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A Field Study of Changing Groundwater Levels in South Jeddah, Saudi Arabia

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Abstract— *The problem of changing groundwater levels in Jeddah had been a subject of several studies in the past. However, conflicting results in the annual groundwater rise still persists. Also, there is not one recharge mechanism responsible for the rising water table for the entire city and it is still to be determined which mechanism is responsible for which part of Jeddah so that an effective remedial measure could be selected appropriately. This field study focuses upon the groundwater level data obtained from 44 water wells located in South Jeddah. The analysis of groundwater levels reveals that although no significant change in the water levels has been observed in South Jeddah, a complex pattern of rise and fall in water levels does exist in several parts of the study area. The rise in water level is primarily associated with the exfiltration from cesspools in the areas where no drainage system exists. Overall, there is some sort of equilibrium established between the recharge and discharge mechanisms in South Jeddah.*

Keywords— *Groundwater, water table, recharge, sewage water.*

I. INTRODUCTION

Jeddah City, located in the eastern shore of the Red Sea, between latitudes 21˚ 54 , 21˚ 30ˈN and longitudes 39˚ 06, 39˚ 38ˈE covers an area of about 1650 km^2. Jeddah is aptly known as the gateway to Makkah and has now grown to the second largest cities (after the capital, Riyadh) of the Kingdom of Saudi Arabia with a population of approximately 3.5 million (STATS, 2010). Also, Jeddah serves as the entry point for pilgrims to Makkah coming from all over the world. Therefore, the City has witnessed a rapid development of infrastructure over the years. At present, metro rail project connecting Jeddah with the holy cities of Makkah and Madinah is in the final stage of its completion.

Groundwater level rise has been observed in Jeddah since 1980s and has been the subject of several investigations. For example, on the basis of a study done in 1984, Abu Rizaiza and Hasan (1989) conclude that the annual groundwater rise in Jeddah is 0.5 m. They attribute this rise in water table to the seepage of waste water from cesspools. Abu Rizaiza and Hasan (1989) suggest the horizontal drainage as a preventive measure and recommend vitrified clay pipes to be laid out because of their resistance to corrosion. Qari and Shehata (1994) point to a remarkable growth in the extent of sabkhas over the last 50 years. The growth of sabkhas is commonly associated with the rising of water table. The close proximity to the Red Sea suggest that sea level changes in the Jeddah region need to be monitored carefully (Vincent, 2003).

Bayumi and Alyamani (2003) conducted an analytical study of flood problem and groundwater rise in Jeddah. The study listed several factors that might have contributed to the rise in groundwater and also highlighted the hydrogeologic properties of the underlying shallow coastal plain aquifer. The factors mentioned by Bayumi et al. (2000) were further supported by Basmad (2001). Based on his research, Basamed (2001) made a list of seven factors that are responsible for the rise of water table in the north of metropolitan area of Jeddah. They included 1) leakages from water supply systems, 2) exfiltration from cesspools, 3) rainfall recharge, 4) excess landscape irrigation, 5) leakage from underground storage tanks, 6) subsurface inflow from the eastern wadis and 7) hydrogeological influence.

Although the problem of rising groundwater levels in Jeddah had been a subject of several studies in the past, conflicting results in the annual groundwater rise still persists. Also, there is not one recharge mechanism responsible for the rising water table for the entire city and it is still to be determined which mechanism is responsible for which part of Jeddah so that an effective remedial measure could be selected appropriately. The efforts done by Bayumi et al. (2000) are laudable as the study mentioned almost all the factors responsible for rising groundwater. Basamad (2001) mentioned the same factors discussed earlier by Bayumi et al. (2000) for the rise in water table. However, Basamed (2001) findings hold good for the North Jeddah, only. Therefore, there is an urgent need to carry out a changing groundwater levels study for the South Jeddah that could identify the recharge mechanism for different zones (Subyani and Al-Modayan, 2012).

II. MATERIALS AND METHODS

2.1 Study Area

Figure 1 shows the location of the study area. It consists of southern part of the City of Jeddah along the Red Sea and covers an area of approx 817 km^2. The southern part of Jeddah was selected for this study because this area was not a subject of any recent groundwater study. The coastal area is densely populated. The surface topography rises from zero at the Red Sea to about 350 m at the mountainous area to the east. The small wadis flow towards the coast making their way through the alluvial plains. The urban development done on the expense of wadi beds and alluvial plains have converted these otherwise permeable area to impermeable areas and was the major cause of Jeddah catastrophic flood in 2009 (Al-Akhaly, 2013).

Jeddah is located between two major wadis, namely, Wadi Fatimah in the south and Wadi Usfan in the north with several local wadis that make up Jeddah basin. Generally the climate is arid, hot in summer with high rates of humidity and warm in winter. The rainfall is scanty with temporal and spatial variations. Its occurrence is in winter, spring and late fall seasons. Jeddah received unexpected amounts of rainstorms of 80 and 124 mm/day on 25 November 2009 and 26 January 2011, respectively (Subyani and Hajjar, 2016).These short and high intense rain storms are causes of interactions concerning environmental, socio-economic, groundwater rise and cultural life of Jeddah City.

Jeddah is not known to have any underground drainage system. Also by 2000, only 21 percent of Jeddah was connected to an underground sewer system (Vincent, 2003).

Fig. 1. Location of the study area.

2.2 Hydrology

Jeddah Basin lies in the western part of the Arabian Shield on the shores of the Red Sea. In the study area, its height ranges between zero at the sea level to 110 m at the eastern part of the basin.

Figure 2 shows the drainage networks of the wadis near Jeddah (Subyani, 2012). It is divided into 4 major basins namely:

(1) South basin that includes Wadi Ghulail, Wadi Mathwab, Wadi Ushair and Wadi Qus,

(2) Bani Malik basin includes Wadi Al-Asla and Wadi Murayykh,

(3) Burayman basin including Wadi Hitil, Wadi Burayman and Wadi Hablain, and

(4) Al-Kura' basin with Wadi Ghurrayah and Wadi Al-Kura.

The wadis present in the South and Bani Malik basins flow to the west and pass through parts of South Jeddah (Subyani and Al-Modayan, 2012). The wadi beds of these basins have been converted into new urban areas thus changing the groundwater levels. Also, the water consumption and disposal might have changed the groundwater quality of the area.

The elevation of the eastern part of Jeddah ranges between 60 m and 350 m above sea level; steep-sided wadis dissect the mountains region, many of which are strongly controlled by series of tectonic events.

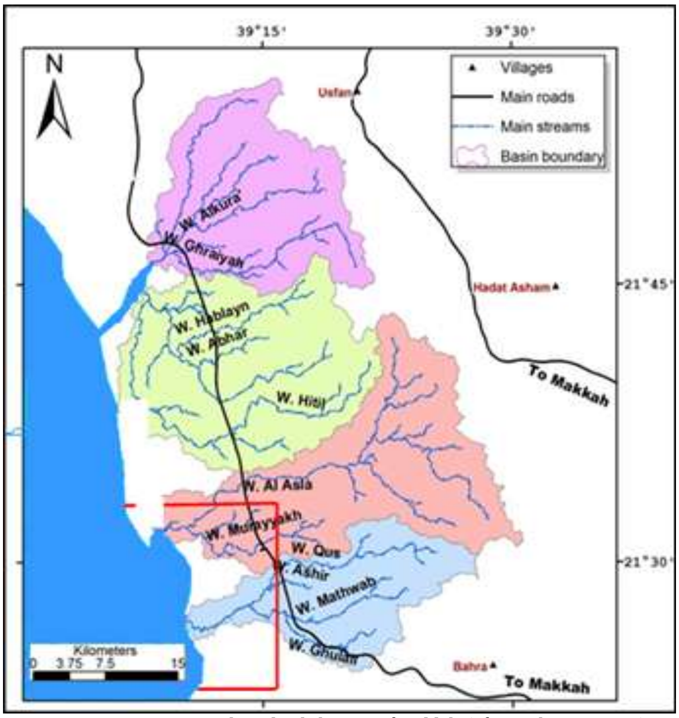

Fig. 2. Drainage network and sub-basins of Jeddah (after Subyani, 2012).

2.3 Groundwater Field Studies

44 wells were visited during the field survey. Figure 3 is a map showing the location of these wells. The survey consisted of measuring coordinates (longitude and latitude), elevation, total depth and depth to water table along with the well diameter.

Before measuring the depth of groundwater, the well was purged three times, by draining unclean water for almost an hour. A pump fitted with hoses was used for this purpose. Then the well was left for some time to recuperate until it was full again to reflect the real level of groundwater. A Solinst® water level meter was used to measure water level.

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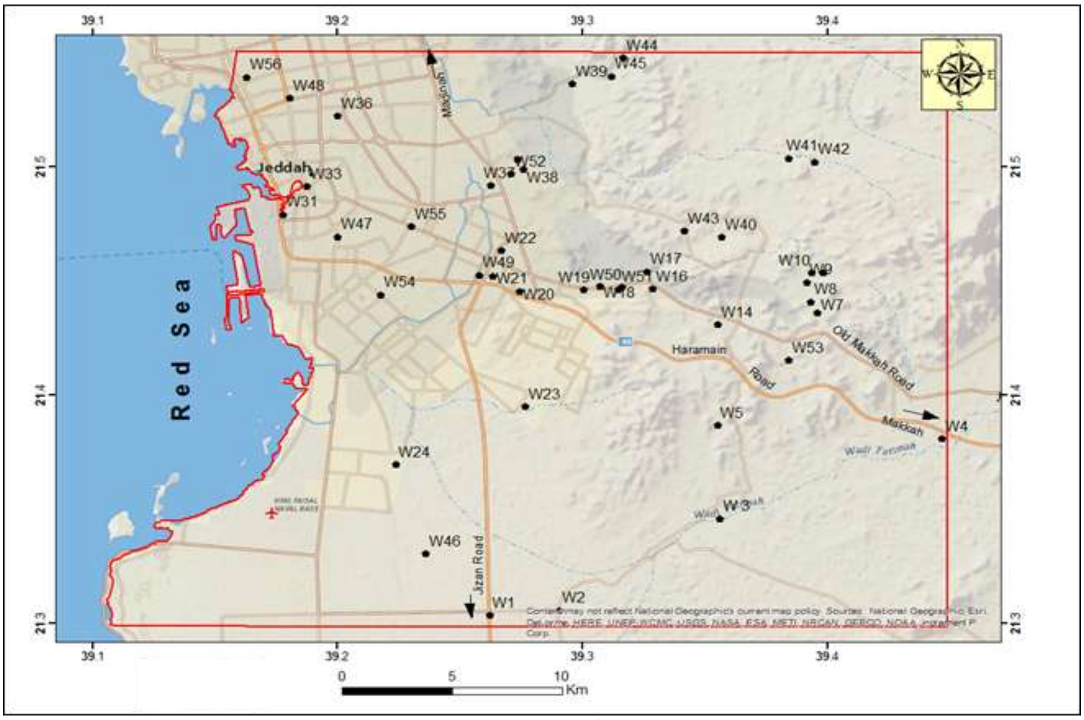

Fig. 3. Groundwater wells of the study area.

III. Results and Discussion

Figure 4 shows the groundwater level map of the study area. The groundwater levels were measured in March 2015. The general groundwater flow direction is towards the west.

The water levels were measured in 44 wells twice during this study. The time span between the two measurements was about 7 months (September 2014-March 2015). The rise or fall in water level is plotted in Figure 5 (fall is indicated by – sign).

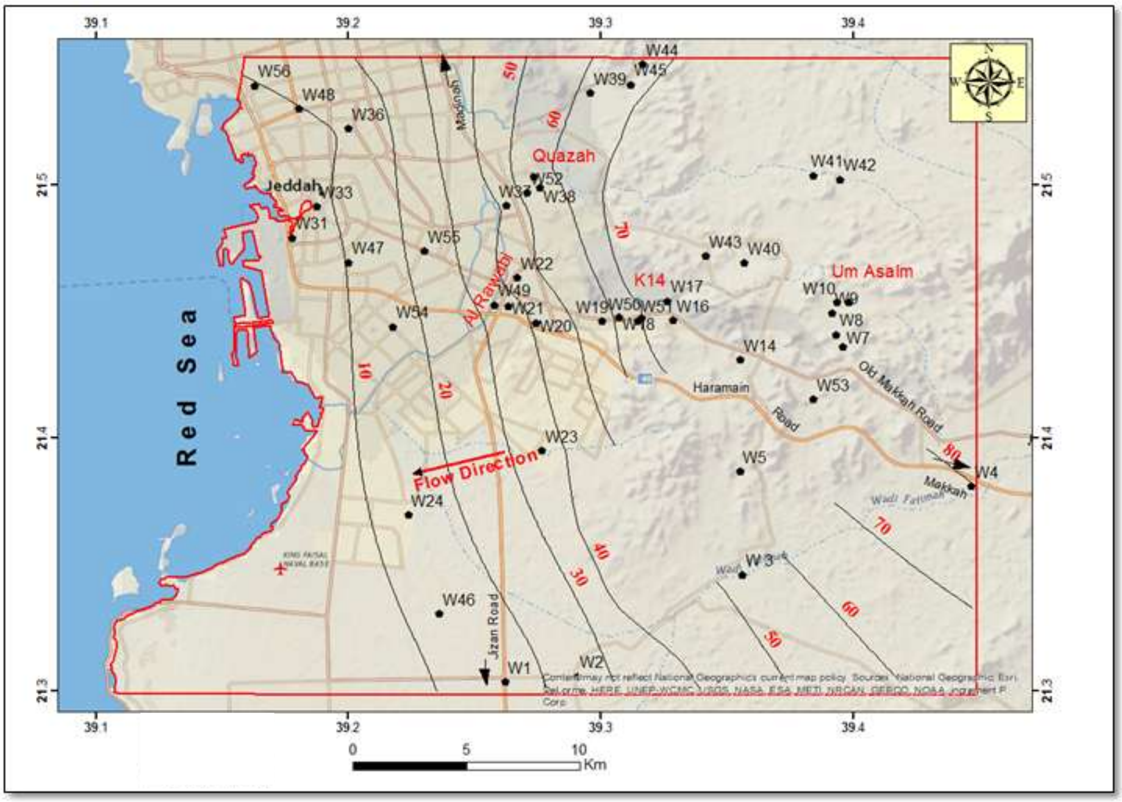

Fig. 4. Groundwater level map of the study area.

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A total number of 22 wells show that the groundwater is rising. However, almost equal number of wells (21 wells) indicate that the groundwater is falling. Only one well (W48) recorded neither a fall nor a rise in groundwater. The maximum rise of 0.35 m was seen in W30 while the maximum fall of 0.7 m witnessed in W45. On average, the water level was found to be falling annually by 0.01m.

Figure 5 does not show any trend and it seems that the groundwater levels are rising or falling without any regular pattern.

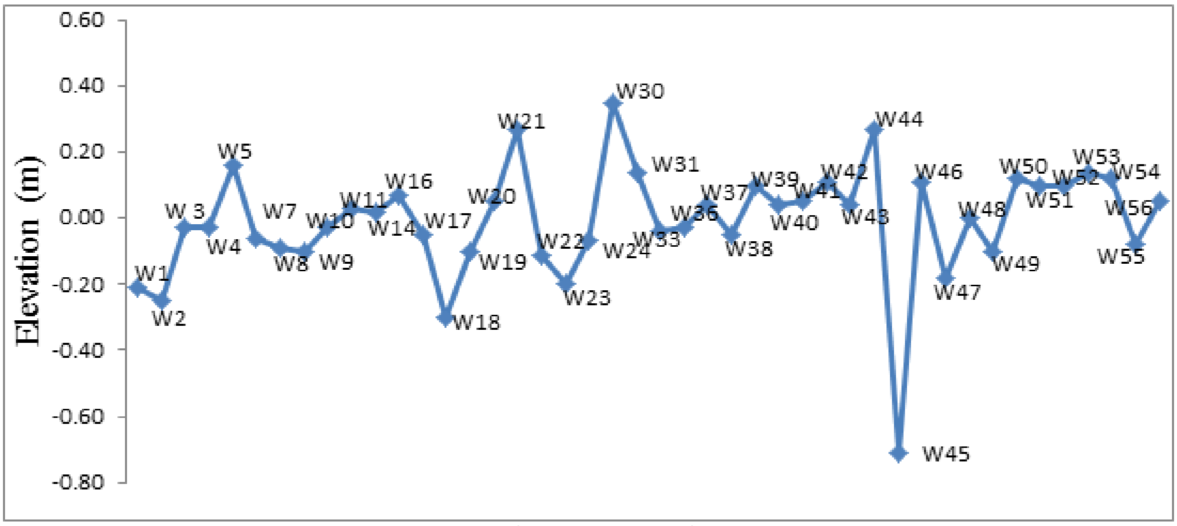

Fig. 5. The rise or fall in water levels of the study area.

Although the data was collected from 44 wells, the water level measurements represented dynamic conditions for most of the wells. The privately owned wells were already being pumped when the measurements were made. In order to overcome the shortcomings emerging from the dynamic nature of water table measurements over a short time frame, long term data was selected.

A total number of 11 wells were used for calculating long-term variations in groundwater. They were drilled by the AECOM for Jeddah Storm Water Drainage Program (Khatib and Alami, 2010). They were not being pumped when the measurements of groundwater levels were made and thus represented the static water table.

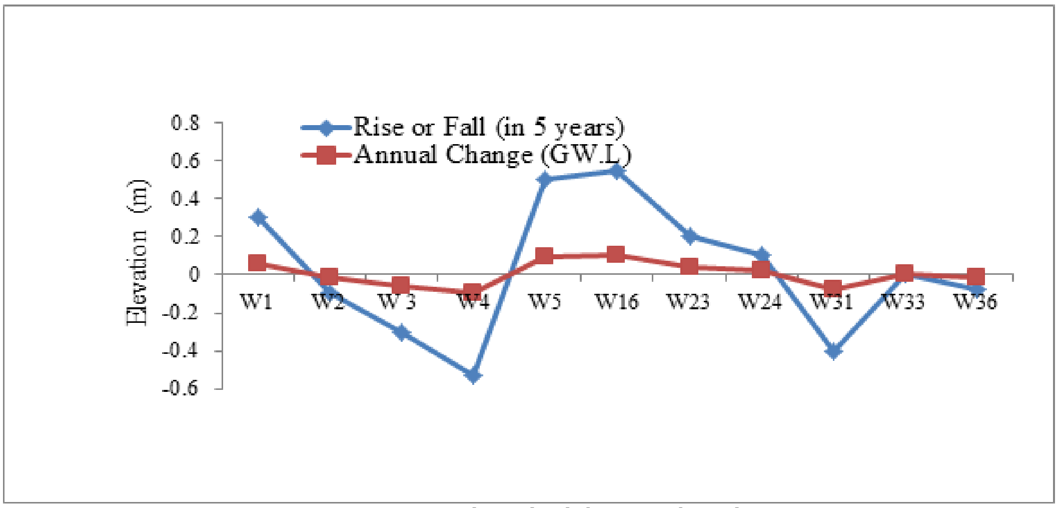

Fig. 6. Long-term groundwater level changes in the study area.

A comparison was made between the groundwater level measurements made in 2010 with March 2015. The rise or fall in groundwater levels is plotted in Figure 5. Five wells (W1, W5, W16, W23, and W24) show a rise in groundwater level. An equal number of wells show fall in groundwater level. These wells are W2, W3, W4, W31, W33, and W36. The results indicate a minor rise in the groundwater levels with an yearly rate of 0.001 m. To find any possible trend in rise or fall values, data from W1 to W5 was studied in detail. These wells lie on one axis (NE-SW). The data reveals that W1 located to the west of the remaining wells show a rise in water levels while water levels continue to fall while going to the east. The rise in water level seen at W5, W16, W23 and W24 (located in K14, As Snabel and Khumrah districts) is primarily due to the exfiltration from cesspools as no drainage system is present for these areas. This fact is supported by high concentration of E-Coli found (Gaid, 2017) in these areas (Figure 7). This may be due the mixing of sewage water with groundwater. Overall, a rise of 0.001 m/year of water level indicates that there is some sort of an equilibrium established between the recharge and the discharge mechanisms for South Jeddah area.

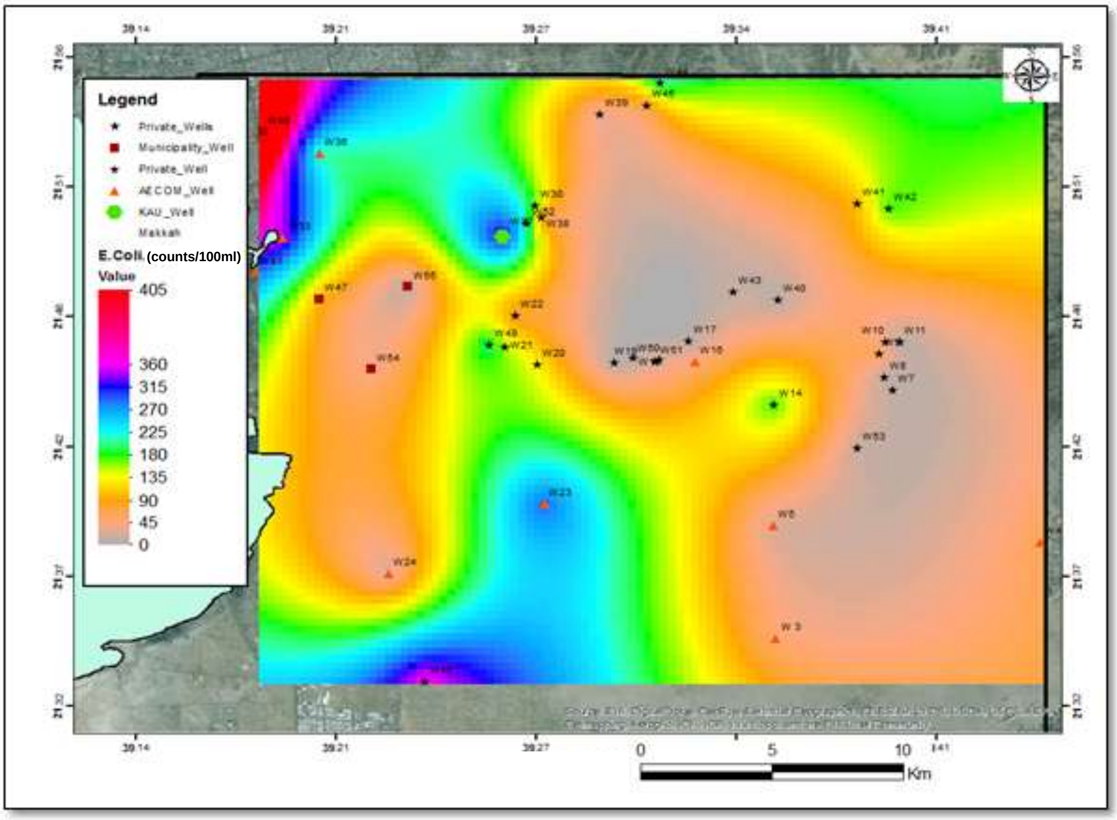

Fig. 7. E-coli map of South Jeddah (Gaid, 2017).

IV. Conclusion

The overall groundwater levels has not changed much indicating an equilibrium established between the recharge and discharge mechanisms for the entire study area. However, a complex pattern of rise or fall in water levels exist in parts of the study area. The rise in water levels is primarily associated with the exfiltration from cesspools.

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