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Monthly Variations of Physico-Chemical Properties from a Man-Made River in Saudi Arabia

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ABSTRACT

This study which was carried between June 2009 and May 2010 highlights the results of periodic monitoring of surface water in a man-made river in Saudi Arabia. The samples were analyzed for pH, electric conductivity, total dissolved solids, alkalinity, metals and inorganic ions. The water quality varied depending on the time of the year and the site studied. In some sites, it exhibited poor water quality as the result of effluent discharge from small-scale industries. The study results is likely to serve as a baseline/benchmark for future evaluation of surface water pollution in similar streams in Saudi Arabia.

Key words: Monthly, season, physical, chemical properties, water quality, effluent, discharge

INTRODUCTION

Water is an essential requirement of life (Bharati *et al*., 2011). The quality of water needed for each individual varies as well as the criteria used to assess its quality. Typically, water quality is determined by comparing the physical and chemical characteristics of a water sample with already established water quality guidelines or standards. Water quality is neither a static condition of a system, nor can it be defined by the measurement of only one parameter (Ayers and Westcot, 1985). Rather, it varies in both time and space and requires routine monitoring to detect spatial patterns and changes over time. A wide range of chemical, physical and biological components that affect water quality can be examined which can provide a general indication of water pollution, whereas others enable the direct tracking of pollution sources (Abulude *et al*., 2007; Adejare *et al*., 2011).

Sources of chemical pollution include industrial, domestic and storm-related wastes. Polluted water is responsible for the spread of a variety of diseases (Bharati *et al*., 2011) making it necessary for monitoring water quality at various locations along a water course. Furthermore, if necessary, to treat the available polluted water to make it safe for human consumption. The assessment of water resources requires knowledge of water quality (Harmanciogammalu *et al*., 1999; UNEPGEMS., 2006) and as a result, it is important that a well-designed water quality monitoring network be put in place (Khalil *et al*., 2011). Normally, the required information about water quality is derived from water quality data analysis and the term “water quality” describes the chemical, physical and biological characteristics of water with respect to its suitability for a particular use (Chapman, 1996). Water quality therefore depends on a number of factors, such as the quality of recharge water and the nature of inputs from various sources (Domenico, 1972; EPA., 1974; Schuh *et al*., 1997).

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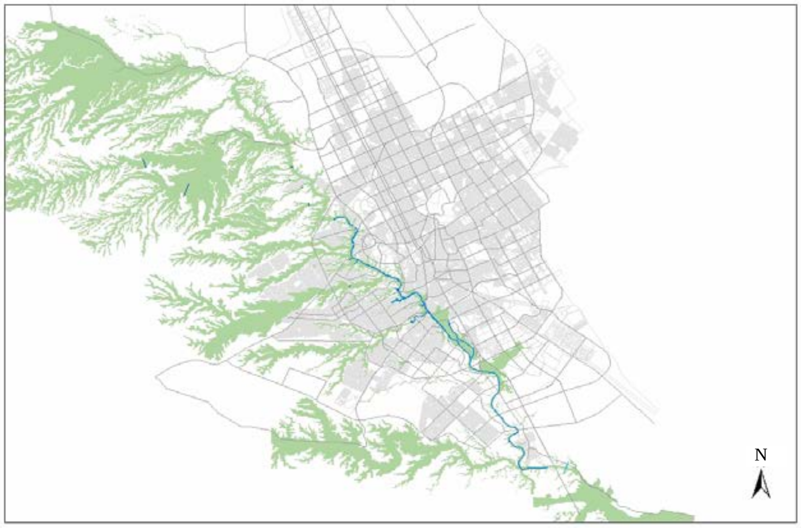

Fig. 1: Man-made river studied here, showing the main storm channels (Alhamid *et al*., 2007)

In Saudi Arabia, water needs are markedly increasing due to the rapid growth in population and agricultural activities (Al-Ahmadi, 2005a), making it even more essential that the suitability of any water supplied to the city be evaluated in terms of both quality and quantity relative to its different uses (George, 2004).

One of the man-made rivers in Saudi Arabia is located in Wadi Hanifa, an area of the Nejd region of central Saudi Arabia. The river runs for a length of 120 km from north to south and passes through the capital city, Riyadh. Several towns and villages lie along the river, including Al-Oyainah, Jobailah, Diriyah, Irqah and Al-Hayir (Al-Homaidan *et al*., 2011). The river flows southward from its source near the town of Al-Oyainah until it flows into the Wadi Sahba, a distance of about 150 km (Fig. 1). The main flood-channel is located slightly east of the center of the catchment area and flows northwest to southeast. Most of Arriyadh city (with a population of more than 4 million) is located on the course of this man-made river's catchment area (ADA., 1994). Prior to extensive urban development, seasonal rainfall provided the major source of water in the main channel. During the last two decades however, considerable urban and agricultural development has occurred in the catchment area, leading to the disposal of large amounts of sewage effluent and agricultural drainage (Siddiqui and Al-Harbi, 1995). Previously, the river was used as a water source. Currently, it principally acts as a convenient depot of Riyadh's wastewater. Following recycling, the water course could potentially supply significant volumes of good quality water in the future (Alhamid *et al*., 2007).

Mirabbasi *et al*. (2008) reported that the suitability of water for various uses depends on the type and concentration of dissolved minerals which in turn depends on the source of a river and ground water. Several criteria for water quality requirements had been recognized which serve as guidelines for use in determining the suitability of water for various uses. In Saudi Arabia, the quality of water is currently receiving considerable attention from environmental and water scientists (Al-Redhaiman and Magid, 2002; Al-Turki and Magid, 2003; Al-Matroud, 2003; Al-Zarah, 2008; Al-Turki, 2009; Al-Hawas, 2002). Therefore, assessment of water quality is a major requirement in the planning stages of any new development. With these considerations in mind, the main aim of this study is to determine monthly variations in various important indicators of surface water quality in the man-made river stream under study. Also, the information is likely to help in future the mangers and planners to install the most appropriate wastewater treatment methods to improve the quality of such water for its safe reuse without environmental issues.

MATERIALS AND METHODS

Study area: The area around the man-made Wadi Hanifa river stream is one of the most important natural landmarks in the central region of Saudi Arabia. A discharge of 400000-600000 m^3 of ground water, rainwater, industrial waste effluent and domestic sewage water reaches the stream every day (Al-Homaidan *et al*., 2011). Table 1 shows the area code, sampling area and a description of region to the north and east of this sampling area.

Sampling procedure: Water samples from specified locations were collected during the months of June, July, August, September, October, November and December of 2009 and during the months of January, February and March of 2010. The samples were transferred to the laboratory of Saudi Berkefeled Filters Co., Riyadh for chemical analysis. Sample temperature in the laboratory was measured and the mean, standard deviations, maximum and minimum temperatures are shown in Table 2. All chemical analyses were conducted according to standard methods (APHA., 1992).

Data statistical analysis: Excel spread sheet was used to obtain the mean, standard deviations, maximum and minimum of all concentrations. The results of different concentrations are shown in Table 3 and 4. The water quality indicators were selected as 28 water quality variables. A correlation matrix was done using Excel. The statistical correlation matrices used were multivariate analyses which correlate the relationships between variables. A correlation matrix is always a symmetric matrix to locate the correlation for any pair of variables and to find the value in the intersection for those two variables as reported by Gawad *et al*. (2010).

Table 1: Area code, sampling area, description of area, northing and easting of sampling area

Area code	Sampling area	Description of area	Northing	Easting
SW1C	Arriyadh	North Diversion Channel- Down stream of confluence of proposed channel and DNC	2724103.251	669451.238
SW12a	Arriyadh	Underneath King Fahad Expressway, Bridge Upstream of Bio remediation	2721476.628	672518.914
SW8A	Al Masane	Manfuha Complex	2720071.397	675685.708
SW8C	Al Masane	Below STP discharge near bridge	2718369.409	675859.770
SW23	Al Masane	Batha Channel before meeting the main river	2716538.376	676839.277
SW14	Al Masane	At inlet of culvert Batha channel in river	2716278.544	676631.335
SW20	Al Masane	100 m downstream of culvert immediately downstream of channel influence of existing channel and tributary from batha	2716194.470	676823.123
SW8g	Al Masoriyah	150 m downstream of tannery	2713161.808	6786648.795
SW10b	Al Hair	Al Hair Bridge	2697973.000	685465.000
SW11b	Near Al Hair Lake	Al Hair Lake	2696646.000	693373.000

Table 2: Mean, standard deviation, maximum and minimum temperature of the laboratory (°C) and in water samples

Area code	Mean	Standard deviation	Maximum	Minimum
SW1C	23.44	1.69	26.50	20.50
SW12a	23.25	1.55	25.00	20.10
SW8A	23.30	1.61	25.10	20.00
SW8C	23.27	1.61	25.00	19.90
SW23	23.32	1.69	25.20	19.80
SW14	23.30	1.64	25.10	20.00
SW20	23.34	1.57	25.00	19.90
SW8g	23.34	1.57	25.00	19.90
SW10b	23.36	1.57	25.00	19.90
SW11b	23.39	1.56	25.00	20.00
Overall mean	23.33	1.61	25.19	20.00
Standard deviation	0.056	0.052	0.465	0.194

Table 3: Monthly variations of pH, EC, TDS and alkalinity in surface water samples and mean, standard deviation (SD), maximum (Max) and minimum (Min) concentration values for different studies sites

	Year (2009)							Year (2010)						
Area code	June	July	Aug.	Sept.	Oct .	Nov.	Dec.	Jan.	Feb.	Mar.	Overall average	SD	Max.	Min.
pH														
SW 1 C	7.85	8.07	7.95	7.76	7.93	7.95	8.26	8.24	8.40	8.21	8.06	0.21	8.40	7.76
SW 12a	7.52	8.03	7.49	7.68	7.68	7.63	8.04	8.13	7.39	8.03	7.76	0.27	8.13	7.39
SW 8 A	7.65	8.02	7.89	7.52	7.75	7.68	8.06	8.00	8.30	8.16	7.90	0.25	8.30	7.52
SW 8 C	7.07	7.52	7.29	7.32	7.20	7.52	7.65	7.54	6.81	7.49	7.34	0.26	7.65	6.81
SW 23	6.96	7.51	7.27	7.32	7.10	7.68	7.52	7.53	6.61	7.43	7.29	0.32	7.68	6.61
SW 14	7.75	8.06	7.74	7.70	7.68	7.78	8.05	8.10	7.45	8.13	7.84	0.23	8.13	7.45
SW 20	7.01	7.57	7.31	7.20	7.24	7.35	7.70	6.92	6.67	7.64	7.26	0.33	7.70	6.67
SW 8 g	7.07	7.62	7.48	7.32	7.25	7.61	7.68	7.60	6.80	7.57	7.40	0.29	7.68	6.80
SW 10 b	7.04	7.46	7.23	7.30	7.15	7.12	7.65	7.84	6.96	7.45	7.22	0.25	7.65	6.84
SW 11 b	7.01	7.53	7.23	7.34	7.25	7.10	7.64	6.93	761	7.52	7.32	0.25	7.65	6.84
Mean	7.29	7.74	7.49	7.45	7.42	7.54	7.83	7.58	7.30	7.76	7.54		8.40	6.61
Max.	7.85	8.07	7.95	7.76	7.93	7.95	8.26	8.24	8.40	8.21				
Min.	6.96	7.46	7.23	7.20	7.10	7.10	7.52	6.84	6.61	7.43				
Conductivity (µS cm^{-1})														
SW 1C	5782	5014	4790	4492	4732	5100	4544	4660	4740	5168	4902	383	5782	4492
SWIC 12 A	3904	4557	4155	3950	3817	3923	3783	3702	3780	3875	3945	248	4557	3702
SWIC 8 A	2223	2342	2347	2285	2235	2311	2070	2248	2153	2243	2246	85	2347	2070
SWIC 8 C	1973	2160	1998	2074	2145	1927	1992	1949	2011	2150	2038	88	2160	1927
SW 23	1962	2186	2146	2063	2135	1980	1960	1995	1953	2114	2039	101	2186	1895
SW 14	4351	4641	4332	4377	4476	4300	4230	4347	4223	4295	4357	123	4641	4223
SW 20	2662	2647	2603	2490	2800	2580	2687	2700	2768	3247	2718	206	3247	2490
SW 8 g	2405	2440	2430	2301	2512	2374	2362	2380	2491	2581	2428	82	2581	2301
SW 10b	2238	2354	2386	2384	2291	2240	2245	2216	2267	2428	2305	76	2428	2216
SW 11b	2345	2430	2451	2351	2349	2325	2455	2274	2405	2515	2390	73	2515	2274
Mean	2985	3077	2964	2877	2949	2906	2833	2837	2879	3062	2937			
Max.	5782	5014	4790	4492	4732	5100	4544	4660	4740	5168				
Min.	1962	2160	1998	2063	2135	1927	1960	1895	1953	2114				
TDS (mg L^{-1})														
SW 1C	4624	3965	3743	3518	3724	4039	3560	3662	3730	4090	3866	329	4624	3518
SWIC 12 A	3011	3570	3227	3051	2938	3027	2910	2841	2907	2987	3047	212	3570	2841
SWIC 8 A	1649	1745	1730	1700	1658	1720	1509	1670	1594	1665	1664	70	1745	1509

Table 3: Continue

	Year (2009)							Year (2010)						
Area code	June	July	Aug.	Sept.	Oct .	Nov.	Dec.	Jan.	Feb.	Mar.	Overall average	SD	Max.	Min
SWIC 8 C	1435	1579	1451	1512	1569	1396	1448	1414	1462	1573	1484	69	1579	1396
SW 23	1426	1621	1574	1504	1560	1439	1423	1320	1416	1543	1483	93	1621	1320
SW 14	3412	3643	3372	3418	3501	3350	3290	3392	3284	3347	3401	106	3643	3284
SW 20	2010	1997	1957	1867	2125	1940	2031	2040	2096	2468	2053	164	2468	1867
SW 8 g	1794	1825	1818	1710	1884	1770	1760	1775	1866	1941	1814	68	1941	1710
SW 10b	1661	1756	1778	1780	1705	1662	1667	1645	1684	1814	1715	61	1814	1645
SW 11b	1794	1817	1833	1752	1750	1731	1837	1690	1796	1886	1784	60	1886	1690
Mean	2277	2352	2248	2181	2241	2207	2144	2145	2184	2331	2231			
Max.	4624	3965	3743	3518	3724	4039	3560	3662	3730	4090				
Min.	1426	1579	1451	1504	1560	1396	1423	1320	1416	1543				
Alkalinity (mg LG^{1})														
SW 1C	190	200	150	180	180	180	180	190	180	190	182	13	200	150
SWIC 12 A	160	190	160	160	170	170	180	180	150	170	169	12	190	150
SWIC 8 A	130	140	130	130	130	120	120	130	130	130	129	6	140	120
SWIC 8 C	80	90	120	100	100	110	120	110	90	120	104	14	120	80
SW 23	90	90	130	100	100	120	120	110	80	110	105	16	130	80
SW 14	140	140	130	150	150	150	160	160	140	160	148	10	160	130
SW 20	100	100	130	100	110	120	140	100	100	150	115	17	150	100
SW 8 g	90	100	130	100	100	110	110	110	90	110	105	12	130	90
SW 10b	110	120	140	120	110	100	120	80	90	110	110	17	140	80
SW 11b	110	130	130	120	110	100	120	90	120	110	114	13	130	90
Mean	120	130	135	126	126	128	137	126	117	136	128			
Max.	190	200	160	180	180	180	180	190	180	190				
Min.	80	90	120	100	100	100	110	80	80	110				

Table 4: Variation of bicarbonate, calcium, chloride and magnesium in surface water samples with months and mean, standard deviation (SD), maximum (Max) and minimum (Min) concentration values for the different studied sites

	Year (2009)							Year (2010)						
Area code	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Overall average	SD	Max.	Min.
Bicarbonate (mg LG^{1})														
SWIC	228	240	180	216	216	210	216	228	216	228	218	16	240	180
SW 12a	192	228	192	192	204	204	216	216	180	204	203	14	228	180
SW 8 A	156	168	156	156	156	144	144	156	156	156	155	7	168	144
SW 8 C	96	108	144	120	120	132	144	132	108	144	125	17	144	96
SW 23	108	108	156	120	120	144	144	132	96	132	126	19	156	96
SW 14	168	168	156	180	180	180	192	192	168	192	178	12	192	156
SW 20	120	120	156	120	132	144	168	120	120	180	138	23	180	120
SW 8 g	108	120	156	120	120	132	132	132	108	132	126	14	156	108
SW 10b	132	144	168	144	132	120	144	96	108	132	132	20	168	96
SW11b	132	156	156	144	132	120	144	108	144	132	137	15	156	108
Mean	144	156	162	151	151	153	164	151	140	163	154			
Max.	228	240	192	216	216	210	216	228	216	228				
Min.	96	108	144	120	120	120	132	96	96	132				
Calcium (mg LG^{1})														
SWIC	700	620	512	496	536	580	484	528	552	572	558	65	700	484
SW 12a	612	616	420	520	384	392	384	372	384	376	446	99	616	372

Table 4: Continue

	Year (2009)							Year (2010)						
Area code	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Overall average	SD	Max.	Min.
SW 8A	252	248	232	260	220	240	228	232	232	240	238	12	260	220
SW 8C	188	208	156	192	152	156	160	160	168	180	172	19	208	152
SW 23	180	192	160	184	148	152	152	148	160	172	165	16	192	148
SW 14	468	460	408	476	416	420	400	428	424	428	433	26	476	400
SW 20	280	280	232	272	224	224	228	236	232	268	248	24	280	224
SW 8 g	252	244	196	248	196	192	196	200	200	208	213	24	252	192
SW 10b	240	252	208	248	176	172	172	176	184	188	202	33	252	172
SW 11b	296	128	208	300	180	184	188	180	180	148	199	57	300	128
Mean	347	325	273	320	263	271	259	266	272	278	287			
Max.	700	620	512	520	536	580	484	528	552	572				
Min.	180	128	156	184	148	152	152	148	160	148				
Chloride (mg L^{-1})														
SWIC	879	670	618	526	574	670	493	557	595	792	637	121	879	493
SW 12a	539	540	583	449	409	441	389	422	455	477	470	64	583	389
SW 8A	178	248	279	224	244	278	170	253	238	247	236	37	279	170
SW 8C	313	365	320	376	319	263	265	281	329	335	316	38	376	263
SW 23	266	378	345	348	415	286	269	281	2326	338	325	49	415	266
SW 14	576	706	557	646	640	585	519	612	577	605	602	52	706	519
SW 20	432	418	410	432	456	392	428	460	501	533	446	43	533	392
SW 8 g	388	421	405	380	429	391	759	409	467	472	452	112	759	380
SW 10b	316	367	366	408	372	375	354	383	396	415	375	28	415	316
SW 11b	361	694	380	396	390	382	410	387	389	463	395	27	463	361
Mean	425	451	426	418	425	406	406	405	427	468	426			
Max.	879	706	618	646	640	670	759	612	595	792				
Min.	178	248	279	224	244	263	170	253	238	247				
Magnesium (mg L^{-1})														
SWIC	123	108	113	110	96	103	108	96	98	106	106	8	123	96
SW 12a	94	108	98	96	106	108	106	103	108	108	103	5	108	94
SW 8A	74	79	77	77	77	79	72	77	72	77	76	3	79	72
SW 8C	31	34	34	34	46	43	43	46	48	50	41	7	50	31
SW 23	36	38	38	36	55	58	60	55	55	60	49	11	60	36
SW 14	108	110	110	110	120	122	125	120	125	127	118	7	127	108
SW 20	46	43	43	43	72	67	72	72	72	84	61	16	84	43
SW 8 g	31	34	34	34	67	62	60	65	67	67	52	17	67	31
SW 10b	26	26	31	31	58	55	58	58	55	58	46	15	58	26
SW 11b	43	46	48	48	60	60	62	60	65	65	56	8	65	43
Mean	61	63	63	62	76	76	77	75	77	80	71			
Max.	123	110	113	110	120	122	125	120	125	127				
Min.	26	26	31	31	46	43	43	46	48	50				

RESULTS AND DISCUSSION

The results of the chemical analysis of surface water from the sites studied are shown in Table 3-6. The data for the results of the chemical analysis show considerable variations among months for water samples collected and the study sites.

Table 5: Variation of nitrate, potassium, sodium and sulphate in surface water samples with months and mean, standard deviation (SD), maximum (Max) and minimum (Min) concentration values for the different studied sites

	Year (2009)							Year (2010)						
Area code	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Overall average	SD	Max.	Min.
Nitrate (mg L^{-1})														
SWIC	190	179	165	182	165	168	161	160	159	124	165	18	190	124
SW 12a	67	84	71	68	69	67	65	65	68	105	73	12	105	65
SW 8 A	23	26	24	23	22	23	23	23	22	23	23	1	26	22
SW 8 C	5	7	6	7	7	7	8	8	8	9	7	1	9	5
SW 23	11	12	11	11	13	12	13	12	12	11	12	1	13	11
SW 14	64	66	63	63	67	65	64	65	66	67	65	2	67	63
SW 20	22	20	21	20	23	21	23	22	22	84	28	20	87	20
SW 8 g	10	10	9	9	11	11	11	11	11	12	11	1	12	9
SW 10b	13	14	12	15	14	13	15	14	14	13	14	1	15	12
SW11b	13	13	14	13	12	13	14	12	15	14	13	1	15	12
Mean	42	43	40	41	40	40	40	39	40	46	41			
Max.	190	179	165	182	165	168	161	160	159	124				
Min.	5	7	6	7	7	7	8	8	8	9				
Potassium (mg L^{-1})														
SWIC	40	38	34	36	36	34	34	33	33	30	35	3	40	30
SW 12a	28	34	30	28	27	29	26	28	28	26	28	2	34	26
SW 8 A	21	23	18	22	23	23	21	23	22	20	22	2	23	18
SW 8 C	23	26	22	24	25	23	21	24	21	20	23	2	26	20
SW 23	23	22	22	22	24	23	22	22	21	21	22	1	24	21
SW 14	25	26	25	25	25	26	27	27	24	25	25	1	27	24
SW 20	27	23	24	24	24	21	22	22	19	21	23	2	27	19
SW 8 g	25	25	23	25	24	21	20	21	19	18	22	3	25	18
SW 10b	22	24	22	24	22	23	23	23	20	21	22	1	24	20
SW 11b	22	23	23	23	23	21	22	20	20	20	22	1	23	20
Mean	26	26	24	25	25	24	24	24	23	22	24			
Max.	40	38	34	36	36	34	34	33	33	30				
Min.	21	22	18	22	22	21	20	20	19	18				
Sodium (mg L^{-1})														
SWIC	720	443	484	417	470	524	447	459	456	565	498	89	720	417
SW 12a	171	316	447	271	363	382	350	352	356	390	340	75	447	171
SW 8 A	127	160	191	136	168	166	112	160	142	150	151	23	191	112
SW 8 C	217	241	253	239	275	213	226	211	229	281	239	25	281	211
SW 23	210	269	286	239	279	209	198	214	206	225	234	33	286	198
SW 14	444	535	492	441	517	453	442	463	425	437	465	37	535	425
SW 20	287	288	224	256	347	290	347	309	339	393	321	43	393	256
SW 8 g	269	287	335	241	307	279	512	269	305	320	313	75	512	241
SW 10b	239	261	308	270	280	275	268	264	274	307	275	21	308	339
SW 11b	233	388	300	176	288	279	305	244	296	369	291	60	388	176
Mean	292	319	342	268	329	307	324	298	303	344	312			
Max.	720	535	492	441	517	524	512	463	456	565				
Min.	127	160	191	136	168	166	112	160	142	150				
Sulphate (mg L^{-1})														
SWIC	1810	1640	1610	1508	1605	1723	1593	1575	1595	1648	1631	84	1810	1508
SW 12 a	1288	1623	1363	1408	1355	1383	1352	1265	1308	1280	1360	103	1623	1265

Table 5: Continue

	Year (2009)							Year (2010)						
Area code	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Overall average	SD	Max.	Min.
SW 8 A	801	776	756	786	733	750	725	730	695	737	749	32	801	695
SW 8 C	545	574	501	504	598	540	565	535	538	576	548	31	598	501
SW 23	580	589	541	530	578	536	548	506	525	570	550	27	589	506
SW 14	1545	1520	1545	1463	1520	1483	1505	1468	1458	1450	1496	36	1545	1450
SW 20	780	789	730	683	823	763	760	781	776	888	777	54	888	683
SW 8 g	695	668	639	638	705	663	655	650	673	695	668	24	705	638
SW 10b	658	653	649	626	628	610	617	616	618	665	634	20	665	610
SW 11b	664	653	684	637	641	653	675	636	673	660	657	17	684	636
Mean	937	948	902	878	918	910	899	876	886	917	907			
Max.	1810	1640	1610	1508	1605	1723	1593	1575	1595	1648				
Min.	545	574	501	504	578	536	548	506	525	570				

Table 6: Variation of ammonium, boron, copper and iron in surface water samples with months and mean, Standard Deviation (SD), maximum (Max) and minimum (Min) concentration values for the different studied sites

	Year (2009)							Year (2010)						
Area code	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Overall average	SD	Max.	Min.
Ammonium (mg LG^{1})														
SWIC	0.65	0.67	0.37	0.59	0.37	0.50	0.32	0.53	0.33	0.52	0.48	0.13	0.67	0.32
SW 12a	0.24	0.39	0.33	0.25	0.33	0.19	0.22	0.20	0.21	0.20	0.25	0.07	0.39	0.19
SW 8 A	0.60	0.58	0.42	0.48	0.38	0.39	0.48	0.41	0.37	0.32	0.44	0.09	0.60	0.32
SW 8 C	0.43	0.67	0.50	0.59	6.26	4.12	4.21	4.39	4.91	5.38	3.14	2.32	6.26	0.43
SW 23	0.48	0.61	0.61	0.61	4.57	3.96	3.85	3.62	3.78	5.19	2.73	1.91	5.19	0.48
SW 14	0.33	0.28	0.28	0.28	0.42	0.33	0.28	0.29	0.23	0.23	0.29	0.05	0.42	0.23
SW 20	0.42	0.58	0.57	0.57	3.45	3.19	4.28	3.35	3.35	4.82	2.46	1.73	4.82	0.42
SW 8 g	0.42	0.58	0.58	0.58	4.62	4.26	4.20	4.00	4.09	5.06	2.84	2.00	5.06	0.42
SW 10b	0.59	0.50	0.89	0.65	3.77	3.18	3.92	3.21	2.99	4.08	2.38	1.52	4.08	0.50
SW11b	0.21	0.48	0.28	0.42	2.68	2.62	3.06	2.40	2.38	3.48	1.80	1.29	3.48	0.21
Mean	0.44	0.53	0.48	0.50	2.68	2.27	2.48	2.24	2.26	2.93	1.68			
Max.	0.65	0.67	0.89	0.65	6.26	4.26	4.28	4.39	4.91	5.38				
Min.	0.21	0.28	0.28	0.25	0.33	0.19	0.22	0.20	0.21	0.20				
Boron (mg LG^{1})														
SWIC	1.08	1.12	1.13	0.98	0.96	0.99	0.96	0.91	0.92	0.92	1.00	0.08	1.13	0.91
SW 12a	0.91	1.04	0.82	0.93	0.82	0.77	0.72	0.72	0.73	0.71	0.82	0.11	1.04	0.71
SW 8 A	0.63	0.67	0.58	0.60	0.71	0.75	0.72	0.69	0.64	0.61	0.66	0.06	0.75	0.58
SW 8 C	0.57	0.66	0.55	0.52	0.82	0.74	0.79	0.77	0.78	0.82	0.70	0.12	0.82	0.52
SW 23	0.73	0.81	0.96	0.68	0.78	0.72	0.73	0.70	0.75	0.78	0.76	0.08	0.96	0.68
SW 14	0.85	0.92	0.82	0.81	0.78	0.81	0.85	0.83	0.78	0.72	0.82	0.05	0.92	0.72
SW 20	0.72	0.69	0.59	0.65	0.81	0.85	0.82	0.89	0.82	0.87	0.77	0.10	0.89	0.59
SW 8 g	0.58	0.64	0.67	0.68	0.74	0.81	0.84	0.78	0.71	0.83	0.73	0.09	0.84	0.58
SW 10b	0.52	0.47	0.75	0.65	0.77	0.82	0.87	0.79	0.81	0.89	0.73	0.14	0.89	0.47
SW 11b	0.56	0.48	0.65	0.53	0.83	0.80	0.87	0.76	0.78	0.81	0.71	0.14	0.87	0.48
Mean	0.72	0.75	0.75	0.70	0.80	0.81	0.82	0.78	0.77	0.80	0.77			
Max.	1.08	1.12	1.13	0.98	0.96	0.99	0.96	0.91	0.92	0.92				
Min.	0.52	0.47	0.55	0.52	0.71	0.72	0.72	0.69	0.64	0.61				

Table 6: Continue

Area code	Year (2009) June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year (2010) Jan.	Feb.	Mar.	Overall average	SD	Max.	Min.
Copper (mg L⁻¹)														
SWIC	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.004	0.003	0.005	0.001	0.005	0.003
SW 12a	0.003	0.003	0.003	0.003	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.003	0.001
SW 8 A	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.001	0.004	0.002
SW 8 C	0.005	0.004	0.005	0.004	0.005	0.004	0.005	0.003	0.003	0.004	0.004	0.001	0.005	0.003
SW 23	0.003	0.004	0.005	0.004	0.004	0.004	0.003	0.003	0.003	0.003	0.004	0.001	0.005	0.003
SW 14	0.004	0.004	0.004	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.001	0.004	0.001
SW 20	0.002	0.003	0.003	0.002	0.004	0.004	0.003	0.003	0.004	0.004	0.003	0.001	0.004	0.002
SW 8 g	0.004	0.004	0.003	0.005	0.006	0.005	0.005	0.003	0.003	0.004	0.004	0.001	0.006	0.003
SW 10b	0.003	0.004	0.004	0.004	0.004	0.004	0.00 5	0.003	0.004	0.003	0.004	0.001	0.005	0.003
SW 11b	0.003	0.003	0.003	0.002	0.005	0.004	0.00 5	0.003	0.003	0.002	0.003	0.001	0.005	0.002
Mean	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.003	0.003	0.003	0.004			
Max	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004				
Min	0.002	0.003	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0.001				
Iron (mg L⁻¹)														
SWIC	0.05	0.05	0.04	0.04	0.02	0.06	0.04	0.08	0.06	0.09	0.05	0.02	0.09	0.02
SW 12a	0.07	0.06	0.04	0.06	0.07	0.05	0.05	0.06	0.03	0.02	0.05	0.02	0.07	0.02
SW 8 A	0.02	0.03	0.03	0.03	0.06	0.06	0.02	0.07	0.05	0.04	0.04	0.02	0.07	0.02
SW 8 C	0.03	0.03	0.02	0.03	0.08	0.06	0.02	0.06	0.05	0.08	0.05	0.02	0.08	0.02
SW 23	0.03	0.03	0.04	0.05	0.09	0.07	0.06	0.07	0.05	0.04	0.05	0.02	0.09	0.03
SW 14	0.03	0.03	0.02	0.02	0.03	0.03	0.02	0.03	0.03	0.04	0.03	0.01	0.04	0.02
SW 20	0.03	0.04	0.02	0.03	0.09	0.08	0.03	0.10	0.05	0.07	0.05	0.03	0.10	0.02
SW 8 g	0.03	0.03	0.05	0.04	0.10	0.09	0.09	0.07	0.06	0.06	0.06	0.03	0.10	0.03
SW 10b	0.03	0.04	0.06	0.04	0.09	0.08	0.08	0.08	0.05	0.06	0.06	0.02	0.09	0.03
SW 11b	0.03	0.03	0.04	0.02	0.09	0.08	0.08	0.07	0.06	0.05	0.06	0.03	0.09	0.02
Mean	0.03	0.04	0.03	0.04	0.07	0.07	0.05	0.07	0.05	0.05	0.05			
Max.	0.07	0.06	0.06	0.06	0.10	0.09	0.09	0.10	0.06	0.09				
Min.	0.02	0.03	0.02	0.02	0.02	0.03	0.02	0.03	0.03	0.02				

pH: An important measure of water quality is its pH. The pH of surface water in the study sites ranged from 6.6-8.4 with an average of 7.5 depending on month and site. The results showed that the water samples ranged from slightly acidic to slightly alkaline (Table 3). Inspection of these values revealed that all site samples lie within the recommended pH limit of irrigation water, i.e., within a permissible range of 6.0-8.5 (Ayers and Westcot, 1985). The highest pH of 8.4 was found during February in S1 and the lowest pH of 6.6 was measured during February in sample S5. The monthly pH was measured and ranged in June (6.96-7.85), July (7.46-8.07), August (7.23-7.95), September (7.2-7.76), October (7.1-7.93), November (7.1-7.95), December (7.64-8.26), January (6.84-8.24), February (6.61-8.40) and March (7.43-8.21). The water samples which were slightly acidic in nature may be due to the presence of low amounts of Ca, Mg, Na and HCO_3 (Mahmud *et al*., 2007).

Electric Conductivity (EC): The EC is an indicator of water quality and is used to determine the concentration of contaminants and thereby determine the purity of a water sample.

Electrical conductance of water sample is a function of the types and quantities of dissolved substances in water (Radtke *et al*., 1998). Distilled water should typically have an EC of less than 0.3 µS cm^{-1}. For groundwater, EC values >500 µS cm^{-1} indicate a polluted water, although values as high as 2000 µS cm^{-1} may be acceptable for irrigation water. The EC values in stream water averaged around 300 µS cm^{-1} (www.gsf.fi/publ/foregsatlas/text/EC.pdf). EC values of samples ranged from 1895-5782 µS cm^{-1} (Table 3), indicating moderate salinity (Al-Ahmadi, 2005b). Regarding EC values, water samples from sites SW1C and SW 14 ranged from 4223-5782 µS cm^{-1} (Table 3). The EC of water samples showed the monthly variations as in June (1963-5782), July (2160-5014), August (1998-4790), September (2063-4492), October (2135-4732), November (1927-5100), December (1960-4544), January (1895-4660), February (1953-4740) and March (2114-5168).

Total Dissolved Solid (TDS): The TDS ranged from 1396-4624 mg L^{-1} with an average value of 2231 mg L^{-1}. Water containing TDS <1000 mg L^{-1} is considered to be 'fresh' (Raghunath, 1987). Accordingly, all water samples were rated as 'not fresh'. It is clear from Table 3 that the TDS of all water samples exceeded the WHO (1993) values for drinking water (1000 mg L^{-1}). The monthly TDS (mg L^{-1}) of water samples were as follows: June (1426-4624), July (1579-3965), August (1451-3743), September (1504-3518), October (1560-3724), November (1396-4039), December (1423-3560), January (1320-3662), February (1416-3730) and March (1543-4090).

Alkalinity (Alk): Alkalinity provides the acid-neutralizing capacity of water and is primarily a function of carbonate, bicarbonate and hydroxide content. Excessive alkalinity levels may cause scale formation (Khanfar, 2008). Most natural waters have an alkalinity range of 10-500 mg L^{-1} (Khanfar, 2008). However, the typical alkalinity range of average surface waters is 20-200 mg L^{-1}, while the alkalinity in surface water of regions with alkaline soils is within 100-500 mg L^{-1} (SWRP., 2011). It is clear from Table 3 that alkalinity values of all water samples were in acceptable range (20-200 mg L^{-1}). Alkalinity values for water samples from sites SW1C and SW8C ranged from 150-200 mg L^{-1} and from 80-120 mg L^{-1}, respectively (Table 3). The alkalinity (mg L^{-1}) of the water samples showed low monthly variations: June (80-190), July (90-200), August (120-160), September (100-180), October (100-180), November (100-180), December (110-180), January (80-190), February (80-180) and March (110-190).

Bicarbonate (HCO_3): The bicarbonate of surface water ranged from 96-240 mg L^{-1} with an average value of 154 mg L^{-1} (Table 4) and all samples were within the regulations set by WHO (1996) which is 250 mg L^{-1} for surface water. Bicarbonate values for the water samples showed a low monthly variation with the highest mean value recorded in July (240 mg L^{-1}) and the lowest values in June, January and February (96 mg L^{-1}). Bicarbonate concentrations in water collected from site SW1C showed higher values than other sites.

Calcium (Ca): Calcium concentration in the watercourse ranged from 128-700 mg L^{-1} with a mean value of 287 mg L^{-1}, well outside the recommended limit of 100 mg L^{-1} in surface water (WHO., 2003) (Table 4). However, it exhibited high monthly variations with the highest mean value of 700 mg L^{-1} recorded in June and lowest mean value of 128 mg L^{-1} in July. It showed the highest value at site SW1C compared to other sites.

Chloride (Cl): Chloride ranged from 170-879 mg LG^1 with a mean value of 426 mg LG^1 which is above the recommended limit of 250 mg LG^1 (WHO., 1996) (Table 4). The chloride content of the water samples showed low monthly variations with the highest mean value in June (879 mg LG^1) and the lowest in December (170 mg LG^1). The sites SW1C and SW14 exhibited the highest range of chloride (519-879 mg LG^1) than other sites.

Magnesium (Mg): Magnesium concentration in water samples ranged from 26-127 mg LG^1 with a mean value of 71 mg LG^1 and was above the recommended limit of 50 mg LG^1 (WHO., 1996) (Table 4). However, sites SW8, SW23 and SW10b had acceptable overall mean magnesium concentrations (41-49 mg LG^1). The magnesium concentration of water samples showed low monthly variations with the highest mean value in March (127 mg LG^1) and the lowest mean value in June and July (26 mg LG^1) (Table 4). The site SW14 showed the highest range of magnesium concentrations (108-127 mg LG^1) and site SW14 had the lowest (26-58 mg LG^1) concentrations compared with other sites.

Nitrate (NO_3): Inorganic nitrogen in the aquatic environment occurs in four forms: Ammonia (NH_3), nitrate (NO_3) nitrite (NO_2) and the ammonium ion (NH_4+) according to Rouse *et al*. (1999). Nitrate is listed as the world's second greatest chemical threat to surface and ground water (Khanfar, 2010) and many water resources faced with problems related to high nitrate concentrations. The maximum limit of nitrate in drinking water is 45 mg LG^1 (Almadini, 2010). Guidelines for the use of water with known nitrate content (Khanfar, 2010) are shown in Table 5. In this study, nitrate concentration was in the range of 5-190 mg LG^1 with a mean value of 41 mg LG^1 (Table 5). The nitrate concentrations of water samples showed the highest variations with site SW14 having the highest range (124-190 mg LG^1) and the site SW8C with the lowest value (5-9 mg LG^1). The mean value of highest and lowest nitrate concentration occurred in June with 190 and 5 mg LG^1, respectively.

Potassium (K): Potassium was in the range of 18-40 mg LG^1 with a mean value of 24 mg LG^1 above the recommended limits of 12 mg LG^1 (Khan *et al*., 1999) as presented in Table 5. Potassium range in site SW1C was 18-40 mg LG^1. The potassium concentration showed very low monthly variations with the highest mean value of 40 mg LG^1 was observed in June and the lowest of 18 mg LG^1 in August (Table 5). The high potassium levels obtained from the samples may have originated from the discharges of the industrial zones located near the area.

Sodium (Na): Concentration of sodium in water above 50 mg LG^1 is defined as unsuitable for domestic use (Alexander, 2008). Sodium concentration ranged from 112-720 mg LG^1 with a mean value of 312 mg LG^1 as shown in Table 5. At site SW1C it ranged from 417-720 mg LG^1. The sodium concentration in the water samples showed moderate monthly variations with the highest mean value observed in June (720 mg LG^1) and the lowest in December (112 mg LG^1) (Table 5). In many natural waters, the concentration of potassium is commonly less than one-tenth the concentration of sodium (Davis and de Wiest, 1970). In the water studied here, the ratio is 0.08.

Sulphate (SO_4): Sulphate concentrations in the water samples ranged between 501-1810 mg LG^1 with an overall mean value of 907 mg LG^1, still outside WHO (1996) level of 250 mg LG^1 (Table 5).

High concentrations of sulphate may cause problems such as respiratory illness and a drinking water sulphate concentration >1000-1200 mg L^{-1} can cause diarrhea, dehydration and weight abatement (Savari, 2006; Pirzada *et al*., 2011). The existence of sulphate in water may be due to natural or anthropogenic sources such as atmospheric precipitation and industrial wastes (Mazloomi *et al*., 2009). The concentration of sulphate in water samples showed low monthly variation with the highest mean observed in June. While, the site SW1C had a value of 1810 mg L^{-1} (Table 5).

Ammonium (Al): Ammonium is found in surface water sources at low levels (up to 1 mg L^{-1} as the ion) and may be due to the biological breakdown of organic nitrogen compounds. Surface water sources can also be contaminated with ammonium from septic systems, animal feed lot runoff, or agricultural runoff from fields fertilized with ammonia or urea. Ammonium is prevalent in municipal waste facilities with levels up to 20 mg L^{-1} as the ion in the effluent, the result of high levels of organic nitrogen compounds and the biological activity (http://www.water-chemistry.in/2008/08/ammonium-nh4/). In this study, ammonium was found to be in the range of 0.19-6.26 mg L^{-1} with a mean value of 1.68 mg L^{-1} (Table 6). The highest value was observed in October (6.26 mg L^{-1}) at site SW8C and the lowest value was in November (0.19 mg L^{-1}) at site SW12a.

Boron (B): Boron concentrations in surface water depend on the amount of boron present in the soils of the drainage area. Surface waters can also accumulate boron from effluent discharges, both from industrial processes and from municipal sewage treatment. Boron concentrations in surface water range widely, from 0.001 mg L^{-1} to as much as 360 mg L^{-1}, although average boron concentrations are typically well below 0.6 mg L^{-1} as suggested by IPCS (1998) and given in Table 7. In the present study, the overall average boron concentration was 0.77 mg L^{-1} (Table 6). During December, the mean boron was highest as compared to other months (0.82 mg L^{-1}). This mean (0.77 mg L^{-1}) is allowable in irrigation water for boron-sensitive plants (Rowe and Abdel-Magid, 1995).

Copper (Cu): Levels of copper found naturally in ground water and surface water are generally very low (4 µg L^{-1} or less; http://dnr.wi.gov/org/water/dwg/copper.htm). The allowable copper level in effluents is 0.2 mg L^{-1} (Al-Motairi, 2001). In the present study, the overall average of copper was 0.004 mg L^{-1} (Table 6). Also, no significant variations were observed between sites and months (0.001-0.005 mg L^{-1}).

Iron (Fe): Iron is one of the most abundant earth elements and in most waters the concentration ranges between 0.5-50 mg L^{-1} with the largest amounts found in ground waters and other natural

Table 7: Average boron in surface water for various regions compared to present study

Regions of the world	Representative boron concentrations in surface water	Reference
Europe, Pakistan, Russia and Turkey	Mean concentrations <0.6 mg L^{-1}	IPCS (1998)
Japan, South Africa and South America	Generally <0.3 mg L^{-1}	IPCS (1998)
North America	Typical concentrations <0.1 mg L^{-1} (with only 10% above 0.4 mg L^{-1})	IPCS (1998)
Present study (overall average)	0.77 mg L^{-1}	

Table 8: Variations of manganse and phosphate in surface water samples with month and mean, standard deviation (SD), maximum (Max) and minimum (Min) concentration values for the different studied sites

	Year (2009)							Year (2010)						
Area code	June	July	Aug.	Sept.	Oct .	Nov.	Dec.	Jan.	Feb.	Mar.	Overall average	SD	Max.	Min.
Manganese (mg LG^{1})														
SWIC	0.0013	0.0014	0.0015	0.0019	0.0001	0.0249	0.0185	0.0208	0.0206	0.0251	0.0116	0.0111	0.0251	0.0001
SW 12a	0.0001	0.0002	0.0016	0.0014	0.0104	0.0101	0.0130	0.0104	0.0140	0.0001	0.0061	0.0059	0.0140	0.0001
SW 8A	0.0001	0.0004	0.0001	0.0001	0.0117	0.0001	0.0014	0.0001	0.0001	0.0001	0.0014	0.0036	0.0117	0.0001
SE 8C	0.0018	0.0021	0.0021	0.0021	0.0212	0.0215	0.0183	0.0139	0.0179	0.0218	0.0123	0.0091	0.0218	0.0018
SW 23	0.0024	0.0027	0.0118	0.0031	0.0114	0.0087	0.0107	0.0211	0.0108	0.0159	0.0099	0.0060	0.0211	0.0024
SW 14	0.0001	0.0001	0.0001	0.0001	0.0013	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0004	0.0013	0.0001
SW 20	0.0012	0.0022	0.0115	0.0014	0.0131	0.0175	0.0119	0.0183	0.0129	0.0238	0.0114	0.0077	0.0238	0.0012
SW 8 g	0.0026	0.0029	0.0321	0.0034	0.0212	0.0342	0.0476	0.0142	0.0210	0.0251	0.0204	0.0151	0.0476	0.0026
SW 10b	0.0032	0.0040	0.0046	0.0034	0.0211	0.0185	0.0212	0.0134	0.0153	0.0184	0.0123	0.0077	0.0212	0.0032
SW 11b	0.0012	0.0026	0.0203	0.0012	0.0119	0.0125	0.0235	0.0107	0.0133	0.0106	0.0108	0.0076	0.0235	0.0012
Mean	0.0014	0.0019	0.0086	0.0018	0.0123	00.0148	0.0166	0.0123	0.0126	0.0141	0.0096			
Max.	0.0032	0.0040	0.0321	0.0034	0.0212	00.0342	0.0476	00.0211	0.0210	0.0251				
Min.	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001				
Phosphate (mg LG^{1})														
SWIC	0.80	0.73	0.78	1.00	0.61	0.97	0.85	0.91	0.99	1.14	0.88	0.15	1.14	0.61
SW 12a	0.35	0.50	0.43	0.32	0.36	0.30	0.33	0.33	0.33	0.23	0.35	0.07	0.50	0.23
SW 8A	0.29	0.43	0.18	0.27	0.41	0.40	0.63	0.39	0.39	0.36	0.37	0.12	0.63	0.18
SE 8C	7.94	11.73	8.96	8.81	11.02	10.60	10.83	10.89	10.85	11.92	10.35	1.32	11.92	7.94
SW 23	7.96	10.75	9.92	9.59	10.18	9.72	9.87	9.57	9.96	10.98	10.03	0.48	10.98	9.57
SW 14	0.39	0.38	0.32	0.21	0.35	0.33	0.31	0.31	0.25	0.27	0.31	0.06	0.39	0.21
SW 20	7.17	9.53	7.35	7.15	7.68	8.12	8.77	8.38	7.96	8,83	8.09	0.79	9.53	7.15
SW 8 g	8.54	9.28	9.79	8.70	9.04	9.65	10.81	9.14	8.79	9.67	9.34	0.67	10.81	8.54
SW 10b	7.41	6.10	9.64	8.37	8.61	8.48	9.63	9.06	7.94	10.27	8.55	1.22	10.27	6.10
SW 11b	7.78	9.26	8.12	9.35	9.06	9.26	9.71	9.52	8.07	9.84.	9.00	0.73	9.84	7.78
Mean	5.04	5.87	5.55	5.38	5.73	5.78	6.17	5.85	5.55	6.35	5.73			
Max.	9.76	11.73	9.92	9.59	11.02	10.60	10.83	10.89	10.85	11.92				
Min.	0.29	0.38	0.18	0.21	0.35	0.30	0.31	0.31	0.25	0.23				

sources (Mazloomi *et al*., 2009). In the studied water samples, iron concentrations ranged from 0.02-0.1 mg LG^{1} with a mean value of 0.05 mg LG^{1} (Table 6). The sites SW8, SW23 and SW10b showed acceptable overall mean iron concentrations (41-49 mg LG^{1}). The iron concentration of the water samples showed low monthly variations and all the samples were within the acceptable range.

Manganese (Mn): Manganese concentration was in the range of 0.0001-0.0476 mg LG^{1} with a mean value of 0.0096 mg LG^{1} (Table 8). The presence of manganese in studied water samples is within the guideline value (0.05 mg LG^{1}) as recommended by both international and Saudi standards for drinking water (Al-Otaibi and Zaki, 2009). The manganese concentration of the water samples studies here showed low monthly variations in all sites.

Phosphate (PO_4): A water sample with phosphate levels <0.03 mg LG^{1} is generally considered to be unpolluted. Phosphate levels between 0.03-0.1 mg LG^{1} are sufficient to stimulate plant growth (Khanfar, 2008). In this study, phosphate was found to be within 0.18-11.92 mg LG^{1} with a mean value of 5.73 mg LG^{1} (Table 8). As such, all the water samples were polluted with phosphate. The site SW8C had a phosphate content of 7.94-11.73 mg LG^{1} while site SW12a had a range of

0.32-0.50 mg L^{-1}. The highest value was in March (11.96 mg L^{-1}) at site SW8C while the lowest value was in August (0.18 mg L^{-1}) at site SW8A.

Correlation coefficient (r): Water quality can also be assessed by the study of correlation coefficients among the physicochemical parameters of studied sites which determines the effect and relationship between cations and anions with each other. Correlation coefficients are presented in Table 9 and showed that pH was associated with some parameters, i.e., EC, TDS, Alk, HCO_3, Ca, Mg, NO_3 and SO_4. On the other hand, a very strong and significant correlation (r =1) was found between EC and TDS. Also, positive correlations were observed between EC and Alk, HCO_3, Ca, Cl, Mg, NO_3, P, Na, SO_4, B and PO_4. Negative (inverse) correlations were found in 56 cases. A linear relationship (Fig. 2) was observed between EC and

Table 9: Correlaation matrix for different water wuality parameters

Parameters	pH	EC	TDS	Alk	HCO_3	Ca	Cl	Mg	NO_3	P	Na	SO_4	NH_4	B	Fe	Mn	Cu
pH	1.00																
EC	0.58	1.00															
TDS	0.58	1.00	1.00														
Alk	0.76	0.84	0.84	1.00													
HCO_3	0.76	0.84	0.84	1.00	1.00												
Ca	0.58	0.95	0.95	0.84	0.84	1.00											
Cl	0.31	0.84	0.84	0.55	0.55	0.75	1.00										
Mg	0.63	0.86	0.86	0.78	0.78	0.79	0.63	1.00									
NO_3	0.59	0.90	0.90	0.84	0.84	0.89	0.69	0.74	1.00								
P	0.48	0.81	0.81	0.75	0.75	0.84	0.60	0.57	0.89	1.00							
Na	0.36	0.83	0.83	0.60	0.59	0.67	0.93	0.64	0.71	0.61	1.00						
SO_4	0.62	0.99	0.99	0.86	0.86	0.95	0.76	0.90	0.89	0.80	0.77	1.00					
NH_4	-0.40	-0.46	-0.46	-0.48	-0.48	-0.55	-0.20	-0.32	-0.40	-0.46	-0.18	-0.51	1.00				
B	0.31	0.62	0.63	0.49	0.49	0.57	0.60	0.57	0.65	0.56	0.58	0.59	0.15	1.00			
Fe	-0.15	-0.14	-0.14	-0.12	-0.12	-0.19	-0.03	-0.06	-0.10	-0.11	-0.02	-0.18	-0.59	0.34	1.00		
Mn	-0.14	-0.19	-0.19	-0.14	-0.14	-0.29	-0.06	-0.18	-0.12	-0.23	-0.10	-0.24	0.66	0.23	0.66	1.00	
Cu	-0.08	-0.17	-0.16	-0.16	-0.16	-0.14	-0.06	-0.31	0.05	0.08	-0.04	-0.21	0.27	0.24	0.32	0.32	1.00
PO_4	-0.68	-0.74	-0.74	-0.76	-0.77	-0.77	-0.37	-0.83	-0.67	-0.56	-0.36	-0.81	0.67	-0.25	0.30	0.46	0.29

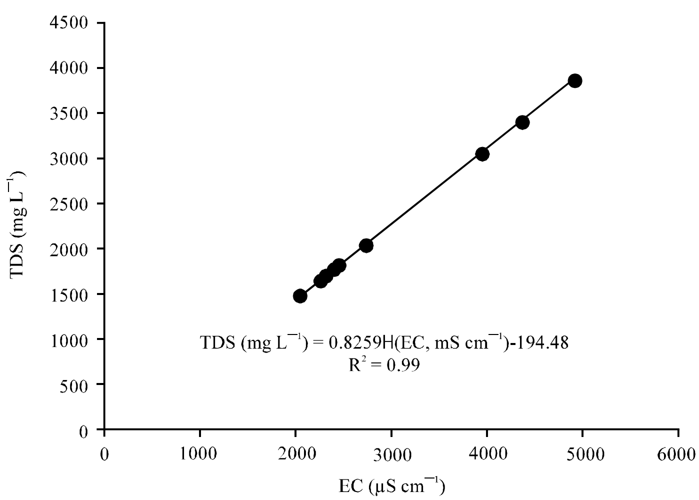

Fig. 2: Relationship of EC with TDS in water samples around the man-made river, Saudi Arabia

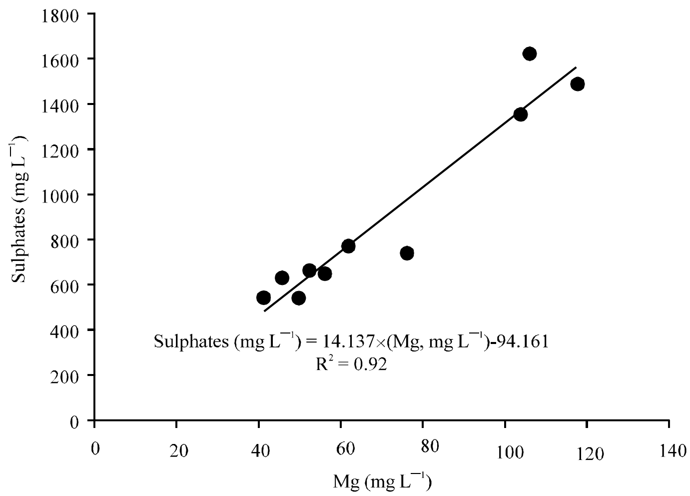

Fig. 3: Relationship of magnesium with sulphate in water samples around the man-made river, Saudi Arabia

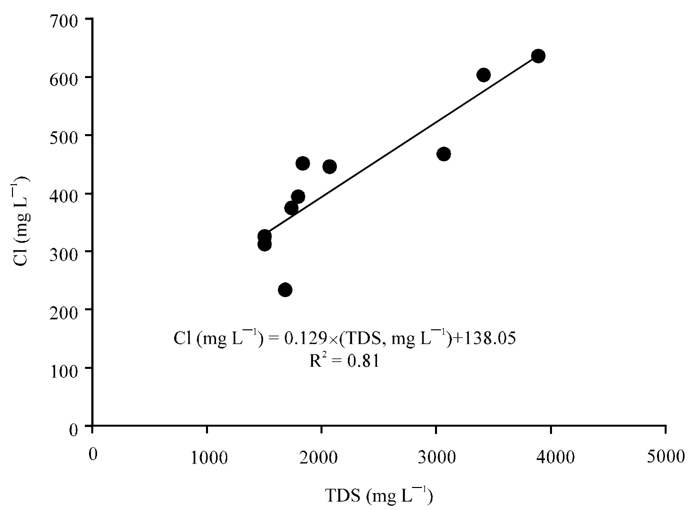

Fig. 4: Relationship of chloride with TDS in water samples around the man-made river, Saudi Arabia

TDS in water samples from the area around the river and this trend was also shown by Al-Matroud (2003). A linear relationship (Fig. 3) was observed between magnesium and sulphates content which confirms this trend observed by Khan *et al*. (1999). Lastly, a linear relationship (Fig. 4) was observed between TDS and chloride content similar to the trend observed by Khan *et al*. (1999).

CONCLUSION

Eighteen physical and chemical characteristics were analyzed from surface water samples collected from 10 sites in a man-made river in Saudi Arabia. The samples studied showed distinct pollution at some sites and is expected to worsen from increased industrial and human activities in the area. It is hoped that the data reported here will form a part of the baseline data-set for use in future studies. The present study may also assist future managers and planners to establish certain control measures and to suggest suitable wastewater treatment methods in the study area to maximize its reuse.

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REFERENCES

ADA., 1994. Wadi hanifah development strategy. Arriyadh Development Authority (ADA), Riyadh, Saudi Arabia.

APHA., 1992. Standard Methods for the Examination of Water and Wastewater. 18th Edn., American Public Health Association, Washington, DC., USA., ISBN-13: 978-0875532073, Pages: 1100.

Abulude, F.O., G.O. Obidiran and S. Orungbemi, 2007. Determination of physicochemical parameter and trace metal contents of drinking water samples in Akure Nigeria. Electron. J. Environ. Agric. Food Chem., 6: 2297-2303.

Adejare, L.I., K.J. Balogun and R.O. Shelle, 2011. Hydro-chemistry and levels of some heavy metals in samples of Ibeshe, Lagos lagoon complex, Nigeria. J. Am. Sci., 7: 625-632.

Al-Ahmadi, M.E., 2005a. Groundwater investigation in Hadat Ash Sham area, Western Saudi Arabia. J. Environ. Sci., 29: 21-36.

Al-Ahmadi, M.E., 2005b. Groundwater quality in some villages northeast of Jeddah city, Saudi Arabia. Proceedings of the 9th International Water Technology Conference, March 12-15, 2009, Hurghada, Egypt, pp: 387-384.

Al-Hawas, I.A., 2002. Irrigation water quality evaluation of al-hassa springs and its predictive effects on soil properties. Pak. J. Biol. Sci., 5: 651-655.

Al-Homaidan, A.A., A.A. Al-Ghanayem and A.H. Alkhalifa, 2011. Green algae as bioindicators of heavy metal pollution in Wadi Hanifah stream, Riyadh, Saudi Arabia. Int. J. Water Resour. Arid Environ., 1: 10-15.

Al-Matroud, S.S., 2003. Evaluation of irrigation water quality and its effect on soil infiltration rate in Riyadh region. M.Sc. Thesis, College of Agriculture, King Saud University, Saudi Arabia.

Al-Motairi, H.A., 2001. Water quality regulation and wastewater treatment and reuse in Saudi Arabia. Proceedings of the Joint WHO/UNEP First Regional Conference on Water Demand Management, Conservation and Pollution Control, October 7-10, 2001, Jordan, pp: 259-269.

Al-Otaibi, E.L. and M.S.A. Zaki, 2009. Physico-chemical quality of drinking water at Mushait, Aseer, South-Western Saudi Arabia. Afr. J. Clin. Exp. Microbiol., 10: 117-127.

Al-Redhaiman, K.N. and H.M.A. Magid, 2002. The applicability of the local and international water quality guidelines to Al-Gassim region of central Saudi Arabia. Water Air Soil Pollut., 137: 235-246.

Al-Turki, A.I. and H.M.A. Magid, 2003. Nitrate content of drinking and irrigation water in AL-Qassim region-central Saudi Arabia. J. Agric. Sci. Mansoura Univ., 11: 7943-7950.

Al-Turki, A.I., 2009. Evaluation of well water quality in Hael region of central of Saudi Arabia. Proceedings of the 13th International Water Technology Conference, March 12-15, 2009, Hurghada, Egypt, pp: 1121-1132.

Al-Zarah, A.I., 2008. Chemistry of groundwater of Al-Ahsa Oasis Eastern region saudi arabia and its predictive effects on soil properties. Pak. J. Biol. Sci., 11: 332-341.

Alexander, P., 2008. Evaluation of ground water quality of mubi town in adamawa state, Nigeria. Afr. J. Biotechnol., 7: 1712-1715.

Alhamid, A.A., S.A. Alfayzi and M.A. Hamad, 2007. Sustainable water resources management plan for Wadi Hanifa in Saudi Arabia. J. King Saud Univ. Eng. Sci., 2: 209-222.

Almadini, A., 2010. Spatial variability of nitrate and phosphate concentrations in waters from main drainage canals at Al-Hassa Oasis, KSA. Damascus Univ. J. Agric. Sci., 17: 98-109.

Ayers, R.S. and D.W. Westcot, 1985. Water quality for agriculture. FAO Irrigation and Drainage Paper No. 29, Rome, Italy, pp: 8-96.

Bharati, D., I.A. Sayyad, G.G. Gaikwad, D.R. Taikar and J. Dhore, 2011. Physicochemical characteristics of borewell water quality in Nagpur region (South Zone). J. Chem. Pharmaceut. Res., 3: 922-927.

Chapman, D.V., 1996. Water Quality Assessments: A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring. 2nd Edn., Taylor and Francis, London, UK., ISBN-13: 9780419215905, Pages: 626.

Davis, S.N. and R.J.M. de Wiest, 1970. Hydrogeology. John Wiley and Sons, New York, USA., Pages: 463.

Domenico, P.A., 1972. Concepts and Models in Groundwater Hydrology. McGraw-Hill, New York.

EPA., 1974. Wastewater-treatment systems: Upgrading textile operations to reduce. United States Environmental Protection Agency, Washington DC., USA., pp: 1-12.

Gawad, E.A., M.M. Lotfy and S.A. Sakroon, 2010. Assessing the organic and inorganic pollutants of oil field brine water in Marmul area, Sultanate of Oman. J. Basic Applied Sci., 4: 859-876.

George, P.R., 2004. Agricultural water quality criteria: Irrigation aspects. Resource Management Technical Report No. 30, Department of Agriculture, Western Australia.

Harmanciogammalu, N.B., O. Fistikoglu, S.D. Ozkul, V. Singh and M.N. Alpaslan, 1999. Water Quality Monitoring Network Design. Kluwer Academic Publishers, Dordrecht, Netherlands, Pages: 290.

IPCS., 1998. Environmental health criteria 204: Boron. United Nations Environment Programme, International Labour Organisation, World Health Organization, Geneva, Switzerland.

Khalil, B., T.B.M.J. Ouarda and A. St-Hilaire, 2011. Estimation of water quality characteristics at ungauged sites using artificial neural networks and canonical correlation analysis. J. Hydrol., 405: 277-287.

Khan, M., M.A. Khwaja and M. Riza, 1999. Physico-chemical characteristics of sub surface water of Kharipur area-Hazara (NWFP). J. Chem. Soc. Pak., 21: 347-352.

Khanfar, A.R., 2008. Groundwater investigation in bel-ahmar, Assir, Kingdom of Saudi Arabia. Saudi Soc. Biol. Sci. J., 15: 289-296.

Khanfar, A.R., 2010. Dissolved nitrogen in drinking water resources in Al-Mahareth Village of Assir-Saudi Arabia. Saudi J. Biol. Sci., 17: 265-268.

Mahmud, R., N. Inoue and R. Sen, 2007. Assessment of irrigation water quality by using principal component analysis in an arsenic affected area of Bangladesh. J. Soil Nat., 1: 8-17.

Mazloomi, S., M.H. Dehghani, M. Norouzi, M.F. Davil and A. Amarluie *et al*., 2009. Physical and chemical water quality of ilam water treatment plant. World Appl. Sci. J., 6: 1660-1664.

Mirabbasi, R., S.M. Mazloumzadeh and M.B. Rahnama, 2008. Evaluation of irrigation water quality using fuzzy logic. Res. J. Environ. Sci., 2: 340-352.

Pirzada, T., M.A. Talpur, A.D. Rajpe, M.R. Shah and S. Naseem, 2011. Quality assessment of potable water of Khairpur city. J. Chem. Soc. Pak., 33: 604-611.

Radtke, D.B., J.V. Davis and F.D. Wilde, 1998. Specific electrical conductance. U.S. Geological Survey TWRI. http://water.usgs.gov/owq/FieldManual/Chapter6/Final508Chapter6.3.pdf.

Raghunath, H.M., 1987. Ground Water. John Wiley and Sons, New Delhi, India, pp: 353.

Rouse, J.D., C.A. Bishop and J. Struger, 1999. Nitrogen pollution: An assessment of its threat to amphibian survival. Environ. Health Perspect., 107: 799-803.

Rowe, D.R. and I.M. Abdel-Magid, 1995. Handbook of Wastewater Reclamation and Reuse. CRC Press, Inc., New York, USA., pp: 550.

SWRP., 2011. Alkalinity. Student Watershed Research Project. http://science.kennesaw.edu/~jdirnber/limno/alkalinity_introduction.pdf.

Savari, J., 2006. Surveys the physical and chemical quality of Ahvaz city drinking water. J. Tehran Univ. Med. Sci., 5: 75-85.

Schuh, W.M., D.L. Klinkebiel, J.C. Gardner and R.F. Meyer, 1997. Tracer and nitrate movement to groundwater in the northern great plains. J. Environ. Qual., 26: 1335-1347.

Siddiqui, A.Q. and A.H. Al-Harbi, 1995. A preliminary study of the ecology of Wadi Haneefah stream with reference to animal communities. Arab Gulf J. Scient. Res., 13: 695-717.

UNEPGEMS., 2006. Water quality for ecosystem and human health. United Nations Environment Programme Global Environment Monitoring System (GEMS)/Water Programme.

WHO., 1993. Guidelines For Drinking Water Quality: Recommendations. 2nd Edn., Vol. 1, World Health organization, Geneva, Switzerland.

WHO., 1996. Trace Elements in Human Nutrition and Health. World Health Organization, Geneva, ISBN: 9789241561730, Pages: 343.

WHO., 2003. Ammonia in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality. Geneva, World Health Organization (WHO/SDE/WSH/03.04/1).