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Microbiological and physicochemical assessments of groundwater quality at Punjab, Pakistan

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The assessment of groundwater is essential for the estimation of suitability of water for safe use. An attempt has been made to study the groundwater at the district level of Punjab, Pakistan. These samples were analyzed for various water quality parameters like pH, color, odor, conductance, total suspended solids, trace metals (Fe, cu, B, Ba, Al, Cr, Cd, Ni, Mn and Se), ionic concentration (HCO_3, CO_3, Cl, SO_4, Na, K, Ca, Mg, NO_3, NO_2, NH_4, F, PO_4 and CN) and for microbiological enumeration (total viable count, total and fecal coliforms *Escherichia coli, Salmonella* spp. and *Pseudomonas* spp.). The data was analyzed with WHO guidelines/ recommendations. The results of physical analysis indicated that all samples are safe except the groundwater of Kasur and Khanewal District. About 66.67% samples are out of total suspended solids (TSS) limit. Microbiologically, only six groundwater of Punjab districts are found potable according to WHO limits. In the trace metals analysis, highest level of iron was detected in Jhang while the groundwater of three districts were not potable due to high level of boron and nickel but the groundwater of all districts was found safe with respect to Ba, Al and Cr. As far as ionic concentration is concerned, 11 districts were found not to be within WHO limit in the case of bicarbonates, seven in phosphates, five in floride, and eight in calcium and potassium. Only 10 districts fall within the limit of chlorine and all samples showed satisfactory results in the case of CN, CO_3, NO_2, NO_3, Mg, SO_4 and NH_4.

Key words: Groundwater, physicochemical, ionic concentration, traces elements, microbiology, WHO guidelines/recommendations.

INTRODUCTION

The quality of groundwater is the resultant of all the processes and reactions that act on the water from the surroundings and it varies from place to place and with depth of the water table (Reid et al., 2003). Groundwater

has many unique characteristics which makes it suitable for public use. It is naturally found in sterile conditions (Mondal et al., 2007). Groundwater particularly accounts for the supply of safe drinking water in rural areas, where

population is dispersed. For proper infrastructure, a high cost treatment setup and transportation of surface water are needed (Langeneggar, 1990).

Unfortunately, in Pakistan, the availability of ground-water is not unlimited nor is it safe for drinking purpose. The problem of groundwater pollution in several parts of the country has become so acute that extensive ground-water resources may be damaged (Gunkel et al, 2007).

There are many reasons and sources of contamination to the groundwater, for example, land disposal of solid wastes, sewage disposal on land, agricultural activities, urban runoff and polluted surface water (Laluraj et al., 2005). The suitability of groundwater has been examined with reference to WHO (2004) and NEQS (2002) standards.

The quality of groundwater in some parts of the Pakistan is changing as a result of human activities. Bacteria occasionally find their way into groundwater, sometimes in dangerously high concentrations. But freedom from bacteria alone does not mean that the water is fit to drink (Khalafalla, 1993; Babiker and Muhammad, 2014). Many unseen dissolved minerals and organic constituents are present in groundwater in various concentrations. Most are harmless or even beneficial; though occurring infrequently, others are harmful, and few may be highly toxic (Longe and Balogun, 2010). Water typically is not considered fit for drinking if the quality of dissolved minerals exceeds 1000 mg/L. Water with a few thousand mg/L of dissolved minerals is classed as slightly saline, but sometimes used in areas where less-mineralized water is not available (WHO, 2004). These dissolved minerals can be hazardous to animals and plants in large concentration; for example too much sodium in the water may be harmful to the people who have heart problem. Boron is the mineral that is good for plants in small amount but it is toxic to some plants in only slight higher concentration. Water that contains a lot of calcium and magnesium is said to be hard. The very hard water is not desirable for many domestic uses; it will leave a scaly deposit on the inside of pipes, boilers and tanks. Groundwater, especially if acidic, in many places contains excessive amount of iron. Iron causes reddish stain on plumbing fixtures and clothing (Mondal et al., 2007).

In recent years, the growth of industry, technology, population and water use has increased the stress on both our land and water resources. Locally, the quality of groundwater has been degraded (Langeneggar, 1990). Municipal and industrial wastes and chemical fertilizers, herbicides and pesticides not properly curtailed have entered into the soil, infiltered some aquifers, and degraded the groundwater quality. Other pollution problems include sewage leakage, faulty septic-tank operation and landfill leachates (Woods, 1990).

In this study, the portability of groundwater of 36 districts of the Punjab province, Pakistan has been assessed for physical, chemical and microbiological quality.

MATERIALS AND METHODS

Samples collection

The samples were collected during March-September, 2012 from different locations of 36 districts of Punjab that are being extensively used for drinking and other domestic purposes (Figure 1). The water samples were taken from average depth of 25-35 m. All water samples were collected in sterile glass Schott bottles (5 L). While sampling, some parameters like pH and conductance were measured in the field by using portable kits. For other parameters, samples were stored and transported in a cool box kept below 4°C (APHA, 2005). The detailed chemical and microbiological analyses were performed as soon as the samples were carried to the laboratory. All tests were performed in triplicate on the random appropriate sampling from each district.

Microbiological analysis

All samples were examined using standard methods of APHA (2005).

Physicochemical analysis

The physico-chemical parameters were determined according to procedures outlined in the Standard Methods for the Examination of Water and Wastewater (APHA, 2005). Turbidity was measured with a HACH 2100 P Turbidimeter. Sodium and potassium were measured by flame emission photometry, trace metals by atomic absorption spectrophotometer, calcium and magnesium by EDTA titration, sulphate by the turbidimetric method, colour by colour comparator and chloride by argentometric tittration. Other analyses included alkalinity by strong acid titration method. Nutrients (nitrate-nitrogen and phosphate-phosphorous) were determined using Dionex-80 ion analyzer and ammonium by direct nesslerisation and spectrophoto-metric determination at 410 nm. Fluoride was determined by SPADNS method, total dissolved solids and suspended solids were measured gravimetrically after drying in an oven to a constant weight at 105°C. Table 1 shows the name of districts of the Punjab, from where the samples of water were collected, with their area and population density (people/km^2).

RESULTS AND DISCUSSION

Physical analysis

As far as physical parameters of the collected samples are concerned, the color and odor of all samples are within the WHO limits (WHO, 2004) except the ground-water of Kasur District. The pH dropped to 5.20 in groundwater of Kasur while the samples collected from Khanewal was found to be alkaline with pH of 8.83 while the rest samples fall within the recommended range (6.5-8.5). According to WHO guidelines, the total suspended solids (TSS) should be zero; but about 66.67% samples are out of range. In this study, the conductivity of the collected samples is observed above permissible limits of WHO. The results of physical parameters of selected
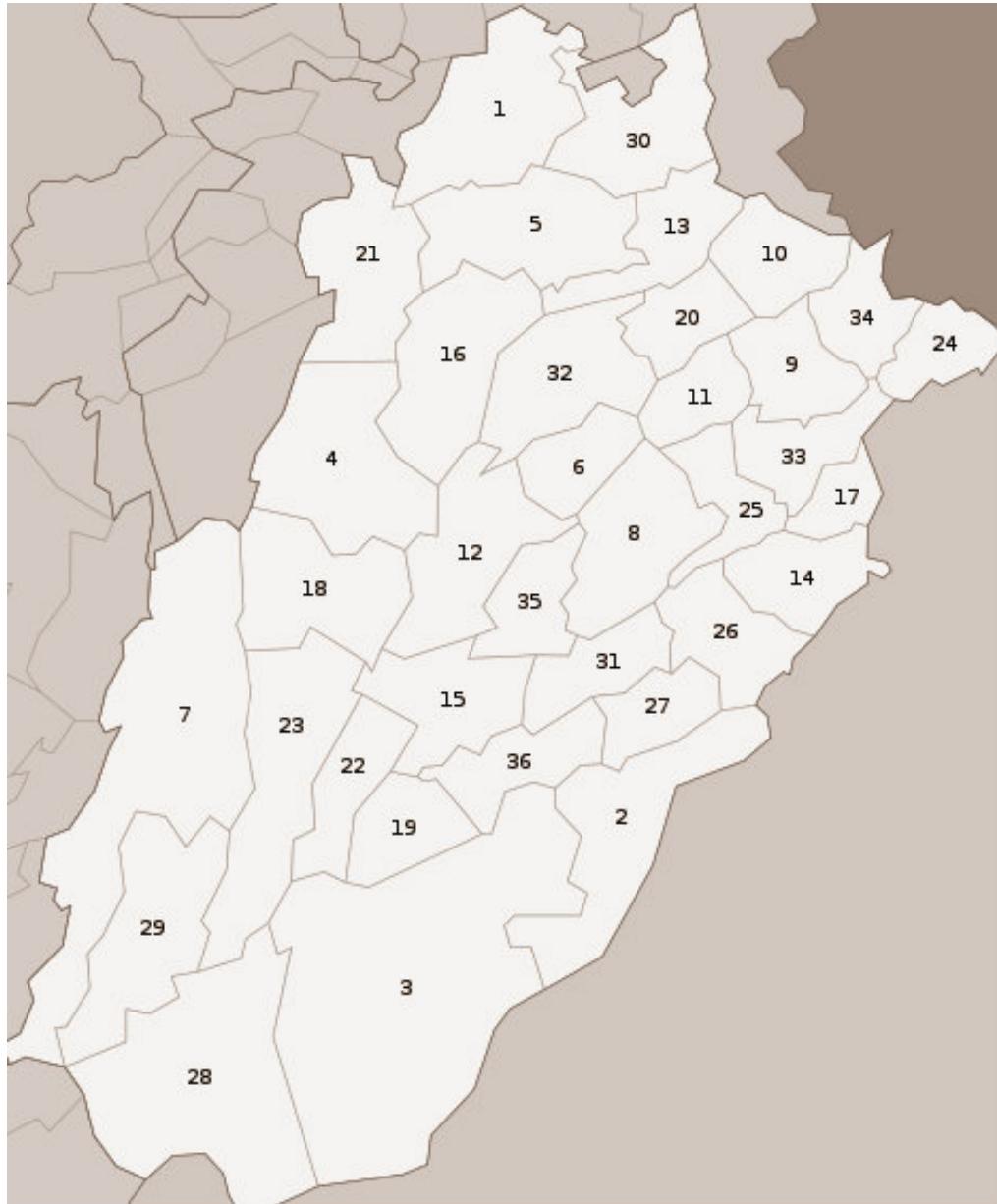
Figure 1. Map of districts of Punjab (refer to Table 1).

samples, along with WHO recommended limits are shown in Table 2.

Microbiological analysis

The most basic test for bacterial contamination of a water supply is the test for total coliform bacteria (Styenberg et al., 1995). Total coliform counts give a general indication of the sanitary condition of a water supply. Total coliforms include bacteria that are found in the soil and in water that has been influenced by surface water, and in human or animal waste (Atherholt et al., 2003). Fecal coliforms

are the group of the total coliforms that are considered to be present specifically in the gut and feces of warm-blooded animals (Crysup and Mott, 2001). If fecal coliform counts are high (over 200 colonies per 100 ml of water sample), there is a greater chance that pathogenic organisms are also present. Diseases and illnesses such as typhoid fever, hepatitis, gastroenteritis, dysentery and ear infections can be contracted in waters with high fecal coliform counts (Francy et al., 2000). According to WHO recommendations/ guidelines, drinking water must have zero total coliforms, fecal coliforms and *E. coli* (WHO, 2004). The results of the present study show that only 22% groundwater samples are found according to the

Table 1. Information on the selected districts of Punjab.

District name	Area (km^2)	Population (1998)	Density (people/km^2)
Attock	6,858	1,274,935	186
Bahawalnagar	8,878	2,061,447	232
Bahawalpur	24,830	2,433,091	98
Bhakkar	8,153	1,051,456	129
Chakwal	6,524	1,083,725	166
Chiniot		965,124	
Dera Ghazi Khan	11,922	1,643,118	138
Faisalabad	5,856	5,429,547	927
Gujranwala	3,622	3,400,940	939
Gujrat	3,192	2,048,008	642
Hafizabad	2,367	832,980	352
Jhang	8,809	2,834,545	322
Jhelum	3,587	936,957	261
Kasur	3,995	2,375,875	595
Khanewal	4,349	2,068,490	476
Khushab	6,511	905,711	139
Lahore	1,772	6,318,745	3,566
Layyah	6,291	1,120,951	178
Lodhran	2,778	1,171,800	422
Mandi Bahauddin	2,673	1,160,552	434
Mianwali	5,840	1,056,620	181
Multan	3,720	3,116,851	838
Muzaffargarh	8,249	2,635,903	320
Narowal	2,337	1,265,097	541
Nankana Sahib	2,960	1,410,000	
Okara	4,377	2,232,992	510
Pakpattan	2,724	1,286,680	472
Rahim Yar Khan	11,880	3,141,053	264
Rajanpur	12,319	1,103,618	90
Rawalpindi	5,286	3,363,911	636
Sahiwal	3,201	1,843,194	576
Sargodha	5,854	2,665,979	455
Sheikhupura	5,960	3,321,029	557
Sialkot	3,016	2,723,481	903
Toba Tek Singh	3,252	1,621,593	499
Vehari	4,364	2,090,416	479

limit of WHO for total coliforms, only eight districts are found free of *E. coli*. The 13 districts are found contaminated with *Salmonella* spp. while only eight districts groundwater was free from the *Pseudomonas* spp. Overall, only six groundwater of Punjab districts are found potable according to WHO limits. The results of microbiological analysis are shown in Table 3.

Trace metals analysis

The results of trace metals are shown in Table 4, according to this study, the highest level of iron (Fe)

was detected in Jhang (0.89) and overall groundwater of 17 districts were found to be outside the range of recommended limits of WHO. Infact, iron is one of the most worrying elements in water supplies (Pradhan et al., 2001). Rainwater as it infiltrates the soil and underlying geologic formations dissolves iron, causing it to seep into aquifers that serve as sources of groundwater for wells (Marian, 1991). Iron and manganese (Mn) are common water contaminants that are not considered health hazards. Their presence in water results in staining as well as offensive tastes and appearances. As groundwater flows through sediments, metals such as iron and manganese (Mn) are dissolved and may later be found

Table 2. Physical parameters for 36 districts of Punjab.

Location	Color	Odor	pH at 26°C	Conductivity (µs/cm)	TSS (mg/L)
Attock	Colorless	Odorless	8.23	679	N.D
Bahawalnagar	Colorless	Odorless	8.29	685	N.D
Bahawalpur	Colorless	Odorless	8.03	46300	36.0
Bhakkar	Colorless	Odorless	7.81	887	N.D
Chakwal	Colorless	Odorless	8.19	276	N.D
Chiniot	Colorless	Odorless	8.44	12960	52.0
Dera Ghazi Khan	Colorless	Odorless	7.20	140	N.D
Faisalabad	Colorless	Odorless	8.23	889	N.D
Gujranwala	Colorless	Odorless	8.29	112	N.D
Gujrat	Colorless	Odorless	8.03	5566	61.0
Hafizabad	Colorless	Odorless	7.81	678	N.D
Jhang	Colorless	Odorless	8.19	431	N.D
Jhelum	Colorless	Odorless	8.44	569	N.D
Kasur	Colored	Odorless	5.20	9888	43.9
Khanewal	Colorless	Odorless	8.83	8886	N.D
Khushab	Colorless	Odorless	8.09	909	N.D
Lahore	Colorless	Odorless	8.04	213	23.6
Layyah	Colorless	Odorless	7.25	2006	19.9
Lodhran	Colorless	Odorless	8.11	334	N.D
Mandi Bahauddin	Colorless	Odorless	8.49	554	55.1
Mianwali	Colorless	Odorless	7.29	665	N.D
Multan	Colorless	Odorless	7.20	881	N.D
Muzaffargarh	Colorless	Odorless	8.03	332	N.D
Narowal	Colorless	Odorless	8.01	321	39.0
Nankana Sahib	Colorless	Odorless	7.24	456	N.D
Okara	Colorless	Odorless	8.29	667	N.D
Pakpattan	Colorless	Odorless	7.44	119	N.D
Rahim Yar Khan	Colorless	Odorless	7.20	443	N.D
Rajanpur	Colorless	Odorless	7.23	663	N.D
Rawalpindi	Colorless	Odorless	8.21	459	22.9
Sahiwal	Colorless	Odorless	8.00	442	16.0
Sargodha	Colorless	Odorless	7.89	112	N.D
Sheikhupura	Colorless	Odorless	8.09	11001	N.D
Sialkot	Colorless	Odorless	7.44	445	22.0
Toba Tek Singh	Colorless	Odorless	7.01	111	N.D
Vehari	Colorless	Odorless	6.99	236	45.9
WHO	Colorless	Odorless	6.5-8.5	14.00	N.D

in high concentrations in water. Industrial discharges, urban activities, agriculture, groundwater pumages and disposal of waste can all affect groundwater quality (Kjoller et al., 2004).

Copper is a metal that occurs naturally in rock, soil, plants, animals and water (Kerbyson and Schandorf, 1966). The level of copper in surface and groundwater is generally very low. High levels of copper may get into the environment through mining, farming, manufacturing operations and municipal or industrial wastewater releases into rivers and lakes. Copper can get into drinking water either directly by contaminating well water or through corrosion of copper pipes if water is acidic. Corrosion of pipes is by far the greatest cause for concern. In human, its causes stomach and intestinal diseases, liver and kidney damage in high doses. But in this study, fortunately all samples were found within limits of WHO for copper concentration.

Boron is the mineral that is good for plants in small amount but it is toxic to some plants in only slight higher concentration and nickel may be found in slate, sandstone, clay minerals and basalt. The main nickel source is pentlandite (Atherholt et al., 2003). Nickel is a dietary requirement for a number of organisms, therefore

Table 3. Microbiological analysis of groundwater samples.

Location	Viable count/ml	Total coliforms (MPN/100 ml)	Fecal coliforms (MPN/100 ml)	*E. coli* (MPN/100 ml)	*Salmonella* spp. /25 ml	*Pseudomonas* spp. (MPN/100ml)
Attock	$90*10^3$	94	70	33	Detected	17
Bahawalnagar	$8.5*10^2$	24	20	23	N.D	23
Bahawalpur	$1.9*10^4$	94	49	80	Detected	23
Bhakkar	$1.2*10^2$	N.D	N.D	N.D	N.D	N.D
Chakwal	$5.0*10^2$	N.D	N.D	N.D	N.D	N.D
Chiniot	$6.2*10^2$	70	39	31	N.D	17
Dera Ghazi Khan	$23*10^3$	84	70	33	N.D	11
Faisalabad	$4.5*10^2$	24	20	23	N.D	23
Gujranwala	$9.9*10^4$	40	20	20	Detected	4.0
Gujrat	$1.4*10^2$	14	14	N.D	N.D	2.0
Hafizabad	$5.5*10^3$	N.D	N.D	N.D	N.D	N.D
Jhang	$6.7*10^2$	40	17	31	Detected	6.8
Jhelum	$60*10^3$	70	63	33	Detected	11
Kasur	$8.7*10^1$	33	20	23	N.D	23
Khanewal	$3.9*10^4$	94	49	80	Detected	20
Khushab	$1.5*10^2$	N.D	N.D	N.D	N.D	N.D
Lahore	$5.9*10^2$	14	11	4.5	N.D	4.5
Layyah	$1.2*10^2$	21	11	11	Detected	17
Lodhran	$50*10^2$	94	70	33	N.D	14
Mandi Bahauddin	$8.5*10^2$	24	20	23	N.D	23
Mianwali	$1.0*10^4$	94	49	80	Detected	33
Multan	$1.5*10^2$	11	6.8	2.0	N.D	N.D
Muzaffargarh	$5.4*10^5$	N.D	N.D	N.D	N.D	N.D
Narowal	$6.5*10^2$	48	39	31	Detected	17
Nankana Sahib	$76*10^3$	70	47	33	Detected	6.8
Okara	$8.4*10^2$	24	20	23	N.D	23
Pakpattan	$1.1*10^4$	84	49	80	N.D	33
Rahim Yar Khan	$1.3*10^4$	120	110	39	Detected	N.D
Rajanpur	$5.2*10^2$	33	33	N.D	N.D	2.0
Rawalpindi	$2.2*10^2$	26	11	17	N.D	17
Sahiwal	$40*10^3$	70	63	33	N.D	20
Sargodha	$1.5*10^1$	17	20	23	N.D	23
Sheikhupura	$6.9*10^4$	63	49	33	Detected	7.8
Sialkot	$2.2*10^2$	N.D	N.D	N.D	N.D	2.0
Toba Tek Singh	$3.9*10^2$	N.D	N.D	N.D	N.D	N.D
Vehari	$3.1*10^4$	40	11	24	Detected	14
WHO	-	Zero	Zero	Zero	N.D	Zero

*N.D = Not detected.

it might be of significance to humans (MacCutcheon et al., 1983). Nickel compounds may be toxic in high concentrations, but these are often water insoluble, limiting potential harm (Singh and Lawrence, 2007). Results show that the groundwater of three districts could not be potable due to high level of boron (B) and Ni in groundwater.

Four districts are found not to be within WHO limits for cadmium which is found in rocks, coals and petroleum and enters the ground and surface water when dissolved

by acidic waters. It causes kidney damage, anemia, high blood pressure and liver damage.

Selenium (Se) occurs naturally in the environment. Selenium that is immobile and will not dissolve in water is less of a risk to organisms. The oxygen levels in the soil and the acidity of the soil will increase mobile forms of selenium. Higher oxygen levels and increased acidity of soils is usually cause by human activities such as industrial and agricultural processes (Kerbyson and Schandorf, 1966). Humans may be exposed to selenium

Table 4. Trace metals (mg/L) analysis of groundwater samples.

Location	Fe	Cu	B	Ba	Al	Cr	Cd	Ni	Mn	Se
Attock	0.78	N.D	0.214	N.D	N.D	N.D	0.01	0.29	0.09	N.D
Bahawalnagar	0.11	N.D	0.4	0.2	N.D	N.D	N.D	N.D	0.02	N.D
Bahawalpur	0.34	N.D	0.47	0.1	N.D	N.D	N.D	N.D	N.D	N.D
Bhakkar	0.36	N.D	1.91	0.1	N.D	N.D	N.D	N.D	N.D	N.D
Chakwal	0.21	0.055	N.D	N.D	N.D	N.D	N.D	0.01	N.D	N.D
Chiniot	0.33	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Dera Ghazi Khan	0.71	N.D	0.20	N.D	N.D	N.D	N.D	0.25	N.D	N.D
Faisalabad	0.35	N.D	0.46	0.2	N.D	N.D	N.D	N.D	N.D	N.D
Gujranwala	0.34	N.D	N.D	0.1	N.D	N.D	N.D	N.D	N.D	N.D
Gujrat	0.22	N.D	N.D	0.1	N.D	N.D	N.D	N.D	N.D	N.D
Hafizabad	0.21	0.051	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Jhang	0.89	N.D	N.D	N.D	N.D	N.D	0.03	N.D	0.01	N.D
Jhelum	0.71	N.D	0.46	N.D	N.D	N.D	N.D	N.D	0.10	N.D
Kasur	0.15	N.D	0.55	0.2	N.D	N.D	N.D	N.D	N.D	N.D
Khanewal	0.25	N.D	0.42	0.1	N.D	N.D	N.D	0.14	N.D	N.D
Khushab	0.16	N.D	0.33	0.1	N.D	N.D	N.D	N.D	N.D	N.D
Lahore	0.26	0.021	0.41	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Layyah	0.30	N.D	N.D	N.D	N.D	N.D	N.D	N.D	0.03	N.D
Lodhran	0.77	N.D	0.14	N.D	N.D	N.D	0.02	N.D	N.D	N.D
Mandi Bahauddin	0.19	N.D	N.D	0.2	N.D	N.D	N.D	N.D	N.D	N.D
Mianwali	0.36	N.D	N.D	0.1	N.D	N.D	N.D	N.D	N.D	N.D
Multan	0.16	0.022	1.99	0.1	N.D	N.D	N.D	N.D	N.D	N.D
Muzaffargarh	0.26	0.020	0.4	N.D	N.D	N.D	N.D	0.01	N.D	N.D
Narowal	0.34	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Nankana Sahib	0.28	N.D	0.11	N.D	N.D	N.D	N.D	0.21	N.D	N.D
Okara	0.10	N.D	0.41	0.2	N.D	N.D	N.D	N.D	0.02	N.D
Pakpattan	0.35	N.D	0.42	0.1	N.D	N.D	N.D	N.D	N.D	N.D
Rahim Yar Khan	0.46	N.D	1.12	0.1	N.D	N.D	N.D	N.D	N.D	N.D
Rajanpur	0.25	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Rawalpindi	0.32	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Sahiwal	0.74	N.D	0.81	N.D	N.D	N.D	0.01	0.03	N.D	N.D
Sargodha	0.11	N.D	0.41	0.2	N.D	N.D	N.D	N.D	N.D	N.D
Sheikhupura	0.45	N.D	0.70	0.1	N.D	N.D	N.D	N.D	N.D	N.D
Sialkot	0.26	N.D	1.60	0.1	N.D	N.D	N.D	N.D	N.D	N.D
Toba Tek Singh	0.21	0.028	0.10	N.D	N.D	N.D	N.D	0.02	N.D	N.D
Vehari	0.31	N.D	N.D	N.D	N.D	N.D	N.D	N.D	0.02	N.D
WHO	0.30	1.0	1.0	1.0	0.02	0.10	0.00	0.05	0.10	N.D

in several ways. Fortunately, all districts groundwater were found safe in the sense of Se.

Barium can cause a variety of cardiac, gastrointestinal and neuromuscular effects. Aluminum occurs naturally in some rocks and drainage from mines. It can precipitate out of water after treatment, causing increased turbidity or dissolved water (Marian, 1991). Chromium has the potential to damage liver, kidney, circulatory and nerve tissues; and cause skin irritation. When released into land, chromium compounds bind to soil and are not likely to migrate to groundwater. They are very persistent in water as sediments. There is a high potential for accumulation of chromium in aquatic life (Singh and Lawrence, 2007) and the results has shown that groundwater of all districts was found safe with respect to Ba, Al, and Cr.

Ions concentration analysis

The presence of carbonates, bicarbonates and hydroxides are the main causes of the alkalinity in the natural water. Bicarbonates represent the major form since they are formed in considerable amount in the soil (MacCutcheon et al., 1983). In this study, we found that 11 districts were outside the WHO limit.

While phosphates limit was exceeded in seven districts, fluoride in five districts, and calcium in eight districts. The fluoride concentration is present in soil strata and the accumulation of fluoride in soil strata results in the leaching process due to percolating water pressure resulting to increased fluoride concentration in groundwater (O'Neil, 1993). When the concentration of phosphates rises, the coagulation processes in drinking water treatment plants may be adversely affected. Manmade sources of phosphate include human sewage, agricultural run-off from crops, sewage from animal feedlots, pulp and paper industry, vegetable and fruit processing, chemical and fertilizer manufacturing and detergents (Marian, 1991).

Only 10 districts samples were found in the limit in the case of chlorine (Cl) and all samples showed satisfactory results in the case of CN, CO_3, NO_2, NO_3, Mg, SO_4 and NH_4. Nitrate is effective plant nutrient and moderately toxic and is considered important for its adverse health effects (Jain and Ram, 1996). The higher nitrate concentration may be attributed to combined effect of contamination from domestic sewage and runoff from fertilized fields (Langanegger, 1987) and cyanides are generally not persistent when released into water or soil, and are not likely to accumulate in aquatic life. They rapidly evaporate and are broken down by microbes. They do not bind to soils and may leach to groundwater. EPA has found cyanide to potentially cause the following health effects when people are exposed to it at levels above the MCL for relatively short periods of time: rapid breathing, tremors and other neurological effects (Marian, 1991).

In the present study, all samples showed satisfactory results for ammonia. NH_3 is the principal form of toxic ammonia. It has been reported toxic to fresh water organisms at concentrations ranging from 0.53 to 22.8 mg/L (DWAF, 1998). Toxic concentrations of ammonia in humans may cause loss of equilibrium, convulsions, coma and death (Bolalak and Frankowaski, 2003). The sulphate contents of water may change significantly with time during infiltration of rainfall and groundwater recharge, which mostly takes place from stagnant pools, puddles and surface runoff water collected in low-lying areas. All samples showed satisfactory results in this study. All samples showed satisfactory results for sodium in this study except that from Gujrat. In fact, sodium concentration more than 50 mg/L make the water unsuitable for domestic use.

Eight districts were found to have unfit groundwater in the case of potassium, with highest value in Mianwali (120 mg/L), which naturally occurs in various minerals, from which it may be dissolved through weathering processes (Chapman, 1996). Potassium plays a central role in plant growth, and it often limits it. Potassium from dead plant and animal material is often bound to clay minerals in soils, before it dissolves in water (O'Neil 1993).

Conclusion

This study has provided information on the water quality status of groundwater from 36 districts of the Punjab, Pakistan. The physical, chemical and microbiological qualities were assessed. The results of physical analysis indicated that pH, color and odor were all within their natural background levels of 6.5-8.5 except the groundwater of Kasur and Khanewal District. According to WHO guidelines, the total suspended solids (TSS) should be zero but about 66.67% samples are not within this limit. In this study, the conductivity of all the collected samples is observed above permissible limits of WHO.

According to WHO recommendations/guidelines, drinking water must have zero total coliforms, fecal coliforms and *E. coli* (WHO, 2004). Results of the present study show that only 22% groundwater samples are found according to the limit of WHO for total coliforms, only eight districts are found free of *E. coli*. 13 districts are found to samples contaminated with *Salmonella* spp., while only eight districts groundwater were free from the *Pseudomonas* spp. Overall, only six groundwater samples of Punjab districts are found potable according to WHO limits.

In the trace metals analysis, highest level of iron (Fe) was detected in Jhang (0.89) and overall groundwater of 17 districts were found to be out of the recommended limits of WHO while the groundwater of three districts could not be potable due to high level of boron and Ni in groundwater. The results of the present study has shown that groundwater of all districts was found safe with respect to Ba, Al and Cr.

As far as ionic concentration is concerned, the 11 districts were found not to be within the WHO limit in the case of bicarbonates while phosphates limit was exceeded in seven districts, fluoride limit was exceeded in five districts, and calcium limit was exceeded in eight districts Table 5. Only ten districts samples were found within the limit in the case of chlorine (Cl) and all samples showed satisfactory results in the case of CN, CO_3, NO_2, NO_3, Mg, SO_4 and NH_4 and eight districts are found to have unfit groundwater in the case of potassium, with highest value in Mianwali (120 mg/L).

Conflict of interest

The authors declare that they have no conflict of interest.

Table 5. Ionic concentration (mg/L) analysis of groundwater samples

Location	HCO₃	CO₃	Cl	SO₄	Na	K	Ca	Mg	NO₃	NO₂	NH₄	F	PO₄	CN
Attock	261.8	N.D	35.0	51.6	116	1.57	8.0	3.4	N.D	N.D	N.D	0.15	N.D	N.D
Bahawalnagar	225.0	N.D	27.2	29.0	95	5.09	14.06	8.54	50.0	N.D	N.D	N.D	N.D	N.D
Bahawalpur	233.6	N.D	121.0	69.9	248	110	820	11.5	N.D	N.D	N.D	N.D	N.D	N.D
Bhakkar	356.0	N.D	80.97	79.0	86	6.0	40	15.5	N.D	N.D	0.85	0.25	0.25	N.D
Chakwal	121.3	N.D	19.9	11.0	10.2	2.1	16	14.58	N.D	N.D	N.D	1.5	N.D	N.D
Chiniot	583.7	N.D	2603	78.0	180	40.8	102	191.0	N.D	N.D	1.02	N.D	N.D	N.D
Dera Ghazi Khan	241.8	N.D	35.9	12.6	121	1.52	8.0	3.1	N.D	N.D	N.D	0.12	N.D	N.D
Faisalabad	229.0	N.D	270.2	29.0	9.51	59.1	14.06	8.4	5.0	N.D	N.D	N.D	N.D	N.D
Gujranwala	222.6	N.D	221.0	67.0	222	90	820	16.5	N.D	N.D	N.D	N.D	1.02	N.D
Gujrat	339.0	N.D	180.9	41.0	281	63.0	40	25.5	N.D	N.D	N.D	N.D	N.D	N.D
Hafizabad	126.0	N.D	19.2	48.0	100	32.0	16	12.21	N.D	N.D	N.D	2.52	N.D	N.D
Jhang	512.5	N.D	280.1	23.0	181	10.0	102	17.9	N.D	N.D	N.D	N.D	N.D	N.D
Jhelum	221.8	N.D	35.1	24.6	102	1.23	8.0	3.1	N.D	N.D	N.D	0.15	N.D	N.D
Kasur	223.0	N.D	22.9	15.0	91	5.01	14.06	8.4	N.D	N.D	N.D	N.D	N.D	N.D
Khanewal	133.6	N.D	121.1	61.0	24.8	112	820	11.5	N.D	N.D	N.D	N.D	N.D	N.D
Khushab	219.0	N.D	820.9	41.0	85.1	60.0	40	15.5	N.D	N.D	0.81	N.D	N.D	N.D
Lahore	131.3	N.D	192.9	22.0	10.21	2.12	16	11.58	N.D	N.D	1.00	2.5	0.50	N.D
Layyah	623.7	N.D	260.1	23.0	124	40.3	102	13.0	N.D	N.D	1.06	4.1	N.D	N.D
Lodhran	281.8	N.D	35.01	65.6	11.3	1.51	8.0	3.6	N.D	N.D	N.D	0.11	N.D	N.D
Mandi Bahauddin	229.0	N.D	27.98	11.0	9.25	59.0	14.06	2.4	5.12	N.D	N.D	N.D	N.D	N.D
Mianwali	231.6	N.D	129.1	61.0	243	120	820	10.5	N.D	N.D	N.D	N.D	N.D	N.D
Multan	322.0	N.D	10.97	89.0	250	6.0	40	11.5	N.D	N.D	N.D	N.D	N.D	N.D
Muzaffargarh	145.3	N.D	101.9	21.0	123	2.0	16	9.50	N.D	N.D	N.D	N.D	0.51	N.D
Narowal	589.7	N.D	269.1	75.0	142	20.9	102	11.0	N.D	N.D	1.02	N.D	N.D	N.D
Nankana Sahib	261.1	N.D	35.1	90.6	216	1.87	8.0	3.49	N.D	N.D	N.D	0.15	N.D	N.D
Okara	221.3	N.D	37.9	22.0	25	5.21	14.06	8.11	5.0	N.D	N.D	0.28	N.D	N.D
Pakpattan	232.8	N.D	421.0	140.0	142	119	820	22.5	1.18	N.D	N.D	N.D	N.D	N.D
Rahim Yar Khan	319.0	N.D	280.1	35.0	231	6.96	40	19.5	N.D	N.D	N.D	N.D	N.D	N.D
Rajanpur	123.1	N.D	49.2	24.0	129	2.33	16	13.5	N.D	N.D	N.D	2.5	N.D	N.D
Rawalpindi	581.7	N.D	260.3	92.0	180	40.3	102	11.0	N.D	N.D	N.D	N.D	N.D	N.D
Sahiwal	261.2	N.D	350.1	21.6	189	1.51	8.0	3.47	N.D	N.D	N.D	0.19	N.D	N.D
Sargodha	222.1	N.D	76.2	20.0	90.4	52.0	14.06	8.14	50.0	N.D	N.D	N.D	N.D	N.D
Sheikhupura	233.3	N.D	12.11	61.0	243	11.0	820	6.5	4.18	N.D	N.D	N.D	1.55	N.D
Sialkot	329.1	N.D	89.8	49.0	120	26.0	40	15.5	N.D	N.D	N.D	1.25	0.25	N.D
T.K Singh	122.3	N.D	11.6	24.0	67.9	20.0	16	14.8	N.D	N.D	N.D	2.1	0.50	N.D
Vehari	583.9	N.D	26.01	96.0	231	40.0	102	1.91	N.D	N.D	1.01	5.0	N.D	N.D
WHO	300	N.D	200-600	250	250	50	250	50	50	50	50	1.5	N.D	N.D

REFERENCES

American Public Health Association (APHA, 2005). Standard Methods for the Examination of Water and Wastewater. 19th ed. American Water Works Association, Water Environment Federation, Washington.

Atherholt T, Feerst E, Hovendon K, Jae R, Joseph D (2003). Evaluation of indicators of fecal contamination in groundwater. Am. Water Works Assoc. 95(10):119-131.

Babiker IS, Mohamed AAM (2014). Groundwater quality assessment using GIS, the case of Omdurman area, central Sudan. 6(1):22-33

Bolalak J, Frankowaski L (2003). Selected nutrients and iron in interstitial, water of the estuary of Southern Baltic in relation to redox potential water and air and soil pollution. J. Am. Sci. 147:39-50.

Chapman D (1996). Water Quality Assessment, 2nd edn. EPFN Spon, London.

Crysup KA, Mott JB (2001). Fecal coliform, enterococci and E.coli as indicators of water quality in the Creek Bay watershed, Corpus Christi, Texas. General Meeting of the American Society for Microbiology, 20-24 May, Orlando, American Society for microbiology, Florida.

DWAF (1998). Quality of Domestic Water Supplies. Assessment Guide, 2nd edn. Department Geol. Survey Bull. 42. Accra, Ghana.

Francy DS, Heise DR, Nally RA (2000). Occurrence and Distribution of microbiological indicators in groundwater and stream water. Water Environment Research 72(2):152-161.

Gunkel G, Kosmol J, Sobral M, Rohn H, Montenegro S, Aureliano J (2007). Sugar cane industry as a source of water pollution-case study

on the situation in ipojuca river, pernambuco, Brazil. Water, Air, Soil Pollution 180(1-4):261-269.

Kerbyson JD, Schandorf JRH (1966). Chemical analysis of Ghana rocks, Ores and Minerals, pp. 1945-1965.

Khalafalla GM, El-Gizawy SA, Ensaf ID (1993). Bacteriological quality of various drinking water sources. Egypt, J. Appl. Sci. 8:809-822.

Kjøller C, Postma D, Larsen F, Kjøller C, Postma D, Larsen F (2004). Groundwater acidification and the mobilization of trace metals in a sandy aquifer. Environ. Sci. Technol. 38 (10), pp. 2829-2835.

Laluraj CM, Gopinath G, Dineshkumar PK (2005). Groundwater Chemistry of Shallow Aquifers in the Coastal Zones of Cochin, India. Appl. Ecol. Environ. Res. 3(1): 133-139.

Langanegger O (1987). Groundwater Quality, An important factor for selecting hand-pumps. BP 1850. 01.

Langeneggar O (1990). Groundwater Quality in Rural Areas of Western Africa. UNDP

Project INT 81(26): 10.

Longe EO, Balogun MR (2010). Groundwater quality assessment near a municipal landfill, Lagos, Nigeria. 2(1):39-44.

MacCutcheon SC, Martin JL, Barnwell TO (1983). Water Quality. In Handbook of Hydrology. McGraw-Hill Inc., New York.

Marian E (1991). Metals and their Compounds in the Environment: Occurrence, Analysis and Biological Relevance. UCH, Weinheim-New York-Basel-Cambridge.

Mondal NC, Singh VS, Saxena VK, Prasad RK (2007). Improvement of Groundwater Quality due to Fresh Water Ingress in Potharlanka Island, Krishna Delta, India. Environ Geol.

O'Neil P (1993). Environmental Chemistry. Chapman and Hall, London. p. 193.

Pradhan SK, Patnaik D, Rout SP (2001). Water quality index for the groundwater in and around a phosphatic fertilizer plant. Indian J. Environ. Prot. 21:355-358

Reid DC, Edwards AC, Cooper D, Wilson E, Mcgaw BA (2003). The quality of drinking water from private water supplies in Aberdeenshire, UK. Water Res. 37: 245 - 254.

Singh DSH, Lawrence JF (2007). Groundwater quality assessment of shallow aquifer using geographical information system in part of Chennai city Tamilnadu. J. Geol. Soc. India 69:1067-1076.

Styenberg MC, Venter SN, de Wet CME, du Plessis G, Holos D, Rodda N, Kfir R (1995). Water Science and Technology. Management of Microbial Water Quality: New Perspectives for developing Areas 32(5-6):183-191.

World Health Organization (2004). Guideliness for Drinking-water quality. 1 Recommendations. 3rd Ed. World Health Organization, Geneva.

Woods L (1990). Groundwater quality in the Nore River Bain, Republic of Ireland. M.Sc. dissertation, University College, London.