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Environmental Assessment of Ground Water Quality of Lahore Area, Punjab, Pakistan

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Abstract: The ground water quality of Lahore (Pakistan) has been assessed to see the suitability of ground water for domestic applications. Sixty ground water samples form shallow and deep wells were collected each during pre and post-monsoon seasons in the month of May and November 2004, respectively. Various water quality constituents pH, conductance, total dissolved solids, alkalinity, hardness, sodium, potassium, calcium, magnesium, chloride, sulphate, nitrate, phosphate and fluoride have been determined. The data was analyzed with reference to NEQS and WHO standards, ionic relationships were studied and hydro chemical facies were determined. Distribution of various constituents indicates that about 10-20% samples of the study area crosses the maximum permissible limit for TDS, hardness, calcium, magnesium, sulphate and fluoride while 20-30% samples crosses the limit for nitrate. The ground water of the study area has also been classified to study various hydro chemical processes.

Key words: Ground water quality, hydro chemical facies, Chadha's classification

INTRODUCTION

The quality of ground water is the resultant of all the processes and reactions that act on the water from the moment it condensed in the atmosphere to the time it is discharged by a well or spring and varies from place to place and with the depth of the water table. Ground water has unique features, which render it particularly suitable for public water supply. It has excellent natural quality, usually free from pathogens, colour and turbidity that can be consumed directly without treatment. Ground water is widely distributed and can be frequently developed incrementally at points near the water demand, thus avoiding the need for large scale storage, treatment and distribution system. Ground water is particularly important as it accounts for about 88% safe drinking water in rural areas, where population is widely dispersed and the infrastructure needed for treatment and transportation of surface water does not exits. Unfortunately, the availability of ground water is not unlimited nor it is protected from deterioration. In most of the instances the extraction of excessive quantities of ground water has resulted in drying up of wells, damaged ecosystems, land subsidence, salt-water intrusion and depletion of the resource. The problem of ground water pollution in several parts of the country has become so acute that unless urgent steps for detailed identification and abatement are taken, extensive ground water resources may be damaged.

There are many sources that contribute contaminants to the ground water, e.g., land disposal of solid wastes, sewage disposal on land, agricultural activities, urban runoff and polluted surface water (Jain *et al*., 1995). The suitability of ground water has been examined with reference to WHO (2000) and NEQS (2002) standards. An attempt has also been made to classify the ground water on the basis of different classification schemes.

Study area: Lahore is one of the second largest cities of Pakistan and is situated on the left bank of The Ravi River. It has been expanding rapidly to the lower alluvial plain without considering the geo-environmental aspects and its consequent impacts. Because of the increasing population pressure, ground water availability has become the most prominent hazard of the study area. Main landform feature is represented by undulating loess plain with mounds and low alluvial plains as a part of the Indus plain. The present study indicates that magnitude of risk is directly related to geomorphology, lithology, annual climatic variation and nature of material.

Lahore area lies between latitudes 31°20 and 31°50 N and longitudes 74°05' and 74°37' E in the Province of Punjab, Pakistan. The area is bounded by the Hudiara Drain in the south across the Ravi River to the Degh Nala in the west and up to the town of Muridke on the General Trunk Road to the north and the International border with India on the east (Sergey, 2001). Late Pleistocene silty loess soils are present here. However, the dating of silty loess is 1-6 million annum (Harland, 1970). The contents of soils are mainly silt, loamy clay, clay and sand while, the loamy clay increase gradually with distance form riverbed (Khan *et al*., 1990). Notably, there are significant

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changes in lithologies. Short absorb capacity of ground; a large amount of water would naturally cause runoff.

The average annual rainfall in the area is about 650 mm, in which 65% occur during the southwest monsoon (June to September) while the contribution from northeast monsoon is nearly 20% and the rest is received during the pre-monsoon period.

MATERIALS AND METHODS

This study was conducted January to December 2005, during pre-and post-monsoon seasons; sixty ground water samples were collected form the study area. The samples were collected form three sources i.e., hand pumps, open wells and bore wells, that are being extensively used for drinking and other domestic purposes. While sampling, some parameters like pH and conductance were measured in the field by using portable kits. For other parameters samples were preserved by adding appropriate reagents and brought to the laboratory for detailed chemical analysis. Table 1 shows details of sampling locations and the source and depth wise distribution of sampling sites is shown in Table 2. The physico-chemical analysis was conducted following standard methods such as (APHA, 1985; Jain and Bhatia, 1988; AOAC, 2000).

Table 1: Description of ground water sampling locations

Sample No.	Location	Source	Sample No.	Location	Source
1	Green Town	BW	31	Shad Bagh	HP
2	Green Town	HP	32	Shad Bagh	OW
3	Green Town	OW	33	Shad Bagh	HP
4	Thokhar	OW	34	Shad Bagh	HP
5	Thokhar	HP	35	Defense	HP
6	Thokhar	OW	36	Defense	HP
7	Model Town	HP	37	Defense	OW
8	Model Town	OW	38	River Ravi	HP
9	Model Town	HP	39	River Ravi	HP
10	Shadra	OW	40	River Ravi	OW
11	Shadra	OW	41	River Ravi	HP
12	Shadra	HP	42	River Ravi	HP
13	Wapda Society	OW	43	River Ravi	HP
14	Wapda Society	OW	44	River Ravi	HP
15	Wapda Society	OW	45	Canal	HP
16	Wapda Society	OW	46	Canal	BW
17	Wapda Society	HP	47	Canal	OW
18	Wapda Society	HP	48	Canal	HP
19	Wapda Society	HP	49	Canal	HP
20	PIA Society	HP	50	P.U. Campus area	HP
21	PIA Society	HP	51	P.U. Campus area	HP
22	PIA Society	HP	52	P.U. Campus area	HP
23	Cantonment	OW	53	P.U. Campus area	HP
24	Cantt.	OW	54	P.U. Campus area	OW
25	Cantt.	OW	55	P.U. Campus area	HP
26	Bund Road	V	56	Town Ship Industrial Estate	HP
27	Bund Road	OW	57	Town Ship Industrial Estate	HP
28	Bund Road	OW	58	Town Ship Industrial Estate	HP
29	Minar-e-Pakistan	HP	59	Town Ship Industrial Estate	HP
30	Minar-e-Pakistan	HP	60	Town Ship Industrial Estate	HP

BW = Bore Well, HP = Hand Pump, OW = Open Well

Table 2: Source and depth wise distribution of sampling sites

	Depth range			
Source structure	<20 m	30-60 m	60 m	Total No.
Hand pumps		55, 59, 60	2,5,7,9,11,14, 19,20,21,22, 29,30,31,33, 34,35,36,37, 39,40,42,43, 44,45,47,48, 49, 50,51,52, 54,56,57,58,	37
Bore Well		1	46	2
Open Wells	3,4,6,8,10, 12,13,15, 16,17,18, 23, 24,25, 26,27, 28, 32,38,41, 53,		21	
Total	21	4	35	60

RESULTS AND DISCUSSION

The hydro-chemical data for the two sets of samples collected during pre-and post-monsoon seasons are presented in Table 3. The pH values in the study area are mostly found within the range 6.5 to 8.6.

Both pre and post-monsoon seasons indicates alkaline nature of the ground water and are well within the limits prescribed for various uses of water including drinking water supplies (WHO, 2000; NEQS, 2002). The Electrical Conductivity (EC) and Dissolved Salts (DS) are basic indicators of the total mineral contents of water and may be related to problems such as excessive hardness, corrosive characteristics or other mineral contamination. The conductivity values varies from (455-16700 μs cm^{-1}) during pre-monsoon season and 315 to 13445 μs cm^{-1} during post-monsoon season with more than 50% samples having conductivity value above (1000 μs cm^{-1}) during both pre and post-monsoon season. The maximum conductivity value of 16700 to 13445 μs cm^{-1} was observed at Lahore during both pre-and post-monsoon seasons, respectively. Conductivity measurements are directly related to the concentration of ionized substance in water and commonly used to determine the purity of de-mineralized water and total dissolved solids in boiler, cooling tower water, irrigation and domestic supply. Solutions of most inorganic acid, bases and salts are relatively good conductors.

In natural water, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron and small amount of organic matter and dissolved gases. In the present study the TDS values varies from 345 to 11025 mg L^{-1} pre-monsoon season and 257 to 9138 mg L^{-1}) during post-monsoon season with more than 85 and 60% samples having TDS values above the desirable limit of 500 mg L^{-1} during pre-and post-monsoon seasons, respectively. Water containing more than 500 mg L^{-1} of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where water with TDS value is not available. For this reason, 500 mg L^{-1} as the desirable limit and 2000 mg L^{-1} as the maximum permissible limit has been suggested for drinking water (BIS, 1991). Water containing TDS more than 500 mg L^{-1} causes gastrointestinal irritation (BPS, 1991). In the study area, 15% sample even crosses the maximum permissible limit of 2000 mg L^{-1} during pre-monsoon season and 10% sample during post-monsoon season. In general TDS content decreases during post-monsoon season due to dilution effect of rainwater.

The presence of carbonates, bicarbonates and hydroxides are the main cause of alkalinity in natural waters. Bicarbonates represent the major form since their are formed in considerable amount of or the action of carbonates upon the basic materials in the soil. The alkalinity values in the study area vary from 110 to 803 mg L^{-1} during pre-monsoon season with majority of samples (>90%) having alkalinity values above the desirable limit of 200 mg L^{-1} but within the maximum permissible limit of 600 mg L^{-1}. Only one sample crosses the maximum permissible limit during pre-monsoon season. The high alkalinity values in the study area may be attributed to the action of carbonates upon the basic materials in the soil. Such water gives unpleasant taste. During post-monsoon season, the alkalinity values vary form 86 to 467 mg L^{-1} with more than 80% samples having alkalinity values within the desirable limit.

Calcium and magnesium, along with their carbonates, sulphates and chlorides makes the water hard, both temporary and permanent. A limit of 300 mg L^{-1} has

Table 3: Hydro-chemical data of ground water samples of Lahore, study area

	Pre-monsoon season		Post-monsoon season		Mean	
Parameter	Min	Max	Min	Max	Pre-monsoon	Post-monsoon
pH	6.5	8.6	6.3	8.7	7.60	7.70
Conductivity (uS cm^{-1})	455	16700	315	13445	2340	1696
TDS (mg L^{-1})	345	11025	257	9138	1476	1045
Alkalinity (mg L^{-1})	110	803	86	467	386	240
Hardness (mg L^{-1})	76	4261	106	4324	766	420
Chloride (mg L^{-1})	5	2700	7.6	25.6	230	151
Sulphate (mg L^{-1})	6	2035	4.6	2578	203	235
Nitrate (mg L^{-1})	0.48	1672	ND	1566	135	142
Phosphate (mg L^{-1})	ND	1.60	ND	0.93	0.18	0.05
Fluoride (mg L^{-1})	ND	5.48	ND	8.46	1.68	1.03
Sodium (mg L^{-1})	32	1688	10.02	1552	306	274
Potassium (mg L^{-1})	2.8	504	ND	607	68	42
Calcium (mg L^{-1})	30	1345	23	1027	184	115
Magnesium (mg L^{-1})	5.3	301	12	338	69	58

been recommended as a desirable limit and 600 mg L^{-1} as the maximum permissible limit for potable water (BIS, 1991). The total hardness values in the study area ranges from 76 to 4276 mg L^{-1} during pre-monsoon season and 106 to 4324 mg L^{-1} during post-monsoon season. Distribution of hardness values clearly indicates that during pre-monsoon season about 43% samples lies within the desirable limit and 38% samples within the maximum permissible limit of drinking water while during post-monsoon season about 6% sample falls within the desirable limit and bout 16% samples within maximum permissible limit. About 15-20% sample even crosses the maximum permissible limit of drinking water in both pre- and post-monsoon seasons.

The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg L^{-1}, respectively (BIS, 1991). In ground water of the study area, the values of calcium and magnesium ranges from 30 to 1345 and 5.3 to 301 mg L^{-1}, respectively during pre-monsoon season. The same was found to vary from 23 to 1027 and 12 to 338 mg L^{-1} during post-monsoon season. The low concentration of calcium and magnesium in the post monsoon season may be attributed to the dilution effect of rain water, ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks (Jain *et al*., 1996). The increase of magnesium is quite proportionate with calcium in both the seasons. Distribution of calcium and magnesium clearly indicates that about 10-20% samples cross the maximum permissible limit of drinking water in both the seasons. The concentration of sodium in the study area varies from 32 to 1688 mg L^{-1} during pre-monsoon season and 10 to 1552 mg L^{-1} during post-monsoon season. The sodium concentration more than 50 mg L^{-1} make the water unsuitable for domestic use. The sodium concentration was found higher at most of the sites. The concentration of potassium in ground water varies from 1.8 to 468 mg L^{-1} during pre-monsoon season and nil to 406 mg L^{-1} during post-monsoon season.

The chloride content ranged from 5 to 2700 mg L^{-1} during pre-monsoon season and 7.6 to 2506 mg L^{-1} during post-monsoon season. The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg L^{-1} chlorides has been recommended as desirable limit and 100 mg L^{-1} as maximum permissible limit for drinking water (WHO, 2000; BIS, 1991). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. Distribution of chloride indicates that more than 80% of the sample lies well within the desirable limits of drinking water during both pre-and post-monsoon seasons.

The concentration of sulphate in the command area varies from 6 to 2035 mg L^{-1} during pre monsoon season and 406 to 2578 mg L^{-1} during post-monsoon season. Sulphate generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate content of water may changes significantly with time during infiltration of rainfall and ground water recharge, which mostly takes place from stagnant pools, puddles and surface runoff water collected in low-lying areas. It is evident from the distribution of sulphate that about 80% samples lies well within the desirable limit of drinking water and about 10% sample crosses the maximum permissible limit of drinking water.

The nitrate content was found to vary from 0.48 to 1672 mg L^{-1} during pre-monsoon season and nil to 1566 mg L^{-1} during post-monsoon season with wide range of variations. Increased level of nitrate at various locations may be attributed due the surface disposal of sewage and agricultural wastes. In general concentration of nitrate was found higher during post-monsoon season at most of the locations. Nitrate is effective plant nutrient and moderately toxic and is considered important for its adverse health effects. Jain has prescribed a limit of 45 mg L^{-1} (Jain and Ram, 1996) and WHO 2000 for drinking water supplies. Its concentration above 45 mg L^{-1} may prove detriment to human health. In higher concentration, nitrate may produce a disease known as methaemoglobinaemia, which generally affects bottle-fed infants (Jain *et al*., 1997). Repeated heavy doses of nitrates may also cause carcinogenic diseases. Distribution of nitrate indicates that about 61% samples has depicted nitrate content less than 45 mg L^{-1}, whereas in about 20% samples the nitrate exceeded the permissible limit of 100 mg L^{-1} during pre-monsoon season. The higher nitrate concentration may be attributed due to combined effect of contamination from domestic sewage and runoff from fertilized fields.

The fluoride concentration varies from nil to 5.48 mg L^{-1} during pre-monsoon season and nil to 8.46 during post-monsoon season with about 85% samples having fluoride concentration within permissible limit of 1.5 mg L^{-1}. The fluoride concentration beyond permissible limit of 1.5 mg L^{-1} was observed in about 15% samples. The fluorides are present in soil strata due to natural geological formations in the form of fluorspar, fluorapatite and amphiboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contributes a major portion of fluorides to natural waters. The accumulation of fluoride in soil strata eventually results in it's leaching due to percolating water pressure resulting increase fluoride concentration in ground water.

CLASSIFICATION OF GROUND WATER

The ground water of the study area has been classified as per Chadha's diagram (Chadha, 1999). The diagram is a somewhat modified version of the piper trilinear diagram. In the piper diagram the milliequivalent percentages of the major cations and anions are plotted in two base triangles and the type of water is determined on the basis of position of the data in the respective cationic and anionic triangular fields. The plotting from triangular fields are projected further into the central diamond field, which represents the overall character of the water. Piper diagram allow comparisons to be made among numerous analyses, but this type of diagram has a drawback, as all trilinear diagram do, in that it does not portray actual ion concentration. The distribution of ions within the main field is unsystematic in hydro chemical process terms, so the diagram lacks certain logic. The method is not very convenient when plotting a large volume of data. Nevertheless, this shortcoming does not lessen the usefulness of the piper diagram in the representation of some geochemical processes (Jain *et al.*, 1999).

In contrast, in Chadha's diagram, the difference in milliequivalent percentage between alkaline earths (calcium plus magnesium) and alkali metals (sodium plus potassium), expressed as percentage reacting values, is plotting on the X-axis and the difference in milliequivalent percentage between weak acidic anions (carbonate plus bicarbonate) and strong acidic anions (chloride plus sulphate plus nitrate) is plotted on the Y-axis. The resulting field of study is a square or rectangle depending upon the size of the scales chosen for X and Y co-ordinates. The milliequivalent percentage differences between alkaline earth and alkali metals and between weak acidic anions and strong acidic anions would plot in one of the four possible sub-fields of the diagram. The main advantage of this diagram is that it can be made simply on most spreadsheet software packages. The square rectangular field describes the overall character of the water. The diagram has all the advantage of the diamond-shaped field of the piper trilinear diagram and can be used to study various hydro chemical processes, such as base cation exchange, cement pollution, mixing of natural waters, sulphate reduction, saline water (end product water) and other related hydro chemical problem (Jain *et al.*, 2001).

From the Table 4 it is evident that during pre-monsoon season (58%) samples fall in sub-field 5-(Ca-Mg-HCO_3 type), 18.8% samples in sub-field 6-(Ca-Mg-CI-NO_3-SO_4 type), 9.10% samples in sub-field 7- (Na-K-CI-NO_3-SO_4 type) and 18.2% samples in sub-field 8-(Na-K-HCO_3 type). However, during post-monsoon season (34%) samples fall in sub-field 5-(Ca-Mg-HCO_3 type), 45.3% samples in sub-field 6-(Ca-Mg-CI-NO_3-SO_4 type), 17% samples fall in sub-field 7-(Na-K-Cl-NO_3- SO_4 type) and 10% samples in sub-field 8-(Na-K-HCO_3 type). The modified diagram has all the advantages of the diamond-shaped field of the piper trilinear diagram and can be conveniently used to study various hydro chemical processes.

Table 4: Summarized results of water classifications as per Chadha's diagram (Chadha, 1999)

	Sample numbers	
Classification/Type	Pre-monsoon	Post-monsoon
5-Ca-Mg-HCO_3	3,4,8,11,12,14,15, 18,18,21,22,25,30, 34-39,41,48-50,54, 57,59	3,4,8,10,15,16,21, 22,23,26,27,29, 30,34,35,37,50, 54,56
6-Ca-Mg-Cl-NO_3-SO_4	13,17,19, 20,20,31,42, 43,44,46, 47,58	1,12,13,14,17,20, 23,25,28,31,38, 39,41-44,46,47, 48,49,55,58
7-Na-K-Cl-NO_3-SO_4	7,33,52, 532,60	7,11,33,40,45, 52,53,47,59,60
8-Na-K-HCO_3	1,2,5,6,16,23,24, 32,40,45,51	2,5,6,24,32, 36,51

CONCLUSIONS

It is noticed that the ground water quality of study table and significant variation from one season to another. The survey of the study area has indicated higher concentration of total dissolved solids, electrical conductivity, hardness, calcium, magnesium, sulphates, nitrates, fluorides, etc. About 92% samples have TDS values above the desirable limit to 500 mg L^{-1} during pre- monsoon season and about 67% samples have TDS values above the desirable limit during post- monsoon season. About 15 to 20% samples even cross the maximum permissible limit of 2000 mg L^{-1} during both pre-and post-monsoon season. From the hardness point of view, an about 18-22% sample crosses the maximum permissible limit. The concentration of nitrate exceeds the maximum permissible limit in about 25 -35% samples. The grouping of samples according to their hydro chemical facies clearly indicates predominance of Ca-Mg-HCO_3 hydro chemical facies during pre-monsoon season. While during post-monsoon season 17.0% samples falls in Ca-Mg-HCO_3 facies 45.3% samples in Ca-Mg-Cl-NO_3-SO_4 hydro chemical facies, 17.0% samples in Na-K-Cl-NO_3-SO_4 facies and 10% samples in Na-K-HCO_3 hydro chemical facies.

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