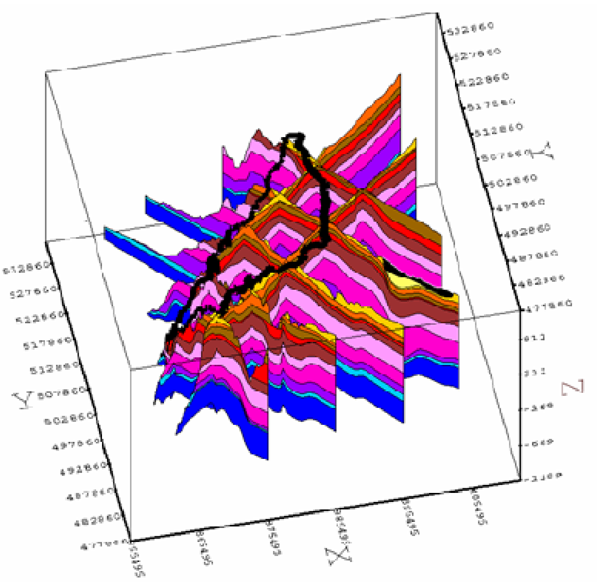

Figure 2: Geological cross sections to create the three dimensional model for the study area.

Geological model, were converted to three hydrogeological units and clipped according to the hydrogeological boundaries of that catchment (Odeh et al. 2015) by the FeFlow software 6.5. The discretization of the aquifers were generated by FeFlow 6 with the finite element method. The total studied discretized area is about 611.25 km² . There are more elements within the fault zones for considering the hydrogeological heterogeneity (Fig. 3). Groundwater flow within an aquifer is governed by the hydraulic head, which is a combination of water pressure, elevation and velocity (Fitts 2002). Groundwater flow in faulted aquifers is considered as one of the most complex groundwater

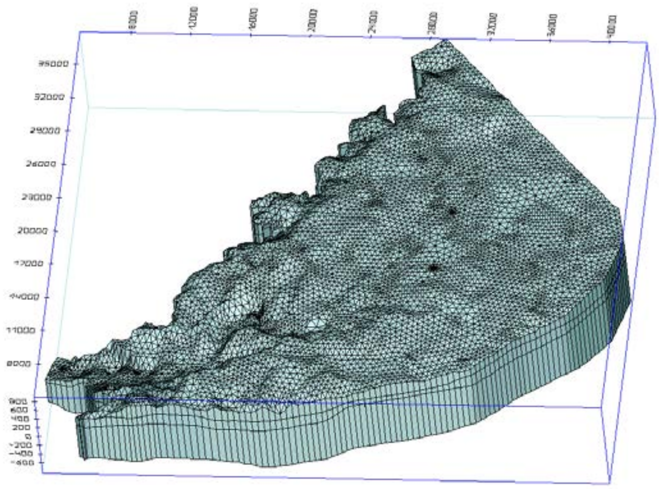

Figure 3: Aquifers geometry. The upper aquifer in the study area is the upper aquifer.

systems because of the different heterogeneous hydraulic conductivity zones as well as the hydrologic barriers and conduits between the hydrogeological units that are generated during the faulting process (Allen & Michel 1999). Hence, numerical groundwater modelling was used to estimate and generate the hydraulic conductivity zones.

Results and discussions

For understanding the effects of faulting on hydrogeological prosperities of aquiferes numerical model is needed (Domenico & Schwartz 1997). That model is used to investigate the groundwater flow directions as a result of the faulting (Allen & Michel 1999). Steady-state groundwater flow occurs when the magnitude and direction of the flow velocity are constant with time at any point in a flow field (Domenico & Schwartz 1997). We carried out the steady-state modelling for evaluating the effect of faults on the groundwater flow.

Heterogeneity of the aquifers refers to water-bearing materials that conform to no single system of groundwater flow (Domenico & Schwartz 1997). The structural features of the limestone lead to more water bearing materials and hence more heterogeneity than the lower sandstone aquifer or any other aquifer (Allen and Michel 1999).

Steady-state conditions indicate that the inputs and outputs of the groundwater are in equilibrium so that there is no net change in the groundwater system with time (Domenico & Schwartz 1997, Freeze and Cherry 1979). According to the simulation, a value of groundwater recharge for the year 2007 of 80 mm/year was used (odeh et al. 215), where a groundwater level map was interpolated by the groundwater level measurement of the same time period, and an average hydraulic conductivity value of 1.5 × 10-5 m/s, that was estimated by a pumping test (Margane et al. 2002). To calibrate the result of the simulation, PEST programme as an interface module was used (Doherty 2003). The benefit of PEST is doing the calibration automatically. It requested three files as follow:

1) Input file so-called template file which is from the FeFlow software.

2) Result file which is instruct file: it is defined by the position of the resulting values for the observation points in the FeFlow results file(Doherty 2003). Figure 4 shows the hydrogeological observation points that were used for the calibration.

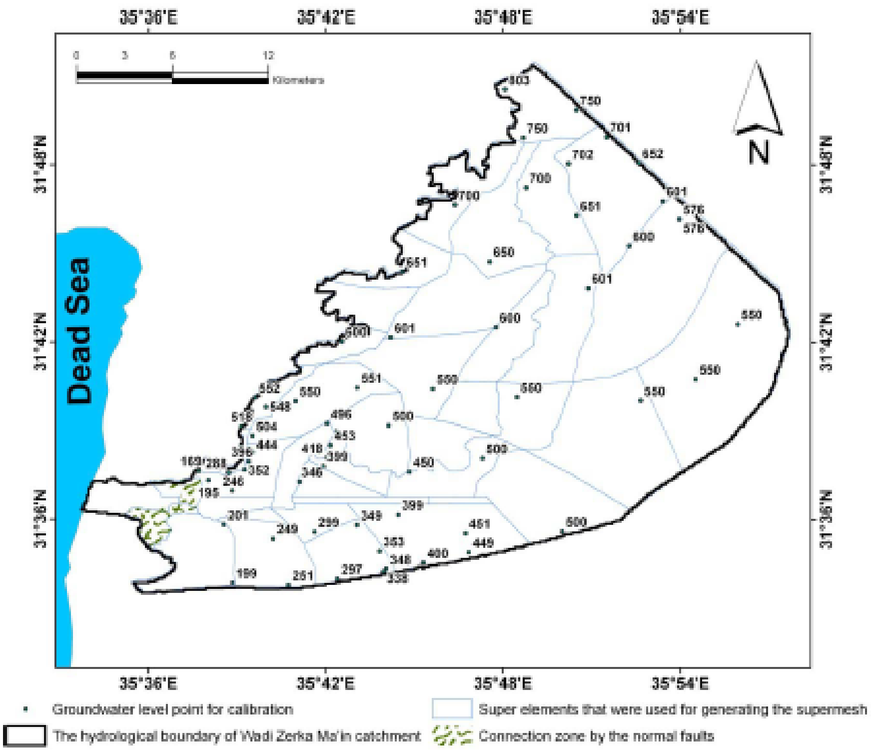

Figure 4: calibration points and polygon in the study area.

3) Higher-ranking file (control file): It compares the template file to the original (*.fem file)

and the instruct file to the original (*.dar file) and arranges all observation point data and the numerical settings (Doherty 2003).

Figure 5 is the result of the steady-state groundwater modelling of the lime stone aquifer. It shows that the groundwater flow directionally from the north to west. However, the groundwater level becomes closer to each other in the middle of the model where is the faulted part of Wadi Zerka Ma'in catchment The major strike slip fault (odeh et al. 2013) divides the modelled area into different zones of permeability where the highest permeability zones are located within the zone of the strike slip fault and it's embedded normal faults (Margane et al. 2002). However, those normal faults generate a permeable zone in the aquiclude unit and make connection, conduit, between the two aquifers (Allen and Michel 1999).

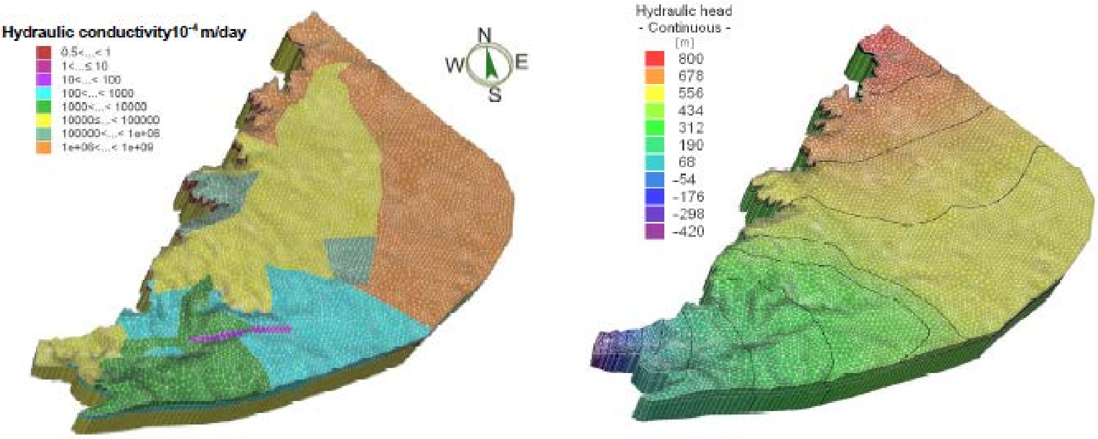

Figure 5: Steady-state groundwater modelling result for the upper aquifer.

Conclusion

The structural setting of the catchment area has led to heterogeneous zones of groundwater recharge and flow. Therefore, a structural evaluation of the Wadi is essential for understanding its groundwater system. The major strike slip fault zone causes a high permeability zone in the upper aquifer with the highest permeability areas located within that zone.

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