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Monitoring and assessment of the groundwater quality in wadi Al-Arish downstream area, North Sinai (Egypt)

Alaa A. Masoud [a,*], Ebtesam A. Meswara [a], Mohamed M. El Bouraie [b], Samir Z. Kamh [a]

[a] Geology Department, Faculty of Science, Tanta University, Tanta 31527, Egypt

[b] Central Laboratory for Environmental Quality Monitoring (CLEQM), National Water Research Center (NWRC), El-Qanater El-Khairiya 13621, Egypt

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ABSTRACT

At a rate of 3 samples a year over 7 years (2008–2014), groundwater quality indicators for 294 samples from 14 groundwater supply wells located on the delta of Wadi Al-Arish, North Sinai (Egypt) were measured and analyzed. The prime objective was to characterize significant and sustained trends in the concentrations of the pH, TDS, Total Alkalinity, Fe^{2+}, Mn^{2+}, Zn^{2+}, NO_3^-, K^+, Pb^{2+}, Al^{3+}, and fecal coliform (FC). Detection and estimation of trends and magnitude were carried out applying the nonparametric Mann-Kendall and Thiel-Sen trend statistical tests, respectively. Geostatistical kriging implemented in ArcGIS 10× was appraised for the spatial distribution of the indicators and their sustained trends. Factor analysis was applied to identify significant sources of quality variation and their loads.

Average contents of all indicators exceeded the permissible limits except for Mn. Violation of groundwater quality standards clarified emergence of FC (99.6%), Pb^{2+} (76.8%), TDS (60.2%), Al^{3+} (56.6%), NO_3^- (46.5%), Fe^{2+} (37.5%), and Mn^{2+} (14%). Out of the 14 wells, notable upward trends (deterioration) were significant (>95% level) for Mg^{2+} (100%), TDS (78.5%), NO_3^- (71.42%), Zn^{2+} (42.85%), pH (14.28%), K^+ (14.28%), and 7.14% for Al^{3+} and FC. Ranges of attenuation rates (mg/l/year) varied for TDS (52.61–37.59), Mg^{2+} hardness (3.81–0.14), K^+ (0.58–1), pH (0.004–0.027), total alkalinity (−1.89-13.18), NO_3^- (1.47 −0.69), Al^{3+} (0.002–0.011), Fe^{2+} (−0.001-0.016), Mn^{2+} (−0.00004-0.01), Pb^{2+} (−0.00001-0.002), Zn^{2+} (0.049–0.018), and FC (5.25–22) in cfu/100 ml.

Out of the 14 wells, well no. 9 showed the largest increasing attenuation rates (mg/l/year) that marked NO_3^- (1.47), K^+ (0.58), pH (0.004), and Al^{3+} (0.002). TDS showed the largest rates of increase of 52.61, and 28.26 for well nos. 5 and 9, respectively. FC showed the highest rate of deterioration of 5.25 in well no. 10. Zn^{2+} recorded strong deterioration rates of 0.049, and 0.046 for well nos. 12 and 9, respectively. Four factors were found to explain 60.48% of the total variance of the quality variables and in particular, a significant load of TDS, Cl^-, EC, SO_4^{2-}, Na^+, Ca^{2+}, Mg^{2+}, NO_3^-, K^+, Pb^{2+} and Total Alkalinity in decreasing order of influence were identified. Variation in quality parameters originated from anthropogenic sources due to improper well head protection in the urban centers or from the agricultural wastes and the flash floodwater stagnation and intense evaporation in low relief areas.

1. Introduction

Groundwater is an important source of water for industrial production and domestic use that has been a key driver for the geographical location and development of cities. Groundwater pollution implies a loss of usable water resources with an alternative cost, impairment of water uses, including irrigated crop yield decrease, and increased expenses for water quality correction and for aquifer remediation, often with limited success.

Groundwater is the major source of drinking water in urban and rural areas and used commonly for agricultural and domestic uses in many arid areas like in North Sinai (Egypt). The combination of water scarcity yet pollution of the available water sources could be one of the worst resource crises Egypt faces. Studies are urgently needed devoted to raising awareness of the public, decision makers and managers on the value of groundwater, the cost of degrading its quality, the large expenses needed for restoration – if feasible at all –, the cost of what is irreversibly lost, and the methods of protection.

* Corresponding author.
E-mail address: alaa_masoud@science.tanta.edu.eg (A.A. Masoud).

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Periodic monitoring of groundwater quality therefore became necessary to meet quality standards for safe use. Environmental monitoring of groundwater is routinely conducted in areas where the risk of contamination is high and for protecting human health and the environment following an accidental release of hazardous constituents. Groundwater monitoring strategies are designed to establish the current status and assess trends in environmental parameters, and to enable an estimate of the risks to human health and the environment (Jones et al., 2014).

Statistical trend analysis proved promising in investigation sustained trends in groundwater quality parameters. Mann Kendall test is a statistical test widely used for the analysis of trend in climatologic (Mavromatis and Stathis, 2011) and in hydrologic time series (Yue and Wang, 2004). True slope in time series data (change per unit time) is estimated by procedure described by Sen (1968) in case the trend is linear. Monotonic trends; increasing, decreasing, or constant are then derived and slopes define the attenuation rates of contaminants.

Factor analysis proved significant in clarifying the factors governing the spatial variability of the quality parameters contents that have impact on the groundwater quality and its hydrochemical processes (Dalton and Upchurch, 1978; Alyamani et al., 1994; Suk and Lee, 1999; Helena et al., 2000; Pereira et al., 2003; El Alfy and Merkel, 2006; Masoud, 2013). First few factors explaining the highest variance are placed foremost, interpreted and linked to a specific hydrochemical process.

The prime objective of the present research is to characterize significant and sustained trends in the concentrations of the groundwater quality indicators in the downstream area of Wadi Al-Arish area, North Sinai (Egypt) and to investigate the factors affecting the variability of indicators.

2. Study area

Located in North Sinai, Wadi Al-Arish basin is considered to be one of the most important geographical features of the Sinai Peninsula. It is the largest drainage basin in Egypt and involves around 33% of entire Sinai (Abdel Ghaffar et al., 2015). The basin covers an area of about 23,798 km^2 (Fig. 1). It flows toward the Mediterranean Sea and its downstream part is Al-Arish City. The climate of the basin exhibits arid to semi-arid conditions sometimes with heavy rainfall that causes flash floods in winter. Geologically, Wadi Al-Arish's surface is covered by several outcrop rock units. It starts from the southern mountainous and rocky terrains of very steep slopes, then goes through the flat sedimentary areas in the middle, and finally ends at the sand dunes near Al-Arish city in the north (Shatta and Attia, 1994). The area is covered by Quaternary (Pleistocene and Holocene), Tertiary and Cretaceous sedimentary rocks (Fig. 2). Holocene deposits include stabilized sand dunes and alluvial wadi deposits while Pleistocene deposits include alluvial deposits and calcareous sandstone (El-Bihery and Lachmar, 1994). The Tertiary Lower Eocene rocks are fossiliferous limestone with chert bands (Conoco Coral. 1987) while the Paleocene sediments are green laminated shales. Cretaceous-Paleocene sedimentary rocks consist of marine chalk with shale intercalations. The upper cretaceous rocks consist of alternate beds of clastic carbonate or argillaceous limestone and shale. Barely and olives are the dominant normal cultivation in the fertile wadi deposits and in the newly-reclaimed lands close to mountains (Fig. 3 a & b). Flash floods are frequent in winter, the floodwater is harvested by Rawafaa man-made dam (Fig. 3c) before it destructs the main roads on the wadi floor when exceeding the capacity of the dam (Fig. 3d). Flood water accumulates in local depressions located after the dam on the wadi course close to well no. 9, the cyclic intense evaporation of such water with the close water table to the ground surface result in waterlogging (Fig. 3e) that leads to severe salinization of the underlying and neighboring soils (Fig. 3f).

Comprehensive studies carried out on Wadi Al-Arish that varied between determining the relationships of the groundwater pumping rates to the variation in the water levels and water quality (El-Bihery and Lachmar, 1994), detecting areas of likely groundwater potential incorporating satellite imagery and GIS (Smith et al., 1997), evaluating the extent of alternative renewable groundwater resources arising from sporadic precipitation (Gheith and Sultan, 2001), evaluating the impact of flash floods on the hydrogeological aquifer system by increasing the water level between 10 cm and 2.3 m and decreasing the salinity (Hassan, 2011), assessing the deterioration in the groundwater levels decline due to the abstraction amounts exceeding the natural recharge which depending mainly on the annual amount of rainfall (Abdelaziz and Bakr, 2012), mapping the potential areas suitable for the runoff water harvesting, the optimum sites for implementing its suitable constructions and the water/land use priority areas for development (Elewa et al., 2013, 2014), developing mathematical model of the transport in subsurface of salts dissolved in the sediment water (Saad and Abd El Aal, 2015), and evaluating the potentiality of soil and water resources (Abdel Ghaffar et al., 2015). There is a lack of studies devoted to the evaluation of the groundwater quality variation in space and time in Sinai despite these are deemed necessary for effectively setting future management and sustainable development plans of the groundwater resources.

3. Data and methods

3.1. Data inventory and preprocessing

Two hundred ninety-four groundwater samples from 14 wells had been collected at a rate of 3 samples a year in the period (Nov. 2008–2014) at 21 samples from each well. These wells have depths ranging from 109 to 127 m. All groundwater samples were collected in clean and sterile polyethylene plastic bottles, which were previously soaked in 10% nitric acid solution and thoroughly rinsed several times with distilled water and finally with a portion of the water sample. In all cases, well water pumps were opened for some little time before taking the samples. All samples were tightly sealed, labelled and immediately taken to the laboratory for analysis. Samples were analyzed for their chemical and physical constituents such as pH, TDS, EC, Total Alkalinity, Na^+, Mg^{2+}, Ca^{2+}, K^+, Cl^-, NO_3^-, SO_4^{2-}, Fe^{2+}, Mn^{2+}, Zn^{2+}, Pb^{2+}, Al^{3+}, and fecal coliform (FC) contents. Sampling analysis was carried out according to standard methods for examination of water and wastewater according to American Public Health Association “APHA” (2005). The measurements of physiochemical parameters (pH, EC, and TDS) were carried out in the field using portable instruments. The pH of water samples was measured using digital portable pH meter, using a glass combination electrode saturated with KCl. Digital conductivity meter was used for measuring values of EC and TDS. Na^+ and K^+ concentrations were determined by flame photometric method. Major anions concentrations (Cl^-, SO_4^{2-}, and NO_3^-) were determined using Ion Chromatography (IC), model DX-500 USA chromatography system. Heavy metals (Fe^{2+}, Mn^{2+}, Zn^{2+}, Pb^{2+}, and Al^{3+}) were measured using Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES) with Ultra Sonic Nebulizer (USN). The ICP-OES model is Perkin Elmer optima 3000, USA. Carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-) were determined by titration a known volume of water against 0.02 N standard sulfuric acid solution using phenolphthalein and methyl orange as indicators. Ca^{2+} and Mg^{2+} cations were determined through total hardness test and calcium hardness test. The titration hardness test involves pH adjustment to 10 with ammonium buffer, addition of Eriochrome Black T (EBT)