Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2015.1094418

57 (2016) 18668–18678
August

Taylor & Francis
Taylor & Francis Group

Vulnerability to climate change of surface water resources of coastal areas of Sindh, Pakistan

Aamir Alamgir[a], Moazzam Ali Khan[a,*], Ilda Manino[b], Syed Shahid Shaukat[a], Shoaib Shahab[a]

[a]*Institute of Environmental Studies, University of Karachi, Karachi 75270, Pakistan, Tel. +92 3003789114; email: aamirkhan.ku@gmail.com (A. Alamgir), Tel. +92 3002454259; email: sherwanis66@gmail.com (M. Ali Khan), Tel. +92 3312845478; email: shahid_shaukat2007@yahoo.co.uk (S.S. Shaukat), Tel. +92 3008296752; email: shoaib.shahab@merckgroup.com (S. Shahab)*

[b]*Thematic Environmental Networks, Venice International University, Isola di San Servolo, 30100 Venezia, Italy, Tel. +39 041 2719 571, Tel./Fax: +39 041 2719 511; email: ilda.mannino@univiu.org*

Received 10 January 2015; Accepted 8 September 2015

ABSTRACT

The coastal district Thatta of Sindh Province is the area where availability of freshwater is a critical factor for the human survival and livelihood. As such, there are no perennial surface water resources available in the district except of River Indus and its canal system. In view of the changing climate change scenario of the coastal areas of Sindh, this study was undertaken to determine the availability and quality of surface water available in Thatta district. Results of the present investigation indicate that the water from the canals was not suitable for drinking as per WHO guidelines and National Standards for Drinking Water Quality Pakistan. Agriculture run-off, sewage leaks and metals quite often contaminate the surface water resources. However, users have no method to judge its quality except for the taste. Thus, most of the residents drink polluted water unknowingly, and do not question its quality. Increasing variability in rainfall pattern and reduced flow in the River Indus at downstream aggravates the problem that further reducing water supply available for human use.

Keywords: Surface water; Public health quality; Coastal areas; Climate change

1. Introduction

Climate change has the potential to compound the prevailing development problems and increase pressure on key resources needed to sustain growth in South Asia. This region is particularly vulnerable to climate change owing to its high population density, concentrated poverty and existing climate variability.

The most densely populated river basins of the world, which supports more than 700 million people, are situated in this region. These rivers basins such as Indus, Ganges, Brahmaputra, Yangtze and Yellow rivers satisfy the water need of almost 1.4 billion people. However, seasonal water availability in these rivers is affected substantially by climate change, but to what extent is yet unclear. Brahmaputra and Indus basins are most susceptible to flow reductions which is responsible for food security of an estimated 60 million

*Corresponding author.

people [1]. WHO already mentioned that most semi-arid river basins in developing countries are vulnerable to climate change mainly because of rising water demand due to increase in population and lower coping capacity [2]. Singh and Bengtsson suggested that 2˚C rise in summer temperature will reduce the river flow up to 18% [3].

Arnell reported that the people living in Pakistan would face severe water stress in coming decades [4]. However, it would be more appropriate to say that actual water stresses will depend on how water resources are managed in the future. Alcamo and Henrichs included Pakistan as water-stressed country because of increase in water withdrawals and decreased water availability [5]. Pakistan is considered as highly sensitive area with respect to global climate changes than other regions. Briscoe and Qamar indicated that Pakistan has already fallen below the water stress threshold and will reach a condition of water scarcity by 2035 [6]. However, their estimate is based on available water and a lower population than currently available estimates. Therefore, the current and projected situation could be more severe than they have estimated [7].

The province of Sindh in Pakistan is located on the western corner of South Asia. On the eastern side, Sindh is bounded by Thar desert, on the western side are the Kherthar mountains and at the south is the Arabian Sea. The central area is fertile plain around the River Indus. There are now 22 districts in Sindh. Of 970 km long coastline of Pakistan, Sindh coastline is about 270 km long [8]. The coastal belt of Sindh is highly vulnerable to climate change as exhibited by severe drought from 1996 to 2003, decreased rainfall up to 10–15% in the last 40 years, and recorded fourteen cyclones from 1970 to 2001 [9].

Thatta is the coastal district of Sindh that occupies an area of 17,355 sq km. The district is administratively subdivided into seven sub-districts; these are Mirpursakro, Ghora bari, Keti Bundar, Shah Bundar, Jati, Kharo Chan and Sujawal. This study focused on the two sub-districts of Thatta namely Keti Bundar and Shah Bundar. Keti Bundar is situated on one of the mouths of River Indus called ochito [10]. The total area of Keti Bundar is approx. 60,969 ha, while that of Shah Bundar is 3,074 km^2.

In broad terms, surface drainage patterns in district Thatta has a hydrological regime similar to that of areas with basin and range landforms found in warm to hot arid areas. The steep gradient of the river bed and the catchments of the tributaries depicted that the flow is available only for a short period following rainfall. This condition rendered little opportunity for infiltration through river bed.

Indus River is the main source of surface water in the district Thatta that provides natural source of water that support local ecosystems. Water is diverted from the river through government or privately owned canals for irrigation of nearby fields and for domestic use in villages.

In Pakistan, on an average 73% of the flow from the Indus is extracted from the canal systems that indicate a highly stressed system. Since the rainfall is quite erratic and the spells of droughts are quiet frequent which rendered the canal system of lower Sindh (district Thatta) virtually devoid of water where in the drought period the situation is more alarming. During the droughts that occurred from 2000 to 2003, virtually the entire flow was abstracted leaving nothing to support the ecology which aggravated salt water intrusion from the Arabian sea on the lower river reaches [7].

In the current face of climate change, it would be imperative to focus not only on the quantity of water but also the quality of water is equally important. This study envisaged to determine the availability and quality of surface water available in the coastal district Thatta of Sindh province.

2. Materials and methods

Emerging trends in the scarcity of water were analysed with respect to climate change in the study area. The analysis was further supplemented with field surveys, and the trends in water scarcity were inquired through interviews conducted with the selected respondents. These respondents were the local farmers, government officials and representative of NGOs.

2.1. Sampling

The water sampling was focused on the surface water available in the study area. The water samples were collected from private and government-owned canals and the water available at downstream of River Indus.

2.2. Physicochemical analysis

The samples were analysed for pH, biological oxygen demand (BOD_5), chloride, chemical oxygen demand (COD), dissolved oxygen (DO), hardness as $CaCO_3$, sulphate, nitrate, phosphate, turbidity (NTU), total dissolved solids (TDS) and total suspended solids (TSS).

pH and DO were determined on site. pH was determined by Hanna portable pH meter (HI98107), while DO was measured by DO meter (Jenway 970).

Biological oxygen demand was measured using azide modification method as mentioned in the Standard Methods for the Examination of Water and Wastewater [11].

Chloride was estimated by Argentometric method [11]. Hardness as $CaCO_3$ of water samples was measured by EDTA titrimetric method [11]. Sulphate, TDS and TSS in the samples were measured by gravimetric method [11]. Turbidity was ascertained by EUTECH meter, Model no. TN-100.

The nutrient parameters such as nitrate and phosphate were determined by brucine method and ascorbic acid method [11].

2.3. Metal analysis

The samples were also analysed for heavy metals including As, Cr, Cu, Fe, Mg, Mn, Pb and Ni. The above-mentioned parameters were analysed using appropriate kits of Merck (NOVA 60), Germany.

2.4. Bacteriological analysis

The public health quality of water samples was assessed using the following parameters, total coliforms count (TCC), total faecal coliforms (TFC) and total faecal streptococci (TFS). The samples were processed in laminar flow hood using sterilized culture media. The sterility of media was checked prior to use. The TC was estimated using lactose broth (Merck, Germany) of single and double strength. The positive lactose tubes were used for the determination of FC using EC broth (Merck, Germany). TFS were determined by using sodium azide broth as reported by Mallmann and Seligmann [12]. The bacterial load of water samples was estimated by most probable number (MPN) technique as per Standard Methods for the Examination of Water and Wastewater (APHA, 2005) [11].

2.5. Statistical analysis

The data were statistically analysed using STATISTICA (99 Edition) software. Descriptive statistics including mean, median, minimum, maximum, quartile range, standard deviation, standard error, skewness and kurtosis were computed for each of the variables. Principal component analysis (PCA) was applied on the normalized data sets of physical, chemical and microbiological characteristics of ground water of different sites. Cluster analysis and PCA were performed using the appropriate software mentioned above. For cluster analysis, Wards method was employed.

3. Results and discussion

The riverine area of Sindh province is about 2.112 million acres lying on both the sides of the main stream of the River Indus, within the two flood protective embankments. The area extended between district Kashmore and Indus delta up to the sea coast. Indus basin is one of the largest river basins in Asia, which is covering an area of 1 million km^2 approximately [13]. Its annual flow is 207 billion cubic metres. The irrigation through River Indus covers an area of approximately 18 million hectares which is 78–80% of Pakistan's total cultivated area [14]. The Indus River and its tributaries provide nearly 60% of the water utilized for irrigation. Kazi reported that after independence, the freshwater flow in Indus River reduced from 150 to 1 million acre-feet (MAF) annually [15]. The flow of water at downstream is reduced tremendously reducing deltaic ecosystem from 3,000 to 250 km^2 [16].

The long-standing dispute on water allocation among provinces in Pakistan is not yet solved. IUCN in its study recommended that at least 27 MAF should be released at downstream of River Indus to maintain and restore the deltaic system [17]. Together with climate change, problems and also the upstream diversion, the water hardly reaches at the delta and just remained 2 MAF during most of the periods of year [18]. Owing to the reduced flow, Indus is now in the list of top 10 rivers of the world that is at risk due to water shortages.

Table 1 represents the flow of western and eastern rivers together with the water availability at the downstream of Kotri barage. Table 1 clearly shows the gradual decrease in the flow of the main tributaries of River Indus. The minimum flow at downstream was 0.29, while the maximum flow recorded was 30.67 MAF. From the period of 1 April 2010 to January 2011, the average flow was 54.42 MAF. This was mainly due to heavy rainfall and flash flood in the entire province and upper reaches of River Indus. Due to the reduced supply of freshwater at downstream, most of the nutrients that the Indus River could supply to the water of the north Arabian Sea do not reach there [19].

The irrigation in Sindh is mainly controlled by largest canal network in Asia. The network comprises 03 barrages/head works and 14 main canals and their tributaries. In addition, the network also includes 44,000 water courses running approximately 1,32,000 km. The entire network feeds an area of 5.0 million hectare along the River Indus.

The average rainfall in district Thatta is only 100 mm against the average rainfall of the country,

Table 1
Western and Eastern Inflows and at Down Stream Kotri, Post Tarbela Average (1976–77 to 2009–10)

Rivers	Discharge point	Maximum flow (MAF)	Minimum flow (MAF)	Average (MAF)
Western Rivers	Indus at Kalabagh	112.18	66.81	89.71
	Jhelum and Chennab	64.69	29.70	48.68
	Total	176.87	96.51	138.39
Eastern Rivers	Ravi at Balloki	10.95	0.29	4.23
	Sutlej at Sulemanki	10.62	0.01	2.59
	Total	21.57	0.30	6.82
Total flow of western and eastern rivers		198.44	96.81	145.21
Flow at downstream Kotri		91.86	0.29	30.67
Flow at downstream Kotri from April 1, 2010 to January 2011		54.42		

Source: Indus River System Authority (IRSA).

200 mm, which makes the survey area heavily dependent on canal water supplies. Canal water supply is highly erratic depending on the seasonal flow of River Indus. The flow of around 50% of the canals in the area was negligible at the time of sampling. These canals were not protected in any way from contamination. Whilst this may be unimportant that where water is used for irrigation or as a water supply for animals, there is a potential for bacteriological contamination that may affect water quality as the same is used for drinking as well.

The lesser availability of water in the canals during sampling is also associated with the fact that the water is available through a controlled irrigation system locally known as wara bandi. During distribution of water through wara bandi system, approximately 35% of irrigation water is lost before reaching the farm gate as reported by Bandaragoda [20]. This would mean that a part of water scarcity still the water distribution network would not give direct benefits to the local farmers as half of the irrigation water delivered from the reservoirs being lost during distribution. It may also be noticed that wara bandi system itself is the major constraint on canal water availability at the farm gate; therefore, the purpose of allocation of water to the farmers on an equitable basis is not being fulfilled [21].

In the present investigation, it was found that since the framers do not have control on water supplies, therefore, they are unable to maximize irrigation water productivity. Wahaj and Asghar already reported that the controlled irrigation system in Pakistan is not working satisfactorily [22]. The people of the study area are having strong resentment regarding the water scarcity; however, no attention is ever given that pertains to effective and equitable use of available water. Since in the study area the irrigation system is controlled and the only available water resource is River Indus, a constant discharge is required at the main and secondary levels of the irrigation system. However, in most of the period of year that seems to be impossible in the current face of climate change and already existing water scarcity in the country. Moreover, district Thatta is located at the tail end of River Indus hardly gets adequate water particularly during dry spell. The irrigation delivery system, by law, remains closed once in a year (generally, in months of December and January) when evaporation rate and crop water demand are low [21]. Moreover, the frequent droughts are common in the study area which is an indication of climate variability; therefore, canal water supplies are minimal. Even if there is no flow in the canal, which is a common phenomenon, the farmers deprived weekly watering opportunity, with no compensation. This inequitable distribution of water scarcity among the farmers has affected the farm area under cultivation and has a large effect on farm incomes particularly in Sindh [21].

The quality of surface is an important issue especially in the areas where it is used for drinking purposes. It was studied in details by many workers [23,24].

3.1. Physicochemical analysis results

The descriptive statistics of all the parameters are given in Table 2. pH of all the samples ranged between 7.4 and 7.9, while the mean of all the samples is 7.64. In general, the pH of all the samples was slightly alkaline.

The main indices generally used to determine the organic pollution load in an aqueous system are biochemical oxygen demand, COD and total organic carbon (TOC). BOD represents the biodegradable

Table 2
Descriptive statistics of physical, chemical and biological parameters of surface water samples

Parameters (mg/l)	Mean	Median	Min.	Max.	Quartile range	Std. dev.	Std. error	Skewness	[a]NSDWQ (mg/l)
pH	7.64	7.60	7.40	7.90	0.10	0.12	0.02	0.17	6.5–8.5
BOD_5	112.09	97.00	68.00	177.00	71.00	36.31	6.23	0.48	N/A
COD	694.09	690.00	378.00	912.00	131.00	117.69	20.18	−0.51	N/A
Chloride	471.68	483.50	325.00	582.00	48.00	63.84	10.95	−0.47	<250
DO	5.75	5.90	4.80	6.2	0.40	16.17	2.77	5.82	N/A
Hardness as $CaCO_3$	423.68	426.50	311.00	516.00	73.00	54.51	9.35	−0.55	<500
Sulphate	174.77	175.50	100.00	199.00	13.00	16.89	2.90	−2.47	N/A
Nitrate	3.15	3.26	1.71	5.32	1.23	0.79	0.13	0.26	N/A
Phosphate	4.96	4.79	4.08	6.28	0.67	0.60	0.10	0.62	N/A
Turbidity (NTU)	33.84	34.43	25.50	39.32	7.08	3.70	0.63	−0.40	<5 NTU
TDS	955.71	947.50	672.00	1,326.00	243.00	157.77	27.06	0.45	N/A
TSS	205.15	198.00	167.00	360.00	29.00	36.55	6.27	2.65	N/A
As	0.04	0.04	0.02	0.08	0.02	0.02	0.00	0.92	<0.05
Cr	0.04	0.03	0.01	0.09	0.04	0.02	0.00	0.51	<0.05
Cu	0.25	0.23	0.02	0.67	0.31	0.20	0.03	0.52	2.0
Fe	0.46	0.47	0.10	0.74	0.16	0.14	0.02	−0.36	N/A
Mg	515.94	513.00	265.00	778.00	205.00	137.65	23.61	0.17	N/A
Mn	0.35	0.31	0.12	0.63	0.22	0.15	0.03	0.41	<0.5
Ni	1.53	1.39	1.16	2.74	0.28	0.43	0.07	1.91	<0.02
Pb	1.10	0.36	0.19	4.02	1.81	1.15	0.20	1.00	<0.05
TCC	2,132.35	2,400.00	1,100.0	2,400.00	0.00	533.55	91.50	−1.52	Must not detectable in any 100 ml sample
TFC	1,839.71	2,400.00	3.00	2,400.00	1,300.00	858.17	147.17	−1.06	N/A
TFS	865.15	1,100.00	3.00	1,100.00	640.00	385.61	66.13	−1.24	N/A

[a]NSDWQ = National Standards for Drinking Water Quality, 2008, Ministry of Environment, Government of Pakistan.

portion of the organic pollutants, while COD represents the pollution load of most wastewater discharges [25].

The average BOD concentration of all the samples is 112.09 mg/l. From the public health view point, the BOD concentration is quiet higher (Table 2) as the source is also used for drinking as well. High levels of BOD are surely an indication of increased organic load mainly of anthropogenic origin. Partly high BOD level close to the human settlements is also due to the dumping of solid waste by the local communities which undergo microbial decomposition and thus increase organic load. A high BOD level tends to reduce DO concentration because oxygen is consumed by bacteria creating anoxic condition also detrimental to aquatic life. High BOD could also be attributed to high SS concentration. EEA reported that over 80% of Rivers in northern Europe have a biochemical oxygen demand of 2.0 mg/l, which indicates a relatively clean river [26]. If that figure is considered as standard, then all the water samples were heavily polluted due to organic load.

Comparatively COD of all the samples were also exceptionally higher as can be seen from Table 2. This could be an indication that the surface water is gravely polluted with organic and inorganic contaminants. Higher COD values are observed particularly at the sites close to the human settlements (SW-9, 10, 16, 17, 18, 23, 24, 25, 31 and 32) (Fig. 1). The trend of COD is depicting similar trend as that of BOD. Mean COD values of all the samples was 694.09 mg/l. Jin et al. opined that there is no apparent linear relationship between BOD and COD in relatively clean seawater samples away from the shore [27]. However, in estuary having relatively high concentration of sewage contamination, a linear correlation does exist between BOD and COD. In the present case, there is no source of industrial waste, which could pollute surface water. However, untreated domestic wastewater from the nearby settlement finds its way to the canal system. The high COD values also indicated continuous accumulation of toxic chemicals. These toxic chemicals may usually come from agriculture run-off.

Sample Code	GIS-Coordinates	Sample Code	GIS-Coordinates
SW-1	24°41′10.06″N, 67°58′38.86″E	SW-18	24°23′48.15″N,67°58′22.51″E
SW-2	24°41′4.55″N, 67°58′27.12″E	SW-19	24°23′27.80″N, 67°58′38.63″E
SW-3	24°40′34.54″N, 67°57′59.31″E	SW-20	24°23′12.29″N, 67°58′36.58″E
SW-4	24°40′8.39″N,68° 3′36.71″E	SW-21	24°22′28.34″N, 67°58′35.29″E
SW-5	24°39′45.69″N, 68° 3′34.09″E	SW-22	24°21′43.52″N,67°58′36.59″E
SW-6	24°35′53.76″N, 68° 2′57.96″E	SW-23	24°23′23.33″N, 67°57′2.28″E
SW-7	24°35′38.44″N, 68° 2′8.45″E	SW-24	24°23′13.32″N,67°56′34.62″E
SW-8	24°34′23.56″N, 68° 1′36.17″E	SW-25	24°22′55.48″N, 67°55′45.30″E
SW-9	24°34′9.01″N, 68° 2′32.27″E	SW-26	24°21′32.66″N,67°52′47.60″E
SW-10	24°33′31.45″N, 68° 1′34.58″E	SW-27	24°19′14.82″N, 67°52′9.25″E
SW-11	24°31′45.45″N, 68° 1′50.74″E	SW-28	24°19′33.48″N, 67°51′44.63″E
SW-12	24°26′45.34″N, 68° 0′32.30″E	SW-29	24°15′42.56″N,67°49′40.22″E
SW-13	24°27′4.35″N, 67°59′20.02″E	SW-30	24°22′6.10″N,67°57′46.60″E
SW-14	24°26′10.56″N, 67°58′35.37″E	SW-31	24°21′9.01″N,67°57′13.23″E
SW-15	24°23′59.05″N, 67°58′27.27″E	SW-32	24°20′52.38″N,67°56′50.84″E
SW-16	24°23′50.53″N, 67°58′16.17″E	SW-33	24°20′18.49″N, 67°57′1.02″E
SW-17	24°23′49.47″N, 67°58′19.39″E	SW-34	24°14′29.64″N, 67°48′6.71″E

Fig. 1. Sites of sample collection of surface water.

The mean DO concentration of all the samples ranged between 4.80 and 6.2 mg/l. This could be mainly because of dissolution of atmospheric oxygen due to high wind velocity in the area.

The concentration of chloride and hardness are typically higher as compared to the National Standards for Drinking Water Quality Pakistan (NSDWQ). The former ranged from 325 to 582 mg/l, while latter was in the range between 311 and 516 mg/l.

It may not out of place to indicate that about 78% of the irrigated land in Sindh is underlain with saline or brackish water, which cannot be used for agriculture. This issue together with already existing brackish ground water in the coastal areas of Sindh is compromising the agriculture sustainability. In fact, the prime cause of water logging and salinity problem is mainly due to the faulty irrigation system [28]. The problem further aggravated due to the contour of the area, seepage from unlined canals and the absence of adequate drainage system. The water sample collected from one of the canal showed the salinity value up to 35.1 part per thousand. Moreover, increase in irrigated area is responsible for rise in the salinity of soil in Sindh [29]. The drastic reduction in flow of Indus is virtually converting agriculture land to a saline desert [28]. Samdani reported that salinity problem in coastline of Sindh is mainly attributed to capillary rise in groundwater, seawater intrusion and flooding [30]. Salinity and water logging remain serious problems in irrigated areas of Sindh particularly in the study where much of the groundwater is naturally saline (of marine origin) and thus unsuitable for irrigation as a substitute for canal diversions. People have no choice except to drink the brackish water. The consumption of such type of water is responsible for a number of non-specific waterborne diseases, which is evident in the local population.

The concentration of nitrate is well within the limit as compared to NSDWQ; therefore, they would not pose any serious threat to human health. The major source of nitrate is through the indiscriminate use of inorganic fertilizer that may enter into the canal system through agriculture run-off.

The guideline value for the sulphate is not available in NSDWQ; however, concentration up to 500 mg/l is safe for drinking. The people consuming water containing sulphate in concentrations exceeding 600 mg/l may suffer from cathartic effects [31].

Maximum permissible limit of phosphate is not available in NSDWQ; however, the possible source of phosphate could be the inorganic fertilizers which are indiscriminately used in the study area. The total phosphate concentration ranged between 4.08 and 6.28 mg/l. The mechanism of flow of nutrients, including phosphorus, between sediments and water is a complex phenomenon which is influenced by biological, physical and chemical processes and depends on pH, temperature and redox potential [32].

All the water samples are highly turbid and have crossed the turbidity limit as reported in NSDWQ (Table 2). The presence of high turbidity is mainly due to the presence of high suspended solids. These suspended solids may include a wide variety of materials, such as silt, decaying plant and animal matter that can increase the turbidity of water. If they are of biological origin, they would tend to increase the biological oxygen demand. Water containing high concentration of TSS does not allow the light to penetrate which is detrimental for submerged vegetation. In extreme conditions, the submerged vegetation may even die due to unavailability of light. The dead vegetation will be decomposed by bacteria that will utilize more oxygen, thereby creating a condition of suffocation that is detrimental to aquatic fauna. The TSS concentration ranged between 167 and 360 mg/l (Table 2). High TSS can also increase surface water temperature as suspended particles absorbed more heat [33]. Generally, the SS concentration is relatively high during high hydraulic load [34]. The concentration of TDS ranged between 672 and 1,326 mg/l with an average of 955.71 mg/l. High TDS concentration deprecate the palatability of water.

The interpretation of these results ascertains that water quality is not good for human consumption and would be a source of ailment in the local population. It has been anticipated that any change in freshwater flows in the River Indus may result in the changes in turbidity, salinity, stratification and nutrient availability, all of which affect estuarine and coastal ecosystems.

3.2. Metal analysis results

The results of metal analysis are shown in Table 2. Arsenic was present in below detectable limit in all the samples (Table 2). It is quite surprising to note that the samples also contain Cr, while there is no industrial activity in and around the area. Cr concentration ranged between 0.01 and 0.09 mg/l. Moreover, no tannery is located in the vicinity. The concentration of Cr although relatively low, however, continuous consumption of water contaminated with Cr would pose serious health implications. Its maximum permissible limit is <0.05 mg/l.

The maximum permissible limit of Cu is 2.0 mg/l as per NSDWQ. As can be seen from the Table 2, the mean concentration of Cu is 0.25 mg/l. The concentration of Fe in water samples ranged between 0.10 and 0.74 mg/l. The maximum permissible limit of Fe is not given in NSDWQ. As such it will not be responsible for causing any serious health problem. The mean concentration of Mg is 515.94 mg/l. Both Ca and Mg are responsible for causing hardness in water. Mn in all the samples ranged between 0. 12 and 0.63 mg/l which is relatively higher as compared to NSDWQ which is <0.05 mg/l. Similarly, the concentration of Ni on an average was 1.53 mg/l, whereas the limit as per NSDWQ is only <0.02. The origin of these metals is quiet uncertain. They may possibly be coming from the soil sediments.

The average concentration of Pb in all water samples was found to be 1.10 mg/l. Farooq et al. reported the heavy metal concentration found in Indus River [35]. They suggested that elevated concentration of Pb can mainly be attributed to anthropogenic activities. The results of Farooq et al. corroborate the present findings [35]. The health risks associated with these metals are also of great concern and were noticed by many workers [36,37].

3.3. Bacteriological analysis results

Bacteriological quality of surface water is reported in Table 2. It was found that none of the water sample was fit for human consumption as per WHO guidelines for drinking water [38]. All the well water samples were reported to be contaminated with the organisms of public health importance (Table 2).

Meyberck reported that the faecal coliforms up to 10^6/100 ml are commonly found in Pakistan, India, Indonesia and Pakistan [39]. These organisms are the continuous source of ailment in the local people of the area. Gumbo reported that infectious water-related diseases are most important in the developing countries [40]. The people have no exception as depicted from the conversation with local people. Gumbo also reported that unless drinking water supplies are improved, there is a little hope of controlling communicable diseases in the population [40].

Since the people have no choice except to consume the contaminated water, waterborne diseases are common among the population. Bacteriological analysis reveals that there is an increase in contamination due to organisms of public health importance after rain. This could be possibly due to the run-off from the surroundings providing favourable conditions for the organisms to sustain and multiply. Since the number of faecal coliforms (FC) and faecal streptococci (FS) discharged by human beings and animals are significantly different, it is suggested that the ratio of FC to FS count in a given sample can be used to detect whether the pollution is derived from the human or from animal wastes. The FC/FS ratio in water in animal origin is generally considered less than 1.0, whereas it is more than 4.0 for human beings. If the ratio is within 1 to 2, the interpretation is uncertain. This ratio is very helpful in determining the source of pollution [41]. The number of FS was relatively low in all the samples. The reason of faecal contamination could be the anthropogenic activities near the canals. Proper selection and protection of water sources as in present case are of prime importance in the provision of safe drinking water. Shar et al. also reported that the quality of surface water is generally poor as compared to groundwater from the public health point of view [42]. Aziz reported that most of the drinking water supplies in Pakistan are faecally contaminated and result in high incidence of waterborne diseases [34]. In general, during the rainfall and flood conditions, the microbial load of the flowing water increases which depreciates the water quality [43]. It is always better to protect water from contamination than to treat it after it has been contaminated. Protection of surface water is, however, a problem, if water supplies are to remain potable, both the source and the catchments need protection. For this purpose, the water should be protected from contamination due to anthropogenic activities.

3.4. Statistical analysis results

The result of PCA ordination is given in Fig. 2 and Table 3. The three dimensional PCA ordination shows a well-defined cluster on the left characterized by high sulphate, high nitrate and lower chloride concentrations. Next to it stands a loose group of stands with high nitrate and phosphate and relatively low in hardness. Next to this group on the lower side of the configuration is a diffuse group of sample characterized by low hardness and higher levels of nitrate and sulphate. The group above this which is somewhat closed includes samples with low BOD and low sulphate and nitrate. The first principal component explained 25.63% of the variance, the second 16.89%, while the third is 9.98%. Together the first three components explained 52.63% of the total variance. The first component is primarily a function of lead (Pb), hardness, turbidity and BOD. The second component is basically controlled by Cu, As, Ni and TFS, while the third component is predominantly related to sulphate, nitrate, Ni and As.

The dendogram derived from weighted pair group method is given in Fig. 3. Group 1 includes eleven samples characterized by higher BOD, chloride, nitrate but low Pb and Ni. Group "2a" including six samples shows high TSS and BOD, low Mg and As, while "2b" that comprises 17 samples exhibits low pH, BOD, nitrate and high sulphate, Ni and Mg.

The study reveals that accessibility to safe drinking water is major problem in the study area. This issue is more dependent on the level of technical water supply infrastructure than on the level of run-off. However, the objective to provide safe drinking water will be difficult to achieve particularly if the run-off in the River Indus would decrease as a result of climate change. The climate change would also enhance additional cost for water supply sector due to variability in water levels affecting water supply infrastructure, which might hamper the extension of water supply services to more people. Furthermore, the impact of climate change on water supply costs will increase in the future, not only because of increasing climate change but also due to increasing demand. Moreover, if irrigation use is allowed to increase in response to increased demands, that would amplify the decreases in run-off and stream flow downstream [44].

It is expected that low flow in the River Indus during summer will reduce water availability for agriculture. During these periods, the water demand for agriculture is expected to increase due to higher temperatures. The major water demanding crop in the study area is rice. In fact, the district Thatta and Badin are the major rice-producing areas in the province. Since the variability of water is highly questionable to these tail end districts, the farmers have switched over to other less water demanding crops. Similarly, the study area was also known for sugar cane production. However, the cultivation of sugar cane is only restricted to some places owing to the shortages of water. During field visits, it was witnessed that the farmers have no choice in the water scarce scenario but to grow water resistant crops like sunflower. Sunflower cultivation is emerging as new cash crop in the study area but farmers hardly get the required income out of sunflower cultivation. It may be pointed out here that climate change is not the only one factor that influences water stress other factors such as population, socio-economic and technological changes may also play important role among water demand and stress.

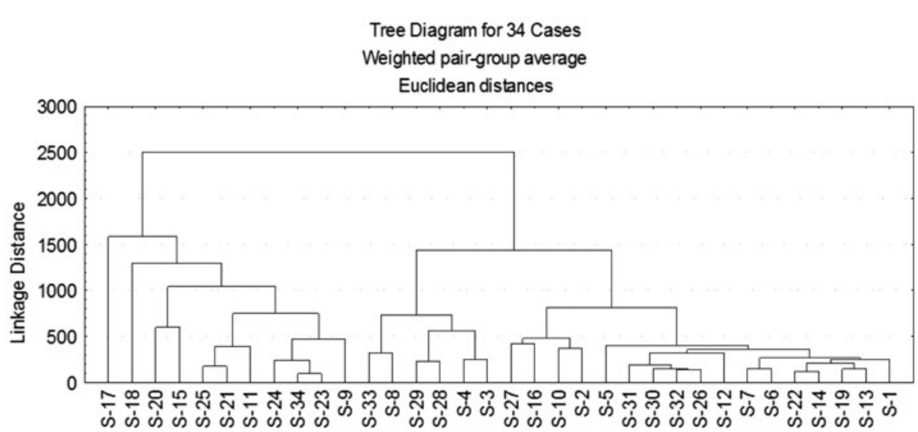

Fig. 2. Dendogram derived from weighted pair group average between 56 sites based on metal quality of water.

Table 3
Results of PCA of physical, chemical and microbiological parameters of surface water samples

Component	Eigenvalue	Percentage variance	Cumulative percentage variance	First 4 eigenvector coefficients	Associated variables
1	5.8956	25.6333	25.8956	0.9129	Pb
				−0.7853	Hardness
				−0.7483	Turbidity
				−0.7412	BOD_5
2	3.8866	16.8985	9.7823	−0.8754	Cu
				−0.7259	As
				−0.7086	Ni
				0.5909	TFS
3	2.2973	9.9883	12.0796	−0.7050	Sulphate
				−0.6821	Nitrate
				0.5032	Ni
				−0.4587	As

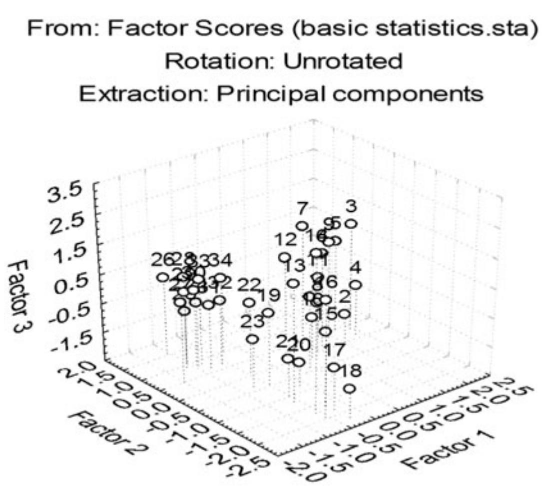

Fig. 3. PCA ordination (3D) of physical, chemical and microbiological parameters of surface water.

4. Conclusions

Supply and demand of water in the study area is mainly based on water management systems. It can be argued that the rainfall patterns in the area are irreversibly altered due to climate change, and the availability of surface water resources is being changed. Due to the non-linear character of hydrological processes, modest changes in rainfall can lead to considerable changes in water availability to the stakeholders [45].

What is anticipated for the coastal areas of Sindh is that climate change will probably alter the desired uses of water. Given that, the climate change enhancing water scarcity relative to demand the area is still not equipped for adaptation strategies that may involve improve water use efficiency especially in the agriculture sector, metering, pricing and the institutional and infrastructure improvements.

The canal water is provided by local municipal authorities. Water is diverted from some canals for irrigation of nearby fields and for domestic use in some villages. However, the discharges in these canals were relatively low. None of the canal that was inspected was protected in any way from contamination of the water after it had been discharged from the source.

Whilst this may be unimportant where water is used for irrigation or as a water supply for other purposes, there is a potential for bacteriological contamination that may affect quality as a drinking water supply for people. Results indicated that on the basis of WHO guidelines, water from the canals was not suitable for drinking at the time of sampling. Agriculture run-off, sewage leaks and metals, however, quite often contaminate this source. However, users have no method to judge its quality except for taste. Thus, most of the residents drink polluted water unknowingly and do not question its quality.

Acknowledgement

The authors gratefully acknowledge the financial support provided by the Higher Education Commission Pakistan.

References

[1] W.W. Immerzeel, L.P.H. van Beek, M.F.P. Bierkens, Climate change will affect the Asian water towers, Science 328 (2010) 1382–1385.
[2] C. Corvalan, S. Hales, A.J. McMichael, Ecosystems and Human Well-Being: Health synthesis, WHO, Geneva, (2005).

[3] P. Singh, L. Bengtsson, Impact of warmer climate on melt and evaporation for the rainfed, snowfed and glacierfed basins in the Himalayan region, J. Hydrol. 300 (2005) 140–154.
[4] N.W. Arnell, Climate change and global water resources: SRES emissions and socio-economic scenarios, Global Environ. Change 14 (2004) 31–52.
[5] J. Alcamo, T. Henrichs, Critical regions: A model-based estimation of world water resources sensitive to global changes, Aquat. Sci. 64 (2002) 352–362.
[6] J. Briscoe, U. Qamar, Pakistan's Water Economy Running Dry, Oxford University Press, Karachi, Commissioned by World Bank, 2007.
[7] D.R. Archer, N. Forsythe, H.J. Fowler, S.M. Shah, Sustainability of water resources management in the Indus Basin under changing climatic and socio economic conditions, Hydrol. Earth Syst. Sci. 14 (2010) 1669–1680.
[8] M.N. Siddiqui, S. Maajid, Monitoring of geomorphological changes for planning reclamation work in coastal area of Karachi Pakistan, Adv. Space Res. 33 (2004) 1200–1205.
[9] D.A. Quadir, M.A. Hussain, M.A. Hossain, The Status of Climate Habitation in Pakistan and its Impacts, SAARC Metrological Resource Centre (SMRC), Dhaka Bangladesh, (2004).
[10] World Wide Fund for Nature, WWF, Keti Bunder (Final Report), Study on Knowledge, Attitudes and Practices of Fisher Folk Communities about Fisheries and Mangrove Resources, Fortune Center 6th Floor, Block 6, PECHS, Shahrae Faisal Karachi, 2005, 606–607.
[11] American Public Health Association (APHA), Standard Methods for the Examination of Water and Wastewater, 2005, 21th ed., American Public Health Association, Washington DC, USA.
[12] W.L. Mallmann, E.B. Seligmann, A comparative study of media for the detection of streptococci in water and sewage*, Am. J. Public Health Nations Health 40(3) (1950) 286–289.
[13] S.M. Nasir, G. Akbar, Effect of River Indus flow on low riparian ecosystems of Sindh: A review paper, Rec. Zool. Surv. Pak. 21 (2012) 86–89.
[14] Z. Habib, Pakistan: Indus Basin water issues, South Asian Journal, South Asian Free Media Association., (2004). Available from: <http://www.Southasianmedia.net/Magazine/journal/previousissue6.html>. (last access: March 2010)
[15] A.M. Kazi, Overview of Water Resources in Pakistan, Special Reports/Water Crisis, viewed on 22 December 2011. (2003). Available from: <http://www.pakissan.com/english/watercrisis/overview.of.water>.
[16] A. Inam, P.D. Clift, L. Giosan, A.R. Tabrez, M. Tahir, M.M. Rabbani, M. Danish. The geographic, geological and oceanographic setting of the Indus River, Large Rivers: Geomorphology and Management, (2007) 333–345.
[17] IUCN Report, The Lower Indus River: Balancing Development and Maintenance of Wetland Ecosystems and Development Livelihoods, The World Conservation Union, (2004).
[18] A.G.N. Abbasi, Restoration of Singh's Primary Rights over River Indus, 2002, 18th Convention of Sana, Cherry Hill, NJ, pp. 4–7.
[19] M.N. Siddiqui, Monitoring Land Erosion and Environmental Changes in Thatta—Badin Districts by Integration of Multi-temporal SRS Data, Proceeding of the International Seminar on Natural Hazards Monitoring, Karachi, Pakistan, (2002) 366–376.
[20] D.J. Bandaragoda, Institutional Conditions for Effective Water Delivery and Irrigation Scheduling in Large Gravity Systems: Evidence from Pakistan, Irrigation Scheduling: From Theory to Practice, Water Reports No. 8, Food and Agriculture Organization of the United Nations, (1996).
[21] N.H. Zardari, I. Cordery, Water Productivity in a rigid irrigation delivery system, Water Resour. Manage. 23 (2009) 1025–1040.
[22] R. Wahaj, L. Vincent, S.A. Prathapar, Farmers' management responses to the gap between supply and demand of canal water. No. H026995, International Water Management Institute, 2000.
[23] M. Varol, B. Şen, Assessment of surface water quality using multivariate statistical techniques: A case study of Behrimaz Stream, Turkey, Environ. Monit. Assess. 159 (2009) 543–553.
[24] T. Ammar, B. Abderrahmane, Hydro chemical analysis and assessment of surface water quality in Koudiat Medouar Reservoir, Algeria, Eur. J. Sci. Res. 41 (2010) 273–285.
[25] L. Liu, H. Ji, Y. Liu, H. Xin, Chemical oxygen demand of seawater determined with a microwave heating method, J. Ocean Univ. China 4 (2005) 152–156.
[26] European Environment Agency (EEA), Oxygen consuming substances in Rivers CSI-019, (2012). Available from: <http://www.eea.europa.eu/data-and-maps/indicators/oxygen-consuming-substances-in-rivers/oxygen-consuming-substance-in-river-5>.
[27] X.L. Jin, M. Jing, X. Chen, Z.X. Zhuang, X.R. Wang, F.S.C. Lee, A study on the relationship between BOD_5 and COD in coastal seawater environment with a rapid BOD measurement system, Water Sci. Technol. 60 (2009) 3219–3223.
[28] F.A. Chandio, A.G. Soomro, A.H. Memon, M.A. Talpur, Influence of water table depth on soil sodicity and salinity, World Acad. Sci. Eng. Technol. 80 (2011). Available from: <http://www.waset.org/journals/waset/v80/v80-31.pdf>.
[29] A. Azad, Sindh Water Resources Management: Issues and Options, FAO Investment Centre, Occasional Paper, (2003), Series No. 15. Available from: <http://ftp://ftp.fao.org/docrep/fao/008/af105e/af105e00.pdf>.
[30] Z. Samdani, Salinization Threatens Irrigation. Economic and Business Review, Daily Dawn, Karachi III, (3–9/06/1995).
[31] World Health Organization, Sulfate in Drinking water. Background Document for Development of WHO Guidelines for Drinking Water Quality, World Health Organization, Geneva, 2004.
[32] R.G. Carlton, R.G. Wetzel, Phosphorus flux from lake sediments: Effect of epipelic algal oxygen production, LimnolOceano 33 (1988) 562–570.
[33] M.K. Mitchell, W.B. Stapp, Field Manual for Water Quality Monitoring, An Environmental Education Program for Schools, GREEN, Ann Arbor MI, (1992).
[34] J.A. Aziz, Management of source and drinking water quality in Pakistan, East. Mediterr. Health J. 11 (2005) 1087–1098.

[35] M.A. Farooq, S.S. Shaukat, M.U. Zafar, Q. Abbas, Variation patterns of heavy metal concentration during pre-and pot-monsoon seasons in the surface water of River Indus (Sindh Province), World Appl. Sci. J. 19 (2012) 582–587.
[36] G.E. Eriyamremu, S.O. Asagba, I.A. Akpoborie, S.I. Ojeaburu, Evaluation of lead and cadmium Niger-Delta oil area of Nigeria, Bull. Environ. Contam. Toxicol. 75 (2005) 278–283.
[37] M. Muchuweti, J.W. Birkett, E. Chinyanga, R. Zvauya, M.D. Scrimshaw, J.N. Lester, Heavy metal content of vegetables irrigated with mixtures of wastewater and sewage sludge in Zimbabwe: Implications for human health, Agric. Ecosyst. Environ. 112 (2006) 41–48.
[38] WHO, Drinking water Quality Guidelines, WHO, Geneva (1996).
[39] M. Meyberck, The GEMS/water programme (1978–1983), Water Qual. Bull. Environ. Canada 10(4) (1985) 167–173.
[40] F.J. Gumbo, Water quality monitoring in Tanzania, Water Qual. Bull. Environ. Canada 10(4) (1985) 174–180.
[41] Metcalf and Eddy, Inc., third ed., Revised by G. Tchobanoglous, Wastewater Engineering Treatment Disposal and Reuse, McGraw-Hill Book Company, NY, 1991.
[42] A.H. Shar, Y.F. Kazi, M. Zardari, I.H. Soomro, Bacteriological quality of drinking water of Sukkur city, Sindh Pakistan, Pak. J. Med. Res. 48 (2009) 88–90.
[43] T. Kistemann, F. Dangendorf, M. Exner, A Geographical Information System (CIS) as a tool for microbial risk assessment in catchment areas of drinking water reservoirs, Int. J. Hyg. Environ. Health 203 (2001) 225–233.
[44] J.W. Eheart, D.W. Tornil, Low-flow frequency exacerbation by irrigation withdrawals in the agricultural midwest under various climate change scenarios, Water Resour. Res. 35 (2010) 2237–2246.
[45] W.G.M. Bastiaanssen, N.R. Harshadeep, Managing scarce water resources in Asia: The nature of the problem and can remote sensing help? Irrig. Drain. Syst. 19 (2005) 269–284.