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Assessment of ground water quality in different areas of Karachi City

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Abstract: The drinking water quality parameters and irrigational water quality indices of water samples from different areas of Karachi city were analysed by classical and instrumental analytical methods. The drinking water quality parameters such as pH, Total dissolved solids (TDS), Electrical conductivity (EC), Turbidity, Total hardness (TH), Total Alkalinity (TA), Calcium (Ca^{2+}) Magnesium (Mg^{2+}), Sodium (Na^{+}), Potassium (K^{+}), Chloride (Cl^{-}) and Sulphate (SO_4^{2-}) were determined by using standard classical and instrumental methods of analysis. The biochemically important parameters such as Nitrate (NO_3^{-}) and Nitrite (NO_2^{-}), Dissolved oxygen (DO) and Biological oxygen demand (BOD) of water samples were also measured to evaluate the biochemical characteristics of water. The important irrigational water quality indices such as Sodium Adsorption Ratio (SAR), Kelley's Index (KI), Mg Hazard (MgH), Residual Sodium Carbonate (RSC) and Langelier Saturation Index (LSI) were also determined from the chemical composition of water samples to evaluate the irrigation utility of ground water samples. Only 25% of the water samples were found suitable for drinking while no sample can be considered as useful for irrigational purpose as per the evaluated irrigational water quality indices.

Key words: TDS, Dissolved Oxygen, Sodium Adsorption Ratio, Langelier Saturation Index, WHO

INTRODUCTION

The underground water is the rain water that infiltrates through the layers of soil and accumulates in the underground reservoirs. The underground water is the second largest source of drinking water after fresh water. In rural areas, the underground water is used for drinking as well as for agricultural purposes. The salinity of underground water depends upon the location and depth of the water reservoir. The wells drilled near coastal areas usually contain highly saline water due to seepage from sea whereas wells near fresh water reservoirs often contain suitable drinking water. Apart from drinking and domestic use, water has numerous applications on industrial scale such as its use as coolant, in agriculture and ice industry.[1]The hydrochemistry plays an important role in determining the chemical characteristics of water reservoirs.[2]The quality of ground water reservoirs needs to be assessed on periodic basis as these reservoirs are subjected to continual changes with the passage of time due to increased population and industrial activity leading to contamination of water reservoirs. However, in recent times there is an increased consideration for the protection of environment leading to the development of waste water treatment facilities, pre-treatment of industrial and domestic waste and dumping of toxic chemical into soil rather than directly into sea[3, 4] .The WHO emphasizes that the drinking water must be free from toxic chemical and pathogenic microorganisms and the physico-chemical and microbiological analysis of drinking water is essential on periodic basis on public and/or private scale.[5]

As the population of the world is increasing day by day; the fresh water reservoirs are getting depleted quickly and there is a need to search such ground water reservoirs that can be used for drinking. However, there is a need to pre-assess the physical, chemical and biological quality of a water reservoir prior to its use as drinking. The main aim of this study is to determine the physical and chemical characteristics of underground water reservoirs in different areas of Karachi city and to predict their feasibility for use as drinking and irrigational water. The focus is on the turbidity, TDS/salinity, important minerals and different water quality parameters of irrigational importance of ground water.

MATERIALS AND METHODS

Materials: All the glasswares used in the classical and instrumental methods of analysis were of Pyrex A-Grade quality. All the chemicals used in analysis were of analytical reagent grade quality. All the chemicals were prepared in double distilled water having conductance of 6.0×10^{-2} $\mu S.cm^{-1}$. The Schimadzu UV-3000 spectrophotometer was used for the analysis of sulphate, nitrate and nitrite while the alkali metal ions Na^+ and K^+ were analyzed by flame photometry using a Sherwood 410 flame photometer.

Sampling: The underground water samples from different locations inside Karachi were collected in plastic containers. The containers were first rinsed twice with the distilled water and then twice with the water to be sampled; and then the water samples were collected. The volume of each sample collected was approximately 2.0 L. The temperature of the samples was determined at the collection site and the water quality parameters of the samples were analyzed within 24 hours of collection. A total of 15 samples were collected for the analysis. The geographical map of Karachi city is shown in Fig. 1. The sampling locations inside Karachi city for assessment of water quality parameters of water supply are given in Table 1.

ANALYTICAL METHODS

The classical as well as instrumental methods were used for the determination of drinking and irrigational water quality parameters of ground water samples. The turbidity, electrical conductance, pH, total dissolved solids (TDS), sodium (Na^+), potassium (K^+), sulphate (SO_4^{2-}), nitrate (NO_3^-), and nitrite (NO_2^-), were determined by instrumental analysis whereas chloride (Cl^-), total hardness (TH) , total alkalinity (TA), calcium (Ca^{2+}), magnesium (Mg^{2+}), dissolved oxygen (DO) and biological oxygen demand (BOD) were determined by determined by classical titrations. The experimental values were compared with the WHO guidelines for the drinking water standards while the irrigational importance of water was evaluated from the determination of sodium adsorption ratio (SAR), Kelly's Index (KI), Magnesium Hazard (MH), residual sodium carbonate (RSA) and Langelier Saturation Index (LSI) were also evaluated.

Figure 1: The geographical map of Karachi city

Table 1: The Sampling Plan for the Collection of Ground Water Samples from Karachi City

Sample No.	Sampling Location	District
KGW1	North Nazimabad	Central
KGW 2	Lalo Khet	Central
KGW 3	Gulshan-e-Iqbal	East
KGW 4	Buffer Zone	Central
KGW 5	Shah Faisal	East
KGW 6	Malir	Malir
KGW 7	Hawks Bay	West
KGW 8	Manzoor Colony	South
KGW 9	Gulberg	Central
KGW 10	Model Colony	Malir
KGW 11	Gulistan-e-Jauhar	East
KGW 12	Orangi Town	West

RESULTS AND DISCUSSION

The drinking water quality parameters of all the ground water samples are tabulated in Table 2.The samples were analyzed in triplicate. The sources of different chemicals in the ground water samples have been discussed in relation with their acceptable concentration in drinking water as per WHO guidelines. The variation in chemical composition of ground water samples from different areas of Karachi has been represented by graphical method and the factors responsible for this variation have been discussed. Agricultural water quality parameters have also been calculated in order to evaluate the worth of these underground water reservoirs as source of irrigation.

Temperature (°C) : The biological activity inside water is very much dependent on the temperature of water streams and extreme temperatures can often adversely affect the biological activities in aquabiotic systems. The temperature of ground water samples was in the range of 25 to 28 °C. The discharge of industrial effluents inside water streams and the variation of environmental temperature have an effect on the density of water streams.[6]

Table 2: Drinking Water Quality Parameters of Ground Water Samples from Karachi City

Sample No.	Physico-chemical					Cations				Anions		Biochemical			
	K (µS)	pH	TDS	TH	TA	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{2-}	NO_2^{-}	NO_3^{-}	DO	BOD
KGW1	2332	7.40	1150	660	600	160	63	163	22.7	565	60	0.2	5.0	4.4	1.0
KGW 2	1100	6.6	514	252	123	57.6	26	87.5	11.4	274	58.8	0.12	4.5	4.4	1.1
KGW 3	3045	6.7	1460	620	162	184	39	200	20.5	675	63.6	0.22	3.0	3.4	0.6
KGW 4	1733	7.1	808	340	170	80	34	125	15	267	98	0.30	6.7	4.6	0.8
KGW 5	6670	6.9	3070	980	750	160	141	750	79.5	1587	46	0.07	28	5.6	0.5
KGW 6	6133	7.35	3120	570	435	120	66	1059	31.5	1800	271	0.35	8.0	4.6	0.6
KGW 7	12030	6.9	5400	1500	1025	288	190	1750	136	2634	94	0.61	12	5.8	1.5
KGW 8	5768	7.20	3148	685	750	184	55	578	25	934	80	0.10	10	5.2	0.7
KGW 9	1256	7.07	640	320	150	64	39	89.5	4.00	300	55	0.05	3.4	5.3	0.9
KGW 10	5034	7.39	2450	830	660	176	95	150	23	930	328	0.24	2.5	4.2	1.0
KGW 11	4360	7.28	2260	560	475	140	50	155	25	540	70	0.17	4.8	4.7	1.2
KGW 12	4660	7.40	2430	550	460	120	48	175	30	650	80	0.15	4.3	4.8	1.0
WHO	1400	6.5-8.5	1000	500	120	100	150	200	-	250	250	1.0	5.0	-	-
Avg. STD	153.5	0.242	75.0	22.4	16.3	4.92	2.40	15.0	1.20	31.6	3.70	0.007	0.263	0.162	0.031

*All the concentrations are measured in units of $mg.L^{-1}$.

Turbidity: The turbidity is caused by fine and colloidal suspended solids in water. The ground water samples are usually little more turbid as compared to fresh water streams due to their presence in underground reservoirs. The turbidity of ground water samples from Karachi was in the range of 0 to 0.5

NTU which is in accordance with WHO guidelines. The turbidity of water samples fluctuates from area to area due to the total suspended solids and sometimes microbial growth.

Electrical conductivity: The capacity of ions in a water sample to conduct electric current is termed as electrical conductivity (EC). The value of electrical conductivity is often used as an index of total dissolved materials in a water sample and is related to the TDS of water sample by a mathematical factor that depends upon the concentration and type of ions present in the water sample. The conductance of drinking water must not exceed 1400 $\mu S.cm^{-1}$. In our study, all the samples except two had higher electrical conductivity than WHO guidelines.

Total alkalinity: The capacity of a water stream to neutralize inputs of acidic industrial and domestic effluents is termed as total alkalinity and is due to anions of hydroxide (OH^-), carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-). The alkalinity of a water stream is subjected to periodic changes depending upon industrial and domestic activities. Furthermore, water with lower alkalinity is vulnerable to significant changes in pH upon receiving industrial effluents.The WHO recommended limit of total alkalinity for drinking water is 120 $mg.L^{-1}$. In our study, only one sample complied with this standard. The other ground water samples were of higher alkalinity and hence there pretreatment is recommended prior to their use as drinking water. The variation in alkalinity of different ground water samples is shown in Fig. 4.

pH : The pH of a water stream is a measure of its acidity and it is very important to ensure that the drinking water has a suitable pH. The WHO guidelines suggest that the pH of drinking water should be in the range of 6.5 to 8.5. In our study, all the ground water samples had pH between 6.5 to 8.5. The upper and lower limitof WHO guidelines have been set on the basis of corrosive effect of water having pH of less than 6.5 whereas water samples with pH more than 8.5 develop an undesirable bitter taste. Also highly alkaline water has high sulphate and hydroxide content which causes scaling of the water supply channels.[7]The irrigational water also must also be in the range of neutral to slightly alkaline. The pH of different ground water samples is shown in Fig. 2.

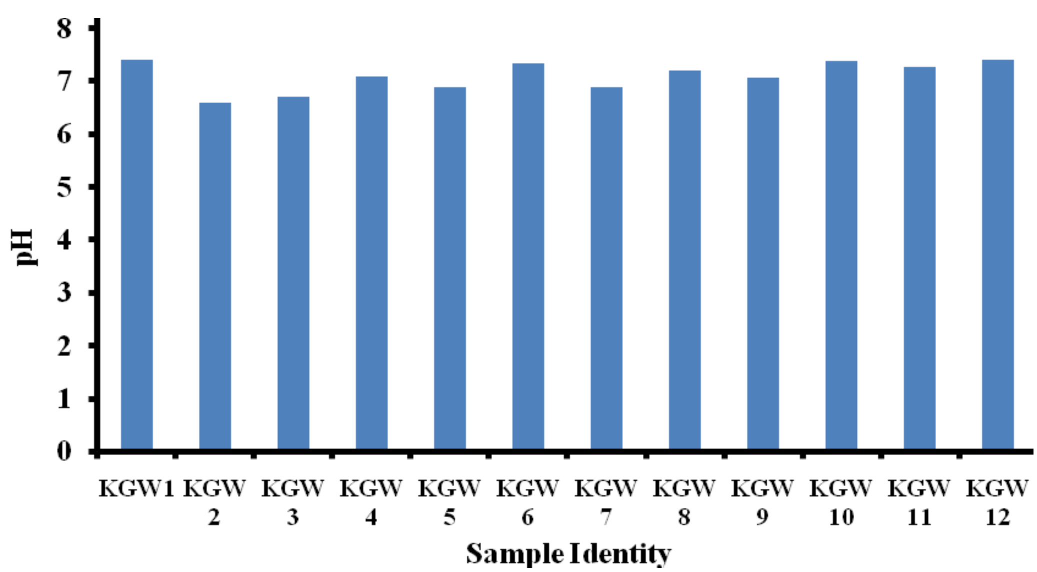

Figure 2: The pH variation of water samples from different areas inside Karachi City

Total dissolved solids: The TDS is a measure of the dissolved inorganic ions such as (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-} and SO_4^{2-}) and also some organic matter that may be present in the water sample.[5] In our study, only 25% of the ground water samples had TDS within the WHO limits while75% of the samples had a higher TDS and hence were not suitable to be used directly for drinking. There is significant different in the TDS of ground water samples from different areas of Karachi due to sampling location. The sample from Hawks bay area has a TDS in excess of 5000 mg.L^{-1} due to seepage of marine water into the ground water reservoir. The high TDS water must be subject to reverse osmosis treatment for lowering the TDS as per WHO limit. In general, water with TDS in the range of 1000 to 3000 mg.L^{-1} is considered as suitable for irrigational use.The variation in TDS of ground water samples is shown in Fig. 3.

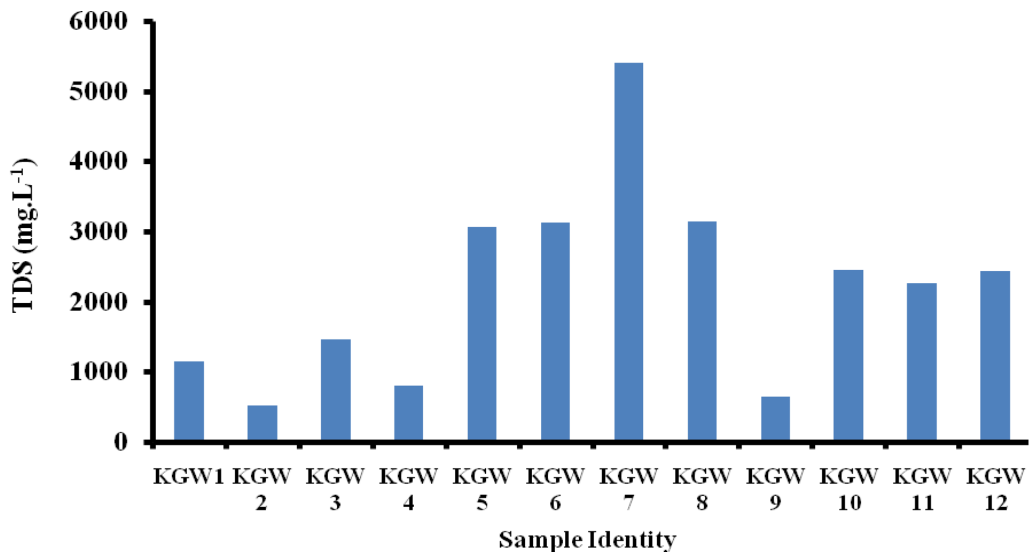

Figure 3: The TDS variation of water samples from different areas inside Karachi City

Total hardness: The "Total Hardness" of a water sample is such a property which prevents formation of lather when soap is mixed with water. The total hardness is actually a combination of permanent hardness and temporary hardness caused by calcium and magnesium salts of different stability. In fact, hardness of a water sample is reported in terms of mg.L^{-1} of calcium carbonate ($CaCO_3$). The WHO limit for drinking water hardness is 500 mg.L^{-1}. The use of "Hard Water" for drinking purpose cause stomach disorders and kidney stones. In our study, only 25% of the samples had suitable hardness while 75% of the water samples were categorized as "Hard Water" as per WHO guidelines.

Calcium: The source of calcium ions in water are the calcium salts leached from the rocky deposits inside and near water bodies. The calcium ions impart a characteristic pleasant sweet taste to water. The calcium ions in water are nutritionally important but if the concentration increases beyond a certain limit, they can cause stomach disorders and kidney stones. The WHO recommends that the concentration of calcium in drinking water must not exceed 100 mg.L^{-1}. In our study, only 25% samples complied with the WHO guidelines whereas other samples had higher concentration of calcium and hence were not suitable for drinking.

Magnesium: The magnesium ions in water contribute to the water hardness but are usually in a much lower concentration than calcium ions. The importance of magnesium ions in drinking water lies in the fact that magnesium ions serve as co-factors for the formation of various enzymes involved in the biochemical interactions inside human body. Also, magnesium ions in irrigational water lay an important role in the photosynthesis. In our study, only one sample showed non-compliance with the WHO standards. This sample (KGW7) was collected from Hawks Bay near coastal belt and hence it had a much higher mineral content.

Sodium: The sodium ions are essentially introduced into water bodies from sodium salts leached from rocks and also sometimes as a result of domestic and industrial activities. The sodium ions are important electrolytes for the human biochemical system.The prescribed WHO limit for concentration of sodium in drinking water is 200 $mg.L^{-1}$. Although, a high amount of sodium in drinking water does not apparently causes any adverse health effects but the persons with hypertension and cardiac abnormalities should be a little carefull in drinking water having high sodium content ($\leq$ 20 $mg.L^{-1}$). In our analysis, 25% samples had higher concentration of sodium than WHO recommendations and hence should be considered as highly unsuitable for drinking.

Potassium: The concentration of potassium in water bodies is usually very low as compared to sodium because potassium salts are much less abundant in rocky deposits. Also, potassium is not much involved in industrial and domestic activities. A high amount of potassium in drinking water causes laxative effects. The WHO does not provide any guidelines for the concentration of potassium in drinking water because it constitutes a very low percentage of TDS in water. However, a concentration greater than 10 $mg.L^{-1}$ produces a distinct bitter taste.The variation in concentration of different cations is shown in Fig. 6.

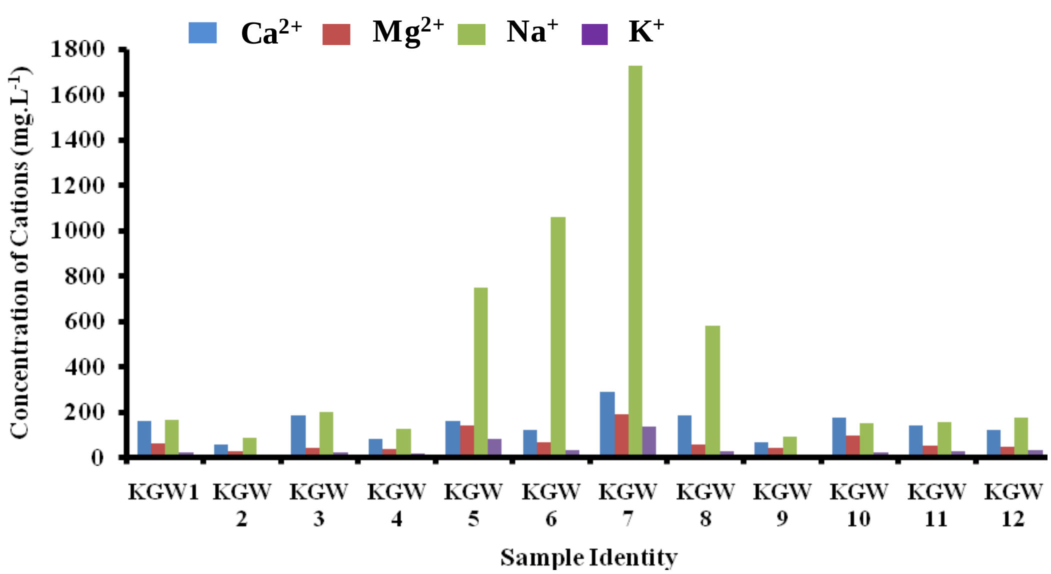

Figure 4: The concentration of cations in water samples from different areas inside Karachi City

Chloride: The chloride ions enter into ground water reservoirs from leaching of chloride salts of different metals and also from seepage of domestic and industrial waste water. The WHO limit for chloride ions in drinking water is 250 $mg.L^{-1}$ basedon the salinity of water. In our study of ground water samples, all the samples had chloride in excess of WHO limits and hence their use as drinking water is not recommended.

Sulphate: Sulphate ions are a constituent of may alkali and alkaline earth metal salts and are discharged into water streams due to leaching from these mineral deposits and from industrial effluents. A high concentration of sulphate in ground water often produces turbidity in water due to combination of sulphate ions with barium resulting in formation of insoluble barium sulphate.The WHO recommends that the concentration of sulphate in drinking water must not exceed 250 mg.L^{-1}. In our analysis, 15% of samples had higher sulphate concentration than WHO limits. The variation in concentration of different anions is shown in Fig. 6.

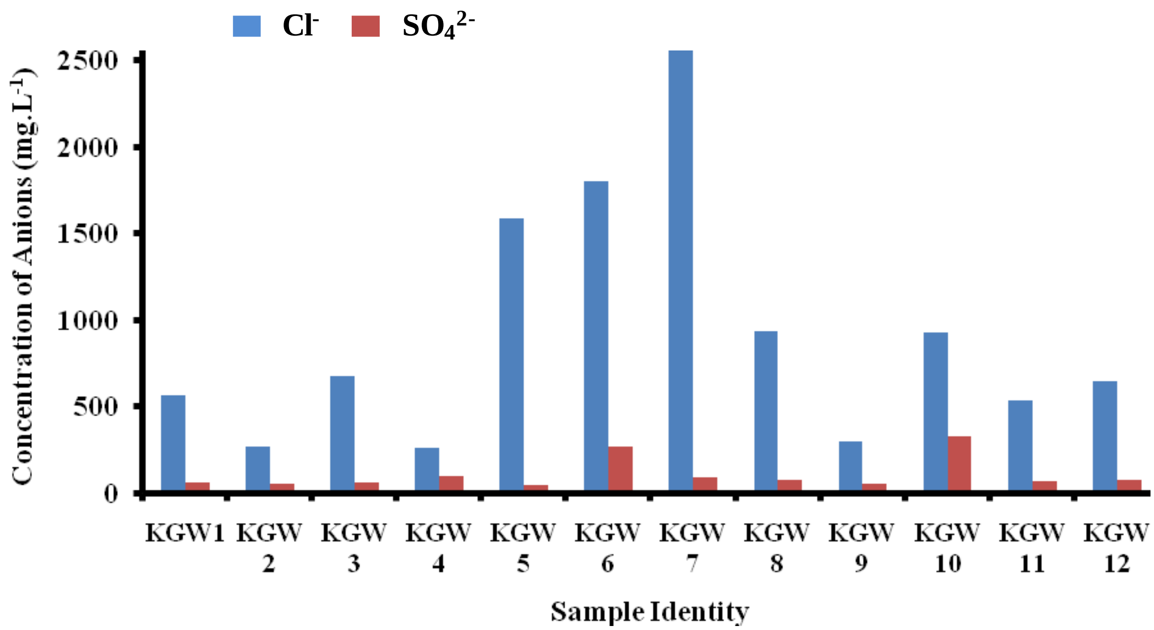

Figure 5: The concentration of anions in water samples from different areas inside Karachi City

Nitrite and nitrate: The nitrite and nitrate are present in ground water reservoirs due to oxidation of nitrogenous inorganic compounds. However, if the concentration of these anions in water increases to a higher level than it is considered as an indication of contamination with human and/or animal faeces. An elevated level on nitrite and nitrate in drinking water is a serious threat for pregnant women and newly born babies of less than 3 months age because of possible occurrence of Methaemoglobinaemia or "Blue Baby Syndrome". The Methaemoglobinaemia or "Blue Baby Syndrome" is a biochemical abnormality in which the nitrate and nitrite ions combine with the hemoglobin molecules instead of oxygen molecules; thereby changing the color of blood from bright red to blue. The removal of nitrites and nitrates can be accomplished by reverse osmosis and distillation although the most preferable precautionary measure is to eliminate the contamination source. The WHO recommended limit for nitrite ionsis 1.0 mg.L^{-1}while for nitrate ions in drinking water is 5.0 mg.L^{-1}. In our study, high levels of nitrate ions were found in ground water samples while the concentration of nitrite was within WHO limits.

Dissolved oxygen: Dissolved oxygen (DO) is a very important biochemical parameter for water quality assessment and it gives vital information about the biological activity going on in water. The concentration of dissolved oxygen in water is inversely related to the bacterial contamination in water. The WHO does not provide any guidelines for the concentration of dissolved oxygen in drinking water but most environmental scientists are of the opinion that the concentration of dissolved oxygen in healthy drinking water should be atleast 4 mg.L^{-1} or greater. In our analysis, no sample was found to contain DO in concentration less than 4 mg.L^{-1}. Furthermore, the concentration of DO in water is also important for the sustainability of aquatic ecosystem.[8]

Biological oxygen demand: The BOD is a measure of bacterial activi:ty in water and an unusually high BOD indicates contamination of water reservoir with bio-sewage.The acceptable value of BOD is ≤ 1 mg.L^{-1} and if a water reservoir has a BOD greater than 1 mg.L^{-1};it is likely to produce water borne infections and/or diseases and is not recommended for drinking. In our analysis, the BOD of water samples is in the range of 0.50 to 1.50 mg.L^{-1}. The samples KGW2, KGW7 and KGW11 had a higher BOD value than acceptable indicating bacterial contamination which can be due to pathogens giving rise to bacterial infections.

There is significant agricultural activity inside Karachi and its nearby areas and hence the ground water samples were also evaluated in terms of their agricultural significance. The TDS of water is an indicator of its utility as agricultural water. The suitable water for irrigational purpose must have a TDS in the range of 1000 to 3000 mg.L-1.In our study, 66% of the water samples were found good for irrigational use on the basis of TDS. However, the worth of a water sample for irrigational use can not only be determined from a measurement of its TDS and thereare many other different indices used for the agricultural importance of water such as sodium adsorption ratio (SAR), Kelly's Index (KI), Magnesium Hazard (MH), residual sodium carbonate (RSA) and Langelier Saturation Index (LSI). Also, the concentration of chlorine must be tested in water prior to its irrigational use. The different water quality parameters of irrigational importance are discussed individually.The experimentally determined irrigational water quality indices are tabulated in Table 3.

Table 3: Irrigational Water Quality Indices of Ground Water Samples from Karachi City

Sample No.	IRRIGATIONAL WATER QUALITY INDICES				
	Sodium Adsoprtion Ratio (SAR)	Kelly's Index (KI)	Mg Hazard	Residual Sodium Carbonate (RSC)	Langelier Saturation Index (LSI)
KGW1	30.873	1.462	28.251	77.348	35.608
KGW 2	27.068	2.093	31.100	-22.090	33.729
KGW 3	37.881	1.794	17.489	-141.986	34.442
KGW 4	33.113	2.193	29.825	-28.953	34.509
KGW 5	122.27	4.983	46.844	74.138	35.248
KGW 6	219.63	11.387	35.484	31.723	35.353
KGW 7	226.40	7.322	39.749	34.689	35.581
KGW 8	105.75	4.837	23.013	136.275	35.557
KGW 9	24.943	1.738	37.864	-27.962	34.407
KGW 10	25.772	1.107	35.055	59.375	35.717
KGW 11	31.805	1.632	26.316	47.708	35.385
KGW 12	38.188	2.083	28.571	62.265	35.387

Sodium adsorption ratio (SAR): The sodium adsorption ration is a measure of the quantity of sodium in water as compared to the overall salinity of the water. The formula for the determination of sodium adsorption ratio (SAR) is given by equation.

$SAR = Na^{+}/[(Ca^{2+} + Mg^{2+})^{1/2}/2]$

The sodium adsorption ratio of higher than 26 is considered as poor for irrigational use.[9]In our study, only two samples had SAR of less than 26 can be considered for irrigational use while all the other samples had a higher SAR and must not be used for irrigational purpose.

Kelley's index: The Kelly's index is an irrigational water quality parameter that determines the concentration of sodium ion in water in comparision with the total concentration of calcium and magnesium ions as determined by the equation.[9]

$KI = Na^{+}/ (Ca^{2+} + Mg^{2+})$

The milliequivalents of sodium must be less than the total milliequivalents of calcium and sodium otherwise the water is considered unsuitable for irrigational purpose. Therefore, suitable water for irrigation must have a Kelley's index of less than 1. In the present study, the Kelley's index of all the water samples was higher than 1. Hence, all the water samples are unsuitable for irrigational use.

Mg hazard: The ground water contains calcium and magnesium as chief alkaline earth metals and their concentration must be in a delicate balance in irrigational water in order to produce higher yield of crops. The ratio of magnesium ions in comparision to the total concentration of calcium and magnesium ions was done by using equation.[10]

$MH = Mg^{2+}/ (Ca^{2+} + Mg^{2+})$

In our study, all the samples have Mg hazard of less than 50. It indicates that the ground water samples contain balanced amount of calcium and magnesium ions. Hence, the water can be used safely for irrigational purpose according to the criterion of Mg hazard.

Residual sodium carbonate (RSC): The concentration of carbonates in irrigational water must be in a limit in order to prevent precipitation of alkaline earth metal ions (Ca^{2+} and Mg^{2+}) as carbonate salts. The safe level of carbonate in irrigational water is determined by an experimental parameter.[9]

$RSC = [(HCO^{3-} + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})]$

A good quality irrigational water must have a RSC value of less than 1.25 $meq.L^{-1}$. In our study, 67% of the water samples had RSC value much higher than 1.25 $meq.L^{-1}$ and hence were considered unfit for irrigational use while 33% of the samples had negative RSC value and can be safely used for irrigational purpose.

Langelier saturation index (LSI): The prediction of calcium carbonate stability is very important to determine the potential for precipitation of calcium carbonate in irrigational water. The parameter used for the determination of this potential is LSI. The LSI is the difference of the actual pH of water and a saturation pH as determined from the chemical composition of water.

$LSI = pH - pHs$

$pHs = (9.3 + A + B) - (C + D)$

where,

$A = (Log10\ [TDS] - 1) / 10$

$B = -13.12 \times Log10\ (°C + 273) + 34.55$

C = Log10 [Ca+2 as CaCO3] - 0.4

D = Log10 [alkalinity as CaCO3]

If the actual pH of water is below the saturation pH, the LSI is negative and the calcium carbonate dissolves in water rather than precipitation. In our study, the LSA values for all the samples were positive indicating that high potential for calcium carbonate precipitation. Hence, the water is not suitable for irrigational purpose.[1]

CONCLUSION

The water samples collected from different locations inside Karachi city were analyzed for different water quality parameters of drinking and irrigational importance. Only 25% of the water samples were found suitable for direct use as drinking water while 75% of the water samples had higher concentration of minerals than recommended by WHO guidelines and must be processed through different water treatment techniques such as filtration and/or reverse osmosis prior to their use as drinking water. The irrigationally important water quality indicesof sodium adsorption ratio (SAR), Kelley's Index (KI), Residual Sodium Carbonate (RSC), and Langelier Saturation Index (LSI) suggested that all the water samples were unsuitable for irrigational importance while the value of Mg Hazard suggested that water can be used for irrigation. However, an improvement in the quality of water is essentially required for its use as irrigational water.

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