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Impact of Waste and Industrial Effluent on Ground Water Quality Index in Rabigh Area, Makkah Region, Kingdom of Saudi Arabia

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The quality of surface water and groundwater has deteriorated as a result of increased industrialization, urbanization and agricultural practices during the last few decades. Contaminated groundwater can cause major health problems in humans, such as typhoid and other infections. Similar in the case of Rabigh Governorate, the groundwater is one of the main sources of water for domestic and agriculture purposes in its villages situated in western Saudi Arabia. Many factories have been established in Rabigh region in recent years and day to day input of numerous untreated/partially treated water resulting in major environmental problems, one of which is the low quality of groundwater causing serious environmental and health issues. The presented study discusses the ground water as the main available and usable source in extremely climatic condition of arid area of Saudi Arabia. The article proceeds with the brief introduction of ground water, its contamination sources and health hazards. For this, 13 water samples were from the randomly selected wells in Rabigh Governorate for quality examine. Water quality index analysis was conducted, which is a useful technique for fast assessment of the quality of any water resource. Various physical and chemical parameters of water quality index such as pH, temperature, conductivity, turbidity, total dissolved solids (TDS), total suspended solids (TSS), total solids (TS), dissolved oxygen (DO), arsenic and *E. coli* are measured and analyzed. The values of all groundwater samples are compared with the standard WHO permissible values. The water quality of the wells were classified into "good, poor, very poor and unsuitable for drinking" based on physico-chemical parameters. According to the observed study, water quality range (WQR) for 5 samples (38% of the samples) are of poor quality, 3 samples (23%) are recorded with a very poor quality and 5 samples (38%) are not suitable for drinking purpose due to presence of high conductivity and TDS values. After taking into consideration the presence of *E. coli* in 31% of the samples (n = 4), about 62% of the samples (n = 8) are not suitable for drinking purpose, only 23% (n = 3) samples are of poor quality and 15% (n = 2) are very poor quality. The findings reveal a decrease in water quality (unsuitable for drinking purpose) in 8 out of 13 collected samples. It is believed that waste and industrial activities have an impact on groundwater quality in the study area, however, a nationwide investigation should be conducted to validate this finding.

Keywords: Groundwater, Water quality index, Water quality, Health hazards, Turbidity, Rabigh, Saudi Arabia.

INTRODUCTION

Water is an essential natural resource and life began in it 3.2 billion years ago. Water makes up two-thirds of a living organism and also makes up 90% of cell composition. Aqueous media is required for biochemical processes in living organisms. As a result, water is critical for the survival of all living species [1]. Saudi Arabia, as a geographical location, is desert and notorious for its scorching heat and wide changes in humidity between the coastal belts and the interior. Low rainfall; high daytime temperatures of 45-48 ºC and above; very high (potential) evaporation rates; surface water is uncommon and only found in oases. Surface water flows are rare and when they do occur, they are usually in the form of floods. Because there is little natural soil water available to growth, the native flora is similar to that of other arid regions around the world; many of the soil types can be classed as soils found in arid areas. Rainfall, groundwater, fossil water, artificial sources of water, such as desalination and waste water treatment and imported water all provide significant amounts of water to Saudi Arabia as a political entity. Regardless of these vast resources, Saudi Arabia faces a severe problem: future water demand is expected to overwhelm availability and current consumption is already exceeding replenishment rates [2]. The impact on water supplies has been compounded by rapid population growth and socio-economic advancement as well as climate change. The mismatch between available water supplies and ever-increasing demands for clean water for human and industrial needs has become a major worry as water managers struggle to properly manage limited water resources, particularly in arid and semi-arid nations. Groundwater becomes a leading source of water to service domestic, industrial, commercial and irrigation sectors in dry and semi-arid climate zones where precipitation is low and evapotranspiration rates are high, especially in areas where perennial rivers are absent, such as Saudi Arabia [3,4].

Groundwater is the most useful source of water among all the water resources (surface, under river flow, ground and frozen (glaciers and ice) water). Ground water, which accounts for around 20% of the world's fresh water supply and 0.61% of all water, is one of the most important sources of drinkable water around the world [5]. Groundwater is the most exploited source of fresh water in every area, including agriculture, industry and domestic use. Fresh water supplies in an arid region like Saudi Arabia are limited to the groundwater system due to infrequent rainfall and significant evaporation rates due to exceptionally high temperatures [6]. Unfortunately, growing groundwater extraction from numerous alluvial aquifers exposes them to contamination activities [7]. This pollution reduces the amount of water available from the ground [8]. Furthermore, increasing industrial expansion and agricultural advancements contribute significantly to uncontrolled groundwater depletion and poor water quality [9]. Groundwater contamination is also caused by the uncontrolled disposal of industrial and urban waste, as well as the use of chemical chemicals (fertilizers, insecticides and herbicides) [10]. Water pollution is a severe problem in many developed countries and several river basins have been discovered to have excessive organic matter concentrations. Untreated sewage and industrial waste put significant strain on water quality in rapidly industrialising countries like India, China and Brazil [11].

Water pollution is caused by two types of sources: point sources and non-point sources. Factories, wastewater treatment facilities, septic systems, industrial properties, municipalities, agricultural installations, manure storage and landfills are all examples of point sources that discharge pollutants directly into water sources. These point sources can be discovered and regulated more readily. Non-point sources include runoff from farms, fields, construction sites and mines, which includes silt, fertilizer, pesticides and animal faeces. Diffuse (non-point) sources include rainfall-induced nitrate and pesticide leaching into surface and ground water, soil infiltration and surface run-off from agricultural land. These types of sources generate significant fluctuations in the pollutant load of water over time [12]. Due to limited water resources in Saudi Arabia, climate change has presented a new problem for water management. The use of groundwater from deep underground aquifers adds to the depletion of water sources that have taken hundreds of years to accumulate. Furthermore, precipitation has no direct effect on recharging the aquifers in this location [13,14].

Assessing the impact of anthropogenic or human activities on groundwater quantity and quality is critical for long-term groundwater resource management. Over-exploitation and poor groundwater quality, influenced by sanitary land filling, unlicensed solid waste dumping and waste water disposal, as well as saltwater intrusion and rising sea levels, have been a growing problem and have garnered special attention over the last two decades [15,16]. Thus, the quality of natural water surfaces and ground water has altered in recent decades as a result of urbanization, industrial activity and other factors that often produce pollution that has severe consequences degraded quality of water [17].

In Saudi Arabia, the quality of groundwater in close vicinity has received a lot of attention during the previous two decades. A number of researchers have reported the assessment of groundwater suitability for irrigation [18,19]. Alfarrah & Walraevens [20] observed that as a result of rising anthropogenic activities connected with population growth, there is a growing demand for groundwater. The main objective of this research is to investigate into the impact of waste and industrial effluent on ground water quality index in Rabigh, Makkah area, Saudi Arabia. For this purpose, 13 water samples were collected from different places in the region of Rabigh. *in situ* measurements for physico-chemical parameters including pH, temperature, conductivity, turbidity, total dissolved solids (TDS), total suspended solids (TSS), total solids (TS), dissolved oxygen (DO) and arsenic were carried out. This work supports the establishment of a consistent long-term monitoring network and management programme and plan, to successfully manage the groundwater in a sustainable manner in Rabigh, Makkah area, Saudi Arabia.

EXPERIMENTAL

Study area: The study was conducted in Rabigh Governorate, province of Makkah, Saudi Arabia (Fig. 1). Rabigh is an old Saudi Arabian town (Makkah Province) situated on the east coast of the Red Sea, (22º48′N, 39º02′E) having an estimated population of 180,352 and is known for its very hot summer and mild winter. Due to the strategic location of Rabigh on the Red Sea, it counted as one of the most important industrial and economic cities in the Makkah region of Saudi Arabia. It contains an industrial city including many petroleum crude refineries, plastics and petrochemical industries and has been the site of several high-profile projects such as the King Abdullah University of Science and Technology, Petro Rabigh and King Abdullah Economic City [21].

Sample collection: Thirteen samples from different wells in Rabigh governorate and its villages was collect on 27 March 2021. Each sample was about 1 L and preserved in a dry plastic bottles after measuring and recording their temperature. The samples were stored in ice boxes immediately and transported to the regional laboratory of the National Water Company in Jeddah to perform the required analyses.

Analysis for water quality parameters: Groundwater samples analysis were performed at the National Water Company. These analyzes included many tests such as, pH, turbidity, electrical conductivity, TSS, TDS, total solid, DO, arsenic and *E. coli*. The pH and temperature were determined by using a pH meter (model Sension, HACH), turbidity was measured

Fig. 1. Location of the study area (Source: google maps)

with a turbidity meter (model 2100Q, HACH). The electrical conductivity was measured by a conductivity meter (model sension 2) whereas the TSS was determined using a Filtration meter and TDS with a pH meter electrode. Total solid was measured by a drying method while dissolved oxygen (DO) was measured by DO meter, Arsenic was analyzed with ICP-OES (model optima8000), while *E. coli* measurement was conducted using the Colilert method at 35.5 ºC.

Water quality index (WQI) and water quality ratings (WQR): Water quality assessment in terms of water quality index was calculated according to National Sanitation Foundation Water Quality Index (NSFWQI) [22,23]. WQI was calculated using the weighted arithmetic index method [24] for the following parameters: temperature, pH, turbidity, electrical conductivity, TSS, TDS, ST, DO and arsenic. The WQI was calculated using eqn. 1:

$$WQI = \frac{\sum Q_n W_n}{\sum W_n} \quad (1)$$

where, Q_n = quality rating of nth water quality parameter and W_n = unit weight of nth water quality parameter.

The quality rating (Q_n) was calculated by using eqn. 2:

$$Q_n = 100\left(\frac{V_n - V_i}{V_s - V_i}\right) \quad (2)$$

where, V_n = actual amount of n[th] parameter present, V_i = ideal value of the parameter [V_i = 0,except for pH (V_i = 7) and DO (V_i = 14.6 mg/L)], V_s = standard permissible value for the n[th] water quality parameter.

The unit weight (W_n) was determined by eqn. 3:

$$W_n = \frac{k}{V_s} \quad (3)$$

where, k = constant of proportionality and was calculated using eqn. 4:

$$k = \left(\frac{1}{\sum V_s = 1, 2, ...n}\right) \quad (4)$$

RESULTS AND DISCUSSION

Physical, chemical characteristics, WQI and WQR of the collected samples: The current study used equation to calculate the water quality index (eqn. 1). It was carried out on the sub-indices of the parameters whose values are derived from a set of equations (eqns. 2-4) [25]. Thus, the WQI for the 13 random wells in Rabigh area was calculated using the weighted arithmetic index method and the physical, chemical parameters, WQI and WQR of the 13 samples are shown in Table-1 [26]. The obtained results for the test parameters were compared to WHO standard values as listed in Table-2.

TABLE-1
WATER QUALITY RATING AS PER DIFFERENT WATER QUALITY INDEX AND WHO STANDARD VALUES FOR WATER QUALITY PARAMETERS

WQI value	Rating of water quality	Grading	Test parameter	WHO standard values
0-25	Excellent	A	pH	6.5-8.5
26-50	Good	B	Turbidity	5
51-75	Poor	C	TSS	100
76-100	Very poor	D	TDS	1000
Above 100	Unstable for drinking purpose	E	TS	1100
			DO	6-10
			Arsenic	0.01

Temperature: Inconsistent behaviour of temperature due to change in climatic conditions it never remains constant in water bodies such as river. In present study, the maximum temperature observed in sample 9, (24.8 ± 1.1 ºC) and minimum in sample 3, (21.8 ± 1.1 ºC). The mean calculated for the sample's temperature was 22.6 ± 1.1 ºC, which is recorded to be in an accepted range according to WHO [26]. Groundwater at greater temperatures may dissolve more minerals from the rocks. As a result, it will have greater electrical conductivity. Moreover, temperature has a significant impact on biological activity and growth of microorganism that will compromise water quality [27]. Maximum values of temperature might be due increasing rates of pollution and wastewater discharged at site 9.

pH: Because most of their metabolic activities are pH dependant, pH has an impact on aquatic species. The pH 6.5-8.2 is the ideal range for aquatic life to thrive. The pH of an aquatic system is a key indication of water quality and pollution levels in watershed areas [28]. During the present study, the overall highest pH was observed for sample 9, ~8.4 ± 0.4 and lowest for sample 10, ~7.2 ± 0.4. The mean for pH was ~7.7 ± 0.4, which is within the standard value according to WHO. Although different pollutants can change water pH, pH itself has no direct adverse effects on health [29]. There was not much fluctuation recorded in pH values in the collected 13 samples. Higher value of pH observed may be due to influx of sewage effluents disposal and low level of water. Similarly, the pH measurements indicate that the groundwater found in the study area is of alkaline nature.

Turbidity: The mean value for turbidity was 3.2 ± 3.8 NTU, which is less than the standard value. However, sites 8 and 13 were recoded with high turbidity (7.5 NTU and 14.4 NTU respectively), which exceeded the standard value of 5 NTU as recommended by WHO. Turbidity is regarded as an important water quality measure since it impacts the water through suspended particles and influences other metrics such as DO [27]. High turbidity in water allow pathogens into water and lead to higher risk that the consumer may develop gastrointestinal diseases [30].

Dissolved oxygen (DO): The mean value for DO in the samples was 7.6 ± 0.7 mg/L, which is within WHO standard range (6-10 mg/L). The lowest value (5.8 mg/L) of DO was recorded in site 12. Low DO indicates that the deoxygenation is maybe due to biological decomposition of organic matter [31]. The highest value of DO (8.6) was recorded in site 6, which may be due to higher temperature, oxygen demanding wastes, inorganic reductant and seasonal variation. Thus, the higher DO attributes maximum where minimum discharge of effluent and human activities exists and lowest DO at the site where maximum discharge of sewage effluent.

Electrical conductivity: The conductivity mean value was 7347.78 ± 5823.5 µS/cm, which is very high level in comparison to the standard value of 250 µS/cm recommended by WHO [32]. Water molecule is highly cohesive, pure water does not conduct electricity; water becomes a conductor once it starts dissolving substances [27]. Due to ion exchange and solubility, the high conductivity detected in the research area indicates high salinity, which can be linked to the presence of high minerals percentage [33].

TABLE-2
PHYSICO-CHEMICAL CHARACTERISTICS OF 13 SAMPLES COLLECTED FROM DIFFERENT WELLS IN RABIGH GOVERNORATE

Sample No.	Temp. (°C)	pH	Turbidity (NTU)	Conductivity (µS/cm)	TSS mg/L	TDS (mg/L)	TS (mg/L)	DO (mg/L)	Arsenic (µg/L)	*E. coli* (cfu/100 mL)	WQI	WQR
1	22.9	7.3	3.1	5740.0	13.0	4140.0	4160.0	7.8	4.4	<1	85.8	D
2	23.1	8.3	2.3	2670.0	5.0	1808.0	1817.0	7.6	1.6	1413.0	69.7	C*
3	21.8	7.3	3.2	8200.0	22.0	6170.0	6200.0	7.3	4.6	46.0	93.5	D*
4	22.5	7.7	1.3	2300.0	1.0	1592.0	1598.0	7.6	6.7	3.0	68.4	C*
5	22.8	8.0	1.0	3230.0	2.0	2240.0	2245.0	8.1	2.8	<1	64.5	C
6	22.4	7.4	2.6	13830.0	31.0	11180.0	11225.0	8.6	15.4	<1	124.9	E
7	21.4	7.5	0.7	6510.0	10.0	4780.0	4794.0	8.1	6.7	<1	76.3	D
8	21.7	8.1	7.5	3560.0	4.0	2480.0	2488.0	7.8	1.5	4.0	102.1	E*
9	24.8	8.4	0.9	2001.0	6.0	1381.0	1390.0	7.8	7.1	<1	70.1	C
10	20.7	7.2	0.6	16940.0	39.0	13700.0	13745.0	6.8	6.3	<1	102.1	E
11	23.2	7.9	1.7	19590.0	34.0	15700.0	15740.0	8.0	3.9	<1	115.6	E
12	24.3	7.3	1.9	3930.0	4.0	2700.0	2708.0	5.8	4.0	<1	67.5	C
13	22.8	7.7	14.4	7020.0	26.0	4970.0	5001.0	7.2	9.3	<1	169.8	E
Mean ± SD	22.6±1.1	7.7±0.4	3.2±3.8	7347.78± 5823.5	15.12± 13.5	5603.2± 4830.1	5623.9± 4844.2	7.6±0.7	5.7±3.7	–	–	–

TSS = Total suspended solids, TDS = Total dissolved solid, TS = Total solid, DO = Dissolved oxygen, WQI = Water quality index, WQR = Water quality rating, A = Excellent, B = Good, C = Poor, D = Very poor, E = Unsuitable for drinking purpose. *Unsuitable for drinking because it contain *E. coli.*

Total suspended solid (TSS): TSS values of the samples were recorded with the mean value of 15.12 ± 13.5 mg/L and compared to the standard value. It is found that the TSS in the groundwater samples less than the standard value. The highest amount of TSS within study area was 39 mg/L, which is observed in site 10.

Total dissolved solid (TDS) and total solid (TS): The mean values for TDS and TS were 5603.2 ± 4830.1 mg/L and 5623.9 ± 4844.2 mg/L respectively. Both values exceed the values of WHO standardized values. TDS and TS were also found to be higher during the wet season as a result of leachate particle transport [31].

Concentration of arsenic: The mean value of arsenic was 5.7 ± 3.7 μg/L which is above the WHO recommended range. In its inorganic form, arsenic is a highly poisonous element. Arsenicosis is a disease caused by arsenic contaminated groundwater. Arsenic exposure from drinking water and food may cause cancer and skin lesions over time [33]. A seasonal analysis of heavy metals such as arsenic in groundwater is important because their concentrations could change directly with climate change [34].

E. coli: About 31% of the samples (site 2, 3, 4 and 8) were reported to be contaminated with *E. coli*. Testing for *E. coli*, an indication of faecal pollution, is one of the verification of the microbiological quality of drinking water. *E. coli* is clear proof of recent faecal contamination and should not be detected in drinking water [25].

According to the WQR, which is based on the WQI calculation, 38% of the samples (n = 5) are of poor quality, 23% (n = 3) are recorded with a very poor quality and 38% (n = 5) are unstable for drinking purpose. After taking into consideration the presence of *E. coli* in 31% of the samples (n = 4), about 62% of the samples (n = 8) are unstable for drinking purpose, only 23% (n = 3) samples are of poor quality and 15% (n = 2) are very poor quality.

Among all of the 13 sampling sites, the value of different parameters varies significantly due to the presence of harmful chemicals in effluent and penetration of effluent into groundwater. On the basis of various parameters studied, it was concluded that the water quality in Rabigh, Makkah is not satisfactory. Environment pressures are factors can cause environmental change; pollution caused by industry is one of these factors. The main causes of groundwater pollution are leaking of pollutants from industry, agriculture and untreated sewage, as well as saltwater (seawater) intrusion caused by over pumping [19]. The study establishes the main pollutants of water are wastages and industrial effluents, synthetic detergents, agriculture chemicals, oil, thermal pollutant, domestic sewage, run off from landfills [35]. Analytical results state unequivocally that the treated water can be utilized in industry as well as for agriculture. If suitable alternative preparations, such as wastewater treatment prior to disposal, are not undertaken, the situation may be frightening to residents in the research area as well as nearby regions. As a result, continuous monitoring and stringent law enforcement are required to design a strategy to control the environmental threats posed by these elements, as well as to improve environmental protection of groundwater, which serves as a reservoir for future water. Our current data in the Rabigh district of Makkah should serve as a baseline for future reference.

Conclusion

Saudi Arabia is naturally arid due to little rainfall, thus, it has a scarcity of surface water. As a result, groundwater is recognized as the primary source of water throughout the country. As a result, groundwater is essential for the residents of Rabigh governate's drinking and irrigation needs. The water quality of 13 sites were randomly selected and investigate the possible impact of waste and industrial effluents based on nine parameters for calculating the WQI. The groundwater samples' results were compared to the WHO permissible limits. The unsuitability of water for residential use was revealed by high electrical conductivity and TDS values, indicating the combined effect of leachate and Red Sea saltwater intrusion. It is believed that the presence of industries near residential and agricultural regions also has significant impact on the quality of groundwater with 62% of the samples (n = 8) being unfit for human consumption. This suggests that dumping solid trash and disposing of waste fluids indiscriminately has a direct impact on groundwater quality and should be avoided. It is also advocated to devise a plan to repair the slightly damaged wells so that they may be used again, as well as implementing new technologies in companies that are environmentally friendly.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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