# RIVERBANK FILTRATION FOR SUSTAINABLE DRINKING WATER SUPPLY

**A**

**Dissertation Work**

**Submitted by**

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*(An ISO 9001:2008 Certified Organization)*

## CERTIFICATE

This is to certify that the dissertation work entitled **"Riverbank Filtration for Sustainable Drinking Water Supply"** is a bonafide dissertation work carried out by **Mr. Sanket Kumar Mohanty** (M.Sc. Applied Geology & Geoinformatics) at the National Institute of Hydrology in the partial fulfillment of requirements for the degree of Master of Science (Applied Geology & Geoinformatics) during the year 2016 under my supervision.

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# DECLARATION

I hereby declare that the project work entitled "**Riverbank Filtration For Sustainable Drinking Water Supply**" submitted to Central University of Karnataka in partial fulfillment of requirements for the award of the Degree of Master of Science in Applied Geology and Geoinformatics is a record of original research work done by me under the guidance of Dr. Narayan C. Ghosh (Scientist-G & Head), Groundwater Hydrology Division, at the National Institute of Hydrology, Roorkee.

Sanket kumar Mohanty

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# SYNOPSIS

Projected estimate of many investigators showed that India's domestic water demands may increase to 8 % (59 BCM/year) and 10% (100 BCM/year) of the total uses of the year 2025 and 2050, respectively against the demands of 42 BCM/year in the year 2010 . The risk enumerating by the deterioration of water quality on the available quantity can be one of the main hurdles in addition to the quantity to be available as utilizable water resources to secure the future demands of domestic water supply. Attainment of India's domestic water supply security with the approach of business usual may be a difficult task and would require a coordinated management of available resources. Riverbank Filtration (RBF) is one of the approaches that consider conjunctive management of surface and ground water by way of inducing surface water when groundwater is pumped in the vicinity of a surface and ground water system, can bring source sustainability in domestic water supply security. India has a lot of potential for employing RBF technique, particularly in the Indo-Gangetic-Brahmaputra alluvium areas, coastal alluvium tracks and scattered inland pockets in different states where surface water bodies are hydraulically connected to the adjoining aquifer, and aquifers have good soil pores.

Selection of potential sites, decision of effective distance of production well, flood proofing of the scheme, post-treatment requirement and risk assessment, efficiency assessment, river-aquifer interaction understanding, etc. are some of the important design considerations which need a good understanding and knowledgebase before such schemes are implemented and promoted at large scale. A large gap of technical knowledge and understanding exists amongst the utility groups and technical professionals in India. Therefore, there is a need of extensive scientific studies and capacity building on this technique before it is promoted in a large scale.

The present dissertation work entitled **"Riverbank Filtration for Sustainable Drinking Water Supply"** has been carried out under the framework of the **"Peya Jal Suraksha" project** funded by the Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India to the National Institute of Hydrology, Roorkee. The project aims at developing riverbank filtration scheme in 6 different locations all over India on pilot basis. In those locations, RBF wells (tube wells) will be dug and groundwater will be pumped out to induce the flow of water from the river towards those wells through subsoil passage. The water from the river, groundwater and RBF well will be constantly monitored and studied. If the filtrate water from RBF wells show significant improvement in quality and adheres to BIS standards then water would be supplied to the targeted areas for drinking water uses. Depending on the success of this pilot program, RBF technology would be up-scaled in other feasible hydrogeological settings of India.

Precisely, RBF is a process by which surface water from rivers, channels and lakes is induced by pumping from nearby production wells to flow through the natural aquifer soil, undergoing many positive changes in water quality before finally mixing with local groundwater in the land side and then extracted for direct use or further treatment. By applying this technique water is extracted conjunctively from two different water resources, surface and shallow ground water

In the present dissertation work, three locations out of six are considered for study. These study sites are; Laksar on banks of the Solani River (Haridwar, Uttarkhand), Agra and Mathura on banks of the River Yamuna (Uttar Pradesh). The goals of the dissertation work are to:

(i) To review and understand the mechanisms of riverbank filtration technique, its various scientific aspects, and performances reported by different investigators,
(ii) To analyze the performances of analytical tools available for computation of riverbank filtrate quantity, and
(iii) To analyze water chemistry of source water (surface and ground water) for the selected sites adopted by NIH to develop pilot demonstration schemes.

For analyzing the water chemistry of the selected sites, water samples from the different locations were collected and a detailed water quality analysis of the major ions and physical parameters were carried out. The water samples were mainly collected from the river and nearby groundwater sources. A total of 16 water samples were collected from Agra and Mathura area, while 13 water samples were collected from Laksar site. A number of water quality parameters namely, pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Turbidity, Biochemical Oxygen Demand (BOD), Sodium ($Na^+$), Potassium ($K^+$), Total Hardness (TH), Calcium ($Ca^{2+}$), Magnesium ($Mg^{2+}$), Ammonium ($NH_4$), Bicarbonate ($HCO_3^-$), Sulphate ($SO_4^{2-}$), Nitrite($NO_2^-$), Nitrate ($NO_3^-$), Fluoride ($F^-$) and Chloride ($Cl^-$) were analyzed to detect their value. Bacteriological parameter namely, coliform bacteria in water samples were carried out for Laksar site. Heavy metal namely, Iron (Fe), and Manganese (Mn) in water samples for Laskar site was also analyzed.

Interpretation of the water quality parameters was carried out by using Piper plots, Durov Plots and linear regression equations. Spatial distributions of different parameters were shown to demonstrate how the parameters varied between SW and GW samples in the study area. A water quality index was developed for the study area to understand the overall quality of water .

A thorough review on mechanism of RBF, factors that influence RBF, its advantages, site suitable for RBF, uses in other countries and performances, and scope of uses in India were also presented. Based on the study, a comprehensive summary and conclusions were also drawn.

The matters of the dissertation work were presented in six chapters. The Chapter-1 gives a brief introduction describing need of the study; the Chapter-2 describes a brief review of the related matter; the Chapter-3 provides the details about the 'Riverbabk Filtration' including its mechanism and scientific aspects; the Chapter-4 offers the analytical tools for computation of bank filtrate; the Chapter-5 brings out the analysis of water chemistry of three pilot sites , and the Chapter-6 gives the summary and conclusion part.

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# CHAPTER 1
# INTRODUCTION

Water is the primary requirement for all aspects of life. It is imperative to make certain, that adequate quantity of water of good quality are maintained for all the needs of entire population of this planet, while preserving the hydrological, biological and chemical functions of ecosystems, adapting human activities within the capacity limits of nature and combating vectors of water-related diseases. Innovative technologies including the improvements in the indigenous technologies are needed to fully utilize limited water resources and to safeguard these resources against pollution.

Amongst the various uses of water, drinking water is the primary requirement. The National Water Policy of India (2012) has also emphasized drinking water supply as the first priority. It is widely accepted that India, with more than 125 crore population, faces daunting challenges in meeting the growing water supply needs of an increasing population. The problem is particularly acute for the urban population, which is about 32% of the total population. The country currently has a population growth of 15.5 million annually. From 1991 to 2001 the population increased by 21.3% with the net addition of 70 million to the urban population. Given the current demographic trends, India's population is projected to be nearly 1.4 billion by 2025.

Domestic water demand in India (excluding agricultural and industrial use) amounted to only 4.8% of the total demand in 1990 and is projected to increase to 20.6% of total water use by 2050 (Sandhu et al, 2010)). This is projected to show an increasing trend from $25 \times 10^9$ $m^3$/year in 1990 to $116 \times 10^9$ $m^3$/year in 2010 and reach $174 \times 10^9$ $m^3$/year by 2025. Providing safe drinking water to an extra 417 million people, in addition to those currently lacking it, is a major concern and will increasingly become a major issue—especially in the urban centers along the major rivers that constitute the densely populated Indo-Gangetic flood plain (known as the "bread basket of India"). Thus, a sustainable supply of water to a city/ town will depend on the quantity and quality of the water available and its distance from that city.

Surface water is the primary source of drinking water for most of the urban areas in India located along or near rivers and groundwater is the major source of drinking water for rural areas. It is stated that 85% of rural domestic needs and 50% of urban and industrial needs are met by groundwater. Shortfalls in water availability from river sources, however, are being amplified by increased upstream diversions for irrigation and other uses. Groundwater quality deterioration from the contaminants of geogenic origin has emerged as a major threat to this important resource and is becoming a limiting factor for its widespread uses.

The three most significant factors affecting water supplies in India are: (a) inadequate supply sources, (b) poorly developed supply infrastructure, and (c) high levels of river water pollution caused by inadequate upstream treatment of domestic sewage and industrial wastewater and increasing groundwater contamination by the sources from anthropogenic and geogenic origin.

Till date, India's main focus to domestic water supply remained onto making the water available to every households and quantity management. There is a lack on quality safety of water being supplied and quality management of source water. Access to safe drinking water remains an urgent necessity, as 30% of urban and 90% of rural Indian population still depend on untreated surface or ground water resources. While access to drinking water in India has increased over the past decade, the tremendous adverse impact of unsafe water for health continues. It is estimated that about 21% of the communicable diseases in India is water born. Though, recent years shift in usage from surface water to groundwater has controlled microbiological problems in rural India at certain extent, but the same has led to newer problems of arsenic, fluorosis, and salinity due to over exploitation of groundwater. Excess iron is an endemic water quality problem in many part of the India. About 17 Indian states were affected by problem of fluorosis in 2002, which has now been extended in more than 20 states, indicating that endemic fluorosis has emerged as one of the most alarming public health problems in the country. Nearly 8 states have exposed to arsenic contamination in groundwater. Deteriorating quality of the available water resources and availability of potable water are being recognized as a major crisis in many parts of India.

Riverbank Filtration (RBF), as a natural pre-treatment technique, is widely used in many European Countries and USA since more than a century for supply of drinking water in urban and semi-urban areas owing to its prospect of removing suspended particles, pathogenic compounds, trace organics and microorganisms present in the source water to a reasonable extent. It is also gaining popularity in India as well. However, its large-scale implementation in India is confronted by a number of issues, which include; a haphazard and an intensive growth of RBF wells can upset stream flow causing adverse effects on the river's habitat and ecology downstream, can affect water budget, catchment water balance and administration rights, etc

Experiences from RBF investigations worldwide demonstrated that it is a highly effective method for significant removal of turbidity, natural organic matter, trace organic chemicals and pharmaceuticals, salinity, as well as taste- and odor-causing compounds, which may not be removed from the surface water by conventional treatment methods. The ability of bank filtration schemes to provide a significant barrier to microorganisms has also been observed, and it has been proven to significantly reduce the presence of Giardia and Cryptosporidium for drinking water applications when flow path length and filtration times are sufficient.

Recognizing the strength, capability, and significance and its potential for large-scale up-scaling in India, the National Institute of Hydrology (NIH), Roorkee together with HTWD, Germany has developed a master plan on RBF indicating feasible river stretches for detailed studies and further initiatives. As a step towards that direction, NIH has taken lead to develop six pilot RBF demonstration schemes in various hydrogeological settings in different parts of the Country. The area chosen for this six pilot demonstration schemes are : one along the river Solani in Uttarakhand; two along the river Yamuna at Mathura and Agra; one along the river Ganga in Sahebganj in Jharkhand; one along the river Ganga in Bhojpur (Bihar); and one in Vishakapattanam in Andhra Pradesh.

Keeping the above points in view and the prospect of RBF technology in India, this dissertation work is undertaken to address the following objectives.

**The objectives of the study:**

The objectives of the study are:

- To review and understand the mechanisms of riverbank filtration technique, its various scientific aspects, and performances reported by different investigators,
- To analyze the performances of analytical tools available for computation of riverbank filtrate quantity, and
- To analyze water chemistry of source water (surface and ground water) for few sites adopted by NIH to develop pilot demonstration schemes.

The tasks carried out in this dissertation work have been presented in six chapters. The Chapter-1 gives a brief introduction describing need of the study; the Chapter-2 describes a brief review of the related matter; the Chapter-3 provides the details about the 'Riverbank Filtration' including its mechanism and scientific aspects; the Chapter-4 offers the analytical tools for computation of bank filtrate; the Chapter-5 brings out the analysis of water chemistry of few pilot sites adopted by NIH and surveyed during the course of this dissertation work, and the Chapter-6 gives the summary and conclusion part. The references consulted in the dissertation work are also included in the end.

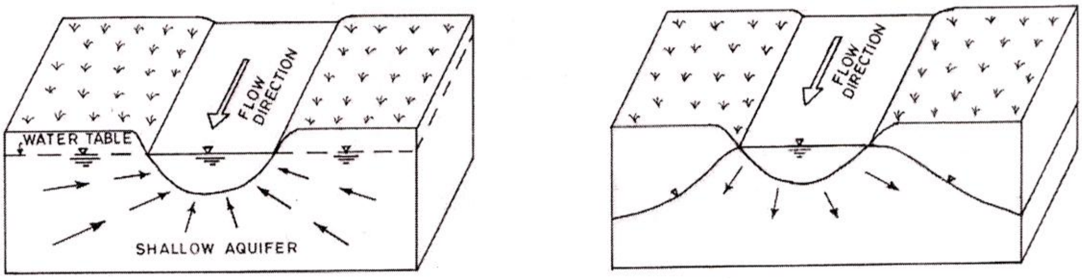
# CHAPTER-2
# REVIEW OF LITERATURE

## 2.1 General

The mechanism of riverbank filtration (RBF) is mainly based on the stream/river-aquifer interaction. Stream/river-aquifer interaction is one of the important hydrological processes that hold the interface between the surface and the ground water flow. A lot of water supply schemes are developed based on the interaction and dependability of flow between these two flow domains. Nevertheless, a known fact but seldom do it is realized that riverbanks serve the purpose of filtering media of water in either of the domains. During lean flow period, the flow appears in a stream is mainly generated from the aquifer, if a stream is not otherwise fed by snow or glacier melt water. Low flows in streams/rivers are largely controlled by stream-aquifer exchange of water; the magnitude of which is governed by the hydraulic properties of both stream and aquifer and the aquifer material beneath the stream in addition to the potential difference of heads between the two domains. An effluent stream receives water from the adjoining aquifer, while an influent stream releases water to the aquifer. The rates of gain and loss of water from/to a domain depends mainly on potential difference of heads between the water levels in the stream and the water table in the aquifer besides the subsurface material below the streambed and other factors. Decrease in stream flow discharges affects the hydraulic quantities and also the water quality and temperature of stream's water.

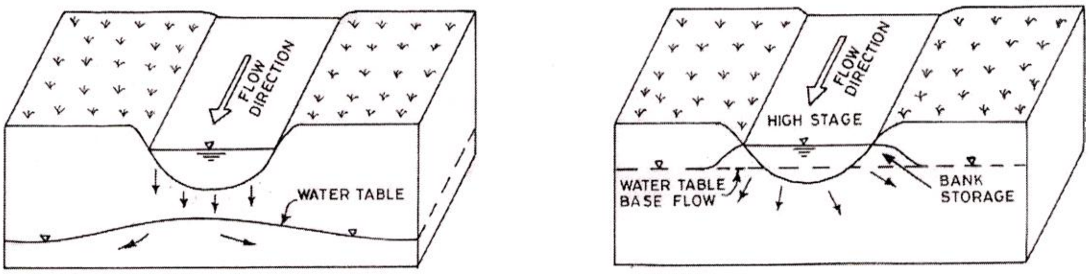
Streams interact with groundwater in all types of landscapes. The interaction may take place in many ways; however, there are three basic ways: (i) gaining or effluent streams; (ii) losing or influent streams, or both, gaining in some reaches and losing in other reaches, and (iii) disconnected streams. Other possible cases are: (a) stream may have no flows through streambed; and (b) in the form of bank storage.

Streams gain water from inflow of groundwater through the streambed when the elevation of the water table adjacent to the streambed is greater than the water level in the stream-water surface (Figure 1A) known as gaining or effluent stream; and when they lose water to groundwater by outflow through the streambed is known as losing or influent stream (Figure 1 B). For surface water to seep to groundwater, the altitude of the water table in the vicinity of the stream must be lower than the altitude of the stream-water surface (Figure 1B). Contours of water-table elevation indicate by pointing in an upstream direction in case of gaining streams, and pointing towards downstream direction in case of losing streams, in the immediate vicinity of the stream. Losing streams can be connected to the ground-water system by a continuous saturated zone (Figure 1A) or can be disconnected from the groundwater system by an unsaturated zone. Where the stream is disconnected from the groundwater system by an unsaturated zone, the water table may have a discernible mound below the stream (Figure 1C). This happens when the rate of recharge through the streambed and unsaturated zone is greater than the rate of lateral groundwater flow away from the water-table mound. An important feature of streams that are disconnected from groundwater is that pumping of shallow groundwater near the stream does not affect the flow of the stream near the pumped wells.



A. GAINING OR EFFLUENT STREAM

B. LOSING OR INFLUENT STREAM



C. DISCONNECTED STREAM

D. BANK STORAGE

**Figure 1: Stream/River-Aquifer Interaction Processes.**

There is enormous literature available on river hydraulics and river flow modeling. These aspects are not included in the review part. This review is focused mainly to groundwater part and RBF technique.

Being a student of geology; to understand more about groundwater part, a brief review of various aspects of groundwater hydrology are included in the subsequent sections.

## 2.2 Groundwater occurrence

Groundwater in nature occurs in two different zones: unsaturated and saturated zone, which are explained below.

### Unsaturated zone

The unsaturated zone occurs immediately below the land surface in most areas and contains both water and air. In the unsaturated zone flow occurs beneath the land surface and above the groundwater table. The groundwater table forms the boundary between unsaturated subsurface flow (above it) and saturated subsurface flow (below it). In the unsaturated zone the preferred path of movement of moisture is vertical, by percolation, toward the saturated zone.

### Saturated zone

Water in the saturated zone is the only water under the surface that is available to supply wells and springs and is the only water to which the name groundwater is correctly applied. Recharge of the saturated zone occurs by percolation of water from the land surface through the unsaturated zone. The water table is the level in the saturated zone at which the hydraulic pressure is equal to the atmospheric pressure and is represented by the water table. Below the water table, the hydraulic pressure increases with increasing depth.

## 2.3 Types of aquifers

There are basically two types of aquifer:-

### Unconfined aquifer

A groundwater aquifer is said to be unconfined when its upper surface (water table) is open to the atmosphere through permeable material. As opposed to a confined aquifer, the water table in an unconfined aquifer system has no overlying impervious rock layer to separate it from the atmosphere.

### Confined Aquifer

A confined aquifer is a water-bearing stratum that is confined or overlain by a rock layer that does not transmit water in any appreciable amount or that is impermeable. Confined aquifers are bounded above and below by aquicludes or aquitards. Water is under pressure from overlying rock and hydraulic pressure from recharge. The groundwater source such as artesian wells and springs are generally found in this aquifer.

**Artesian well** — a situation in which groundwater under pressure rises above the level of the aquifer.

**Spring** – A place where groundwater naturally comes to the surface resulting from water table meeting the land surface.

## 2.4 Aquifer terminology

**Aquifer**

Permeable rock strata or sediment that transmits groundwater freely (e.g. sand gravels or fractured limestone). An aquifer is permeable enough to allow for the storage, flow and pumping (extraction) of groundwater.

**Aquitard**

A geological formation or a group of formation through which virtually no water moves. It is a semi-confining stratum that permits some groundwater flow at a very low transmission rate. eg. a leaky confining bed.

**Aquiclude**

A geological formation of low permeability, which can absorb water, but cannot transmit it at a rate sufficient for economic extraction by wells.

**Aquifuge**

An aquifuge is a geological formation with low permeability and porosity. This does not transmit any groundwater and does not contain groundwater in appreciable quantities.

## 2.5 Parameters of an Aquifer

**Porosity and Void Ratio**

Porosity is defined as the part of rock that is void space, expressed as a percentage

$$n = \frac{V_v}{V_T}$$

Where $V_v$ is the void volume [$L^3$] and $V_T$ is the total volume [$L^3$]. A related parameter is termed the **void ratio**, designated as e, and stated as:

$$e = \frac{V_v}{V_s}$$

Where $V_v$ is the solid volume [$L^3$]. As the total volume is the sum of the void and solid volume, the following relationship can be derived to relate void ratio and porosity.

$$e = \frac{n}{1-n} \text{ or } n = \frac{e}{1+e}$$

Primary porosity is reserved for interstitial porosity and the secondary porosity is used for fractured or solution porosity.

**Permeability**

The permeability of rock is its capacity for transmitting a fluid. Degree of permeability depends upon the size and shape of the pores, the size and shape of their interconnections. The Darcy is the standard unit of permeability.

1 Darcy = 0.987×10-8cm$^3$ or 1.062×10-11ft$^2$.

**Specific Yield in Unconfined Aquifer**

Specific yield is the volume of water that is released from storage in an unconfined aquifer per unit surface area of the aquifer per unit decline in the water table. To determine this coefficient, given volume of the aquifer is extracted and put on a mesh surface. The ratio of the volume of water discharged from the sample, considering the gravity, over total volume of the sample is its specific yield.

$$S_y = \frac{dV}{Adh}$$

Where $S_y$ is the Specific Yield (dimensionless); $dV$ is the volume of withdrawn water [L$^3$]; $dh$ is the change in water level water in the aquifer [L]; $A$ is the aquifer area, [L$^2$].

**Specific Retention**

Specific retention (dimensionless) is described as:

$$S_r = n - \hat{n}$$

Where, $S_r$ is the specific retention; $n$ is the porosity; $\hat{n}$ is the effective porosity, which is the same as the specific yield for all practical purposes.

The summation of Specific yield and Specific retention of an aquifer gives the porosity of an aquifer:

$$n = S_y + S_r$$

**Storage Coefficient (S)**

It is the property of aquifer to store water in the soil/rock pores. The storage coefficient/ storativity is defined as the volume of water released from storage per unit area of the aquifer per unit decline in hydraulic head. It is a dimensionless parameter.

**Specific Storage ($S_s$)**

This is the volume of water which a unit volume of the confined aquifer releases from storage because of expansion of water and compression of the aquifer under a unit decline in the average hydraulic head. It has the dimension of L$^{-1}$, $S_s$ is used exclusively in confined aquifer analysis.

$$S_s = \rho g (\alpha + \eta\beta)$$

**Transmissivity (T)**

It is the property to transmit water. It is defined as the rate at which water is transmitted through unit width and full saturated thickness of the aquifer under a unit hydraulic gradient. It has the dimension of $[L^2T^{-1}]$.

**Hydraulic Conductivity (K)**

Hydraulic conductivity (K) is a measure of the capability of a medium to transmit water. It is defined in two separate parts considering the saturation or unsaturation status of the media .It has the dimension of $[LT^{-1}]$.

$$K = \frac{T}{h}$$

Where h is the thickness of the aquifer [L]; and T is the Transmissivity $[L^2T^{-1}]$.

**Hydraulic Diffusivity (T/S)**

This is the single formation characteristic that combines the transmission property, K and storage property, $S_s$ or alternately or T and S.

$$\frac{T}{S} = \frac{K}{S_s}$$

It has dimensions of $L^2T^{-1}$ and is a significant property of the medium for transient flow. In argillaceous materials, the Hydraulic diffusivity is generally less than ($10^{-9} - 10^{-7}$ $m^2s^{-1}$) than in crystalline rocks, ($10^{-7}$ to $10^{-5}$ $m^2s^{-1}$), which appears to be due to the low specific storage of crystalline rocks.

## 2.6 Darcy's law

The basic principle based on which the ground water flow equation is derived is the continuity equation and the Darcy's law in a soil pore.

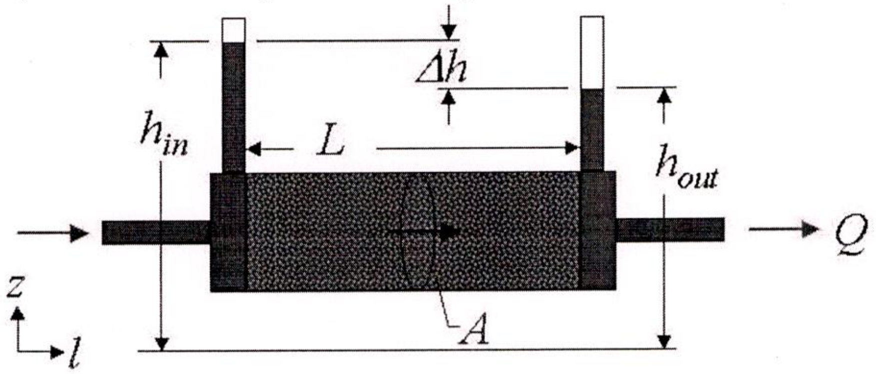


**Figure 2:- Representation of Darcy Law**

The Darcy's law, which states that the rate of flow (i.e., volume of water per unit time), Q, is (i) proportional to the cross- sectional area A, (ii) proportional to the difference in water level elevations in the inflow and exit reservoirs of the filter ($h_1$-$h_2$), and (iii) inversely proportional to the filters length, L. Mathematically, $q = K\ A\ (h_1 - h_2)/L$, where K is a coefficient of proportionality. The heights $h_1$ and $h_2$ are measured with respect to some common datum level. In simple term, the Darcy's law can be written as,

$$q = \frac{Q}{A} = K\frac{dh}{dl} \tag{1}$$

Where Q is the flow rate and A is the cross sectional area through which groundwater flow takes place and K is a coefficient of proportionality or hydraulic conductivity, which is defined as:

$$K = \frac{k\,\rho\, g}{\mu} \tag{2}$$

Where k is the intrinsic permeability of the porous material; p is the pressure head, ρ is the density of the fluid.

## 2.7 A review on Riverbank Filtration

Riverbank filtration, as a pre-treatment technique for drinking water supply, has successfully been practicing in many European countries namely, in Germany, Hungary, the Netherlands, the Slovak Republic, and many other countries since more than 100 years. In Germany the Düsseldorf waterworks have used RBF since 1870 (Schubert, 2002), and the Saloppe waterworks in Dresden have used RBF since 1875 (Fischer et al.,2006). In USA, it has been practicing more than 50 years. A number of Indian cities, such as, Ahmedabad, Delhi, Haridwar, Mathura, Medinipur and Kharagpur, Nainital, Patna and Srinagar with source waters of significantly varying quality, are using RBF technique. In most of these cities no significant additional treatment is provided to the filtrate for their water supply.

The process of bank filtration (riverbank filtration or "RBF" in cases where the surface water body is a river) is initiated by the lowering of a groundwater table below that of an adjoining surface water table (Figure 3). Provided that no artificial (e.g., brick- or concrete-lined bed) or natural (e.g., a low-hydraulic-conductivity layer such as clay) barriers exist, the difference in water levels causes the surface water to infiltrate through the permeable riverbed and bank or lakebed into the aquifer. The infiltration may be the direct result of an influent river under natural conditions or it may be induced by purpose-built groundwater extraction wells (tube wells). Wells for extracting bank filtrate may be either vertical or horizontal. The aquifer serves as a natural mechanical filter and also biochemically attenuates potential contaminants present in surface water. Compared with direct surface water abstraction, bank filtration with its effective natural attenuation processes eliminates bacteria, biodegradable compounds, parasites, particles, suspended solids, and viruses; partly eliminates adsorbable compounds; and equilibrates temperature changes and concentrations of dissolved constituents in the bank filtrate (Hiscock and Grischek *2002*).

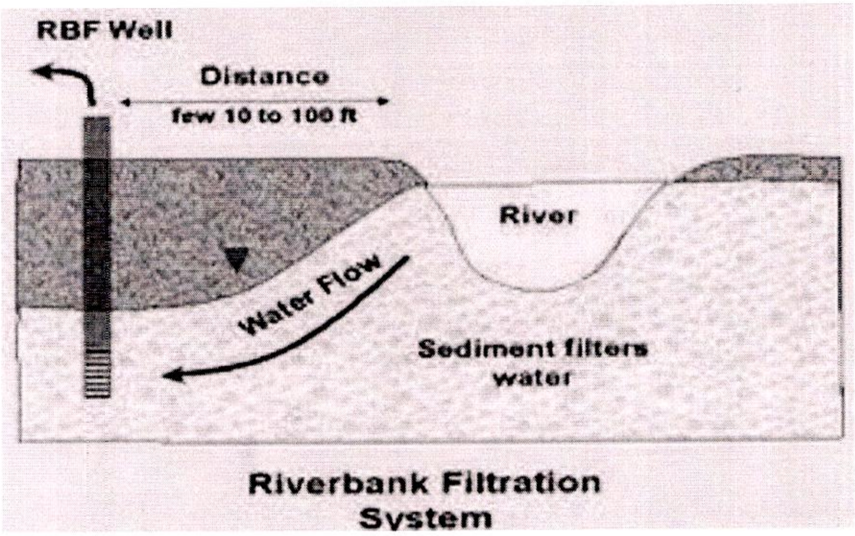


**Figure 3**: Schematic diagram of a RBF well showing its connectivity with the river and aquifer (source: internet images on BF).

## 2.8 Scope of Riverbank Filtration in India

Projected estimate of many investigators (Kumar et al, 2005; Sandhu et al, 2011) showed, India's domestic water demands that amounted to only 5.13% (30 BCM/year) and 6.75% (42 BCM/year) of the total uses in the year 1999 and 2010 respectively, may increase to 8 % (59 BCM/year) and 10% (100 BCM/year) of the total uses of the year 2025 and 2050, respectively. The risk enumerating by the deterioration of water quality on the available quantity can be one of the main hurdles in addition to the quantity to be available as utilizable water resources to secure the future demands of domestic water supply. Attainment of India's domestic water supply security with the approach of business usual may be a difficult task and would require a coordinated management of available resources. RBF is one of the approaches that consider conjunctive management of surface and ground water by way of inducing surface water when groundwater is pumped in the vicinity of a surface and ground water system can bring source sustainability in domestic water supply security. India has a lot of potential for employing BF technique, particularly in the Indo-Gangetic-Brahmaputra alluvium areas, coastal alluvium tracks and scattered inland pockets in different states where surface water bodies are hydraulically connected to the adjoining aquifer, and aquifers have good soil pores. The map (Figure 4) showing major river networks superimposed on the hydrogeology of India indicates the river stretches underlain by alluvium formation have the potential for RBF.

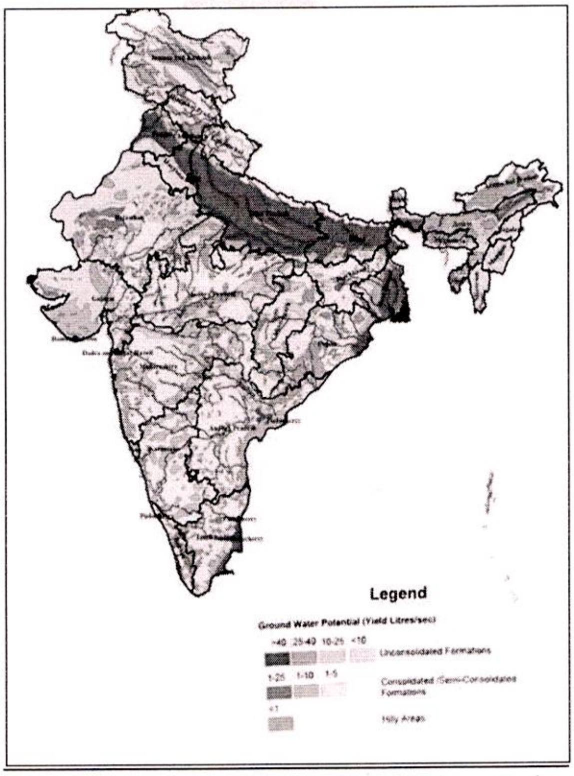


**Figure 4**: Map showing river networks superimposed on Hydrogeology of India.

Selection of potential sites, decision of effective distance of production well, flood proofing of the scheme, post-treatment requirement and risk assessment, efficiency assessment, river-aquifer interaction understanding, etc. are some of the important design considerations which need a good understanding and knowledgebase before such schemes are implemented and promoted at large scale. A large gap of technical knowledge and understanding exists amongst the utility group and technical professionals in India.

## 2.9 Potential and Performance of RBF in India

Bank filtration is used as a reliable method of providing drinking water with a superior esthetic appearance when compared to water supplied by direct extraction of surface water. It eliminates bacteria, biodegradable compounds, parasites, particles, suspended solids, and viruses; partly eliminates adsorbable compounds (Hiscock and Grischek, 2002). High concentration of organic wastes in water requires higher degree of chlorination thereby increasing the level of chemicals in the treated water. RBF comes as an alternative at this point by acting as a pretreatment step and reducing the degree of chlorination and required flocculation.

Existing RBF facility in Haridwar has performed successfully by reducing DOC and coliform level in water. it has provided safe drinking water during monsoon fluctuations and also at the peak occasions like Kumbh Mela. Similarly in Delhi we observe a marked reduction in the concentration of aluminum, copper, lead, ammonia, arsenic, nitrates, fecal coliform and pesticides in the bank filtrate. In Mathura RBF facility has not only mitigated the problems of turbidity, organics and pathogens which earlier existed in the water of river

Yamuna but also as an alternative of pre-chlorination. In Ahmedabad RBF caters the drinking demands through 7 radial collector wells which supply water with a minor level of disinfection in non-monsoon period. However it fails to perform during flooding and monsoon period owing to the increased level of turbidity and sand content in the filtrate.

In Nainital the concept of RBF is utilized when water is extracted by help of tubewell adjacent to Lake Nainital as a result of which the water passes through a formation of clay, sand and shale. This helps in removal of fecal coliform to such an extent that chlorination is avoided. In districts of Medinipur and Kharagpur (West Bengal) water is extracted by RCW which caters the demands of Indian Railways and IIT Kharagpur without any need of disinfection. In the city of Srinagar (Uttarakhand) RBF is utilized to meet drinking demands instead of direct water abstraction from Alkananda River. RBF has proved its worth because the bank filtrate is devoid of bacteriological contamination and low values of turbidity. In Patna RBF wells provide a sustainable supply of drinking water a period of time when groundwater table is declining in some areas of the region and surface water treatment plant is an expensive option to operate. Low amount dissolved organic carbon is observed in the filtrate and disinfection by chlorination is required.

Apart from the existing facilities which are mainly located in the Indo-Gangetic plains, the prospects of RBF can be tested and challenged in different hydro-geological scenario of India. Riparian cities adjacent to River Ganga are the default choices for RBF applications. If we move towards peninsular India then confluences of peninsular rain-fed river and perennial snow fed rivers promises a potential location. Based on the available hydrogeological and geological data potential locations for additional RBF sites include Allahabad (Uttar Pradesh), Bhubaneswar (Orissa), Guwahati (Assam), and Vijayawada (Andhra Pradesh). These cities are observing an significant increase in population coupled by strained safe drinking water supply and polluted water sources.

Allahabad which has the greatest potential of RBF is reeling under the menace of Arsenic, Cadmium, chromium, copper, lead and zinc in groundwater and surface water of Ganga. Bhubaneswar which is dependent on the river Kuakhai and Daya for its drinking needs has seen a detoriation of surface water in terms of biochemical oxygen demand, chemical oxygen demand, and total and fecal coliform. Guwahati situated on the banks of river Brahmaputra falls short of meeting its daily water requirement by 11 MLD. Its faces a severe challenge in form of high fluoride and iron content in drinking water, partially functioning surface water treatment plant and pollution of river Brahmaputra. Vijayawada in Andhra Pradesh gets only 38% of drinking water from water treatment plant and fluctuations in water consumption is noticed in summer and winter. These above discussed cites hold enough potential for RBF which can be exploited by detailed geologic and hydrological studies of the areas. RBF can prove to be a cost effective, sustainable method of fulfilling the drinking water demands.

# CHAPTER – 3
# RIVER BANK FILTRATION

## 3.1 General

Good quality water sources are getting scarce by the pollution/contamination originated from the anthropogenic and geogenic sources. Overexploitation of water resources to meet the increasing water demand and insufficient sanitation services provision is continuously on the rise. On the other hand, water quality guidelines are getting more stringent due to the increasing number of emerging contaminants in water and consequently the cost of water treatment is increasing. In many developing countries, disinfection (very often chlorination) is the only treatment applied to public water supply. This eventually suggests that there is a need for a robust water treatment technology, which is cost effective, efficient and easy to operate and maintain in developing countries.

Surface water in river systems is dynamic, it flows downstream, it evaporates or takes up by riparian vegetation, it infiltrates into groundwater, and its ability to do all of these is highly impacted by the geologic composition of the immediate environment. There is also a dynamic interaction between surface and ground water's in natural settings. When the river experiences floods, water from the river gets stored in the soils along the bank areas and in the low-lying areas between the floodplains. When the river level drops, the stored water from the bank areas slowly drains back to the river.

## 3.2 What is riverbank filtration?

Riverbank filtration (RBF) or simply bank filtration (BF), an unified term for river and lake, is a process by which surface water from rivers, channels and lakes is induced by pumping from nearby production wells to flow through the natural aquifer soil, undergoing many positive changes in water quality before finally mixing with local groundwater in the land side and then extracted for direct use or further treatment (Figure 5). By applying this technique water is extracted conjunctively from two different water resources, surface and shallow ground water.

RBF or BF has been successfully used in USA and many countries in Europe for last more than 100 years for drinking water supply to the communities located on riverbanks (Schmidt et al, 2003). It is currently practiced for water supply in many countries. For example, 50% of potable water supplies in the Slovak Republic, 45% in Hungary, 16% in Germany and 5% in the Netherlands are obtained from the riverbank filtration system (Grischek et al., 2002; Hiscock and Grischek, 2002; Tufenkji et al., 2002 and Lee and Lee, 2010).

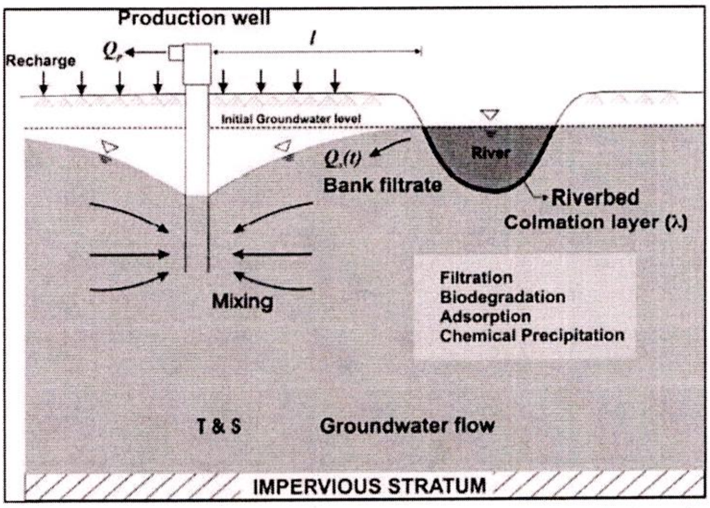


**Figure 5:-** Schematic diagram of a bank filtration process affecting the quality of groundwater and extracted water (source: Ghosh et al, 2015).

### 3.3 Processes of bank filtration

RBF is a process in which pumping of wells located along riverbanks induce a portion of the river water to flow toward the pumping wells. The process has many similarities to the slow sand filtration process. River water contaminants are attenuated due to a combination of processes such as filtration, microbial degradation, sorption to sediments and aquifer sand, and dilution with background groundwater.

The aquifer serves as a natural filter and also biochemically attenuates potential contaminants present in the surface water. Compared with direct surface water abstraction, bank filtration with its effective natural attenuation processes eliminates suspended solids, particles, biodegradable compounds, bacteria, viruses and parasites; partly eliminates adsorbable compounds and equilibrates temperature changes and concentrations of dissolved constituents in the bank filtrate (Hiscock & Grischek, 2002). The removal of microbial pathogens from drinking water is crucial. Pathogens such as *Cryptosporidium*, *Giardia* and viruses are not completely inactivated through common drinking water disinfection using chlorine or UV radiation. Thus expensive filtration technologies (e.g. nano filtration) are needed to produce safe drinking water. RBF effectively removes these pathogens by natural processes during subsurface passage depending on flow path length, residence time and environmental factors. Hence it can serve as a pre-treatment step in drinking water production, and in some instances, also as final treatment before disinfection

### 3.4 Treatment processes of bank filtration

Several physical, chemical and biochemical processes are involved in the improvement of water quality during subsurface passage (Sharma & Amy, 2009). The processes that remove substances in the bank filtrate include:

- **Straining or filtration**: The mechanical filtration process retains suspended matter in the soil, depending on pore throat size.
- **Biodegradation and decay:** biodegradation and radioactive decay are the only sustainable removal processes. Biodegradation is the main driver for redox processes occurring during subsurface passage and is responsible for the breakdown of dissolved and/or sediment-bound organic matter.
- **Sorption and desorption:** Trace elements such as iron, manganese and various heavy metals are eliminated during ground passage, mainly by sorption processes (Schmidt et al., 2003) and by accumulating on the surface of an adsorbent or substrata. Biological contaminants such as protozoa, bacteria and viruses are reduced by a combination of processes including adsorption to aquifer materials and inactivation (Schmidt et al., 2003).
- **Ion exchange:** In aerobic aquifers, removal is achieved by ion exchange processes at negatively loaded surfaces of clay minerals, amorphous ferric oxides and alumina and organic solid matter (Schmidt et al., 2003).

The removal of biological contaminants through BF is most efficient when groundwater velocity is slow and when the aquifer consists of granular materials with high grain surface contact. Levels of many organic micro pollutants can be reduced or even eliminated during both aerobic and anaerobic underground passages (Mueller et al., 2010; Maeng et al., 2009). Attenuation is extremely dependent on the underlying redox processes (Schmidt et al., 2004). The purification capacity of BF schemes regarding surface-water pollutants depend on (Schmidt et al., 2003):

## 3.5 Factors which influence RBF

The performance of RBF with respect to water quality improvements depends on a number of variables:

- hydro geologic conditions including characteristics and composition of alluvial aquifer materials, aquifer thickness, hydraulic conductivity, transmissivity & porosity
- river/lake water quality,
- groundwater dilution,
- filtration velocity and distance of the well(s) from river/lake
- water temperature in river and aquifer
- pumping rate
- Soil/sediment characteristics at the river/lake-aquifer interface.
- Stability of the river channel
- Seasonality of river flow
- Flow velocity and bed load characteristics.
- Storage coefficient of the aquifer
- Site geometry & river-bed quality

Most RBF systems are constructed in alluvial aquifers located along riverbanks. These aquifers can consist of a variety of deposits ranging from sand, to sand and gravel, to large cobbles and boulders. Ideal conditions typically include coarse-grained, permeable water-bearing deposits that are hydraulically connected with riverbed materials. RBF systems can even be constructed in low permeability zones (typically, clay and silt layers) within an alluvial aquifer.

## 3.6 Site suitable for RBF

Hydro geologic conditions impact the effectiveness of RBF. The permeability of the sediment affects seepage velocity and often internal clogging is associated with sediments having low hydraulic conductivity and small vertical gradients. Sediments that have excessively high conductivity will not be efficient in removing contaminants.

The followings are the primary requirements to select a RBF site:

- River/stream or water body should be perennial,
- River/stream or other surface water body should be hydraulically connected to the aquifer,
- Alluvial formations,
- Well should be in the concave side of the river/stream,
- More retention time of water between river/stream or water body and well,
- Well field should be free from contamination of pathogenic and geogenic pollution,

## 3.7 Advantages of RBF:

- BF is a natural treatment process, avoids or reduces the use of chemicals and produces biologically stable water.
- BF improves water quality by removing particles (suspended solids), organic pollutants, turbidity, microorganisms, heavy metals and nitrogen.
- BF dampens concentration peaks associated with spills (in river/lake) and dampens temperature peaks.
- BF replaces or supports other treatment processes by providing a robust barrier and reduces the overall cost of water treatment. BF serves as a pre-treatment step in the drinking water treatment system. It therefore lowers the maintenance compared to the conventional treatment methods and helpful in reducing the use of chemicals and disinfection by-products in drinking water.
- Equilibration of temperature and concentration changes of dissolved constituents in the bank filtrate;
- Attenuation of adsorbable compounds.
- Increased storage capacity to balance supply and demand in areas with high variations of precipitation and run-off or to buffer extreme climatic conditions (floods, droughts)

## 3.8 Disadvantages

- Enhanced clogging of the infiltration zone is likely to be observed with high levels of suspended solids that may render BF unsustainable

- High organic pollution and higher mean temperatures (often found in developing countries) both promote microbial growth and may lead to oxygen depletion, thereby lowering the removal efficiency of BF systems.
- The presence of dissolved heavy metals (e.g. arsenic) may severely impair BF quality.
- Polar, persistent organic substances are often not completely removed during underground passage (dependent on residence time, length of subsoil passage, redox status).(Schmidt et al., 2003)
- Other post-treatment methods are necessary such as oxidation and adsorption to reach drinking water quality.

## 3.9 Success stories of RBF from Europe and USA

BF technology has become popular in Europe, the United States and some Asian countries. Many European countries have adopted RBF method as a common practice for more than 130 years for supply drinking water to communities along the Rhine, Elbe, Danube, and Seine rivers. Particularly in countries such as, Switzerland where 80 % of drinking water comes from RBF wells, 50 % in France, 48 % in Finland, 40 % in Hungary, 16 % in Germany, and 7 % in the Netherlands. In Europe, post-World War II when the rivers were significantly polluted with municipal and industrial effluents, RBF was the most efficient method of producing high quality drinking water **(Ray et al. 2002).** In Germany, the City of Berlin depends 75% on bank filtration while Dusseldorf, situated on the Rhine, has been using RBF since 1870, with bank filtration the most important source for public water supply in this densely populated and industrialized region. European countries use this technology to augment the removal of natural organic matter (NOM), organic contaminants, and pathogenic microbes from as much as 80% of their drinking water. On the basis of a century of successful riverbank filtration in Europe and improved understanding of the contaminant removal processes, utilities outside Europe are moving to capitalize on the benefits of RBF. In most European countries, there are no specific regulations regarding the implementation of bank filtration; rather, local authorities recommend guidelines to water utilities to help ensure acceptable drinking water quality. In USA also, RBF systems have been successfully practicing for supply of drinking water to several communities for nearly 50 years.

## 3.10 RBF in India

RBF is also gaining popularity in India as a reliable method of providing drinking water in terms of the volume of (pre-) treated water obtained. Since 2005, RBF systems are operational in Ahmedabad (Sabarmati River), Delhi (Yamuna River), Haridwar and Rishikesh (Ganga River), Mathura (Yamuna River), Medinipur and Kharagpur (Kangsabati River), Dehradun (Bandal River),Vadodara (Mahi River), Nainital (Nianital Lake), Patna (Ganga River) and Srinagar (Alkananda River) in these locations. Investigations are continuing for finding out the suitability of RBF for Allahabad (Ganga river), Bhubaneswar (Mahanadi River), Kota (Chambal River), Lucknow (Gomti River) Guwahati (Brahmaputra River), and Vijayawada (Krishna River) based on hydrogeology and land use and required parameters. These Indian cities receive surface water by direct abstraction for drinking and other domestic purposes; but the direct use of such type of water is not safe especially during low water flow condition due to high concentration of untreated waste. At these places, RBF technology has been considered as a suitable method to supply water of good quality. Figureure 2 and Table 1 provide information on some of these existing bank filtration systems studied by Sandhu et al., (2010).

**Table 1**: Summary of siting and design parameters of some existing operational small- and large-scale bank filtration systems in India (Source: Sandhu el al., 2010)

| **Location** | **Source water body** | **Well-type** | **Production capacity in $m^3$/day** | **Depth in m** | **Distance from source water in m** | **Travel time of bank filtrate** |
|---|---|---|---|---|---|---|
| Haridwar | Ganga | CW | 33,000 | 7–10 | 15–110 | 2–>100 days |
| Patna | Ganga | VFW | >3500 | 150–300 | 9–236 | – |
| Srinagar | Alaknanda | VFW | 259–518 | 32–86 | 47–390 | – |
| Nainital | Lake Nainital | VFW | 24,100 | 22–37 | 5–84 | 8–30 days |
| Dehradun | Bandal | RCW(s) | 140–430 | 1.5–2 | Beneath riverbed | 2–4 min |
| Muzaffar Nagar | Kali | VFW | 29–300 | 8–15 | 68 | – |

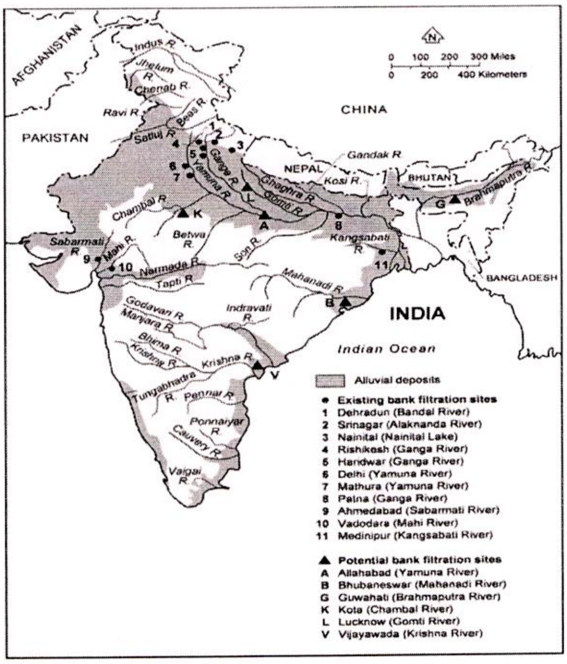


**Figure 6**: - Location of existing and potential riverbank filtration sites (Source: Sandhu et al, 2010).

# CHAPTER 4

# ANALYTICAL SOLUTION TO CALCULATE RIVERBANK FILTRATE

## 4.1 A review of analytical solutions

The problem of stream depletion by pumping near to a river has been extensively studied by many researchers (Theis, 1941; Glover and Balmer, 1954; Hantush, 1965; Jenkins, 1968; Wallace et al., 1990; Hunt, 1999, 2003, 2008; Swamee et al, 2000; Butler et al., 2001; Fox, 2004, 2007; Chen and Yin, 2004; Zlotnik, 2004; Darama, 2004; Sun and Zhan, 2007; Miller et al., 2007; Zlotnik and Tartakovsky, 2008; Christensen et al., 2009; Baalousha, 2012).

Theis (1941) first derived an analytical expression for predicting river contribution to pumping from a fully penetrating well near the river in an unconfined aquifer, which is in hydraulic connection with the river. Later on, Glover and Balmer (1954) gave an exclusive close form solution to Theis' equation. Hantush (1965), considering the streambed lined with semi-pervious material, first developed an analytical model in terms of the complementary error function for a partially penetrating stream to determine rate of stream depletion as a function of SDF (stream depletion factor) and time. After those pioneering works, many other investigators extensively analyzed stream depletion problems considering different complex cases, Jenkins (1968) developed dimensionless plots of volume and rate of stream depletion based on the equations of Glover and Balmer (1954); Wallace et al. (1990) analyzed stream depletion caused due to cycling pumping from a well applying superposition principles using equations derived by Jenkins (1968); Hunt (1999) analyzed unsteady stream depletion for unconfined aquifer and developed an analytical solution considering streambed conductance and clogging and also generalized the solution given by Hantush (1965); Hunt (2003, 2008) carried out similar analysis for semi-confined aquifer and for aquifers and streams with finite widths. Swamee et al. (2000) applying numerical methods to Glover and Balmer's (1954) solution presented empirical equations for the stream depletion rate and total volume of stream flow; Butler et al., (2001) analyzed stream flow depletion in a partially penetrating stream and derived an independent analytical solution in a mixed form of improper and proper integral for a finite width stream of shallow penetration and compared the results with Glover and Balmer's (1954) and Hantush's (1965) solution; Fox (2004, 2007) rigorously analyzed the Hantush's (1965) analytical solution for a specific case study and emphasized importance of streambed conductance. Chen and Yin (2004) derived a semi-analytical solution for a partially penetrating gaining stream based on Hunt (1999). Zlotnik (2004) derived an analytical solution for a partially penetrating leaky aquifer using the concept of MSDR (Maximum Stream Depletion Rate). Darama (2004) analysed effects of nonlinear variation of evaporation on steady-state stream depletion rate using the model developed by him. Sun and Zhan (2007) analysed stream flow depletion from two parallel streams using Hantush's (1965) model. Miller et al. (2007) studied behaviour of SDF near impermeable boundaries using the solution of Glover and Balmer (1954). Zlotnik and Tartakovsky (2008) derived explicit analytical solutions for steady-state and transient conditions considering combined effect of streambed leakage, stream penetration, and aquifer leakage. Christensen et al. (2009), by analyzing multi-layers leaky aquifer incorporating streambed conductance and aquitard leakage coefficient, determined optimal pumping test site for obtaining aquifer parameters to predict stream depletion. Baalousha (2012) derived analytical solutions for streams having conceptually line-width and finite-width in unconfined/confined aquifers based on the principle of superposition and verified that the solutions are identical to Hantush's (1965) and Hunt's (1999, 2003) solutions.

The step response function derived by Glover and Balmer (1954) for dimensionless stream depletion is:

$$\frac{Q_s(t)}{Q_p} = erfc\left(\sqrt{\frac{S\,l^2}{4\,T\,t}}\right) \tag{4.1}$$

The solution given by Hantush (1965) and Hunt (1999) for partially penetrating stream with streambed conductance and clogging is:

$$\frac{Q_s(t)}{Q_p} = \left[erfc\left(\sqrt{\frac{S\,l^2}{4\,T\,t}}\right) - exp\left(\frac{\lambda^2\,t}{4\,S\,T} + \frac{\lambda\,l}{2\,T}\right) erfc\left(\sqrt{\frac{\lambda^2\,t}{4\,S\,T}} + \sqrt{\frac{S\,l^2}{4\,T\,t}}\right)\right] \tag{4.2}$$

where $Q_s(t)$ is the flow rate from the stream/river $[L^3T^{-1}]$; $Q_p$ is the pumping rate by the production well, $[L^3T^{-1}]$; $S$ is the storage coefficient, [dimensionless]; $T$ is the transmissivity of the aquifer, $(L^2T^{-1}]$; $l$ is the linear distance between the pumping well and the stream/river, [L]; $\lambda$ is the riverbed hydraulic conductivity, $[LT^{-1}]$; $t$ is the time since onset of pumping, [T]; 'erfc(x)' is the complementary error function of x= $1 - erf(x)$; and $erf(x) = \frac{2}{\sqrt{\pi}} \int_0^X e^{-u^2} du$ .

From appraisal of the previous works, it is concluded that the step response function for stream depletion in a linear aquifer-stream-well system, derived by Glover and Balmer (1954) for a fully penetrating stream and that derived by Hantush (1965) for a partially penetrating stream, which later was modified by Hunt (1999) incorporating streambed conductance, are the basic solution for stream depletion analysis for wells operate near a stream.

## 4.2 Performance of solution given by Glover and Balmer (1954) and Hunt (1999)

The solution given by Glover and Balmer (1954) is for fully penetrating stream/river, while the solution given by Hunt (1999) is for partially penetrating stream/river. For performance analysis, the data given in Box 1 are used.

**Box 1 :** Storage coefficient, S= 0.01; Transmissivity, T = 1200 m$^2$/day; Distance between the pumping well and the river, $l$ = 100 m; riverbed conductance, $\lambda$ = 0.035 m/day; and time of observation, t = 50 days.
It is intended to determine the flow rate from the river to the production well because of pumping using equations (4.1) and (4.2)

The responses of eqs (4.1) and (4.2) corresponding to the data in Box 1 are shown in Figureure 4.1. The values in ordinate indicate the ratio of $Q_s(t)/Q_p$, which means for 1 unit of pumping through production well,( $Q_p$), the magnitude shown by the respective curve at a specific time would be the rate of flow from the river. From Figureure (4.1), it is clearly evident that for a specific time, the solution given by Glover and Balmer (eq. 4.1) for fully penetrating river/stream indicates more induced flow from river/stream than the solution given by Hunt (eq. 4.2) for partially penetrating stream/river. For example, at time 500 hours, the solution by Hunt indicates, about 40% of pumped water from river and 60% from groundwater, while the solution given by Glover and Balmer indicates, about 97% of water from river and 3% from groundwater. In the both the cases, as pumping continues with time, pumping rate from the river increases and tends towards 100%. It is further noted that the induced flow from a river is more in case of a fully penetrating river/stream than a partially penetrating river/stream and bed conductance reduces the entry of river flow to the aquifer.

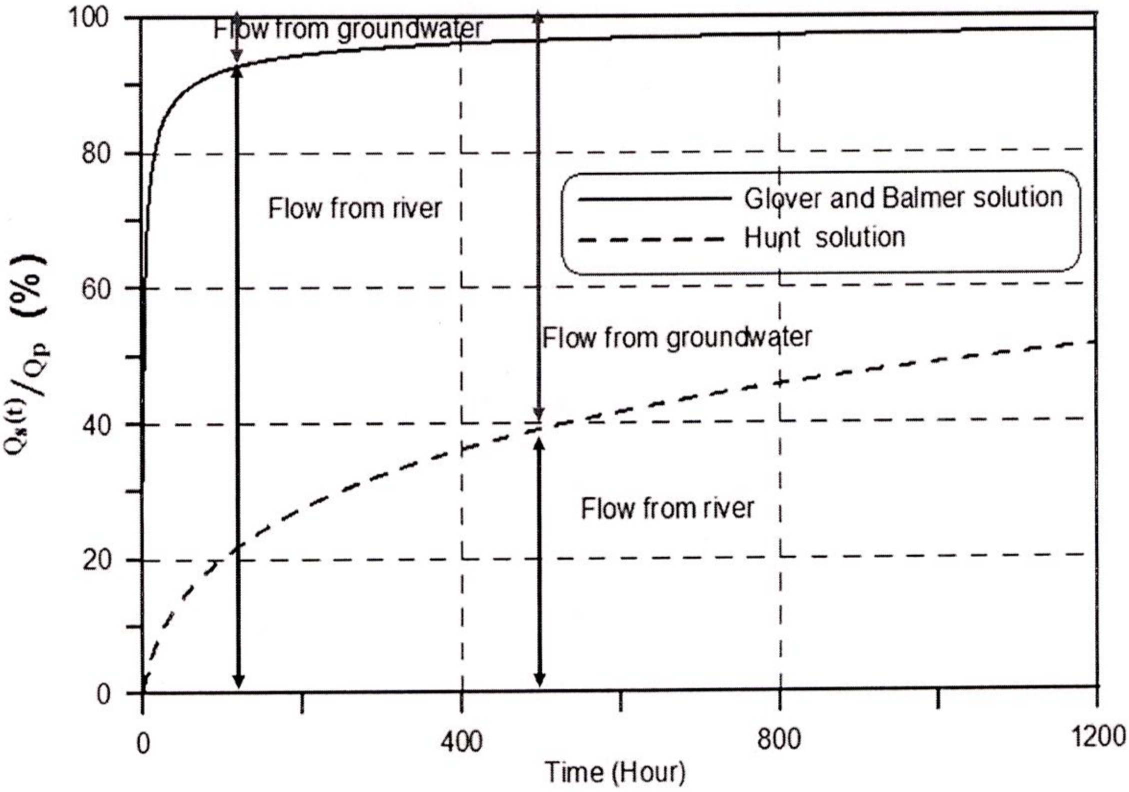


**Figure** 7:- Variation of induced river flow rate to the pumping rate for fully penetrating river (Glover and Balmer, 1954 )and partially penetrating river (Hunt, 1999).

# Chapter-5

# RESULTS AND DISCUSSION

## 5.1 General

The earlier chapters described scientific and technical details of Riverbank Filtration. As case study analysis, few sites selected by the National Institute of Hydrology, Roorkee for developing pilot demonstration scheme for RBF have been considered and the analyses results are reported in this section. These sites are: (i) site along the river Solani near Kuwan Khera Gaon, Laksar (Uttarakhand), (ii) site along the river Yamuna in Mathura (Uttar Pradesh); and (iii) site along the river Yamuna in Agra (Uttar Pradesh). The objectives emphasized to develop these pilot demonstration schemes are : (a) baseline data collection and investigations; (b) performance and limitations analysis of RBF schemes; (c) effectiveness of RBF technique in different river-aquifer settings and river flow conditions; (d) analysis of RBF under variable pollutants loads and flood situations; (e) development of technical elements for flood-proof water abstraction schemes; and (f) scope of extending the technique in attaining drinking water security.

Under the present study, few field investigations and sampling campaigns are carried out. The samples collected from the field investigations are analyzed in the water quality laboratory of Ground Water Hydrology Division. For water quality analysis, HACH portable water quality testing equipment# DR 2800 is used. The HACH DR 2800 is a portable Spectrophotometer. A total of 22 water quality parameters were analyzed. These are: pH, EC, Turbidity, TDS, Total hardness, $F^-$, $Cl^-$, HCO3-$^-$, $SO_4^{2-}$ , NO3$^-$ $NO_2$, $Na^{2+}$, $Ca^{2+}$, $Mg^{2+}$, $Na^+$ , $K^+$, $NH_4^{+,}$ BOD, DO, and Total Coliform.

The description of the study sites and the results of physico-chemical parameters of the samples of Laksar, Agra, and Mathura sites are given in subsequent sections.

## 5.2 Laksar, (Haridwar)

**Laksar** is a block, town and a panchayat in Haridwar district in Uttarakhand. Laksar is located at 29.77°N 78.05°E (Figureure 5.1). It has an average elevation of 227 metres (745 feet). As of 2011 India census, Laksar had a population of 21,760. The river flowing nearby the Laksar town is Solani River, which is a tributary of river Ganga. Solani river is a local river and it carries a lot of flow during monsoon period. During lean period, the upper stretches of the river mostly remain dry. As the river flows to downstream, flow in the river increases because of water feeding by the aquifer and discharge of untreated wastewater from

Roorkee municipal area and IIT Roorkee campus. Thus, the downstream stretches of the river remain perennial.

Due to its location away from any major water body and its proximity to the Himalayas, Laksar has an extreme and erratic continental climate. Summers start in late March and go on until early July, with average temperatures around 28 °C (82 °F). The monsoon season starts in July and goes on until October, with torrential rainfall, due to the blocking of the monsoon clouds by the Himalayas. The post monsoon season starts in October and goes on until late November, with average temperatures sliding from 21 °C (70 °F) to 15 °C (59 °F). Winters start in December, with temperature close to freezing point and frequent cold waves due to the cold katabatic winds_blowing from the Himalayas. The average annual rainfall is about 2600 mm (102 in).

Water Samples were collected from the Laksar block at three villages- Kuwan Khera, Dhadeki and Mohammadpur Buzurg. The Solani River flows through these villages. The water samples included surface water samples of Solani River and groundwater samples from different hand pumps. Finally by taking in account the need of drinking water requirement and site conditions, Kuwan Khera village was finalized for detailed investigations for developing RBF scheme.

### 5.2.1 Geology of Haridwar

Geologically, Haridwar region is divided into five physiographic units namely the: Shiwaliks, Dun Valley, River Basin, Bhabar, Tarai. The Shiwaliks are separated from the outer Himalayas by a continuous reverse fault. They fall into three main divisions- the Upper Shiwaliks composing the conglomerates of sand and clay, the middle Shiwaliks that consists of sand-rock and the Nahan sandstone. The surface soil in most places is a thin alluvial deposit. The Ganga and Bhagirathi river basin has mixed geology. The northern part of the region has Jaunsar Series and Shimla slates of upper Pre-Cambrian and ·lower Paleozoic periods. The southern part of the region is formed of the rocks of Jurassic and Triassic periods.

The lithology controls the geology of the region. The Shivaliks are composed of Plio Pleistocene and Miocene period, while the *Bhabar* and *Tarai* are composed of Recent Alluvium. Further south of the *Tarai* lies the alluvial tract of Ganga and its tributaries. The sediments are sand, silt and clay with occasional gravel beds.

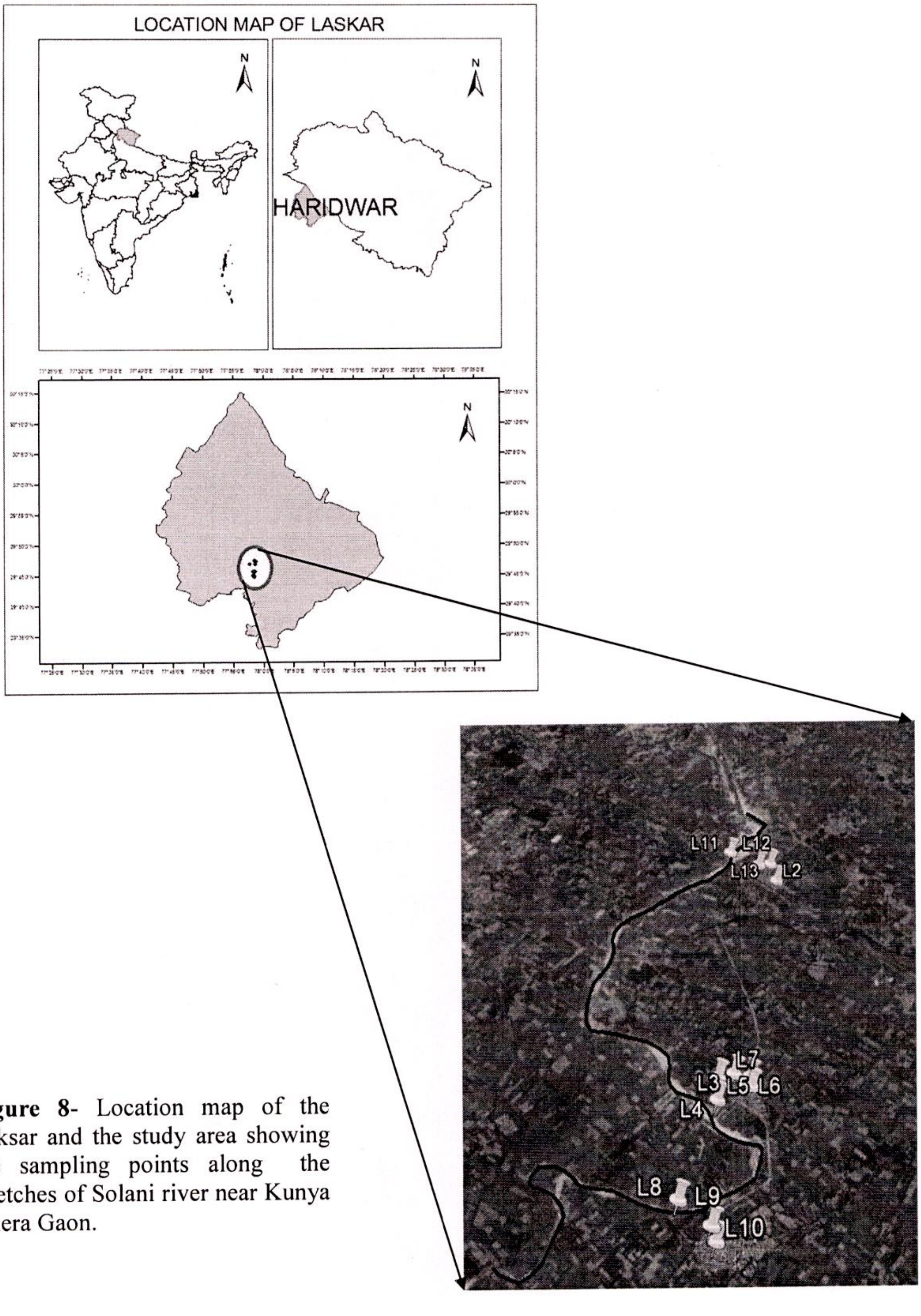


**Figure 8**- Location map of the Laksar and the study area showing the sampling points along the stretches of Solani river near Kunya Khera Gaon.

## 5.3 Mathura (Uttar Pradesh)

Mathura is a city in the North Indian state of Uttar Pradesh located along the bank of the river Yamuna. It is approximately 50 kilometers (31 mi) north (upstream)of Agra, and 145 kilometers (90 mi) south-east of Delhi; about 11 kilometers (6.8 mi) from the town of Vrindavan, and 22 kilometers (14 mi) from Govardhan. It is the administrative center of Mathura District of Uttar Pradesh. During the ancient period, Mathura was an economic hub, located at the junction of important caravan routes.

Mathura is located at 27.28°N and 77.41°E(Figureure 5.2). It has an average elevation of 174 meters (570 feet). The climate of Mathura is tropical extreme with very hot summers with temperatures rising beyond 44 °C, and cold and foggy winters with temperature dipping to 5 °C. The average rainfall is 593 mm, received mostly during the monsoons from July to September. The 2011 census of India estimated the population of Mathura to be 441,894, a decadal growth rate of 22.53 per cent from 2001 census of India. The population density of Mathura is 120 person/ $km^2$.

Water requirements for 4.42 lakh people @ of 140 lpcd are worked out to be about 62 mld. An estimate by expert indicated, the city would require about 90 mld @ 140 lpcd by 2021. The main source of water in the city is through ground water and then surface water. About, 18-20% of the present demands are met using surface water source from the Gokul Barrage, located 15 Kms downstream of Mathura. Around 25 mld of water is being supplied from groundwater, remaining through hand pumps supply. Around 75% of the population receives water at varied intervals and durations. This is partly due to the city's undulating terrain. A study conducted to analyze different physico-chemical parameters of groundwater samples showed, the groundwater quality in Mathura city is within the permissible limits for drinking water. The river water quality has also shown within the ambit of drinking water standards after suitable treatment.

## 5.4 Agra (Uttar Pradesh)

Agra is a city on the banks of the river Yamuna in the northern state_of_Uttar Pradesh, India. _It is 378 kilometers (235 mi) west of the state capital,_Lucknow, 206 kilometers (128 mi) south of the national capital New Delhi. The geographical coordinates of Agra are latitude- 27° 10' N Longitude- 78° 05' E (Figureure 5.3).

The city experiences tropical type of climate. The summer is very hot and dry while winter is very cold. The maximum mean monthly atmospheric temperature, 41.880 C, has been recorded in May and the minimum 7.40 C in January. The average annual maximum and minimum temperatures are 32.30 C and 19.00 C, respectively. The city receives rainfall mainly from the South-West monsoon, which is effective between June and September. The annual rainfall is 679 mm of which 90% is contributed by the South-West monsoon. According to the 2011 India census, Agra has a population of 1,775,000. The population density of Agra is 433/ km$^2$. According to the Agra Jal Nigam (AJN), the existing water demand of the city is 230 mld @140 lpcd. This may increase to 332 mld @ 140 lpcd by year 2025. Presently, the city's water demand is met from Yamuna river by two water treatment plants having capacity to treat 410 mld. In some areas, AJN has been providing drinking water using installed Mark-II Hand-pumps. The groundwater quality in Agra, by and large, has alkaline water, moderately to highly mineralized and excessively hard to brackish. The status of river water quality reported by many investigators indicated improved condition of DO levels over the years.

The soil mostly consists of the quaternary sediments of the Indo-Gangetic plains. It consists of recent unconsolidated fluvial formations containing sand, silt and clay. Its texture is mostly fine.

River Yamuna forms the major drainage of the city and it flows from North to South-East of the city. The overall drainage is controlled by the Yamuna River. Groundwater occurs under unconfined to semi-confined conditions. Depth to water level varies from 17 to 23 m bgl but in the topographic lows and in the vicinity of Agra canal and Yamuna, water table is within depth of 10 m bgl. The water level data show a declining trend. The local topography plays an important role in controlling the ground water movement in the area.

## 5.5 Geology of Agra and Mathura Region

The area comprising Agra and its adjoining districts has been geologically mapped by Mallet (1869), Hacket (1870), and Heron (1922, 1936). The general geological sequence of Agra region has been classified broadly into three fold geological sequence viz. Algonkian-Delhi system, Cambrian (Upper Vindhyan) and Quaternary (Pleistocene, Recent to Upper Pleistocene).

| | | | |
|---|---|---|---|
| **Quaternary** | Recent to Upper Pleistocene | Newer Alluvium | Sand and gravel |
| | Pleistocene | Older Alluvium Laterite and Clay | Sand, clay, silt and kankar |
| **Cambrian** | Upper Vindhayan | Upper Bhander Sandstone | Sandstone, hard and compact |
| | | Lower Rewa Sandstone | Sandstone, hard and compact |
| **Algonkian** | Delhi system | Ajabgarh Series | Slates, pHylites, quartzite and quartzite's, impure, limestones |
| | | Alwar Series | Quartzite's, grits, conglomerates and impure limestone |

### 5.5.1 Geology of Mathura area

The basement in Mathura area is formed of the rocks of Delhi System of Precambrian age, which have been divided into Alwar Series and Ajabgarh Series. The Central Ganga Alluvium of Quaternary age is deposited on this basement. The rocks of Delhi System occur as inliers within the Gangetic Alluvium and they form the Strike ridges such as Gobardhan ridge. The flood plain (FP) deposits overlay the Central Ganga alluvium. Channel Alluvium occurs on the beds of rivers and *nallas*. The Gangetic alluvium, flood plain deposits and channel alluvium play the main role in the riverbank filtration.

### 5.5.2 Geology of Agra area

Geologically, Agra area is represented by the Gangetic alluvium, which has been named as Varanasi Alluvium. This formation has a wide spread and it is overlain on the basement formed by the rocks of Super Vindhyan Group of Neoproterozoic age. Locally along river courses Flood Plain Deposits overlay the Varanasi Alluvium. The Channel Alluvium is deposited on the river and *nalla* beds etc. Varanasi alluvium, flood plain deposits and channel alluvium are of interest for riverbank filtration studies.

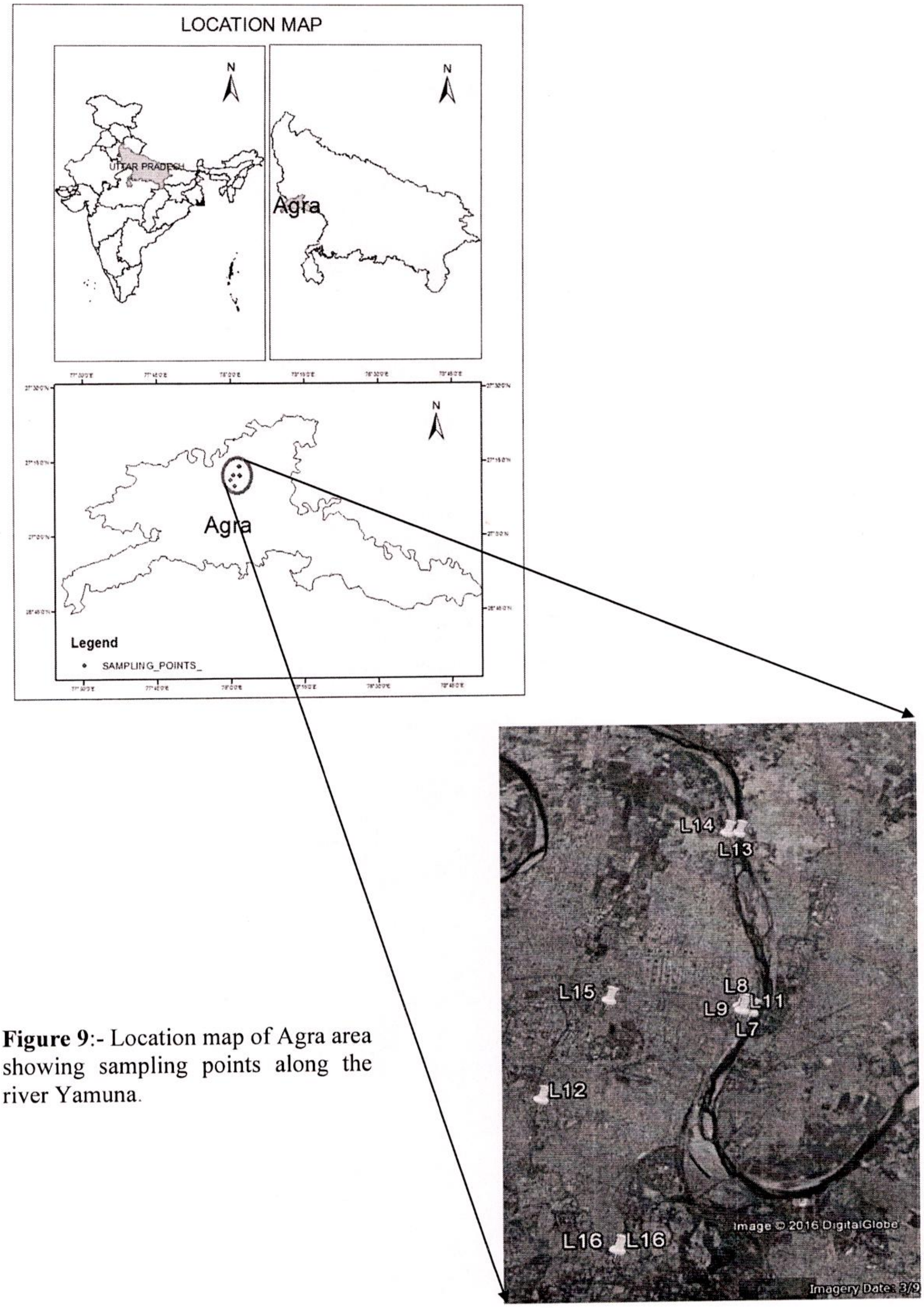


**Figure 9**:- Location map of Agra area showing sampling points along the river Yamuna.

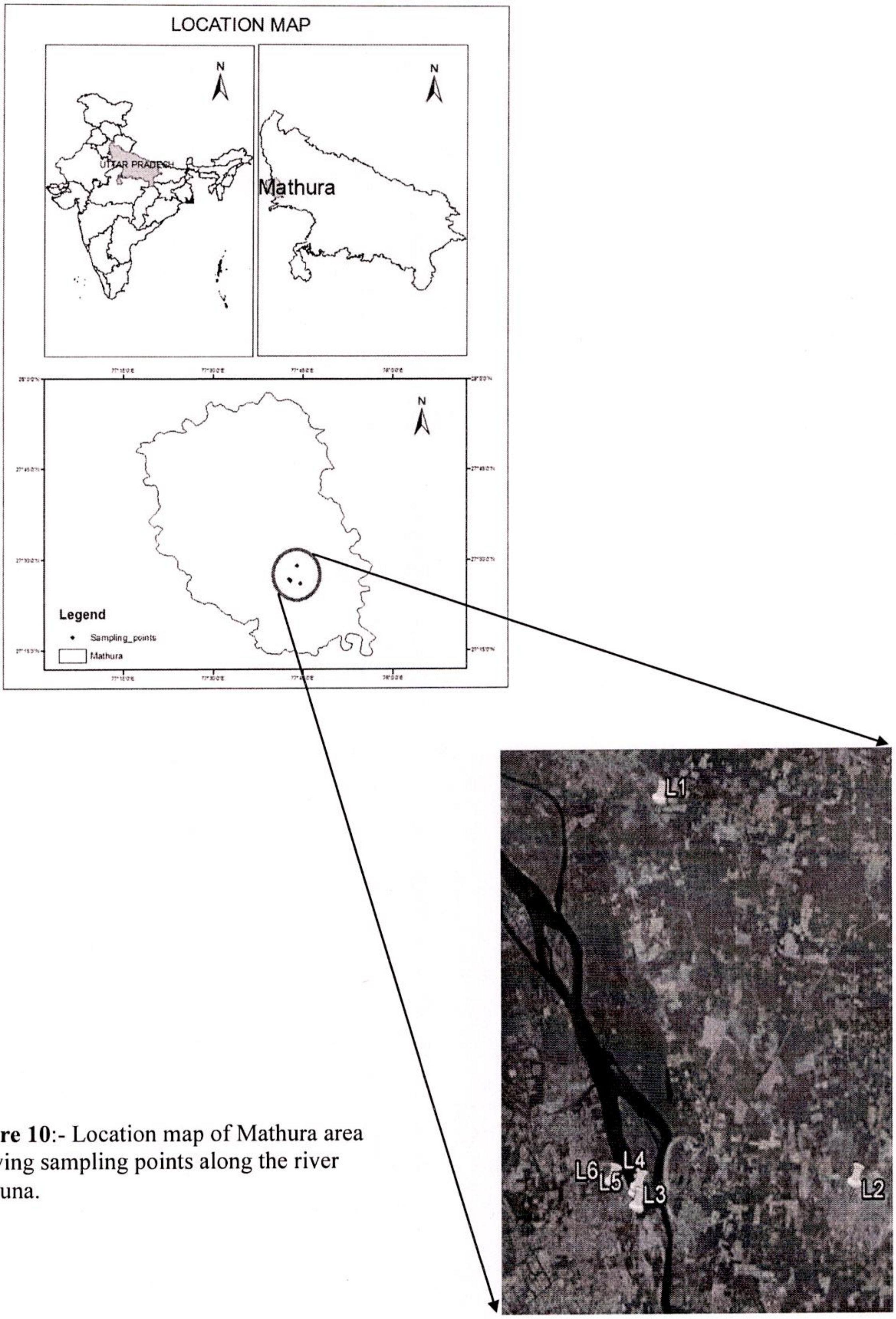


**Figure 10**:- Location map of Mathura area showing sampling points along the river Yamuna.

## 5.6 Methodology

### 5.6.1 Sample Collections

The water samples collected from different sources, which included surface and ground water samples. Collected water samples were immediately stored in high density polythene (HDPE) bottles in order to minimize container pollution and better sample preservation. Samples from each site were collected in 4 bottles mainly for, 4 different analyses such as, one sample for physio-chemical analysis (500 ml), BOD (250 ml), bacteriological analysis (100 ml) and Isotope analysis (20ml). The samples were stored in refrigerators at 4°C prior to analyses. DO test was conducted at the field. Concentrated Nitric acid was used for preservation of the samples prior to the initiation of the water quality test.

- From Laksar area, 13 water samples were collected from 3 locations namely, Kuwan khera, Dhadeki and Mohammadpur Buzjurg. . The samples collected included, 4 surface water samples and 9 groundwater samples.
- From Mathura area, 5 water samples were collected from 2 locations namely, Mathura Road and Gokul Barrage. The samples collected included 1 surface water sample and 4 groundwater samples.
- From Agra area, 10 water samples were collected from 5 locations namely, Agra water works, Wazirpura, Baleuganj, Poiya ghat and Raja ki mandi. The samples collected included 2 surface water samples and 8 groundwater samples.

Latitude and Longitude of the sampling locations were recorded by using GPS. DGPS was used to find out the relative height of the sampling locations above M.S.L. Water level indicator was used to measure the depth to groundwater table in open wells.

The sampling was done in month of January and February for Agra and Mathura sites. The temporal variations in the water quality of the collected samples were studied. The sampling for the Laksar site was done in the month of January. The samples were analyzed in the NIH's laboratory to determine water quality constituents.

### 5.6.2 Instrument Used

**In Field**

- Hach DR800, PH- EC Meter
- GPS
- DGPS
- Water level Recorder

**In Laboratory**

- Hach DR800, pH- EC Meter
- Hach Turbidity Meter
- Hach 2800d

- BOD Incubator
- Titration kit
- Autocleaving Equipment
- Flame Photometer
- Hach BOD meter
- UV sterilizer
- Hach DO meter

### 5.6.3 Software Used

- **Aquachem 2014 –** Water Quality Interpretation
- **Rockworks 14 –** Stiff Diagram
- **Surfer 9 –** Spatial distribution of parameters
- **Arc GIS 10.1**- Study area Maps

### 5.6.4 Parameters Analyzed

The list of parameters analyzed is given in Table 5.1 and analytical methods followed for analysis of the parameters are in Table 5.2. The list of sampling locations is given in Table 5.3

**Table 2**: List of parameters analyzed

| **Physical Parameters** | **Cation** | **Anions** | **Heavy Metals** |
|---|---|---|---|
| TEMP | Na | Cl | Fe |
| pH | K | F | Mn |
| EC | Ca | SO4 | |
| HARDNESS | Mg | NO3 | |
| ALKANITY | NH4 | HCO3- | |
| BOD | | PO4 | |
| COD | | **NO2** | |
| TDS | | | |
| TURBIDITY | | | |
| DO | | | |

**Table 3**: Analytical procedures followed for water analysis

| SL.NO | PARAMETERS | ANALYTICAL METHOD |
|---|---|---|
| 1 | pH | Hach 30d EC-Ph Meter |
| 2 | EC | Hach 30d EC-Ph Meter |
| 3 | Turbidity | Hach 30d Turbidity Meter |
| 4 | TDS | Gravimetric Method |
| 5 | Total Hardness (TH) | EDTA Titrimetric Method |
| 6 | Alkanity | Titration |
| 7 | Bicarbonate | Acid Titration Method, ICM-MS |
| 8 | Chloride ($Cl^-$) | Argentometric Method, ICM-MS |
| 9 | Sulphate | Method 8051 SulfaVer 4 Method; Hach 2800d Spectrophotometer, ICM-MS |
| 10 | Nitrate | Method 8171 Nitraver 5 Method; Hach 2800d Spectrophotometer, ICM-MS |
| 11 | Nitrite | ICM-MS |
| 12 | Ortho Phosphate | Method 8178 Amino Acid Method; Hach 2800d Spectrophotometer, ICM-MS |
| 13 | Flouride | Method 8029 SPADNS method; Hach 2800d Spectrophotometer, ICM-MS |
| 14 | Phosphate | Method 8190 Acid Persulfate Digestion Method Hach 2800d Spectrophotometer, ICM-MS |
| 15 | Ammonium | ICM-MS |
| 16 | Calcium | Method 8204 Titration Method using EDTA Hach 2800d Spectrophotometer, ICM-MS |
| 17 | Magnesium | Method 8329 Titration Method using EDTA Hach 2800d Spectrophotometer, ICM-MS |
| 18 | Sodium | Inductively Coupled Plasma Spectrometer (ICM-MS) , Flame Photometer |
| 19 | Potassium | Inductively Coupled Plasma Spectrometer (ICM-MS) .Flame Photometer |
| 20 | Iron | Method 8204 Ferrover Method Hach 2800d Spectrophotometer, (ICM-MS) |
| 21 | Manganese | Method 8304 Periodate oxidation Method Hach 2800d Spectrophotometer, ICM-MS |
| 22 | Biochemical Oxygen Demand | 5 day BOD Test, Standard Method |
| 23 | Dissolved Oxygen | Hach DO Meter |

**Table 4:** List of Sampling Locations in Agra & Mathura

| SN | Sample Code | Location | District | Source | Latitude | Longitude |
|---|---|---|---|---|---|---|
| 1 | L1 | OW | Mathura | GW | 27.482028 | 77.733194 |
| 2 | L2 | HP | Mathura | GW(hand pump) | 27.434111 | 77.742306 |
| 3 | L3 | HP near GB AG | Mathura | GW(hand pump) | 27.441833 | 77.712972 |
| 4 | L4 | River GB | Mathura | River | 27.443611 | 77.713897 |
| 5 | L5 | GB HP | Mathura | GW(hand pump) | 27.443111 | 77.713381 |
| 6 | L6 | GB temple HP | Mathura | GW(hand pump) | 27.445306 | 77.71075 |
| 7 | L7 | River Agra-R2 | Agra | River | 27.202983 | 78.033350 |
| 8 | L8 | AWW HP | Agra | GW | 27.203917 | 78.031617 |
| 9 | L9 | Agra Waterworks | Agra | GW (bore well) | 27.203267 | 78.031967 |
| 10 | L10 | Mainroad AW | Agra | GW(hand pump) | 27.203917 | 78.031617 |
| 11 | L11 | Treated | Agra | GW (bore well) | 27.203267 | 78.031967 |
| 12 | L12 | Raja ki mandi | Agra | GW(hand pump) | 27.189167 | 78.001417 |
| 13 | L13 | River Poighat | Agra | River | 27.235214 | 78.030836 |
| 14 | L14 | GW Poighat | Agra | GW (bore well) | 27.235272 | 78.028825 |
| 15 | L15 | Wazirpura | Agra | GW(hand pump) | 27.20525 | 78.010778 |
| 16 | L16 | Baleuganj | Agra | GW(hand pump) | 27.166806 | 78.014639 |

**GW- Groundwater, SW- Surface Water**

**Table 5**:- List of Sampling Locations in Laksar

| S.N. | Sample | Location | Type | Source | Latitude | Longitude |
|---|---|---|---|---|---|---|
| 1 | L1 | Solani River Bridge | SW | Surface Water | 29.46813 | 77.57663 |
| 2 | L2 | Dosni PHatak Temple | GW | Handpump | 29.46817 | 77.5877 |
| 3 | L3 | Kuwan Khera Village | GW | Pvt. Handpump | 29.45556 | 77.58507 |
| 4 | L4 | Kuwan Khera Ghat | SW | Surface Water | 29.45447 | 77.58398 |
| 5 | L5 | Kuwan Khera Village | GW | Farm- Packer | 29.4565 | 77.58321 |
| 6 | L6 | Kuwan Khera Village | GW | Tubewell 250ft | 29.45634 | 77.58559 |
| 7 | L7 | Kuwan Khera Village | GW | Shallow Aquifer | 29.45618 | 77.58547 |
| 8 | L8 | Dhadeki Solani River | SW | Surface Water | 29.44928 | 77.58223 |
| 9 | L9 | Dhadeki Village | GW | Pvt.Tubewell 90ft | 29.44801 | 77.58394 |
| 10 | L10 | Dhadeki Vilage | GW | Pvt. Tubewell 180ft | 29.44794 | 77.58415 |
| 11 | L11 | Muhammadpur Bujurg Railway Bridge | SW | Surface Water | 29.47356 | 77.58442 |
| 12 | L12 | Muhammadpur Bujurg | GW | Handpump 50ft | 29.47215 | 77.5864 |
| 13 | L13 | Muhammadpur Bujurg | GW | Handpump | 29.47257 | 77.58689 |

**Table 6**:- Physical parameters of Water samples From Laksar Site

| Sample Code | pH | Temp | Turbidity (NTU) | EC (µs/cm) | TDS (mg/l) | Hardness (mg/l) | BOD (mg/l) | Alkanity (mg/l) | DO (mg/l) |
|---|---|---|---|---|---|---|---|---|---|
| **L1** | 7.34 | 24 | 7.25 | 588 | 376 | 550 | 4.64 | 352.5 | 1 |
| **L2** | 6.87 | 24.1 | 26.4 | 630 | 403 | 555 | 1.14 | 246.7 | 2 |
| **L3** | 6.56 | 25 | 65.5 | 878 | 562 | 500 | 3 | 227.9 | 2 |
| **L4** | 7.24 | 22.9 | 5.51 | 625 | 400 | 480 | 5.64 | 321.3 | 1.2 |
| **L5** | 6.52 | 25 | 4.57 | 503 | 322 | 420 | 2.96 | 213.1 | 1.6 |
| **L6** | 6.75 | 22.5 | 38.9 | 387 | 248 | 300 | 1.34 | 229.5 | 1.6 |
| **L7** | 6.9 | 24.53 | 8.87 | 581 | 372 | 486.3 | 0.46 | 241.8 | 1.55 |
| **L8** | 7.65 | 24.05 | 3.01 | 626 | 401 | 552.5 | 7.88 | 375.4 | 1.1 |
| **L9** | 6.93 | 24.55 | 14.1 | 474 | 303 | 527.5 | 1.02 | 254.1 | 1.75 |
| **L10** | 7.21 | 23.95 | 3.31 | 385 | 246 | 490 | 0.24 | 301.6 | 1.65 |
| **L11** | 7.98 | 23.95 | 6.65 | 602 | 385 | 450 | 7.74 | 393.4 | 1.45 |
| **L12** | 6.95 | 23.75 | 78.1 | 539 | 345 | 360 | 2.91 | 266.4 | 1.55 |
| **L13** | 7.02 | 23.25 | 1.72 | 796 | 509 | 425 | 0.68 | 290.2 | 1.8 |

**Table 7**:-Statistical Analysis of Physical parameters of Water samples From Laksar Site

| Statistical Parameters | pH | Temp | Turbidity (NTU) | EC (µs/cm) | TDS (mg/l) | Hardness (mg/l) | BOD (mg/l) | Alkanity (mg/l) | DO (mg/l) |
|---|---|---|---|---|---|---|---|---|---|
| Avg. | 24.0 | 7.1 | 20.3 | 585.7 | 374.8 | 468.9 | 285.7 | 3.1 | 1.6 |
| Max | 25 | 7.98 | 78.1 | 878 | 561.92 | 555 | 393.442623 | 7.88 | 2 |
| Min | 22.5 | 6.52 | 1.72 | 385 | 246.4 | 300 | 213.1147541 | 0.24 | 1 |

**Table 8**:- List of Major Cations and Anions in Water samples From Laksar Site

| Sample Code | $F^-$ (mg/l) | $Cl^-$ (mg/l) | SO4-<br>2- (mg/l) | $NO3^-$ (mg/l) | $PO4^-$ (mg/l) | $HCO_3^-$ (mg/l) | $Na^+$ (mg/l) | $K^+$ (mg/l) | $Ca^{2+}$ (mg/l) | $Mg^{2+}$ (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| L1 | 0.18 | 151 | 16 | 12.4 | 0.18 | 430 | 33.63 | 18.6 | 190 | 25.1 |
| L2 | 0.22 | 150.9 | 12 | 3.2 | 0.15 | 301 | 59.39 | 16.08 | 180.2 | 24.8 |
| L3 | 0.39 | 138.1 | 31 | 5.6 | 0.12 | 278 | 15.1 | 16.68 | 76.4 | 9.7 |
| L4 | 0.1 | 56 | 15 | 11.6 | 0.12 | 392 | 35.99 | 14.31 | 160 | 24.3 |
| L5 | 0.04 | 17 | 3 | 3.2 | 0.105 | 260 | 14 | 15.89 | 13.5 | 19.4 |
| L6 | 0.15 | 16 | 2 | 2 | 0.15 | 280 | 17.91 | 3.86 | 80.2 | 24.3 |
| L7 | 0.18 | 83.98 | 10 | 3.2 | 0.09 | 295 | 62.35 | 17.47 | 99.3 | 22.175 |
| L8 | 0.2 | 150.95 | 17 | 12.8 | 0.18 | 458 | 34.22 | 18.32 | 185.1 | 24.95 |
| L9 | 0.31 | 144.5 | 3 | 1.6 | 0.23 | 310 | 12.2 | 9.85 | 170.1 | 24.55 |
| L10 | 0.25 | 97.05 | 2 | 2.4 | 0.22 | 368 | 16.45 | 13.8 | 118.2 | 17 |
| L11 | 0.07 | 36.5 | 14 | 22 | 0.27 | 480 | 34.81 | 18.04 | 135.1 | 24.7 |
| L12 | 0.1 | 16.5 | 5 | 3.2 | 0.195 | 325 | 11.8 | 14.7 | 46.85 | 21.85 |
| L13 | 0.17 | 83.5 | 37 | 7.6 | 0.12 | 354 | 11.7 | 11.85 | 44.95 | 14.55 |

**Table 9**:-Statistical Analysis of Major Cations and Anions in Water samples From Laksar Site

| Statistical Parameters | $Na^+$ (mg/l) | $K^+$ (mg/l) | $Ca^{2+}$ (mg/l) | $Mg^{2+}$ (mg/l) | $F^-$ (mg/l) | $Cl^-$ (mg/l) | $SO4^{2-}$ (mg/l) | $NO3^-$ (mg/l) | $HCO_3^-$ $(mg/l)^-$ | $PO4^-$ (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| Avg. | 27.66 | 14.57 | 115.38 | 21.34 | 0.18 | 87.84 | 12.85 | 6.98 | 348.54 | 0.16 |
| Max | 62.35 | 18.6 | 190 | 25.1 | 0.39 | 151 | 37 | 22 | 480 | 0.27 |
| Min | 11.7 | 3.86 | 13.5 | 9.7 | 0.04 | 16 | 2 | 1.6 | 260 | 0.09 |

**Table 10**:- List of Heavy Metals in Water samples From Laksar Site

| **Sample Code** | **Fe (mg/l)** | **Mn (mg/l)** |
|---|---|---|
| L1 | 3.81 | 0.6 |
| L2 | 3.81 | 3 |
| L3 | 3.6 | 4.3 |
| L4 | 4.99 | 0.3 |
| L5 | 1.07 | 0.9 |
| L6 | 1.36 | 0.5 |
| L7 | 2.44 | 1.6 |
| L8 | 3.81 | 0.7 |
| L9 | 3.71 | 1.1 |
| L10 | 4.3 | 0.4 |
| L11 | 3.03 | 0.9 |
| L12 | 1.22 | 2.6 |
| L13 | 2.59 | 1.2 |

**Table 11**:-Statistical Analysis of Heavy Metals in Water samples From Laksar Site

| **Statistical Parameters** | **Fe (mg/l)** | **Mn (mg/l)** |
|---|---|---|
| Avg. | 3.06 | 1.39 |
| Max | 4.99 | 4.3 |
| Min | 1.07 | 0.3 |

**Table 12**:- Physical parameters of Water samples of Agra and Mathura in January

| Sample Code | pH | Temp (°C) | EC (µs/cm) | Turbidity (NTU) | TDS (mg/l) | Alkanity (mg/l) | Total Hardness (mg/l) | Ca-Hardness (mg/l) | Mg-Hardness (mg/l) |
|---|---|---|---|---|---|---|---|---|---|
| L1 | 7.49 | 19.0 | 1025 | 0.76 | 656 | 232.79 | 307.07 | 105.44 | 201.63 |
| L2 | 7.14 | 22.0 | 2360 | 2.56 | 1510.4 | 262.30 | 518.44 | 289.84 | 228.60 |
| L3 | 7.02 | 22.5 | 1020 | 3.68 | 652.8 | 150.82 | 357.63 | 234.90 | 122.74 |
| L4 | 6.94 | 16.5 | 1431 | 2.25 | 915.84 | 147.54 | 254.61 | 155.07 | 99.54 |
| L5 | 7.01 | 22.0 | 1056 | 0.6 | 675.84 | 236.07 | 226.79 | 142.90 | 83.89 |
| L6 | 6.94 | 22.2 | 1682 | 0.68 | 1076.48 | 229.51 | 306.13 | 175.63 | 130.50 |
| L7 | 6.98 | 16.4 | 1509 | 9.04 | 965.76 | 245.90 | 344.33 | 221.41 | 122.92 |
| L8 | 6.89 | 22.6 | 2048 | 0.18 | 1310.72 | 344.26 | 475.31 | 211.89 | 263.42 |
| L9 | 7.06 | 24.0 | 1447 | 2.85 | 926.08 | 295.08 | 427.77 | 254.18 | 173.59 |
| L10 | 6.93 | 25.5 | 1717 | 0.22 | 1098.88 | 327.87 | 510.47 | 207.26 | 303.22 |
| L11 | 7.04 | 19.3 | 1472 | 8.58 | 942.08 | 295.08 | 308.66 | 192.38 | 116.28 |
| L12 | 7.05 | 25.0 | 2280 | 0.31 | 1459.2 | 262.30 | 323.09 | 150.82 | 172.28 |
| L13 | 7.12 | 17.6 | 1459 | 4.61 | 933.76 | 245.90 | 229.98 | 132.72 | 97.25 |
| L14 | 6.98 | 22.3 | 2017 | 0.23 | 1290.88 | 295.08 | 486.63 | 268.46 | 218.17 |
| L15 | 6.63 | 24.0 | 8680 | 287 | 5555.2 | 262.30 | 2764.50 | 1318.89 | 1445.60 |
| L16 | 6.78 | 22.0 | 8140 | 0.32 | 5209.6 | 360.66 | 2064.51 | 670.81 | 1393.70 |

**Table 13**:- Physical parameters of Water samples of Agra and Mathura in January

| Statistical Parameters | pH | Temp (°C) | EC (µs/cm) | Turbidity (NTU) | TDS (mg/l) | Alkanity (mg/l) | Total Hardness (mg/l) | Ca-Hardness (mg/l) | Mg-Hardness (mg/l) |
|---|---|---|---|---|---|---|---|---|---|
| Avg. | 7.00 | 21.43 | 2458.94 | 20.24 | 1573.72 | 262.0902 | 619.1 | 295.8 | 323.3 |
| Max | 7.49 | 25.50 | 8680.00 | 287.00 | 5555.2 | 360.6557 | 2764.50 | 1318.89 | 1445.60 |
| Min | 6.63 | 16.40 | 1020.00 | 0.18 | 652.8 | 147.541 | 226.79 | 105.44 | 83.89 |

**Table 14**:- Water Quality Report showing the major cations and anions of Agra and Mathura in January

| **Sample Code** | **$HCO_3^-$ (mg/l)** | **$F^-$ (mg/l)** | **$Cl^-$ (mg/l)** | **$NO_2^-$ (mg/l)** | **$SO_4^{2-}$ (mg/l)** | **$NO_3^-$ (mg/l)** | **$Na^+$ (mg/l)** | **$NH_4^+$ (mg/l)** | **$K^+$ (mg/l)** | **$Mg^{2+}$ (mg/l)** | **$Ca^{2+}$ (mg/l)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| L1 | 284 | 7.02 | 107.60 | 29.36 | 63.12 | 33.27 | 86.86 | 5.29 | 13.52 | 49.00 | 42.28 |
| L2 | 320 | 4.87 | 290.74 | 42.20 | 331.46 | 11.95 | 279.39 | 11.65 | 16.32 | 55.55 | 116.23 |
| L3 | 184 | 2.41 | 154.87 | 28.58 | 113.03 | 9.40 | 41.68 | 3.16 | 5.25 | 29.82 | 94.19 |
| L4 | 180 | 5.83 | 186.21 | 33.28 | 116.04 | 24.70 | 144.12 | 15.52 | 13.45 | 24.19 | 62.18 |
| L5 | 288 | 6.88 | 159.26 | 19.02 | 6.75 | 2.92 | 119.16 | 3.44 | 10.63 | 20.39 | 57.30 |
| L6 | 280 | 1.67 | 211.97 | 29.52 | 223.92 | 6.13 | 222.43 | 4.56 | 4.59 | 31.71 | 70.43 |
| L7 | 300 | 6.99 | 226.25 | 16.88 | 124.11 | 34.35 | 161.19 | 11.49 | 14.17 | 29.87 | 88.78 |
| L8 | 420 | 3.75 | 298.59 | 36.10 | 283.10 | 42.88 | 238.49 | 6.19 | 14.16 | 64.01 | 84.97 |
| L9 | 360 | 2.15 | 197.25 | 44.59 | 151.74 | 5.66 | 131.25 | 4.03 | 11.08 | 42.18 | 101.93 |
| L10 | 400 | 7.85 | 242.68 | 52.95 | 198.87 | 92.34 | 154.34 | 7.07 | 4.91 | 73.68 | 83.11 |
| L11 | 360 | 5.52 | 215.45 | 88.07 | 120.21 | 24.77 | 153.83 | 7.46 | 13.68 | 28.26 | 77.15 |
| L12 | 320 | 3.15 | 262.54 | 38.88 | 253.46 | 129.95 | 263.13 | 4.08 | 4.20 | 41.86 | 60.48 |
| L13 | 300 | 0.87 | 181.93 | 24.41 | 109.39 | 17.41 | 145.33 | 21.91 | 13.46 | 23.63 | 53.22 |
| L14 | 360 | 6.45 | 281.60 | 40.08 | 281.05 | 7.68 | 209.22 | 5.88 | 9.25 | 53.01 | 107.65 |
| L15 | 320 | 33.43 | 2053.94 | 116.49 | 1815.32 | 1139.66 | 992.59 | 49.98 | 60.65 | 351.28 | 528.88 |
| L16 | 440 | 36.44 | 1603.90 | 94.44 | 1603.42 | 609.49 | 989.91 | 23.20 | 15.12 | 338.67 | 268.99 |

**Table 15**:- Water Quality Report showing the major cations and anions of Agra and Mathura in January

| **Statistical Parameters** | **$HCO_3^-$ (mg/l)** | **$F^-$ (mg/l)** | **$Cl^-$ (mg/l)** | **$NO_2^-$ (mg/l)** | **$SO_4^{2-}$ (mg/l)** | **$NO_3^-$ (mg/l)** | **$Na^+$ (mg/l)** | **$NH_4^+$ (mg/l)** | **$K^+$ (mg/l)** | **$Mg^{2+}$ (mg/l)** | **$Ca^{2+}$ (mg/l)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Avg. | 319.75 | 8.45 | 417.17 | 45.93 | 362.19 | 137.04 | 270.81 | 11.56 | 14.03 | 78.57 | 118.61 |
| Max | 440.00 | 36.44 | 2053.94 | 116.49 | 1815.32 | 1139.66 | 992.59 | 49.98 | 60.65 | 351.28 | 528.88 |
| Min | 180.00 | 0.87 | 107.60 | 16.88 | 6.75 | 2.92 | 41.68 | 3.16 | 4.20 | 20.39 | 42.28 |

**Table 16**:- Physical parameters of Water samples of Agra and Mathura in February

| Sample Code | pH | Temp (°C) | EC (µs/cm) | Turbidity (NTU) | TDS (mg/l) | Alkanity (mg/l) | Total Hardness (mg/l) | Ca-Hardness (mg/l) | Mg-Hardness (mg/l) |
|---|---|---|---|---|---|---|---|---|---|
| L1 | 7.28 | 28.0 | 1044 | 0.37 | 668.16 | 311.48 | 346.2 | 104.7 | 241.6 |
| L2 | 6.94 | 28.8 | 2420 | 0.85 | 1548.8 | 295.08 | 628.3 | 341.2 | 287.0 |
| L3 | 7.24 | 26.7 | 1036 | 2.53 | 663.04 | 180.33 | 319.5 | 191.1 | 128.4 |
| L4 | 7.51 | 25.3 | 1441 | 1.34 | 922.24 | 311.48 | 253.8 | 151.3 | 102.6 |
| L5 | 6.56 | 25.9 | 1489 | 0.68 | 952.96 | 311.48 | 213.7 | 135.5 | 78.3 |
| L6 | 7.27 | 26.7 | 1701 | 0.77 | 1088.64 | 311.48 | 250.7 | 121.4 | 129.3 |
| L7 | 7.82 | 24.1 | 1694 | 6.45 | 1084.16 | 321.31 | 238.2 | 136.9 | 101.3 |
| L8 | 7.29 | 26.8 | 2044 | 1.17 | 1308.16 | 393.44 | 369.9 | 150.4 | 219.5 |
| L9 | 7.30 | 26.1 | 1540 | 0.26 | 985.6 | 321.31 | 359.9 | 197.0 | 163.0 |
| L10 | 7.41 | 28.6 | 1794 | 0.58 | 1148.16 | 360.66 | 491.5 | 176.3 | 315.2 |
| L11 | 7.82 | 21.9 | 1575 | 1.73 | 1008 | 377.05 | 261.0 | 155.3 | 105.7 |
| L12 | 7.55 | 28.9 | 2260 | 0.21 | 1446.4 | 295.08 | 369.4 | 154.2 | 215.2 |
| L13 | 8.08 | 24.6 | 1641 | 20.8 | 1050.24 | 327.87 | 269.2 | 163.5 | 105.6 |
| L14 | 7.20 | 26.2 | 2033 | 0.12 | 1301.12 | 360.66 | 514.8 | 289.1 | 225.7 |
| L15 | 7.36 | 27.1 | 9050 | 115 | 5792 | 360.66 | 2018.3 | 778.5 | 1239.7 |
| L16 | 7.13 | 27.5 | 7850 | 6.26 | 5024 | 426.23 | 1929.9 | 601.2 | 1328.6 |

**Table 17**:- Statistical Analysis of Physical parameters of Water samples of Agra and Mathura in February

| Statistical Parameters | pH | Temp (°C) | EC (µs/cm) | Turbidity (NTU) | TDS (mg/l) | Alkanity (mg/l) | Total Hardness (mg/l) | Ca-Hardness (mg/l) | Mg-Hardness (mg/l) |
|---|---|---|---|---|---|---|---|---|---|
| Mean | 7.36 | 26.45 | 2538.25 | 9.95 | 1624.48 | 329.10 | 552.15 | 240.48 | 311.67 |
| Min | 6.56 | 21.90 | 1036.00 | 0.12 | 663.0 | 180.3 | 213.75 | 104.66 | 78.29 |
| Max | 8.08 | 28.90 | 9050.00 | 115.00 | 5792.0 | 426.2 | 2018.27 | 778.53 | 1328.64 |

**Table 18**:- Water Quality Report showing the major cations and anions of Agra and Mathura in February

| Sample Code | $HCO_3^-$ (mg/l) | $F^-$ (mg/l) | $Cl^-$ (mg/l) | $NO_2^-$ (mg/l) | $SO_4^{2-}$ (mg/l) | $NO_3^-$ (mg/l) | $Na^+$ (mg/l) | $NH_4^+$ (mg/l) | $K^+$ (mg/l) | $Mg^{2+}$ (mg/l) | $Ca^{2+}$ (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **L1** | 380 | 7.88 | 109.17 | 25.58 | 89.64 | 28.49 | 84.24 | 12.84 | 12.71 | 58.70 | 41.97 |
| **L2** | 360 | 10.02 | 449.65 | 0.00 | 499.97 | 25.45 | 340.37 | 18.24 | 6.61 | 69.75 | 136.84 |
| **L3** | 220 | 5.26 | 159.67 | 0.00 | 135.53 | 3.11 | 42.13 | 5.91 | 3.90 | 31.21 | 76.62 |
| **L4** | 380 | 7.81 | 214.62 | 0.00 | 156.49 | 81.41 | 155.26 | 6.34 | 12.23 | 24.93 | 60.65 |
| **L5** | 380 | 5.48 | 180.12 | 28.71 | 40.96 | 25.23 | 120.38 | 6.00 | 8.48 | 19.03 | 54.32 |
| **L6** | 380 | 4.19 | 237.30 | 0.00 | 47.45 | 231.56 | 225.70 | 7.71 | 3.45 | 31.42 | 48.68 |
| **L7** | 392 | 5.05 | 184.65 | 17.20 | 140.00 | 73.43 | 158.48 | 5.29 | 12.77 | 24.62 | 54.89 |
| **L8** | 480 | 0.00 | 224.31 | 31.36 | 197.27 | 12.69 | 203.38 | 9.71 | 11.46 | 53.34 | 60.33 |
| **L9** | 392 | 6.16 | 174.02 | 26.29 | 142.95 | 6.59 | 126.25 | 5.94 | 10.33 | 39.60 | 78.99 |
| **L10** | 440 | 2.83 | 210.86 | 29.81 | 285.01 | 78.35 | 155.33 | 9.76 | 4.20 | 76.60 | 70.70 |
| **L11** | 460 | 4.83 | 212.75 | 24.56 | 148.17 | 85.20 | 158.67 | 5.33 | 12.81 | 25.67 | 62.29 |
| **L12** | 360 | 6.11 | 340.55 | 37.69 | 351.62 | 171.47 | 317.02 | 9.94 | 3.62 | 52.29 | 61.83 |
| **L13** | 400 | 4.25 | 219.87 | 19.81 | 152.86 | 77.02 | 160.01 | 5.88 | 13.30 | 25.66 | 65.58 |
| **L14** | 440 | 2.72 | 297.64 | 39.87 | 319.48 | 9.35 | 209.65 | 6.67 | 4.56 | 54.85 | 115.92 |
| **L15** | 440 | 18.52 | 1531.52 | 33.33 | 1739.93 | 882.14 | 977.59 | 35.12 | 12.64 | 301.26 | 312.19 |
| **L16** | 520 | 13.85 | 1485.71 | 86.60 | 1630.65 | 619.67 | 922.06 | 23.00 | 7.94 | 322.86 | 241.10 |

**Table 19**:-Statistical Analysis of major cations and anions of Agra and Mathura in February

| Statistical Parameters | $HCO_3^-$ (mg/l) | $F^-$ (mg/l) | $Cl^-$ (mg/l) | $NO_2^-$ (mg/l) | $SO_4^{2-}$ (mg/l) | $NO_3^-$ (mg/l) | $Na^+$ (mg/l) | $NH_4^+$ (mg/l) | $K^+$ (mg/l) | $Mg^{2+}$ (mg/l) | $Ca^{2+}$ (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 401.50 | 6.56 | 389.53 | 25.05 | 379.87 | 150.70 | 272.28 | 10.86 | 8.81 | 75.74 | 96.43 |
| Min | 220.00 | 0.00 | 109.17 | 0.00 | 40.96 | 3.11 | 42.13 | 5.29 | 3.45 | 19.03 | 41.97 |
| Max | 520.00 | 18.52 | 1531.52 | 86.60 | 1739.93 | 882.14 | 977.59 | 35.12 | 13.30 | 322.86 | 312.19 |

## 5.7 Result and Discussions

### 5.7.1 Agra and Mathura

### 5.7.1.1 Physical Parameters

- **pH and Electrical Conductivity (EC)**

pH is a numeric scale used to specify the acidity or basicity (alkalinity) of an aqueous solution. It is roughly the negative of the logarithm to base 10 of the molar concentration, measured in units of moles per liter, of hydrogen ions. More precisely it is the negative of the logarithm to base 10 of the activity of the hydrogen ion. Solutions with a pH less than 7 are acidic and solutions with a pH greater than 7 are basic. Pure water is neutral, being neither an acid nor a base.

Electrical conductivity (EC) is a measure of total mineral contents of water dissolved solids and depends upon the ionic strength of the solution. Increase in the concentration of dissolved solids, increases the ionic strength of the solution which indicates a proportional relationship between dissolved solids and electrical conductivity.

The pH of the analyzed samples varies from 6.63 to 7.49 (Avg. 7.00) in month of January, while it varies from 6.56 to 8.08 (Avg. 7.36). The increase in pH is clearly showed that the water has turned more alkaline in the month of February. In the month of January the pH of water was low and was slightly acidic at many locations. Increase in pH indicates that groundwater recharge has due to rainfall. Rainwater has a slightly acidic pH, therefore it tends to dissolve solid minerals in the soil and in the aquifer. In the month of February the values suggest that Agra water samples are overall having more pH i.e. they are more alkaline than the Mathura samples. Hence we can conclude that Agra has received more rainfall for a longer duration. High values of pH in SW & GW samples can also be due to waste discharge and microbial decomposition in water body. The pH of the water is within the permissible limit as prescribed by the BIS standards.

The electrical conductivity (EC) values varied from 1020 to 8680 $\mu S\ cm^{-1}$ with an average value of 2458.94 $\mu S\ cm^{-1}$in the month of January, while it varies from 1036 $\mu S\ cm^{-1}$ to 9050 $\mu S\ cm^{-1}$ with an average of 2538.25 $\mu S\ cm^{-1}$ in the month of February.

Increase in overall EC between January and February can be attributed to rainfall in the area which has enhanced increased the dissolution of solids. The EC of the study area has increased due to increase in the temperature of water. We can find exception at **Baleuganj** where a significant decrease in EC has been observed along with **Raja ki Mandi** where a slight decline in EC has been observed.

The high value of EC indicates high salinity of water in the study area. The Ec of water samples is very high in Wazirpura, Baleuganj, Pioyaghat and Raja ki Mandi in Agra making it completely unfit for drinking purposes. This also makes the water it unfit for irrigation purposes. The high degree of salinity in the water samples can also be attributed to the faulty agricultural practices and water logging problems.

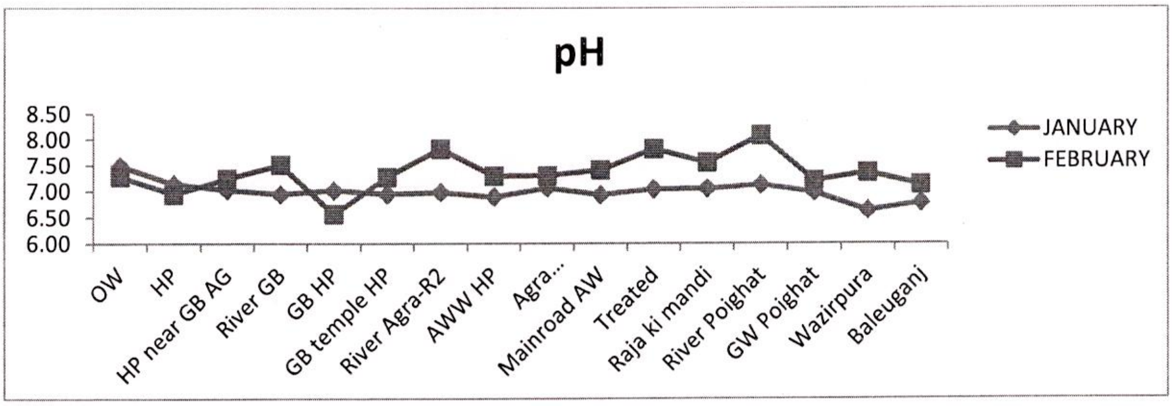


**Figure 11**:- Temporal Variation of pH in different sampling locations

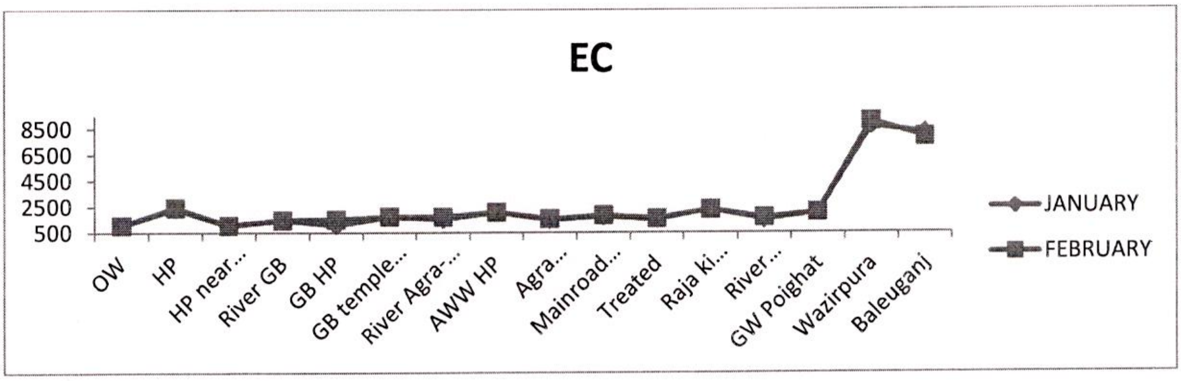


**Figure 12**:- Temporal Variation of Conductivity in different sampling locations

- **Turbidity**

Turbidity is the cloudiness or haziness of a solution caused by individual particles (total suspended or dissolved solids) that are generally invisible to the naked eye. The measurement of turbidity is a key test of water quality. Fluids can contain suspended solid matter consisting of particles of many different sizes. These small solid particles cause the liquid to appear turbid. Turbidity in open water may be caused by growth of phytoplankton, Human activities, high bank erosion rates and certain industries such as quarrying & mining.

In the month of January the measured turbidity in the Mathura and Agra water samples varies between 0.87 to 287 NTU with an average value of 20.24 NTU. In the month of February the measured turbidity in the Mathura and Agra water samples varies between 0.12 to 115 NTU with an average value of 9.95 NTU. The decrease in turbidity in water samples is mainly due to the decrease the concentration of suspended solids. This happened mainly due to rainfall in the area which has led to the dilution of the water and increased the dissolution of solid particles.

We find that the turbidity is exceptionally high in Sample L15 (Wazirpura GW sample) which is mainly due iron precipitation and settling of suspended sediment particles. Similarly High turbidity can be noticed in sample L11 (Agra water works borewell) and sample L7 (Yamuna River in Agra). All samples are having turbidity values within permissible limits of 5 NTU with exception to the above 3 sample which exceeds the limit.

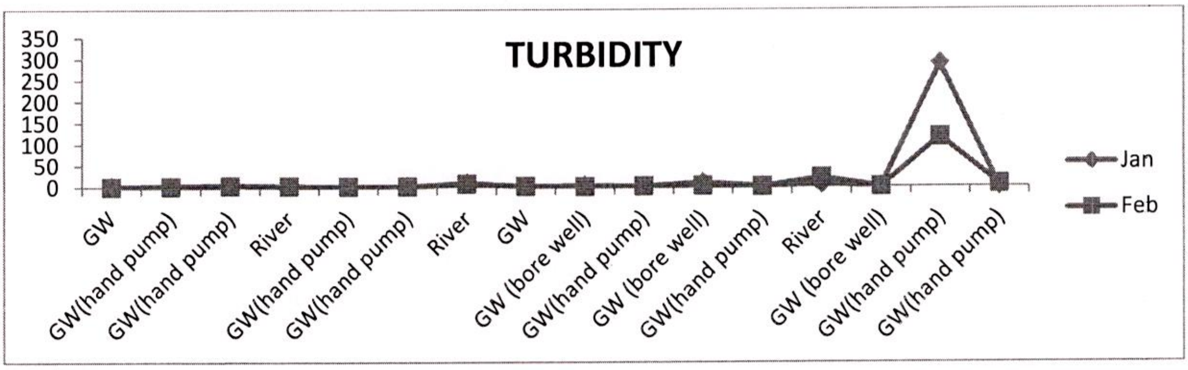


**Figure 13**:- Temporal Variation of Turbidity in different sampling locations

➢ **Total Dissolved Solids (TDS)**

In the Month of January TDS concentration in the water samples of the study area ranged from 652.8 (mg/l) in sample L3 to 5555.2 (mg/l) in sample L15 with an average value of 1573.7 (mg/l). In the month of February TDS concentration in the water samples of the study area ranged from 663 (mg/l) in sample L3 to 5792 (mg/l) in sample L15 with an average value of 1573.7 (mg/l). The TDS content has increased over period of time from January to February. The TDS content is higher in water samples of Agra as compared to Mathura. SW water samples are showing higher TDS content. High TDS content in water is due influence of human activities, discharge of industrial and domestic waste into river bodies and agricultural runoff. Samples like L15 and L16 which are GW samples show exceptionally high values of TDS which can be due to rock water interaction in that area.

In January and February TDS content in all samples are within permissible limit but exceeds desirable limit whereas L15 & L16 are far beyond the permissible limit. Based on TDS contents, water can be classified in to four categories as fresh, brackish, saline and brine water. TDS of all the analyzed water samples fall in the category of fresh water.

| TDS (mg/l) | Water Quality | % Samples |
|---|---|---|
| 0 – 1,000 | Fresh Water | 31% |
| 1,000 – 10,000 | Brackish Water | 50% |
| 10,000 – 100,000 | Saline Water | 12.5% |
| >100,000 | Brine | Nil |

We find that only 31% samples fall in freshwater category while majority of samples fall in brackish water category. This indicates that water of Agra and Mathura is having high degree of salinity.

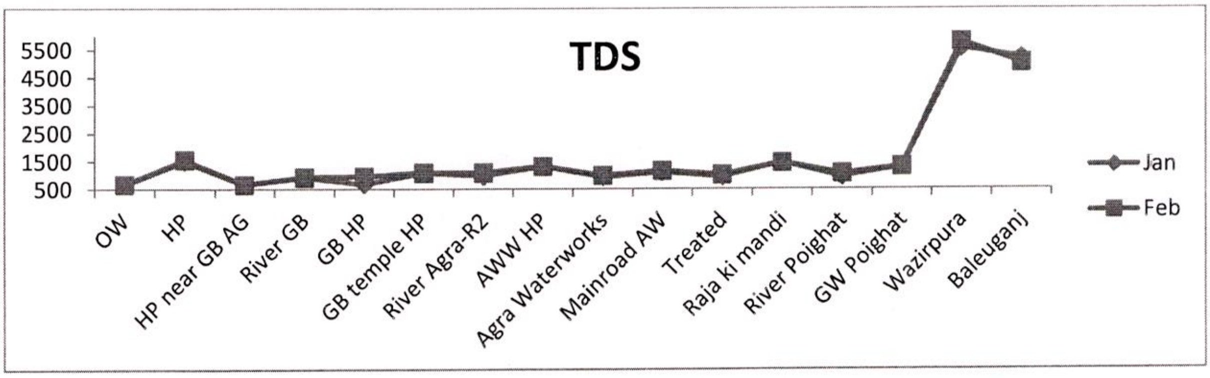


**Figure 14**:- Temporal Variation of TDS in different sampling locations

### ➢ Total Hardness

In the Month of January Total Hardness in the water samples of the study area ranged from 226 (mg/l) in sample L5 to 2764.5(mg/l) in sample L15 with an average value of 619.1 (mg/l). In the month of February Total Hardness in the water samples of the study area ranged from 213 (mg/l) in sample L3 to 2018.7(mg/l) in sample L15 with an average value of 552.15 (mg/l). In January total hardness in all samples are within permissible limit but exceeds desirable limit whereas L15 & L16 are far beyond the permissible limit. In February total hardness in all samples are within permissible limit but exceeds desirable limit whereas L2, L15 & L16 are beyond the permissible limit. The total hardness has decreased on average between January and February. This is due to rainfall which has occurred leading to dilution of water.

High values of hardness in water indicate the presence of Ca- rich rocks like Calcareous shale and calcite or limestone and dolomite in the lithology. From water quality analysis it is clear that we have high concentration of bicarbonate and calcium which increases hardness in water.

| Hardness (mg/l) | Water Class | % Sample |
|---|---|---|
| 0-75 | Soft | Nil |
| 75-150 | Moderately hard | Nil |
| 150-300 | Hard | 25% |
| >300 | Very hard | 75% |

From the above inference it is concluded that water of Agra and Mathura region is having very hard water.

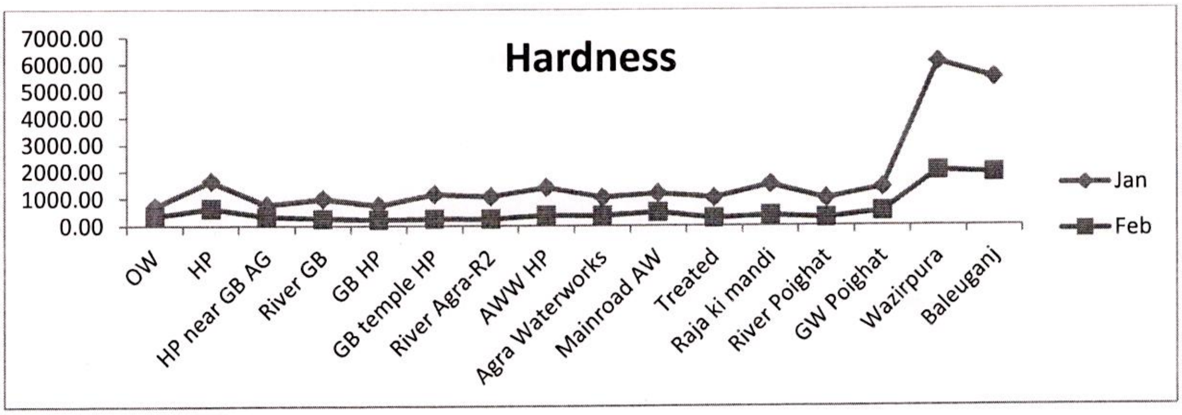


**Figure 15**:- Temporal Variation of Total Hardness in different sampling locations

### 5.7.1.2 Major Anions ($F^-$, $Cl^-$, HCO3-$^-$, $SO_4^{2-}$ , NO3$^-$ $NO_2^-$)

The anion chemistry of the analyzed samples shows that HCO3-$^-$, $Cl^-$ and $SO_4^{2-}$ are the dominant anions both in GW & SW samples. Based on the summation of total amount of anions in every samples of study area we find that in month of January the abundance of anions lies in order of $Cl^- > SO_4^{2-} >$ HCO3-$^-$ $> NO_3^- > NO_2^- > F^-$. In the month of February the abundance of anions lies in order of HCO3-$^-$$>Cl^->SO_4^{2-}>NO_3>NO_2>F^-$.

If we analyze individual samples then we find that the abundance of anions lies in order of HCO3-$^-$ $>Cl^- >SO_4^{2-} >F^-$ for all the samples except for samples L15 and L16 which has an exceptional abundance order which lies in $Cl^- > SO_4^{2-} >$ HCO3-$^-$ $> NO_3^- > NO_2^- > F^-$.

| ANIONS | January | February |
|---|---|---|
| | % | % |
| HCO3- | 24.78 | 29.67 |
| F | 0.66 | 0.48 |
| Cl | 32.33 | 28.79 |
| NO2 | 3.56 | 1.85 |
| SO4 | 28.07 | 28.07 |
| NO3 | 10.62 | 11.14 |

- **Bicarbonate**

Concentration of bicarbonate (HCO3-$^-$) varies from a minimum of 180 (mg/l) in L4 sample to a maximum value of 440 (mg/l) in L16 sample (Avg. 319.75) in month of January while the concentration varies from a minimum of 220 (mg/l) in L3 sample to a maximum value of 520 (mg/l) in L16 sample (Avg. 401.50) in month of February. The concentration of bicarbonate has increased in all the samples collected from Agra and Mathura

The bicarbonates are derived mainly from the soil zone $CO_2$ and at the time of weathering of parent minerals. Bicarbonate may also be derived from the dissolution of carbonates and/or silicate minerals by the carbonic acid. The cause of increase in bicarbonate conc. the water samples in month of February are due to rainfall and increased dissolution.

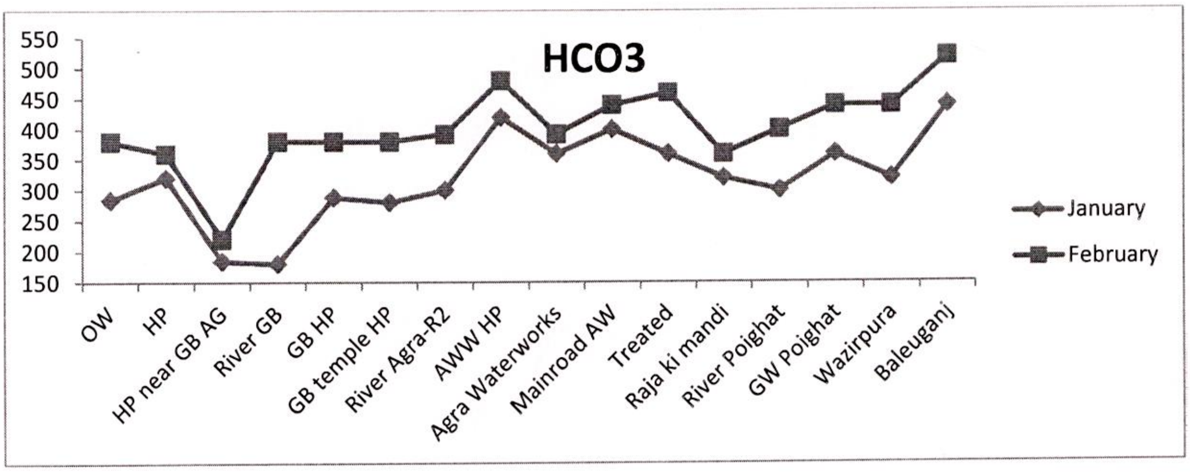


**Figure 16**:- Temporal Variation of Bicarbonate in different sampling locations

- **Chloride**

In the month of January the chloride ($Cl^-$) concentration in the analyzed samples varies between 107.60 in sample L1 to 2053.94 (mg/l) in sample L15 (Avg. 417) while in the month of February the chloride ($Cl^-$) concentration varies between 109.17 in sample L1 to 1531.52 (mg/l) in sample L15 (Avg. 389.53). The concentration of chloride has increased in Mathura samples and Agra samples from Poiyaghat Area while we find a decreasing trend in Agra Samples collected from Agra Water Works, Wazirpura, & Baleuganj.

In the month January the samples like L15 & L16 have exceeded the permissible limit, samples like L14, L12, L8 & L2 have exceeded the desirable limit but within permissible limit. In the month February the samples like L15 & L16 have exceeded the permissible limit, samples like L14, L12 & L2 have exceeded the desirable limit but within permissible limit.

Chloride is present in lower concentrations in common rock types and it is assumed that bulk of the chloride in ground water is primarily either from atmospHeric source, sea water contamination or from anthropogenic sources. Abnormal concentration of chloride may result from pollution by sewage wastes. The high chloride concentration in water samples like L15, L16, L12, L14, L2 indicate the contamination by untreated industrial and domestic waste effluents from nearby area. This can also be due to dissolution of halite rocks in water.

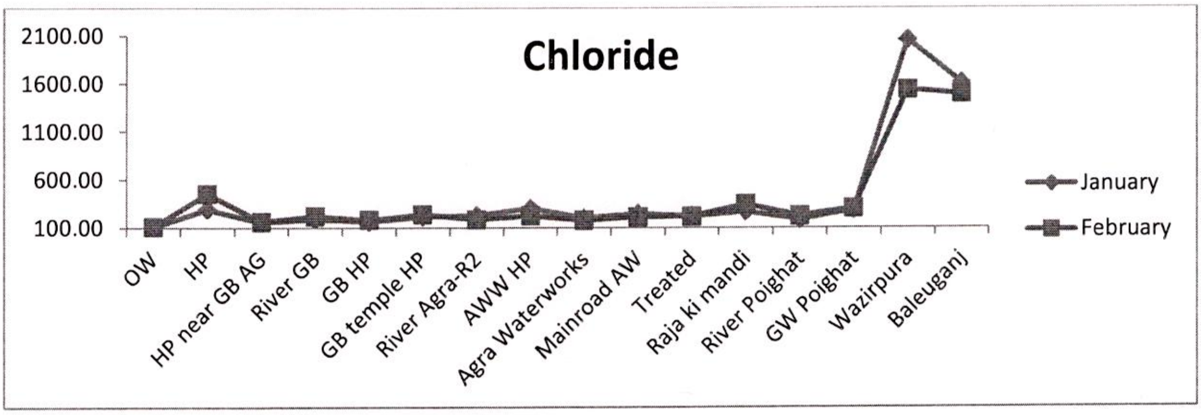


**Figure 17**:- Temporal Variation of Chloride in different sampling locations

- **Sulphate**

In the month of January Sulphate ($SO_4^{2-}$) concentration in water samples varies between 6.75 in sample L5 to 1815.32(mg/l) in sample L15 (Avg. 362.92(mg/l)), while in the month of February the Sulphate ($SO_4^{2-}$) concentration varies between 40.96 (mg/l) in sample L5 to 1739.93 (mg/l) in sample L15 (Avg. 379.87 (mg/l)). The concentration of sulphate has increased in all the samples collected from Agra and Mathura except L6 & L8 which has decreased. In the month January the samples like L15 & L16 have exceeded the permissible limit, samples like L2, L6, L8, L2 & L14 have exceeded the desirable limit but within permissible limit. In the month February the samples like L15, L16 & L2 have exceeded the permissible limit, samples like L14, L12 & L9 have exceeded the desirable limit but within permissible limit.

The sulphate is usually derived from the oxidative weathering of sulpHide bearing minerals like pyrite, gypsum or anhydrite. Apart from these natural sources, sulphate may be introduced through the application of sulphatic fertilizers. The observed high concentration of $SO_4$ in some samples like L15, L16 & L2 indicates the effects of industrial and anthropogenic activities in the area.

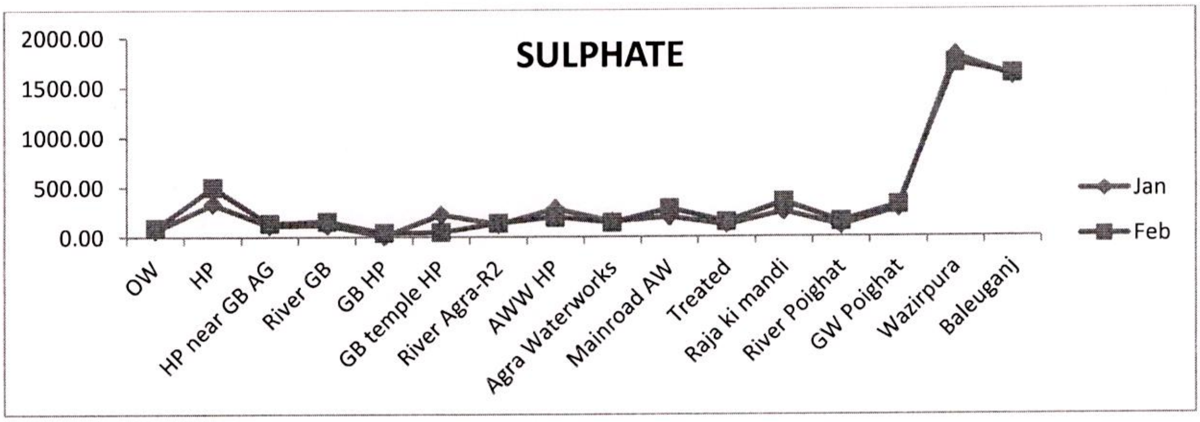


**Figure 18**:- Temporal Variation of Sulphate in different sampling locations

➢ **Nitrate and Nitrite**

In the month of January nitrate ($NO_3^-$) concentration in water samples varies between 2.92 in sample L5 to 1139.66 (mg/l) in sample L15 (Avg. 137.04 (mg/l)), while in the month of February the nitrate ($NO_3^-$) concentration varies between 3.11 (mg/l) in sample L3 to 882.14 (mg/l) in sample L15 (Avg. 150.70 (mg/l)). The concentration of nitrate has increased in all the samples collected from Agra and Mathura except L1, L3, L8, L10 & L15 where it has decreased.

In the month January the samples like L15, L16, L10 & L13 have exceeded the permissible limit. In the month February the samples like L15, L16, L4, L6, L10, L11, L12, L13 have exceeded the permissible limit. In the month of January nitrite ($NO_2^-$) concentration in water samples varies between 16.88 in sample L7 to 116.49 (mg/l) in sample L15 (Avg. 45.36(mg/l)), while in the month of February the nitrate ($NO_2^-$) concentration varies between 0.00 (mg/l) in sample L3,L2,L4,&L6 to 86.20 (mg/l) in sample L15 (Avg. 25.05 (mg/l)). The concentration of nitrite has decreased in all the samples collected from Agra and Mathura except L7 where it has increased.

There are three major sources of nitrogen in the water - biological fixation, precipitation, and the application of fertilizers. The anthropogenic sources of nitrogen include (i) point source including industrial sewage, refuse dumps etc. discharged directly in to the surface water, (ii) diffuse source including runoff and leaching from rural and urban land and (iii) precipitation.

The high concentration of nitrate is noticed around Agra Water Works which is possible due to discharge from waste water plant while in Wazirpura and Baleuganj it is can due to anthropogenic pollution, agricultural runoff or contamination with human or animal waste. In Mathura we observe that around Gokul barrage there is significant increase in nitrate conc. in Yamuna River and nearby hand pumps which is mainly due to increased agricultural runoff, discharge of industrial effluents and sewage. This action is increased due to rainfall.

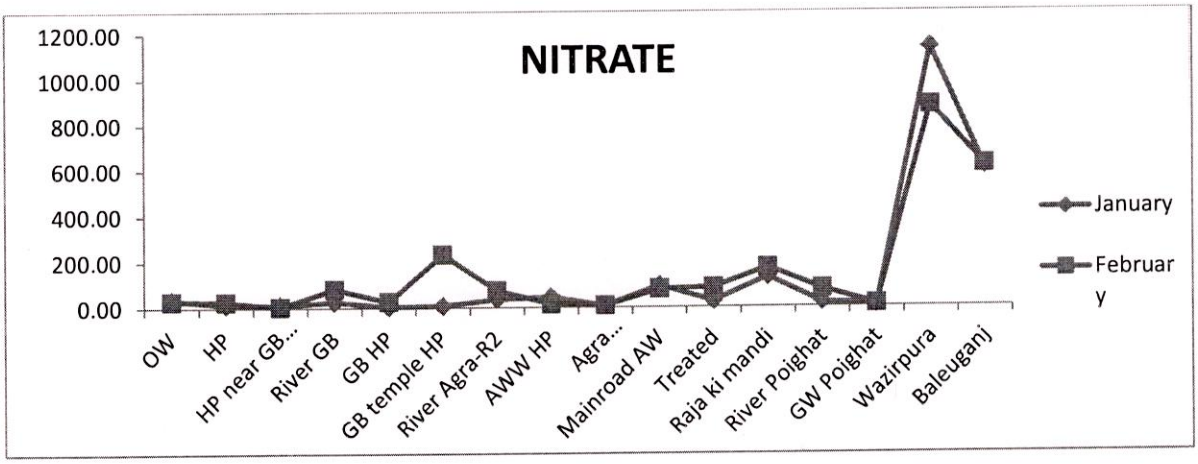


**Figure 19**:- Temporal Variation of Nitrate in different sampling locations

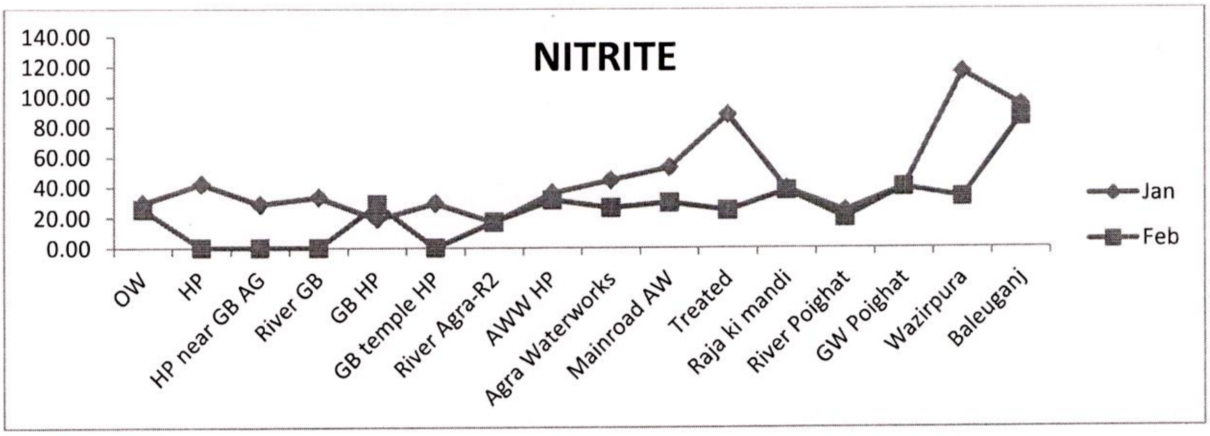


**Figure 20**:- Temporal Variation of Nitrite in different sampling locations

- **Fluoride**

In the month of January fluoride (F$^-$) concentration in water samples varies between 0.87 in sample L13 to 36.87 (mg/l) in sample L16 (Avg. 8.45 (mg/l)), while in the month of February the fluoride (F$^-$) concentration varies between 0.00 (mg/l) in sample L8 to 18.52 (mg/l) in sample L15 (Avg. 6.56 (mg/l)). The concentration of fluoride has increased in all the samples collected from Agra and Mathura except L5, L7, L8, L10, L11, L14, L15 & L16 where it has decreased. In the month January all samples have exceeded the permissible limit and only L11 is within desirable limit. In the month February all the samples have exceeded the permissible limit, and only L8 is within desirable limit. This indicates that study area is having excess of fluoride in water and most likely to suffer from fluorosis.

The fluoride may be derived from the weathering of rocks and pHospHatic fertilizers used in agricultural field. Among the factors, which control the concentration of fluoride includes climate of the area and the presence of accessory minerals in the rock mineral assemblage through which the groundwater is circulating. The excess conc. of fluoride in water samples in Agra and Mathura is mainly due geogenic reasons attributed to rock assemblages and lithology of the region and to some extent can be due to application of phosphatic fertilizers.

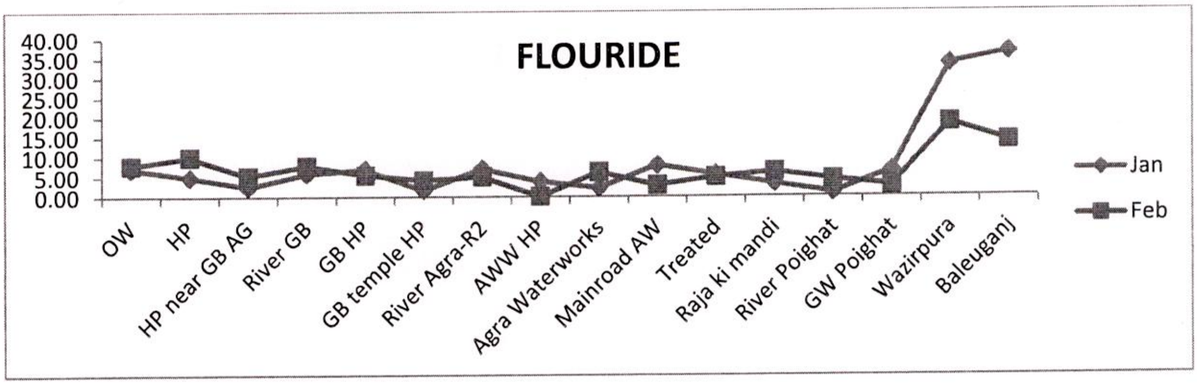


**Figure 21**:- Temporal Variation of Fluoride in different sampling locations

### 5.7.1.3 Major Cations ($Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$,$NH_4^{+}$):

The cation chemistry of the analyzed samples shows that $Na^{+}$ ,$Ca^{+2}$ ,$Mg^{+2}$ are the dominant cations both in GW & SW samples.

Based on the summation of total amount of cations in every samples of study area we find that in month of January the abundance of cations lies in order of $Na^{+} > Ca^{+2} > Mg^{+2} > K^{+} > NH_4^{+}$. In the month of February the abundance of cations lies in order of $Na^{+} > Ca^{+2} > Mg^{+2} > NH_4^{+} > K^{+}$

| CATIONS | January | February |
|---|---|---|
| | % | % |
| Na | 54.87 | 58.67 |
| NH4 | 2.34 | 2.34 |
| K | 2.84 | 1.90 |
| Mg | 15.92 | 16.32 |
| Ca | 24.03 | 20.78 |

The water chemistry of the Agra & Mathura is dominated by alkali metals. The weathering and cation exchange processes normally control the levels of these cations in the water.

- **Sodium**

In the month of January sodium($Na^{+}$) concentration in water samples varies between 41.48 (mg/l)in sample L3 to 992.59 (mg/l) in sample L15 (Avg. 270.81 (mg/l)), while in the month of February the sodium ($Na^{+}$) concentration varies between 42.13 (mg/l) in sample L3 to 977.59 (mg/l) in sample L15 (Avg. 272.28 (mg/l)). The concentration of sodium has slightly increased in all the samples collected from Agra and Mathura except L1, L7, L8, L9, L15 & L16 where it has slightly decreased. Samples like L2, L6, L8, L12 have very high conc. of sodium i.e. more than 200 (mg/l) while extremely high conc. of sodium is observed in L15, L16 samples which is more than 900 (mg/l).

Sodium is exceeding calcium and magnesium concentration in all of samples of the area. The sodium in the water is derived from the atmospheric deposition, evaporite dissolution and silicate weathering. The evaporate encrustation's of sodium/potassium salts may also be developed due to cyclic wetting and drying periods causes the formation of alkaline/saline soils, which may also serve as a source of sodium. The weathering of Na and K silicate minerals like albite, anorthite, orthoclase and microcline are the major source of the Na in the water. The high concentration of Na in Agra and Mathura samples is mainly due to silicate weathering and dissolution of evaporate salt in water.

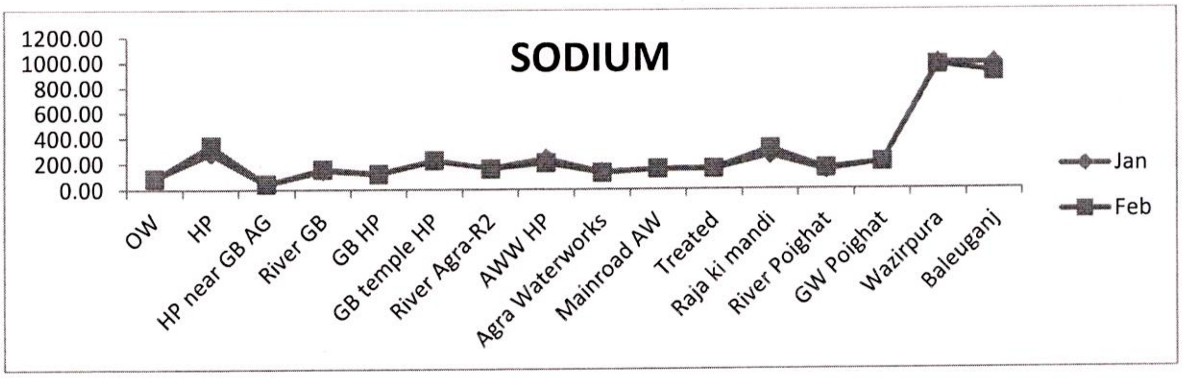


**Figure 22**:- Temporal Variation of Sodium in different sampling locations

➢ **Potassium**

In the month of January potassium ($K^+$) concentration in water samples varies between 4.20 (mg/l)in sample L5 to 60.65 (mg/l) in sample L15 (Avg. 14.03 (mg/l)), while in the month of February the potassium ($K^+$) concentration varies between 3.45 (mg/l) in sample L6 to 13.30 (mg/l) in sample L13 (Avg. 8.81 (mg/l)). The concentration of sodium has decreased in all the samples collected from Agra and Mathura.

Although potassium ($K^+$) is nearly as abundant as sodium in igneous rocks and metamorphic rocks, its concentration in groundwater is one-tenth or even one-hundredth that of sodium. Two factors are responsible for the scarcity of potassium in groundwater, one being decomposition of potassium minerals to by weathering and the other the fixation of potassium in clay minerals formed due to weathering. The weathering of silicate minerals like albite, anorthite, orthoclase and microcline are the major source of the K in the water.

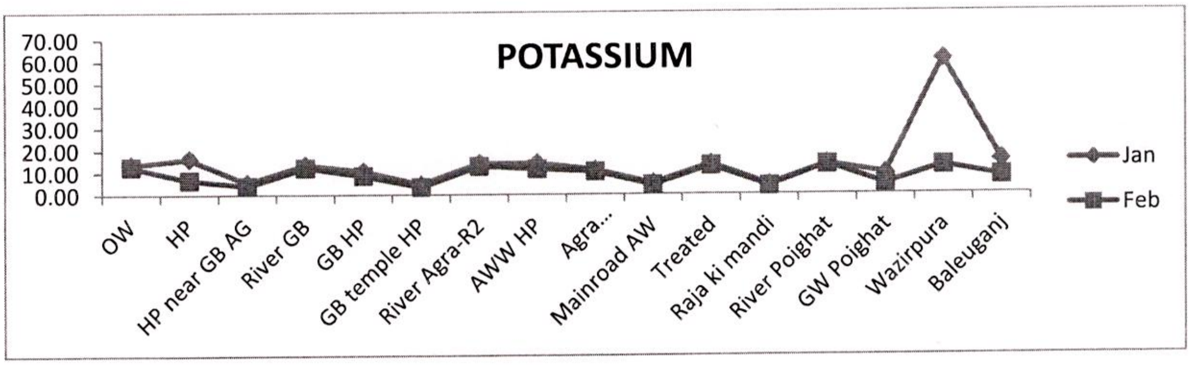


**Figure 23**:- Temporal Variation of Potassium in different sampling locations

➢ **Calcium**

In the month of January calcium ($Ca^{2+}$) concentration in water samples varies between 42.28 (mg/l)in sample L1 to 522.88 (mg/l) in sample L15 (Avg. 118.61 (mg/l)), while in the month of February the calcium ($Ca^{2+}$) concentration varies between 41.97 (mg/l) in sample L6 to 312.19 (mg/l) in sample L13 (Avg. 96.43 (mg/l)). The concentration of calcium has decreased in all the samples collected from Agra and Mathura except in samples L2, L12, L13, L14 where it has increased. In the month January the samples like L15 & L16 have exceeded the permissible limit, samples like L2, L3, L7, L8, L9,L10,L11 & L14 have exceeded the desirable limit but within permissible limit. In the month February the samples like L15, L16 have exceeded the permissible limit, samples like L2, L3,L9 & L14 have exceeded the desirable limit but within permissible limit.

Calcium in water comes mostly from dissolution of Ca bearing minerals and often it is the most abundant cation in water. Weathering and dissolution of calcium carbonate (limestone and dolomite), calcareous shale and calc-silicate minerals (amphiboles, pyroxenes, olivine, biotite etc) are the most common source of calcium is water. In Agra and Mathura source of calcium in water is mainly due to dissolution of carbonate rocks. High conc. of calcium indicates that water in study area is very hard.

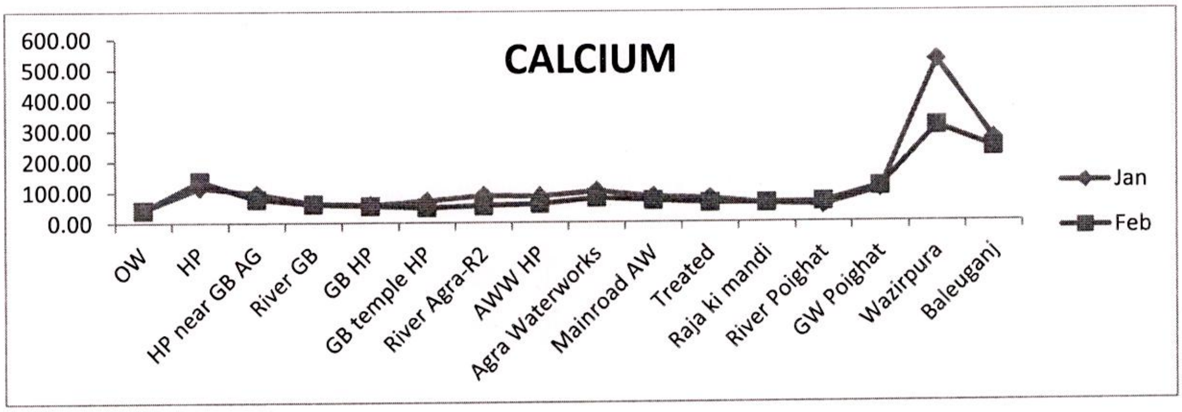


**Figure 24:** Temporal Variation of Calcium in different sampling locations

> **Magnesium**

In the month of January magnesium ($Mg^{2+}$) concentration in water samples varies between 20.39 (mg/l)in sample L5 to 351.28(mg/l) in sample L15 (Avg. 78.57 (mg/l)), while in the month of February the calcium ($Mg^{2+}$) concentration varies between 19.03 (mg/l) in sample L5 to 322.86 (mg/l) in sample L16 (Avg. 75.74 (mg/l)). The concentration of calcium has increased in all the samples collected from Agra and Mathura except in samples L5, L6, L7, L8, L9, L11, L15, L16 where it has decreased.

In the month January the samples like L15 & L16 have exceeded the permissible limit, samples like L2, L3, L7, L8, L9, L10, L11 & L14 have exceeded the desirable limit but within permissible limit. In the month February the samples like L15, L16 have exceeded the permissible limit, samples like L2, L3,L9 & L14 have exceeded the desirable limit but within permissible limit.

The principle source of magnesium in natural water is ferromagnesian mineral in igneous rock and magnesium carbonate in sedimentary rock. Olivine, clay minerals, dolomite, pyroxenes are the common source minerals for magnesium in the waters. As magnesium compounds (sulphate, chloride & carbonate) are more soluble, large amount of magnesium are rarely precipitated. Natural sources contribute more magnesium to the environment than all anthropogenic sources.

The presence of $Mg^{2+}$ is attributed to lithology of the rocks in the study area.

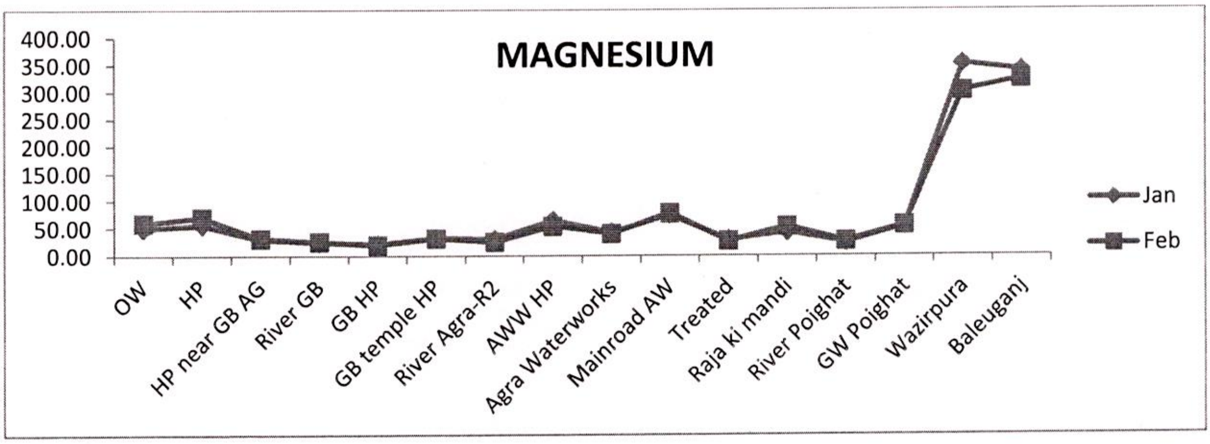


**Figure 25**:- Temporal Variation of Magnesium in different sampling locations

- **Ammonium**

In the month of January ammonium ($NH_4^+$) concentration in water samples varies between 3.16 (mg/l)in sample L3 to 49.98(mg/l) in sample L15 (Avg. 11.56 (mg/l)), while in the month of February the ammonium ($NH_4^+$) concentration varies between 5.29 (mg/l) in sample L7 to 35.12 (mg/l) in sample L15 (Avg. 10.16 (mg/l)). The concentration of calcium has increased in all the samples collected from Agra and Mathura except in samples L4, L7, L13, L15, L16 where it has decreased. In the month January & February all the samples have exceeded the permissible limit of 0.5(mg/l).

Natural levels in groundwater are usually below 0.2 mg of ammonia per litre. Surface waters may contain up to 12 (mg/l)itre (1). Ammonia may be present in drinking-water as a result of disinfection with chloramines. The presence of ammonia at higher levels is an important indicator of fecal pollution. The presence of the ammonium water may result in drinking-water containing nitrite as the result of ammonium-oxidizing bacteria.

Ammonia gets into water supplies most frequently as runoff in agricultural areas where it is applied as fertilizer and it easily finds its way into underground aquifers from animal fecal runoff. It also get added in water by the action denitrifying bacteria by natural processes.

Presence of high conc. of ammonium in Agra and Mathura can be due to fecal and agricultural runoff. In water samples in and around Agra water works it is due to waste water disinfection processes which are being undertaken.

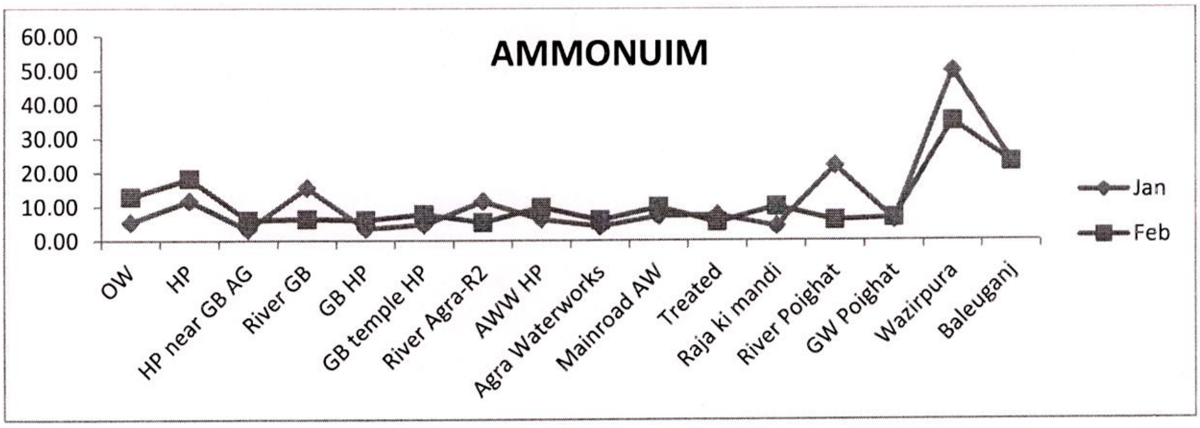


**Figure 26**:- Temporal Variation of Ammonium in different sampling locations

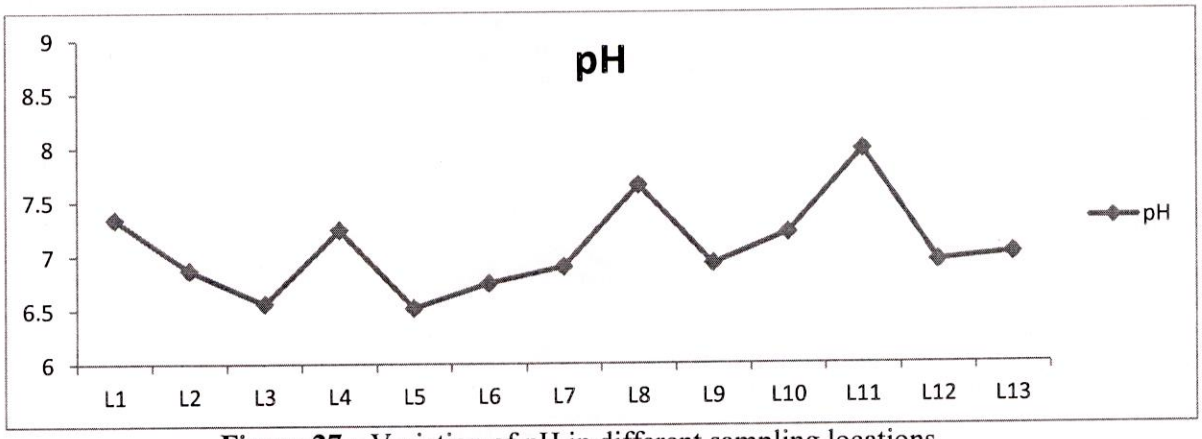
### 5.7.2 Laksar

#### 5.7.2.1 Physical Parameters

- **pH and Electrical Conductivity (EC)**

The PH of analyzed samples varies between 6.52 and 7.98 with an average of 7.07. We observe that the surface water samples have more PH that the groundwater indicating their more alkaline nature. Majority of the groundwater samples are slightly acidic in nature. The pH of the water samples fall within the permissible limit of BIS standards making is water fit for human consumptions. The SW samples are more alkaline in nature when compared to GW samples which are mainly due to higher content of bicarbonate in it.

The Ec values vary between 385 µS cm$^{-1}$ to 878 µS cm$^{-1}$ with an average of 585.69 µS cm$^{-1}$. From the Ec values we conclude that water falls in low salinity zone and it is good for irrigation purpose and fit for drinking purposes.



. **Figure 27:-** Variation of pH in different sampling locations

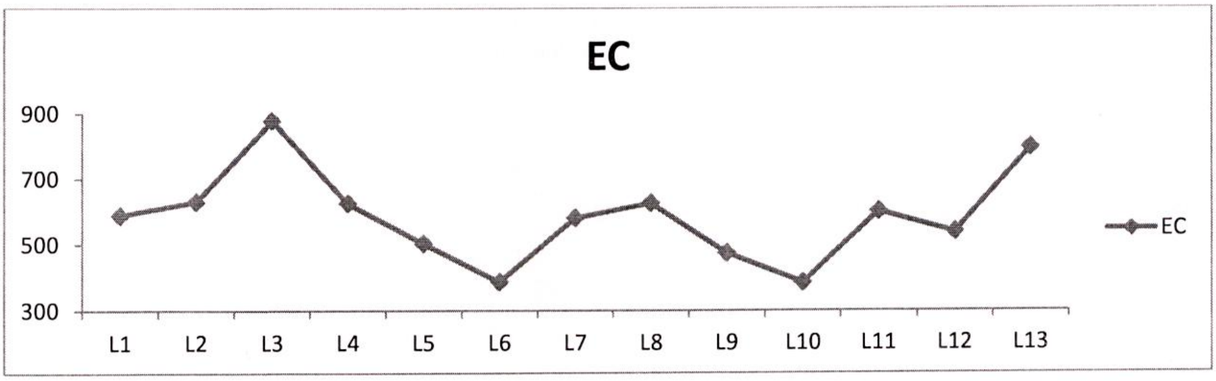


**Figure 28**:- Variation of Conductivity in different sampling locations

- **Total Dissolved Solids (TDS)**

Total Dissolved Solid (TDS) in water includes all dissolved material in solution, whether ionized or not. TDS is numerical sum of all mineral constituents dissolved in water and is expressed in (mg/l). The total dissolved solids concentration in the groundwater of the study area ranged from 246 to 562 mg\l with an average value of 375 (mg/l). The TDS content is high in SW samples while the GW samples like L13 and L3 which has high values of TDS. The groundwater samples show relatively low TDS as compared to the SW samples. Based on TDS contents, water can be classified in to four categories as fresh, brackish, saline and brine water. TDS of all the analyzed water samples fall in the category of fresh water. all the samples are having TDS within desirable limit except samples L3 and L13 where it has exceeded the desirable limit.

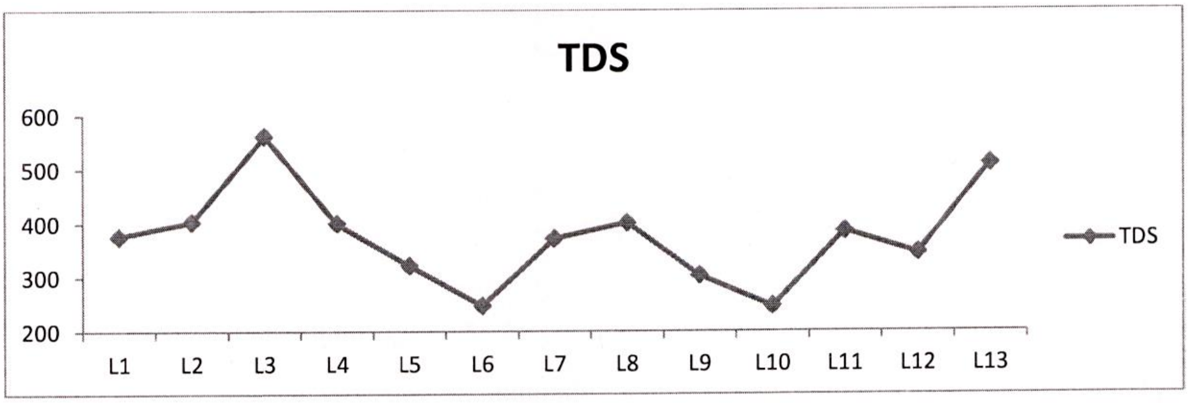


**Figure 29**:- Variation of TDS in different sampling locations

| TDS (mg/l) | Water Quality | % Samples |
|---|---|---|
| 0 – 1,000 | Fresh Water | 100% |
| 1,000 – 10,000 | Brackish Water | Nil |
| 10,000 – 100,000 | Saline Water | Nil |
| >100,000 | Brine | Nil |

The water samples of Laksar region comes in Fresh water Quality based on amount of TDS found in it.

- **Turbidity**

The measured turbidity in the Laksar water samples varies between 1.72 to 78.1 NTU with an average value of 20.29 NTU. We observe that samples L12, L2, L3, L6 show very high turbidity which is mainly due to the precipitation of iron in water. All these are groundwater samples. Surface water samples of Solani River showed turbidity beyond permissible limit of 5 NTU except at Dhadeki Village (L8). This is mainly due to the high concentration of suspended particles in the water samples. Turbidity is found within maximum permissible limit of 5 NTU in samples L4, L8, L10 & L13.

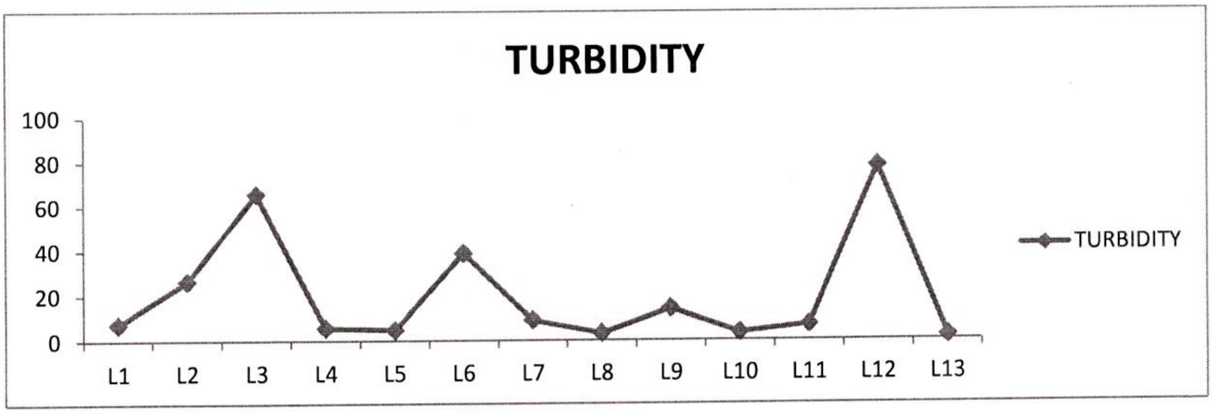


**Figure 30**:- Variation of Turbidity in different sampling locations

- **Total Hardness (TH)**

Hardness is the property of water which prevents the lather (foam) formation with the soap and increased the boiling point of the water. Principal cations imparting hardness are calcium and magnesium. These ions react with soap to form precipitates and with certain anions like sulphates present in the water.

The measured hardness in the Laksar water samples varies from 300 to 555 (mg/l) with an average value of 468(mg/l). The water samples of Laksar region show hardness within permissible limit but more than the desired limit. The SW samples are overall showing more hardness than GW samples in all the sampling sites. This indicates that SW samples have higher conc. of calcium and magnesium bicarbonate content which further suggest their flow on a terrain containing carbonate rock in its lithology. Maximum hardness is observed in the samples like L1, L2, L3, L8 & L9 which has values more than 500(mg/l). Hardness is customarily expressed in ppm (mg/l) as carbonate and classified in to four categories as soft water, hard water, moderately hard water and very hard water.

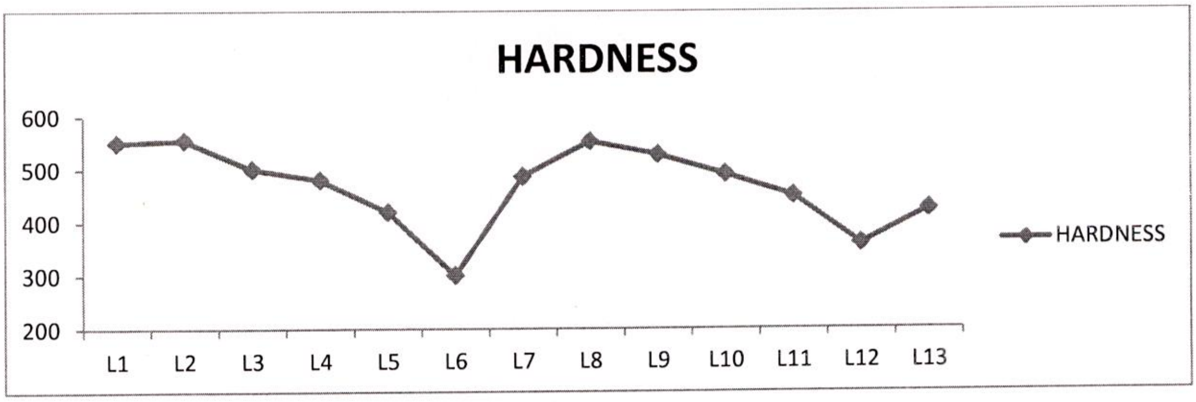


**Figure 31**:- Variation of Hardness in different sampling locations

| Hardness (mg/l) | Water Class | % Sample |
|---|---|---|
| 0-75 | Soft | Nil |
| 75-150 | Moderately hard | Nil |
| 150-300 | Hard | Nil |
| >300 | Very hard | 100% |

In general, groundwater of the Laksar is very hard in nature. The reason for high hardness is due the presence of calcium sulphates or magnesium sulphates in the water, which do not precipitate out.

- **Dissolved Oxygen**

Dissolved oxygen (DO) refers to the volume of oxygen that is contained in water. A high DO level in a community water supply is good because it makes drinking water taste better. Oxygen levels also can be reduced by run-off from farm fields containing fertilizers of phosphates and nitrates and higher temperature.

The water samples of Laksar site show DO between 1(mg/l) to 2 (mg/l) (Avg 1.55 (mg/l)). All the samples are below the desirable limit of 4 (mg/l). We observe that SW samples having lower DO than the GW samples. This indicates organic pollution and algal growth in SW samples. This also that eutrophication has taken SW samples where microorganisms in order to decompose the organic matter are consuming the oxygen in water. The source of organic pollution may me direct discharge of sewage and household wastes in the river.

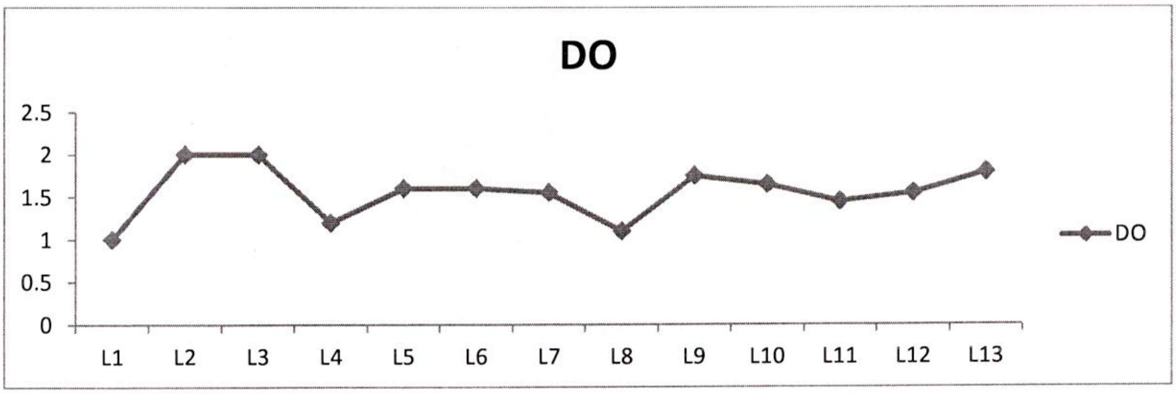


**Figure 32**:- Variation of Dissolved Oxygen in different sampling locations

## ➢ Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) (also called biological oxygen demand) is the amount of dissolved oxygen needed by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific time period. Higher the BOD level more polluted is the water. The water samples of Laksar site show BOD between 0.24 (mg/l) to 7.88 (mg/l) (Avg 3.05 (mg/l)).. We observe that SW samples having higher BOD than the GW samples. This indicates the surface water is polluted and also has higher concentration of organic content in it. The main sources of these organic wastes are domestic and municipal sewage which is being dumped into the river without proper treatment. Thus SW samples are unfit for human consumption.

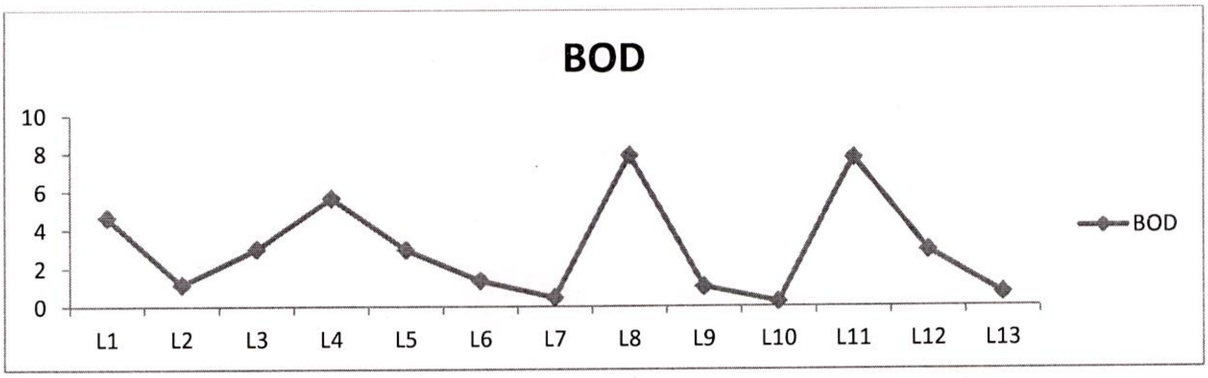


**Figure 33**:- Variation of BOD in different sampling locations

### 5.7.2.2 Major Anions ($F^-$, $Cl^-$, HCO3-$^-$, $SO_4^{2-}$ ,$NO_3^-$)

The anion chemistry of the analyzed samples shows that HCO3-$^-$, $Cl^-$ and $SO_4^{2-}$ are the dominant anions both in GW & SW samples. If we analyze samples on an average then we find that the abundance of anions lies in order of HCO3-$^-$>$Cl^-$>$SO_4^{2-}$>$NO_3$>$F^-$>$PO_4^-$.

| ANIONS | % |
|---|---|
| HCO3- | 76.340 |
| Cl | 19.241 |
| SO4 | 2.814 |
| NO3 | 1.530 |
| F | 0.040 |
| PO4 | 0.036 |

- **Bicarbonate**

The water samples of Laksar site show bicarbonates between 280(mg/l) in sample L5 to 480 (mg/l) in sample L11 (Avg 348.53 (mg/l)). All the samples are within permissible limit but have exceeded the desirable limit. We observe the SW samples have an overall higher concentration of bicarbonate than the GW samples indicating their flow over carbonate rocks like limestone or dolomite. Moreover the significant presence of bicarbonate in GW samples indicates presence of carbonate rocks in the lithology.

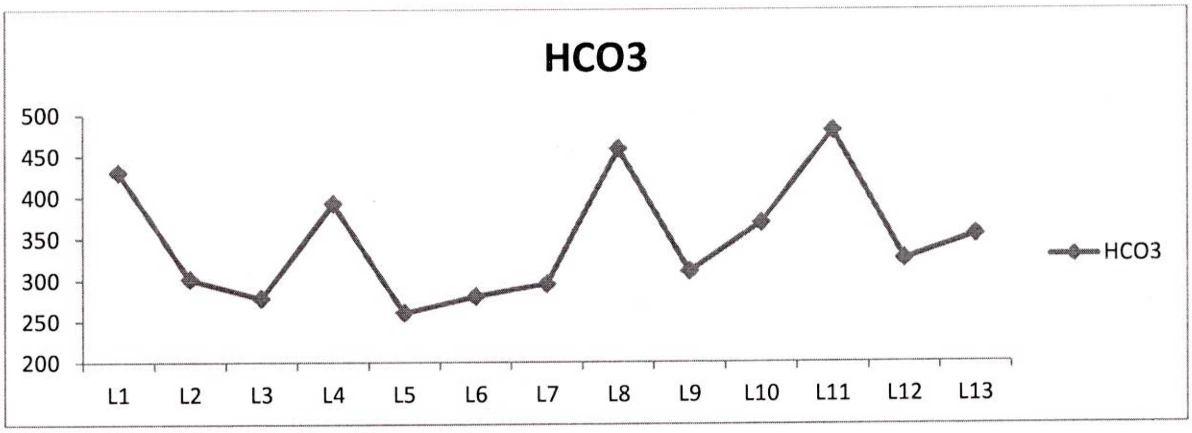


**Figure 34**:- Variation of Bicarbonate in different sampling locations

- **Chloride**

The water samples of Laksar site show chlorides between 16(mg/l) in sample L6 to 151 (mg/l) in sample L1 (Avg 87.84 (mg/l)). All the samples have chloride conc. within the desirable limit. High conc. of chloride in SW samples of Solani River indicates discharge of untreated domestic waste in the river water. We observe that some GW samples also show high chloride conc. which may be due to local recharge or influence of contamination by domestic/industrial effluents from nearby area. Chloride is not a problem in this region.

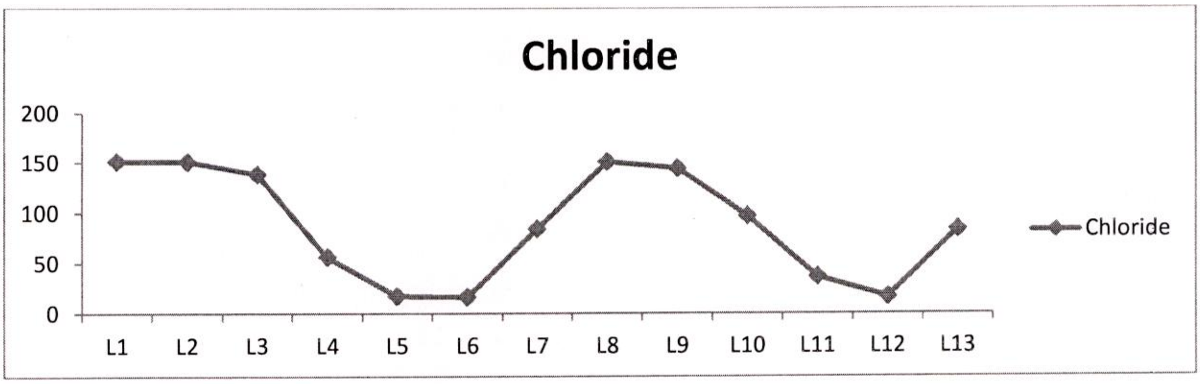


**Figure 35**:- Variation of Chloride in different sampling locations

- **Sulphate**

The water samples of Laksar site show sulphate conc. between 2mg/l in sample L6 to 37 mg/l in sample L13 (Avg 12.84 mg/l). All the samples have sulphate conc. within the desirable limit. We observe that SW samples have an overall higher sulphate conc. which indicates the runoff from agricultural field which may use sulphatic fertilizers. GW samples have very low sulphate content with some exception of samples L13 and L3. Sulphate is not a major concern in this region.

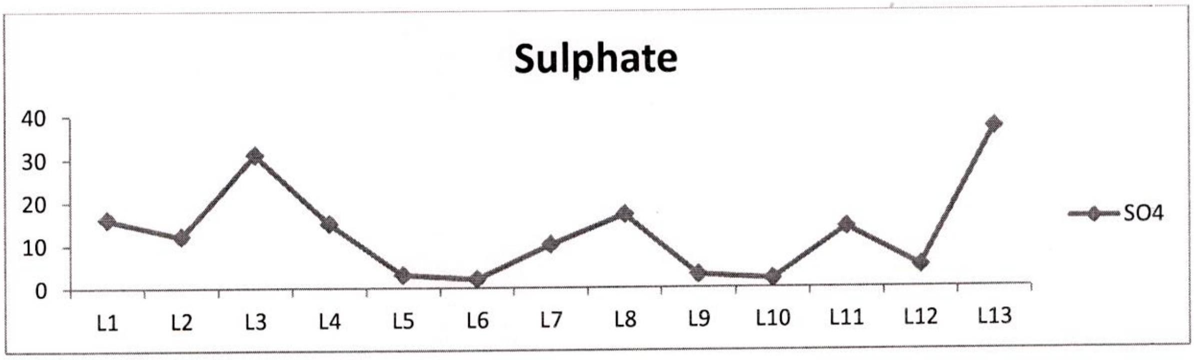


**Figure 36**:- Variation of Sulphate in different sampling locations

- **Nitrate**

The water samples of Laksar site show nitrate conc. between 1.6(mg/l) in sample L9 to 22 (mg/l) in sample L11 (Avg 6.84 (mg/l)). All the samples have nitrate conc. within the desirable limit. We observe that all the SW samples have a higher nitrate conc. than GW samples which indicates the some discharge of industrial waste in river and runoff from agricultural field which may use nitrogen based fertilizers. Nitrate content in river water is an indicator of algal growth and subsequent eutrophication and we have observed algal growth in Solani river at sampling sites. Nitrate is not a major concern in this region.

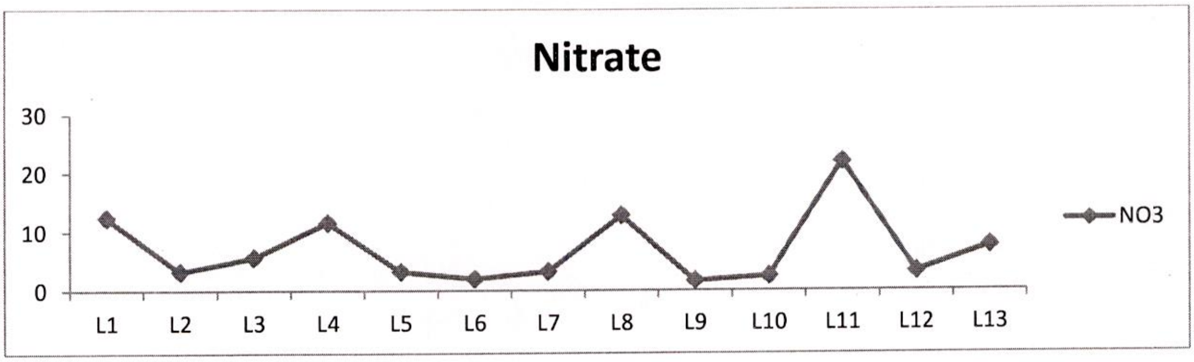


**Figure 37**:- Variation of Nitrate in different sampling locations

➢ **Fluoride**

The water samples of Laksar site show flouride conc. between 0.04(mg/l) in sample L5 to 0.39 (mg/l) in sample L3 (Avg 0.18 (mg/l)). All the samples have fluoride conc. within the desirable limit. All the SW samples show lower fluoride content than GW samples. Fluoride is not a major concern in this region.

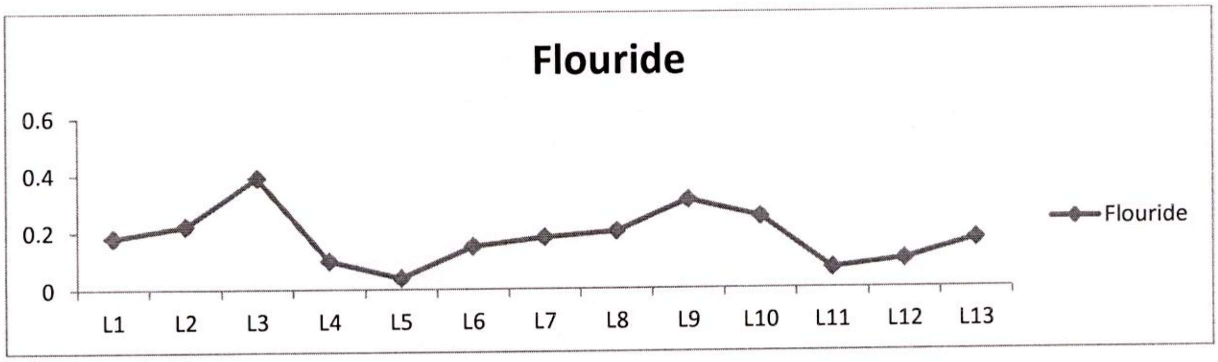


**Figure 38**:- Variation of Fluoride in different sampling locations

➢ **Phosphate**

The water samples of Laksar site show phosphate conc. between 0.09(mg/l) in sample L7 to 0.27 (mg/l) in sample L11 (Avg 0.16 (mg/l)). All the samples have low phosphate concentration. We observe that all the SW samples have a higher phosphate conc. than GW samples which indicates runoff from agricultural field which may use phosphatic fertilizers. Phosphate content in river water is an indicator of algal growth and subsequent eutrophication and we have observed algal growth in Solani River at sampling sites. Phosphate is not a major concern in this region.

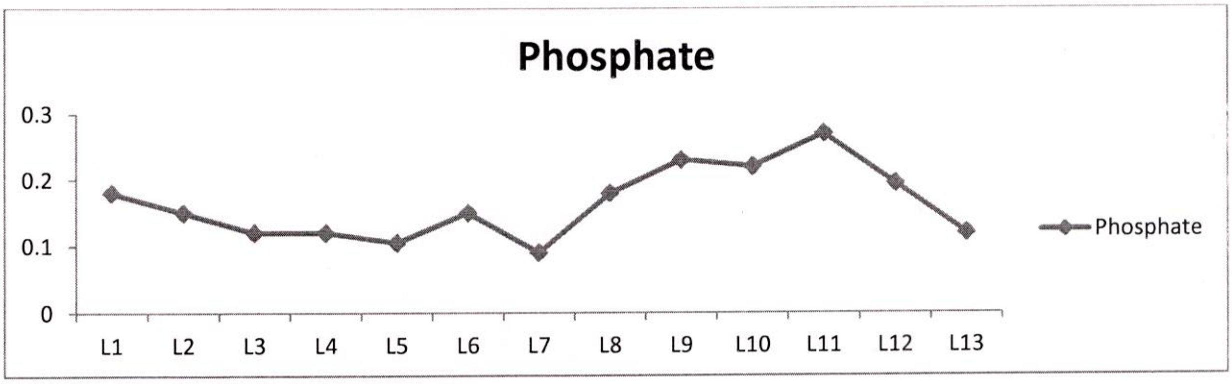


**Figure 39**:- Variation of Phosphate in different sampling locations

### 5.7.2.3 Major Cations ($Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$):

The cation chemistry of the analyzed samples shows that - $Na^{+}$ ,$Ca^{+2}$ ,$Mg^{+2}$ are the dominant anions both in GW & SW samples. If we analyze samples on an average then we find that the abundance of cations lies in order of $Ca^{+2} > Mg^{+2} > Na^{+} > K^{+}$.

| CATIONS | % |
|---|---|
| $Na^{+}$ | 15.46 |
| $K^{+}$. | 8.14 |
| $Ca^{+2}$ | 64.48 |
| $Mg^{+2}$ | 11.92 |

This shows that calcium is the most dominant cation in Laksar water samples.

- **Calcium**

The water samples of Laksar site show calcium between 13.5 (mg/l) in sample L5 to 190 (mg/l) in sample L1 (Avg. 115.37 (mg/l)). All the samples are within permissible limit but have exceeded the desirable limit. The samples L5, L12, L13 are within the desirable limit. We observe the SW samples have an overall higher concentration of calcium than the GW samples indicating their flow over carbonate rocks like limestone or dolomite. It is also indicates an higher dissolution of Ca- rich rocks in river. We observe in Dhadeki Village the both SW and GW samples have higher conc. of calcium indicating the presence of Ca-rich rocks like limestone or dolomite nearby. The calcium enrichment also occurs due to the cationic exchange and sediment groundwater interaction

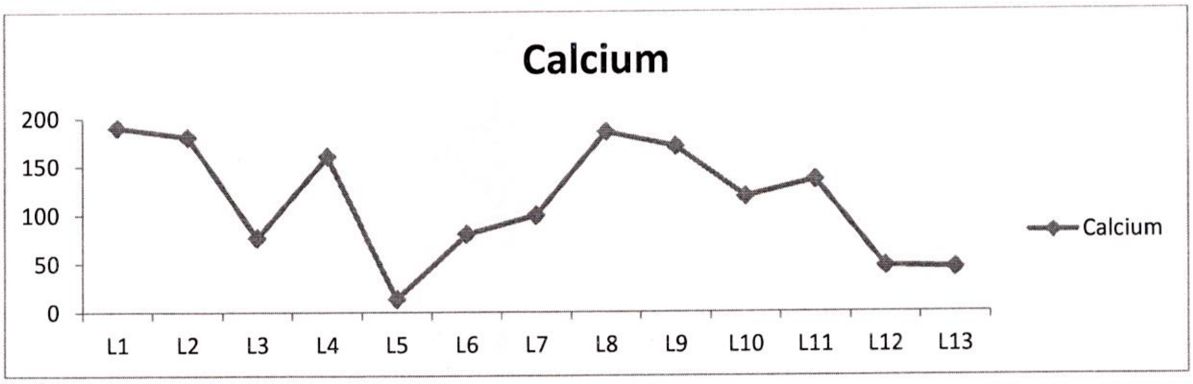


**Figure 40**:- Variation of Calcium in different sampling locations

- **Magnesium**

The water samples of Laksar site show magnesium between 9.7(mg/l) in sample L3 to 25.1 (mg/l) in sample L1 (Avg. 21.33 (mg/l)). All the samples are within desirable limit. We observe the SW samples have an overall higher concentration of magnesium than the GW samples. This indicates the presence of clay minerals and ferromagnesian minerals may be present in lithology. This also indicates the presence of dolomite in study area. The magnesium enrichment also occurs due to the cationic exchange and sediment groundwater interaction.

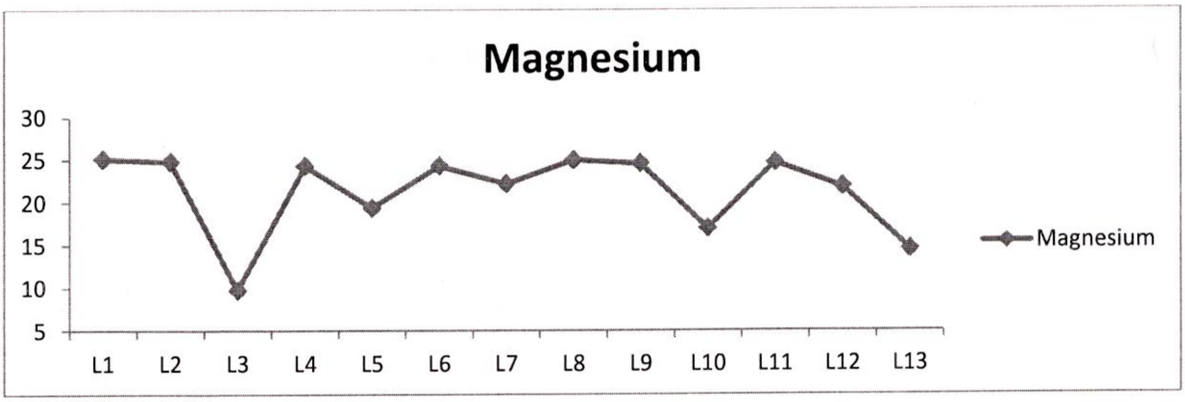


**Figure 41**:- Variation of Magnesium in different sampling locations

- **Sodium**

The water samples of Laksar site show sodium between 11.7 (mg/l) in sample L13 to 62.37 (mg/l) in sample L7 (Avg. 27.66 (mg/l)). All the samples are within desirable limit. We observe that in almost all the sampling locations the SW & GW samples have same amount of Na in the water samples. The source of Na in Laksar samples is mainly from weathering of silicate minerals like albite and plagioclase feldspar. This also indicates the presence of plagioclase feldspar rich sedimentary rocks like sandstone in the region.

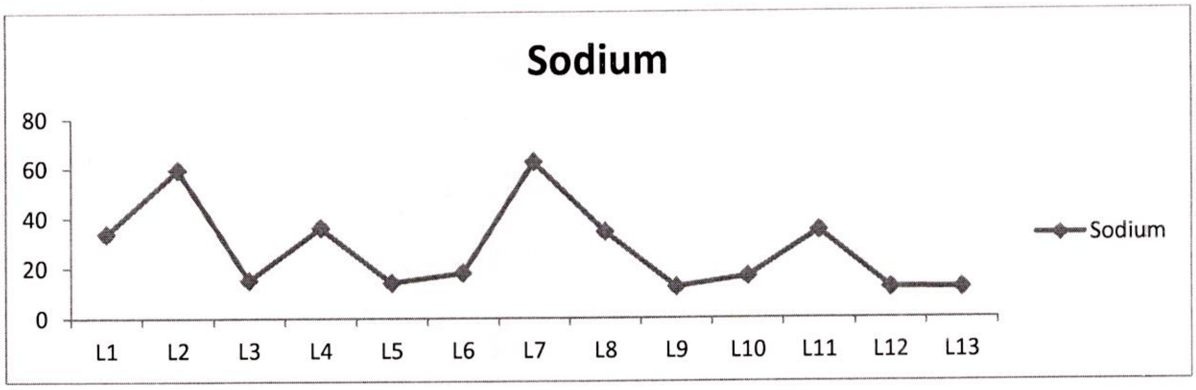


**Figure 42**:- Variation of Sodium in different sampling locations

- **Potassium**

The water samples of Laksar site show potassium between 3.86 (mg/l) in sample L6 to 18.6 (mg/l) in sample L1 (Avg.6.55 (mg/l)). All the samples are within desirable limit. We observe that in almost all the sampling locations the SW samples have same amount of K in the water samples than GW samples. The source of K in Laksar samples is mainly from weathering of silicate minerals. This also indicates the presence of feldspar rich sedimentary rocks like sandstone in the region.

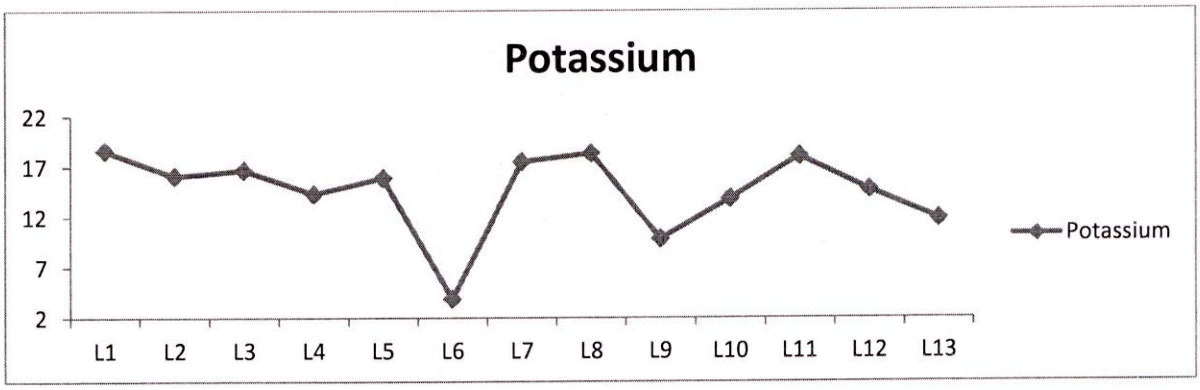


**Figure 43**:- Variation of Potassium in different sampling locations

### 5.7.2.4 Bacteriological Analysis

#### Laksar

The presence of coliform in water is an indicator of contamination by human or from animal excrement. The presence of fecal coliform in groundwater indicates a potential public health problem, because fecal matters are source of pathogenic bacteria and viruses. The groundwater contamination from fecal-coliform bacteria is generally caused by water percolation into the aquifer from a contamination source like domestic sewage, drains and septic tanks. The poor sanitation around the source water also caused bacteriological contamination. Shallow well are particularly susceptible for such contamination.

Coliform bacteria are present in the environment and feces of all warm-blooded animals and humans. Their presence in drinking water indicates that disease-causing organisms (pathogens) could be in the water system. Most pathogens that can contaminate water supplies come from the feces of humans or animals.

**Table 5.19**: Concentration of Total Coliform in Laksar Samples

| Sample | Location | TC (MPN/100ml) |
|---|---|---|
| L1 | Solani river bridge | 2400 |
| L2 | Dosni PHatak temple | 15 |
| L3 | Kuwankhera Village | 7 |
| L4 | Kuwankhera Ghat | 2400 |
| L5 | Kuwankhera Village | 7 |
| L6 | Kuwankhera Village | 3 |
| L7 | Kuwankhera Village | 7 |
| L8 | Dhadeki Solani River | 2400 |
| L9 | Dhadeki Village | 3 |
| L10 | Dhadeki Vilage | 3 |
| L11 | Muhammadpur Bujurg Railway bridge | 2400 |
| L12 | Muhammadpur Bujurg | 7 |
| L13 | Muhammadpur Bujurg | 3 |

All the water samples in Laksar site have coliform bacteria in it and it more than the permissible limit of 0MPN/100 ml. We found that almost all the GW samples have coliform bacteria in it making it unfit for human consumption and most likely to cause water borne diseases among the people who use it. Inadequate maintenance of wells and unhygienic condition around the water sources are major cause for bacteriological contamination. In SW samples there is extremely high presence of coliform bacteria (>2400 MPN/100) indicating high degree of organic contamination mostly due to discharge of sewage and mixing of animal feces in water.

**Table 5.20:-** BIS Standards for various Water Quality Parameters

| **Parameters** | ***Maximum Desirable*** | ***Highest permissible*** |
|---|---|---|
| pH | 6.5-8.5 | 8.5-9.2 |
| EC ($\mu S\ cm^{-1}$) | - | - |
| TDS | 500 | 2000 |
| Turbidity (NTU) | 1 | 5 |
| Total Hardness | 200 | 600 |
| $F^-$ | 1.0 | 1.5 |
| $Cl^-$ | 250 | 1000 |
| $HCO_3^-$ | - | - |
| $SO_4^{2-}$ | 200 | 400 |
| $NO_3^-$ | 45 | No relaxation |
| $Ca^{2+}$ | 75 | 200 |
| $Mg^{2+}$ | 30 | 100 |
| $Na^+$ | - | - |
| $K^+$ | - | - |
| HEAVY AND TRACE METALS | | |
| Fe | 300 | No relaxation |
| Mn | 100 | 300 |

**Table 5.21:-** Health Hazards Associated with different water quality parameters.

| | |
|---|---|
| **Ca** | Hypercalcaemia. |
| **Mg** | Hypotension, cardiac arrest, muscle weakness, urine retention |
| **Mn** | Lethargy, increased muscle tone, tremor and mental disturbances. |
| **F** | Enamel and skeletal fluorosis associated with osteosclerosis, calcification of tendons and ligaments and bone deformities. |
| **NH4** | Disturbs the acid–base equilibrium, reduces the tissue sensitivity to insulin |
| **Na** | Nausea, vomiting, convulsions, muscular twitching and rigidity, and cerebral and pulmonary oedema, chronic congestive heart failure |
| **K** | Chest tightness, nausea and vomiting, diarrhea, hyperkalaemia, shortness of breath and heart failure |
| **NO2/NO3** | Methaemoglobinaemia, Blue Baby syndrome |
| **Cl** | Congestive heart failure, impaired sodium chloride metabolism |
| **SO4** | Causes catharsis, dehydration from diarrhea, decreases gastrointestinal retention of food |
| **Fe** | (Haemochromatosis), haemorrhagic necrosis and sloughing of areas of mucosa in the stomach |

## 5.8 Water Quality Index

### Weighted Arithmetic Water Quality Index Method

Weighted arithmetic water quality index method classified based on the water quality according to the degree of purity is used. It uses common water quality parameters like pH, chlorides, fluorides, alkalinity, DO, sulphates etc.

$$WQI = \frac{\sum W_I\, Q_I}{\sum W_I}$$

Where, Qi is the quality rating scale

$$Q_I = \frac{(V_I - V_O)}{(S_I - V_O)} * \ 100$$

Where,
$V_i$ is estimated concentration of the parameter,
$V_o$ is the ideal value; Vo = 0

The unit weight ($W_i$) for each water quality parameter is calculated by using the following formula:

$$W_i = K/Si$$

Where,
K = proportionality constant, Si is the rating of water quality accordingly

| Index | Short form | Formulae |
|---|---|---|
| **Relative weightage** | Wi | $Wi=Wi/\sum_{=1}^{n} Wi$ |
| **Qualitative Rating Scale** | Qi | $Qi=(Ci/\sum i)*100$ |
| **Sub index** | SIi | $SIi=Wi*Qi$ |
| **Water Quality index** | WQI | $\sum SIi$ |

| WQI Range | Condition |
|---|---|
| **<50** | Excellent drinking water |
| **50 – 100** | Good portable water |
| **100 – 200** | Poor water |
| **200 – 300** | Very poor water |
| **>300** | Water not suitable for drinking |

**Table 5.22:-** Water Quality Index of Lakar

| **S.NO** | **Chemical Parameters** | **BIS** | **Weightage (wi)** | **Relative Weightage (Wi)** | **Quality Rating (Qi)** | **Sub Index (SIi)** | **Mean** | **Max** |
|---|---|---|---|---|---|---|---|---|
| 1 | pH | 6.5-8.5 | 4 | 0.07 | 94.40 | 6.99 | 7.1 | 7.49 |
| 2 | TDS | 500-2000 | 4 | 0.07 | 18.74 | 1.39 | 374.8 | 2000 |
| 3 | EC | 750 | 3 | 0.06 | 78.09 | 4.34 | 585.7 | 750 |
| 4 | turbidity | 1.0-5.0 | 4 | 0.07 | 405.98 | 30.07 | 20.3 | 5 |
| 5 | Alkalinity | 200-600 | 4 | 0.07 | 47.61 | 3.53 | 285.7 | 600 |
| 6 | Iron | 0.3 | 4 | 0.07 | 1018.97 | 75.48 | 3.06 | 0.3 |
| 7 | Nitrate | 45 | 5 | 0.09 | 15.52 | 1.44 | 6.98 | 45 |
| 8 | Flouride | 1-1.5 | 4 | 0.07 | 12.10 | 0.90 | 0.18 | 1.5 |
| 9 | Hardness | 200-600 | 2 | 0.04 | 78.16 | 2.89 | 468.9 | 600 |
| 10 | Chloride | 250-1000 | 3 | 0.06 | 8.78 | 0.49 | 87.84 | 1000 |
| 11 | Manganese | 0.1-0.3 | 4 | 0.07 | 464.10 | 34.38 | 1.39 | 0.3 |
| 12 | Magnesium | 30-100 | 2 | 0.04 | 21.34 | 0.79 | 21.34 | 100 |
| 13 | Sulphate | 200-400 | 4 | 0.07 | 3.21 | 0.24 | 12.85 | 400 |
| 14 | Calcium | 75-200 | 4 | 0.07 | 57.69 | 4.27 | 115.38 | 200 |
| 15 | Bicarbonate | 244-732 | 3 | 0.06 | 47.61 | 2.65 | 348.54 | 732 |
|  |  |  | **54** | 1.00 | **2372.33** | **169.84** |  |  |

**Table 5.23:-** Water Quality Index of Agra and Mathura

| S.NO | Chemical Parameters | BIS | Weightage (wi) | Relative Weightage (Wi) | Quality Rating (Qi) | Sub Index (SIi) | Mean | Max |
|---|---|---|---|---|---|---|---|---|
| 1 | pH | 6.5-8.5 | 4 | 0.07 | 93.46 | 6.92 | 7.00 | 7.49 |
| 2 | TDS | 500-2000 | 4 | 0.07 | 78.69 | 5.83 | 1573.72 | 2000 |
| 3 | EC | 750 | 3 | 0.06 | 327.86 | 18.21 | 2458.94 | 750 |
| 4 | turbidity | 1.0-5.0 | 4 | 0.07 | 404.84 | 29.99 | 20.24 | 5 |
| 5 | Alkalinity | 200-600 | 4 | 0.07 | 43.68 | 3.24 | 262.09 | 600 |
| 6 | Iron | 0.3 | 4 | 0.07 | 101.46 | 7.52 | 0.304 | 0.3 |
| 7 | Nitrate | 45 | 5 | 0.09 | 304.52 | 28.20 | 137.04 | 45 |
| 8 | Flouride | 1-1.5 | 4 | 0.07 | 12.00 | 0.89 | 0.18 | 1.5 |
| 9 | Hardness | 200-600 | 2 | 0.04 | 103.19 | 3.82 | 619.12 | 600 |
| 10 | Chloride | 250-1000 | 3 | 0.06 | 34.03 | 1.89 | 340.34 | 1000 |
| 11 | Manganese | 0.1-0.3 | 4 | 0.07 | 250.00 | 18.52 | 0.750 | 0.3 |
| 12 | Magnesium | 30-100 | 2 | 0.04 | 78.57 | 2.91 | 78.57 | 100 |
| 13 | Sulphate | 200-400 | 4 | 0.07 | 90.55 | 6.71 | 362.19 | 400 |
| 14 | Calcium | 75-200 | 4 | 0.07 | 59.31 | 4.39 | 118.61 | 200 |
| 15 | Bicarbonate | 244-732 | 3 | 0.06 | 43.68 | 2.43 | 319.75 | 732 |
|  |  |  | **54** | 1.00 | **2025.83** | **141.46** |  |  |

From the water quality index we can conclude that the water samples of Laksar and Agra & Mathura fall in 'poor' category and we are hopeful that Riverbank Filtration project can be helpful in improving the water quality of this region.

## 5.9 Linear Regression Model

The mathematical models used to estimate water quality require two parameters to describe realistic water situations. Correlation analysis measures the closeness of the relationship between chosen independent and dependent variables. If the correlation coefficient is nearer to +1 or –1, it shows the probability of linear relationship between the variables x and y. **The correlation between the parameters is characterized as strong, when it is in range of +0.8 to 1.0 and -0.8 to -1.0, moderate when it is having value in the range of 0.5 to 0.8 and -0.5 to -0.8, weak when it is in the range of +0.0 to 0.5 and -0.0 to -0.5**. This analysis attempts to establish the nature of the relationship between the variables and thereby provides a mechanism for predictions or forecasting. In this study the relationship of water quality parameters on the each other in data of water analyzed was determined by calculating Karl Pearson correlation coefficient R by using the formula as given

$$R = \frac{\sum (X-\bar{X})(Y-\bar{Y})}{\sqrt{\sum (X-\bar{X})^2 \sum (Y-\bar{Y})^2}}$$

Where, x (x =values of x-variable, =average values x) and y (y =values of y-variable, =average values y) represents two different water quality parameters. If the values of correlation coefficient 'R' between two variables X and Y are fairly large, it implies that these two variables are highly correlated.

To determine the straight linear regression, the following equation of straight line can be used.

$$Y = a + bX$$

Where, y and x are the dependent and independent variable respectively. A is the slope of the line; b is the intercept on y axis.

The value of empirical parameters a and b are calculated with the help of the following equation

$$b = \frac{\sum XY - \bar{X}\sum Y}{\sum X^2 - \bar{X}\sum Y}$$

And

$$a = \bar{Y} - b\bar{X}$$

In the statistics correlation is a broad class of statistical relationship between two or more variables. The correlation study is useful to find a predictable relationship which can be exploited in practice. It is used for the measurement of strength of the relation between two or more water quality parameters.

The systematic calculation of correlation coefficient between water quality variables and regression analysis provide indirect means for rapid monitoring of water quality. The correlation coefficients measure the degree of association that exists between two variables, one taken as dependent variable. The greater the value of regression coefficient, the better is the fit and more useful the regression variables. Correlation is a mutual relationship between two variables. Direct correlation exists when increase or decrease in the value of one parameter is associated with a corresponding increase or decrease in the value of other parameter.

**Table 20**:- Pearson Correlation Matrix of Water Quality of Agra & Mathura in January

| | **EC** | **HCO3-$^-$** | F | Cl | N02 | SO4 | NO3 | Na | NH4 | K | Mg | Ca | **pH** | **TDS** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **EC** | 1 | 0.387 | 0.957 | 0.990 | 0.824 | 0.998 | 0.948 | 0.996 | 0.821 | 0.726 | 0.988 | 0.919 | -0.671 | 1 |
| **HCO3-$^-$** | | 1 | 0.361 | 0.327 | 0.451 | 0.367 | 0.240 | 0.410 | 0.073 | 0.062 | 0.403 | 0.220 | -0.263 | 0.387 |
| F | | | 1 | 0.955 | 0.797 | 0.952 | 0.908 | 0.950 | 0.763 | 0.675 | 0.974 | 0.863 | -0.599 | 0.957 |
| Cl | | | | 1 | 0.832 | 0.993 | 0.977 | 0.979 | 0.860 | 0.794 | 0.985 | 0.958 | -0.686 | 0.990 |
| NO2 | | | | | 1 | 0.826 | 0.817 | 0.808 | 0.681 | 0.669 | 0.945 | 0.809 | -0.568 | 0.824 |
| SO4 | | | | | | 1 | 0.954 | 0.990 | 0.825 | 0.741 | 0.990 | 0.935 | -0.674 | 0.998 |
| NO3 | | | | | | | 1 | 0.928 | 0.889 | 0.858 | 0.945 | 0.971 | -0.652 | 0.948 |
| Na | | | | | | | | 1 | 0.800 | 0.699 | 0.978 | 0.894 | -0.668 | 0.996 |
| NH4 | | | | | | | | | 1 | 0.902 | 0.797 | 0.882 | -0.570 | 0.821 |
| K | | | | | | | | | | 1 | 0.714 | 0.895 | -0.479 | 0.726 |
| Mg | | | | | | | | | | | 1 | 0.913 | -0.632 | 0.988 |
| Ca | | | | | | | | | | | | 1 | -0.680 | 0.919 |
| **pH** | | | | | | | | | | | | | 1 | -0.671 |
| **TDS** | | | | | | | | | | | | | | 1 |

### Interpretation of Corelation Matrix of Agra and Mathura in January

The correlation coefficients (r) among 14 water quality parameters namely pH, EC, TDS, Ca, Mg, Na, NH4, K , NO2, HCO3-, Cl , SO4, NO3 and F were calculated for correlation analysis. Interpretation of correlation gives an idea of quick water quality monitoring method. In the correlation matrix the values varies between +1 to -1. +1 indicates very strong and perfect positive relation and -1 indicate very strong and perfect negative relation while 0 indicates totally correlated pair.

EC is showing positive correlation with all the cations and anions. It is showing very strong correlation with ions like $F^-$, $Cl^-$ , $NO_2^-$ , $NO_3^-$, $Na^+$, $K^+$, $Mg^{2+}$, $Ca^{2+}$. Weak positive correlation was noticed with HCO3-$^-$. PH is showing a strong negative correlation with all the major ions, TDS and EC. TDS is showing strong positive correlation with EC and all major ions. Weak positive correlation is being observed with HCO3-.

Strong positive correlation is observed in between ions pairs with like (R< 0.8) F- Cl, N02-Cl, SO4-NO2, SO4-Cl, SO4-F, NO3-F, NO3-Cl, NO3-NO2, NO3-SO4, Na-F, Na-Cl, Na- SO4, Na- NO3, Na-NO2, NH4-CL, NH4-Na, NH4-NO3, NH4-SO4, Mg-NH4, K-NH4, K-NO3, Mg-F, Mg-Cl, Mg-NO2, Mg-SO4, Mg-NO3, Mg-Na, Ca-F, Ca-Cl, Ca-NO2, Ca-SO4, Ca-NO3, Ca-Na, Ca- Mg, Ca-NH4, Ca- K.

**Table 21**:-Pearson Correlation Matrix of Water Quality of Agra & Mathura in February

| | **pH** | **EC** | **HCO3-$^{-}$** | F | Cl | N02 | SO4 | NO3 | Na | NH4 | K | Mg | Ca | TDS | TH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **pH** | 1 | -0.120 | 0.095 | -0.171 | -0.146 | -0.112 | -0.132 | -0.017 | -0.126 | -0.223 | 0.417 | -0.170 | -0.185 | -0.120 | -0.177 |
| **EC** | | 1 | 0.487 | 0.831 | 0.994 | 0.606 | 0.988 | 0.958 | 0.989 | 0.909 | 0.118 | 0.975 | 0.960 | 1.000 | 0.984 |
| **HCO3-$^{-}$** | | | 1 | 0.127 | 0.458 | 0.697 | 0.454 | 0.402 | 0.494 | 0.333 | 0.321 | 0.494 | 0.374 | 0.487 | 0.461 |
| F | | | | 1 | 0.848 | 0.291 | 0.844 | 0.828 | 0.830 | 0.871 | 0.211 | 0.813 | 0.849 | 0.831 | 0.837 |
| Cl | | | | | 1 | 0.608 | 0.993 | 0.945 | 0.991 | 0.902 | 0.079 | 0.979 | 0.962 | 0.994 | 0.988 |
| NO2 | | | | | | 1 | 0.616 | 0.487 | 0.602 | 0.396 | 0.014 | 0.675 | 0.496 | 0.606 | 0.625 |
| SO4 | | | | | | | 1 | 0.924 | 0.983 | 0.917 | 0.071 | 0.984 | 0.971 | 0.988 | 0.994 |
| NO3 | | | | | | | | 1 | 0.947 | 0.869 | 0.113 | 0.916 | 0.885 | 0.958 | 0.919 |
| Na | | | | | | | | | 1 | 0.908 | 0.065 | 0.963 | 0.943 | 0.989 | 0.970 |
| NH4 | | | | | | | | | | 1 | 0.109 | 0.900 | 0.915 | 0.909 | 0.918 |
| K | | | | | | | | | | | 1 | 0.066 | 0.068 | 0.118 | 0.068 |
| Mg | | | | | | | | | | | | 1 | 0.935 | 0.975 | 0.993 |
| Ca | | | | | | | | | | | | | 1 | 0.960 | 0.970 |
| TDS | | | | | | | | | | | | | | 1 | 0.984 |
| TH | | | | | | | | | | | | | | | 1 |

### Interpretation of Corelation Matrix of Agra and Mathura in February

The correlation coefficients (r) among 14 water quality parameters namely pH, EC, TDS, Ca, Mg, Na, NH4, K , NO2, HCO3-, Cl , SO4, NO3 and F were calculated for correlation analysis.. In the correlation matrix the values varies between +1 to -1. +1 indicates very strong and perfect positive relation and -1 indicate very strong and perfect negative relation while 0 indicates totally correlated pair.

EC is showing positive correlation with all the cations and anions. It is showing very strong correlation with ions like $F^-$, $Cl^-$ , $NO_3^-$, SO4, $Na^+$, NH4, $Mg^{2+}$, $Ca^{2+}$. Weak positive correlation was noticed with HCO3-$^-$, K, and NO2. PH is showing a negative correlation with all the major ions, TDS and EC except HCO3- where a very weak positive correlation is observed. TDS is showing strong positive correlation with EC and almost all major ions. Weak positive correlation is being observed with HCO3-, NO2, and K. Hardness is showing very strong positive correlation with all the major ions K, $SO_4^{2-}$ and $HCO_3^-$. Ph is showing weak negative correlation with all the major ions, total hardness and conductivity and total dissolved solids.

Strong positive correlation is observed in between ions pairs (R< 0.8) like Cl-F, SO4-Cl, SO4-F, NO3-F, NO3-Cl, NO3-SO4, Na-F, Na-Cl, Na- SO4, Na- NO3, NH4-F, NH4-CL, NH4-Na, NH4-NO3, NH4-SO4, Mg-F, Mg-Cl, Mg-SO4, Mg-NO3, Mg-Na, Ca-F, Ca-Cl, Ca-SO4, Ca-NO3, Ca-Na, Ca- Mg, Ca-NH4.

**Table 22**:- Pearson Correlation Matrix of Water Quality of Laksar Site

| | Ph | Cond | TDS | Hard | Na | K | Ca | Mg | HCO3 | Cl | SO4 | NO3 | F | BOD | DO | PO4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ph** | 1 | -0.029 | -0.029 | 0.287 | 0.245 | 0.384 | 0.563 | 0.460 | 0.969 | 0.102 | 0.083 | 0.847 | -0.267 | 0.710 | -0.615 | 0.647 |
| **Cond** | | 1 | 1 | 0.302 | 0.092 | 0.432 | -0.062 | -0.525 | 0.078 | 0.349 | 0.933 | 0.317 | 0.303 | 0.208 | 0.215 | -0.373 |
| **TDS** | | | 1 | 0.302 | 0.092 | 0.450 | -0.069 | -0.541 | 0.082 | 0.369 | 0.936 | 0.328 | 0.303 | 0.211 | 0.259 | -0.373 |
| **Hard** | | | | 1 | 0.463 | 0.622 | 0.737 | 0.102 | 0.342 | 0.880 | 0.231 | 0.223 | 0.478 | 0.201 | -0.137 | 0.102 |
| **Na** | | | | | 1 | 0.462 | 0.511 | 0.464 | 0.168 | 0.281 | -0.012 | 0.208 | -0.090 | 0.119 | -0.162 | -0.206 |
| **K** | | | | | | 1 | 0.254 | -0.020 | 0.439 | 0.334 | 0.279 | 0.498 | -0.062 | 0.499 | -0.305 | 0.006 |
| **Ca** | | | | | | | 1 | 0.600 | 0.565 | 0.677 | -0.053 | 0.377 | 0.270 | 0.370 | -0.410 | 0.402 |
| **Mg** | | | | | | | | 1 | 0.378 | -0.035 | -0.539 | 0.266 | -0.444 | 0.356 | -0.562 | 0.348 |
| **HCO3** | | | | | | | | | 1 | 0.175 | 0.207 | 0.874 | -0.235 | 0.759 | -0.696 | 0.563 |
| **Cl** | | | | | | | | | | 1 | 0.340 | 0.011 | 0.750 | -0.013 | 0.040 | 0.072 |
| **SO4** | | | | | | | | | | | 1 | 0.369 | 0.282 | 0.165 | 0.129 | -0.316 |
| **NO3** | | | | | | | | | | | | 1 | -0.337 | 0.861 | -0.567 | 0.378 |
| **F** | | | | | | | | | | | | | 1 | -0.345 | 0.453 | 0.024 |
| **BOD** | | | | | | | | | | | | | | 1 | -0.670 | 0.313 |
| **DO** | | | | | | | | | | | | | | | 1 | -0.164 |
| **PO4** | | | | | | | | | | | | | | | | 1 |

**Interpretation of Correlation Matrix of Laksar**

The correlation coefficients (r) among 14 water quality parameters namely pH, EC, TDS, BOD, DO, Hardness, Ca, Mg, Na, K , PO4, HCO3-, Cl , SO4, NO3 and F were calculated for correlation analysis In the correlation matrix the values varies between +1 to -1. +1 indicates very strong and perfect positive relation and -1 indicate very strong and perfect negative relation while 0 indicates totally correlated pair.

EC is showing positive correlation with all the cations and anions except PO4, Ca and Mg. PH is showing a negative correlation with all the major ions, TDS and EC. TDS is showing positive correlation with EC, DO and all major ions except PO4. It is showing very strong correlation with SO4. pH is showing strong positive correlation with NO3, HCO3- and PO4 and BOD. Hardness is showing positive correlation with all ions and moderate to strong correlation with ions like Ca, Cl and K.

Among the ions moderate positive correlation with r values (0.8>R> 0.5) is observed between Cl- F, Ca–Mg, Ca–HCO3, Ca–Cl, Na–Ca, HCO3–NO3, HCO3–PO4.

A strong negative correlation exists between DO and BOD. These indicates that as the organic contaminants in water increases the BOD of water increases and DO decreases as it is used up by microbes for decomposition. Similarly we notice that a strong positive relation exist between BOD and NO3. This indicates that presence of nitrogenous compounds in water increases the algal growth in water thereby increasing the BOD and further it reduces the DO of water. This leads to situation called eutrophication. Algal growth has been observed in the surface water samples in all the sampling locations.

**Table 23**:- Linear correlation coefficient R and regression equation for some pairs of parameters which have significant value of positive correlation for Laksar site.

| **Pairs of parameters** | **R value (n=21** | **Regression equation** |
|---|---|---|
| pH - Ca | 0.563 | Ca = 81.475(pH) - 460.71 |
| pH – HCO3 | 0.969 | HCO3 = 169.42(pH) - 849.42 |
| pH – NO3 | 0.847 | NO3 = 12.451(pH) - 81.051 |
| pH – PO4 | 0.710 | PO4 = 0.0848(pH) - 0.4359 |
| pH - BOD | 0.647 | BOD = 4.576(pH) - 29.306 |
| EC – SO4 | 0.933 | SO4 = 0.073(EC) - 29.907 |
| TDS –SO4 | 0.936 | SO4 = 0.1141(TDS) - 29.907 |
| TH – K | 0.622 | K = 0.0333(TH) - 1.0426 |
| TH – Ca | 0.737 | Ca = 0.5726(TH) - 153.16 |
| TH - Cl | 0.880 | Cl = 0.6312(TH) - 208.15 |
| Na - Ca | 0.511 | Ca = 1.7399(Na) + 67.254 |
| Ca – Mg | 0.600 | Mg = 0.0487(Ca) + 15.723 |
| Ca – HCO3 | 0.565 | HCO3 = 0.6255(Ca) + 15.679 |

| | | |
|---|---|---|
| Ca – Cl | 0.677 | Cl = 0.6255(Ca) + 15.679 |
| HCO3 – NO3 | 0.874 | NO3 = 0.0735(HCO3) - 18.625 |
| HCO3 – PO4 | 0.759 | PO4 = 0.0004(HCO3) + 0.0166 |
| HCO3 - BOD | 0.563 | BOD = 0.028(HCO3) - 6.7029 |
| Cl – F | 0.750 | F = 0.0013(Cl) + 0.0658 |
| NO3 – BOD | 0.861 | BOD = 0.3779(NO3) + 0.4105 |

**Table 24**:- Linear correlation coefficient R and regression equation for some pairs of parameters which have significant value of positive correlation for Agra & Mathura site in the February.

| Pairs of parameters | R value (n=21 | Regression equation |
|---|---|---|
| EC – F | 0.831 | F= 0.0016(EC) + 2.5243 |
| EC – Cl | 0.994 | Cl = 0.1879(EC) - 87.446 |
| EC – SO4 | 0.988 | SO4 = 0.2204(EC) - 179.67 |
| EC –NO3 | 0.958 | NO3 = 0.1008(EC) - 105.25 |
| EC - Na | 0.989 | Na = 0.1159(EC) - 21.811 |
| EC – NH4 | 0.909 | NH4 = 0.0032(EC) + 2.8157 |
| EC – Mg | 0.975 | Mg = 0.039(EC) - 23.292 |
| EC – Ca | 0.960 | Ca = 0.0309(EC) + 18.072 |
| EC – TDS | 1.000 | TDS = 0.64(EC) |
| EC - TH | 0.984 | TH = 0.2375(EC) - 50.785 |
| F - Cl | 0.848 | Cl = 83.848(F) - 160.41 |
| F – SO4 | 0.844 | SO4 = 98.438(F) - 265.75 |
| F – NO3 | 0.828 | NO3 = 45.564(F) - 148.14 |
| F – Na | 0.830 | Na = 50.832(F) - 61.111 |
| F – NH4 | 0.871 | NH4 = 1.5859(F) + 0.4538 |
| F – Mg | 0.813 | Mg = 17.001(F) - 35.767 |
| F – Ca | 0.849 | Ca = 14.264(F) + 2.8745 |
| F – TDS | 0.831 | TDS = 277.95(F) - 198.49 |
| F - TH | 0.837 | TH = 105.53(F) - 140.02 |
| Cl – SO4 | 0.993 | SO4 = 1.1713(Cl) - 76.368 |
| Cl – NO3 | 0.945 | NO3= 0.5258(Cl) - 54.121 |
| Cl - Na | 0.991 | Na = 0.6143(Cl) + 32.98 |
| Cl – NH4 | 0.902 | NH4 = 0.0166(Cl) + 4.378 |
| Cl – Mg | 0.979 | Mg = 0.2072(Cl) - 4.9918 |
| Cl - Ca | 0.962 | Ca = 0.1635(Cl) + 32.726 |
| Cl – TDS | 0.994 | TDS = 3.3636(Cl) + 314.27 |
| Cl - TH | 0.988 | TH = 1.2607(Cl) + 61.07 |
| SO4 – NO3 | 0.924 | NO3 = 0.5258(SO4) - 54.121 |
| SO4 - Na | 0.983 | Na = 0.0143(SO4) + 5.4146 |
| SO4 –NH4 | 0.917 | NH4= 0.5163(SO4) + 76.137 |
| SO4 - Ca | 0.971 | Ca = 0.14(SO4) + 43.249 |
| SO4 - Mg | 0.984 | Mg= 0.1765(SO4) + 8.6965 |
| SO4 - TDS | 0.988 | TDS = 2.8364(SO4) + 546.99 |

| | | |
|---|---|---|
| SO4 - TH | 0.994 | TH = 1.0754(SO4) + 143.64 |
| NO3 – Na | 0.947 | Na= 1.0548(NO3) + 113.33 |
| NO3 – NH4 | 0.869 | NH4 = 0.0288(NO3) + 6.5178 |
| NO3 – Ca | 0.885 | Ca = 0.2705(NO3) + 55.664 |
| NO3 – Mg | 0.916 | Mg = 0.1438(NO3) + 33.886 |
| NO3 – TDS | 0.958 | TDS = 5.8291(NO3) + 746.05 |
| NO3 - TH | 0.919 | TH = 2.1081(NO3) + 234.47 |
| Na- NH4 | 0.908 | NH4 = 0.027(Na) + 3.5064 |
| Na- Ca | 0.943 | Ca = 0.2588(Na) + 25.972 |
| Na- Mg | 0.963 | Mg= 0.3288(Na) - 13.788 |
| Na- TDS | 0.989 | TDS = 5.3997(Na) + 154.23 |
| Na- TH | 0.970 | TH = 1.9983(Na) + 8.0291 |
| NH4 – Ca | 0.915 | Ca = 8.4391(NH4) + 4.8238 |
| NH4- Mg | 0.900 | Mg = 10.337(NH4) - 36.475 |
| NH4- TDS | 0.909 | TDS = 166.92(NH4) - 187.48 |
| NH4- TH | 0.918 | TH = 63.585(NH4) - 138.07 |
| Mg – Ca | 0.935 | Ca = 0.7514(Mg) + 39.524 |
| Mg – TDS | 0.975 | TDS = 15.594(Mg) + 443.47 |
| Mg – TH | 0.993 | TH = 5.989(Mg) + 98.564 |
| Ca- tds | 0.960 | TDS= 19.111(Ca) - 218.41 |
| Ca - TH | 0.970 | TH = 7.2829(Ca) - 150.14 |
| TDS- TH | 0.984 | TH = 0.3712(TDS) - 50.785 |

## 5.10 Graphical Presentation of Data

### 5.10.1 Piper Diagram

Trilinear plotting systems were used in the study of water chemistry and quality developed by Hill (1940) and Piper (1944). Facies are recognizable parts of different characters belonging to any genetically related system. Hydrochemical facies are distinct zones that possess action and anion concentration categories. The water types are designated according to the area in which they occur on the diagram segments. It's comprised of three pieces: a ternary diagram in the lower left representing the cations, a ternary diagram in the lower right representing the anions, and a diamond plot in the middle representing a combination of the two. Piper divided waters into four basic types according to their placement near the four corners of the diamond. Water that plots at the top of the diamond is high in Ca2+ + Mg2+ and Cl- + SO42-, which results in an area of permanent hardness. The water that plots near the left corner is rich in Ca2+ + Mg2+ and HCO3-- and is the region of water of temporary hardness. Water plotted at the lower corner of the diamond is primarily composed of alkali carbonates (Na+ + K+ and HCO3-- + CO32-). Water lying nears the right-hand side of the diamond may be considered saline (Na+ + K+ and Cl- + SO42-).

### 5.10.1.1 Site- Agra & Mathura

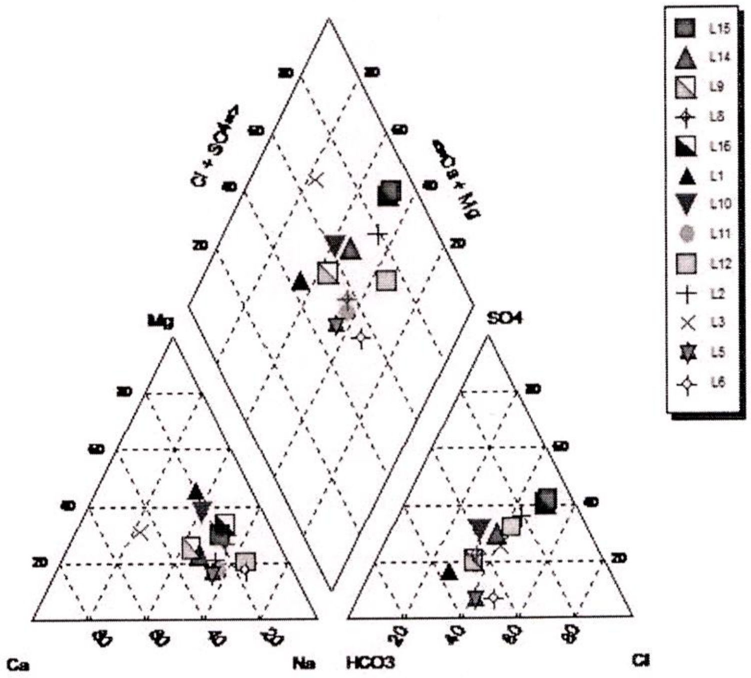


**Figure 44**:- Piper plot of GW samples of Agra & Mathura

The GW samples of Agra and Mathura fall in 4 different categories. Samples like L16, L15, L2, L6, L4, L8, L11 and L12 are having **Na-Cl water** type. These samples are having primary salinity which exceeds 50% and are dominated by alkalis and weak acids. Samples like L9, L3, L10, L14 are having **Mixed Ca- Mg- Cl water type**. In These samples no cation–anion pair exceeds 50%. Sample like L1 is having **Ca- HCO3-** type water and sample L5 is having **Ca-Mg- HCO3-** type water. L1 is having secondary hardness which exceeds 50% and are dominated by alkaline earth elements and weak acids. In L5 no cation–anion pair exceeds 50%. We find that samples lying in the right hand side of the diamond fields like L16, L15, L2, L6, L4, L8, L11 and L12 are saline in nature. The sample in the left side of the diamond field like L1 is having temporary hardness.

The water samples are an increasing trend of Na indicating presence of halite and plagioclase feldspar like albite in lithology with the occurrence of ion exchange in water samples.

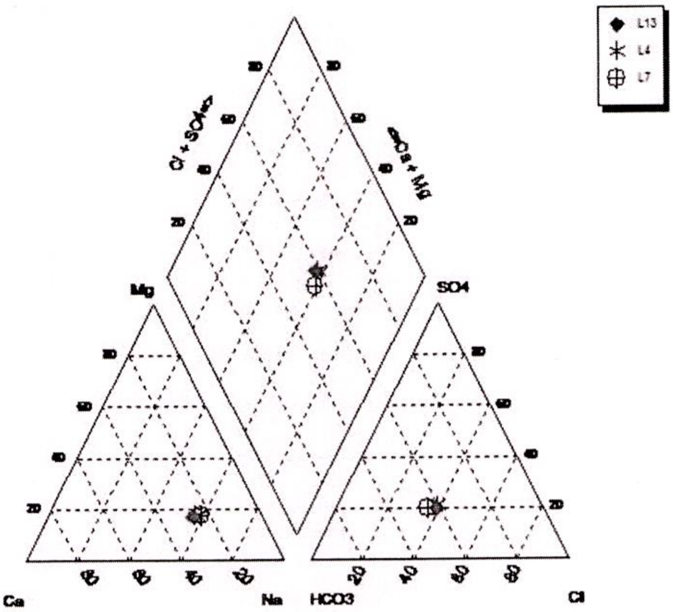


**Figure 45**:- Piper Plot of SW samples of Agra & Mathura

The SW samples are showing almost Na-Cl type water. These samples indicate presence of albite weathering with ion exchange occurring in it. This can inferred from the increasing trend of Na which is observed in cation triangle.

The samples which are close to surface water bodies are of no dominant type. Basically there is trend from no dominant type to mixing type of the groundwater.

### 5.10.1.2 Site- Laksar

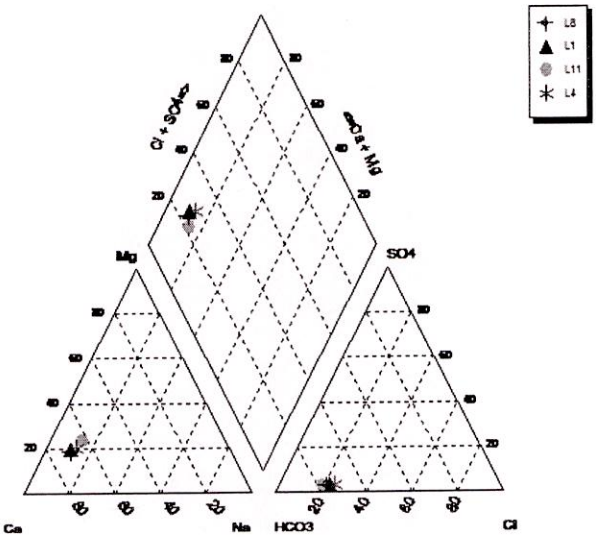


**Figure 46**:- Piper plot of SW samples of Laksar

The surface water samples belong to Ca-HCO3 water type. This water has temporary hardness in it. This further indicates their flow over a terrain containing dolomite and calcite in its lithology.

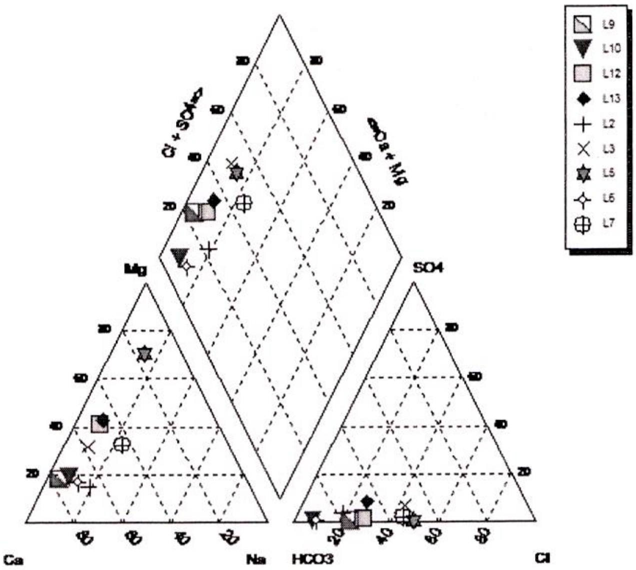


**Figure 47**:- Piper plot of GW samples of Laksar.

The GW samples of Laksar region fall in fall in 3 different categories. Samples like L10 and L6 fall in Ca-Mg –HCO3 type while samples like L2, L9, L12, L13, L7 are having Ca – HCO3 type water. The samples like L3 and L5 are showing Mixed Ca – Mg – Cl type water. In all the sample Ca + Mg exceeds the Na+ K in concentration. We can deduce from the above piper diagram that the lithology contains calcite and limestone in it. But by observing the sample L5 we can infer occurrence of ferromagnesian silicate mineral weathering.

Most of the groundwater in this region is observed as Ca-HCO3- ground water which indicates that it is of young age. So all the groundwater samples have a signature of modern day monsoon or precipitation which changes upon interaction with the river water in the respective sample places. By observing the piper diagram we can conclude that the area is having Limestone, dolomite or calcite in its lithology

### 5.10.2 Durov Diagram

Durov, (1948) introduced another diagram which provides more information on the hydrochemical facies by helping to identify the water types and it can display some possible geochemical processes that could help in understanding quality of groundwater and its evaluation. The diagram is a composite plot consisting of 2 ternary diagrams where the cations of interest are plotted against the anions of interest; sides form a binary plot of total cation vs. total anion concentrations; expanded version includes electrical conductivity (μS/cm) and pH data added to the sides of the binary plot to allow further comparisons.

### 5.10.2.1 Site - Agra and Mathura

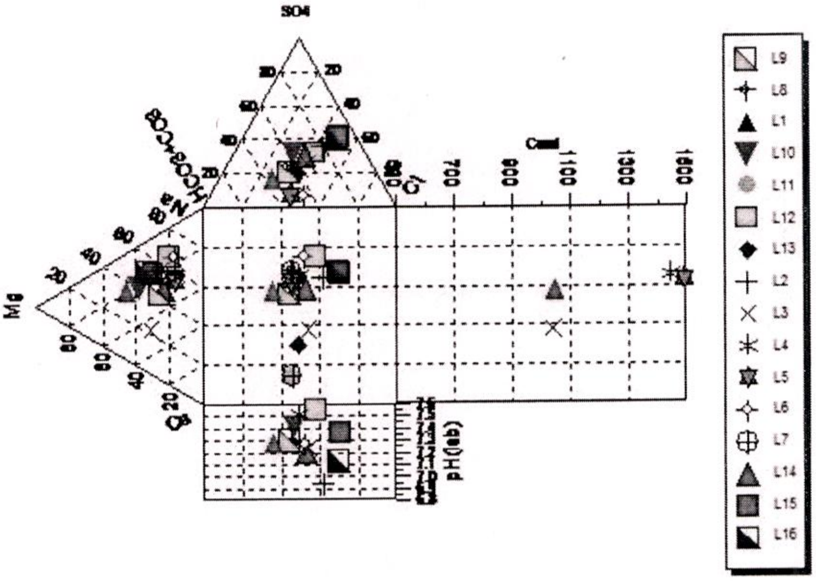


**Figure 48**:- Durov Plot of Agra and Mathura

Majority of the samples have no dominant anion or cation, indicating water type that exhibits simple dissolution or mixing. The samples like L7. L13 and L3 have Cl dominant anion and Na dominant cation, indicating that the water samples are undergoing reverse ion exchange.

### 5.10.2.2 Site - Laksar

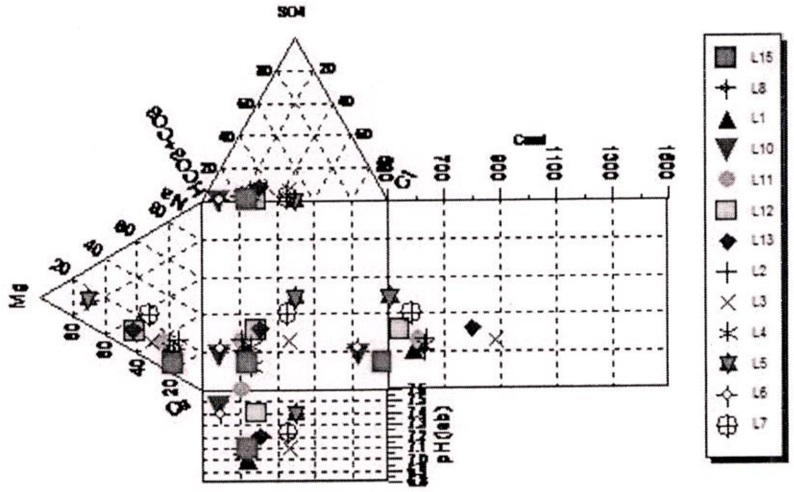


**Figure 49:**- Durov Plot of Laksar

Significant spatial variation is observe in all the groundwater sample with respect to the TDS and pH value of the groundwater samples which implies a strong aquifer-groundwater interaction in the respective sampling places. This water type is dominated by Ca and HCO3 ions. However, those samples in which Na is significant, an important ion exchange is presumed. The water samples are undergoing ion and reverse ion exchange.

## 5.11 Spatial Distribution of Various Parameters

Spatial distribution of different water quality parameters are shown by the help of Surfer software. This helps us to understand how different parameters vary spatially between different sampling locations. The following plots shows how the SW samples (River) vary from GW samples. The thick blue line passing through each map indicates the river in the study area. It is river Yamuna in Agra and Mathura while it is Solani River in Laksar.

### 5.11.1 Study Area - Agra

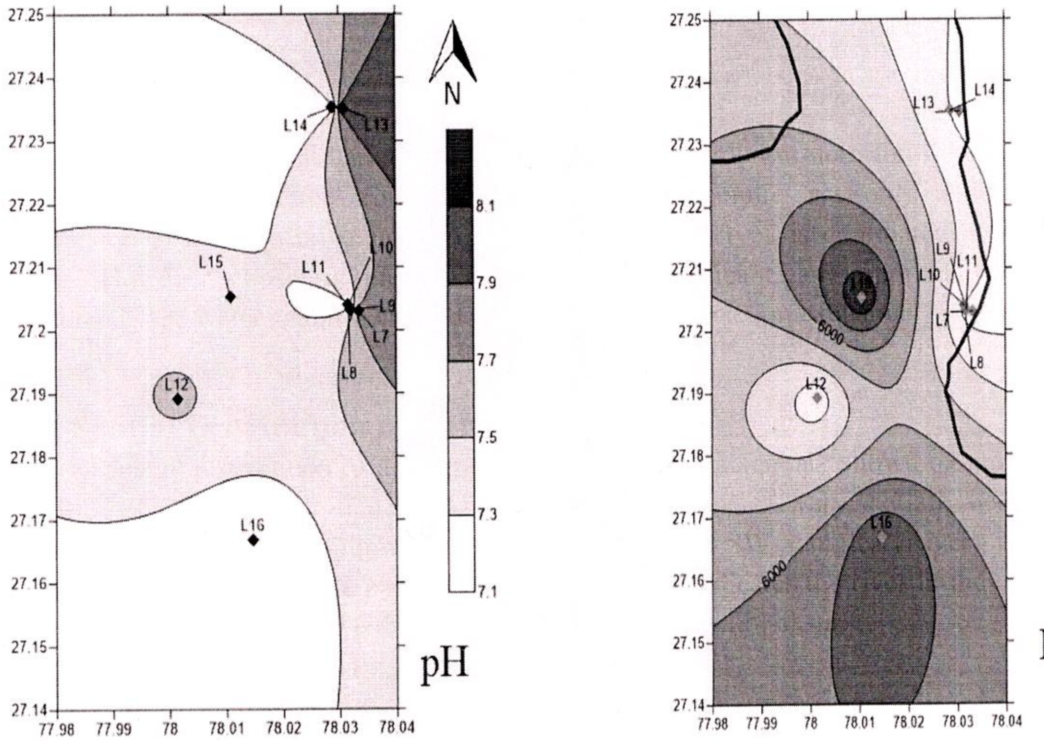


**Figure 50**:- Spatial Distribution of (a) pH (b) EC of Agra

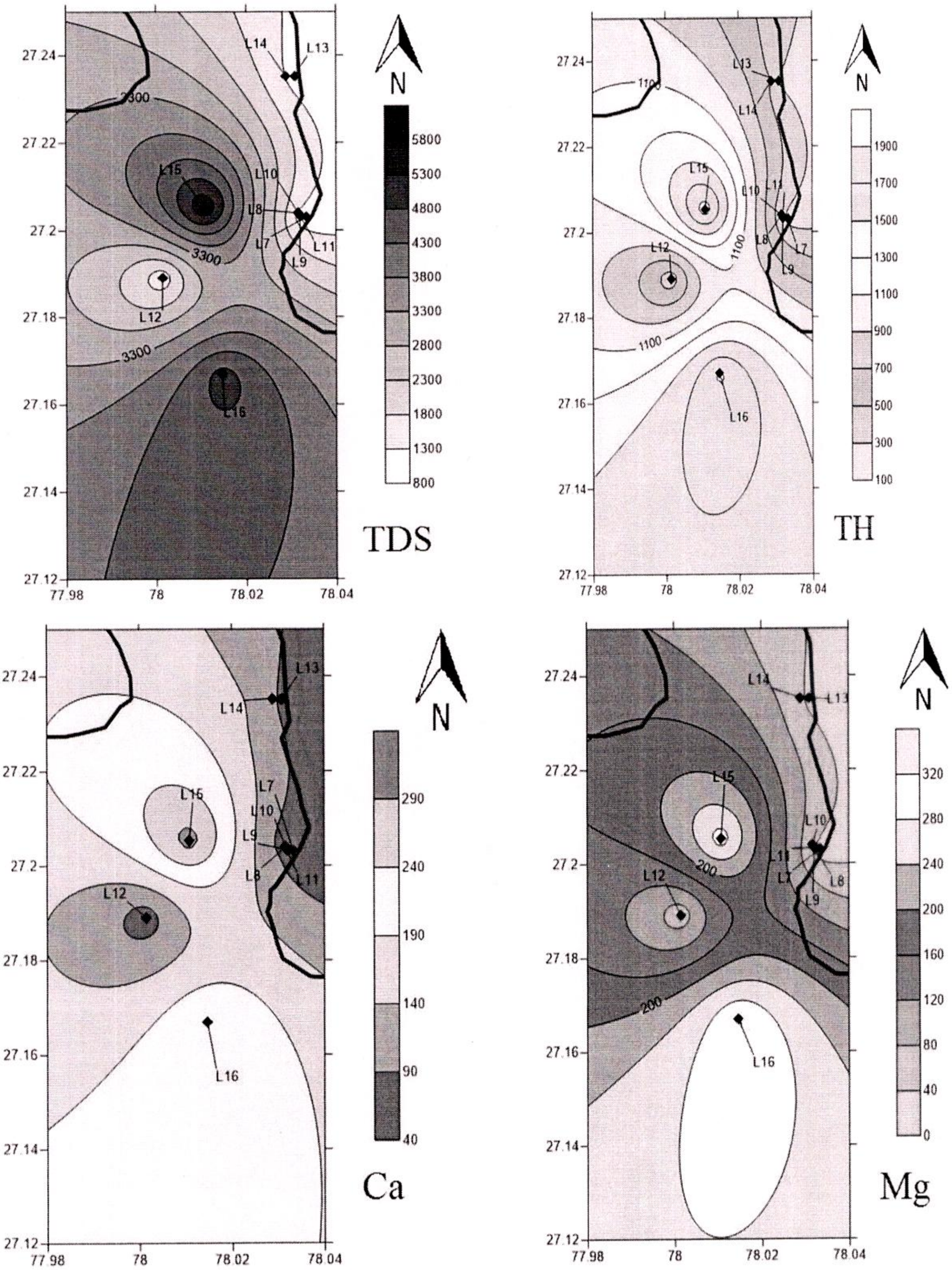


**Figure 51**:- Spatial Distribution of (a) TDS (b) Total Hardness (c) Ca (d) Mg of Agra

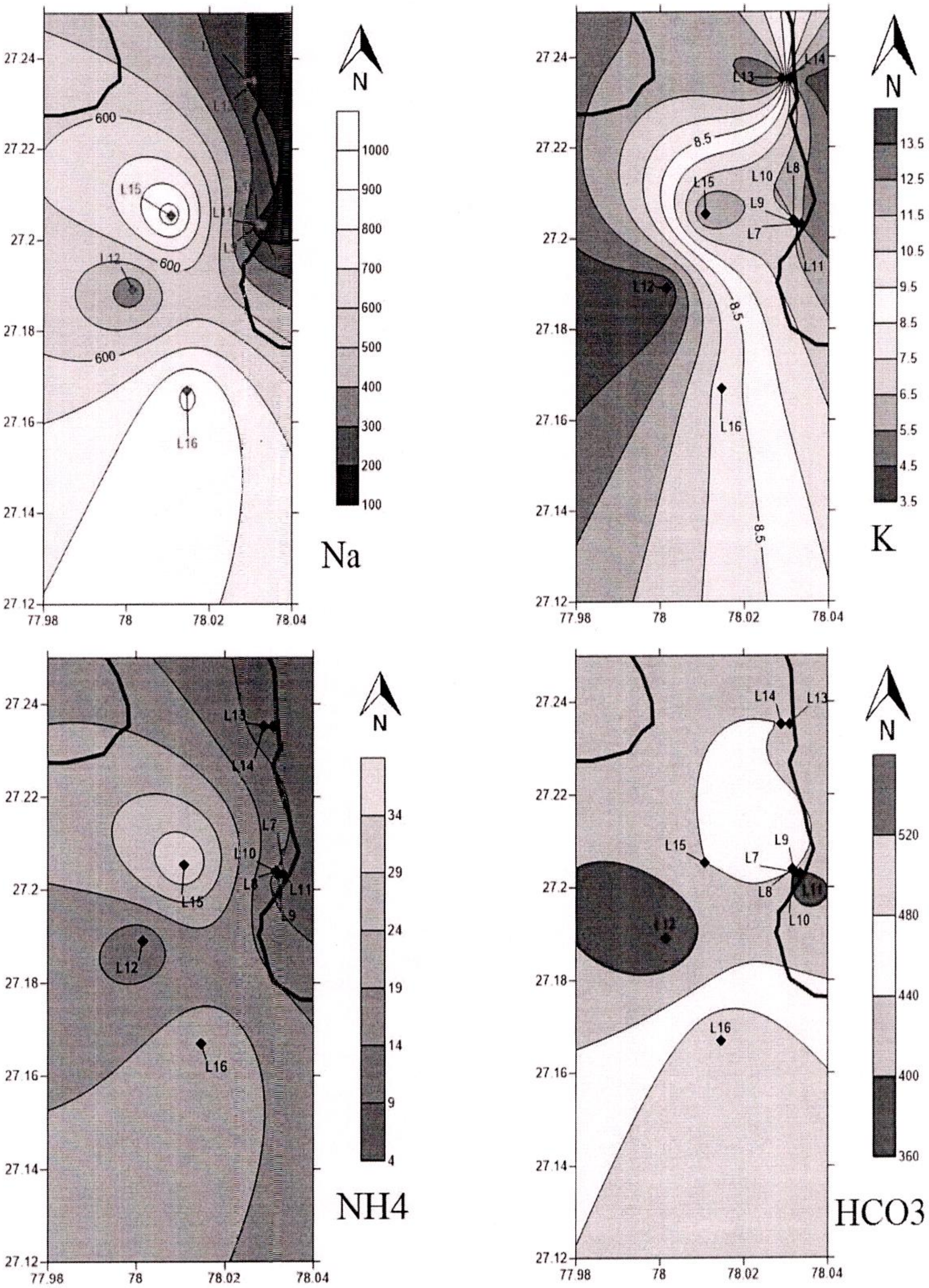


**Figure 52**:- Spatial Distribution of (a) Na (b) K (c) NH4 (d) HCO3 of Agra

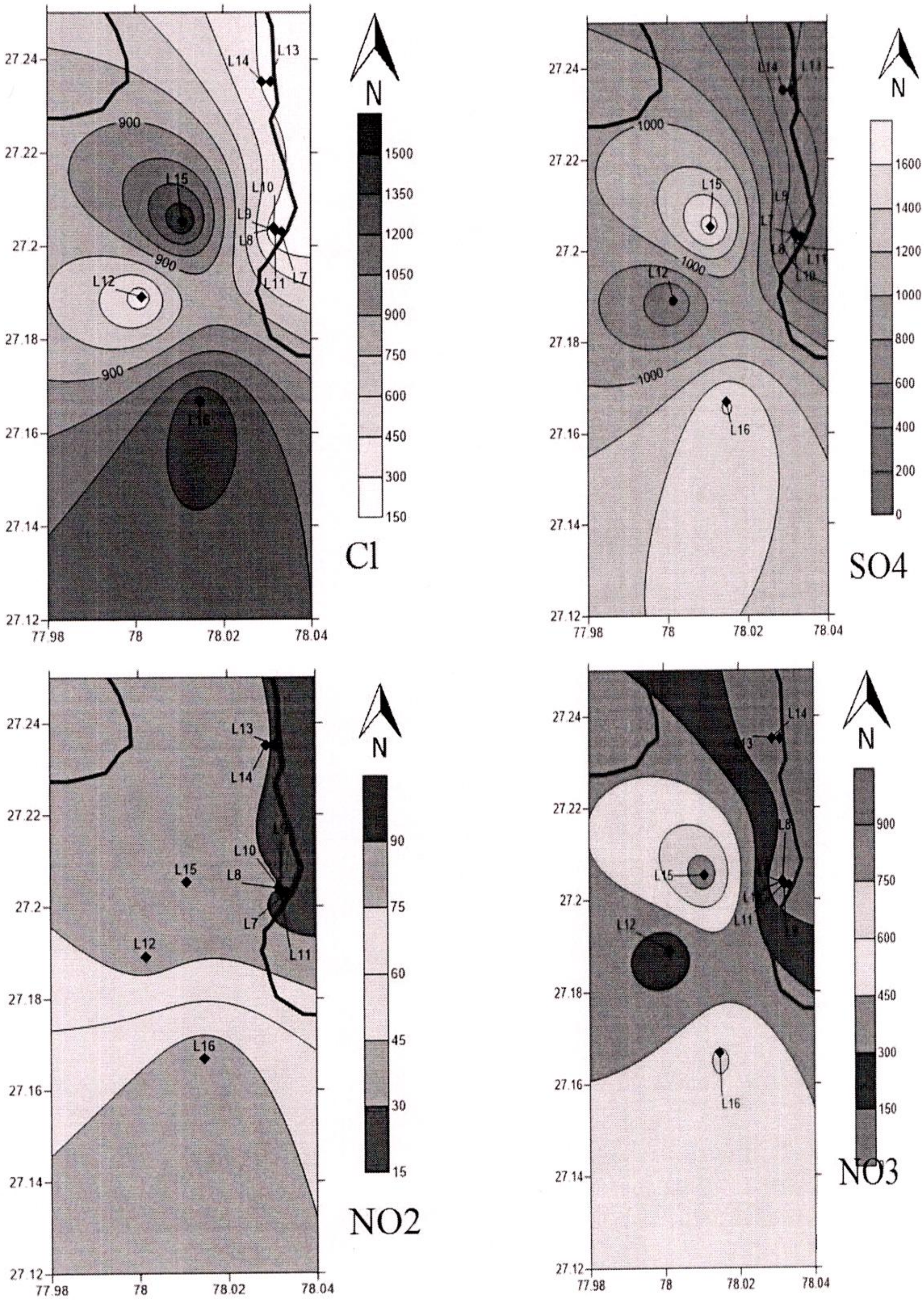


**Figure 53**:- Spatial Distribution of (a) Cl (b) SO4 (c) NO2 (d) NO3 of Agra

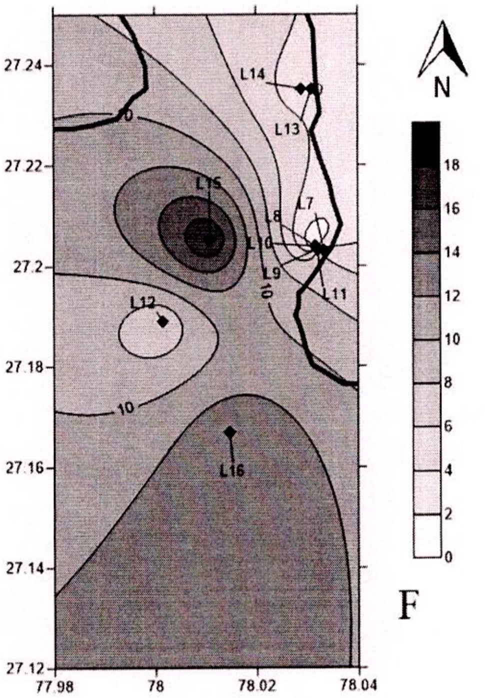


**Figure 54**:- Spatial Distribution (a) F of Agra

### 5.11.2 Study Area - Mathura

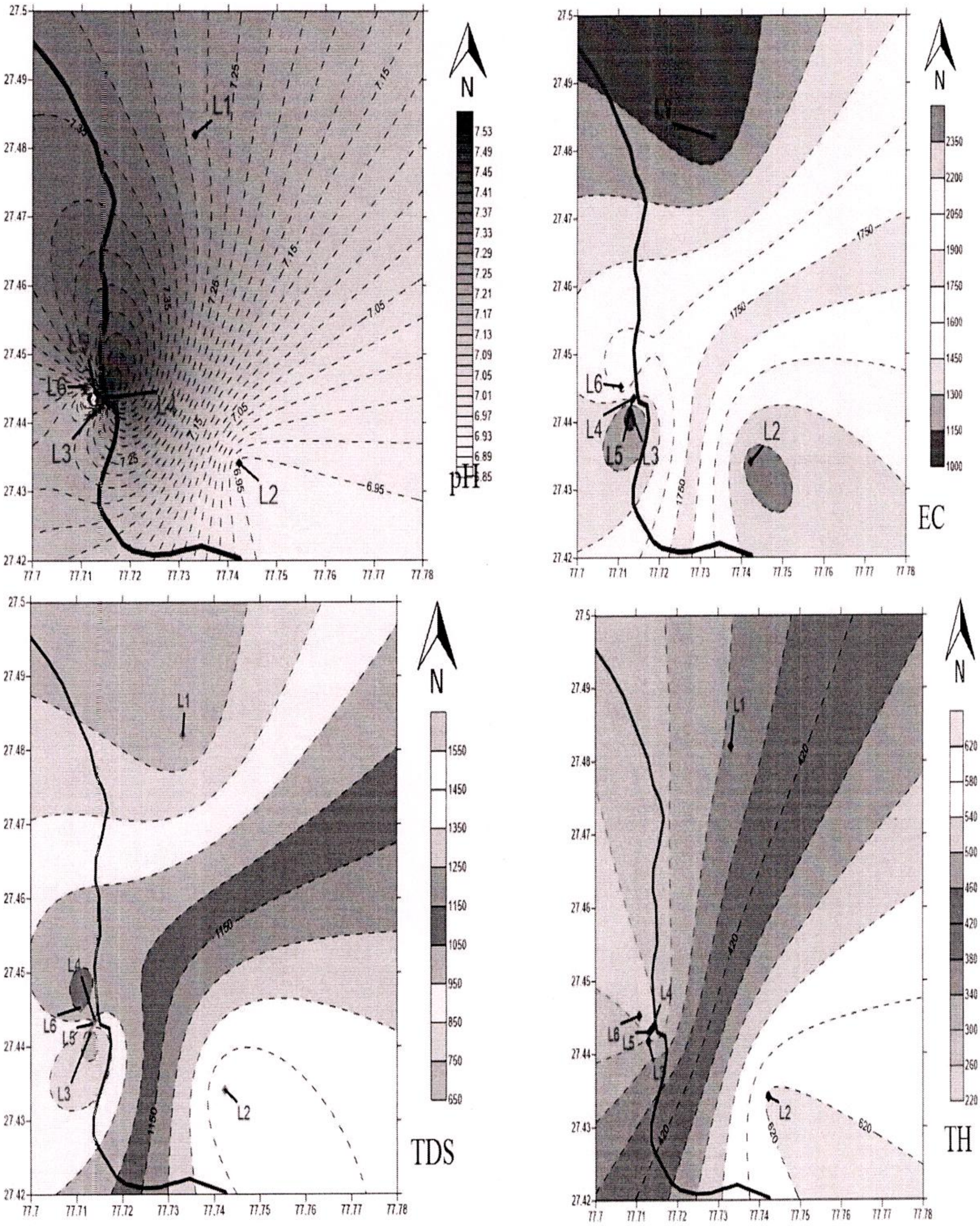


**Figure 55**:- Spatial Distribution of (a) pH (b) EC (c) TDS (d) TH of Mathura

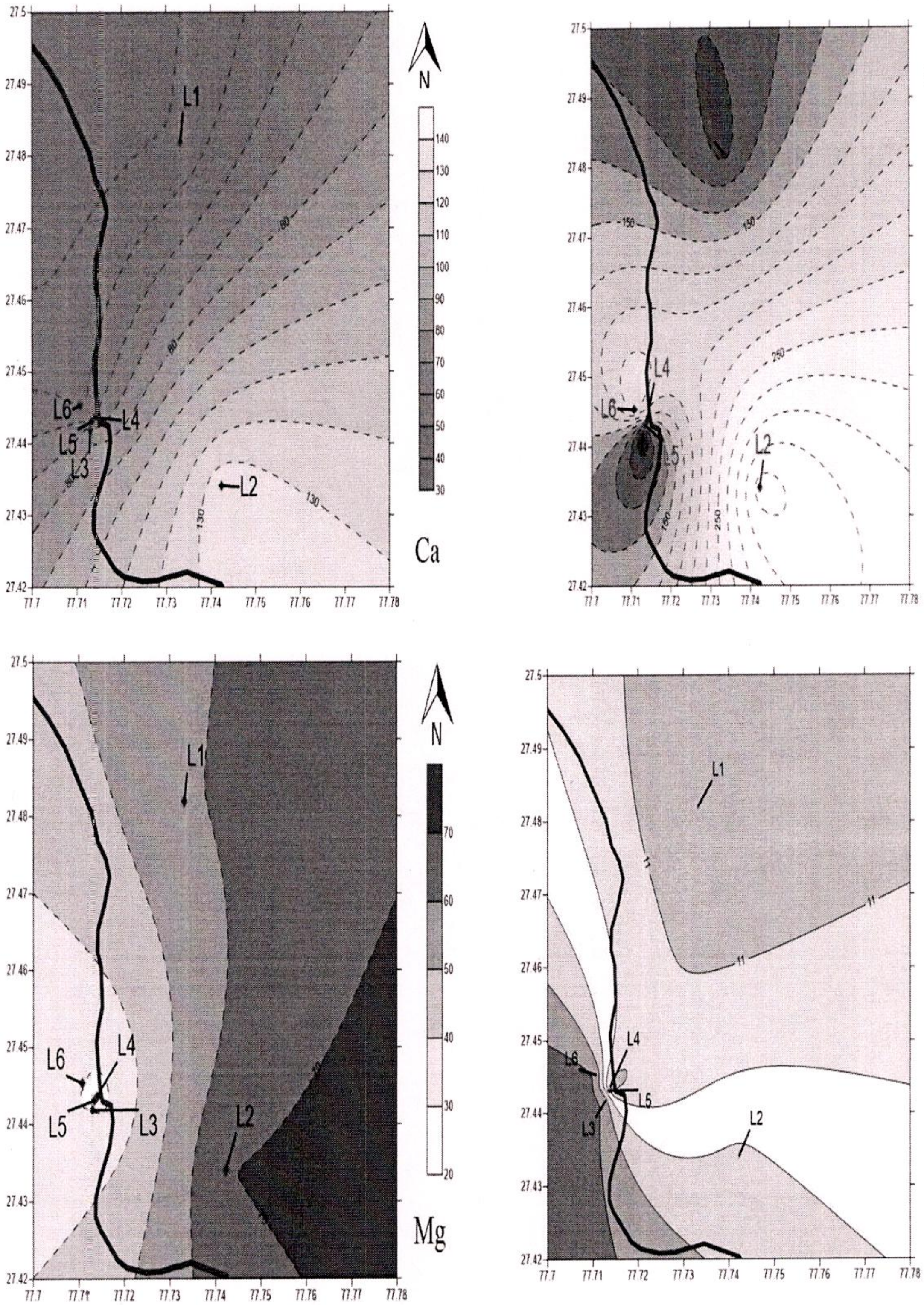


**Figure 56**:- Spatial Distribution of (a) Ca (b) Na (c) Mg (d) K of Mathura

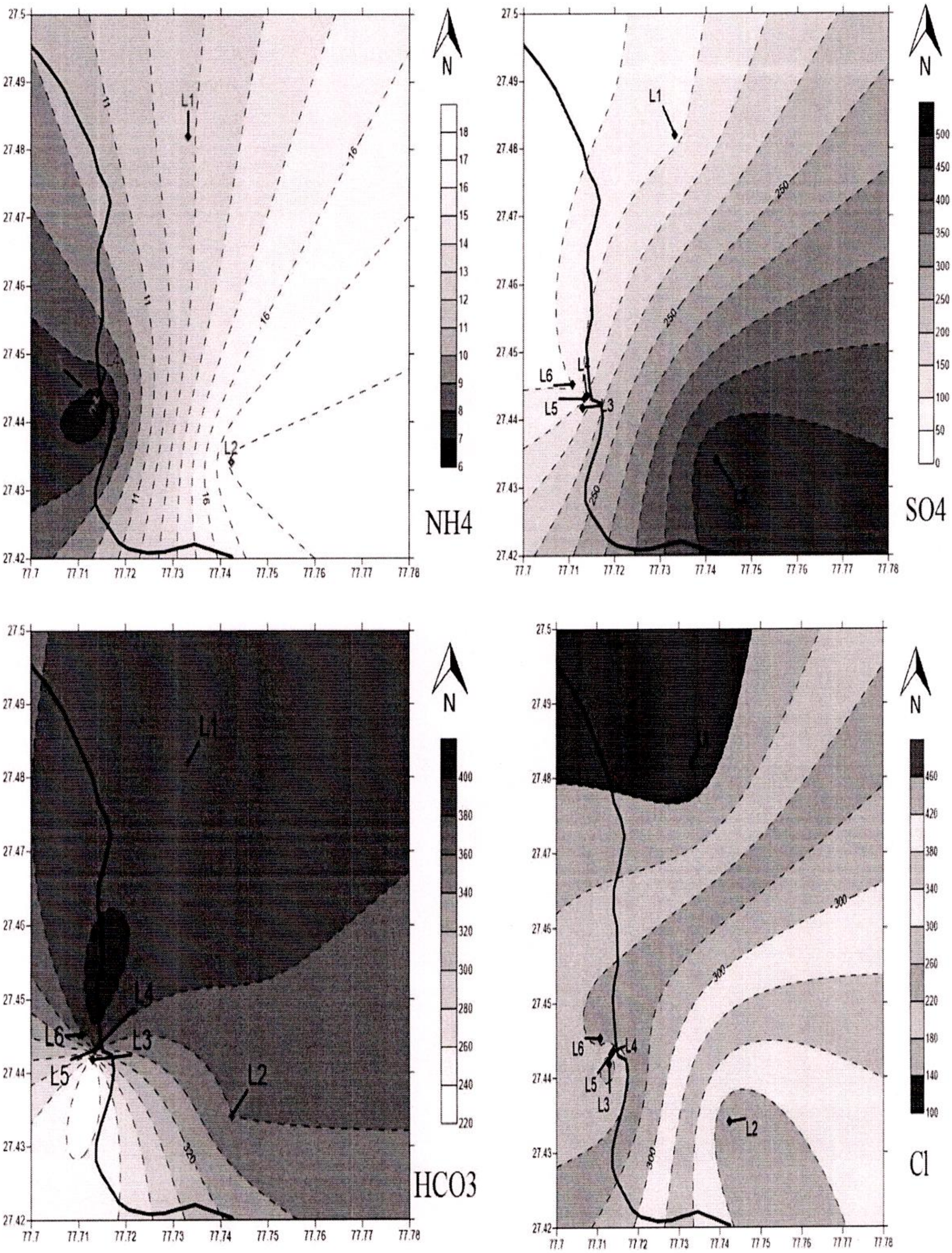


**Figure 57**:-Spatial Distribution of (a) NH4 (b) SO4 (c) HCO3 (d) Cl of Mathura

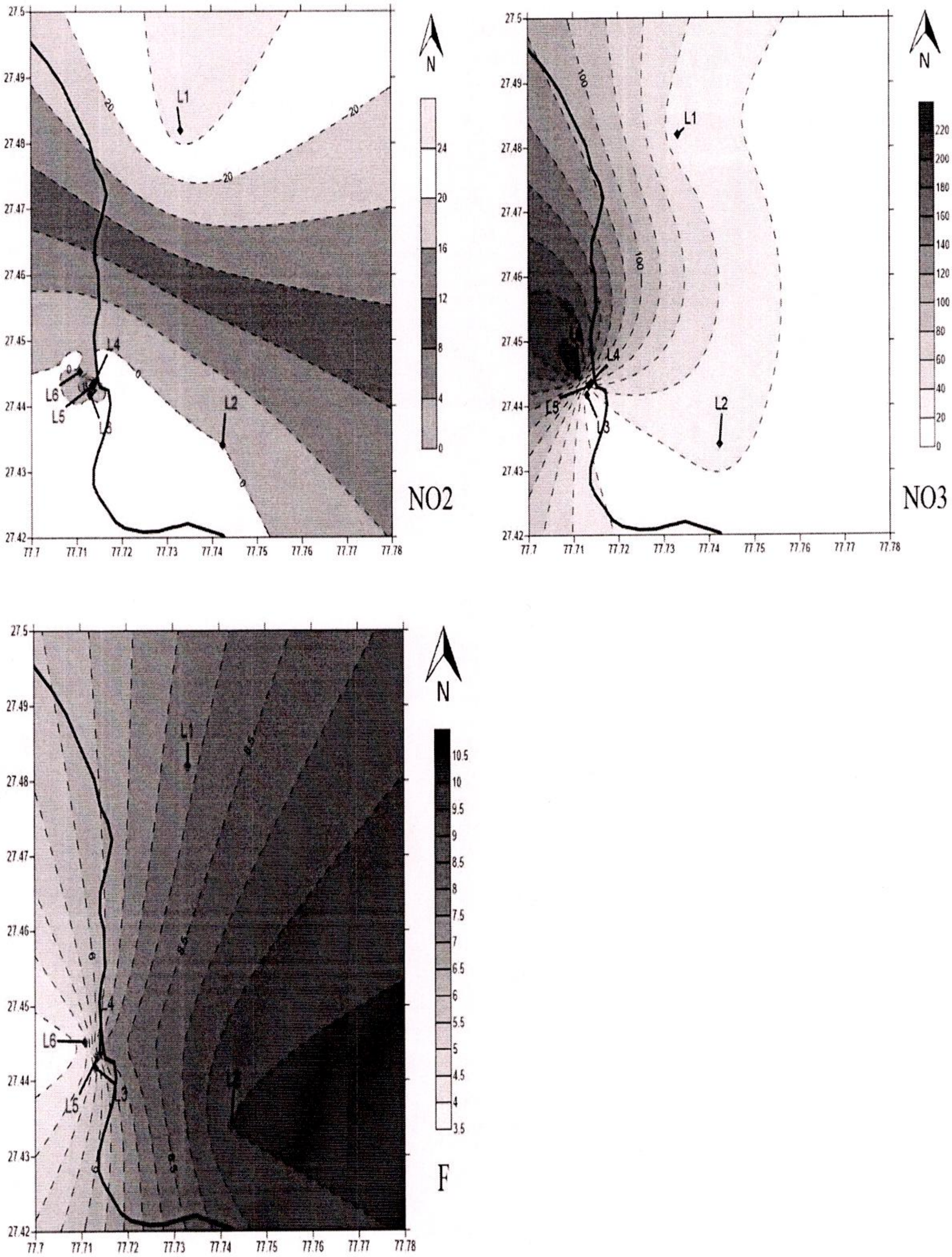


**Figure 58**:- Spatial Distribution of (a) NO2 (b) NO3 (c) F of Mathura

### 5.11.2 Study Area - Laksar

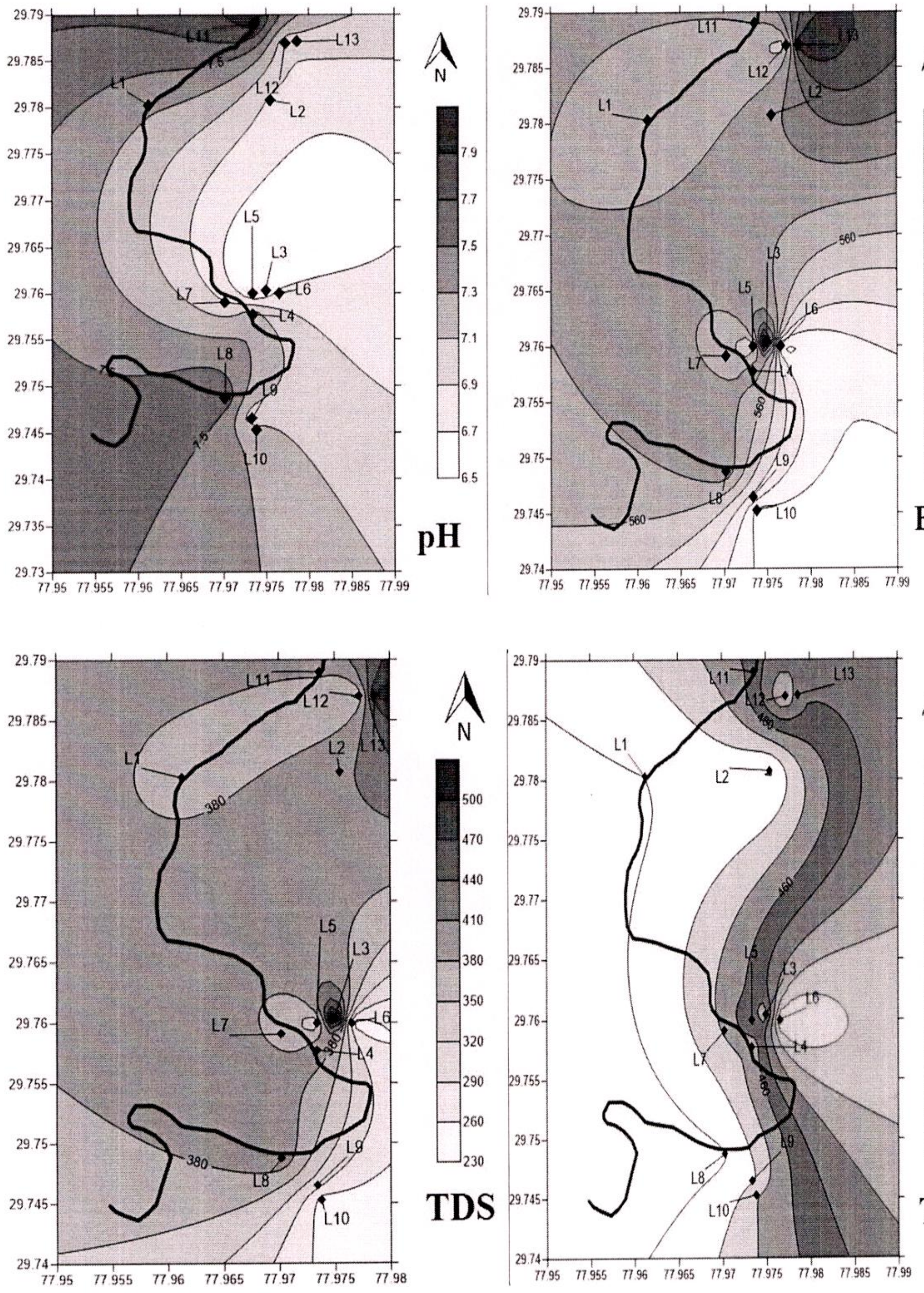


Figure 59:- Spatial Distribution of (a) pH (b) EC (c) TDS (d) TH of Laksar

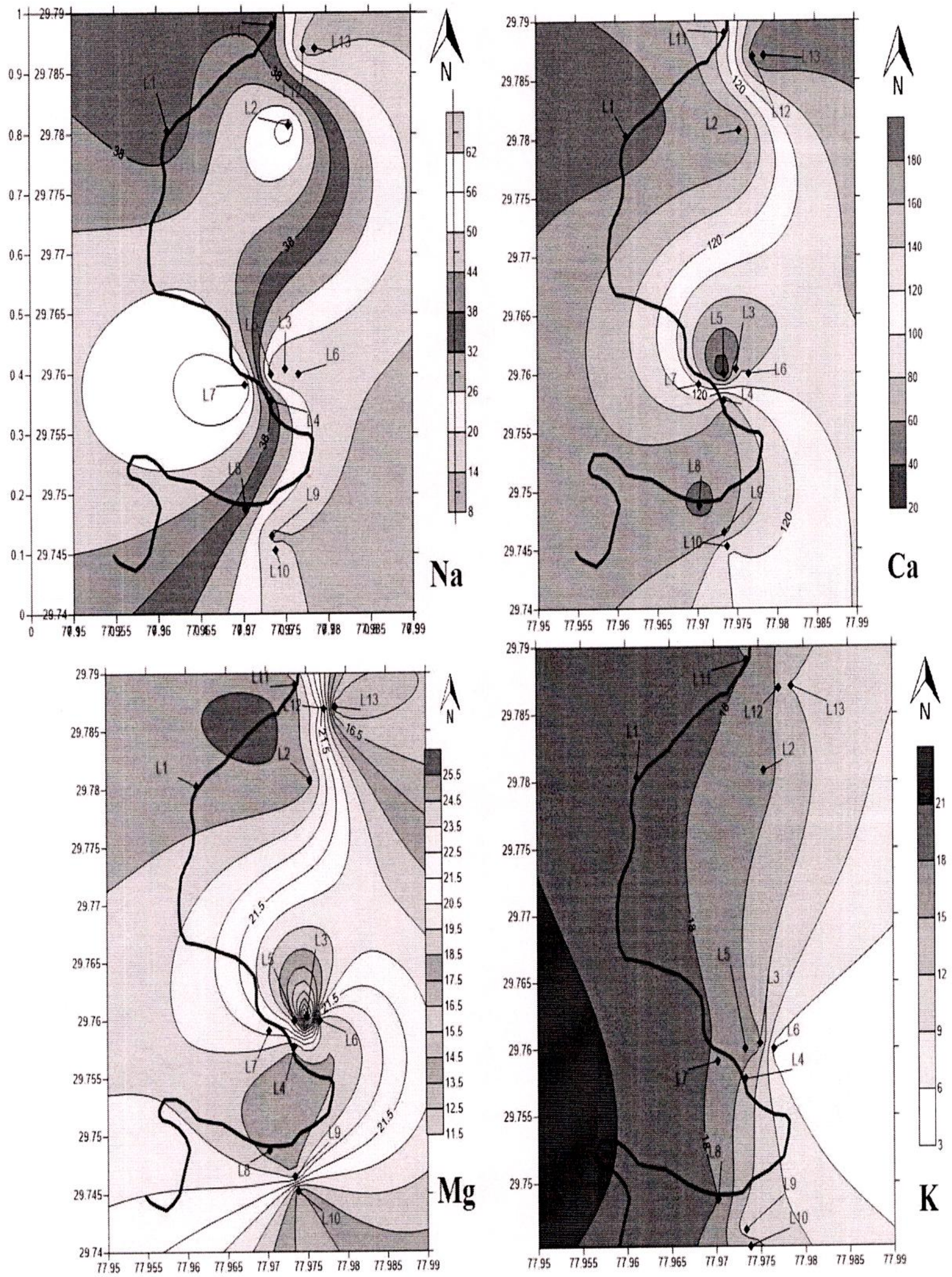


**Figure 60**:- Spatial Distribution of (a) Ca (b) Na (c) Mg (d) K of Laksar

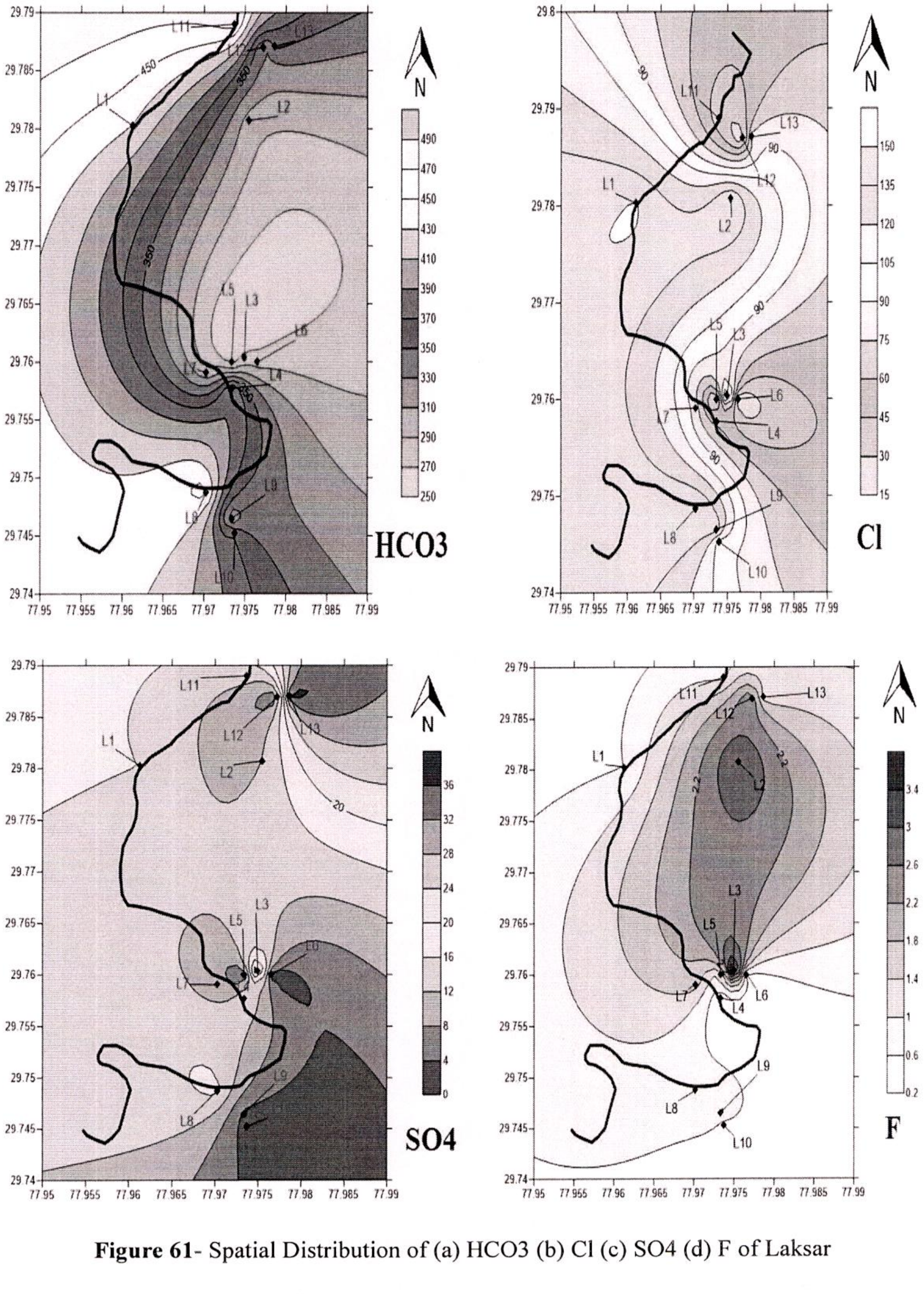


**Figure 61**- Spatial Distribution of (a) HCO3 (b) Cl (c) SO4 (d) F of Laksar

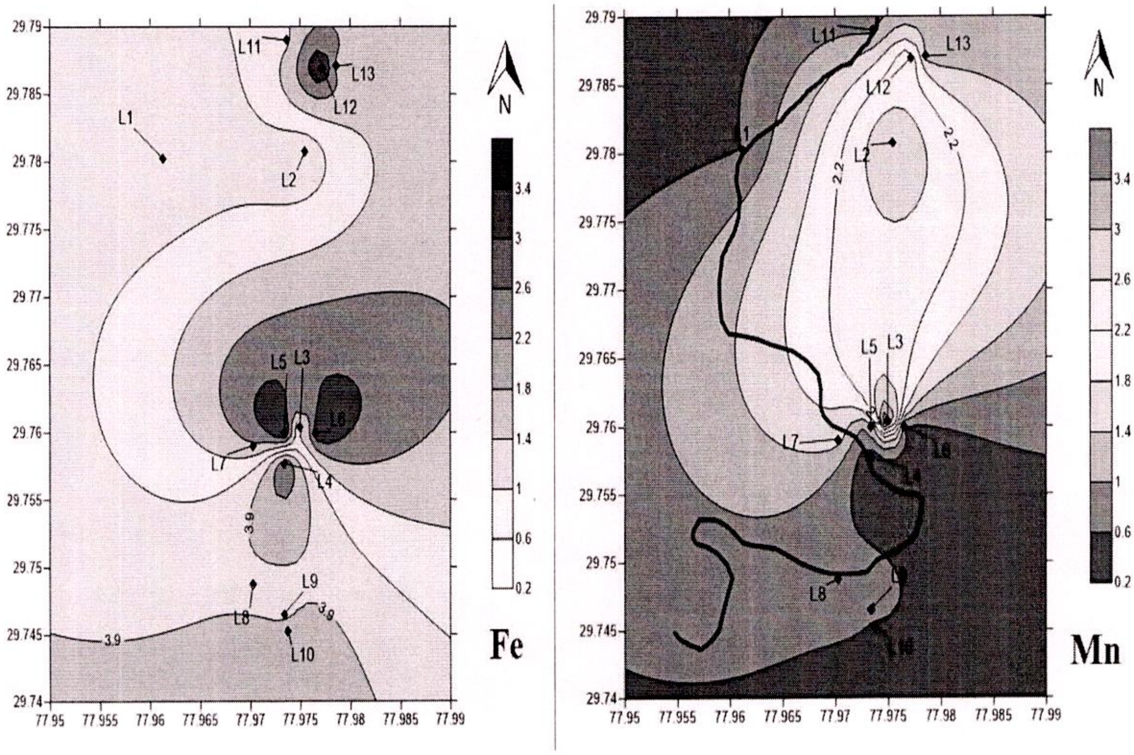


**Figure 62**:- Spatial Distribution of (a) Fe (b) Mn of Laksar

# CHAPTER 6
# SUMMARY AND CONCLUSIONS

## 6.1 Summary

A comprehensive study on the "Riverbank Filtration (RBF)" technique has been presented in this dissertation work. The study includes: RBF process understanding, mechanisms involved in RBF technique, factors which influence RBF, site selection, advantages of RBF, performances of RBF in other countries, and scope of RBF in India.

To study the feasibility of RBF in different hydrogeological settings in India, three pilot demonstration sites, one located along Solani river in Laksar(Uttarakhand), two along the river Yamuna at Mathura and Agra (Uttar Pradesh) have been studied. The study included; water sampling campaign and water chemistry analysis of river and ground water to detect presence of water quality constituents. A number of water quality parameters have been analyzed; those are : pH, EC, Turbidity, TDS, Total hardness, $F^-$, $Cl^-$, $HCO^3$-, $SO_4^{2-}$ , $NO3^-$ $NO_2$, $Na^{2+}$, $Ca^{2+}$, $Mg^{2+}$, $Na^+$ , $K^+$, $NH_4^{+,}$ BOD, DO, and Total Coliform. Based on the analysis of results of water quality parameters, the following conclusions are drawn:

## 6.2 Conclusions

(i) RBF or simply BF is a low-cost pre-treatment natural technique that works on stream/river-aquifer interaction. The technique is capable to remove suspended solids, particles, biodegradable compounds, pathogen loads, bacteria, viruses and parasites.

(ii) The performances of RBF technique in developed countries, mainly in Europe and USA have demonstrated its effectiveness towards removal of SS, Turbidity, biodegradable compounds, pathogen loads, bacteria, etc. to a great extent and satisfactory supply of drinking water to the communities living along riverbank. The performances of the technique to scattered implementation in India have also shown its potential and effectiveness to upscale in feasible locations for supply of safe drinking water in urban, peri-urban, and rural villages..

(iii) There are many other scientific/technical aspects of RBF such as, protect against flood, removal of micro-pollutants, impact of climate change on RBF, etc. need to be studied before its large scale implementation.

(iv) The pilot case study analyses of three sites conceived by NIH for developing RBF schemes in different hydrogeological settings showed the following results:

Water of the Laksar block is slightly acidic to alkaline in nature with SW samples more alkaline than GW samples. The water samples fall in low to medium salinity category. The spatial differences between the EC and TDS values reflect the wide variation in the activities and processes prevailing in the region. $HCO_3$, Cl, and $SO_4$ are the dominant anions both in surface and groundwater samples. Water chemistry of the Laksar district is dominated by $Na^+$, $Mg^{2+}$ and $Ca^{2+}$ cations. Alkaline earth cations (Car and Mg) dominate over alkali cation in almost all the samples. On an average Ca alone constitute 75% of the total cations ($TZ^+$) in the water samples of the area. The water samples of this region are mainly of **Ca – HCO3** and **Mixed Ca- Mg- Cl** type. The water samples of this region are very hard in nature due to dominance of Calcium. The water samples show a wide range of turbidity and many samples have exceeded the permissible limit. On critical examination of heavy metal concentrations in water samples we find that Fe and Mn exceeded the permissible levels in all the water samples. The water samples of this region fall in poor category according to WQI. The values of TDS are within the desirable level in all the samples. The concentration of $F^-$, $NO_3^-$ and $SO_4^{2-}$ are within the desirable limit in the water samples. In some samples anions like $HCO_3^-$ and $Cl^-$ have exceeded their desirable limit. Presence of Total Coliform in the water samples indicates high degree of organic pollution in water. Similarly high degree of BOD is observed in surface water samples indicates high degree of pollution. The level of DO is low in the water samples than its prescribed limit of 4mg/l.

Water samples of the Agra and Mathura district are slightly acidic to alkaline in nature. The water samples fall in high to very high salinity category. The spatial differences between the EC and TDS values reflect the wide variation in the activities and processes prevailing in the region. $HCO_3$, Cl, and $SO_4$ are the dominant anions both in surface and groundwater samples with $Cl^-$ as the dominant anion, Water chemistry of the Agra and Mathura district is dominated by Na, Mg and Ca cations. Alkali cations dominate over alkaline earths (Ca and Mg) in many samples and on average Na alone constitute 54 % of the total cations ($TZ^+$) in the water samples of the area. The water of the region is mainly of **Na –Cl, Mixed Ca- Mg- Cl water type, Ca- HCO3, Ca- Mg- HCO3-** type water. The water samples L15 and L16 are completely unfit for human consumption as almost all the parameters have exceeded their permissible limit. The water samples of this region fall in poor category according to WQI. The values of TDS OF EC are high making the indicating the saline nature of water. The water samples of this region are hard to very hard in nature. Concentration of $F^-$ and $NH_4^+$ exceeds the permissible limit in all water samples. Concentrations of $SO_4^{2-}$ and $NO_3^-$ are also exceeding the permissible levels in some groundwater of the area. In general, violation of drinking water standards in respect of TDS, F, $NO_3^-$, Cl, $SO_4$, Ca, Mg and hardness has been observed.

(v) Today the most important serious challenges before us are depletion of groundwater and pollution of surface water. Therefore, it is believed that that RBF canl be a suitable and sustainable technique to ensure drinking water supply in many areas where feasible RBF sites exist.

(vi) An excellent scope of future research on this area exists, particularly, on effectiveness of the technique in removal of micro-pollutants, impact of climate change on RBF, impact of RBF to downstream stretches of a river, etc.

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