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Assessment of underground water resources of Gharo city, Sindh, Pakistan

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Abstract
This investigation focuses on the extent of public health quality of underground water available in Gharo city, Sindh Pakistan that represents a very poor socioeconomic profile. The city has a very limited piped water supply and the people mostly rely on well water. Underground water samples were collected from 28 different locations and the water quality was assessed through a deterministic sampling programme followed by an intense physicochemical and bacteriological analysis. The results of these analyses disclosed that the underground water is grossly polluted due to domestic and agricultural discharges. The problem is further aggravated by poor sanitation conditions. None of the water samples met the water quality criteria set by NSDWQ and WHO. The groundwater was found to be fecally contaminated and poses serious human health hazards. Effective measures are urgently required for water quality management in the city.

Keywords
underground water, Gharo, public health quality, contamination, Sindh

Introduction

The most critical issue, which the countries of South Asia are facing, is the availability of potable water. HDR (2006) reported that by 2050 nearly 2.5 billion people of this region would expected to suffer from water scarcity, whereby per capita water availability from 1950 has already reduced by 70% (Langton and Prasai 2012). Arnell (2004) estimated that Pakistan may experience chronic water shortage in upcoming years. However, it is pertinent to explain that real water shortage is actually linked with how water resources are managed in the coming decades. Briscoe and Qamar (2007) opined that Pakistan has already crossed water stress threshold and the country may reach to the level of water scarcity by 2035. Pakistan is already in the list of water stressed country (Alcamo and Henrichs 2002) mainly because of water shortages and increase in water withdrawals. Sindh province of Pakistan is located on the western curve of South Asia. Geographically, the province has a strategic position. On the east is the Thar Desert, on the west are the Kherthar Mountains and on the south is the Arabian Sea. Administratively Sindh is divided into 22 districts. Sindh coastline stretches over 270 km out of 970 km long coast line of Pakistan (Siddiqui and Maajid 2004).

This coastal belt of Sindh is highly vulnerable to climate change as the area faced chronic droughts from 1996-2003 whereas, the rainfall declined up to 10-15%. The coastal belt also exhibited fourteen cyclones from 1970-2001 (Quadir et al. 2004). It has been reported that after early 1990, the mean temperature of Sindh coastal areas has increased up

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to 0.6 to 1.0 ^{O}C (Farooq and Khan 2004). The array of rise in temperature and erratic pattern of rainfall tends to continue in the coming years that may cause chronic water scarcity that would be unable to satisfy domestic and agriculture demands (Quadir et al. 2004).

In Sindh, fresh groundwater prevails only in 10% area (Panhwar 2002). Ground water is available as suspended aquifers in silty/ sandy layers wrapped below by the layers of clay. The water table generally varies from 10-30m.The ground water is generally considered as safe for human consumption and free from pollution compared to surface water (Ranjana 2010). Currently, the ground water quality is compromised particularly in urban centers owing to the greater urbanization, industrialization , population growth and the disruption of monsoon system (Karunakaran et al. 2009). Percolation of domestic and industrial discharges are the main causes of ground water contamination (Sargaonkar and Deshpande 2003).

Gharo city is situated in Thatta district of Sindh at 24.7414°N, 67.5858°E having a population of approximately 30,000. District Thatta is considered as poorest district in the country. The poverty sketch of Thatta reveals that 54% of the population is categorized as "poorest" while the remaining population may be considered as "poor". Approximately 90% population of the district is thriving under the poverty line; therefore, all family members have to take part in income generation processes to sustain their life.

The communities living in the Gharo city are having very limited livelihood options. A sizeable population is engaged in fisheries, while the second important livelihood option is agriculture. The physical infrastructure and the provisions of basic amenities are insufficient and underprivileged. The health care facilities are almost negligible. Due to deplorable sanitation conditions the water borne diseases are prevalent among the local population. The piped water supply is limited and intermittent.

The quality of water is a major issue in the area. The quality of water is poor from the public health viewpoint but the people have no choice except to consume contaminated water. Although, the governmental schemes of water supply have been approved but remain dormant for one reason or the other. Unavailability of water impacts on the productive use of total man working hours. The people spend much of the time for fetching and carrying water. The quality of water is also objectionable and people have no means to judge the quality of polluted water. As a result, a high proportion of the population, especially children, and elderly people suffer from water-borne ailments. The wells mostly dug manually and the use of bucket and rope system to fetch the water is common. At some places the people are using a diesel operated centrifugal pump fixed on the ground surface.

The major aim of the present study was to evaluate the underground water quality. The study also aims to demonstrate whether the quality of water is not up to the standard when it was harvested or the water gets contaminated during storage or due to the use of contaminated utensils.

Materials and Methods

Sampling survey

The wells inspected were mostly dug manually up to only a few meters depths at the stagnant water table. In general, the wells did not have any type of lining. However, some of the wells were lined only up to the upper sections. Generally, the wells were having a separation distance of 100 -125 meters. The wells are generally bounded by a small bund of dug out sand that controls the surface water ingress. Usually, there are no effective methods in place to avert water contamination in the dug wells.

Water Quality Monitoring

Sampling. In all 28 underground water samples were collected from the Gharo city. The samples for chemical and bacteriological analysis were collected separately. The samples for chemical analysis were collected in clean plastic containers while the samples for bacteriological examination pre-sterilized glass bottles were used. Samples were kept at a low temperature in an ice box and were conveyed to the Institute of Environmental Studies, University of Karachi.

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Table 1. *Sites for sample collection*

Sample Code	GIS Coordinates	Sample code	GIS Coordinates
G-1	24°44’45.74”N, 67°34’27.15”E	G-15	24°44’40.51”N, 67°34’51.52”E
G-2	24°44’34.26”N, 67°34’21.84”E	G-16	24°44’35.50”N, 67°34’49.19”E
G-3	24°44’20.84”N, 67°34’29.73”E	G-17	24°44’32.16”N, 67°35’0.91”E
G-4	24°44’13.08”N, 67°34’35.86”E	G-18	24°44’35.79”N, 67°35’9.84”E
G-5	24°44’19.40”N, 67°34’46.47”E	G-19	24°44’45.22”N, 67°35’10.48”E
G-6	24°44’17.63”N, 67°35’02.54”E	G-20	24°44’52.59”N, 67°34’58.62”E
G-7	24°44’07.34”N, 67°35’16.97”E	G-21	24°45’04.10”N, 67°34’42.45”E
G-8	24°44’16.66”N, 67°35’19.15”E	G-22	24°45’13.84”N, 67°34’53.77”E
G-9	24°44’19.67”N, 67°35’13.77”E	G-23	24°44’59.55”N, 67°34’60.00”E
G-10	24°44’24.28”N, 67°35’15.36”E	G-24	24°44’58.85”N, 67°35’20.16”E
G-11	24°44’24.95”N, 67°35’08.34”E	G-25	24°45’02.01”N, 67°35’40.50”E
G-12	24°44’27.92”N, 67°34’50.90”E	G-26	24°44’51.77”N, 67°35’41.29”E
G-13	24°44’49.52”N, 67°34’43.57”E	G-27	24°44’34.56”N, 67°35’23.01”E
G-14	24°44’46.84”N, 67°34’54.20”E	G-28	24°44’37.66”N, 67°35’55.46”E

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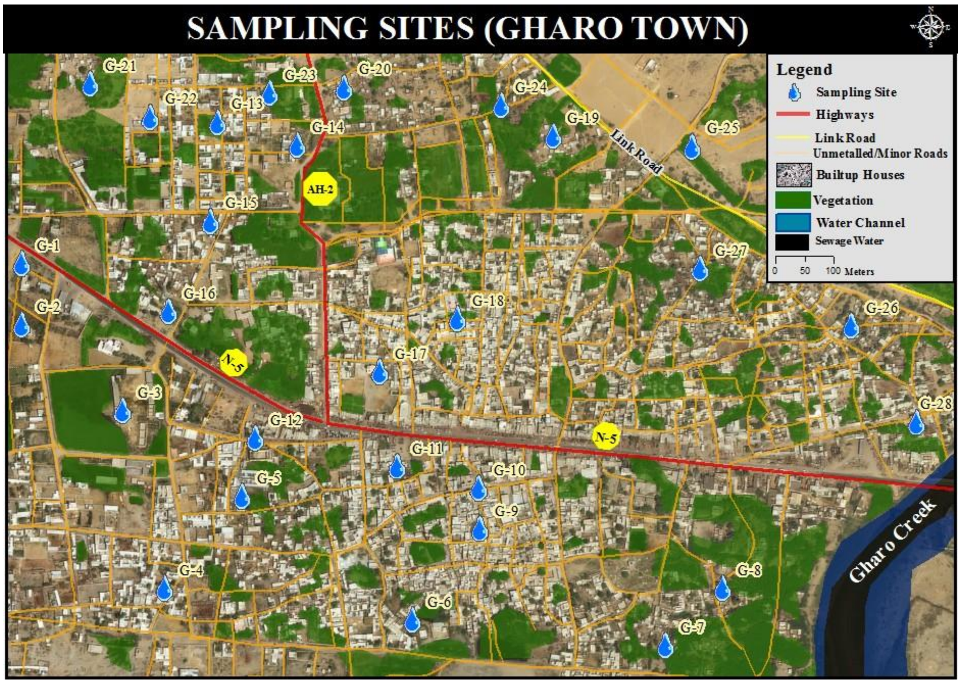

Figure 1. *Map of sampling sites of Gharo city.*

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Physico-chemical analysis. The water samples were analyzed for pH, Solids (Total dissolved and suspended solids; TDS and TSS), chloride, hardness (as $CaCO_3$), nitrate, phosphate and sulphate. pH was noted on site by Hanna pH meter (HI98107).TSS, TDS and sulphate of water samples were analyzed by gravimetric method (APHA 2005). Argentometric method was employed for chloride estimation while EDTA titration method was applied for estimation of Hardness (as $CaCO_3$). Nitrate was estimated by brucine-reagent method and total phosphate was examined by ascorbic acid method. The above mentioned parameters were analyzed in accordance with the methods described (APHA 2005).

Metal analysis. The heavy metals were also analyzed by using Merck NOVA 60, Germany through appropriate kits. The heavy metals tested were As, Cd, Cu, Cr, Fe, Ni, Pb, and Zn.

Bacteriological analysis. Bacteriological analysis was performed by MPN technique (APHA 2005). The water samples were investigated for the detection of Total Coliforms Count (TCC), Total Fecal Coliforms Count (TFC) and TFS Total Fecal Streptococci Count (TFS). Sterility was maintained throughout the analysis by using laminar flow hood. TCC was estimated by lactose broth (Merck, Germany) of single and double strength. TFC were examined through EC broth (Merck, Germany) by using positive single and double strength lactose broth tube.

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

The field survey and interviews with the local population revels that the underground water is extensively polluted mainly due to municipal effluent and the agriculture discharge. This has rendered the indigenous people to consume contaminated water thus responsible for water borne diseases. Table 2 presents the descriptive statistics of all the above parameters. The average pH of all the water samples is 7.34 with fluctuated between 7.1 to 7.7.Overall, pH of water samples is mostly neutral to alkaline however, a high pH was noted (7.7) at G-19.

Suspended solids (SS) symbolizes concentration of inorganic and organic matter, which contained in water bodies and generally present naturally (Bilotta and Brazier 2008; Ryan 1991). Physical, chemical and biological properties of the water body altered, if SS concentration is exaggerated. The physical disparities induced by SS may comprise due to temperature changes, filling of water basins through the accumulation of solids and low sunlight penetration. These physical changes depreciates aesthetic quality (Lloyd et al. 1987) while chemical alterations result in the release of chemical contaminants mostly in the form of heavy metals, pesticides (Dawson and Macklin 1998; Kronvang et al. 2003) and nutrients such as phosphorus (Harrod et al. 2002; Haygarth et al. 2006) into the water body. The mean TSS value was found to be 154.61 mg/l. Ideally the water if used for human consumption should have 0.0 mg/l TSS values. The analysis of these result concluded that quality of water is bad for human use and would be a source of illness in the indigenous people. The TDS value fluctuated between 1000-1562 mg/l with mean value of 1267.79 mg/l. Elevated concentration of TDS depreciate water palatability. This was also confirmed by the local population that water is generally hard having an unpleasant taste. Renal problems, liver dysfunction, and gastric upsets are the common ailments prevailing in the area which might be due to the high TDS concentration (Mahmood et al. 2014).

The concentration of chloride ranged between 234-369 mg/l while the hardness was in between 556 to 932 mg/l that are characteristically higher when compared to the WHO (2011) and NSDWQ (2008). Elevated levels of chloride and hardness may be accompanying with the problem of salinity and water logging prevailing in the area. Such problems along with the presence of brackish ground water in the study area limit the agriculture activities. The major cause of salinity and water logging is the defective irrigation system (Soomro et al. 2011). These results corroborate the findings of Alamgir et al (2016) and Memon et al (2011).The absence of suitable drainage system, leakage from unlined canals and contour of the area further intensifies the problem. Furthermore, soil salinity increases due to increase in irrigated area

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in Sindh (Azad 2003). Samdani (1995) described that sea water intrusion, flooding and capillary rise in ground water are responsible for salinity problem in Sindh coastal area. Water logging and Salinity pose stern problems in Sindh irrigated areas including the study area and thus inappropriate for irrigation. The use of such brackish water is liable for a variety of non-infectious water borne ailments as evidenced by the health of indigenous people.

Table 2. *Physical, chemical, metal and microbial characteristics of groundwater samples of Gharo city*

Parameters	Mean	Median	Min.	Max.	Std. dev.	Std. error	NSDWQ	WHO Guidelines2011
pH	7.34	7.30	7.10	7.70	0.17	0.03	6.5-8.5	6.5-8.5
TSS (mg/l)	154.61	156.00	125.00	189.00	18.57	3.51	N/A	N/A
TDS (mg/l)	1267.8	1239.5	1000. 0	1562.0	163.99	30.99	<1000	<1000
Chloride (mg/l)	291.04	289.50	234.00	369.00	33.40	6.31	<250	250
Hardness as $CaCO_3$ (mg/l)	754.57	757.00	556.00	932.00	81.71	15.44	<500	500
Sulphate (mg/l)	290.39	303.50	234.00	341.00	32.69	6.18	N/A	250
Nitrate (mg/l)	9.73	9.50	8.20	12.40	1.01	0.19	<50	50
Phosphate (mg(l)	4.03	4.40	2.40	4.90	0.71	0.13	N/A	N/A
Ca (mg/l)	58.90	61.70	36.90	72.50	9.48	1.79	N/A	N/A
Mg (mg/l)	695.68	693.20	500.70	883.70	84.92	16.05	N/A	N/A
As (mg/l)	0.02	0.01	0.00	0.08	0.02	0.00	< 0.05	0.01
Pb (mg/l)	1.48	1.34	1.01	3.11	0.48	0.09	<0.05	0.01
Cu (mg/l)	0.46	0.40	0.21	0.87	0.19	0.04	2.0	2.0
Ni (mg/l)	0.29	0.31	0.12	0.51	0.11	0.02	<0.02	0.07
Zn (mg/l)	0.31	0.35	0.11	0.48	0.10	0.02	5.0	N/A
TCC MPN/100ml	1992.14	2400	150	2400	820.4	155	0	0
TFC MPN/100ml	1491.79	2400	64	2400	1028	194.3	0	0
TFS MPN/100ml	37.89	11	3	210	57.17	10.80	0	0

NSDWQ= National Standards for Drinking Water Quality, 2008 , Ministry of Environment, Government of Pakistan; N/A= Not available : MPN= Most probable number; TAC=Total aerobic count; TCC = Total Coliform Count; TFC = Total Faecal Coliform; TFS=Total Faecal Streptococci

Sulphate and nitrate concentrations are within the limits of NSDWQ therefore, no likely threat is expected with respect to human health. Maximum allowable concentration of phosphate is not reported in NSDWQ but indiscriminate use of fertilizers is the likely source of phosphate in the study area.

The metal concentrations in the samples are presented in Table 2. The concentration of arsenic was below detectable limit (0.0001mg/l). According to NSDWQ, the maximum acceptable limit of Cu is 2mg/l. From Table 2 it can be seen that the Cu concentration is comparatively low with an average of 0.46 mg/l. While the mean concentration of Ni was 0.29 mg/l which is exceptionally higher as compared to NSDWQ that reported the maximum allowable limit of 0.02 mg/l. As such there is no apparent source of Ni identified which needs further investigations.

The mean concentration of Pb in the samples was 1.48mg/l. Farooq et al (2012) described high concentration of Pb in water of lower Sindh area which is mainly due to manmade deeds. The Zn concentration is well within the limit (0.11 to 0.48 mg/l) and will not be an issue with respect to public health.

Public health quality of underground water fails to meet the WHO guidelines (2011). The bacterial load was exceptionally higher which revels the organic contamination. In Pakistan, the fecal coliforms up to 10^6 per 100 ml are very common (Meyberk 1985) in drinking water resources which is persistent cause of water borne diseases among the local population. Gumbo (1985) stated that specific water borne diseases is a matter of serious concern in developing countries. Since the people of the study area have no other alternative therefore, they hardly bothered about the quality of water and unknowingly consume polluted water that is responsible for water borne ailments.

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The situation becomes further aggravated after rain that proliferate the number of pathogenic microorganisms. Since the wells are operated without any protection therefore, the contamination of well water with runoff is common that have rendered the microorganisms to multiply and sustain. Subsequently the number of fecal streptococci and fecal coliforms discharged by animals and human beings would substantially higher.

The number of fecal streptococci was quite low in all the samples. It may be due to the fact that such organisms cannot thrive in harsh environmental conditions and may die off when the distance between the source and receiver increases. It may be argued that anthropogenic activities near the source could be the prime source of fecal contamination. This is somewhat true as the sanitation facilities are in highly deplorable condition in the study area.

The study also confirms the findings of Aziz (2005) who advocated that almost all of the drinking water supplies in the Pakistan are fecally contaminated which consequently results in high incidences of water borne ailments. The contamination of water in the study area is also due to the use of contaminated utensils used for the collection and storage of water. The utensils used for drinking water are also often not cleaned properly, which may increase the bacterial load in drinking water.

It was also noticed that excessive pumping of ground water has resulted in falling of the water table. Because of reduced rainfall and unavailability of water through government owned canal water there is an over-harvesting of ground water mainly from the agriculturalists in the form of private tube wells. Water quality deterioration (from natural and anthropogenic sources) impacted livestock, human, ecosystem health and agriculture and make valuable water resources unfit. Furthermore, contamination of ground water resources could also add extensive cost in terms of health impacts.

Table 3. *Results of principal component analysis of physical, chemical, metals and microbiological parameters.*

Component	Eigenvalue	Percentage variance	Cumulative percentage variance	First 4 eigenvector coefficients	Associated variables
1	3.929918	21.83288	21.83288	-0.116663	Nitrate
				0.115453	Phosphate
				0.088090	Sulphate
				0.087047	pH
2	2.616766	14.53759	36.37047	-0.097830	TFC
				0.028688	Pb
				-0.008866	Chlorides
				0.007081	Ni
3	2.072260	11.51256	47.88303	0.145933	Nitrate
				-0.126134	TFC
				0.090200	Sulphate
				-0.027516	Zinc

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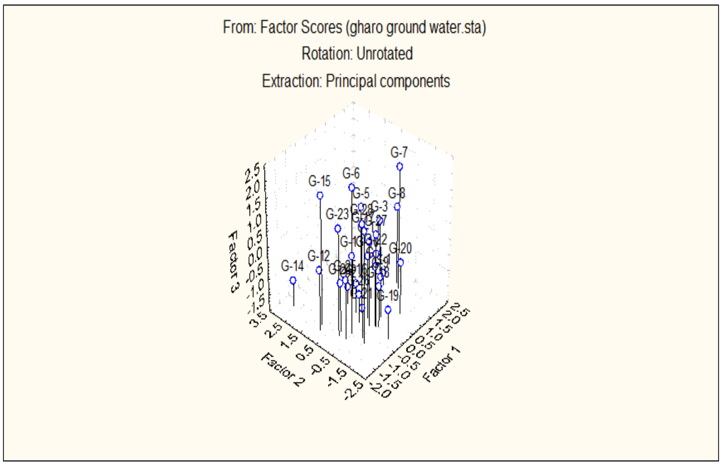

Figura 2. *Principal Component analysis ordination (3D) of physical, chemical, metal and microbiological parameters of underground water samples of Gharo city.*

The first component of PCA explained 21.83 percent of the total variance inherent in the data matrix while the first three components together accounted for 47.883 % of the overall variability. The first component is primarily a function of nitrate, phosphate, sulphate and pH. Thus it represents a gradient of water chemistry. The second component accounting for 14.53 % of the total variance is essentially regulated by TFC, Pb, Chlorides and Ni, and therefore represents an amalgam of heavy metals and microbiological characteristics. On the other hand, the third component is a sort of an admixture of the first two components. The three dimensional ordination configuration essentially depicts the gradients and trends outlined above.

The dendrogram derived from Ward's clustering strategy clearly shows two major groups. The first group on the left is a large group comprising of 22 samples represents mostly the samples collected from areas closer to agricultural fields from where PO_4, NO_3 and many of the heavy metals are derived as the latter are constituents of many pesticides. The group on the right comprising of a small group consisting of 6 samples are those that come from relatively unpolluted situations.

Conclusions

From the above discussion it is clear that the study area has unavailability of sustained piped water supply which is expected to be of relatively better quality. Therefore, majority of the population is relying on underground water resources. Since there is an over exploitation of ground water mainly due to water scarcity it ought to be regularly monitored and regulated. At the same time unhygienic and insanitation, conditions prevailing in the area need immediate attention. The system of sewerage is faulty, therefore, the domestic wastewater seeps into the ground and causes contamination of the

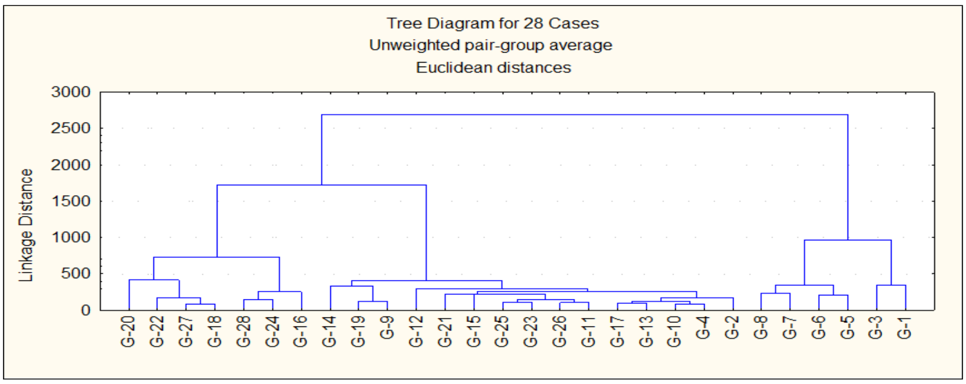

Figure 3. *Dendogram derived from Ward's method between 28 sites based on Physical, chemical, metal and microbiological quality of underground water samples of Gharo city.*

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aquifer. Whilst this is also pertinent that present water harvesting system is highly prone to bacterial contamination. Results indicated in the discussion showed that water is unfit for human consumption. However, people have no system to appraise its quality but for taste. Thus, majority of the population drink contaminated water unintentionally without regard to its quality.

Conflict of Interest

The authors declare that they have no conflict of interest. This article does not contain any study on the collected or captured animals. Informed consent was obtained from all individual participants of this study.

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