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PUBLIC HEALTH ASSESSMENT AND WATER QUALITY INDEX OF TANKER WATER AVAILABLE IN KARACHI CITY

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ABSTRACT

The current assessment aimed to evaluate physico-chemical, metal and microbiological characteristics along with Water Quality Index (WQI) of tanker water (12 samples) which were collected during 2018 from Karachi city. The water samples were investigated for pH, Turbidity, TDS (Total dissolved solids), Chloride, Hardness (as $CaCO_3$), Alkalinity, Nitrate, Phosphate and Sulphate. These parameters were well within the guidelines prescribed by WHO (2011) and NSDWQ (2008) with the exception of TDS, Hardness and Sulphate. The mean concentration of examined metals (As, Pb, Cr, Ni, Ca, Mg, Fe and Zn) were in the order of Ca > Mg > Zn > Pb > Ni > Fe > As > Cr in all the samples. Most Probable Numbers (MPN) Technique was used to find Total Coliform Count (TCC), Total Fecal Coliform Count (TFC) and Total Fecal Streptococci (TFS) for microbial assessment. Presence or absence of *Escherichia coli* was also monitored through florocult media. Seventy five percent samples were faecally contaminated and failed to meet the guidelines set by WHO and NSDWQ. According to WQI results, 91.6 % samples were found to be good with respect to physico-chemical properties. In terms of metals, WQI value of all the samples revealed unfit for human use. Possible contamination sources are unhygienic condition of water tankers and delivery pipes, untreated sewage discharge, cross contamination, agricultural runoff, human and animal waste which may cause disease associated with public health. Water monitoring plans of water management and awareness programs of innocuous waste dumping have been recommended.

Keywords: Tanker Water, Water Quality Index, Heavy metals, Hydrant, Microbiology, Karachi,

INTRODUCTION

Increase in population, urbanization and industrialization has placed massive pressure on water resources in Pakistan, which will eventually result in severe water stress during the upcoming decades (Soomro *et al.*, 2011; Arnell, 2004). In Pakistan, approximately 44% of people do not have approach to safe water whereas 90% of the people lack such access in rural areas and rely on contaminated water which is liable for 60% fatalities in Pakistan (UNSP, 2003). Approximately, 88% of existing water supply schemes are unfit for human use because of the existence of pathogens (PCRWR, 2012). Poor quality of water is responsible for 30% of all illnesses and 40% of all deaths in Pakistan while diarrhea is stated as the leading cause of fatality especially in children and each fifth inhabitant suffers from water borne ailments due to polluted water (Kahlown et al., 2006). The fundamental reasons of waterborne illnesses are the addition of community sewage and industrial wastewater at exclusive sites of the water dissemination system and absence of water disinfection and it is calculated that water borne diseases incurred each year countrywide earnings losses of USD 380–883 million (UNDP, 2003). People belonging to developing countries have no choice but to rely on contaminated water which is responsible for water borne diseases especially in children due to water scarcity (Aziz, 2005).

Karachi is the biggest financial hub, most populous and industrialized city of Pakistan having an estimated area of 3,527 km^2. According to 2017 official census the population of Karachi is 16.21 million, however unofficial reports proposed that the population is around 25 million. Due to low economic rate the adequate supply of water is a big task (Chandio *et al.,* 1998). The KWSB (Karachi Water and Sewerage Board) is the official organization accountable for the supply of potable water to the citizens of Karachi. Water is being supplied to Karachi through the River Indus (645 MGD) and Hub dam (for 30- 50 MGD). The water supply from Hub dam is erratic as it is reliant on rain. Around 650 MGD total available water supplied to Karachi claimed by KWSB that hardly satisfies the requirement. In addition, KWSB conveyed that if the per capita water demand is 54 GPCD then the city water requirement would be around 1080 MGD that has generated a shortfall of 430 MGD. In 2015, KWSB claimed that city water demand was 1242 MGD generating a shortfall of 600 MGD. In the current situation it would mean that 100 MGD of surplus water would be required after every 5 years. KWSB has a quota of 417.65 MGD for the residential area including cantonment area and Defence housing authority. However, the real water supply is only about 293 MGD reaches to the towns (Rahman *et al.,* 1997). Moreover, 30-35% water losses due to obsolete, rusty, mugging and chronic leakages of water distribution system which shows inadequate maintenance and deprived management (Ahmed and Sohail, 2003). In order to meet the demand of water supply the people have no other choice except to rely on alternate water resources such as dug well and commercially available water tankers. Various researches have been employed to evaluate water quality of Karachi and highlights grossly chemical and bacteriological adulteration in Karachi (Arain *et al.,* 2009; Hasnie and Qureshi, 2004; Alamgir *et al., 2015a*, 2015b, 2020). Possible sources of contamination are non-point origins of untreated domestic and industrial effluents, inappropriate water dissemination, mugging, seepage and leakage of rusty and old pipelines and technical complications.

Water supply through water tankers are independent from a public network is the sale of bulk water and transport from surface water sources and groundwater wells (Zozmann *et al.,* 2019). Water tankering (also called as water trucking) can be a fast means of transporting water to areas in need during the early stage of an emergency. However, tankering maneuvers are expensive and comparatively time-consuming to govern. Water tankers made from flatbed trucks with storage tank attached. Water tanks are made up of stainless steel or other material suitable for the storage of drinking water. According to KWSB, around 26 authorized water hydrants are available for Karachi city but unfortunately some hydrants are not functioning. In Karachi, illegal and private water tankers are also available and taking advantage of water shortages and delay to transport water through official water tankers in a city. They charge Rs 5,000 for 1,000 gallons water, Rs 7,000 for 2,000 gallons and Rs 9,000 for 3,000 gallons despite the water rates fixed by the KW&SB as per the government's official rates of Rs 1,000 for 1,000 gallons, Rs 1,300 for 2,000 gallons and Rs 1,700 for 3,000 gallons for residential consumers. According to KWSB, due to 150 illegal hydrants KWSB failed to supply water in a city.

This paper focuses on physicochemical and microbiological quality of tanker water supplied in the city.

MATERIAL AND METHODS

Sampling

A total of 12 tanker water samples were collected during March to April, 2018. The sites for sample collection are mentioned in Table 1. The samples for physico-chemical and bacteriological investigation were collected separately. Clean plastic bottles (1.5 L) were used for collection of samples for physic-chemical and metal analysis while 1 litre of pre-sterilized glass bottles were used for sample collection for microbiological investigation. Samples were kept at a low temperature in an ice box and were conveyed to the laboratory in the Institute of Environmental Studies, University of Karachi.

Physico-chemical Analysis

The water samples were investigated for pH, Turbidity, Total dissolved solids (TDS), Chloride, Hardness (as $CaCO_3$), Alkalinity, Nitrate, Phosphate and Sulphate . Hanna pH meter (HI98107) and EUTECH turbidity meter (TN-100) were used on site for pH and Turbidity measurements. Gravimetric method was employed for the estimation of TDS and Sulphate. Argentometric method was employed for chloride estimation while EDTA titration method was applied for Hardness (as CaCO3) estimation. The above mentioned parameters were analyzed in accordance with the methods described in APHA (2005). Appropriate Merck Kits were used for the analysis of As, Pb, Cr, Ni, Ca, Mg, Fe and Zn by using Merck super NOVA 60 photometry (Germany).

Microbiological Analysis

MPN technique (APHA 2005) was used for Bacteriological examination. The water samples were examined for the detection of TCC (Total Coliforms Count), TFC (Total Fecal Coliforms Count) and TFS (Total Fecal Streptococci Count). Sterility was maintained throughout the analysis by using laminar flow hood. TCC was assessed by lactose broth (Merck, Germany) of single and double strength. TFC were examined through EC broth (Merck, Germany) by means of positive single and double strength lactose broth tubes. In addition, Florocult media was used to check the presence or absence of *E.coli*.

WQI Model

Water Quality Index Model

In this study, the WQI model was computed using water quality parameters and their relevant WHO guidelines. According to the literature (Sahu and Sikdar 2008; Ketata-Rokbani et al. 2011; Shabbir and Ahmad 2015; Sener et al. 2017), physicochemical, metal and microbiological parameters were assigned a weight (wi) from 1 to 5 depending upon their significance in water quality evaluation for human health as shown in Table 2-4. In this study, the highest weight of 5 was assigned to As, Pb, Cr, Ni and Microbiological parameters because of its higher impact on human health. To calculate, WQI three steps were followed. In the first step, the relative weight (Wi) was computed using Eq. (1) (Ketata-Rokbani et al. 2011).

$$\mathrm{Wi} = \frac{\mathrm{wi}}{\sum_{i=1}^{n} wi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where Wi, wi and n were the relative weight, each parameter's assigned weight, and a total number of observed parameters, respectively, while the water quality rating scale (Qi) for each of the observed water quality parameters was calculated using Eq. (2).

$$Qi = \frac{\mathrm{Vo}}{\mathrm{Vs}}\ \mathrm{X}\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Where Vo, and Vs were the observed levels of each parameter and each parameter's WHO threshold level. In the end, the WQI was calculated using Eq. (3).

$$WQI = \sum_{i=1}^{n} Wi\ \mathrm{X}\ Qi \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Table 1. Sites for sample collection

S.NO	SAMPLE CODE	NAME OF HYDRANT	SITE ADJACENT TO
1	T-1	Safoora Goth Hydrant	Safoora Goth Malir Cantt. Near Race Course Ground
2	T-2	Nipa Hydrant	Gulshan-e-Iqbal Block 6, Near Nipa Aero Club
3	T-3	Sakhi Hassan Hydrant	Sakhi Hassan Chowrangi, Near D.C Office
4	T-4	Sitara Pak Hydrant	Nishtar Road, Near Filmistan Cinema, Tin Hatti
5	T-5	Landhi-1 Future Colony Hydrant	Future Colony, Illahi Pumping Station, Landhi
6	T-6	Crush Plant Hydrant	Crush Plant Hub Pumping Station
7	T-7	Cattle Colony Hydrant	Cattle Colony Road, 5 Mehran Highway Bin Qasim Town
8	T-8	Baldia Hydrant	Football Ground 4, Baldia Town
9	T-9	German School Hydrant	Survey No.92, Ramzan Goth, Manghopir Road
10	T-10	Qasba-1 Hydrant	Kati Pahari, Orangi
11	T-11	Shah Faisal Hydrant	Shah Faisal Colony No.4
12	T-12	Chakra-2 Hydrant	Plot No. 606, Near Maria Medical Center, Korangi No.2 Chakra Goth Karachi

Table 2. Relative weight of Physicochemical Parameters.

Parameters	WHO Guidelines	Weight wi	Relative weight Wi
pH	8.5	3	0.11
Turbidity (NTU)	5	3	0.11
TDS	1000	3	0.11
Chloride	250	3	0.11
Hardness (mg/L)	500	2	0.07
NO3	12	4	0.14
PO4	3	4	0.14
SO4	250	3	0.11
Chlorine	0.5	3	0.11
		$\sum$ wi =28	$\sum$ Wi =1.00

Table 3. Relative weight of Metal parameters.

Parameters	WHO Guidelines	Weight wi	Relative weight Wi
Ca	150	2	0.071428571
Mg	100	2	0.071428571
As	0.01	5	0.178571429
Pb	0.01	5	0.178571429
Cr	0.05	5	0.178571429
Fe	0.3	2	0.071428571
Zn	0.5	2	0.071428571
Ni	0.07	5	0.178571429
		$\sum$ wi =28	$\sum$ Wi =1.00

Table 4. Relative weight of Microbiological parameters.

Parameters	WHO Guidelines	Weight wi	Relative weight Wi
TAC	2	5	0.25
TCC	2	5	0.25
TFC	2	5	0.25
TFS	2	5	0.25
		$\sum$ wi =20	$\sum$ Wi =1.00

Statistical Analysis

The data obtained through physico-chemical and bacteriological analysis was subjected to statistical software (STATISTICA, 99 Edition, Tulsa, Oklahoma) for computing descriptive statistics of each variable. Cluster analysis and principal component analysis (PCA) were also executed using the software mentioned above. Ward's method was used for Cluster analysis.

RESULTS AND DISCUSSION

Physico-chemical Analysis

The physico-chemical analyses of tanker water available in Karachi city are presented in Table 5.

pH

In this study, mean pH value of 7.325 ± 0.062 was noted for all the samples. Minimum (6.9) and maximum (7.7) pH were observed in T-2 (Nipa hydrant, Gulshan-e-Iqbal) and T-10 (Qasba hydrant, Orangi Town). This shows that the water samples are neutral and towards slightly alkaline but within the permissible limits set by NSDWQ (2008) and WHO (2011). These findings substantiate with the results of piped water of Shah Faisal Town (Alamgir *et al.*, 2019), Orangi Town (Alamgir *et al.*, 2015a) and Malir Town (Alamgir *et al.*, 2015b), Karachi.

Turbidity

Turbidity in water bodies depends upon fine and colloidal suspended solids (Shittu *et al.*, 2008) reported that grossly turbid water are often provided auspicious environments for the growth of variety of disease causing bacteria and other parasites. During this research, all the water samples were below the guidelines set by NSDWQ (2008) and WHO (2011). Crush Plant Hub Pumping Station (T-6) reported highest turbidity level of 4.9 NTU while Shah Faisal Hydrant (T-11) registered lowest turbidity level of 0.16 NTU. Overall, mean turbidity level was 2.223±0.537 NTU. Turbidity of piped water in Shah Faisal Town (Alamgir et al. 2019) and Malir Town (Alamgir *et al.*, 2015b), Karachi counterparts the finding of this study.

TDS

TDS involves the total amount of dissolved minerals existent in the water. Water TDS should be <1000 mg/L declared by WHO (2011) and NSDWQ (2008). During this research, TDS value varied from 460 to 1471 mg/L with an average of 850±106.55 mg/L. Only 4 samples out of 12, go across the limits for drinking water (Table 2). These samples belongs to German School (T-9), Qasba-1 (T-10), Shah Faisal (T-11) and Chakra (T-12) hydrants. Change in water taste (salty) is the indication of high TDS level in water. Moreover, excessive discoloration or corrosion may appears in domestic instruments and water pipes due to elevated TDS concentration (Ahamed *et al.,* 2013).

Chloride

Chloride in water is considered to be safe at low concentration to humans but it could amend water taste at a concentration of >250 mg/L. In this study, mean chloride value 71.266 ± 11.75 mg/L was observed. Result of all the samples were well within the guidelines proposed by WHO (2011) and NSDWQ (2008). These findings validates with the results of Shah Faisal Town (Alamgir *et al.,* 2019), Orangi Town (Alamgir *et al.,* 2015a) and Malir Town (Alamgir *et al.,* 2015b) Karachi.

Hardness

From Table 5, the mean concentration of total hardness is 503.667 ± 76.26 mg/L during this study. Maximum hardness (1076 mg/L) was observed in T-9 (German School Hydrant) while minimum hardness (288 mg/L) was noted in T-7 (Cattle colony Hydrant). In this study, 41.67 % samples crossed hardness guideline set by WHO (2011) and NSDWQ (2008). Water hardness > 500 mg/L would have adverse health effects on human and may be responsible for kidney stone formation and cardiovascular diseases. Unnecessary usage of soap and detergents occurs due to high hardness in water.

Alkalinity

Water Alkalinity is the capability of water to neutralize acid. Presence of Bicarbonates, Carbonates and hydroxyl ions are responsible for alkalinity in water. In this study, Alkalinity of 12 samples was within the WHO guideline of 300 mg/l with a mean value of 115±6.33 mg/l.

Nitrate

Nitrate contaminated water is accountable for blue baby syndrome (Methemoglobinemia). Elevated nitrate content in water available in Sindh and Punjab (Tahir and Rasheed, 2008) and is attributed due to agricultural runoff (Pak EPA, 2005). From Table 2, all the samples were well within the maximum allowable limit set by WHO (2011) and NSDWQ (2008).

Phosphate

The mean concentration of phosphate was found to be 4.10±0.64 mg/L and varied from 0.93 (T-6) to 8.74 (T-5) mg/L, respectively. Non point anthropogenic sources and discharge of inorganic fertilizers from nearby agriculture fields could be major sources. Addition of 1 µg/L of Phosphate augmented bacteriological growth considerably in water (Miettinen *et al.,* 1997).

Sulphate

Sulphate is a non-toxic anion, copiously present in almost all water bodies and originated from dissolution of salts of sulfuric acid. Sun *et al.,* (2019) reported that high level of sulphate is responsible for catharsis, gastrointestinal impatience and dehydration. Maximum allowable limit for sulphate is 250 mg/L set by WHO(2011). During this study, only 1 sample collected from Shah Faisal hydrant (T-11) showed 321 mg/L sulphate which was beyond the WHO limit. Alamgir *et al.,* (2019) has already reported maximum sulphate concentration of 361 mg/L from piped water sample collected from Drigh road, Shah Faisal town, Karachi. Mean sulphate level of 150.608±22.99 mg/L was observed with a minimum level of 63 mg/L (T-2, Nipa Hydrant) in this study. Similarly, 65.47 to 396.4 mg/L sulphate was observed in tap water of 9 different locations of Karachi by Kazi (2014).

Heavy metals are persistence in environment and bioaccumulation capacity gives important consideration to recognize the prospective threat of perilous heavy metals in water bodies (Alves *et al.,* 2014; Misaghi *et al.,* 2017; Kumar et al. 2020). Table 6 presents the metal concentrations of tanker water. Mean metal concentration were in the order of Ca > Mg > Zn > Pb > Ni > Fe > As > Cr over all the samples.

Arsenic

Khan *et al.,* (2004) reported that higher As level (>150 ppb) in tanker water of Karachi. They also indicated that piped water supplied to the city having As contents >150 ppb. While Jaleel *et al.,* (2001) reported absence of As in tanker water of Karachi. Alamgir *et al.,* (2020) already reported maximum As concentration of 0.092 mg/L in piped water available in Saddar Town, Karachi. All the water samples except (T-4) having arsenic contamination above maximum permissible limit set by WHO (2011) in this study. The average As concentration of 0.076±0.016 mg/L was noted. Highest As concentration of 0.179 mg/L was noted in T-11 (Shah Faisal Hydrant). Long term uses of As contaminated water even in low level may cause diabetes, lung and heart diseases, cancer and disruption in cell communication (Järup, 2003).

Table 5 Physico-chemical analysis of Tanker water available in Karachi city.

Sample Code	pH	Turbidity (NTU)	TDS	Chloride	Hardness	Alkalinity	Nitrate	PO4	SO4
T-1	7.3	3.04	547	49.984	344	100	9.8	4.51	87
T-2	6.9	2.05	580	53.983	320	80	7.1	3.68	63
T-3	7.4	4.5	460	43.986	332	120	10.8	1.74	101
T-4	7.6	3.9	530	48.987	360	140	5.6	5.92	94
T-5	7.2	3.2	670	45.985	292	100	8.3	8.74	103
T-6	7.3	4.9	680	37.988	312	110	4.1	0.93	141
T-7	7.2	3.7	510	27.89	288	90	3.6	2.78	121
T-8	7.1	0.16	987	47.985	508	100	11.3	4.47	118.3
T-9	7.4	0.25	1471	141.3	1076	130	13.6	6.62	247
T-10	7.7	0.63	1204	128.4	596	150	9.7	1.87	162
T-11	7.3	0.16	1314	104.6	875	120	15.6	4.66	321
T-12	7.5	0.18	1247	124.1	741	140	14.7	3.28	249
Mean ±SE	7.325 ± 0.062	2.223 ± 0.537	850 ± 106.55	71.266 ± 11.75	503.667 ± 76.26	115 ± 6.33	9.517 ± 1.14	4.10 ± 0.64	150.60 ± 22.99
Min-Max	6.9-7.7	0.16-4.9	460-1471	27.89-141.3	288-1076	80-150	3.6-15.6	0.93-8.74	63-321
% CV	2.98	83.75	43.43	57.13	52.45	19.09	41.61	54.54	52.89
WHO (2011)	6.5-8.5	5	<1000	250	500	300	50	N/A	250
NSDWQ (2008)	6.5-8.5	<5	<1000	<250	<500	N/A	<50	N/A	N/A

NSDWQ= National Standards for Drinking Water Quality, 2008 , Ministry of Environment, Government of Pakistan; N/A= Not available, %CV= percent Coefficient of Variance

Lead

During this study, all the samples were heavily contaminated with lead and exceeded the maximum allowable limit of WHO (2011) and NSDWQ (2008). Pb concentration fluctuated between 0.28 to 3.36 mg/L with a mean concentration of 1.774±0.29 mg/L, respectively. Highest Pb concentration was observed at German School Hydrant, Manghopir (T-9). Jaleel *et al.*, (2001) has already mentioned average concentration of Pb of 0.3734±0.0062 mg/L in tanker water available in Karachi. Similarly, Haq *et al.*, (2011) reported mean Pb level of 0.0771 mg/L in tap water supplied to Karachi city. Cross contamination with untreated industrial discharge are the major sources of Pb. Sherlock *et al.*, (1986) and Hozhabri *et al.*, (2004) mentioned a positive relationship of elevated Pb concentration in blood with the use of drinking water polluted with Pb. This contaminated water is liable for variety of health vulnerabilities (Rahman *et al.*, 1994). Long-lasting lead poisoning symptoms are headaches, sleeplessness, gastrointestinal, joint pains, fatigue and tetchiness.

Chromium

Chromium is widely used in industries such as glass manufacturing, electroplating, dyes and paint, tannery, chemicals and steel alloy (Das and Mishra 2010). Cr (III) and Cr (VI) are two oxidation states usually present in the environment. IARC (International Agency for Research on Cancer) placed Cr (VI) in Group 1 (human carcinogen) and Cr (III) in Group 3 (not classifiable as to its carcinogenicity to humans) (IARC 2015). Cr (VI) is highly soluble in water, prominently reactive and having capability to enter into living cells as compared to Cr (III) (Alloway 2012, Emsley 2001, Kotas and Stasicka, 2000, Rai et al., 1987). Furthermore, it has been reported that bioavailable form of Cr is Cr (VI) which is extremely cancer-causing via ingestion (OHHEA 2011, Stern 2010; Smith and Steinmaus 2009; Beaumont *et al.*, 2008; Smith, 2008; Sedman *et al.*, 2006; Costa 2003; Proctor *et al.*, 2002; O'Flaherty 1996). In addition, reproductive toxicity due to Cr (VI) in male and female has been reported (Marouani *et al.*, 2015; Tiwari *et al.*, 2012).

From Table 6, it is obvious that chromium value fluctuated between 0.01 to 0.21 mg/l with a mean value of 0.071±0.016 mg/l during this study. Chakra-2 Hydrant, Korangi (T-12) have highest Cr concentration. This site is close to KIA (Korangi Industrial Area) and confirms cross contamination from untreated industrial effluent. From Table 6, it can also be seen that only 5 samples out of 12 were well within the guidelines set by WHO (2011) and NSDWQ (2008). These results agree with the finding of Jaleel *et al.*, (2001).

Nickel

Ni and its alloys are extensively used in food, metallurgical, chemical industries. In general, <10 µg/L Ni present in drinking water (Cempel and Nikel, 2006). Ni oral bioavailability via drinking water is as high as around 27 % as compared to food which is only 1 % (ATSDR, 2005). From Table 6, all the samples failed to meet the guidelines provided by WHO (2011) and NSDWQ (2008) with a mean Ni level of 0.856±0.14 mg/L. Highest Ni level (1.87 mg/l) was observed in T-7 (Cattle Colony). Ni is carcinogenic, neurotoxic, hematotoxic, hepatotoxic, immunotoxic and effects on pulmonary and reproductive systems (Das *et al.*, 2008)

Calcium

Daily calcium requirement for an adult is 1000 mg to do work accurately. Just about, 95 % calcium deposited on bones and teeth in humans. Maximum allowable limit for calcium in drinking water are 75 mg/L and 200 mg/L prescribed by WHO (2011) and PSQCA (2002). In this study, all the samples are well within the guidelines and having mean concentration of 46.216±2.31 mg/L (Table 6). The current outcomes of calcium allied with piped water results of Shah Faisal Town (Alamgir et al., 2019) (51.68 mg/l) and Malir Town (53.85 mg/L) (Alamgir *et al.*, 2015b). Elevated concentration of calcium is detrimental for washing, laundering and bathing.

Magnesium

Magnesium in water is vital for living things due to its greater bioavailability. As compared to food, Mg is readily absorbed in water as hydrated ions (Theophanides *et al.*, 1990; Durlach, 1989). Around 25 g of Mg found in human body (60 % stored in bones). From Table 6, it can be noticed that Mg content in water is fairly lower than Ca. Mg content varied from 6.77 to13.76 mg/l with an average of 11.223 ± 0.56 mg/L, respectively. All the samples were below the guideline of 150 mg/L set by WHO (1996). It is estimated that intake of nutritional magnesium is less than the prescribed value of 6 mg/ Kg (Durlach, 1989). Consumption of water having magnesium could be helpful for marginal Mg deficit peoples (Haring and Delft, 1981).

Iron

Iron plays an important role in the nourishment of humans. Water is deliberated unhealthy having zero iron content (Sharath *et al.*, 2018). In this examination, all the samples have low iron content as compared to WHO (2011) with a mean value of 0.27 ± 0.03 mg/L Maximum iron content of 0.54 mg/l was observed in T-12 (Chakra-2 Hydrant, Korangi). Jaleel *et al.*, (2001) already reported mean iron content of 0.6025±0.0591 in Tanker water available in Karachi.

Zinc

In this study, Zn level ranged from 0.37 to 11.23 mg/L with an average of 4.866±1.01 mg/L. 58.34 % samples exceed with the WHO guideline. Maximum Zn level was noted at T-11 (Shah Faisal Hydrant). These findings provide much higher values as compared to the findings of Jaleel *et al.*, (2001). Zn is nontoxic metal (NAS/ NRC,

1980) extensively used and released in huge amount in manufacturing of paints, fabrics, ceramics, sun block and batteries (Sawyerr, *et al.,* 2019; Dimirkou and Doula, 2008).

Table 6. Metal analysis of Tanker water available in Karachi city.

Sample Code	As	Pb	Cr	Ni	Ca	Mg	Fe	Zn
T-1	0.045	2.13	0.01	0.38	49.984	12.14	0.19	9.4
T-2	0.078	1.55	0.04	0.71	53.983	13.11	0.23	7.1
T-3	0.015	0.48	0.06	1.41	43.986	10.68	0.11	2.3
T-4	BDL	1.07	0.02	0.63	48.987	11.90	0.26	1.5
T-5	0.033	0.68	0.03	0.25	45.985	11.17	0.15	0.37
T-6	0.074	3.11	0.05	1.33	37.988	9.22	0.26	1.28
T-7	0.125	2.19	0.04	1.87	27.89	6.77	0.21	5.32
T-8	0.088	0.28	0.09	0.71	47.985	11.65	0.31	4.17
T-9	0.178	3.36	0.08	0.92	55.1	13.38	0.47	2.69
T-10	0.038	2.48	0.13	0.37	56.7	13.77	0.19	8.64
T-11	0.179	2.55	0.096	0.48	44.2	10.73	0.33	11.23
T-12	0.056	1.41	0.21	1.21	41.8	10.15	0.54	4.39
Mean ± SE	0.076±0.016	1.774±0.29	0.071±0.016	0.856±0.14	46.216±2.31	11.223±0.56	0.271±0.03	4.866±1.01
Min-Max	0.015-0.179	0.28-3.36	0.01-0.21	0.25-1.87	27.89-56.7	6.77-13.76	0.11-0.54	0.37-11.23
% CV	77.30	57.59	78.34	58.47	17.34	17.34	46.74	72.51
WHO (2011)	0.01	0.01	0.05	0.07	75	N/A	3.0	3.0
NSDWQ (2008)	<0.05	<0.05	<0.05	<0.02	N/A	N/A	N/A	5.0

NSDWQ= National Standards for Drinking Water Quality, 2008 , Ministry of Environment, Government of Pakistan; N/A= Not available, %CV= percent Coefficient of Variance

Microbiological Analysis

Microbiological analysis of water is the most important part in context to waterborne ailments (Bain *et al.,* 2014). Table 7 provides the microbiological analysis of Tanker water available in Karachi city. According to WHO (2011) guidelines there should be no coliform in treated water. Coliforms are the indicator of bacterial contamination and particularly fecal pollution. The presence of coliforms indicates the biological hazards of drinking water (LeChevallier et al., 1991). During this assessment, only 3 samples (25%) out of 12 samples were fit for human use.

According to Table 7 , 41.67 % samples had >2400 (MPN/100ml) both Total Coliform Count and Total fecal coliform count while 8.33 % and 16.67 % samples had 460 and 150 (MPN/100mL) TCC. Similarly, only 1 sample have 460 (MPN/100mL) TFC and 16.671% receives 93 (MPN/100mL) TFC. Total Fecal Streptococci count of 7, 4 and 3 (MPN/100mL) in 16.67%, 25% and 8.33% samples, only 5 samples out of 12 have <3 (MPN/100mL) TFS. The outcomes of the current study are in accordance with the findings of Amin *et al.*, (2019), Alamgir *et al.*, (2017), Hussain *et al.,* (2014) and Shaikh *et al.,* (2008) where they have stated that water supplied to Karachi city is adulterated with microorganisms and it is credited to prevailing deprived sanitation facilities, unsuitable water distribution system, non-point sources of untreated domestic and industrial effluents, technical complications, seepage and leakages of old rusty pipe lines. Moreover, unhygienic condition of water tankers and delivery pipes were also another source of contamination found in this assessment.

Meyberck *et al.,* (1985) reported that fecal coliforms up to 10^6cfu/100 ml are commonly detected in India, Bangladesh Indonesia and Pakistan. Gastroenteritis, diarrhea and vomiting also associated with waterborne disease and people do not have alternate source for the consumption of potable water (Kistemann *et al.,* 2001). Mehmood *et al.,* (2014) has been reported that water samples collected from lower Sindh were highly contaminated with fecal coliforms and fecal streptococci in post monsoon seasons and their source are derived from human and animal waste. Shar *et al.,* (2010) also reported 25% pre-storage and 100 % post storage water samples in Rohri city were highly contaminated with total coliforms. Similarly, Kandhar and Ansari (1998) reported that the Hyderabad inhabitants were supplied un-chlorinated and fecally contaminated drinking water mostly in summer.

Presence of *Escherichia coli* showing fecal contamination (Ram *et al.,* 2009). Alamgir *et al.,* (2015c) reported that piped water supplied to District Korangi were highly contaminated with *E.coli*. Existence of *E. coli* in 9 samples (75%) was observed during this study. In water bodies, presence of faecal coliform and *E. coli* indicated the source of human and animal waste in it. These waste causing different disease like cramps, diarrhoea, nausea, headache or other symptoms. These microbes may pose a serious health issues for infants, young children and people with severely compromised immune systems (Hasnie and Qureshi, 2004). *E. coli* are always present in feces; most of the strains are not pathogenic, although some strains can cause diarrhoea. Untreated water supplies are the main sources of fecal coliform (Hasnie and Qureshi, 2004). Possible sources of pathogens are cross contamination of untreated domestic and industrial effluent into rusty and leaked water pipelines, faulty and obsolete water distribution network, improper sewerage system, runoff, storm water which was noted during collection of samples. Subsequently, the Karachi individuals hardly discomfort about the water quality, they unwittingly drink adulterated water that is accountable for water borne disorders.

Table 7. Microbiological analysis of Tanker water available in Karachi city.

Sample Code	***E.coli* (Present OR Absent)**	**MPN / 100mL**			
		TCC	**TFC**	**TFS**	**Remarks**
T-1	**Present**	**≥2400**	**≥2400**	**3**	**UFHC**
T-2	**Absent**	**<3**	**<3**	**<3**	**FHC**
T-3	**Absent**	**<3**	**<3**	**<3**	**FHC**
T-4	**Present**	**150**	**93**	**4**	**UFHC**
T-5	**Present**	**≥2400**	**≥2400**	**7**	**UFHC**
T-6	**Present**	**21**	**3**	**<3**	**UFHC**
T-7	**Present**	**150**	**93**	**4**	**UFHC**
T-8	**Present**	**≥2400**	**≥2400**	**4**	**UFHC**
T-9	**Present**	**≥2400**	**≥2400**	**7**	**UFHC**
T-10	**Present**	**460**	**460**	**<3**	**UFHC**
T-11	**Absent**	**<3**	**<3**	**<3**	**FHC**
T-12	**Present**	**≥2400**	**≥2400**	**11**	**UFHC**

TCC = Total Coliform Count; TFC = Total fecal coliform count; TFS= Total fecal Streptococci; UFHC = Unfit for human consumption; FHC = Fit for human consumption

Water Quality Index

Different models of WQI have been established and applied to appraise the quality of surface and groundwater for drinking purposes. WQI model is one of the most effective assessment tools, which transforms a complex set of water quality data into a simple and single non-dimensional form (Ketata-Rokbani et al. 2011; Shabbir and Ahmad 2015; Ewaid and Abed 2017; Khangembam and Kshetrimayum 2019). Therefore, the water suitability in this study was investigated on the basis of WQI models as proposed by Shabbir and Ahmad (2015). To evaluate drinking water suitability, this model is applied by many water investigators worldwide (Singh et al. 2015). Water is generally categorized into five sets in terms of WQI (Sahu and Sikdar 2008; Ketata-Rokbani et al. 2011; Shabbir and Ahmad 2015). The classes of water are excellent (WQI < 50), good (WQI, 50–100), poor (WQI, 100–200), very poor (WQI, 200–300), and unfit for drinking purpose (WQI > 300).

WQI in terms of Physico-chemical Characteristics

In the current examination the WQI of Tanker water with respect to physico-chemical parameters are presented in Table 8. The mean WQI of all the samples were 67.18 and ranged from 49.09-99.7. All the samples were in good quality except T-6 (WQI <50) which categorized excellent quality. It has been reported that WQI of underground water in New Karachi town was >180 and unfit for drinking use (Khan and Qureshi, 2018). Solangi et al., (2019) indicated that 57 % and 15 % samples collected from district Thatta were found to be poor and unfit for human use on the basis of WQI.

Table 8. Water Quality index (WQI) of Tanker water available in Karachi in terms of Physico-chemical characteristics.

Sample code	**WQI**	**Remarks**
T-1	61.20	Good
T-2	52.21	Good
T-3	50.90	Good
T-4	70.53	Good
T-5	83	Good
T-6	49.09	Excellent
T-7	51.20	Good
T-8	63.41	Good
T-9	99.70	Good
T-10	62.39	Good
T-11	86.97	Good
T-12	75.63	Good
Mean	67.18	
Min-Max	49.09-99.7	

WQI in terms of Metal Characteristics

As such no study of WQI was reported with respect to metal characteristics to compare with. From Table 9, it can be seen that the WQI of all the samples in terms of metal characteristics were unfit for drinking purpose with a mean WQI of 3564.67. WQI ranged from 886.48 to 6594.85 at T-8 and T-9.

WQI in terms of Microbiological Examination

WQI of Tanker water with respect to microbiological examination are presented in Table 10. During this investigation it was observed that 75 % samples were unfit for drinking use. Samples collected from T-2, T-3 and T-11 declared good quality (WQI=100). Mean WQI value of all the samples was 35405.56. Maximum WQI (80183.34) was noted at Korangi, Chakra-2 Hydrant (T-12).

Statistical Analysis

(Principal Component Analysis)

Fig. 1 and Table 11 show the results of PCA (Principal Component Analysis). The first eigen value explain 40.718 percent of the total variance while second and third components explained 17.016 and 13.595 of the overall variance. The first Principal component (PC) is primarily of function of TDS, Hardness, Chloride and Turbidity (based on the magnitude and direction of their eigen vectors coefficient). The first three have negative direction of

PCI. The second principal component is largely controlled by Ni, PO_4, Ca and Mg (the last three have a negative direction of PC II).The third component is basically governed by TFS, Ca, Mg and Zn (the last three have negative direction with respect to PC III). Thus the first component is predominated by physical quality factors. The second component chiefly represents the influence of metals and ions while the third component is an amalgam of microbiological quality factor (TFS).

CA (Cluster Analysis)

Fig 2. is the dendogram resulting from agglomerative cluster analysis. Two main groups are readily apparent. Group A comprises of 7 hydrants sites. Group A comprises of mostly sites with moderate TDS, Hardness and sulphate but low in Ca, Mg and chloride. Group B contain 5 sites. Group B has low turbidity with high Ca and Mg.

Table 9. Water Quality index (WQI) of Tanker water available in Karachi in terms of Metal characteristics.

Sample code	**WQI**	**Remarks**
T-1	4012.90	unfit for drinking purpose
T-2	3126.08	unfit for drinking purpose
T-3	1275.74	unfit for drinking purpose
T-4	2088.46	unfit for drinking purpose
T-5	1354.12	unfit for drinking purpose
T-6	6050.80	unfit for drinking purpose
T-7	4641.56	unfit for drinking purpose
T-8	886.48	unfit for drinking purpose
T-9	6594.85	unfit for drinking purpose
T-10	4664.65	unfit for drinking purpose
T-11	5062.45	unfit for drinking purpose
T-12	3017.97	unfit for drinking purpose
Mean	3564.67	
Min-Max	886.48-6594.85	

Table 10. Water Quality index (WQI) of Tanker water available in Karachi in terms of Microbiological characteristics.

Sample code	**WQI**	**Remarks**
T-1	80050	unfit for drinking purpose
T-2	100	Good
T-3	100	Good
T-4	4116.67	unfit for drinking purpose
T-5	80116.67	unfit for drinking purpose
T-6	433.34	unfit for drinking purpose
T-7	4116.67	unfit for drinking purpose
T-8	80066.67	unfit for drinking purpose
T-9	80116.67	unfit for drinking purpose
T-10	15366.67	unfit for drinking purpose
T-11	100	Good
T-12	80183.34	unfit for drinking purpose
Mean	35405.56	
Min-Max	100-80183.34	

Table 11. Results of PCA (Principal Component Analysis) of physico-chemical, metal and microbiological parameters.

Component	Eigenvalue	Percentage variance	Cumulative percentage variance	First 4 eigenvector coefficients	Associated variables
1	8.14367	40.71835	40.71835	-0.960285	TDS
				-0.941730	Hardness
				-0.939154	Chloride
				0.878715	Turbidity
2	3.403380	17.01690	57.73525	0.725273	Ni
				-0.668391	PO4
				-0.633449	Ca
				-0.633449	Mg
3	2.040105	13.59536	71.33061	0.695815	TFS
				-0.568156	Ca
				-0.568156	Mg
				-0.539010	Zn

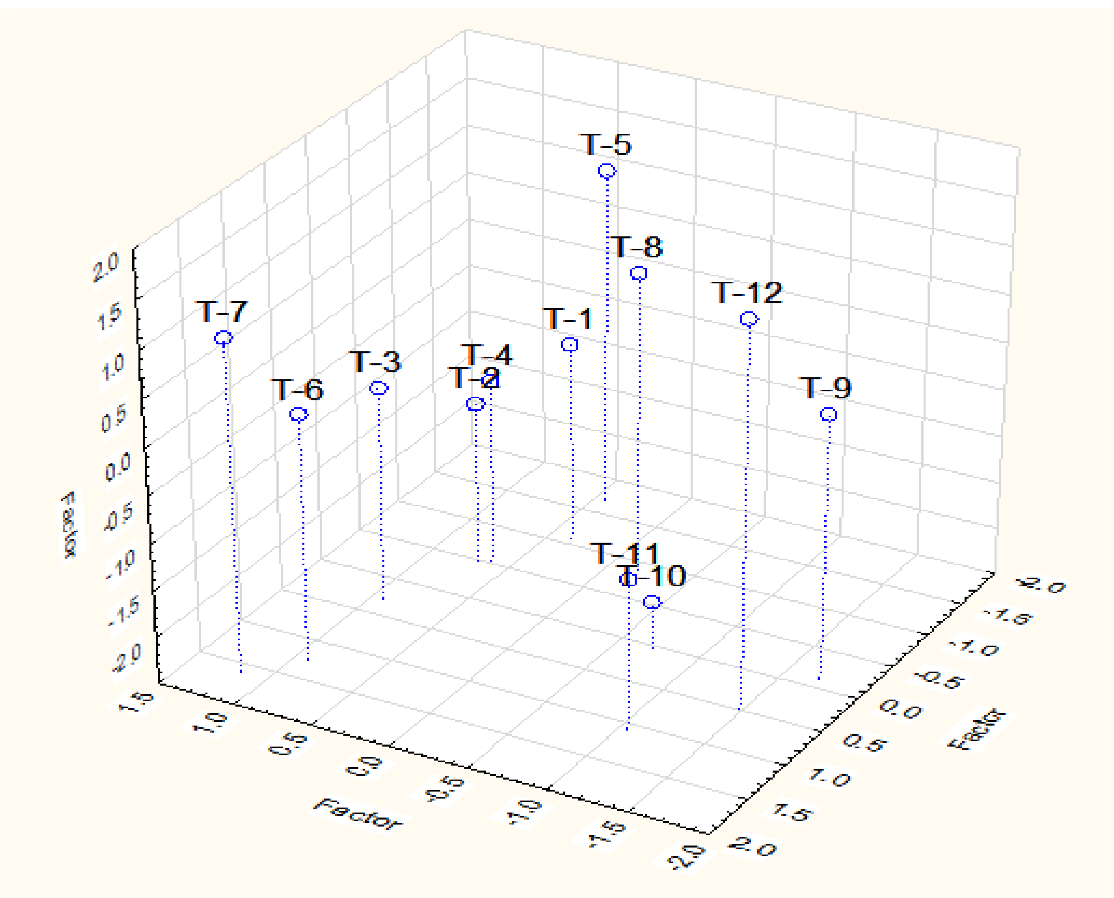

Fig 1. PCA (Principal Component Analysis) ordination (3D) of physico-chemical, metal and microbiological parameters Tanker water, Karachi

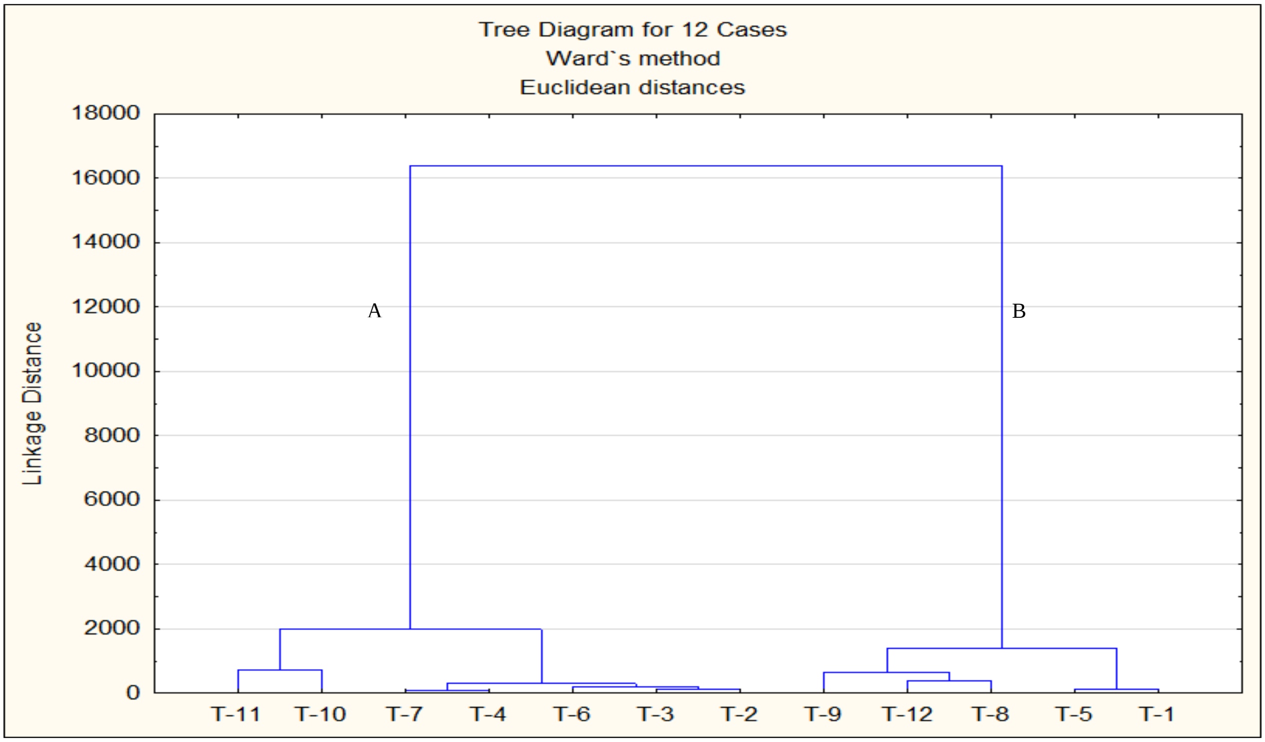

Fig 2. Dendogram derived from Ward's method average between 12 sites based on physico-chemical, metal and microbiological parameters Tanker water, Karachi.

Conclusion

This assessment revealed that water obtained from Tanker is suitable in context to its physicochemical parameters but unfortunately not suitable for drinking with respect to metal and microbial contamination. Unsanitary conditions of water tankers and transportation pipes, non- point sources of untreated domestic and industrial discharge which were mixing with drinking water supplies due to the faulty and poor sanitation system are responsible for metal and microbial contamination. These components are liable to waterborne diseases. There is need to maintain and upgradation of water distribution and treatment system to the consumer without compromising its quality. This study also depicted for attention of the authorities that sewage contamination with drinking water must be considered as a significant environmental and health concern for millions of Karachi residents that use tanker water.

REFERENCES

Ahamed, J. A., K. Loganathan and S. Ananthakrishnan (2013). A comparative evaluation of groundwater suitability for drinking and irrigation purposes in Pugalur area, Karur district, Tamilnadu, India. *Arch. Appl. Sci. Res.* 5 (1): 213–223

Ahmed, N. and M. Sohail (2003). Alternate water supply arrangements in peri-urban localities: awami (people's) tanks in Orangi township, Karachi. *Environment and Urbanization*, 15 (2): 33-42.

Alamgir, A., M.A. Khan, S. U. Fatima, M. Z. Hassan and S.S. Shaukat (2020). Public health quality of street-vended fresh fruit juices sold in Saddar Town, Karachi. *Int. J. Biol. Biotech*., 17 (3): 589-597.

Alamgir, A., M.A. Khan, S. S. Shaukat, R. Majeed and S. Urooj (2019). Communal health perception of tap water quality supplied to Shah Faisal Town, Karachi. *Int. J. Biol. Biotech*., 16 (1): 189-198.

Alamgir, A., O. E. Hany, M. A. Khan, S. Rao and S. K. Sherwani (2017). Biological Hazards of Drinking Water Supplied to Karachi City, Pakistan. *American-Eurasian Journal of Agricultural & Environmental Sciences,* 17 (2): 179-185.

Alamgir, A., M. A. Khan, O. E. Hany, S. S. Shaukat, K. Mehmood, A. Ahmed, S. Ali, K. Riaz, H. Abidi, S. Ahmed and M. Ghori (2015a). Public health quality of drinking water supply in Orangi town, Karachi, Pakistan. *Bulletin of Environment, Pharmacology and Life Sciences*, 4 (11): 88-94.

Alamgir, A., M. A. Khan, S. S. Shaukat, O. E. Hany, F. Ullah, M. R. K. Abbasi, S. Memon and A. Hussain (2015b). Physico-Chemical and Bacteriological Characteristics of Drinking Water of Malir Town, Karachi, Pakistan. *American-Eurasian Journal of Agricultural & Environmental Sciences*, 15 (5): 896-902.

Alamgir, A., M. A. Khan, S. Hashmi, O. Hany, K. Mahmood and S. S. Shaukat (2015c). Prevalence of fecal contamination within a public drinking water supply in District Korangi, Karachi, Pakistan. *Bull. Env. Pharmacol. Life Sci*, (4): 87-92.

Alloway, B. J. (2012). Heavy metals in soil, 3rd edition. *Springer, New York.*

Alves, R. I. S., C. F. Sampaio, M. Nadal, M. Schuhmacher, J. L. Domingo and S. I. Segura-Muñoz (2014). Metal concentrations in surface water and sediments from Pardo River, Brazil: human health risks. *Environ. Res.* (133): 149–155.

Amin, R., M. B. Zaidi, S. Bashir, R. Khanani, R. Nawaz, S. Ali and S. Khan (2019). Microbial contamination levels in the drinking water and associated health risks in Karachi, Pakistan. *Journal of Water, Sanitation and Hygiene for Development*, 9 (2): 319-328.

APHA (American Public Health Association) (2005). *Standard Methods for the Examination of Water and Wastewater*. 21ST edition. APHA. Washington DC. USA.

Arain, M. A., Z. Haque, N. Badar and N. Mughal (2009). Drinking water contamination by chromium and lead in industrial lands of Karachi. *The Journal of the Pakistan Medical Association*, 59 (5): 270-274.

Arnell, N. W. (2004). Climate change and global water resources: SRES emissions and socio-economic scenarios. *Global environmental change*, 14 (1): 31-52.

ATSDR (Agency for Toxic Substances and Disease Registry) (2005). Toxicological profile of nickel. Atlanta, GA: *Agency for Toxic Substances and Disease Registry*.

Aziz, J. A. (2005). Management of source and drinking water quality in Pakistan. *Eastern Mediterranean Health Journal*, 11 (5-6): 1087-1098.

Bain, R., R. Cronk, J. Wright, H. Yang, T. Slaymaker and J. Bartram (2014). Fecal contamination of drinking-water in low-and middle-income countries: a systematic review and meta-analysis. *PLoS Med*, 11(5), e1001644.

Beaumont, J. J., R. M. Sedman, S. D. Reynolds, C. D. Sherman, L. H. Li and R. A. Howd (2008). Cancer mortality in a Chinese population exposed to hexavalent chromium in drinking water. *Epidemiology*, (19): 12–23.

Cempel, M., and G. J. Nikel (2006). Nickel: A review of its sources and environmental toxicology. *Polish Journal of Environmental Studies*, 15 (3).

Chandio, B. A., M. Abdullah and M. A. Tahir (1998). Drinking water quality and standardization in Pakistan. *In Proceedings of the national workshop on quality of drinking water*, 14-18.

Costa, M. (2003). Potential hazards of hexavalent chromate in our drinking water. *Toxicol. Appl. Pharmacol.*, (188): 1–5.

Das, A. P. and S. Mishra (2010). Biodegradation of the metallic carcinogen Hexavalent Chromium Cr(VI) by an indigenously isolated bacterial strain. *Journal of Carcinogenesis* (9): 6.

Das, K. K., S. N. Das and S. A. Dhundasi (2008). Nickel, its adverse health effects & oxidative stress. *Indian J Med Res*, 128 (4): 412–425.

Dimirkou, A. and M. K. Doula (2008). Use of clinoptilolite and an Fe overexchanged clinoptilolite in Zn2+ and Mn2+ removal from drinking water. *Desalination*, 224 (1–3): 280–292.

Durlach, J. (1989). Recommended dietary amounts of magnesium: Mg RDA. *Magnes Res.*, 2 (3): 195-203.

Emsley, J. (2001). Chromium. Nature's building blocks: An A–Z guide to the elements. *Oxford University Press, Oxford.*

Ewaid, S. H and S.A. Abed (2017). Water quality index for Al-Gharraf river, southern Iraq. *The Egyptian Journal of Aquatic Research*, *43*(2), 117-122.

Haring, B. S. and V. W. Delft (1981). Changes in the mineral composition of food as a result of cooking in hard and soft waters. *Arch Environ Health*, (36): 33–35.

Hasnie, F. R. and N. A. Qureshi (2004). Assessment of drinking water quality of a coastal village of Karachi. *Pakistan Journal of Scientific and Industrial Research*, 47 (5): 370-375.

Haq, N., M. A. Arain, N. Badar, M. Rasheed and Z. Haque (2011). Drinking water: a major source of lead exposure in Karachi, Pakistan. *EMHJ-Eastern Mediterranean Health Journal*, 17 (11): 882-886.

Hozhabri, S., F. White, M. H. Rahbar, M. Agboatwalla and S. Luby (2004). Elevated blood lead levels among children living in a fishing community, Karachi, Pakistan. *Archives of Environmental Health: An International Journal*, *59* (1): 37-41.

Hussain, R., L. Ali, I. Hussain and S. A. Khattak (2014). Source identification and assessment of physico-chemical parameters and heavy metals in drinking water of Islampur area, Swat, Pakistan. *Journal of Himalayan Earth Sciences*, 47 (1): 99.

IARC (International Agency for Research On Cancer) (2015). *Agents Classified by the IARC Monographs*, 1–114.

JALEEL, M. A., R. NOREEN and A. BASEER (2001). Concentration of heavy metals in drinking water of different localities in district east Karachi. *Journal of Ayub Medical College Abbottabad,* 13 (4): 12-15.

Järup, L. (2003). Hazards of heavy metal contamination. *British medical bulletin*, *68* (1): 167-182.

Kahlown, M. A., M. A. Tahir, H. Rasheed and K. P. Bhatti (2006). Water quality status, national water quality monitoring programme. *Fourth Technical Report PCRWR*, 5.

Kandhar, I. A., and A. K. Ansari (1998). Drinking water quality of Hyderabad city. Water, engineering and development centre. In: *WEDC conference,* (24): 254-257.

Kazi, A. (2014). Appraisal of Air and Water Pollution in Hyderabad and Karachi, Pakistan. *Quaid-e-Awam University Research Journal of Engineering, Science & Technology*, 13 (1).

Khan, A and F.R. Qureshi (2018). Groundwater quality assessment through water quality index (WQI) in New Karachi Town, Karachi, Pakistan. *Asian Journal of Water, Environment and Pollution*, 15(1), 41-46.

Khan, J. M., H. Naz, O. Hany, M. A. Khan, S. A. Hasan, M. Azeem and N. A. Zaigham (2004). Arsenic levels in drinking water of Karachi Region. *Int. J. Biol. and Biot,* 1 (4): 693-698.

Khangembam, S and K.S. Kshetrimayum (2019). Evaluation of hydrogeochemical controlling factors and water quality index of water resources of the Barak valley of Assam, Northeast India. *Groundwater for Sustainable Development*, *8*, 541-553.

Kistemann, T., F. Dangendorf and E. Ener (2001). A geographical information system as a tool for microbial risk assessment in catchment areas of drinking water reservoir, *International Journal of Hygiene Environment and Health*, (203): 225-233.

Ketata-Rokbani M, M. Gueddari., and R. Bouhlila (2011). Use of geographical information system and water quality index to assess groundwater quality in El Khairat Deep Aquifer (Enfidha, Tunisian Sahel). *Iranica J Energy Environ* 2:133–44

Kotas, J. and Z. Stasicka (2000). Chromium occurrence in the environment and methods of its speciation. *Environ. Pollution*, 107 (3): 263–283.

Kumar, A., M. C. Pinto, A. Kumar, M. Kumar and P. A. Dinis (2020). Estimation of risk to the eco-environment and human health of using heavy metal in the Uttarakhand Himalaya, India. *Appl. Sci*. 10 (20): 7078.

LeChevallier, M.W., W. Norton, and R. Lee, (1991). Giardia and Cryptosporidum spp. in filtered drinking water supplies. *Applied and Environmental Microbiology,* 57 (9): 2617-2621.

Marouani, N., F. Tebourbi, D. Hallegue, M. Mokni, S. Yacoubi Mohsen, M. Benkhalifa and K. B. Rhouma (2015). Mechanism of chromium hexavalent-induced apoptosis in testis rats. *Toxicol. Ind. Health.*

Meyber, M. (1985). The GEMS/Water Programme (1978-1983), *Water Quality Bulletin Environment Canada,* (10): 167-173.

Miettinen, I. T., T. Vartiainen and P. J. Martikainen (1997). Phosphorus and bacterial growth in drinking water. *Applied and environmental microbiology*, 63 (8): 3242-3245.

Misaghi, F., F. Delgosha, M. Razzaghmanesh and B. Myers (2017) Introducing a water quality index for assessing water for irrigation purposes: a case study of the Ghezel Ozan River. *Sci Total Environ.* (589): 107–116.

NAS/NRC (National Academy of Sciences) (1980). Drinking water and health. *The contribution of drinking water to mineral nutriton in humans. Washington,* 265-403.

NSDWQ (National Standards for Drinking Water Quality) (2008). *Ministry of Environment*, Government of Pakistan.

O'Flaherty, E. J. (1996). A physiologically based model of chromium kinetics in the rat. *Toxicol Appl. Pharmacol,* (138): 54–64.

OHHEA (Public health goal of hexavalent chromium in drinking water) (2011). Office of Environmental Health Hazard Assessment California Environmental Protection Agency, *Corrected portions of draft PHG document for hexavalent chromium 2010*.

PAKEPA (Pakistan Environmental Protection Agency) (2005). *State of environment report,* Islamabad, Government of Pakistan., Pakistan.

PCRWR (2012). Bottled Water Quality Report. *Pakistan Council of Research in Water Resources,* Islamabad.

Proctor, D. M., J. M. Otani, B. L. Finley, D. J. Paustenbach, J. A. Bland, N. Speizer and E. V. Sargent (2002). Is hexavalent chromium carcinogenic via ingestion? a weight-of-evidence review. *J Toxicol Environ Health,* (65): 701–746.

PSQCA (Pakistan Standards and Quality Control Authority) (2002). Drinking Water. *Pakistan Standards and Quality Control Authority (PSQCA),* Karachi, Pakistan.

Rai, D., B. M. Sass and D. A. Moore (1987). Chromium(III) hydrolysis constants and solubility of chromium hydroxide. *Inorganic Chemistry*, (26): 345–349.

Ram, S., P. Vajpayee, R. L. Singh and R. Shanker (2009). *Ecotoxicol. Environ. Saf.*, (72): 490–495.

Rahman, A., H. K. Lee and M. A. Khan (1997). Domestic water contamination in rapidly growing megacities of Asia: Case of Karachi, Pakistan. *Environmental Monitoring and Assessment,* 44 (1-3): 339-360.

Rahman, A., M. N. Gazdar and A. Farooqi (1994). Future groundwater resources at risk. *Poster papers of the international conference, Helsinki, Finland, 13–16 June 1994.* Helsinki, Painatuskeskus.

Sahu P and P.K. Sikdar (2008). Hydrochemical framework of the aquifer in and around East Kolkata Wetlands, West Bengal. India. *Environ Geol* 55:823–35

Sawyerr, H. O., M. Raimi, A. T. Adeolu and O. E. Odipe (2019). Measures of Harm from Heavy Metal Pollution in Battery Technician within Ilorin Metropolis, Kwara State, Nigeria. *Communication, Society and Media, ISSN*, 2576-5388.

Sedman, R. M., J. Beaumont, T. A. McDonald, S. Reynolds, G. Krowech and R.Howd (2006). Review of the evidence regarding the carcinogenicity of hexavalent chromium in drinking water. *J Environ Sci Health Part C*, (24): 155–182.

Şener, Ş., E. Şener and A. Davraz (2017). Evaluation of water quality using water quality index (WQI) method and GIS in Aksu River (SW-Turkey). *Science of the Total Environment, 584*, 131-144.

Shabbir, R and S.S. Ahmad (2015). Use of geographic information system and water quality index to assess groundwater quality in Rawalpindi and Islamabad. *Arab J Sci Eng* 40:2033–47

Shaikh, S. A., N. Gul and L. Sultana (2008). Surveillance of drinking water of Karachi City: microbiological quality. *Biological Sciences-PJSIR,* 51 (5): 272-275.

Shar, A. H., Y. F. Kazi, N. A. Kanhar, I. H. Soomro, S. M. Zia and P. B. Ghumro (2010). Drinking water quality in Rohri city, Sindh, Pakistan. *African Journal of Biotechnology*, *9* (42): 7102-7107.

Sharath, R. B., K. Channabasappa, C. Sethi and M. A. Mohammed-Aslam (2018). Physical–chemical characterisation and water quality index (WQI) assessment of Bhusnoor Area, Kalaburagi District, Karnataka. *J Appl. Geochem*, 20 (4): 474–481.

Sherlock, J.C. and M. J. Quinn (1986). Relationship between blood lead concentration and dietary lead intake in infants: The Glasgow Duplicate Diet Study 1979–1980. *Food Additives and Contaminants,* (3): 167–176.

Shittu, O. B., J. O. Olaitan and T. Amusa (2008). Physico-chemical analysis of water used for drinking and swimming purposes in Abeokuta, Nigeria. *Afr. J. Biomed. Res*. 11: 285–290

Singh, S.K., P.K. Srivastava, D. Singh, D. Han, S.K. Gautam and A.C. Pandey (2015). Modelling groundwater quality over a humid subtropical region using numerical indices, earth observation datasets, and X-ray diffraction technique: a case study of Allahabad district, India, *Environ. Geochem. Health*, 37, 157–180

Smith, A. H. (2008). Hexavalent chromium, yellow water, and cancer: a convoluted saga. *Epidemiology*, (19): 24–26.

Smith, A. H. and C. M. Steinmaus (2009). Health effects of arsenic and chromium in drinking water: recent human findings. *Annu Rev Public Health,* (30): 107–122.

Solangi, G. S., A.A. Siyal., M.M. Babar and P. Siyal (2019). Evaluation of drinking water quality using the water quality index (WQI), the synthetic pollution index (SPI) and geospatial tools in Thatta district, Pakistan. *Desalination and Water Treatment*, 160, 202-213.

Soomro, Z. A., M. I. A. Khokhar, W. Hussain and M. Hussain (2011). Drinking Water Quality Challenges in Pakistan. *World Water Day*, 17-28.

Stern, A. H. (2010). A quantitative assessment of the carcinogenicity of hexavalent chromium by the oral route and its relevance to human exposure. *Environ Res,* (110): 798–807.

Sun, P., F. Yu, J. Lu, M. Zhang, H. Wang, D. Xu and L. Lu (2019). In vivo effects of neomycin sulfate on non-specific immunity, oxidative damage and replication of cyprinid herpesvirus 2 in crucian carp (Carassius auratus gibelio). *Aquaculture and Fisheries*, 4 (2): 67-73.

Tahir, M. A. and H. Rasheed (2008). Distribution of nitrate in the water resources of Pakistan, *African Journal of Environmental Science and Technology*, 2 (11): 397-403.

Theophanides, T., J. F. Angiboust and M. Polissiou (1990). Possible role of water structure in biological magnesium systems. *Magnes Res.*, (3): 5–13.

Tiwari, R.R., A. Saha, N. G. Sathwara and J. R. Parikh (2012). Blood chromium levels of children working in gem-polishing industries in India. *Toxicol Ind Health*, 28 (2): 170–173.

UNDP (United Nation Development Program) (2003). Water Crisis, Karachi. *Pakistan National Human Development Report*, 7-103.

UNSP (United Nation System in Pakistan) (2003). The United Nations System in Pakistan: *Water-A Vital Source of Life*, Islamabad, 63.

WHO (World Health Organization) (1996). *Guidelines for Drinking Water Quality*. *Recommendation,* Geneva: (WHO), (1).

WHO (World Health Organization) (2011). *Guidelines for drinking-water quality*. Geneva. WHO, 104-108.

Zozmann, H., C. Klassert, K. Sigel, E. Gawel and B. Klauer (2019). Commercial Tanker Water Demand in Amman, Jordan—A Spatial Simulation Model of Water Consumption Decisions under Intermittent Network Supply. *Water*, 11-254.

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