WATER QUALITY ASSESSMENT AND HYDROCHEMICAL CHARACTERISTICS OF GROUNDWATER IN PUNJAB, PAKISTAN

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ABSTRACT

Water quality is the critical factor that influence on human health and quantity and quality of grain production in semi-humid and semi-arid area. To assess the quality of groundwater and to characterize the hydrochemical characteristics of the groundwater in Punjab Pakistan, groundwater samples were collected from different cities of Punjab Province and analyzed for 28 water quality parameters. Groundwater suitability for domestic and irrigation purposes was assessed by using WHO and USDA standards. The study yielded that in most of Punjab province area the groundwater samples are suitable for irrigation and agriculture purposes.

Keywords: *Punjab, Groundwater, Water Quality, Hydrochemical*

1. INTRODUCTION

In Pakistan,The rise in population coupled with changing lifestyle has led to higher consumption of water for domestic, industrial, and irrigation purposes.It has been reported that the water quality of major cities in Pakistan, is deteriorating because of unchecked disposal of untreated municipal and industrial wastewater and unscrupulous use of fertilizers, pesticides and insecticides (Bhutta et al., 2002). (Ullah et al., 2009) found that concentrations of EC, TDS, SO4, Cl, hardness, NO_3, Zn, Pb and Fe were above the permissible levels established by World Health Organization in Sialkot, an industrial city of Pakistan. The situation arisen has made it imperative to prevent and control water pollution and have reliable information on water quality for its effective management (Taqveem,2011).The water quality assessment is mostly based on hydrochemical analysis.World Health Organization (WHO) published the guidelines for drinking water to protect public health. The concentrations of naturally occurring chemicals,such as chloride, iron, manganese, sodium etc. are not of health concern at levels, but may affect acceptability of drinking water. The guidelines of water quality for agriculture is provide by the Food and Agriculture Organization (FAO) of the United Nations (Ayers and Westcot, 1985).The water quality for irrigation may affect the soils and crops, especially in the saline alkali soil areas. Salinity and sodium hazard indicators can be used as a criterion to find the suitability of irrigation waters (Nishanthiny et al., 2010). The USDA (United States Department of Agriculture) method is the most recognized worldwide, and sodium absorption ratio (SAR) is an effective evaluation index for most irrigation water (Al- Bassam and Al-Rumikhani, 2003; Ayers and Westcot, 1985; Richards, 1954).Elevated values of SARresult in decreased hydraulic conductivity decreased aggregate stability, clay dispersion, swelling of expandable clays, surface crusting and reduced tillage (Suarez et al., 2006).

In Pakistan, the irrigation system was designed for very low cropping intensities, but with population pressure,the design capacity is unable to cope with the actual cropping intensities. The difference between crop waterrequirements and canal supplies is met through exploitation of groundwater. The analysis of groundwater monitoring data indicated that groundwaterminingis taking place in many areas of the country.

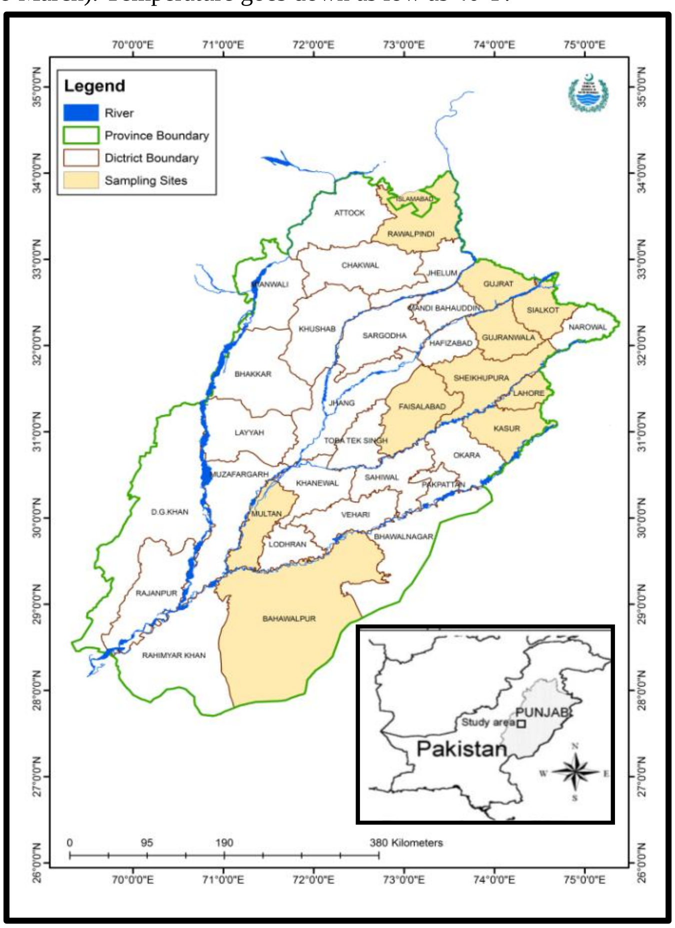
In Punjab, the importance of groundwater can be ascertained from the fact that quantitatively, it is contributing over 50% of canal water supplies available at the farm-gate. Canal system provides about 55 MAF of water to Punjab each year. Of this amount approximately 40% recharge goes to the groundwater. This recharge and additional irrigation water is provided through groundwater extraction. Presently there are about 500,000 private tubewells in the Province abstracting 30 MAF to cover an area of 51 MAC. Discharge of the private tubewells varies from less than 0.5 cusecs to more than 1.5 cusecs and operation factor ranges from about 3% to more than 30% with an average of 10.5%. Additional groundwater 4 MAF is extracted for SCARPs, industrial and domestic use (Muhammad Amin, 2013).

A lot of work has been carried out in Punjab on seepagefrom the irrigation system and the resulting recharge to the groundwater (PPSGWP, 1998).The sole potential of groundwater exist in Indus Plain in Punjab province.This groundwater potential is based on rainfall recharge, groundwater recharge and recharge from irrigation system. The total available groundwater resource of the Punjab Province was estimated 42.75 MAF.(GhulamMujtabaet al., 2007) concluded thatgroundwater resources are being depleted gradually, due to extensive tubewell development for irrigation water since 1990 and reduction in the canal deliveries due todrought conditions, prevailing for the last 6 to

10 years, which reduced the groundwater-rechargecomponent, canal deliveries and ultimately, canal seepage and canal recharge to groundwater in Punjab Pakustan. Also they concluded that Groundwater recharged by rivers would cause groundwater pollution due to polluted surface water bodies receiving city and industrial toxic drainage.
In this study the water samples were collected and analyzed to characterize the groundwater hydrochemical, and to assess the water quality for drinking andirrigation usage in Punjab province, Pakistan.

2. STUDY AREA

Punjab is Pakistan's second largest province. It occupies an area of about 205,344 km^2. It is located between 27°44′N 69°20′E and 34°15′N 75°20′E at the northwestern edge of the geologic Indian plate in South Asia. Nearly 60% of Pakistan's population lives in the Punjab province,Figure (1). This provincelies on the northwestern part of Indian Shield where meta-sedimentary, igneous and sedimentary rocks ranging in age from pre-cambrian to recent are exposed.consolidated outcrops mainly cover northen part, striking generally in east west direction from Murree to Dera Ghazi Khan covering mountain ranges partly or wholly namely salt range, Sulaiman range, Kala Chitta range and Himalayan foot hill. These rocks range in age from precambrain to Holocene, and are exposed in the form of low hills rising abruptly from basin plain in the north. In the central part of Punjab plain, rocks consisting of meta-sedimentary complex are exposed as isolated low hills which are belived to be the extension of buried DehiShahpur ridgeSalt range exhibits more or less complete stratigraphic sequence of sedimentary rocks and forms a series of irregular ridges. It raises from the Punjab plains trending east west and is separated from Kala Chitta range. Though the salt range terminates at Mari in the west yet continues beyond the Indus to constitute the Trans Indus range.The alluvial deposits occur chiefly in irregularly shaped tabular layers of silt and clay. It is found that lenses of silt,clay and silty sand compose about 25 to 35 percent of the entire bulk of the alluvial complex. These fine grained deposits, of low permeability, generally are discontinuous so that beds of sand constituting the remaining 65 to 75 percent of the alluvium serve as a unified highlytransmissive aquifer (WAPDA1989).
Climatically, Punjab has three major seasons: hot weather (April to June) when temperature rises as high as 110°F, Rainy season (July to September); Average rainfall annual ranges between 96 cm sub-mountain region and 46 cm in the plains and mild weather (October to March). Temperature goes down as low as 40°F.



Figure(1): Study area

3. METHODOLOGY

3.1Water Sampling

For the collection of water samples, a uniform site selection criterion was adopted and a grid size of 1 $km^2$for small cities 4and 9 km^2 for medium cities and 16 and 25 km^2 for big cities was established. The water quality monitoring network was distributed through the most important eleven cities in Punjab province as shown in Table (1). The water samples were analyzed for physical parameter such as color, taste, turbidity, electrical conductivity, pH, and odor , chemical parameter such as alkalinity, hardness, total dissolved solids, chromium, arsenic, chlorides, sulphate, nitrate, fluorides, sodium, potassium, calcium, magnesium, bicarbonate,iron,and bacteriological parameter such as coliform and Escherichia coliform.

Table (1): Details of Water Quality Monitoring Network

No.	City Name	City Code	Grid Size (Km^2)	Total Sample points
1	Islamabad	ISL	4	24
2	Rawalpindi	RAW	9	14
3	Gujrat	GUT	1	8
4	Lahore	LAH	16	16
5	Silkot	SIA	4	10
6	Sheikhupura	SHE	4	11
7	Gujranwala	GUJ	4	14
8	Faisalabad	FAI	4	14
9	Kasur	KAS	1	10
10	Bahawalpur	BAH	16	25
11	Multan	MUL	16	16

Water samples for physico-chemical analysis were collected in polystyrene bottles of 0.5 and 1.5 liter capacities. Before collecting the samples, the bottles were washed properly and rinsed thoroughly several times first with water and then with distilled water. For bacterial analysis, samples were collected in sterilized containers (200 ml). Hydrochloric acid and boric acid were used as preservatives in the sampling bottles for trace elements and nitrate nitrogen respectively before going to field. The water samples from tube wells were collected after allowing them to flow for at least 10 minutes to get representative sample of the groundwater. Water samples were collected from hand pumps or dug wells after purging of the hand pump or well. The purging was carried out by making one stroke for every foot of depth (A hand pump or dug well having 30 feet of depth, needs 30 strokes for its purging).

3.2 HydrochemicalCharacteristics

A need developed to find a more convenient way to refer to water compositions byidentifiable categories and this is where the concept of hydrochemical facies wasdeveloped. Hydrochemical facies are distinct zones that have cation and anionconcentrations describable within defined composition categories.A variety of graphic techniques have been developed for showing major chemical constituents;Piper Diagrams are one of the most useful ways of representing and comparing waterquality. In the Piper Diagram cations, expressed as percentages of total cations inmilliequivalents per liter, plots as a single point on the left triangle and anionssimilarly expressed as percentages of total anions, appear as a single point in the righttriangle. These two points are then projected into the central diamond-shaped areparallel to the upper edges of the central area. This single point is thus uniquelyrelated to the total ionic distribution. The Piper Diagram also conveniently revealssimilarities and differences among groundwater samples. Those samples with similar qualities willtend to plot together as groups (Todd & Mays, 2005).

3.3 WaterQuality Indices

Excessive sodium and salinity concentrations in irrigationwater result in sodium hazard, as well as salinity hazard.Sodium ion in water replacing calcium and magnesium ionsin soil causes reduced permeability and soil hardens (Shaki andAdeloye, 2006). To assess irrigation water quality, theparameters such as percent sodium (Na%) and sodiumadsorption ratio (SAR) were calculated based on the chemicalvariables of water samples (Singh et al., 2005). The irrigationwater assessment indices including: percentage sodium;

$$\mathrm{Na\%} = \frac{\mathrm{Na}^{+}}{\mathrm{Na}^{+} + \mathrm{Ca}^{+2} + \mathrm{Mg}^{+2} + \mathrm{K}^{+}} \times 100\% \qquad (1)$$

And sodium adsorption ratio;

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{+2} + Mg^{+2})/2}} \qquad (2)$$

where all the ionic concentrations are expressed in mille equivalentsper liter (meq/L) of the respective ions. The SAR isprobably the only one in current use and is generally considered asan effective evaluation index for most water used inirrigated agriculture (Ayers and Westcot, 1985).

4. Results and Discussion

4.1 Water Quality parameters

Using Arc GIS 9.3 and Aquachem 2010.1 Figures (2-a)&(2-b) showthe map plot to display the distribution of maximum values of the major cations and anions, Figure (2-a) and TDS and Conductivity, Figure (2-b) through the eleven cities in the study area. As Shown the maximum values of Na, Ca, Mg, Cl, HCO_3, SO_4, TDS and Conductivity are found in Faisalabad.

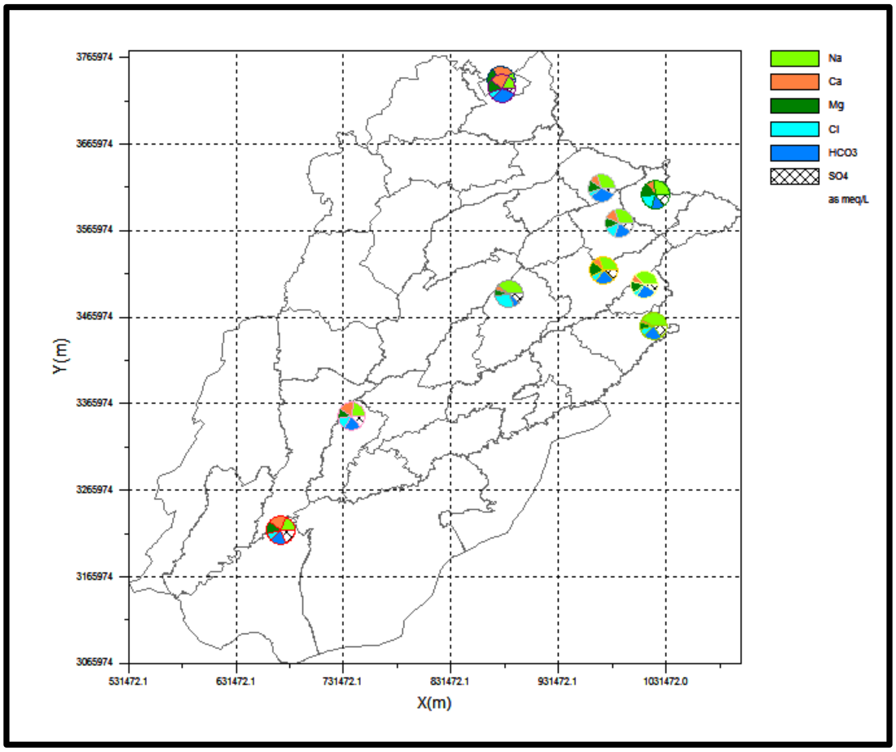


Figure (2-a): Distribution of maximum values of major anions and cations

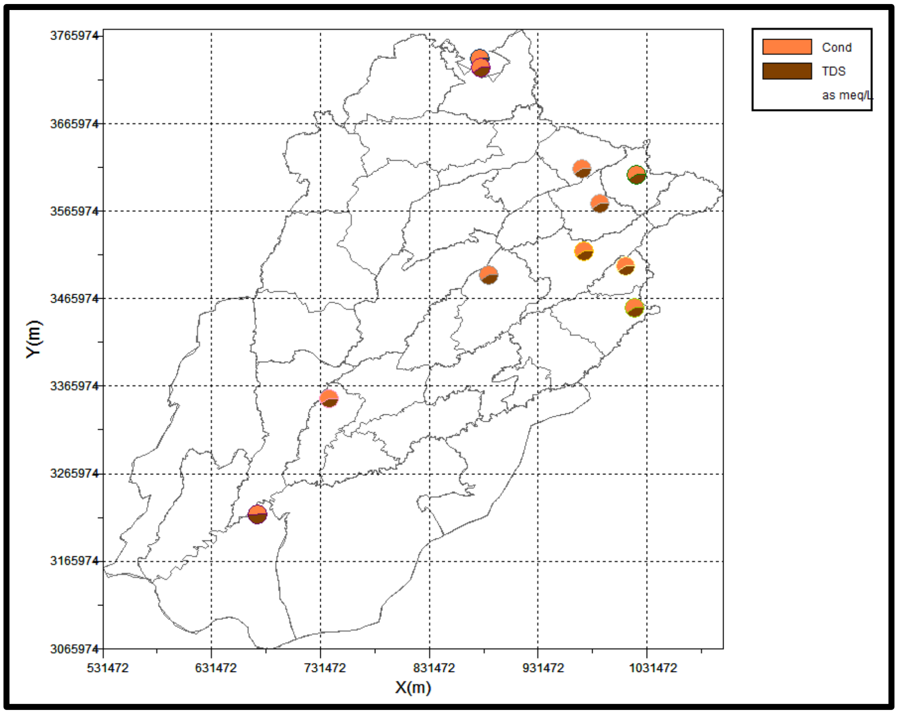


Figure (2-b): Distribution of maximum values of TDS and Ec.

Table (2) presents the evaluation of water quality parameters in groundwater of the eleven cities in Punjab. The details of the results are presented under the three main categories of water quality analysis:(i) Aesthetic and Physical Quality; (ii) Chemical Quality; and (iii) Bacteriological Quality; with respect to WHO limits

Table (2): Evaluation of water quality parameter with respect to WHO limits

Parameter	WHO Limits	Results
Aesthetic & Physical Quality		
Colour		All drinking water samples collected from Islamabad, Faisalabad, Gujranwala, Gujrat, Kasur, Lahore, Multan, Sheikhupura, were found colourless. However, about 13% samples from Rawalpindi, 10% from Sialkot, About 16% samples from Bahawalpur
Odour		Water samples from most of cities were found unobjectionable, however, 21% samples from Kasur, 10% from Sialkot and 25% from Hyderabad had objectionable smell.
EC	50-500 µS/cm	EC values in all 11 cities lie in the range of 272-6100µS/cm.Water samples from Bahawalpur (8%), Faisalabad (36%), have EC exceeding 2000 µS/cm
PH	6.5 to 8.5	The pH of collected samples varied from 6.10 to 9.0
Turbidity	5 NTU	4% water samples from Islamabad, 16% from Bahawalpur, 7% from Gujranwala, 33% from Gujrat, 6% from Multan, 20% from Rawalpindi, exceeded the WHO guidelines.
Chemical Quality		
Arsenic		60% water samples from Bahawalpur, 7% from Gujranwala, 30% from Kasur, 31% from Lahore, 75% from Multan, 45% from Sheikhupura and were unsafe due to the contents exceeding the WHO limits. The other cities have arsenic value within permissible limits.
Chloride	250 mg/l	only 36% samples of Silkot did not meet the safe limit.
Chromium	50 mg/l	Samples from all cities were found within safe limits.
Fluoride	1.5 mg/l	4% samples from Bahawalpur, 7% from Faisalabad, 30% from Kasur, are excessive fluoride concentration.

Hardness	500 mg/l	12% water samples from Bahawalpur, 21% from Faisalabad, 9% from Sheikhupura exceeded the limit.
Iron	0.3 mg/l	4% water samples from Islamabad, 60% from Bahawalpur, 33% from Gujrat, 6% from Lahore, 31% from Multan, 7% from Rawalpindi, and exceeded WHO guidelines.
Magnesium		All samples collected from urban areas were found within safe limit in respect of magnesium
Nitrate	10 mg/l	concentration in all cities was found within safe limits
Potassium		Potassium concentration in all samples was found within European Community (EC) recommendation of 12 mg/l as guideline value .
Na	200 mg/l	8% water samples from Bahawalpur, 75% from Faisalabad, 7% from Gujranwala, 11% from Gujrat, 30% from Kasur, 27% from Sheikhupura, 10% from Sialkot, exceeded from the safe limits
Sulfate	250 mg/l	12% water samples from Bahawalpur, 36% from Faisalabad, 11% from Gujrat, 20% from Kasur, 9% from Sheikhupura, 10% from Sialkot exceeded WHO limits
TDS	1000 mg/l	16%water samples from Bahawalpur, 43% from Faisalabad, 7% from Gujranwala, 11% from Gujrat, 30% from Kasur, 7% from Rawalpindi, 18% from Sheikhupura, 10% from Sialkot, exceeded WHO limits
Bacteriological Quality		
Bacterial contamination		Only 26% samples in Islamabad, 24% in Bahawalpur, 21% in Faisalabad, 71% in Gujranwala, 60% in Kasur, 87% in Lahore, 13% in Multan, 13% in Rawalpindi, 45% in Sheikhupura, 60% in Sialkot, were found fit for drinking purpose. Unfortunately, all samples from Gujrat, were found unsafe for human consumption.

The hydrochemical characteristics of groundwater in the study area are shown in Table (3) by descriptive statistics method.

Table (3): Descriptive statistics of groundwater hydrochemistry in study area.

Water Quality Parameter	EC	TDS	pH	HCO3	Cl	CO3	So4	Ca	Mg	K	Na
Number of Samples	150	150	150	150	150	150	150	150	150	150	150
Mean	950.82	670.33	7.74	287.27	62.90	9.93	101.71	62.11	32.39	6.68	111.44
S.D	733.45	517.47	0.58	97.66	137.19	23.39	153.77	30.19	20.04	8.77	150.43
Min	272.00	165.00	6.10	29.00	3.00	0.00	0.00	12.00	8.00	0.70	7.00
Max	6100.00	4270.00	9.00	620.00	1296.00	140.00	1286.00	180.00	127.00	53.00	1200.00
Mode	585.00	470.00	7.30	300.00	10.00	0.00	30.00	80.00	31.00	1.40	50.00
Median	732.50	517.00	7.55	280.00	31.50	0.00	54.00	60.00	29.08	4.35	73.00

4.2 HydrochemicalFacies

The Piper Diagram by AquaChem software was used to identify the hydrochemical facies of groundwater in Punjab.As plotted in Figure (3) 44% of water sample falls in zone of no dominant cation type , 32% of water samples falls in zone of Na^+ sodium type and 24% of water samples falls in Zone of Ca^+ calcium type. For the predominate anion it is clear that the HCo_3 and Co_3 are exceed the other anion.Figure (3) also shows that the prominent hydrogeological facies is $CaHCo_3$ followed by CaNa HCo_3.the diagram also shows that there are different water types are present in the groundwater systemas given in Table (4).

Table (4): Hydrochemical facies as worked out by Piper Diagram

Facies Type	CaHCo3	Na Cl	CaNaHCo3	Ca Mg Cl	Ca Cl	Na HCo3
Percentage	60%	11%	17%	8%	0%	3%

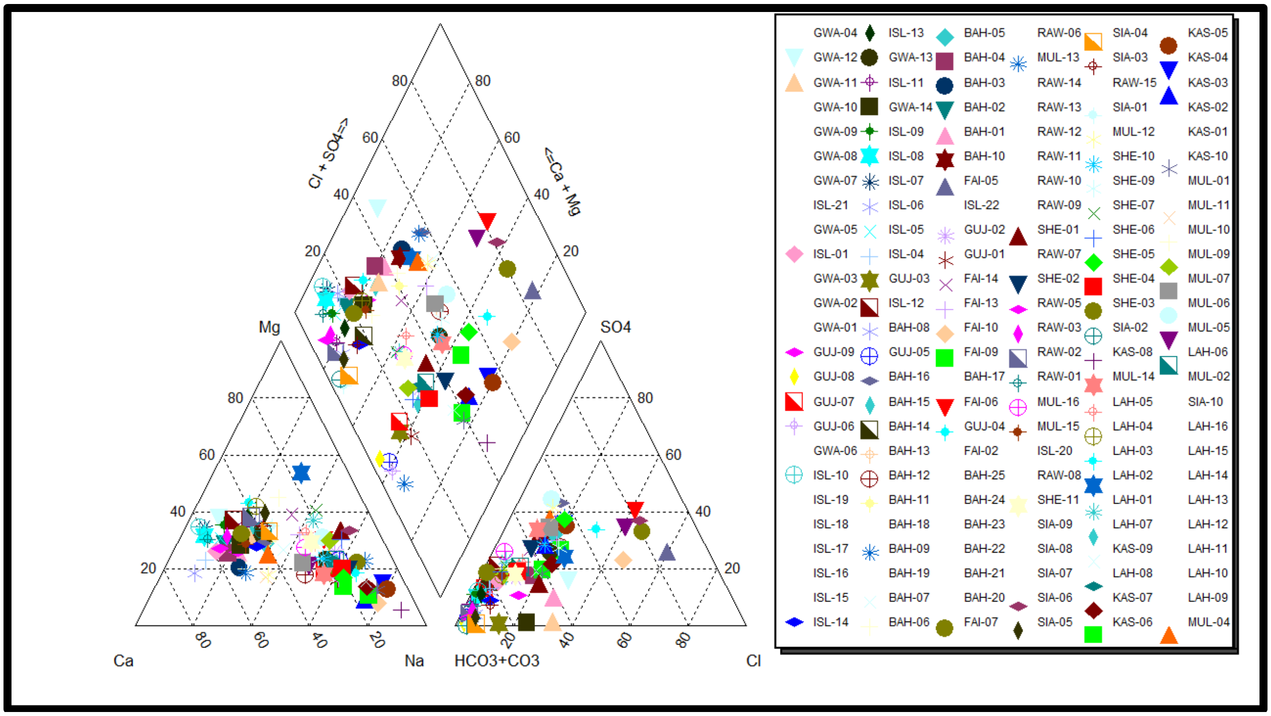


Figure (3): Piper Digram showing hydrochemical facies of groundwater in Punjab

4.3 Water Quality Assessment for Irrigation

Suitability of water for irrigation is based on its salinity, sodicity and toxicity.The parameters such as electrical conductivity, sodium adsorption ratio (SAR), and percent sodium (Na%) were estimated to assess the suitability of groundwater for irrigation purpose.

Figure (4) shows thegroundwater samples classification for irrigation purpose based on Richards, 1954 and Wilcox, 1955. In this diagram, EC in µs/cm is taken as salinity hazard and SAR in meq/L as alkalinity hazard. It is clear that no samples fall in the category ofexcellent to good, for irrigation (C1-S1).The good to permissible irrigation water contributed 73% of water samples fall in category C2-S1 indicating medium salinity and low sodium and 26% of water samples fall in category C3-S1indicating high salinity and low sodium.8% of water samples fall in category of C3-S2 indicating high salinity and medium sodium. 3% of water samples fall in category of C3-S3 indicating high salinity and high sodium.3% of water samples fall in category of C4-S4 indicating very high salinity and very high sodium.

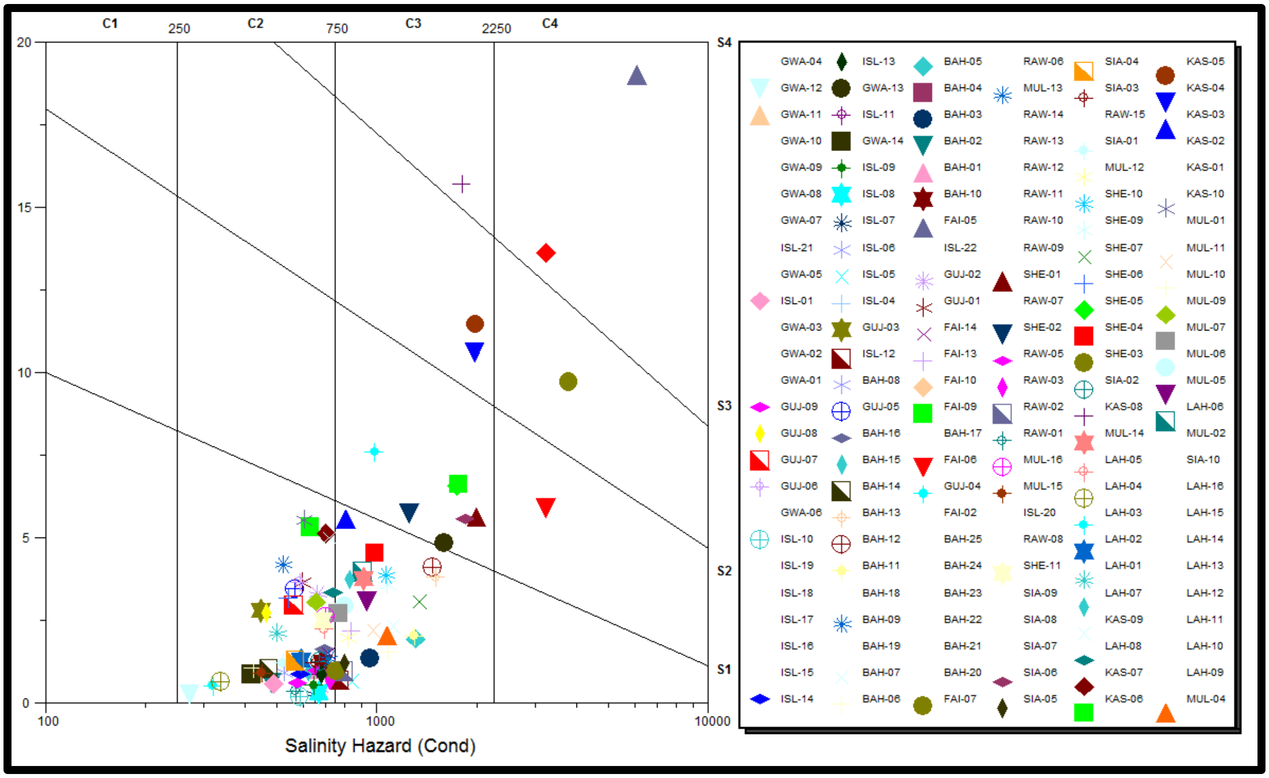


Figure (4):Irrigation waters classification

5. CONCLUSION

Groundwater were sampled and analyzed for their hydrochemical characteristics and evaluation of the water quality for drinking and irrigation purposes. SAR values and the sodium percentage (Na %) in locations indicate that majority of the groundwater samples are suitable for irrigation. The hydrochemical analysis demonstrates that the groundwater in Punjab Pakistan is typical of shallow fresh waters.In general the physical quality of groundwater was found good except ina few cases where the presence of colour in samples was due to the high level of turbidity andother dissolved and un-dissolved substances. In most of the cities, the value of turbidity in somesamples exceeded the WHO standard value of 5 NTU including these from Rawalpindi,Bahawalpur, and Gujrat. However, the EC value in all elevencities ranged from 170-7930 µS/cm. Similarly, the pH value of all the collected samples rangedfrom 6.1-9.0 against the recommended WHO guideline range of 6.5-8.5 for drinking water.The chemical quality of water was found within the recommended level with respect tocalcium and chromium. For alkalinity, bicarbonate, carbonate and phosphate, no guideline valueshave been set by WHO or others. However, higher arsenic contents (WHO limit for arsenic is 10ppb) were found in some samples collected from 8 cities. The contaminated samples comprised60% from Bahawalpur, 7% from Gujranwala, 30% from Kasur, 31% from Lahore, 75% fromMultan,and 45% from Sheikhupura. However, other chemical parameterswere found within safe limits, the salt concentrations generally were on the higher side forgroundwater.Overall the water samples were found bacteriologically contaminated. All samples in Gujrat, were found bacterially contaminated and unsafe for humanconsumption. Theoverall deteriorating quality of groundwater may also be associated with continuous drop in thewater-table in addition to industrial and agricultural activities and the natural condition ofaquifers. It has been observed that in most of the cities the water table is falling from one to 10feet every year. Such alarming conditions lead to the observation that there is a need for a properand continuous monitoring of the overall water resources of the country.This investigational study indicates that water in many cities of Pakistan is unsafe forhuman consumption due to both bacterial and chemical contamination.

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7. REFERENCES

Al-Bassam, A.M., Al-Rumikhani, Y.A., 2003. Integrated hydrochemical method of water quality assessment for irrigation in arid areas: application to the Jilh aquifer, Saudi Arabia. Journal of African Earth Sciences 36 (4), 345-356.

Ayers, R.S., Westcot, D.W., 1985. Water quality for agriculture. FAO, Rome

Bhutta, M.N., M. Ramzan and C.A. Hafeez. 2002. Groundwater quality and availability in Pakistan. Proc. Seminar on "Strategies to Address the Present and Future Water Quality Issues".Pakistan Council of Research in Water Resources (PCRWR), Islamabad, Pakistan.

GhulamMujtaba, Zulfiqar Ahmed, Duke Ophori, 2007. Management of groundwater resources in Punjab, Pakistan, using a groundwater flow model.Journal of EnvironmentalHydrology.Volume 15 Paper 31 December

K. Karunakaran, P. Thamilarasu, R. Sharmila, 2009. Statistical study on physicochemical characteristics of groundwater in and around Namakkal, Tamilnadu, India. E-Journal of Chemistry, 6(3), 909-914

Muhammad Amin Member Water, WAPDA. Pakistan's Groundwater reservoir and its sustainability.http://www.watertech.cn/english/amin.pdf, 16Feb. 2013

Nishanthiny, S.C., Thushyanthy, M., Barathithasan, T., Saravanan, S., 2010. Irrigation water quality based on hydrochemical analysis, Jaffna, Sri Lanka. American-Eurasian Journal of Agricultural &Environmental Science 7 (1), 100-102.

PPSGWP, 1998. Annual Progress Report, Punjab Public Sector Ground Water Project, Lahore.

Richards, L.A., 1954. Diagnosis Improvement Saline Alkali Soils.US Department of Agriculture Handbook. No. 60

Shaki, A., Adeloye, A., 2006. Evaluation of quantity and quality of irrigation water at Gadowa irrigation project in Murzuq basin, southwest Libya. Agricultural Water Management 84 (1-2), 193-201.

Singh, A.K., Mondal, G.C., Singh, P.K., Singh, S., Singh, T.B., Tewary, B.K., 2005. Hydrochemistry of reservoirs of Damodar River basin, India: weathering processes and water quality assessment. Environmental Geology 48 (8), 1014-1028.

Suarez, D., Wood, J., Lesch, S., 2006. Effect of SAR on water infiltration under a sequential rain-irrigation management system. Agricultural Water Management 86 (1-2), 150-164.

Taqveem Ali Khan, 2011.Multivarianteanalysis of hydrochemical of the groundwater in Partos of Karwan-Segarbus- Basin , Central Ganga Basin, India. Global NEST Journal, Vol 13, No 3, pp 229-236.

Todd, D.K. & Mays, L.W, 2005. Groundwater Hydrology, Third Edition, John Wiley & Sons,Inc.

Ullah, R., R.N. Malik , A. Qadir. 2009. Assessment of groundwater contamination in an industrial city, Sialkot,Pakistan. Afr. J. Environ. Sci. Technol. 3:429-446.

WAPDA, 1989. Booklet on Hydrogeological Map of Pakistan scale 1:2,000,000 First edition.

Wilcox, L.V., 1955. Classification and use of irrigation waters.USDA.Circ 969, Washington, DC.

World Health Organization, 2011. Guidelines for drinking-water quality, fourth ed. World Health Organization.