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BASELINE STUDY OF DRINKING WATER QUALITY: A CASE STUDY OF LUDHIANA DISTRICT, PUNJAB, INDIA

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ABSTRACT

The Ludhiana is one of the fastest growing and most centrally located district of Punjab. It is the largest city in Punjab, both in terms of area (3860 sq km) and population (approximately 34, 87, 882 as per 2011 census). Ludhiana is the first metropolitan city, popularly known as “Manchester of India”. The rapid population growth in Ludhiana continues to be a matter of concern due to its manifold effects on environment and one of the most important being groundwater and surface water contamination and over exploitation. The major driving force affecting the study area is increase in population due to urbanization and industrialization seems to have a severe impact on the climate change as indicated by change in temperature, rainfall pattern and relative humidity in the study area. 44 groundwater samples and 22 surface water samples were analyzed during pre-monsoon and post-monsoon periods respectively from different depths to evaluate the groundwater quality for drinking purposes. The perusal of inter-ionic relationship, correlation analysis and hydro chemical data is indicative of the fact that there are substantial differences in the composition of the groundwater and surface water taken. For this purpose, the implementation of the sustainable management water will require an integrated approach to strike a fine balance between urbanization and environmental protection.

Keywords: *Urbanization, Industrialization, Sustainable Management and Environmental Protection*

INTRODUCTION

The chemical properties of water (ground water and surface water) are very significant to study their impact on water (ground and surface water). The quality of the ground water varies with depth of the aquifer and its proximity to the canals. In addition, the distribution of rainfall pattern also influences the hydro chemical nature of the groundwater. In general, chemistry of ground water is interrelated with geology and hydrology of the area, physico-chemical characteristics of rocks and soils through which water percolates, nature of plant cover, extent of pollution and various other regional and local factors.

Over exploitation and direct anthropogenic alteration of the land cover such as agriculture, deforestation, mining, urbanization and interference on hydrological regime like irrigation and damming have resulted in a marked change in water quality in various catchment areas (Sreekumar *et al.*, 2009). Easily and regularly available clean drinking water is still a harsh task to achieve not only in deserts but also in most of the small towns and mega cities (Mehta, 2011). The United Nations has proclaimed the years of 2005-2015 as the international decade for action on water for life (United Nation's General Assembly, 2004). According to FAO's definition of sustainable agricultural development given in (1990a) "*Appropriate steps must be taken to ensure that agricultural activities do not adversely affect water quality so that subsequent uses of water for different purposes are not impaired.*" The various geochemical parameters used for this purpose are described in this paper. The paper deals with the hydrochemistry of water (surface and groundwater) to evaluate their impact drinking water quality of the study area.

Description of the Study Area

Geographically, Ludhiana district lies between North Latitude 30°-34' and 31°-01' and East longitude 75°-18' and 76°-20' as shown in Figure 1. It is the most centrally located district of Punjab. It is the largest city in Punjab, both in terms of area (3860 sq km) and population (approximately 34, 87, 882 as per 2011 census). Ludhiana is the first metropolitan city, popularly known as “Manchester of India”.

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The district constitutes a typical alluvial plain. It owes its origin to the augmentation of the Sutlej River. The alluvium deposited by the river was reworked by aeolian activities to give rise to a number of small dunes and sand mounds.

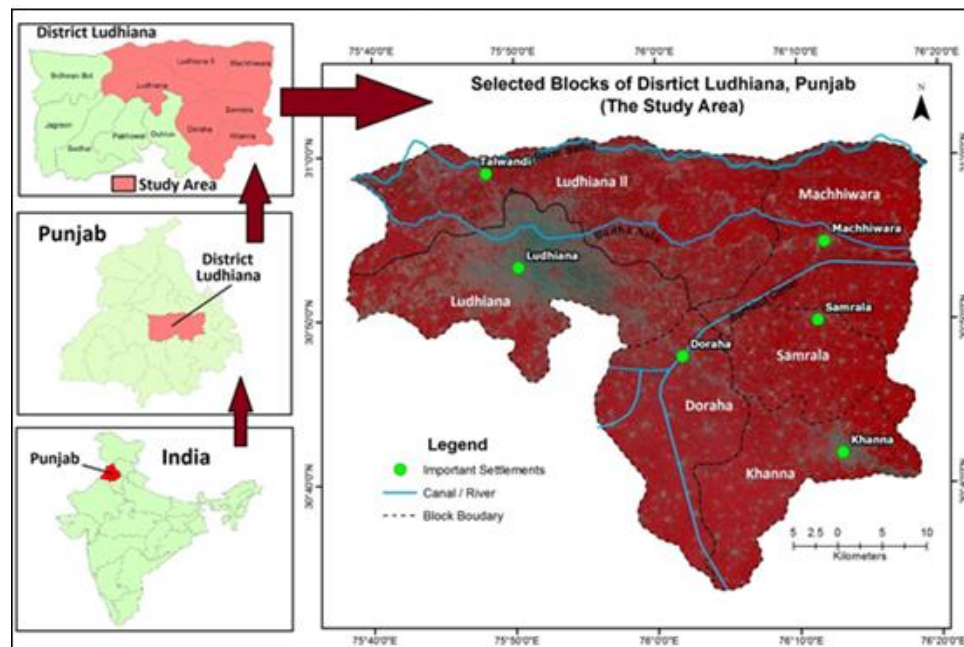


Figure 1: Location Map of Study Area

The climate of the district is characterized as tropical steppe (hot and semi-arid) except a brief spell of monsoon season in a very hot summer and a bracing winter. There has been a consistent increase in the average minimum and maximum temperature in Ludhiana District due to climate change. The rainfall in the district increases from southwest towards the northeast. The average annual rainfall is 681mm. Based on the average monthly rainfall pattern, months have been categorized as major rainfall season (June-September), and intermediate rainfall season (January-May) and minor rainfall season (October-December).

The monthly average relative humidity of Ludhiana district shows the cyclic. As per 2011 census, the population touched the mark of 34,87,882 which shows that the population increased almost double during the span of 30 years (1981-2011). The increase in population due to urbanization and industrialization seems to have a severe impact on the climate change as indicated by change in temperature, rainfall pattern and relative humidity in the study area. After the great strides in the field of agriculture, the total number of industries has increased tremendously after 1980s. The maximum exports of Rs.23 billion were from district Ludhiana comprising 57.5% of total exports from the state (Tiwana *et al.*, 2005), which have severe effect on the quality of water and thus affecting its quality.

MATERIALS AND METHODS

Methodology

For performing the present study, a well-tested scientific, systematic and proven methodology was adopted.

The field and laboratory investigations carried out for the present study are discussed below.

Field Investigations and Sample Collection

- Reconnaissance survey was carried out to familiarize with the research area and to collect the preliminary baseline data pertaining to sustainable agriculture in the area and meteorological parameters from different government and non-government organizations.
- A total of 66 locations, 44 for ground water and 22 for surface water were identified to collect the samples of ground and surface water from the study area.

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- Careful sampling was done to collect the water samples (ground water and surface water) from the area covering the selected blocks.
- The water samples were collected in clean polythene bottle of two-liter capacity. Bottles were thoroughly rinsed two to three times with distilled water and the sample water to ensure no contamination at the time of sampling.
- Before collecting sample initially, the hand pump and tubewell was run for ten minutes so that the stagnant water in contact with metallic casing was removed and fresh water sample representative of that particular aquifer was acquired. Thereafter, water samples in duplicate were filled to the capacity of the bottle, sealed and labeled.
- 44 groundwater samples were collected from the tube wells and hand pumps from the six developmental blocks of Ludhiana district and 22 surface water samples from the Sirhind canal and the Buddha Nallah, during pre-monsoon (May 2012 and 2013) and post-monsoon (November 2012 and 2013) were collected to study the quality of ground water and surface water and to assess their suitability for drinking and agricultural sustainability.
- The physical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS) and temperature were measured in the field using water and soil analysis kit. To ensure accuracy in the data, the analysis was repeated 2-3 times and mean values were calculated.

Laboratory Investigations

Determination of Water Quality

- The chemical analysis of water samples were analyzed in the geochemical laboratory of the Department of Geology Panjab University, Chandigarh, immediately after bringing the samples to the laboratory according to the standard methodology given by American Public Health Association (2005), Bureau of Indian Standards (BIS, 2012) and Indian Meteorological Department (IMD, 2013).
- Water samples were filtered with the help of Whatman filter paper No.71 to remove the suspended and extraneous matter.
- The account of analytical methods used for chemical analysis of the surface and groundwater samples acquired from the study area along with description is given in brief in Table 1.
- Water quality of the study area was assessed for suitability to agriculture in terms of critical pollutants as mentioned above was also calculated.

Table 1: Summary of Analytical Methods Used for Chemical Analysis of the Water Samples

Parameters	Analytical Methods
Temperature ($^{\circ}\text{C}$)	Thermometer
Electrical Conductivity (EC)	Soil and Water analysis kit (Electronic India,model-161)
Total Dissolved Solids (TDS)	By Factor (Multiplying EC with 0.65)
pH	pH Meter
Turbidity	Nephelometer
Calcium	Titrimetry (EDTA as Titrant and Murexide as Indicator))
Magnesium	Titrimetry (EDTA as titrant and erichrome black T as Indicator)
Sodium	Flame Photometer
Potassium	Flame Photometer
Chloride	Titrimetry (AgNO_3 with Potassium Chromate as Indicator)
Sulphate	Spectrophotometer (BaCl_2 as Conditioning Agent)
Fluoride	Spectrophotometer (SPADNS Reagent)
Nitrate	Spectrophotometer (Phenol Disulphonic Acid)
BOD	BOD Incubator (3 days at 27°C) (Winkler's Method)
COD	Dichromate Reflux Method

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The data were subjected to statistical analysis using different computer programmes like Minitab16, Microsoft Office Excel, Map Info. 6.5 and Rockworks 15. The results and discussions following the field and laboratory investigations are discussed in sequel.

RESULTS AND DISCUSSION

Chemical Analysis of Groundwater and Surface water

I.pH

The pH is dependent on carbon dioxide-carbonate-bicarbonate equilibrium in most natural waters (Abowei, 2010). The pH is an important indicator for the water quality and thus, provides an important information in many types of solubility calculations and geochemical equilibrium (Hem, 1985).

The pH value of groundwater during pre-monsoon season varied between 6.41 to 7.58 with the average value 6.83 and during post-monsoon varied from 5.87 to 7.12 with the average value 6.59. pH value of surface water during pre-monsoon is between 6.5 to 8.5 with the mean value 7.35 and the value of surface water during post-monsoon varied between 5.98 to 8.3 with the average value of 7.0.

II.EC

The term EC denotes the characteristics of a medium to passage of electricity and is a function of temperature, type of ions present and concentration of various ions (Walton, 1970). The unit of measurement of specific conductance is micro-siemens /cm ($\mu\text{S}/\text{cm}$ at 25°C).

In the present study, EC values of groundwater ranged between $514\mu\text{S}/\text{cm}$ to $1317\mu\text{S}/\text{cm}$ with the mean value of $898.40\mu\text{S}/\text{cm}$ and $512\mu\text{S}/\text{cm}$ to $1310\mu\text{S}/\text{cm}$ with the mean value of $876.77\mu\text{S}/\text{cm}$ during pre and post monsoon, respectively. The EC values of surface water during pre-monsoon ranged between $326\mu\text{S}/\text{cm}$ to $4692\mu\text{S}/\text{cm}$ with the mean value of $1771.27\mu\text{S}/\text{cm}$ and $315\mu\text{S}/\text{cm}$ to $4587\mu\text{S}/\text{cm}$ with the mean value of $1734.5\mu\text{S}/\text{cm}$ during post-monsoon.

III.Total Dissolved Solid (TDS)

Total Dissolved Solids are the measure of total concentrations of all the constituents dissolved in water. Carbonates, bicarbonates, magnesium, sodium, silica and sulfates and chlorides of calcium form the major part while the minor part includes the potassium, chloride, nitrate and boron. The chemical in equilibrium between the water and deposited salts resulted in increased value of TDS in groundwater (Durfor and Becker, 1964). The high value of TDS results in laxative effect on human system.

The concentration of TDS in groundwater ranged from $334\text{mg}/\text{l}$ to $856\text{mg}/\text{l}$ during pre-monsoon with the average value of $583.9\text{mg}/\text{l}$ and varied from $332\text{mg}/\text{l}$ to $851\text{mg}/\text{l}$ with the average value of $569.9\text{mg}/\text{l}$ during post-monsoon. The value of TDS in surface water varied from $211.9\text{mg}/\text{l}$ to $3049.8\text{mg}/\text{l}$ with the average value of $1151.32\text{mg}/\text{l}$ during pre-monsoon and $204.7\text{mg}/\text{l}$ to $2981.5\text{mg}/\text{l}$ with the average value of $1127.4\text{mg}/\text{l}$ during post-monsoon.

IV.Total Hardness

Calcium and magnesium ions cause the principal hardness in fresh waters. The degree of hardness of drinking water may be classified in terms of its calcium carbonate concentrations as given by McNeely *et al.*, (1979), Durfor and Becker (1964) and Environment Protection Agency (EPA, 1973).

The concentration of total hardness in the groundwater of the study area during pre- monsoon varies from $471.66\text{mg}/\text{l}$ to $587.43\text{mg}/\text{l}$ with the mean value of $508.29\text{mg}/\text{l}$ and $186.2\text{mg}/\text{l}$ to $475.02\text{mg}/\text{l}$ with the mean value of $349.49\text{mg}/\text{l}$ during post-monsoon.

The total hardness in surface water during pre-monsoon varies from $87.78\text{mg}/\text{l}$ to $327.71\text{mg}/\text{l}$ with the mean value of $228.36\text{mg}/\text{l}$ and $84.57\text{mg}/\text{l}$ to $325.31\text{mg}/\text{l}$ during post-monsoon with the mean value of $220.22\text{mg}/\text{l}$.

V.Calcium

Calcium is the second major constituent after bicarbonate in most surface water of the world and is generally among the top three to four ions in groundwater (Hem, 1985).

Calcium in the groundwater varied from $63.23\text{mg}/\text{l}$ – $109.63\text{mg}/\text{l}$ with the average value of $77.90\text{mg}/\text{l}$ during pre-monsoon and $63.04\text{mg}/\text{l}$ – $109.21\text{mg}/\text{l}$ with the average value of 76.21mg during post-monsoon. The amount of calcium in surface water varied from $25.08\text{mg}/\text{l}$ to $76.11\text{mg}/\text{l}$ with the average

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value of 55.41mg/l during pre-monsoon and 22.31mg/l to 77.84mg/l with the average value of 53.15 during post-monsoon.

VI. Magnesium

It is an essential element of our body and its daily requirement for the adult is 200- 300 mg. Excess of magnesium in our body leads to laxative effect and its deficiency leads to many structural and functional changes, chronic mal absorption problems, chronic renal failure, severe diarrhoea and protein calorie malnutrition (Montgomery, 1985).

The amount of magnesium in groundwater during pre-monsoon varied from 23.06mg/l to 40.21mg/l with the mean value of 29.92mg/l and 23.11mg/l to 35.84mg/l with the mean value of 28.49mg/l during post-monsoon. The amount of magnesium in surface water during pre-monsoon varied from 6.13mg/l to 35.21mg/l with the mean value of 21.91mg/l and 6.54mg/l to 34.19mg/l with the mean value of 21.30mg/l during post-monsoon.

VII. Sodium

As far as health is concerned sodium is the most abundant cation in the extra cellular fluid. The minimum sodium requirement for our body is 120mg/day (WHO, 1996).

The amount of sodium in ground water during pre-monsoon varied from 30.01mg/l to 50.31mg/l with the mean value of 40.35mg/l and 30.82mg/l to 50.31mg/l with the mean value of 40.99mg/l during post-monsoon. The amount of sodium in surface water during pre-monsoon varied from 14.07mg/l to 68.31mg/l with the mean value of 39.63mg/l and 12.89mg/l to 61.02mg/l with the mean value of 37.66mg/l during post-monsoon.

VIII. Potassium

The amount of potassium in soil is controlled by amount of clays, organic matter and moisture content (Buckmann and Brady, 1960). Higher concentration of potassium is an indication of the ground water pollution.

The concentration of potassium in groundwater varied between 7.01mg/l to 31.63mg/l with mean value 12.95mg/l during pre-monsoon and 7.98mg/l to 29.8mg/l with mean value 12.58mg/l during post-monsoon. Potassium content in surface water varied between 4.08mg/l to 33.16mg/l with mean value 15.40mg/l during pre-monsoon and 3.26mg/l to 32.11mg/l with mean value 13.31mg/l during post-monsoon.

IX. Bicarbonate

The water charged with CO₂ passes through soil and rock dissolves carbonate to give bicarbonate (Berner, 1971).

The concentration of bicarbonate in ground water during pre-monsoon varied between 102mg/l to 110mg/l with the mean value of 104.5mg/l and 102mg/l to 109mg/l with the mean value of 103.7mg/l during post-monsoon. The amount of bicarbonate in surface water varied between 75mg/l to 215mg/l with the average value of 133.5mg/l during pre-monsoon and 74mg/l to 205mg/l with the average value of 132mg/l during post-monsoon.

X. Chloride

Chloride is the major inorganic anion in water and wastewater. The concentration of chloride is generally less than that of sulphates and bicarbonates (Trivedy and Goel, 1986).

The concentration of chloride in groundwater varied between 6.04mg/l to 20.05mg/l with the mean value of 10.2mg/l during pre-monsoon and 5.96mg/l to 18.13mg/l with the mean value of 8.96mg/l during post-monsoon. The concentration of chloride in surface water varied between 23.21mg/l to 167mg/l with the mean value 101.38mg/l during pre-monsoon and 22.01mg/l to 160.23mg/l with the mean value 94.38mg/l during post-monsoon.

XI. Sulphate

Sulphate is commonly found anion in most natural waters. Higher concentrations of sulphate ions (200-300mg/l) in drinking waters may result in a therapeutic effect to human beings (Mc Neely *et al.*, 1979).

The concentration of sulphate in groundwater ranged between 5.02mg/l to 13.61mg/l with the mean value of 8.20mg/l during pre-monsoon and 5.02mg/l to 13.61mg/l with the mean value of 7.26mg/l during post-

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monsoon. The concentration of sulphate in surface water during pre-monsoon ranged between 4.02mg/l to 23.36mg/l with the mean value of 15.24mg/l and 5.01mg/l to 23.03mg/l with the mean value of 15.82mg/l during post-monsoon.

XII. Nitrate

Natural nitrate level in ground water is generally very low (less than 10mg/l) but gradually increases due to human activities like agriculture, industry, domestic effluents and emissions from combustion engines (WHO, 1996).

The concentration of nitrate in ground water of the study area varied between 33.12mg/l to 92.01mg/l with the mean value of 45.8mg/l during pre-monsoon and 33.01mg/l to 91.84mg/l with the mean value of 43.92 during post-monsoon. The concentration of nitrate in surface water of the study area varied between 19.14mg/l to 95.35mg/l with the mean value of 58.06mg/l during pre-monsoon and 19.13mg/l to 90.21mg/l with the mean value of 56.0mg/l during post-monsoon.

XIII. Phosphate

Phosphorous is important to plants and animal metabolism and as an essential nutrient used by biota (Matthess, 1982).

Phosphate concentration in the groundwater of study area ranged between 0.011mg/l to 0.093mg/l with the mean value 0.03mg/l during pre-monsoon and 0.011mg/l to 0.74mg/l with the mean value of 0.09mg/l during post-monsoon.

The concentration of phosphate in surface water during pre-monsoon ranged between 0.021mg/l to 2.07mg/l with the mean value of 0.748mg/l and 0.021mg/l to 2.06mg/l with the mean value of 0.69mg/l during post-monsoon.

XIV. Fluoride (F⁻)

Fluoride is the most electronegative of all the halogens as it has unique chemical characteristics. Fluoride present in volcanic gases may be the important sources of fluoride in drinking water (Hem, 1985).

Fluoride concentration in groundwater ranged between 0.68mg/l to 1.1mg/l with the mean value of 0.84mg/l during pre-monsoon and 0.53mg/l to 1.1mg/l with the mean value of 0.83mg/l during post-monsoon.

Fluoride concentration in surface water ranged between 0.18mg/l to 1.47mg/l with the mean value of 0.80mg/l during pre-monsoon and 0.11mg/l to 1.09 mg/l with the mean value of 0.83mg/l during post-monsoon.

XV. Biological Oxygen Demand (BOD)

Biochemical Oxygen Demand (BOD) is a measure of the dissolved oxygen consumed by microorganisms during oxidation of reduced substances in water and wastes. It is not a precise quantitative test, although it is widely used as an indicator of organic quality of water (Clair *et al.*, 2003).

In pre-monsoon season the BOD concentration ranged between 51 mg/l to 192 mg/l with mean value of 119.5 mg/l in surface water samples. In post-monsoon season the concentration of BOD ranged between 49.12 mg/l to 190 mg/l with mean value of 119.4 mg/l in surface water samples. The BOD values of the study area above the permissible limit of 2mg/l (BIS, 2012), which indicate the presence of high organic pollution loading. This is mainly due to the high population density and presence of industries in the area.

XVI. Chemical Oxygen Demand (COD)

The Chemical Oxygen Demand determines the amount of oxygen required for chemical oxidation of organic matter using a strong chemical oxidant, such as potassium dichromate under reflux condition.

In pre-monsoon season the COD concentration of surface water samples ranged between 98 mg/l to 443 mg/l with mean value of 262.68 mg/l. In post-monsoon season the concentration of COD in the surface water samples ranged between 96 mg/l to 441mg/l with mean value of 262.5 mg/l.

Inter-Ionic Relationship between Chemical Parameters

The inter-ionic relationships have been studied to determine whether their source have been similar or divergent.

The scatter point on diagram indicates that various natural reaction and anthropogenic inputs are involved in controlling the chemical composition of ground water of the study area.

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TH – Ca^{2+} , Mg^{2+} and K^+

The statistical relationship between TH- Ca^{2+} , TH- Mg^{2+} and TH- K^+ showed the strong positive correlation (0.9787), (0.8995) and (0.8804) respectively between the two ions, indicating the same source of origin of ions. Calcium and Magnesium ions are contributing to the total hardness of the ground water as shown in Figure 2.

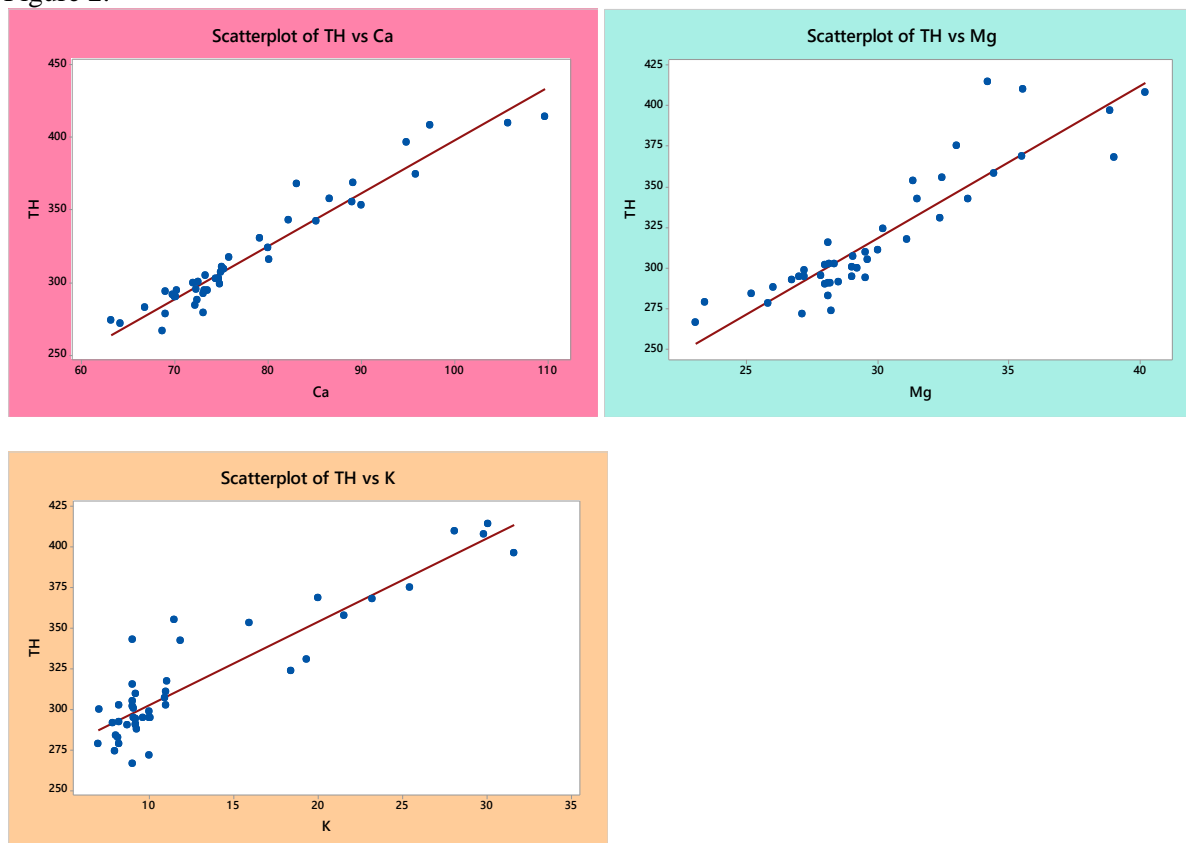


Figure 2: Scatter Plot of TH – Ca^{2+} , Mg^{2+} and K^+

K^+ - Ca^{2+} and Mg^{2+}

The statistical relationship between the K-Ca and Mg (0.8826) and (0.747) respectively showed a positive strong correlation between the ions. There is general pre dominance of Ca and Mg over K ions. It implies that apart from the common source, some additional sources might be leaching from fertilizer, effluent and soil amendments are associated with Calcium and Magnesium as shown in Figure 3.

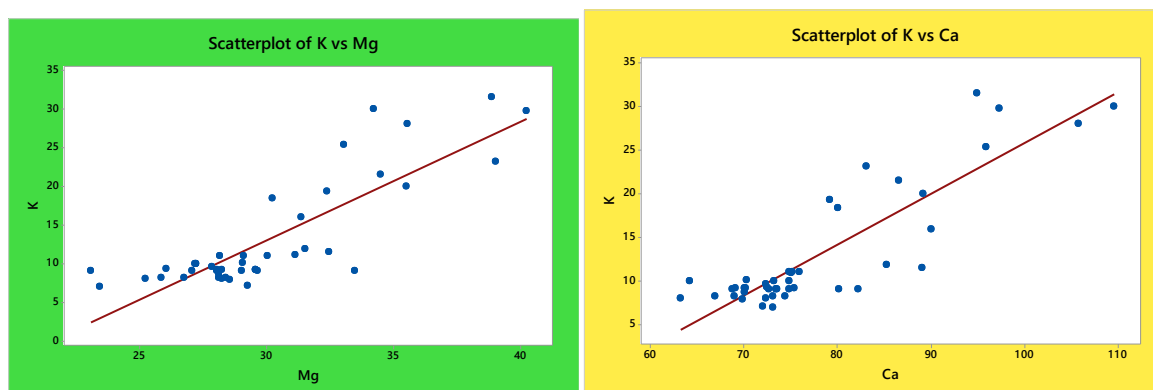


Figure 3: Scatter plot of K^+ - Ca^{2+} and Mg^{2+}

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Cl^- -TH, Ca^{2+} , Mg^{2+} and K^+

The statistical relationship between the Cl^- -TH (0.886), Ca^{2+} (0.885), Mg^{2+} (0.758) and K^+ (0.836) respectively showed a positive strong correlation between the ions. It points towards some additional sources might be leaching from fertilizer, industrial effluent and domestic sewage are associated with that apart from the common source as shown in Figure 4.

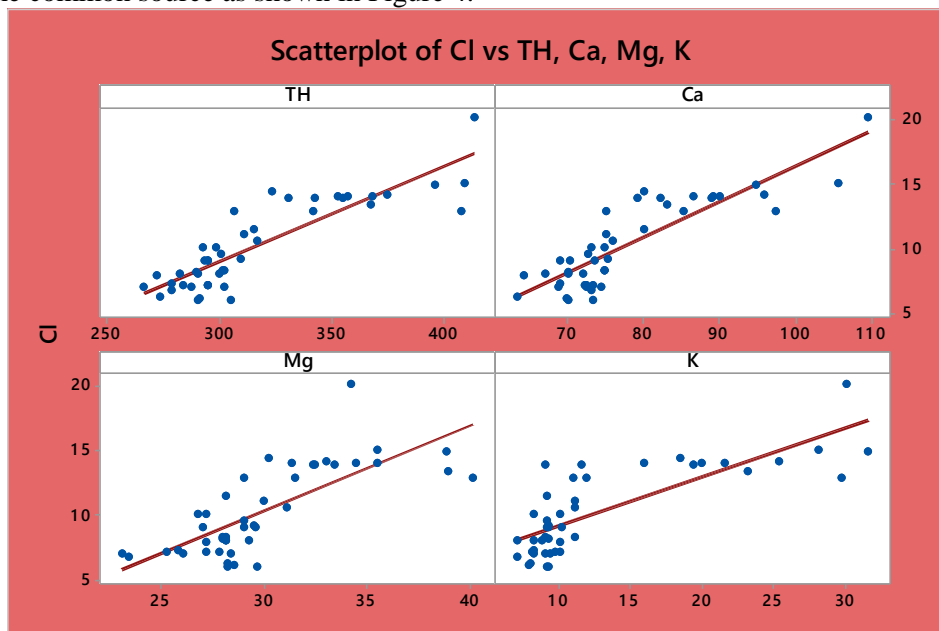


Figure 4: Scatter Plot of Cl^- -TH, Ca^{2+} , Mg^{2+} and K^+

SO_4^{2-} -TH, Ca^{2+} , Mg^{2+} and K^+

The statistical relationship between the SO_4^{2-} -TH (0.7331), Ca^{2+} (0.724), Mg^{2+} (0.639) and K^+ (0.672) respectively showed a positive strong correlation between the ions indicating some anthropogenic inputs i.e. might be leaching from fertilizer, industrial effluent apart from common sources as shown in Figure 5.

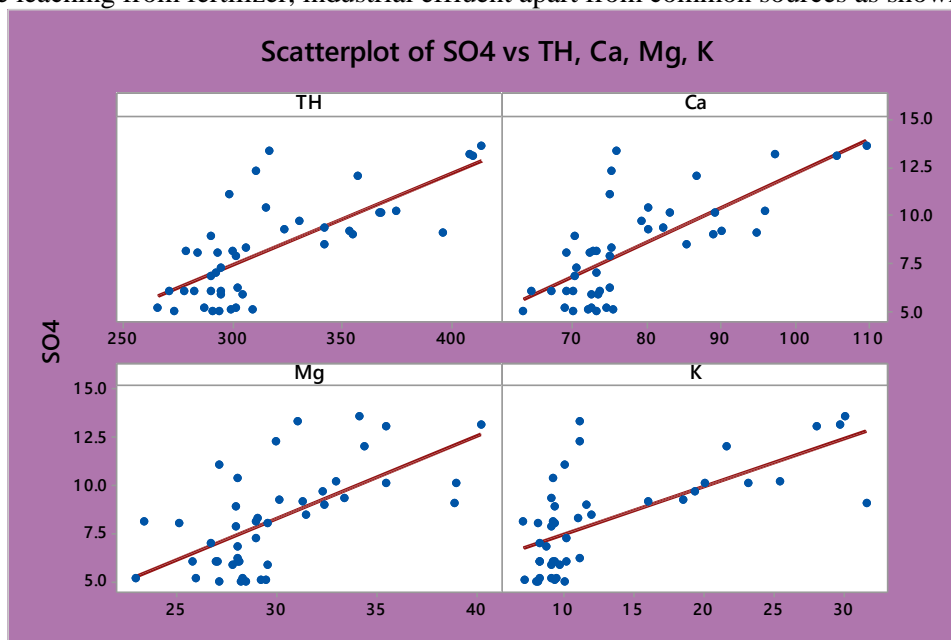


Figure 5: Scatter Plot of SO_4^{2-} -TH, Ca^{2+} , Mg^{2+} and K^+

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NO_3^{2-} -TH, Ca^{2+} , Mg^{2+} and K^+

The statistical relationship between the NO_3^{2-} -TH (0.8946), Ca^{2+} (0.884), Mg^{2+} (0.78) and K^+ (0.93) respectively indicating a positive strong correlation between the ions signifying some anthropogenic inputs i.e. might be leaching from fertilizer, industrial effluent together from common sources as shown in Figure 6.

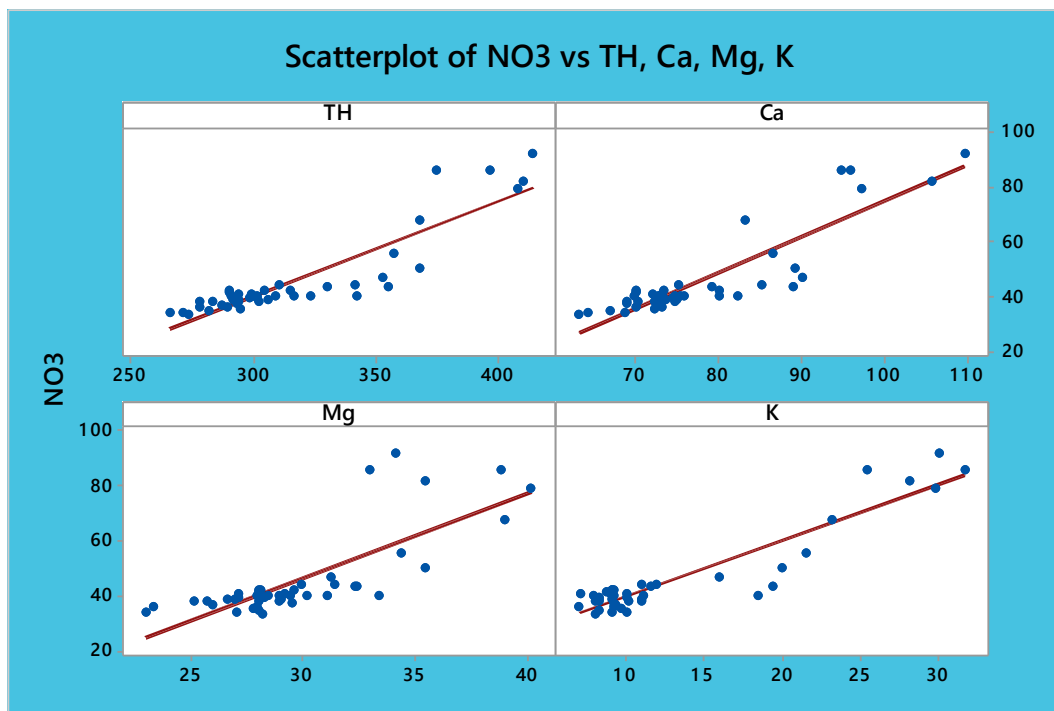


Figure 6: Scatter Plot of NO_3^{2-} -TH, Ca^{2+} , Mg^{2+} and K^+

Correlation Analysis

Correlation refers to any of a broad class of statistical relationships involving dependence. A correlation coefficient of +1 indicates that two variables are perfectly related in a positive linear sense, a correlation coefficient of -1 indicates that two variables are perfectly related in a negative linear sense, and a correlation coefficient of 0 indicates that there is no linear relationship between the two variables.

The direction of the dependent variable's change depends on the sign of the coefficient. If the coefficient is a positive number, then the dependent variable will move in the same direction as the independent variable; if the coefficient is negative, then the dependent variable will move in the opposite direction of the independent variable.

The correlation matrices for 13 variables were prepared for both pre and post monsoon periods for the study area using Minitab 16. The results of correlation matrix in pre and post-monsoon for district Ludhiana is shown in Table 2 and 3, which indicated a significant impact on drinking and agriculture in the area.

Hydro Chemical Facies of Groundwater and Surface water

The hydro chemical facies of a particular place are influenced by geology of the area and distribution of facies by the hydro-geological controls. In the present study, the surface and groundwater of the study area has been classified as per Chadha's diagram (Chadha, 1999).

The diagram is a modified version of Piper trilinear diagram (Piper, 1944) and the expanded Durov diagram (Durov, 1948). In Chadha's diagram, the difference in milli equivalent percentage between alkaline earths (calcium plus magnesium) and alkali metals (sodium plus potassium), expressed as percentage reacting values, were plotted on the X axis and the difference in milli equivalent percentage

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between weak acidic anions (carbonate plus bicarbonate) and strong acidic anions (chloride plus sulphate) was plotted on the Y axis.

Table 2: Correlation Analysis of Groundwater During Pre-Monsoon

	pH	EC	TDS	TH	Ca	Mg	K	Na	HCO ₃	Cl	SO ₄	NO ₃	PO ₄	F
pH	1													
EC	-0.2	1												
TDS	-0.2	1	1											
TH	-0.2	0.59	0.5876	1										
Ca	-0.2	0.65	0.6534	0.9671	1									
Mg	-0.1	0.39	0.3909	0.9062	0.769	1								
K	-0.1	0.55	0.5518	0.9132	0.874	0.844	1							
Na	0.24	-0.07	-0.074	-0.218	-0.17	-0.259	-0.14	1						
HCO ₃	0.18	0.37	0.3696	0.5562	0.564	0.461	0.545	0.039	1					
Cl	-0.3	0.5	0.4996	0.8737	0.868	0.753	0.794	-0.19	0.41	1				
SO ₄	-0.2	0.45	0.4545	0.7331	0.724	0.639	0.672	0.021	0.34	0.774	1			
NO ₃	-0	0.57	0.5721	0.8946	0.884	0.78	0.93	0.115	0.54	0.713	0.621	1		
PO ₄	-0.1	0.59	0.5881	0.3297	0.371	0.212	0.363	0.03	0.22	0.289	0.232	0.372	1	
F	0.34	-0.01	-0.014	0.2364	0.222	0.225	0.196	0.218	0.06	0.233	0.095	0.302	-0.1	1

Table 3: Correlation Analysis of Groundwater During Pre-Monsoon

	pH	EC	TDS	TH	Ca	K	Mg	Na	HCO ₃	Cl	SO ₄	NO ₃	PO ₄	F
pH	1													
EC	-0.2	1												
TDS	-0.2	1	1											
TH	-0.4	0.65	0.6539	1										
Ca	-0.4	0.66	0.6607	0.9787	1									
K	-0.2	0.58	0.5842	0.8804	0.8826	1								
Mg	-0.2	0.54	0.5441	0.8995	0.7906	0.747	1							
Na	0.1	-0.1	-0.118	-0.019	0.0157	0.064	-0.09	1						
HCO ₃	-0.1	0.38	0.3808	0.4781	0.4867	0.317	0.39	0.255	1					
Cl	-0.4	0.59	0.5883	0.886	0.8853	0.836	0.758	-0.01	0.42	1				
SO ₄	-0.3	0.62	0.6164	0.8143	0.8515	0.828	0.617	0.088	0.41	0.884	1			
NO ₃	-0.3	0.56	0.5637	0.911	0.9175	0.935	0.764	0.269	0.39	0.79	0.767	1		
PO ₄	0.09	0.31	0.3141	0.0317	0.0507	0.014	-0.01	-0	-0.1	0.021	0.189	0.01	1	
F	-0.1	0.35	0.3535	0.4791	0.4511	0.423	0.469	0.027	0.14	0.473	0.423	0.425	0.01	1

The milli equivalent 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 square or rectangular field describes the overall character of the water. The diagram can be used to study various hydro chemical processes, such as base cation exchange, cement pollution, mixing of natural waters, sulphate reduction, saline water and other related hydro chemical problems. The chemical analyses data of all the ground water and surface water samples collected from the study area have been plotted on Chadha's diagram (Figure 7 a & b and Figure 8) and results have been summarized in Table 4. The study of the Chadha's diagram revealed that the groundwater samples fall in Group 5 (Ca²⁺-Mg²⁺-HCO₃⁻) which indicates temporary hardness in groundwater sample.

It is evident from the results that the surface water samples fall in Group 5 (Ca²⁺-Mg²⁺-HCO₃⁻) and Group 6 (Ca²⁺-Mg²⁺-Cl⁻-SO₄²⁻) type. However, majority of the surface water sample fall in Group 6 (Ca²⁺-Mg²⁺-Cl⁻-SO₄²⁻) which means alkaline earths exceed alkali metals and strong acidic anions exceed weak

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acidic anions. Such water has permanent hardness and does not deposit residual sodium carbonate in irrigation use.

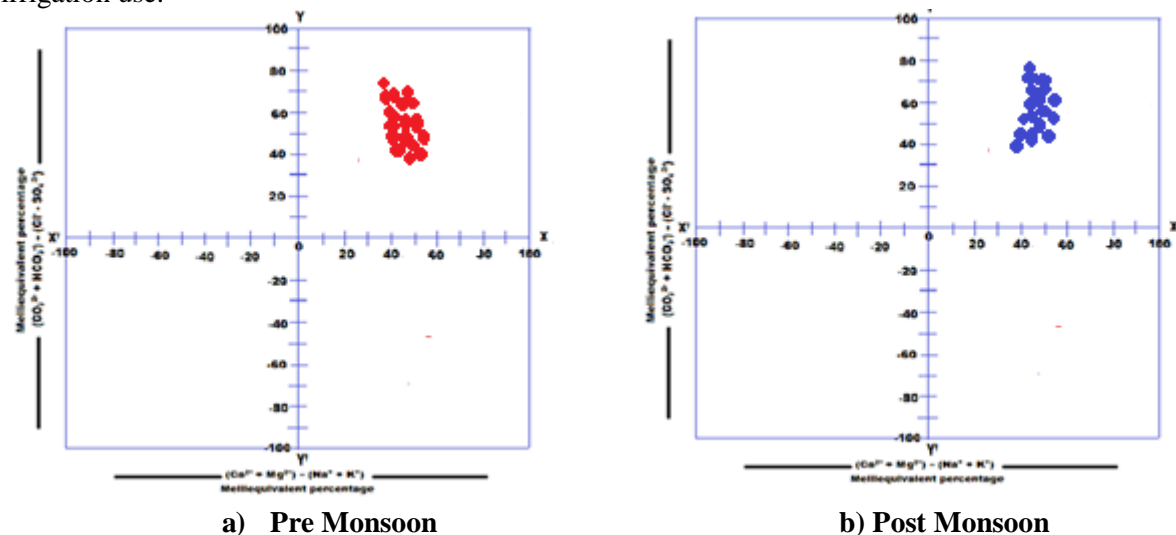


Figure 7: Chadha's Diagram for Groundwater Samples

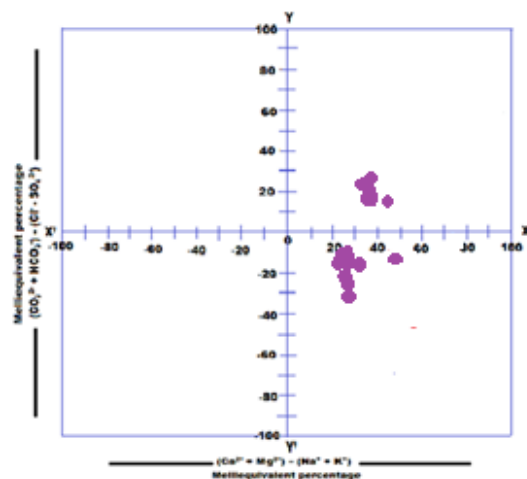


Figure 8: Chadha's Diagram for Surface Water Samples

Table 4: Summarized Results of Chadha's Classification

Classification/ Type	Surface water	Groundwater
Group 1 (Ca^{2+} - Mg^{2+} - Na^{+} - K^{+})	-----	-----
Group 2 (Na^{+} - K^{+} - Ca^{2+} - Mg^{2+})	-----	-----
Group 3 (HCO_3^{-} - Cl^{-} - SO_4^{2-})	-----	-----
Group 4 (SO_4^{2-} - HCO_3^{-} - Cl^{-})	-----	-----
Group 5 (Ca^{2+} - Mg^{2+} - HCO_3^{-})	06	44
Group 6 (Ca^{2+} - Mg^{2+} - Cl^{-} - SO_4^{2-})	16	-----
Group 7 (Na^{+} - K^{+} - Cl^{-} - SO_4^{2-})	-----	-----
Group 8 (Na^{+} - K^{+} - HCO_3^{-})	-----	-----

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Conclusion

Increasing population in Ludhiana has caused rapid changes in water quality and increased environmental degradation. Major effect of increase in urbanization, industrialization and agricultural activities is seen on water resources which are getting depleted due to over extraction of groundwater resources and brought the study area under over exploited category where no more groundwater exploitation is possible. The status of water resources in Ludhiana district becomes a serious challenge. The policies should be formulated according to the need of the present environment. The over-exploited blocks need immediate sustainable effective management plan. General population awareness through mass-media, campaigns, public speaking should be conducted to sensitize the harmful impacts of soil and water health on agriculture.

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