DEVELOPMENT OF A CONCEPTUAL NUMERICAL MODEL OF THE SHARED DIBDIBBA AQUIFER BETWEEN KINGDOM OF SAUDI ARABIA, KUWAIT AND IRAQ

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ABSTRACT

This study aims at developing a better understanding of the hydrogeology of the shared Dibdibba aquifer between Saudi Arabia, Kuwait and Iraq. The enhanced understanding of the hydrogeology of this regional aquifer will pave the way to develop a numerical model to simulate its sustainable yield capability to produce water with brackish quality for the three countries sharing the aquifer. This assessment is essential to make sure that the produced water quantities from this shared aquifer meet the water needs of these countries for different uses of water with suitable water quality for each use. Therefore, it is very important to determine the sustainable yield of the shared aquifer (quantity and quality) in the areas of existence of this shared aquifer in the three countries. The study carried out extensive fieldwork to determine the regional recharge of the aquifer, trans-boundary fluxes between Kingdom of Saudi Arabia on one side and Kuwait and Iraq on the other side. This study provide results about the conceptual model of the regional Dibibba aquifer. The results show that the recharge to the aquifer is about 300 Mm^3/yr and the total abstraction from thousands of wells in the 3 countries sharing the regional aquifer is about 470 Mm^3/yr. The results also show that the aquifer is heterogeneous with a minimum value of transmissivity of 81 m^2/d and a maximum value of 1700 m^2/d.

Keywords. Numerical modelling, conceptual model, regional and shared aquifer, trans-boundary flow.

1 INTRODUCTION

The regional aquifer of Dibdibba extends over Kingdom of Saudi Arabia (KSA), Kuwait and Iraq as shown in Fig. 1. Water demand in Kuwait, KSA and Iraq is increasing constantly because of population growth (Aliewi, et al. 2017). In other words, the pressure on brackish groundwater resources has increased significantly in recent decades due to the expansion of irrigated agriculture and industrial activities in the three countries sharing the aquifer. Therefore, there is a need to rely on groundwater resources and to assess the level of their contribution in meeting the agricultural and industrial water demands. The focus of this study is on the shared Dibdibba aquifer (Fig 1). The aim of the paper is to provide a better hydrogeological understanding of the shared/regional Dibdibba Aquifer in Kuwait, KSA and Iraq.

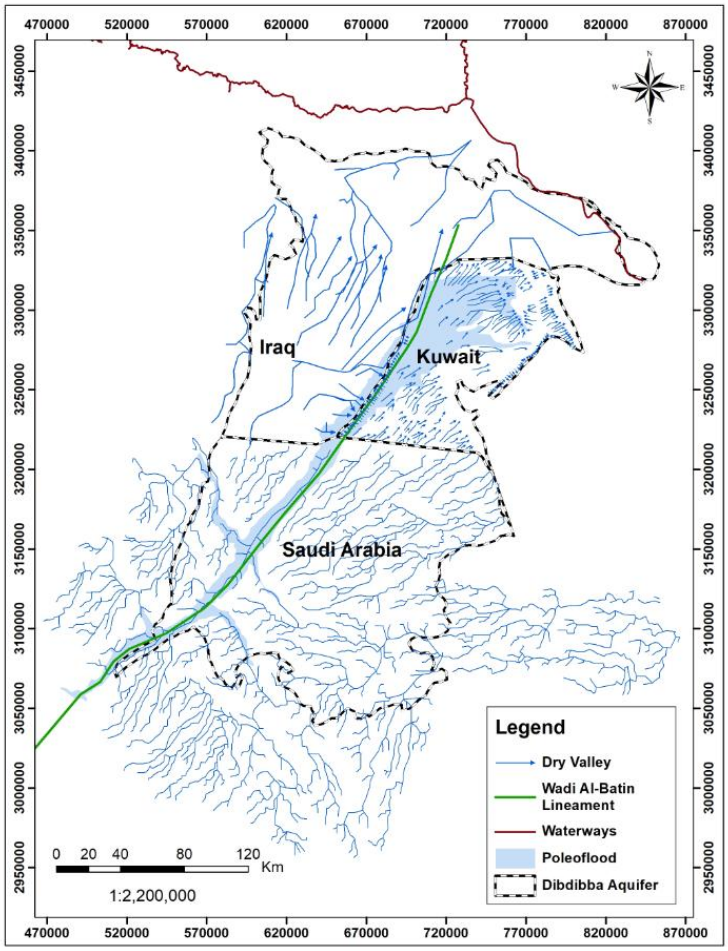

Figure 1. Location of Dibdibba Aquifer in the three sharing countries showing drainage system in the area

The utilization of groundwater from Dibdibba Aquifer is of vital importance to Kuwait, KSA and Iraq as sharing countries to the regional aquifer. Understanding the regional scale processes and how they can affect the aquifer will be a significant improvement in the knowledge. The development of a groundwater flow model will increase technical capacity and practice by allowing a calibrated model to be used to predict how changes in hydraulic heads can affect water availability the aquifer in the future. This ability can help ensure that the sharing countries maintain and develop the Dibdibba aquifer in a sustainable manner. There is no estimation of the sustainable yield of Dibdibba as a regional aquifer. Some studies were carried out on Dibdibba but they were on local scales in Kuwait, Iraq and KSA (Aliewi et al., 2015; Atiaa and Aboodi, 2005; Al-Kubaisi, 1999, Al-Sulaimi and Pitty, 1995; Makkawi, 2010). The sustainable yield of the regional aquifer cannot be oversimplified by just adding arithmetically the sustainable yields of the portions in Kuwait, Iraq and KSA, which were estimated separately. The sustainable yield will be influenced by the regional changes of the aquifer in terms of geometry and water levels to represent more accurately the aquifer dynamics in KSA and Kuwait as a whole. When the aquifer is studied on the regional level, a more accurate sustainable yield of the aquifer will be obtained. In general, the shared aquifers can be mismanaged to lead to depletion of groundwater supplies if the sharing countries lack essential information about the sustainable yield of the regional aquifer. This paper is about developing a conceptual model for the regional aquifer of Dibdibba (Fig. 1).

2 METHODOLOGY

The methodology in this study is based on hydrogeological, hydro-geochemical investigations, and groundwater modeling of the movement of brackish groundwater in the regional aquifer of Dibdibba. The hydrogeological investigations include well inventory in Kuwait, Iraq and Saudi Arabia. The well inventory comprise of determining locations (x, y, z) of all wells, groundwater levels, pumping rates, pumping tests data (wherever available) and groundwater quality parameters. The Visual MODFLOW FLEX Version 6.0 was used to develop the conceptual model of Dibdibba aquifer which is considered as a shallow aquifer in the three sharing countries.

3 RESULTS AND DISCUSSION

Hydrogeology of the regional aquifer. The Dibdibba Aquifer is overlain by alluvial Quaternary deposits (Abadi, 2002; Al-Awadi et al. 1988; Al-Sulaimi, 1994). The existence of Dibdibba aquifer in the three sharing countries in terms on name and lithology is presented in Table 1. The outcrop areas of the shared aquifer are as follows: Kuwait portion is 9,717 km^2 which is 16.4%; Saudi Arabia is 26,957 km^2 which is 45.5%; Iraq is 22,544 km^2 which is 38.1%. Total area of the aquifer in the three countries is: 59,218 km^2. In Kuwait and Iraq, it is named Dibdibba. In Saudi Arabia it is named Hofuf. It is of Pliocene to Upper Miocene age. Its lithology is described by the UN ESCWA and BGR, 2013 as gravelly sand, often calcretized with subordinate clays. Underneath Dibdibba is a formation (Fars) of Middle Miocene which acts as an aquitard. Below that is the Lower Miocene formation (named as Ghar in Iraq and Kuwait, Hadrukh in Saudi Arabia) (see Fig 2 which is a stratigraphy of the aquifers in the region).

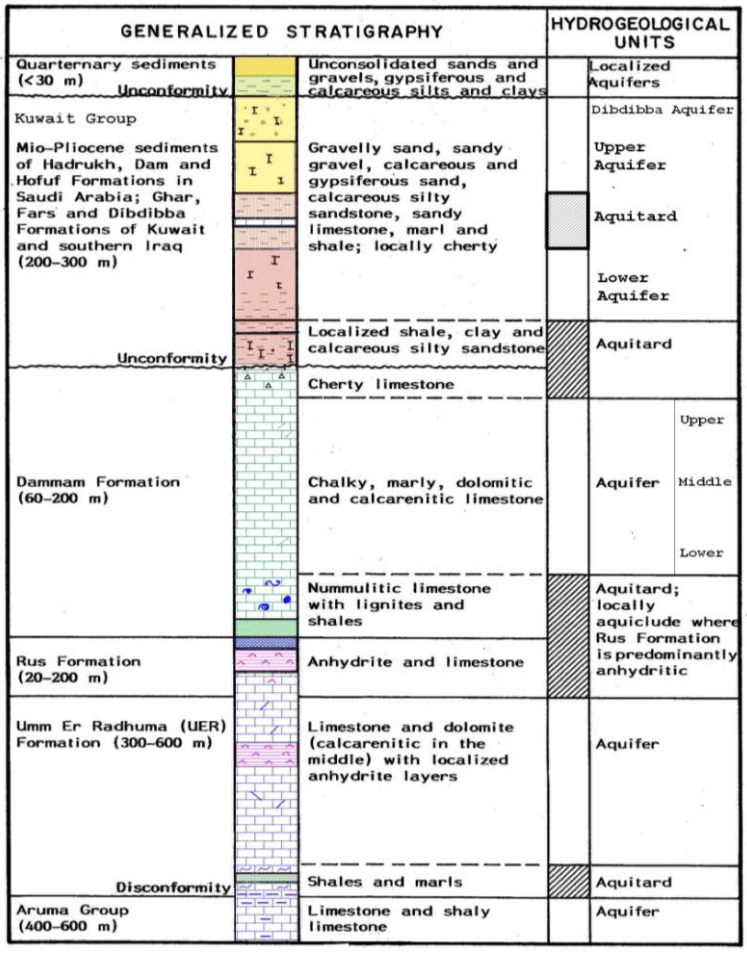

Figure 2. Starthraphy of the aquifers in the region

Sometimes the Pliocene and Miocene formations acts as a one hydraulic Unit called an aquifer in Kuwait named as Kuwait Group Aquifer. In this study, the emphasis is given to the Dibdibba aquifer which is Hofuf in Saudi Arabia. The average rainfall over this shared aquifer is about 100–200 mm/yr (ESCWA and BGR, 2013). Wadi Al-Batin is the major drainage system of the Dibdibba Delta (Fig. 1). Wadi Al-Batin is considered as a lineament as shown in Fig. 1. This feature from Saudi Arabia runs alongside the Kuwaiti political boundary into Iraq through paleochannels. Wadi Al-Batin lineament is a reflection of secondary permeability development in the aquifers underneath it.

Table 1. Names and lithology of Dibdibba in Kuwait, Iraq and KSA (UN ESCWA and BGR, 2013)

Period	**Formation Name and General Lithology, per Country**		
	Iraq	Kuwait	Saudi Arabia
Pliocene Upper Miocene	Dibdibba	Dibdibba	Hofuf
	Continental (Fluviatile): gravelly sand, often calcretized with subordinate clays.		
Middle Miocene	Lower Fars	Lower Fars	Dam (Ladam)
	lagoonal: alternating beds of limestone, anhydrite, gypsum, clay and marls with subordinate sandstone.	Continental (Fluviatile): calcretized sandstone.	Coastal (Shallow marine littoral with supply of clastics): sandy and silty clay, calcareous marl, fossilferous limestone, sandstone and shale.
Lower Miocene	Ghar	Ghar	Hadrukh
	Continental (Fluviatile): sands and gravels, rare clays, anhydritic and calcretic sands.		

The water levels of the aquifer are at relatively shallow depth. This encourages local people to exploit Dibdibba for agricultural purposes especially along the eastern bank of the Wadi al Batin and near the mouth of the delta where freshwater leakages from shallow lenses may occur. In Kuwait, almost the northern part of the country utilizes Dibbdiba. This is also true for Iraq in the southern country. In KSA, the population of the city of Hafr al Batin and other smaller communities survive on shallow groundwater from Dibdibba especially for agricultural use and development. UN ESCWA and BGR (2013) reported that the Dibdibba as a regional aquifer holds available water of 11 Billion Cubic Meter (Bm^3) as a reserve. This project investigated that the available reserve in Dibdibba aquifer in Kuwait only is 45 Bm^3.

The conceptual model

The grid (Fig. 3) of the numerical model of the study area covers around 59,218 km2. This includes urban areas around Hafr Al-Batin City (Saudi Arabia), part of Kuwait City (Kuwait) and Al-Basrah City (Iraq). At this very initial step, the finite difference grid is developed of equal size cells but these cells will be made smaller near the location the many pumping wells in the domain of the study area. Hydraulic gradient = 0.00018. The grid size was made uniform as 15000 m x 15000 m which is a reasonable size for a regional model.

Boundary conditions. **Fig. 3** illustrates the boundary conditions used in the model. The southern boundary, eastern and most of the western boundaries were assumed as no-flow boundaries. It is assumed that the eastern and western boundaries are almost parallel to the direction of groundwater flow. The political boundary between KSA and Kuwait and Iraq was simulated as a general head

boundary to allow additional influx to take place in response to the operation of the thousands of pumping wells in the study area. The northern boundary was assigned to have two parts of hydrogeological boundaries. One part is a general head boundary and the second part is a river boundary to reflect the hydrogeological meaning of Euphrates River and Shat Al-Arab part of the River in the study area. The boundary where there is a contact between the aquifer and the Arabian Gulf was modelled as specified head boundary.

Aquifer Geometry. The model treats Dibdibba Aquifer as one layer with an impermeable base. The bottom of this layer was assumed to be the top of the aquitard (Al-FARS in Kuwait and Iraq and DAM in Saudi Arabia) of marl and shale content of a very low permeability. Many geological cross sections were utilized to determine the total thickness of the modelled layer. It is about 130-400 m in Saudi Arabia, about 60-270 m in Kuwait and ranges between 100-200 m in Iraq.

Recharge from rainfall and wadi runoff. The recharge from rainfall and wadi runoff was assumed (based on chloride-bromide mass balance investigations) to vary between 5 to 11% of rainfall over Dibdibba outcrops. Recharge from rainfall is approximated about 300 Mm^3/yr.

Urban Recharge. The estimation of urban recharge was carried out based on analyzing the water supply volumes to the urban cities (Hafr Al-Batin, part of Kuwait City and Al-Basrah City) and the wastewater generated from these urban areas in order to approximate leaks from water supply and wastewater networks in the study area. Aliewi et al. (2019) showed that the urban recharge in Kuwait was estimated between 263 and 272 $m^3/d/km^2$.

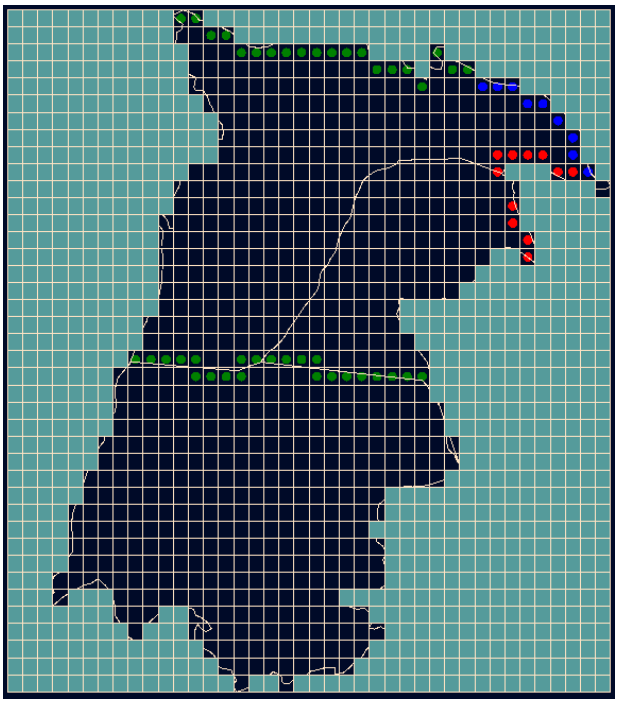

Figure 3. Model grid and boundary conditions of for regional Dibdibba Aquifer (green circles are flux general head boundary, red circles are constant head boundary, blue circles are river boundary)

Aquifer Properties. Initial aquifer properties as input to the model were taken from the pumping tests for thousands of wells in Kuwait, Iraq and KSA. A summary of the hydraulic properties of the aquifer is presented in Table 2.

Abstraction from the modelled area. There are thousands of wells in Kuwait, Iraq and Saudi Arabia. The annual groundwater abstraction of the regional/shared Dibdibba aquifer is around 370-

470 Mm^3/yr (UN-ESCWA and BGR, 2013). The distribution of wells in Iraq and Kuwait only is presented in Fig. 3.

Table 2. Reasonable Hydraulic Properties for the Modelled Aquifer (Aliewi et al., 2015; Atiaa and Aboodi, 2005; Al-Kubaisi, 1999, Al-Sulaimi and Pitty, 1995; Makkawi, 2010)

	T (m^2/d)	K (m/d)	Sy	S
Kuwait	170-840	1.4 to 7.0	0.05 to 0.20	$1x10^{-5}$ to $1x10^{-3}$
Iraq	81 - 1700	W = 7 to 140 E = 16 to 70	0.01 to 0.2	$1x10^{-5}$
Saudi Arabia	100-600	1.1 – 6.3	-	-

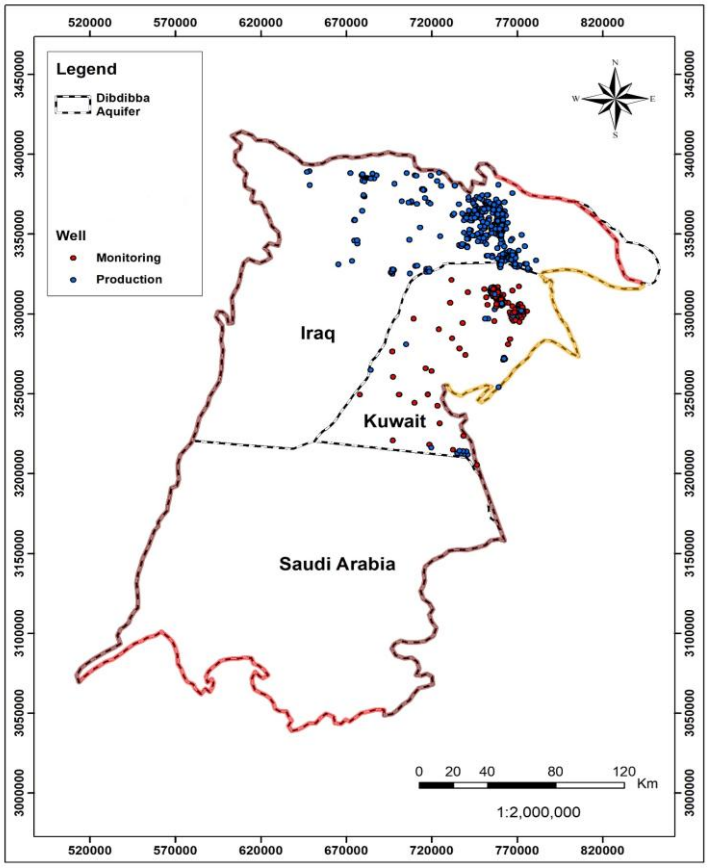

Figure 3. Wells in the study area (wells in the Saudi arabia are classified)

Initial water levels.

The initial water levels were in Kuwait prior to heavy development of pumping schemes in 1960 varies between about 10 m asl in northeast to 100 m asl in southwest. In KSA varies between 18 m asl to 250 m asl. However in the far south end of Dibdibba aquifer in KSA, the static watyer level may reach up to 400 m asl. In iraq, the initial water level was taken from wells shown in Fig 3 to vary between (-11) to (26) m asl.

4 CONCLUSIONS

A reasonable conceptual model for the Dibdibba as a regional aquifer between Saudi Arabia, Kuwait and Iraq was developed based on the available data from literature and from many existing wells that were made available for this study. This conceptual model is essential to develop a steady

state model and a transient model for the regional aquifer of Dibbdiba. The models that will be developed for future studies will aim at estimating the sustainable yield of the regional aquifer in order to develop reasonable utilization plan for the brackish water of this aquifer.

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