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A Survey of the Quality of Water drawn from Nine Domestic Wells in Al Qurayyat, Al-Jouf Region, KSA

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ABSTRACT

AlQurayyat meets the growing demands for water of its overcrowded population from a fossil groundwater aquifer, namely the Saq which is the Saudi sector of the Disi aquifer. A survey has been done and a detailed account has been given of the groundwater delivered from nine private, domestic wells drilled in AlQurayyat, Al-Jouf Region, northern KSA. One of the objectives of the present investigation was to raise the awareness of the community about the maintenance and sustainability of the groundwater resources. The sampling schedule comprised spaced locations in AlQurayyat to obtain mirror data of the properties of such water sources. The domestic wells in the present study varied in depth, water volume and water quality. The depth of the studied wells varied between 30 and 70 m and their age ranged between 20 and 60 years. The pH values are located on the weak alkaline scale and ranged between 6.27 and 8.11. Out of 9 domestic wells, 5 recorded TDS level over 5000 mg/L, indicating marked salinization of the soil and rock layers nourishing such shallow unconfined groundwater aquifers. Only one water sample was contaminated with bacteria. The challenges to the sustainability of water resources in the groundwater aquifers are discussed. Local groundwater sustainability agencies should be established to assess conditions in their local water basins and educate well owners on how to reduce risks to their water supplies. Future aspirations of the water sector should focus on smart maintenance and sustainability of the surface/shallow groundwater pumped through widespread domestic wells.

INTRODUCTION

There is no perennial rivers or freshwater lakes in Saudi Arabia. The kingdom depends merely on desalinated and groundwater sources to meet the rising demands for water of the ever growing population. AlQurayyat governorate obtains its water supply from a fossil groundwater aquifer, namely the Saq which is the Saudi sector of the Disi aquifer. The generous aquifer provides Al-Jouf Region with about 1000 million cubic meters of valuable water per year. Al-Ahmadi (2013) reported that the ground water aquifers depend primarily on the downward infiltration of the surface water to enrich resident water. It is hypothesized that the interaction between the rock lithology and water and influences of the anthropogenic factors on the groundwater are the key parameters of the seasonal and spatial fluctuations of the chemistry of the groundwater (Kumar *et al*., 2006).

The Saq aquifer is regarded as one of the most important groundwater sources in the Kingdom of Saudi Arabia (Lloyd and Pim, 1990; Edgell, 1997; Al-Ahmadi, 2009).Such amazing aquifer stores huge quantities of fossil ground water, which is estimated to be 280000 million cubic meters, the age of which ranges between 10000 and 30000 years (Al-Ahmadi, 2009 and many references therein). Al-Ahmadi (2009) reported that the total amount of water extracted from the wells connected to or penetrating into the aquifer is 336960 m^3/day northwest of Tabuk. Such over-pumping of the groundwater led to a dramatic decline of the water table between 2.3 and 10.5 m/year, however no obvious change was found in the essential minerals between 2000 and 2004 (Al-Ahmadi, 2009).

Recently, a great deal of attention has been paid to the groundwater wealth as a major source of clean water in many geographical regions of the world. In KSA as well as other arid and semi-arid countries, the groundwater is the sole source of potable water, indicating that it is crucial to the sustainability of life. Water table in the groundwater aquifers is rapidly declining because of the overconsumption that seems likely to increase the salinity of water, decrease the water level of the aquifer, duplicate the cost of water mining and purification, and deprive coming generations from their rights of obtaining clean water in adequate amounts. Al-Naeem (2014) found that the mean depletion of groundwater level in the Saq Aquifer at Ha′il region was 25 m over a period of 12 years (from 2002 to 2013).The water table is referred to as the surface in which the water pressure head is equal to the atmospheric pressure. Molden (2007) reported that about 1.2 billion people live in areas of physical scarcity, while another 1.6 billion people live in developing countries which lack the infrastructure necessary to abstract water from its natural sources.

The present study aims to evaluate the physicochemical and bacteriological properties of the water extracted from nine private domestic wells drilled in AlQurayyat City, Al-Jouf Region, northern KSA. The present study aims also to raise the awareness of the community about the maintenance and sustainability of the groundwater resources in order to avoid water depletion and environmental degradation. The adequate geographical coverage of the present investigation provides a foundation for an improved understanding of the quality of water from the major aquifers tapped by domestic supply wells in such amazing city with geographical and security importance.

MATERIALS AND METHODS

Water Sampling and Analysis:

Nine private, domestic wells were selected for the present investigation. The sampling schedule comprised spaced locations in AlQurayyat to obtain mirror data of the properties of such varying water sources, in terms of the recharge rates, extraction rate, usage purposes, etc. Water samples were collected and processed according to the method described by El−Naggar (2015). Chemical and bacteriological tests were conducted at AlQurayyat Water Purification Plant. “Coliform Bacteria” is a term describing a group of bacteria whose presence indicates contamination of the water body.

The authors complied with the instructions that have been approved by the laboratory of AlQurayyat Water Purification Plant as follows: (1) the sample bottle must be sterilized, (2) the water sample must be kept clean and free of contamination, (3) the sample must not be boiled, (4) the white powder inside the bottle must not be removed, (5) the water sample must be kept out of the sunlight and heat, (6) the cap of the sample bottle should not be set down, (7) the inside of the cap or sample bottle should not be touched, (8) the faucet should not be allowed to touch the bottle, (9) the bottle must be delivered to the lab as soon as possible, and (10) if the delivery time of the sample is more than an hour, the water sample should be transported in a cooler with ice.

Total dissolved solids (TDS) in each water sample was determined by a HQ 14d conductivity meter (HACH). Water salinity was measured from the relationship with TDS. Salinity is measured in microSiemens per cm (uS/cm) (or EC units). TDS are measured in mg/L or parts per million (ppm).

TDS (mg/L) = Salinity (EC) x 0.5-0.7 depending on the water source. Salinity is a measure of the amount of dissolved particles and ions in water. There are two methods to measure water salinity: (1) Total Dissolved Solids (TDS) and (2) Electrical Conductivity (EC) that means the ability of an electric current to pass through water and is proportional to the amount of dissolved salts in water. EC is a measure of the amount of dissolved ions in water, and is calculated as µmhos/cm (micromhos per centimeter) or µS/cm (microsiemens per centimeter), whereas µmho is equivalent to a µS. EC is also known as specific conductance or specific conductivity and can be measured in a laboratory or with a field conductivity meter.

The hydrogen ion concentration (pH) was measured using HQlld pH meter (HACH). The total depth of each well in the study area, the water level and the diameter of the casing were documented. Total chlorine, iron, sulfate, phosphate, nitrate and nitrite were measured using DR5000 spectrophotometer (HACH). To follow the population growth of bacteria, 100 ml water were mixed with Colitag (an indicator medium for the growth of bacteria) and kept at 37 ºC for 24 hrs. Then, bacterial growth was demonstrated by inspecting the change in colour from yellow at the initial stage to deep yellow or orange at the terminal stage (24 hours post treatment).A water sample was considered to be contaminated when total coliform bacteria were present or when nitrate concentrations exceeded their maximum contamination level (MCL) established by the Environmental Protection Agency (EPA) for public water systems (10 mg/L).

RESULTS

All the studied water types are abstracted from the Saq aquifer, the Saudi part of the Disi aquifer (Figure 1). The domestic wells in the present investigation varied in depth, water volume and water quality. The depth of the studied wells varied between 30 and 70 m and their age ranged between 20 to 60 years. Field trips revealed that the water pumped from the wells is unpurified and directly used in cleaning and agricultural purposes. All the domestic wells are tube wells, a type of water well in which a long 30–40 cm wide cylindrical steel tube (Figure 2) penetrates deeply into an underground aquifer depending on the level of the water table. The owners of the private wells stated that the water extracted from the wells is used in agricultural (Figure 3) and household purposes. The vast majority of the wells are provided by pumps that discharge through the top of the well; however they do not use a suitable seal to protect the delivered water.

Data reflecting the chemistry and bacteriology of the studied water samples are shown in Table 1. There was a marked variability of the hydrogen ion concentration (pH) in the water samples delivered from the domestic wells. Data from Table 2reveal that the pH values are located on the weak alkaline scale and ranged between 6.27 and 8.11. Data of the Total Dissolved Solids (TDS) are worrying (Table 1). The lowest TDS level was 520 mg/L and the highest level was 14000 mg/L. Out of 9 studied wells, 5 wells recorded TDS level over 5000 mg/L (Figure 4), indicating marked salinization of the soil layers nourishing such shallow unconfined groundwater aquifers. Out of 10 examined water samples, only one sample was contaminated with bacteria (Table 1).

Domestic wells water has a considerable amount of nitrate salts (Table 1), the level of which ranged between 1.9 and 2.27 mg/L. Sulphate content of the studied water samples is shown in Figure 5. It could be noticed that the level of sulphate salts varies greatly from 89 to over range (more than 150 mg/L). Data from Table 1illustrates that the amount of nitrites in 17% of the studied water samples seem likely to pose a potential risk to health whenever employed for drinking and/or irrigation. A markedly high nitrite value (0.576 mg/L) was measured in a domestic well drilled in a highly populated area. The remainder nitrite values fluctuated between 0.019 mg/L and 0.061 mg/L. Phosphate levels of the domestic wells in AlQurayyat are relatively low. The maximum value is 5 mg/L whereas the minimum value is 1.68 mg/L.

All domestic wells water samples were weakly chlorinated but adequately fluorinated (Table 1). Total chlorine in domestic wells water ranged between 0.09 and 0.22 mg/L (Table 1). On the other hand, fluoride level varied between 0.72 and 2.56 mg/L. Turbidity levels varied markedly among studied water samples. A ratio of 33% of the well water exhibited turbidity levels over 1 NTU colour units which is the permissible turbidity threshold. The maximum turbidity is 24 NTU whereas the minimum value is 0.36 NTU colour units (Table 1).

Al-Jouf University launched a strong awareness campaign, in partnership with the Ministry of Education, Ministry of Electricity and Water, Ministry of Health and some electronic newspapers, in order to preserve water resources for current and future generations (Figures 5, 6,7and 8). The activities of the campaign propaganda included intensive field trips, meetings with youth, and scientific dialogues with officials in the water and agriculture sector, citizens and residents. Friday sermon entitled: “water blessing” was made in 23/3/1436 hijra. Moreover, a variety of services, for example analysis of water samples collected from private wells, AlSabeel water coolers, ablution water in mosques, washing water in restaurants and drinking water in poultry farms, and the distribution of water-saving materials, educational leaflets and booklets. Events lasted for 45 days and the number of beneficiaries of the campaign reached 5,000.

DISCUSSION

TDS means total dissolved solids and is made up of inorganic salts (calcium, magnesium, potassium and sodium), as well as a little amount of organic matter (carbonates, nitrates, bicarbonates, chlorides and sulfates). TDS mined from natural sources vary from less than 30 mg/L to as much as 6000 mg/L (WHO, 2003), according to the solubility of minerals in different geological regions. Water containing TDS concentrations below 1000 mg/L is usually acceptable to consumers. However, the presence of high levels of TDS in water may be unpleasant to consumers owing to the taste and excessive scaling in water facilities. Similarly, water attaining small amounts of TDS may also be unpalatable due to its insipid taste. High TDS levels are also often corrosive to water-supply systems. No health-based guideline value is proposed for TDS (WHO, 2003). Certain components of TDS such as chlorides, sulfates, magnesium, calcium, and carbonates cause corrosion in the water-distribution systems. High TDS levels (>500 mg/L) result in excessive scaling in water pipes, water heaters, boilers, and household appliances such as kettles and steam irons. Such scaling can shorten the service life of these appliances.

TDS may taste bitter, salty, or metallic and may have repulsive odors. High TDS water is less refreshing. High TDS interferes with the taste of food items and makes them disagreeable to human. Some of the individual mineral salts that make up TDS pose a variety of health hazards. The most problematic are Nitrates, Sodium, Sulfates, Barium, Cadmium, Copper, and Fluoride. TDS can give water a murky appearance and detract from the taste quality of the water. Gastrointestinal irritation in some individuals can be caused by high TDS levels. A person drinking 2 pints of water a day is likely to accumulate 4500 gallons of water over a 70 year span. Such amount of water will include between 200 and 300 pounds of rock deposits in the living tissues. The majority of these deposited will be eliminated, however the remainder will precipitate in the body, causing stiffness in the joints, hardening of the arteries, kidney stones, gall stones and blockages of arteries, microscopic capillaries and other passages in which liquids flow through our entire body.

The EPA Secondary Regulations advise a maximum contamination level (MCL) of 500 mg/L (500 ppm) for TDS. When TDS levels exceed 1000 mg/L it is generally considered unfit for human consumption. A high level of TDS is an indicator of potential concerns, and warrants further investigation. Most often, high levels of TDS are caused by the presence of potassium, chlorides and sodium. These ions have little or no short-term effects, but toxic ions (lead arsenic, cadmium, nitrate and others) may also be dissolved in the water (Oram, 2007; Benham *et al*., 2011).

Out of 9 studied private, unlicensed domestic wells in AlQurayyat, 5 attained TDS level over 5000 mg/L, indicating marked salinization of the soil and rock layers nourishing such shallow unconfined groundwater aquifers. Surprisingly, two of the studied wells showed obviously high TDS values (over 10000 ppm). Elevated TDS levels in the waterbody of the studied wells could be removed with the aid of reverse osmosis technology. However, this treatment process removes beneficial minerals, such as calcium and magnesium. In this respect, treated water should be filtered through a magnesium and calcium mineral bed to be enriched with these important nutrients. The mineral bed also increases the pH and decreases the corrosive potential of the water.

Hydrogen ion concentration (pH) is an effective measure of the water quality. Surface water gains a pH value between 6.5 and 8.5 and groundwater tends to have a pH between 6.0 and 8.5. The pH of a water source is affected by the type of rock and soil. The carbon dioxide mixes with the water to produce a weak carbonic acid that decreases the pH of the water body. Industrial activities, individuals and communities produce a range of chemicals that prone the water body more acidic. Acid rain can have pH values near 4. There are concerns that acid rain is having effects on vegetation and aquatic fauna. Once on the ground, some of the acidic precipitation infiltrates downward to mix with ground water and can affect the ground water pH. Hydrogen ion concentration must be tested when a new well is drilled. It is recommended to adjust the hydrogen ion concentration of the water body of the well to comply with the guidelines of the World Health Organization and/or local institutions. The pH of the water is increased with limestone or reduced by sodium hydroxide treatments.

Groundwater quality varies markedly from one geographical area to another. Ackah *et al*. (2011) assessed the quality of groundwater for drinking and irrigation in Teiman-Oyarifa Community, Ghana and found that the hydrogen ion concentration (pH) varied between 4 and 7.4. The conductivity, total dissolved solids (TDS), chloride, bicarbonate, nitrate and sulphates ranged from 214 to 2830 µS/cm, 110 to 1384 mg/L, 28.41 to 813.8 mg/L, 8.53 to 287.7 mg/L, 1.9 to 4625 mg/L and 16.35 to149.88 mg/L, respectively. El Tahlawi *et al*. (2008) recorded a direct relationship between iron concentration in water and human blood; the mean value of iron was 3.076 mg/l in the blood and 0.149 mg/L in groundwater. Zaghloul *et al*. (2005) showed that the mean value of iron is 2.182 mg/l in human blood and 0.057 mg/l in surface water samples.

The sustainability of water resources in AlQurayyat faces a number of challenges, for example water logging, salinity and over drafting accompanied by depletion in the water table of the domestic wells. Water table depletion-induced overdraft comes beyond the reach of existing wells. To overcome depletion crisis, wells must be drilled deeper to reach the groundwater. Regarding surface water resources, the possible consequences of climate changes on the groundwater at unconfined zone can be expected to include alteration in the groundwater level fluctuation (Chen *et al*., 2004), effects on water pressure in the soil (Collison *et al*. 2000), deviation of groundwater flow patterns (Scibek and Allen, 2006) and fluctuations in the quantity and quality of groundwater resources (Brouyère *et al*., 2004; Konikow and Kendy, 2005; Bloomfield *et al*. 2006). The global warming, the most relevant feature of the climatic changes, exerts profound impacts on the hydrologic cycle (Hetzel *et al*., 2008).

Arid and semi-arid countries are considered as the locations at the greatest risk of freshwater supply problems – induced climate change (Hetzel *et al*., 2008).Rapid population growth and improper water supply and sanitation services pose an increasing pressure on the groundwater resources of AlQurayyat. According to Galloway *et al*. (2001), groundwater depletion consequences comprise exhausting the wells, high costs of water abstraction and infrastructure facilities, subsidence of the land and encroachment or impingement of salt water. Moreover, Ponce *et al*. (1997) highlighted the changes in the reflecting power of the surface and subsequent changes of the climate.

Contamination can be a health risk to both people and livestock. To protect the waterbody from contamination, the owners of the domestic wells are advised to extend the wellhead 6 to 12 inches above the surface of the ground. The wellhead should be capped to keep contaminants out. The owners are asked also to seal the ground in the close proximity of the wellhead. The new wells should be drilled 50 feet from a septic tank, 100 feet from the edge of a drain field, fuel tank, barn, and any storage shed for fertilizers and pesticides, and 250 feet from a manure stack. Poor understanding of the hydrology of the groundwater likely increases the chance of contamination. The domestic well acts as a direct path transporting surface water contaminants to the groundwater. Unsecure well caps allow vermin, insects and other organisms to reach and deteriorate the waterbody well.

According to WHO (1996), the permissible amount of chloride ranges between 10 and 250 mg/L. Elevated levels of chloride may be a reflection of the contamination of the groundwater due to seepage from the septic systems, fertilizers, animals or landfill. In the present study, chloride levels were fairly low. They ranged from 0.09 to 0.22 mg/L. The nitrate concentration of the samples ranged from 0.019 to 9.75 mg/L. According to WHO (1996), nitrate levels in drinking water must not exceed 10 mg/L. High nitrate gradients can lead to many health problems, for example increased methemoglobin levels in the blood (Methemoglobinemia), elevated blood pressure, and goitre (Baird and Cann, 2004).

Flouride is one of the highly important minerals required for the maintenance of the ideal development of teeth and bones. Dental caries may be contributed to lower levels (below 0.6 mg/L) of this essential element. However, consumption of increased amounts (above 1.2 mg/L)leads to dental flourosis (Rao, 2006) and even skeletal flourosis in extreme cases (Dissanayake, 1991).

There is a lack of awareness among the owners and workers of the domestic wells in AlQurayyat. An educational program should be carried out to raise their awareness about water-related diseases and contaminants in private water wells, well maintenance and water testing. People that rely on dug or bored wells for their drinking water should be informed about the potential hazards of ingesting water from these wells.

Users of household wells are advised to test for bacteria once a year or quarterly if any changes in the water's taste, odor, or color occurs, and after heavy rainfall or floods (EPA, 1990). The EPA suggests annual testing for nitrate, when coliform bacteria are found in the water, and after repairs to the well, pump, storage tank and piping. Immediate disinfection of the well when a repeat sample confirms the presence of bacteria is a critical procedure. Water used for drinking or food preparation should be boiled before use. Well water with nitrate-nitrogen levels more than 10 mg/L must not be introduced to infants under 6 months of age, either directly or in formula.

Preventive maintenance programs monitoring domestic wells should be developed and upgraded. These may include periodic tests for water quality and sanitary surveys, technical assistance and educational programs for well drillers, owners, and consumers of well water. Encourage domestic well owners to routinely maintain their wells. Maintenance involves the early detection and correction of problems that could impair water quality and well performance. The wellhead must be protected from contamination and waterborne disease surveillance should be enhanced. The life span of a well can vary greatly, but is usually about 50 years. It depends on water quality, as minerals may clog the screen in the well and the pump. The following questions should be answered by the owners of the wells: What is the actual depth of the wells? What are the infrastructural facilities involved in the construction of the well? How much water is in the water well? How long will the water well continue? What is the well replenishment rate? What are the well static head, flow rate, and abstraction? How does well static head vary over time? What happens to well flow when we install a more powerful water pump? Are production water wells in compliance with the codes relating to construction and operation of the wells?

Future aspirations of the water sector in AlQurayyat should focus on smart maintenance and sustainability of the surface/shallow groundwater pumped through the widespread domestic wells. A comprehensive water plan that includes investments in water conservation, water recycling, expanded water storage is intended to ensure a reliable water supply for years to come. Local groundwater sustainability agencies should be formed to assess conditions in their local water basins and adopt locally-based management plans. A substantial time– 20 years to implement plans and achieve long-term groundwater sustainability. Unlike the deep groundwater, shallow groundwater interacts with surface water. Regarding water cycle in the nature, deep groundwater recycles at markedly slow rate than surface water. Moreover, turnover rates of the groundwater differs from years to millennia, according to the location, depth, type, connectivity and properties of the aquifer. Over pumping can cause depletion of the groundwater because the groundwater extraction rate is faster than the replenishment rate.

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Table (1). Physicochemical parameters of the water samples collected from nine domestic wells at different localities of the study area.

Location	pH	TDS	Sulphate	Nitrate	Nitrite	Phosphate	Chloride	Turbidity
A	8.11	14000	> 150	47.6	9.75	13.73	0.17	7.9
B	7.95	6580	> 150	6.7	0.468	3.54	0.15	3.5
C	7.45	3650	127	3.2	0.576	2.47	0.11	1.3
D	7.42	2280	130	7.8	0.075	1.98	0.13	0.65
E	6.27	11850	> 150	1.9	0.019	1.68	0.09	0.84
F	6.57	5600	> 150	5.9	0.025	2.23	0.15	0.46
G	6.80	2530	120	9	0.044	5.00	0.19	1.3
H	6.40	6900	> 150	27.7	0.061	5.56	0.22	24
I	6.29	520	8.9	4.8	0.029	2.9	0.21	0.36

Fig. (3). A small scale cultivated area nursing a composite of palm and olive trees. Such cultivated land relies merley on the water pumped from the well to flourish.

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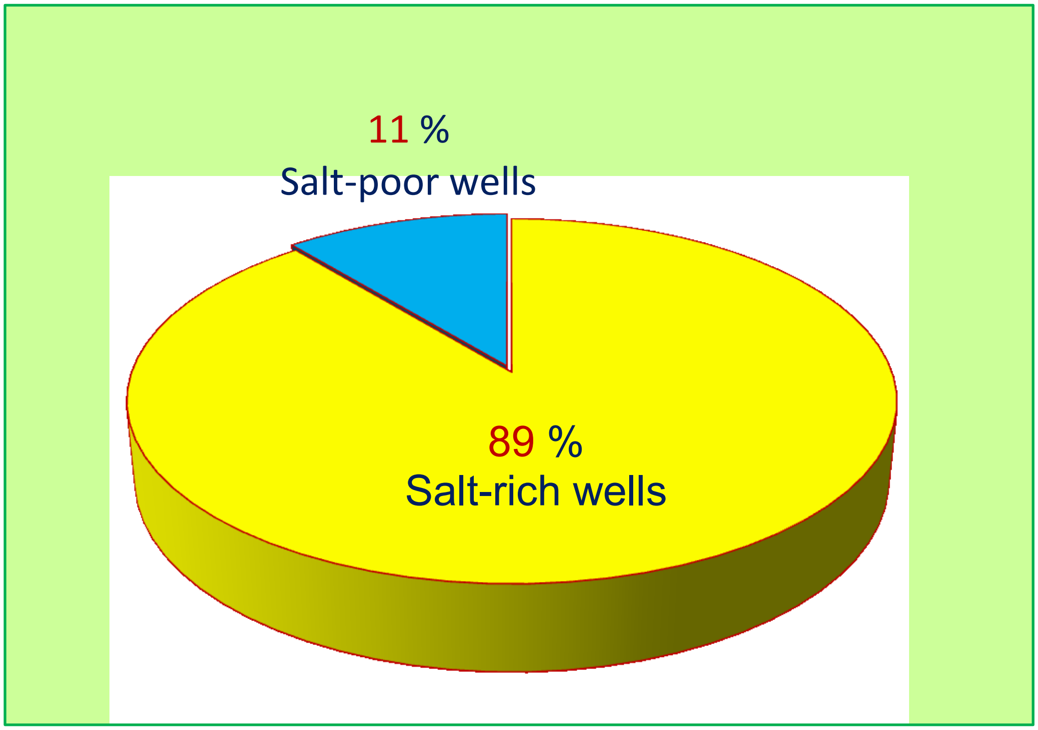

Fig. (4). Percentage of salt-rich wells (89%) to salt-poor wells (11%) in AlQurayyat, KSA.

Fig. (5). One of the advertising posters of the campaign.

Fig. (6). Advertising materials of the campaign named: Water for our Grandchildren.

Fig. (7). Distribution of water saving facilities and awareness pamphlets.

Fig. (8). An educational/awareness meeting in one of the famous resturants.