

Full Length Research Paper

Quality assessment of traditional water resources in Khamis Mushait City, Abha Metropolitan, Assir Province, Saudi Arabia

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The physical and chemical quality within traditional water resources of Khamis Mushait City, Saudi Arabia, that are being used for various urban purposes were assessed to explore consistency. The network sampling and cross-sectional techniques were implemented. Google earth digital satellite map of the study area was used as a master map for sampling. A total of 66 water samples were collected randomly from surface and well water located at and around the city. All samples were subjected to standard analysis. The results have revealed the overall means of turbidity, conductivity, total dissolved solids, pH, chlorides, hardness as CaCO₃, sulphate, ammonia, nitrate, copper, iron, manganese, and zinc in water samples taken from deep wells, shallow wells and surface water. These results showed that shallow wells had the highest values for conductivity, total dissolved solids, chloride, hardness, sulphate, nitrate, copper, manganese, and zinc. However, surface water had the highest levels for turbidity, pH, and ammonia. Iron contents of deep wells and surface water samples were nearly the same. Thus, samples taken from deep wells were superior to those from shallow wells and surface water sources. There were significant correlations with each other between physicochemical parameters except for manganese, which showed no significant correlation with any parameter. Iron showed only a significant correlation with zinc. Recommended hygienic measures are also discussed.

Keywords: Physicochemical, traditional water resources quality, hygienic measures, Khamis Mushait, satellite map, Saudi Arabia.

INTRODUCTION

To assess traditional water sources quality, we must look at its two major systems, surface water and groundwater. These systems are very important to Saudi Arabia (SA), since it relies mainly on these resources to supply drinking water for human and livestock consumption and for other purposes such as agricultural and industrial production.

In the case of SA, surface waters (dams, lakes, and open water reservoirs) are considered to be extremely

limited resources and are exploited for almost every use. They are also exposed to wastewater disposal from both wastewater stations (stages 3-4), which has greatly polluted the surface water resources in many areas, especially valley's water. The frequent outbreaks of water-borne diseases are the result of a direct discharge of untreated or partially-treated domestic sewage water sources located beside local gutters (AlOtaibi, 2009; Goel, 1997; Sobih et al., 1988). The inorganic chemical quality of these waters is, however, rarely adequately tested before wells are put into production especially private wells. Due to variation in local and regional geology and water/rock interactions, high concentrations of many chemical elements can occur. During the last 10

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years, several studies have shown that wells in areas with particular geological features may yield water that does not meet established drinking water norms without any influence from anthropogenic contamination (Misund, 1999; Frengstad et al., 2000).

It is often assumed that natural, uncontaminated water from deep wells is clean and healthy. This is usually true with regard to bacteriological composition (Banks et al., 1998). Other sources of pollution may occur and is mostly derived from watershed corrosion as well as drainage from sewage, swamps, or soil with high humus content. This type of hazard exists particularly in lime-stone areas where underground chambers or fissures may permit water to flow without appreciable filtration into the freely moving streams. Such suspected polluted water sources cannot be used for drinking because of the inherent risks to human health (Ibrahim, 1998).

The origin of groundwater is meteoric, and shallow groundwater constitutes the basic flow of surface water. In addition, streams have a dominant overland flow when there is a significant rainy season influx (Galindo et al., 2007).

The water resources are under threat from pollution, including from human behavior manifested by the low levels of hygiene practiced (Punmia et al., 1998; Ikem, 2002; Akujieze et al., 2003). Environmental health involves all the factors, circumstances, and conditions in the environment or human surroundings that can influence health and well-being. The neglect of rural areas in most developing countries in terms of basic infrastructures exposes villagers to a variety of water health-related problems such as water-borne diseases (Sridhar, 2000).

In this study, researchers have turned their focus to examine the levels of certain significant physical and chemical water quality parameters in and within major traditional water resource groups; groundwater (wells) and surface water around the residential areas and in the vicinities of municipal waste dumpsites in Khamis Mushait City. The study's main objective was to explore differences within this major source and to monitor its sanitary condition as an urban water source.

MATERIALS AND METHODS

Study area

This study was conducted in an urban zone of Khamis Mushait City (about 43 km × 25 km centered at 18.3° N, 42.8° E, with a population of 497,000 (APHA, 1998)), which covers about 1075 km², with an elevation ranging from about 982 to 1946 m (mean 1464 m) above sea level (Figure 1a, 1b and 1c), an average annual rainfall of 355 mm (range 160 to 450 mm), 70% of which occurs between August and September (short rainy season), and average minimum and maximum temperatures of 19.3 and 29.70°C, respectively.

Sample collection

For this study, a total of 66 surface and groundwater samples (33

each) were collected randomly from different water source locations) (Figure 1c and Figure 2). Surface water samples were taken from the *Tandaha* dam area (Ibrahim 1998), open water surfaces (Banks et al., 1998), treated water sources (Adekunle et al., 2007) and surface valley water (Frengstad et al., 2000). Groundwater samples were taken from its groups; deep wells (20 samples) and shallow wells (13 samples). In deep wells, depths were ≥31 m, while for shallow wells, depths were ≤30 m.

Adoption of a two-stage sampling scheme

- i) Careful planning and choice of representative sampling groups and sites according to the adopted network sampling technique and certain criteria such as control sites where major sampling groups exist (that is, surface water points, valleys, and wells), impact sites where contamination is expected such as polygons, and outlets (for example, treated water discharge sites) to maximize understanding urban water sources quality, and with the least risk of missing the correct representative sampling groups and sites.
- ii) Attention was paid to ensure inclusion in the sampling frame, all groups and locations (sites, roads, venues, and so on) via screening, browsing, and delineation from a satellite digital map of the Khamis Mushait governorate zone, because pre-local knowledge was preferred for accessibility, safety, and permission.
- iii) Selection of an appropriate major sampling method (that is simple random sample, network sampling). Planning of pilot visits to samples of each group to review strategy (Figure 3).

Sampling phase

During this phase, the following were done:

- i) Simple random selection procedures were used when feasible to select representative samples of each location for each group.
- ii) Water specimens were gathered from each sampled location with a probability proportional to the estimated total of the target population.
- iii) All eligible persons were interviewed with regard to this site (as auxiliary data). Collect auxiliary data (on sampled site, it may affect the probability of selection)

Analysis phase

During this phase, standard analysis procedures were performed, which includes:

- i) The need to use statistical program that incorporate the design effect of such a cross-sectional study was assessed.
- ii) Findings related to the collected samples were compared with expected results of the groups.
- iii) All water samples were collected in 1.5-L colorless glass containers with metal screw caps, and were dispatched to the laboratories of the Medical Laboratory Technology Department, Khamis Mushait Community College, King Khalid University.

Statistical data analysis

Statistical analyses of the obtained results were performed using the t-student test, analysis of variance (F test), and LSD SPSS-PC statistical software version 8.0 (McBean and Rovers, 1998).

DISCUSSION

Tables 1 and 2 present the summary (mean and range)

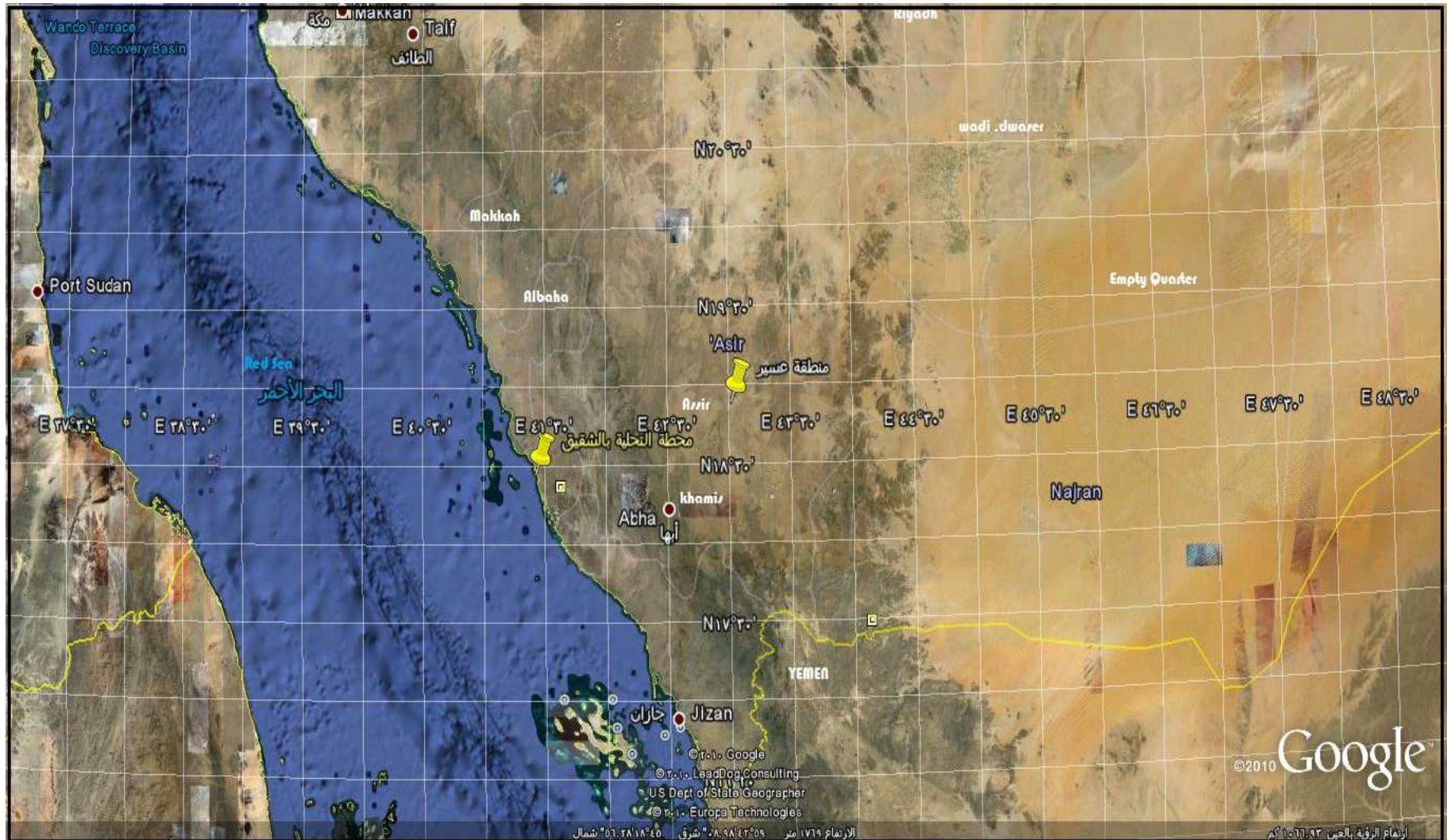


Figure 1a. Study area within the Saudi topo-satellite map.

of the physicochemical results for both types of wells (shallow and deep) and different surface

water sources used in Khamis Mushait City, SA. To facilitate interpreting study results, the researchers

categorized water source-physicochemical parameters into the following four major groups:

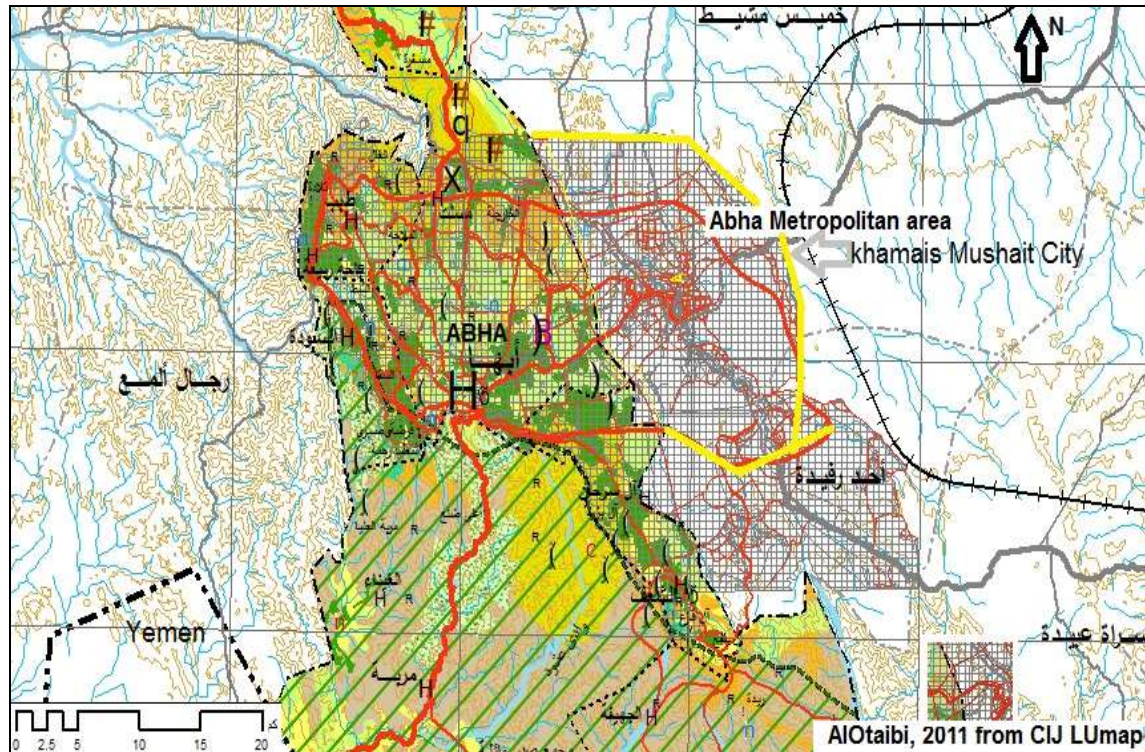


Figure 1b. Study area within the Abha Metropolitan topo-lu- map.

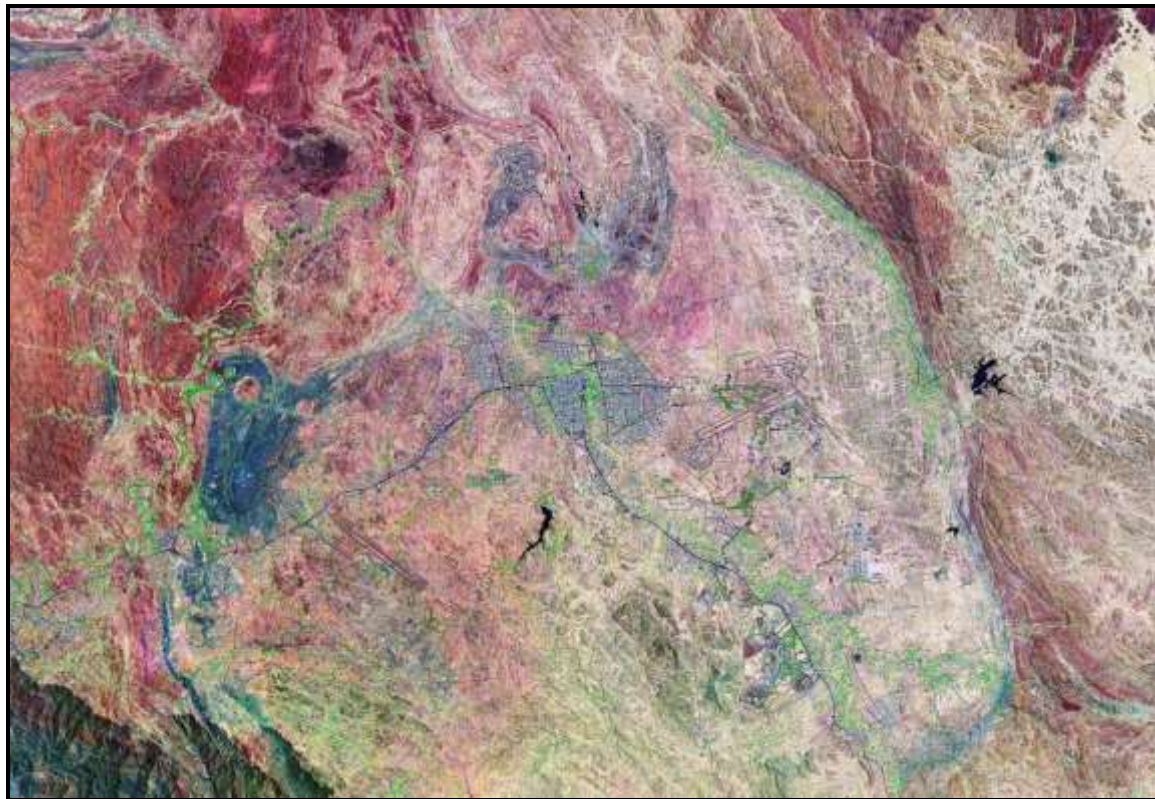


Figure 1c. the Study area within the Abha Metropolitan topo-satellite map. Produced by AIOtaibi using The Enhanced Thematic Mapper Plus (ETM+), as a master map for fieldworks and sampling, 2008. Satellite digital data source: Saudi Institute for Space Researches, KACST, Riyadh, KSA.



Figure 2. Surface water resource environment of study area 2009.

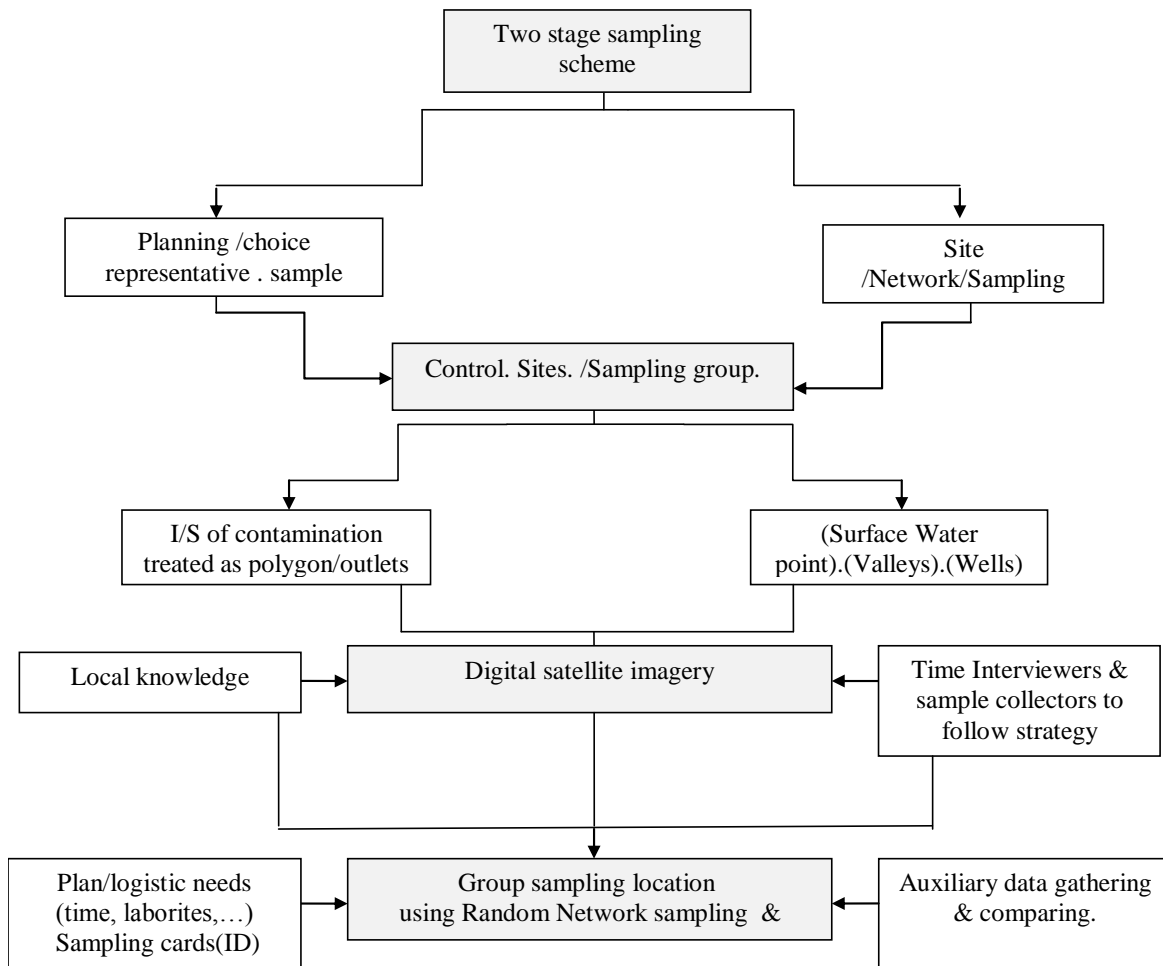


Figure 3. Methodology flow chart of major sequences.

Table 1. Physical and chemical constituent assessments of shallow and deep well water samples in Khamis Mushait City, Abha Metropolitan, Assir, Saudi Arabia, 2007.

Water source/Physicochemical parameter	Deep wells (n=20)		Shallow wells (n=13)	
	Range	Mean \pm SE	Range	Mean \pm SE
Turbidity (FAU)	0.0-25.0	9.85 \pm 1.82	1.0-24.0	10.92 \pm 2.03
Conductivity (μ S/cm)	120.0-2210.0	708.00 \pm 130.60	140.0-7590.0	2194.62 \pm 670.42***
Total dissolved solids (mg/l)	86.0-1502.0	510.5 \pm 9.30	88.0-4523.0	1225.5 \pm 405.6***
pH	6.67-7.90	7.45 \pm 0.07	7.05-7.90	7.41 \pm 0.07
Chloride (mg/l)	11.5-448.6	123.78 \pm 28.69	14.0-3415.0	1026.10 \pm 317.47***
Total hardness as CaCO ₃ (mg/l)	11.52-255.38	85.76 \pm 18.78	14.39-680.75	248.59 \pm 70.03***
Sulphate (mg/l)	7.0-1100.0	318.70 \pm 71.64	9.0-4000	1252.58 \pm 418.15***
Ammonia (mg/l)	0.0-0.12	0.05 \pm 0.01	0.0-2.70	0.35 \pm 0.21**
Nitrite (mg/l)	ND-4.0	-	ND-4.0	-
Nitrate (mg/l)	0.0-64.63	17.08 \pm 3.54	0.0-126.61	31.13 \pm 13.38**
Copper (mg/l)	0.01-6.61	1.33 \pm 0.50	0.03-9.80	3.30 \pm 1.04*
Iron (mg/l)	0.0-1.03	0.25 \pm 0.11	0.0-2.20	0.19 \pm 0.09
Manganese (mg/l)	0.0-0.7	0.20 \pm 0.05	0.0-38.5	7.83 \pm 3.90***
Zinc (mg/l)	0.0-1.58	0.4 \pm 0.09	0.0-2.42	0.77 \pm 0.22*

FAU = Formazin Attenuation Unit. One FAU is equivalent to one Nephelometric Turbidity Unit (NTU). *, **, *** Mean difference is significant at the 0.05, 0.01 and 0.001 levels, respectively.

Group 1: Turbidity, conductivity, and total dissolved solids

Table 1 shows that the average turbidity (FAU) of the examined water from deep and shallow wells was 9.85 \pm 1.82 and 10.92 \pm 2.03, respectively. Moreover, there was no significant correlation between turbidity levels of both deep and shallow wells. Regarding surface water, the variation of turbidity within each source was large. The highest mean was recorded in treated water samples, which had an average of 37.47 \pm 20.92, followed by valley water (22.40 \pm 12.70). The lowest mean turbidity value (1.43 \pm 0.95) was reported in samples taken from the Tandaha dam source. There was no significant correlation of the recorded turbidity levels between different surface water sources (Table 2). However, the overall mean of the turbidity value in surface water (23.55 \pm 9.83) was not significantly correlated with deep or shallow well water samples (Table 3). There was also no significant correlation of the turbidity level between surface and well water (Table 4). The statistically significant correlations ($p \leq 0.01$) were observed between turbidity and other chemical parameters analyzed, such as total dissolved solids, conductivity, chloride, hardness, NH₃, NO₃, SO₄, Cu, and Zn. In addition, there was a significant correlation at the 0.05 level between turbidity and pH (Table 5).

The recorded turbidity levels in our research were within the ranges recorded in a previous study (Adekunle et al., 2007). Lower turbidity values were recorded previously in groundwater (Ortiz, 2007). It is known that at high levels of turbidity, water loses its ability to support

a diversity of aquatic organisms. Water becomes warmer as suspended particles absorb heat from sunlight, causing oxygen levels to fall (Stapp and Mitchell, 1997). However, the colloidal materials provide adsorption sites for chemicals that may be harmful to health or cause undesirable tastes or odors. The consumption of highly turbid water may constitute a health risk, as excessive turbidity can protect pathogenic microorganisms from the effects of disinfectants as well as stimulate the growth of bacteria during storage (Adekunle et al., 2007; WHO, 1996).

The mean value of conductivity (μ S/cm) in deep and shallow water samples was 708.0 \pm 130.6 and 2194.62 \pm 670.42, respectively. The mean difference in the recorded conductivity in both types of wells was significant at the 0.001 level (Table 1). In samples taken from surface water, the highest conductivity value (μ S/cm) was detected in open water surfaces (1143.33 \pm 418.67), followed by treated water surfaces (762.67 \pm 112.43), valley water (402.0 \pm 170.92), and lastly the *Tandaha* dam area (187.14 \pm 39.80). There was a significant correlation of the recorded conductivity between samples taken from open water surfaces and the *Tandaha* dam area as well as between samples collected from treated water and the *Tandaha* dam area ($p \leq 0.05$). There was also a significant correlation at the 0.05 level between valley water and open water surfaces. From the results obtained in the study, conductivity was seen to have had a large variation within the different surface water sources (Table 2). The overall mean value of conductivity in surface water samples was 460.06 \pm 106.42 (Table 3). The higher conductivity value recorded in shallow water samples was

Table 2. Physico-chemical constituent assessments of the different surface water sources in Khamis City, Abha Metropolitan, Assir, Saudi Arabia, 2007.

Water source/ Physicochemical parameter	Tandaha dam area (n=7)		Open water surface (n=6)		Treated water sources (n=15)		Valley water (n=5)	
	Range	Mean±SE	Range	Mean±SE	Range	Mean±SE	Range	Mean±SE
Turbidity (FAU)	0.0-7.0	1.43±0.95	9.0 - 25.0	15.50±2.53	2.0 - 304.0	37.47 ± 20.92	6.0 - 73.0	22.40 ± 12.70
Conductivity (µS/cm)	120.0-420.0	187.14 ± 39.80	120.0 - 2470.0	1143.33 ^a ± 418.67	110.0 - 1870.0	742.67 ^a ± 112.43	90.0-820.0	402.00 ^b ± 170.92
Total dissolved solids (mg/l)	85.0-300.5	130.7 ± 27.9	88.0 -1690.8	808.9 ^a ± 299.5	79.0-1195.8	518.4 ^b ± 78.5	66.0-558.0	282.5 ^b ± 113.6
pH	7.25-7.90	7.60± 0.10	7.13 - 8.20	7.59 ± 0.17	7.25 - 8.06	7.50 ± 0.06	7.50-8.40	7.91 ^c ± 0.81
Chloride (mg/l)	11.50-44.80	19.67 ± 4.40	25.60 - 1138.0	459.80 ^a ± 201.52	10.10 - 750.0	197.20 ^b ± 45.91	9.80-200.0	87.56 ^b ± 45.93
Total hardness as CaCO ₃ (mg/l)	3.07-18.96	9.94 ± 2.53	68.16 - 410.0	213.14 ^a ± 63.14	14.94 - 276.7	58.98 ^b ± 18.78	13.63-151.0	76.96 ^b ± 30.98
Sulphate (mg/l)	7.0-160.0	50.29 ± 20.45	49.0 - 1600.0	642.17 ^a ± 282.72	3.0 - 1300.0	320.53 ± 78.53	7.0-250.0	110.40 ^b ± 57.20
Ammonia (mg/l)	0.0-0.08	0.02± 0.01	0.07 - 0.89	0.42 ± 0.13	0.0 - 1.95	0.63 ^a ± 0.16	0.0 - 0.25	0.10 ^c ± 0.05
Nitrite (mg/l)	ND	-	ND - 3.0	-	ND - 3.0	-	ND	-
Nitrate (mg/l)	0.0-14.61	8.10 ± 1.84	3.01 - 63.75	30.05 ^a ± 10.06	0.0 - 29.66	17.31 ^b ± 2.19	0.0 - 17.26	10.27 ^b ± 3.33
Copper (mg/l)	0.01-0.72	0.13 ± 0.10	0.04 - 10.10	3.24 ^a ± 2.02	0.0 - 4.34	0.49 ^b ± 0.29	0.0 - 0.80	0.33 ^b ± 0.19
Iron (mg/l)	0.09-2.20	0.47± 0.30	0.0 - 0.16	0.05 ± 0.03	0.04 - 0.81	0.28 ± 0.06	0.0 - 0.23	0.06 ± 0.04
Manganese (mg/l)	0.0-0.5	0.13 ± 0.07	0.0 - 1.30	0.57 ^a ± 0.22	0.0 - 1.10	0.23 ± 0.11	0.0 - 0.30	0.14 ± 0.06
Zinc (mg/l)	0.13-1.58	0.49± 0.20	0.11 - 169	0.64 ± 0.29	0.0 - 1.75	0.32 ± 0.12	0.0 - 0.18	0.10 ± 0.04

FAU = Formazin Attenuation Unit [One FAU is equivalent to one Nephelometric Turbidity Unit (NTU)]; ND= Not Detected; a= Variation against water samples taken from Tandaha dam area (the mean difference is significant at 0.05 level); b= Variation against water samples taken from open water surface (the mean difference is significant at 0.05 level); c = Variation against water samples taken from treated water (the mean difference is significant at 0.05 level). Fieldwork and sample analysis have extended from November, 2006 to February, 2007.

significantly correlated at the 0.05 level with deep wells and surface water samples (Table 3). In comparison, with regard to the mean conductivity values recorded in well water (both shallow and deep) and surface water samples, Table 4 shows a significant correlation at the 0.01 level. In previous studies, the results of conductivity were within the conductivity ranges of our study (Adekunle et al., 2007; Hoko, 2005; Karavoltos et al., 2008). Lower conductivity values have also been reported (Hill, 2005), while higher levels have been recorded as well (Galindo et al., 2007).

Table 5 shows that statistically significant correlations at $p \leq 0.01$ were observed between conductivity and other physicochemical parameters analyses, such as turbidity, total dissolved solids, pH, chloride, hardness, NH_3 , NO_3 , SO_4 , Cu, and

Zn.

Conductivity indicates the presence of dissolved solids and contaminants, especially electrolytes, but gives no information about specific chemicals. The conductivity levels of well water in the vicinities of dumpsites, defecation sites, and residential areas were very high. It was concluded that taste was objectionable for water with the highest conductivity, while for water with the lowest conductivity, taste was satisfactory (Adekunle et al., 2007; Hoko, 2005).

As regards mean values, total dissolved solids (mg/l) in the collected water samples from deep and shallow wells were generally found to be 510.5 ± 9.30 and 1225.5 ± 405.6 , respectively. The recorded total dissolved solids (mg/l) in both types of wells were significant at the 0.001 level (Table

1). In terms of the mean value obtained in surface water sources, the lowest recorded total dissolved solids value (mg/l) was 130.07 ± 27.9 for *Tandaha* dam water, followed by valley water (282.5 ± 113.6). However, the highest total dissolved solids (mg/l) were recorded in water samples taken from open water surfaces (808.9±299.5). The highest total dissolved solids recorded in open water surfaces were significantly correlated at the 0.05 level with water samples taken from the *Tandaha* dam area, treated water surfaces, and valley water (Table 2). In Table 3, the highest mean value of the total dissolved solids recorded in water samples collected from shallow wells was significantly correlated at the 0.05 level with samples taken from deep wells and surface water (mean value= 452.2 ± 75.65). In

Table 3. Multiple correlation analysis of the examined physical and chemical parameters between deep wells, shallow wells and surface water in Khamis Mushait City, Abha Metropolitan, Assir , Saudi Arabia, 2007.

Water source/ Physicochemical parameter	Deep wells (n=20)		Shallow wells (n=13)		Surface water (n=33)	
	Range	Mean±SE	Range	Mean±SE	Range	Mean±SE
Turbidity (FAU)	0.0 - 25.0	9.85 ± 1.82	1.0 - 24.0	10.92 ± 2.03	0.0 - 304.0	23.55 ± 9.83
Conductivity (µS/cm)	120.0 - 210.0	708.0 ± 130.60	120.0 - 590.0	2194.62 ^a ± 670.42	90.0 - 740.0	646.06 ^b ± 106.42
Total dissolved solids (mg/l)	86.0 - 1502.0	510.5 ± 9.30	88.0 - 4523.0	1255.5 ^a ± 405.6	66.0 - 690.0	452.2 ^b ± 75.56
pH	6.67 - 7.90	7.45 ± 0.07	7.05 - 7.90	7.41 ± 0.07	7.13 - 8.40	7.6 ± 0.06
Chloride (mg/l)	11.50 - 448.6	123.78 ± 28.96	11.50 - 415.0	1026.1 ^a ± 317.47	9.80 - 138.0	190.68 ^b ± 47.64
Total hardness as CaCO ₃ (mg/l)	11.52 - 55.38	85.76 ± 18.78	14.39 - 80.67	248.59 ^a ± 70.03	3.07 - 410.0	79.33 ^b ± 18.48
Sulphate (mg/l)	7.0 - 1100.0	318.7 ± 71.64	7.0 - 4000.0	1252.58 ^a ± 418.15	3.0 - 1600.0	289.85 ^b ± 69.48
Ammonia (mg/l)	0.0 - 0.12	0.05 ± 0.01	0.0 - 2.7	0.35 ± 0.21	0.0 - 1.95	0.38 ^a ± 0.09
Nitrite (mg/l)	ND - 2.0	-	ND - 2.0	-	ND - 3.0	-
Nitrate (mg/l)	0.0 - 64.63	17.08 ± 3.54	0.0 - 126.61	31.13 ± 13.38	0.0 - 63.75	16.6 ± 2.42
Copper (mg/l)	0.01 - 6.61	1.33 ± 0.50	0.03 - 9.80	3.30 ^a ± 1.04	0.0 - 10.10	0.89 ^b ± 0.42
Iron (mg/l)	0.0 - 2.20	0.25 ± 0.11	0.0 - 1.03	0.19 ± 0.09	0.0 - 2.20	0.25 ± 0.07
Manganese (mg/l)	0.0 - 0.70	0.20 ± 0.05	0.0 - 38.50	7.83 ^a ± 3.90	0.0 - 1.30	0.26 ^b ± 0.07
Zinc (mg/l)	0.0 - 1.58	0.40 ± 0.09	0.0 - 2.42	0.77 ± 0.22	0.0 - 1.75	0.38 ^b ± 0.09

FAU = Formazin Attenuation Unit [One FAU is equivalent to one Nephelometric Turbidity Unit (NTU)]; ND= Not Detected; a= Variation against water samples taken from deep wells (the mean difference is significant at 0.05 level); b= Variation against Water samples taken from shallow wells (the mean difference is significant at 0.05 level).

Table 4. Statistical analysis assessments of the examined physical and chemical parameters between well and surface water sources in Khamis Mushait City, Abha Metropolitan, Assir , Saudi Arabia, 2007.

Physicochemical parameter	Well water (n=33)		Surface water (n=33)		F	P value
	Mean value	Std. error	Mean value	Std. error		
Turbidity (FAU)	10.27	1.35	23.55	9.83	5.974	0.17
Conductivity (µS/cm)	1293.64	298.37	646.06	106.42	10.679	0.002**
Total dissolved solids (mg/l)	810.15	190.91	452.20	75.56	9.549	0.003**
pH	7.43	0.05	7.6	0.06	1.218	0.274
Chloride (mg/l)	479.24	145.81	190.68	47.64	14.858	0.000***
Total hardness as CaCO ₃ (mg/l)	149.90	32.39	79.33	18.48	5.946	0.018*
Sulphate (mg/l)	686.59	184.89	289.85	69.48	12.005	0.001***
Ammonia (mg/l)	0.17	0.08	0.38	0.09	3.021	0.087
Nitrite (mg/l)	-	-	-	-	-	-
Nitrate (mg/l)	22.35	5.49	16.60	2.42	4.885	0.031*
Copper (mg/l)	2.11	0.53	0.89	0.42	6.183	0.016*
Iron (mg/l)	0.22	0.07	0.25	0.07	0.105	0.746
Manganese (mg/l)	3.21	1.64	0.26	0.07	14.053	0.000***
Zinc (mg/l)	0.54	0.11	0.38	0.09	1.490	0.227

FAU = Formazin Attenuation Unit [One FAU is equivalent to one Nephelometric Turbidity Unit (NTU)]; *, **, *** Mean difference is significant at the 0.05, 0.01 and 0.001 levels, respectively.

comparison, Table 4 showed a significant correlation at the 0.01 level between mean total dissolved solids recorded in well water (both shallow and deep) and surface water samples. Almost the same results have been reported in previous studies (Galindo et al., 2007; Karavoltsos et al., 2008; Lars-Olof, 2000). Lower total

dissolved solid levels have also been recorded previously (Adekunle et al., 2007; Ortiz, 2007; Hill et al., 2005), as have higher levels (Hoko 2005). In some wells investigated in SA, it was found that total dissolved solids (mg/l) ranged from 180 to 9350 with a mean of 754 (Alaa-El-Din et al., 1993). However, in samples taken from

Table 5. Pearson correlation coefficient for physicochemical interrelationship in the examined water samples in Khamis Mushait City, Abha Metropolitan, Assir , Saudi Arabia, 2007.

Para	Approach	pH	TDS	Turbidity	Conduct.	Hardness	Chloride	NH3	NO3	SO4	CU	Mn	Zn	Fe
PH	Pearson correlation	1.000	-.621**	-.274*	-.630**	-.531**	-.5188*	-.289*	-.513**	-.636**	-.657**	.040	-.579**	-.235
	Sig. (2-tailed)	.	.000	.031	.000	.000	.000	.023	.000	.000	.000	.758	.000	.066
TDS	Pearson correlation	-.621**	1.000	.616**	.952**	.796**	.799**	.475**	.591**	.979**	.859**	.020	.721**	-.073
	Sig. (2-tailed)	.000	.	.000	.000	.000	.000	.000	.000	.000	.000	.876	.000	.571
Turbidity	Pearson correlation	-.274*	.616**	1.000	.627**	.596**	.550**	.378**	.444**	.617**	.522**	.026	.368**	-.064
	Sig. (2-tailed)	.031	.000	.	.000	.000	.000	.002	.000	.000	.000	.842	.003	.621
Conduct.	Pearson correlation	-.630**	.952**	.627**	1.000	.833**	.855**	.355**	.625**	.956**	.837**	.020	.700**	-.072
	Sig. (2-tailed)	.000	.000	.000	.	.000	.000	.005	.000	.000	.000	.876	.000	.578
Hardness	Pearson correlation	-.531**	.796**	.596**	.833**	1.000	.916**	.346**	.659**	.805**	.722**	-.173	.727**	-.061
	Sig. (2-tailed)	.000	.000	.000	.000	.	.000	.006	.000	.000	.000	.179	.000	.635
Chloride	Pearson correlation	-.518**	.799**	.550**	.855**	.916**	1.000	.295*	.658**	.816**	.647**	-.126	.762**	-.059
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.	.020	.000	.000	.000	.330	.000	.650
NH ₃	Pearson correlation	-.289*	.475**	.378**	.355**	.346**	.295*	1.000	.477**	.561**	.632**	.215	.412**	.179
	Sig. (2-tailed)	.023	.000	.002	.005	.006	.020	.	.000	.000	.000	.094	.001	.164
NO ₃	Pearson correlation	-.513**	.591**	.444**	.625**	.659**	.658**	.477**	1.000	.670**	.659**	.152	.530**	-.031
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.	.000	.000	.240	.000	.810
SO ₄	Pearson correlation	-.636**	.979**	.617**	.956**	.805**	.816**	.561**	.670**	1.000	.898**	.052	.741**	-.019
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.	.000	.690	.000	.885
Cu	Pearson correlation	-.657**	.859**	.522**	.837**	.722**	.647**	.632**	.659**	.898**	1.000	.015	.645**	.137
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.	.908	.000	.288
Mn	Pearson correlation	.040	.020	.026	.020	-.173	-.126	.215	.152	.052	.015	1.000	-.159	-.172
	Sig. (2-tailed)	.758	.876	.842	.876	.179	.330	.094	.240	.690	.908	.	.216	.181
Zn	Pearson correlation	-.579**	.721**	.368**	.700**	.727**	.762**	.412**	.530**	.741**	.645**	-.159	1.000	.374**
	Sig. (2-tailed)	.000	.000	.003	.000	.000	.000	.001	.000	.000	.000	.216	.	.003
FE	Pearson correlation	-.235	-.073	-.064	-.072	-.061	-.059	.179	-.031	-.019	.137	-.172	.374**	1.000
	Sig. (2-tailed)	.066	.571	.621	.578	.635	.650	.164	.810	.885	.288	.181	.003	.

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

Zamzam well water, total dissolved solids (mg/l) were quite similar to our results, with an average of 835 (Al-Zuhair and Khounganian, 2006).

The levels of total dissolved solids recorded in this study were statistically correlated at $p \leq 0.05$ with other physicochemical parameters, including turbidity, conductivity, pH, chloride, hardness, NH_3 , NO_3 , SO_4 , Cu, and Zn (Table 5). From the hygienic perspective, high levels of total dissolved solids may affect the taste, hardness, and corrosion properties of water. However, water with extremely low levels of total dissolved solids may also be unacceptable due to its flat and insipid taste (WHO, 1996).

Group 2: pH, chloride, total hardness, and sulphate

The mean value of pH was 7.45 ± 0.07 and 7.41 ± 0.07 in the water samples from deep and shallow wells, respectively. Moreover, there was no significant correlation of pH values recorded between deep and shallow wells (Table 1). Regarding surface water sources, the variation of pH values was small, where the recorded mean pH values were 7.60 ± 0.10 , 7.59 ± 0.17 , 7.50 ± 0.06 , and 7.91 ± 0.81 in the *Tandaha* dam area, open water surface, treated water sources, and valley water samples, respectively (Table 2). The statistical analysis (Table 2) reveals a significant correlation only between the pH value of treated water sources and that of valley water samples ($p \leq 0.05$). A statistical analysis of pH values in the water sources is presented (Tables 3 and 4) where there are no significant correlations of the recorded pH between water samples collected from wells and surface water. The pH results were within the previously recorded pH ranges (Adekunle et al., 2007; Hoko, 2005; Karavoltos et al., 2008; Hill et al., 2005; Reimann et al., 2003). A lower pH figure has been reported (Galindo et al., 2007), while a higher pH level has also been recorded in samples taken from *Zamzam* well water in SA (Al-Zuhair and Khounganian, 2006).

Statistically significant correlations at $p \leq 0.01$ were observed between pH and other physicochemical parameters analyzed, such as turbidity, conductivity, total dissolved solids, chloride, hardness, NO_3 , SO_4 , Cu, and Zn, while significance at $p \leq 0.05$ was between pH and NH_3 (Table 5).

Low pH tends to make water corrosive, while high pH will result in complaints about taste (Hoko, 2005). The mean value of the chloride content (mg/l) in water samples taken from deep and shallow wells was 123.78 ± 28.69 and 1026.10 ± 317.47 , respectively. The mean difference in the chloride content between deep and shallow wells was significant at the 0.001 level (Table 1). With regard to different water surfaces, the mean chloride values (mg/l) were 19.67 ± 4.40 , 459.80 ± 201.52 , 197.20 ± 45.91 , and 87.56 ± 45.93 in water from the *Tandaha* dam area, open water surface, treated water sources, and valley water, respectively. There was

a significant correlation at the 0.05 level between the chloride content of open water surface and the *Tandaha* dam area. Moreover, there was also significant correlation at the 0.05 level between the chloride content of treated water sources and valley water with the chloride content of open water surfaces (Table 2). For comparison, shallow water samples showed the highest chloride value (mean= 1026.1 ± 317.47), followed by surface water, where the mean chloride value was $190.68.01 \pm 47.64$ mg/l. However, there was a significant correlation at the 0.05 level between the chloride content of shallow wells, deep and surface water (Table 3). There was a significant variation at $p \leq 0.001$ in the amount of chloride between well water (both shallow and deep wells) and surface water (Table 4). Lower chloride levels have previously been reported (Galindo et al., 2007; Karavoltos et al., 2008; Reimann et al., 2003; Zaki, 2002). In a previous study carried out in SA on water samples taken from *Zamzam* well water, the mean chloride value was 163.3 mg/l (Al-Zuhair and Khounganian, 2006).

As presented in Table 5, there was hardly any significant relationship between chloride and other physicochemical characteristics, including NH_3 ($p \leq 0.05$), turbidity, conductivity, total dissolved solids, pH, chloride, total hardness, NO_3 , SO_4 , Cu, and Zn ($p \leq 0.01$).

Finer soils might be the cause of the capillary rise in water and concentration of salts due to evaporation (Galindo et al., 2007; Losinno et al., 2002). Water enriched with salt may occur either naturally or be due to over-pumping, resulting in the intrusion of marine waters in groundwater. It should be emphasized that the parametric values established, especially regarding chloride, are not health related but are set in order to avoid corrosion in pipes and an unpleasant taste (Karavoltos et al., 2008).

Total hardness is an expression of the total Ca and Mg content of water expressed in the equivalent of CaCO_3 . Table 1 shows that the overall mean of total hardness as CaCO_3 (mg/l) in water samples taken from deep and shallow wells was 85.6 ± 76 and 248.59 ± 70.03 , respectively. There was a significant correlation at the 0.001 level between the recorded hardness in deep wells and shallow wells. In surface water sources, the mean values of total hardness were 9.94 ± 5.23 , 213.14 ± 63.14 , 58.98 ± 18.87 , and 76.96 ± 30.98 in samples taken from the *Tandaha* dam area, open water surfaces, treated water sources, and valley water, respectively. The total hardness showed a significant correlation at $p \leq 0.05$ between water samples taken from open water surfaces and the *Tandaha* dam area, open water sources, and valley water (Table 2). It is obvious from Table 3 that there was a significant difference between the total hardness of water collected from shallow and deep wells as well as surface water ($p \leq 0.05$). Meanwhile, in comparison, in the results of total hardness recorded in water taken from wells (both types) and surface water, Table 4 shows a significant correlation at the 0.05 level. A higher hardness level has

been previously recorded (Zaki, 2002).

A statistically significant correlation at $p \leq 0.01$ was observed between total hardness and other chemical parameters analyzed, such as turbidity, conductivity, total dissolved solids, chloride, NH_3 , NO_3 , SO_4 , Cu, and Zn (Table 5).

Calcium and magnesium are known to occur naturally in water, due to its passage through mineral deposits and rock strata, and they contribute to its total hardness (Karavoltos et al., 2008). From the hygienic aspect, there is a causal link between water hardness and cardiovascular disease as well as mortality (Gardner, 1976; COMA, 1994).

The mean value of sulphate (mg/l) in deep and shallow water samples was 318.70 ± 71.64 and 1252.58 ± 418.15 , respectively. The mean difference in the recorded sulphate in both types of wells was significant at the 0.001 level (Table 1). In samples taken from different surface water sources, Table 2 showed that a highest sulphate value (mg/l) was detected in open water surfaces (642173 ± 282.17), followed by treated water surfaces (320.53 ± 78.53), valley water (110.40 ± 57.20), and lastly the Tandaha dam area (50.29 ± 20.45). There was a significant correlation of the recorded sulphate between samples taken from open water surfaces and the Tandaha dam area as well as between samples collected from treated water and the Tandaha dam area and between open water surfaces and valley water ($p \leq 0.05$).

From the results obtained in this study, sulphate was seen to have a large variation within the different surface water sources (Table 2). The overall mean value of sulphate in surface water samples was 289.85 ± 69.84 . The higher sulphate value recorded in shallow water samples was significantly correlated at the 0.05 level with deep wells and surface water samples (Table 3). In comparison, with regard to the mean sulphate values recorded in well water (both shallow and deep) and surface water samples, Table 4 shows a significant correlation at the 0.001 level. Higher sulphate levels have been previously recorded (Adekunle et al., 2007; Karavoltos et al., 2008), while lower sulphate figures have also been reported (Galindo et al., 2007; Al-Zuhair and Khounghanian, 2006; Reimann et al., 2003).

It is concluded from Table 5 that sulphate was significantly correlated at $p \leq 0.01$ with other physico-chemical parameters investigated, including pH, turbidity, conductivity, total dissolved solids, chloride, hardness, NH_3 , NO_3 , Cu, and Zn.

Sulphate occurs naturally in many water sources that come into contact with particular rock strata and mineral deposits (Beamonte, 2007). Considering groundwater in particular, such substances may be associated with a health risk. Diarrhoea may be associated with the consumption of water polluted with sulphate (Karavoltos et al., 2008), although at levels above 600 mg/l, sulphate acts as a purgative in humans (Esry, 1991).

Group 3: Ammonia, nitrite, and nitrate

It is seen in Table 1 that the mean value of ammonia (mg/l) in the examined deep and shallow water samples was 0.05 ± 0.01 and 0.35 ± 0.21 , respectively. The higher ammonia in shallow well water was significantly correlated at the 0.01 level with ammonia levels in deep well water (Table 1). In samples taken from the different surface water sources, the mean values of ammonia (mg/l) were 0.02 ± 0.01 , 0.42 ± 0.13 , 0.63 ± 0.16 , and 0.10 ± 0.05 in the Tandaha dam area, open water surfaces, treated water sources, and valley water, respectively. Ammonia levels varied significantly between treated water sources and the Tandaha dam area as well as valley water samples ($p \leq 0.05$). For comparison, surface water samples showed the highest mean chloride value (0.38 ± 0.09), followed by shallow and deep well water. However, there was a significant correlation at the 0.05 level between the ammonia content of surface water and the ammonia content of the Tandaha dam area (Table 3). There was no significant variation in the recorded amount of chloride between well water (both shallow and deep wells) and surface water (Table 4). Higher ammonia levels have been previously recorded (Karavoltos et al., 2008; Zaki, 2002).

A statistically significant correlation was observed between ammonia and other chemical parameters analyzed such as pH and chloride ($p \leq 0.05$), turbidity, conductivity, total dissolved solids, hardness, NO_3 , SO_4 , Cu, and Zn at $p \leq 0.01$ (Table 5).

The presence of higher ammonia levels is an indicator of recent faecal pollution from sewage, and it poses a serious threat to public health. This may be attributed to the fact that ammonia may also result from fertilizers, although in this case in soil it is relatively easily oxidized to nitrite and finally to nitrate (Karavoltos et al., 2008).

It is obvious from Table 1 that the nitrite (mg/l) content ranged from non-detectable to 4.0 in both deep and shallow well water. Regarding different surface water samples, a nitrite content was not detected in samples taken from the Tandaha dam area and valley water, while samples taken from open water surfaces and valley water showed that ranges of nitrite were between ND to 3.0 mg/l (Table 2).

Regarding nitrate, Table 1 reveals that the average nitrate content (mg/l) in the deep and shallow water samples was 17.08 ± 3.54 and 31.13 ± 13.38 , respectively. The highest recorded nitrate content of shallow well water was significantly correlated at the 0.05 level with water samples taken from deep wells. In surface water sources, Table 2 shows that the highest nitrate value was recorded in samples taken from open water surfaces, with an average of 30.05 ± 5.85 mg/l, followed by treated water sources, valley water, and the Tandaha dam area, where values were 17.31 ± 2.19 , 10.27 ± 3.33 , and 8.10 ± 1.84 mg/l, respectively. Moreover, in open water surfaces, nitrate showed significantly high levels, more

than in the Tandaha dam area and in valley water samples ($p \leq 0.05$). The overall mean value of nitrate (mg/l) in surface water samples was 16.6 ± 2.42 . The higher mean nitrate value recorded in shallow water samples was not significantly correlated with deep wells and surface water samples (Table 3). In comparison, with regard to the mean nitrate values recorded in well water (both shallow and deep) and surface water samples, Table 4 shows a significant correlation at the 0.05 level. Nearly the same results have been obtained previously (Adekunle et al., 2007). Nitrate levels higher than the results obtained in this study have been previously recorded (-El-Din et al., 1993; Reimann et al., 2003). However, lower nitrate figures have also been reported (Galindo et al., 2007; Ortiz, 2007; Karavoltzos et al., 2008; Hill et al., 2005; Zaki, 2002). However, nitrate concentrations up to 124 mg/l and nitrite up to 1.2 mg/l have previously been obtained in shallow groundwater near pollution sources in southwest Nigeria (Malomo et al., 1990).

The nitrate level recorded in this study was statistically correlated at $p \leq 0.01$ with the other physicochemical parameters investigated, including turbidity, conductivity, total dissolved solids, pH, chloride, hardness, NH_3 , SO_4 , Cu, and Zn (Table 5).

From the hygiene perspective, nitrates migrate easily to groundwater (Papa, 2001). Their presence indicates old faecal pollution but does not represent an immediate threat (IOS, 1986). A higher nitrate level in water is dangerous to pregnant women and poses a serious threat to infants younger than three to six months old, because of its ability to cause methaemoglobinaemia or blue-baby syndrome, in which blood loses its ability to carry sufficient oxygen (Fecham et al., 1986; Burkart and Kolpin, 1993). Nitrate and nitrite at higher levels have a potential to cause diuresis, increased starchy deposits, and haemorrhage of the spleen, as well as methaemoglobinaemia (Goel, 1997; USEPA, 2003).

Group 4: Copper, iron, manganese, and zinc

Generally, with regard to copper (mg/l) in water samples collected from deep and shallow wells, mean values were found to be 1.33 ± 0.50 and 3.30 ± 1.04 , respectively. The recorded copper (mg/l) in both types of wells was significant at the 0.05 level (Table 1). In terms of the mean value obtained in surface water sources, the lowest recorded copper value (mg/l) was 0.13 ± 0.10 for Tandaha dam water, followed by valley water (0.33 ± 0.19). However, the highest copper value was recorded in water samples taken from open water surfaces (3.24 ± 2.02) and treated water sources (0.49 ± 0.29). The highest copper value recorded in open water surfaces was significantly correlated at the 0.05 level with samples taken from the Tandaha dam area, treated water surfaces, and valley water (Table 2). As seen in Table 3, the highest mean

value of copper recorded in water samples collected from shallow wells was significantly correlated at the 0.05 level, with the mean value of copper content recorded in surface water (0.89 ± 0.42). In comparison, Table 4 shows a significant correlation at the 0.05 level between mean copper content recorded in well water (both shallow and deep) and surface water samples. Lower figures for copper have been previously recorded (Galindo et al., 2007; Reimann et al., 2003), while a higher figure for copper has also been reported (Karavoltzos et al., 2008).

The levels of copper recorded in this study were statistically correlated at $p \leq 0.05$ with the other physicochemical parameters investigated, including turbidity, conductivity, total dissolved solids, pH chloride, hardness, NH_3 , NO_3 , SO_4 , Cu, and Zn (Table 5).

Copper is essential at low concentration and is widely distributed in nature. However, the ingestion of water with high copper concentrations may lead to gastrointestinal distress, jaundice, and Wilson's disease, which is characterized by the destruction of new cells, liver cirrhosis, ascitis, oedema and hemolytic anemia, cardiovascular collapse, and hepatic failure (Gossel and Bricker, 1990).

The mean value of iron (mg/l) in deep and shallow water samples was 0.25 ± 0.11 and 0.19 ± 0.09 , respectively. The mean difference in the recorded iron in both types of wells was not significantly correlated (Table 1). For different surface water samples, Table 2 shows the highest iron value (mg/l) in the Tandaha dam area (0.47 ± 0.30), followed by treated water surfaces (0.28 ± 0.06), valley water (0.06 ± 0.04), and open water surfaces (0.05 ± 0.03). There was no significant correlation of the recorded iron content between different surface water samples. The overall mean value of the iron content in surface water samples was 0.25 ± 0.07 . Furthermore, there was no significant correlation of the recorded iron content between well and surface water samples (Tables 3 and 4). In previous studies, lower iron figures were reported in the groundwater supply (Galindo et al.; 2007; Reimann et al., 2003), while for surface water, a higher iron level was also recorded (Galindo et al., 2007). A higher iron level was recorded in groundwater sources as well (Ortiz, 2007).

A statistically significant correlation at $p \leq 0.01$ was observed only between iron and zinc (Table 5).

Iron is mostly a naturally derived metallic pollutant, its sources being in soil and rocks. Iron is essential in low concentration, while iron poisoning is highly evident in children younger than 5 years of age. The gastrointestinal tract and liver are the main targets of iron toxicity, which can lead to coagulative necrosis, bleeding, and death (Goel, 1997; Bryson, 1989).

It is shown in Table 1 that the mean value of manganese (mg/l) in the deep and shallow water samples was 0.20 ± 0.05 and 7.83 ± 3.90 , respectively. The higher manganese level in shallow well water was significantly correlated at the 0.001 level with the levels in deep well water (Table 1). In samples taken from the

different surface water sources, the mean values of manganese (mg/l) were 0.13 ± 0.07 , 0.57 ± 0.22 , 0.23 ± 0.11 , and 0.14 ± 0.06 in the Tandaha dam area, open water surfaces, treated water sources, and valley water, respectively. Manganese levels varied significantly between water samples taken from open water surfaces and the Tandaha dam area ($p\leq 0.05$). In Table 3, the highest mean value of the manganese recorded in samples from shallow wells was significantly correlated at the 0.05 level with the mean value of the copper content recorded in the Tandaha dam area and in surface water (mean = 0.26 ± 0.07). In comparison, Table 4 shows a significant correlation at the 0.001 levels between the mean copper content recorded in well water (both shallow and deep) and surface water samples. A lower Mn value has previously been reported (Ortiz, 2007; Reimann et al., 2003). With regard to samples taken from surface water sources, a highly similar result for iron has been observed (Galindo et al., 2007).

There was no significance variation between the recorded Mn values and other chemical parameters investigated (Table 5).

Excessive manganese concentration may exist in groundwater from soil and rocks as well as in decaying organic matter. Moreover, groundwater is also exposed to point pollution sources (for example, septic wells, domestic and farming effluents) that increase manganese and iron concentrations. Chronic manganese poisoning may result and is manifested by a progressive deterioration of the central nervous system, lethargy, and symptoms stimulating Parkinson's syndrome (Goel, 1997; WHO, 2004).

Table 1 shows that the overall mean of zinc (mg/l) in water samples taken from deep and shallow wells was 0.4 ± 0.09 and 0.77 ± 0.22 , respectively. There was a significant correlation at the 0.05 level between the recorded zinc levels. In surface water sources, the mean values of zinc were 0.49 ± 0.20 , 0.64 ± 0.29 , 0.32 ± 0.12 , and 0.10 ± 0.04 in samples taken from the Tandaha dam area, open water surfaces, treated water sources, and valley water, respectively. The analysed zinc showed no significant correlation between water samples taken from different water sources (Table 2). It is obvious from Table 3 that there was a significant difference between the recorded mean zinc levels in water collected from shallow wells and surface water sources ($p\leq 0.05$). Meanwhile, in comparison, results of zinc recorded in water taken from wells (both types) and surface water (Table 4) shows no significant correlation. Lower zinc levels have been previously reported (Galindo et al., 2007; Reimann et al., 2003).

It is concluded from Table 5 that zinc was significantly correlated at $p\leq 0.01$ with other physicochemical parameters, with the exception of manganese.

Zinc is widely distributed in water and in agricultural land. It is an essential component for at least eight enzyme systems. A high concentration of Zn ingested in water may lead to gastrointestinal irritation with nausea,

vomiting, and watery diarrhea as well as to central nervous system depression and tremors (Gossel and Bricker, 1990; WHO, 2004).

Conclusion

From the aforementioned results, it can be concluded that water derived from shallow wells followed by surface water showed increases in most of the investigated parameters as compared to deep wells or surface water sources. This may be attributed to the fact that shallow wells and surface water are at risk of contamination as indicated by the higher levels of most physicochemical parameters. Moreover, groundwater is exposed to point pollution sources such as septic wells and domestic and farming effluents and to soil with high humus content. An improvement in waste-water management could reduce higher concentrations of most of the physical and chemical parameters analyzed in groundwater and surface water. Thus, the water quality situation is spatially heterogeneous, and must be considered. More research is needed to determine the best water supply source at a local level and whether specific treatment is feasible for specific purposes. Strict sanitary measures should be applied to improve water quality and avoid deleterious effect on human health. This could be achieved by implementing an effective monitoring program for the different water supplies. The Saudi government has announced lately (June, 2011) a thirty three billion dollars plan to be invested in wastewater networks and stations and this will help in preserving a valuable water resource for sustainable development.

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