

**ASSESSMENT OF IMPACT OF LEACHATE ON GROUNDWATER  
POLLUTION DUE TO MUNICIPAL SOLID WASTE LANDFILL SITE**

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**IN**

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## DECLARATION

I hereby declare that this work which is being presented in the thesis entitled “**ASSESSMENT OF IMPACT OF LEACHATE ON GROUNDWATER POLLUTION DUE TO MUNICIPAL SOLID WASTE LANDFILL SITE** ” in partial fulfillment of the requirement for the award of degree of **Master of Engineering** in the field of **Civil Engineering** with specialization in **Infrastructure Engineering** submitted at **Thapar Institute of Engineering & Technology (Patiala)** is authentic record of my own work carried out during the period from 10.01.2019 to 30.7.2019 under the guidance of Dr. Dwarika Nath Ratha and Dr. B.R. Yadav.

The matter embodied in this thesis has not submitted by me for the award of any other degree or diploma.

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# ABSTRACT

In the recent years, due to the rapid increase in industrialization and population, the waste generated due to both industries and household has escalated in an uncontrolled fashion. In developing countries like India, the municipal solid waste management is majorly done using conventional methods like landfills and abandoning the waste at dumpsites. These landfills and dumpsites have become a major threat to groundwater quality. The present study focuses on the landfills of Patiala region of Punjab, India. The main aim of the study is to calculate the amount of harmful components in groundwater and to check the effect of leachate on the quality of groundwater. For this task, samples of groundwater were collected from various locations of the city. The leachate samples were produced in the lab from the garbage collected from different locations and using the artificial rainfall machine. Different physio-chemical parameters are calculated from these samples like pH, temperature, TDS (ppm), total hardness (TH), Magnesium Hardness, Calcium Hardness, turbidity, alkalinity, sulphate, chloride, salinity (%), conductivity ( $\mu\text{s}/\text{cm}$ ), resistivity ( $\Omega\cdot\text{cm}$ ),  $\text{Ca}^{2+}$  ions and  $\text{Mg}^{2+}$  ions. These parameters were compared with the IS 10500:2012 standard. Thereafter, correlation was calculated from these samples. The Pearson correlation coefficients are calculated for this task. Statistical parameters like average, minimum, maximum and standard deviation are also calculated. This provides the variations in different samples from various dump sites. The impact of each variable on groundwater contamination is also studied along with their collective influence. It has been observed from the results that the parameters calculated from the clean water or IS 10500:2012 standard do not match with either the groundwater samples or the leachate data collected in the study. Therefore, groundwater collected from the sites was found not suitable for drinking purpose. The use of proper designing in landfills construction and appropriate leachate collection systems are to be installed in order to solve this problem.

# CHAPTER 1

## INTRODUCTION

Water is the most useful and important resource present on earth in different forms, quantities, and qualities. It is used for different sort of purposes like drinking, cleaning, farming, etc. subjected to its quality. Nearly seventy percent of the human body is made up of water whereas, in plants, this percentage is reported to be 60-70%. With its dynamic quantity scattered across the globe, water serves as the baseline for human civilization existence. The world is currently facing a severe problem of shortage of clean and good quality water. This problem is even more dominant in developing and underdeveloped countries. The complete food cycle is being hampered due to this fact and contamination of water is the leading problem for it. Groundwater serves as a major source of clean water and once adulterated, it remains polluted without proper treatment. Due to its everyday use and susceptibility for adulteration, water pollution, especially groundwater pollution causes a lot of diseases (Ahmed and Ali, 2004).

Even though water is present in ample amounts in the form of both surface and groundwater, but only about 1% of it is liquid freshwater. Most of the water on earth is either in oceans or frozen in ice caps and glaciers. Groundwater, rivers, lakes, springs, man-made reservoirs, glaciers, icecaps, rainwater, desalination of seawater are among the major sources of clean water. The different uses of water for humans include its use in everyday living, agriculture, manufacturing, and power generation (Khan and Ali, 2011).

### **1.1 Water Pollution: Problem and Cause**

Water is a crucial resource on earth for life of both flora and fauna. Currently, the world is facing a huge problem of water pollution. Water pollution happens when toxic materials get mixed in groundwater or other water bodies like the ocean, lake, river, etc. Nearly 80% of the wastewater produced currently in the world goes untreated into the environment.

This results in the contamination of water. Only 1% of clean water is accessible to humans and the demand is increasing day by day. It is expected that by 2050, the demand for clean water will rise by one-third of its presentvalue(Kathirvale et al., 2003; Irfai, 2016).

Water pollution can be caused by one of the following many ways (Shaato et al., 2007):

- City sewage discharge
- Industrial waste
- Contaminants entering the water supply from soils
- Contamination from the atmosphere via rain
- Contamination due to residues of agriculture (fertilizers and chemicals)
- Contamination due to leachate created in landfills.

## **1.2 Groundwater Pollution due to Solid Waste**

Groundwater is created as a result of seeping of water into the earth surface. It is the foremost source of clean water for everyone. Groundwater is very susceptible to contaminations. It gets polluted due to contaminations from leachate created in landfills of municipal solid waste (MSW) and septic systems or from pesticides and fertilizers from agricultural activities seeps into earth's surface, thereby contaminating the groundwater (Parthet al.,2011).

In underdeveloped and developing countries, landfills are the major source for disposal of MSW. Due to the recent advances in industrialization and economy, the MSW generated by these countries is increasing day by day (Varol and Davraz, 2010). This is the result of increase in consumption of natural resources by the industries and large cities. These landfills and dumpsites pose a threat to both human health and environment (Melloul, 1998).

The solid waste generation has increased rapidly in India due to urbanization and increase in population. Leachate is considered to be a severe pollutant which is disturbing the natural resources of both surface water and groundwater resources. Leachate is generally considered as a contaminated liquid which originates from both dumpsites and landfills which contain organic and inorganic compounds (Mahleret al., 1988). The quality, amount, and features of leachate depends majorly on the type of waste management used, weather conditions, waste characteristics (Kathirvale et al., 2003).

Due to the complex nature of leachate, its characteristics fluctuate greatly from one landfill to other and even in a single landfill over space and time. The composition and type of waste, amount of humidity present, particle size of waste, climate and age of dumpsite effects the composition of leachate. The pre-treatment of solid waste like separation of recyclable and non-recyclable waste also decides the leachate composition (Mason, 2015).

The current study aims at the chemical characterization of leachate produced as a result of MSW in dumpsites and landfills at Patiala, India and to study its impact on the quality of groundwater around the region. For this task, different parameters are calculated from both the leachate and groundwater samples. Upon the statistical processing of these samples, the effect of leachate on groundwater is summarized in terms of correlation coefficients.

### **1.3 Advancements in MSW Management System**

Advancements in MSW management began to develop in the late 19<sup>th</sup> century. In the US, sturdier vehicles were employed for the collection and transportation of wastes from garbage cans. The first refuse incinerator was developed and installed in England in 1874. The use of solid waste grinders, compaction vehicles, and collection systems has revolutionized the MSW management. Studies have proven that duping of solid waste and improper incineration causes health problems and affects the environment. Therefore, the concept of sanitary landfills came into existence. Sanitary landfill (also known as controlled tipping) is a method of solid waste disposal in which waste is deposited in thin layers of 1 meter to 3 feet and compressed using bulldozers. Using this technique, a total of up to 3 meters, or 10 feet, a thick layer of solid waste called refuse cell is constructed. Finally, the refused cell is covered with a layer of soil to prevent odor. The landfill is capped with clay or a synthetic liner to stop water from being mixed with the solid waste. Different methods are used for solid waste disposal and management which are as follows (Mason, 2015):

- Burning of solid waste in open air
- Throwing away waste into the sea water
- Landfills
- Composting

- Plowing in fields
- Hog feeding
- Crushing and exoneration into gutters
- Salvaging
- Fermentation & organic breakdown

In many developed countries, the MSW is divided into hazardous and nonhazardous waste and then treated separately. A lot of emphases are given on recycling and waste reduction practices. Even then, however, most of the countries like India are still using open dumping on land or in water (Al-Sabahiet al., 2009).

#### **1.4 Leachate**

Solid wastes are usually processed by using landfills and dumpsites because it is an inexpensive and simple technique. Leachate is defined as “liquid that takes in substances from the material through which it passes, often making the liquid harmful or poisonous” (Watkinset al., 1996; Alleret al., 1987). As the leachate is produced by landfills, therefore landfills raise serious issues about the health of living organisms of all types around them. Landfills also affect the soil which intern affects the agriculture process. Therefore, the study of effect of leachate on groundwater quality becomes a major concern (Wanget al., 2012).

In developing countries like India, the problems caused by leachate are even more severe because the present landfills do not have appropriate facilities like bottom liner, advanced waste treatment systems. Even most of the MSW is not put into landfills but thrown on open dumpsites. This increases the risk of water contamination to a large extent. The leachate produced by MSW consists of biodegradable and non-bio degradable organic substance as well as synthetic inorganic components. Dangerous compounds like mercury, lead, diffused products, plastic, dyes are also present in the MSW which becomes a part of leachate.

The treatment of leachate is possible by its proper decomposition with appropriate measures. The microbiological elements also play a major role in this process (Kaur and Rosi, 2011). But the existence of metal compounds and other poisonous substances in MSW does not allow the microflora to grow. This microflora is very essential for the decomposition of leachate. Morphological analysis of MSW leads to adaptation of essential measures to provide healthy environment to microflora. For this task, many advanced tools are used currently in the society.

As the understanding about the leachate, its chemical and physical composition and other parameters is crucial in evaluating its impact on groundwater resources, the aim of current study is to study the physio-chemical characteristics of leachate and groundwater in the uncontrolled landfill site in Patiala, Punjab, India. Various statistical parameters are calculated from the leachate and groundwater samples taken from different locations. Correlation among these parameters is calculated which allows a more detailed analysis on the impact of MSW in landfills and dumpsites on the groundwater.

## **1.5 Research Problems**

Landfills across the world are used as disposal sites for different kinds of waste may it be municipal waste and sewage or industrial harmful chemical waste. One of the byproducts generated from these landfills is leachate which consists of organic, inorganic and xenobiotic organic materials. This leachate also contains insecticides and heavy metals which makes it even more dangerous. Leachate is considered as the major cause of groundwater contamination resulting in various health problems. Therefore, it becomes the need of the hour to restrict and treat the leachates present across the globe (Parth et al., 2011).

The city of Patiala is located in southeastern Punjab state of India. With 131.25 sq mi area and the human population of around 446,246 according to the Census 2011, it is the fourth largest city in Punjab. The average annual temperature in Patiala is 24.5 °C and the average rainfall is 754 mm. The least amount of rainfall occurs in the month of November (3 mm) and most in August (227 mm).

According to the annual report for implementation of MSW from 01.01.2017 to 31.12.2017, the solid waste generation of Punjab state for the year was 4632.27 TPD out of which 4498.57 TPD was collected, only 696.396 was treated and 3801.75 TPD was land filled. This is alarming data and even though Patiala is considered one of the cleanest cities in Punjab, still the problem of

groundwater contamination due to land filling of waste is observed in Patiala. People in villages around Patiala constituency have farming as their major occupation and rely on groundwater boreholes and hand-dug wells for its water needs which makes the problem of groundwater contamination more severe. It is therefore important to study the effect of leachate and quality of water in the vicinity of these landfills in order to test its impact on humans and other living organisms.

## **1.6 Objectives of the Study**

The aim of this research is to study the effect of wastewater and municipal solid waste on groundwater. In particular, the objectives of this research are as follows:

1. To determine the physico-chemical characteristics of ground water of study area in-order to identify the impacts of leached water through municipal waste on ground water.
2. To identify the impact of leachate water through mix municipal solid waste by experimental simulation.
3. To correlate physio-chemical parameters in-order to indicate their relationship.

## **1.7 Thesis Organization**

The thesis is organized as follows: Chapter 1 gives the introduction about current scenarios of groundwater contamination and its reasons. Thereafter, the research problems, objectives and methodology are presented. The process of sampling of leachate and groundwater and its physico-chemical analysis method is also introduced. These methods are further explained in detail in Chapter 3. Chapter 2 gives a comprehensive literature survey of the groundwater contamination by leachate, its causes, and effects. Chapter 3 presents the methods and techniques used for data collection of the leachate and groundwater. The results obtained from various tests and its discussion is given in Chapter 4. Chapter 5 contains the concluding remarks and future work of the dissertation.

## **CHAPTER 2**

### **LITERATURE SURVEY**

Effective waste management has emerged as one of the most serious issues faced by current civilization due to the changing consumption patterns and increasing urban populations. According to a study in 2012 (UNEP, 2013; UNPD, 2012), more than half of the world population is now living in urban centers. With this, the municipal waste disposal system has become ineffective due to the scarcity of capacity or funding. Especially in developing countries like India, open dumpsites have been the most commonly used method of solid waste disposal. Among various other harmful effects, the leachate produced as a result of these dumpsites poses a threat of soil as well as water pollution. Depending on the characteristics, leachates produced in different areas of the globe have different effects. This chapter gives a comprehensive literature survey describing the state of art published work in related areas of leachate production, effects, and monitoring.

A lot of work has been done to study the impact of leachate on groundwater quality using their chemical composition and characteristics in India by Vasanthi et al. (2008); Mohan and Gandhimathi (2009) and Jha et al. (2003). Still, landfills and dumpsites remain a major problem faced by the current society. No suitable solution is currently been implemented by the government in order to save the environment from the harmful effects of leachate.

A study by M. Kholghi (2010) established the association of humans with nature. It is explained in the study that how the commercialization has affected the atmosphere to a very large extent. Currently, the annual MSW collection is approximately 11.2billion tons per year. The most recent reports by World Bank have anticipated the cost of MSW management to reach USD 375.5 billion by 2025. So the solid waste management becomes a very important aspect in the development of humans (Kathirvale et al., 2003; Irfai et al., 2016).

Several studies are conducted in order to assess the problems faced in the process of waste management. The study of leachate characteristics and its impact on human health is also a major concern among the research fraternity.

Khan (2011) conducted a study on solid waste management systems. It was concluded that in India, due to the deprived collection productivity of MSW and poor processing, the complete energy value of MSW is not consumed and it is usually left in open landfills or dumpsites. This study also gave different techniques for implementation of appropriate techniques for decreasing the harmful environmental effect of discharged leachate. The variations in chemical composition of landfills with time have been studied by Aziz et al. (2015). They observed that the features of MSW change from one dumpsite to other. They concluded that a priority based system should be developed in order to check which landfills require instant consideration for the remediation. An index for checking the extent of contamination due to leachate on groundwater and comparison with clean water has also been proposed in the study.

An index called leachate pollution index (LPI) is developed by Kumar and Alappat (2003) to check the amount of contamination in landfills and dumpsites. This index serves as a reference for checking the quality of surface water and groundwater in the vicinity of landfills. Aziz et al. (2005) in their research provided the data about MSW data: about 40-60% of MSW produced in India is biodegradable; therefore green compost can be made from it. Moreover, the Carbon-Nitrogen ratio of MSW was also reported to be suitable for compost. But, the presence of metals was found to create the problem in this process.

Parth et al.(2011) in a similar study reported that the proper treatment of leachate and gas collection is not opted by almost every landfill in India. This results in surface and groundwater contamination. Moreover, the presence of both organic and inorganic substances along with heavy metals was found to be a part of leachate produced by various dumping sites and landfills. The impact of leachate on soil and groundwater was also studied in (Parth et al., 2011). Several other studies have shown the ill effects of leachate on soil, surface water and groundwater (USEPA, 1985; Varol and Davraz, 2010). One important observation from these studies is that as soon as the groundwater is contaminated, it becomes a hideous task to remove it fully.

The four phases of landfill decomposition are studied in (Christensen and Kjeldsen, 1994). These include aerobic phase, anaerobic acid phase, methanogenic phase, methanogenic phase. A fifth phase of decomposition called as aerobic or humic phase is proposed by (Kjeldsen et al., 2002). Another study for leachate decomposition based on time phases such as transition (0 to 5 years), acid formation (5-10 years), methane fermentation (10-20 years) and maturity (>20 years).

Afolayan et al., (2012) studied the dependence of leachate production on type of waste, weather, time and waste management tactics are explored. Further, the migration and pollution due to the produced leachate are shown to be a function of landscape, type of soil and remoteness from leachate source. Ohwohere and Aweto (2013) worked on this study further to conclude that the depth and distance of leachate source from the sink plays a major role in groundwater contamination.

The presence of heavy metals like chromium, arsenic, and cadmium in groundwater as a result of landfills is studied by Longe and Enekwechi (2007). In this study, it is found that the amount of leachate production depends on meteorological and hydrogeological properties of the site as well as the area of landfill location. They also make an emphasis on the importance of capping in this regard. A similar study is made by Lee et al. (1993).

The issue of leachate production within or below an unlined landfill as a result of degradation of waste is raised in a study by Taylor and Allen (2006). Mason (2015) in his study proved that contamination in groundwater generally exists as a concentrated plume. This is because groundwater flows at a slow pace with very little mixing or dilution. The dependence of leachate relocation from the place of disposal on various factors is studied by Lee and Jones (1993). They observed that the site design, geochemistry, hydrogeology, and meteorological conditions of disposal site affect the leachate relocation. Alsaibi et al. (2009) worked on the health effects of leachate on groundwater. The chemical composition of leachate is studied in by Vasanthi et al. (2008).

Tilahun and Merkel (2010) used the Overlay-index method to study groundwater susceptibility and concluded that this method can be very efficiently used along with geographic information systems. In another study, Watkins et al. (1996) explored the use of groundwater models in geographic information systems. This resulted in increased efficiency of susceptible area prediction. Along with it, the data of depth to groundwater from the surface and annual rainfall is also used.

Aller et al. (1987) created a model known as DRASTIC for the United States Environmental Protection Agency. This model consists of 7 parameters i.e. Water depth, net recharge, aquifer media, soil media, topography, impact of the vadose zone, hydraulic conductivity. This model is used in many studies like (Rahman, 2008; Fritchett al., 2000; Wanget al., 2012; El-Naqaet al.,

2006; Al-Rawabdehet al., 2013; Chitsazan and Akhtari, 2009; Lynch et al., 1994), due to its high efficiency for measuring groundwater vulnerability.

Fatta et al. (1999) reported the effect of leachate created from landfills on quality of groundwater in AnoLiosia landfill situated in Attica, Greece. It was concluded that the groundwater near the landfill was not suitable for wither drinking or irrigation purpose. Hydrologic evaluation of landfill performance (HELP) model was utilized in this study. Salam and Abu-Zuid in their work evaluated the environmental impacts of solid waste landfilling and the leachate on groundwater quality. The BOD<sub>5</sub>/COD ratio was used to calculate the biodegradability of leachate and it was found that the leachate was biodegradable and un-stabilized.

A comparison of their hydro chemical nature was made between the samples of solid waste; leachate and groundwater are made in (Singh et al., 2007). K/Mg ratio has been used to calculate the effect of leachate on groundwater. Factor analysis and cluster analysis have been utilized in this study. A similar study was performed in Akure, Nigeria by Akinbile and Yusoff (2011). This study included the physical, chemical and bacteriological investigation of water samples from three boreholes near landfills. Turbidity, temperature, pH, dissolved oxygen, TDS, TH, total iron, nitrate were calculated in this study and it concluded that two out of three boreholes were contaminated to a very heavy extent. The landfill site of Gazipur Delhi was studied by Mor et al. (2006) to study the impact of leachate percolation on groundwater quality. Harmful chemicals like Cl<sup>-</sup>, NO<sup>-</sup><sub>3</sub>, SO<sup>2-</sup><sub>4</sub>, NH<sup>+</sup><sub>4</sub>, Phenol, Fe, Zn and COD were found in considerable amount in the test samples. The influence of depth and distance of bore well from land site was also investigated.

Numerical modeling methods were employed to study the impact of landfill leachate on groundwater quality by Papadopoulou and Karatzas (2006). It was shown that the permeability of soil at leakage location affects the degree of contamination of groundwater. A risk assessment model was also proposed in this study.

## **Concluding Remarks**

A comprehensive literature survey has been presented in the chapter. It has been observed that the leachate created due to MSW creates a lot of problems with respect to contamination of groundwater resources.

## CHAPTER 3

### STUDY AREA

#### 3.1 Location

The landfill location under study is situated in the city of Patiala in Punjab state of India. Patiala is a well-known city of Punjab which has a rich history of ostentatious rulers. This resulted in a very ironic inheritance of art and architecture. With the establishment of Qila Mubarak in 1763, the city of Patiala prospered with time. Fig. 3.1 shows the relative location of Patiala in Punjab, India.

Patiala is situated in the south-eastern side of Punjab with  $29^{\circ}49'$  and  $30^{\circ}47'$  as its latitude and  $75^{\circ}58'$  and  $76^{\circ}54'$  as the east longitude encircled by districts of Rupnagar&Fatehgarh Sahib (Punjab); Chandigarh in north, Ambala, Kurukshetra (Haryana) in east and Kaithal district (Haryana) in south and district Sangrur (Punjab) in west. The total area of the district is 4,63,426 hectare. The district of Patiala is further divided into six tehsils, two sub-tehsils and eight blocks. A detailed map of Patiala district is shown in Fig. 3.2. There are two main rivers in this district: Patialawalinadi and the Ghaggarriver. These rivers overflow in the rainy seasons causing flooding of neighboring areas.

The climate in Punjab has quite diversified nature with heat in summer, rain in monsoon and cold in winter. Patiala, due to its location, experiences extreme summers and winters. The summer season in Patiala starts from April and stretches till June. The time between February and April is generally called a post-winter season which is a transition from winter to the summer season. The temperature in Patiala can go as high as  $45^{\circ}\text{C}$  during summer. Thereafter, monsoon comes in July and lasts till September. Punjab receives rainfall of 250 mm to 1000 mm with Patiala 754 mm average rainfall based on rainfall records from 1931 to 1970. Due to such a healthy rainfall, the lands in Patiala and around are fertile and suitable for agriculture. Winter in Patiala spans from October to February. Weather in October and November remains pleasant but becomes extremely chilling in the month of December and may even fall to  $0^{\circ}\text{C}$ .

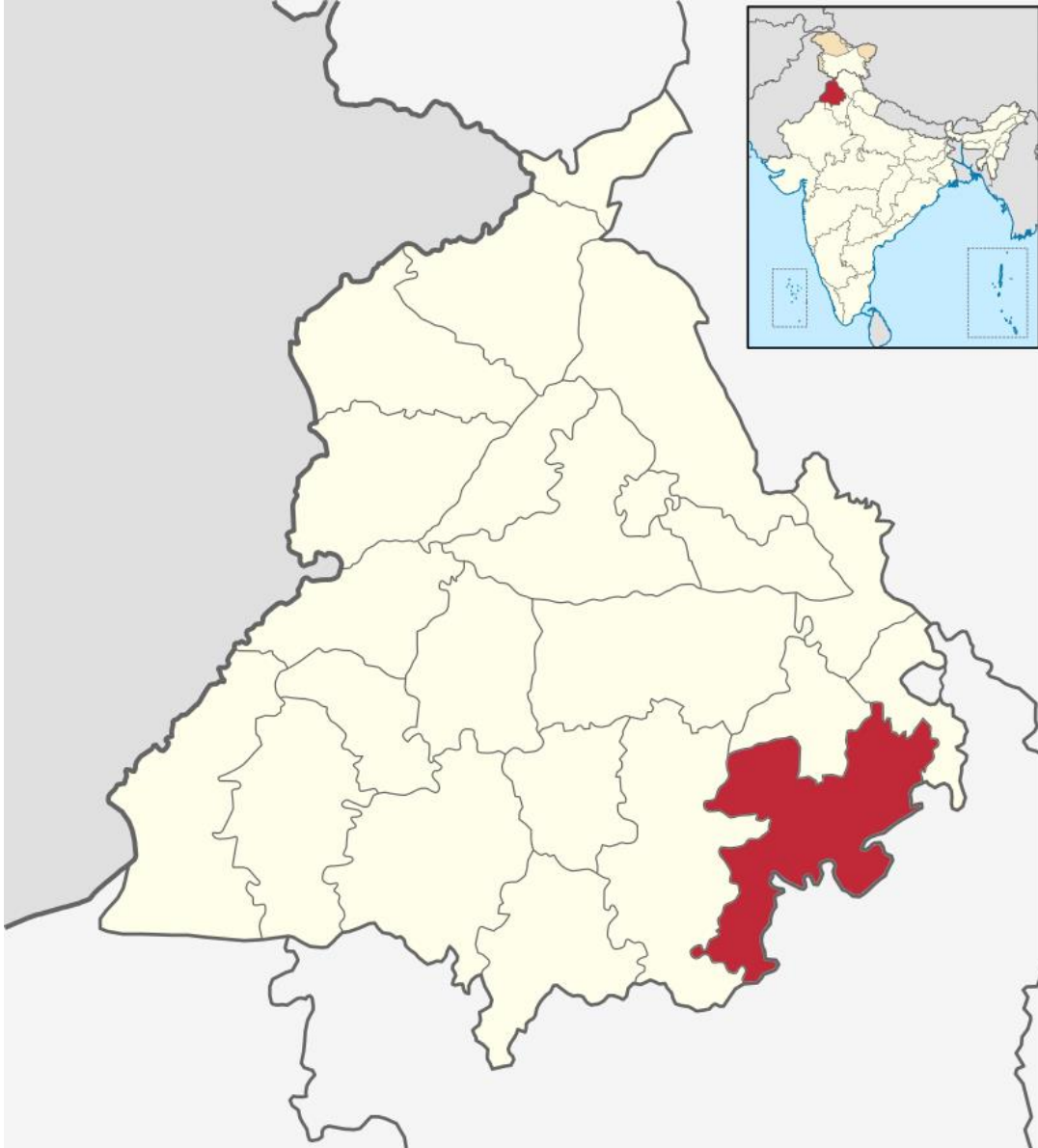


Fig. 3.1: Relative location of Patiala in Punjab, India (Sehgal et al., 1998)



Fig. 3.2: Map of Patiala district (Sehgal et al., 1998)



Fig. 3.3: Political map of Punjab State (Sehgal et al., 1998)

### 3.2 Solid waste trends in Patiala

Patiala falls under the constituency of Punjab state and in order to combat the problem of MSW treatment, the state is divided into 8 clusters. Integrated Municipal Solid Waste Management Plants are created in these clusters at Patiala, Ludhiana, Pathankot, Amritsar, Jalandhar, Bathinda, Mohali and Ferozpur. These plants are designed for the following operations:

- collection of MSW from homes
- transference of MSW to dumpsites
- treatment of MSW
- scientific disposal into the landfill facility

Table 3.1 shows the details of MSW data in ton per day (TPD) for Punjab state for 2015-2017. This data is taken from website <http://www.ppcb.gov.in/MunicipalSolidWaste.aspx>. Till date, only the land to be used in these projects is finalized. In Patiala, the Environmental Clearance under Govt. of India EIA notification 14.09.2006 has not been granted yet. A 20 Acre piece of land is given by D.C. of Patiala to Municipal Corporation for the construction of the project.

Table 3.1: MSW data (in Ton per day) for Punjab state for 2015-2017

(Taken from Punjab Govt. website: <http://www.ppcb.gov.in/MunicipalSolidWaste.aspx>)

Year	Solid waste generation	Collected	Treated	Landfilled
2017	4632.27	4498.57	696.396	3801.75
2016	4544.35	4520.35	39.175	3278.6
2015	4456.2	4435	3.72	3214

### 3.3 Methodology

In order to achieve the objectives defined in this work, an experimental setup was utilized to learn the effect of leachate produced from MSW on groundwater. The solid waste generated by the household and industry is disposed in open/uncontrolled dump site in Patiala.

To study the effect of leachate produced from MSW on groundwater, twenty four sites were sampling points were carefully chosen within 15 km radius of the various dump sites of Patiala.

The samples were collected in clean 500 ml plastic bottles from wither tube wells or taps. While collecting these samples, water from the source was allowed to run freely for 5 minutes. This was done in order to average the samples and even out the electrical conductivity.

As the dumpsites were not furnished with any leachate collection systems, leachate was collecting from the base of dumpsites. Three different samples were taken from each site. The samples for microbiological analysis were taken in 50ml sterile universal containers. Table 3.2 lists the locations for water sample collection in Patiala and their Latitude & longitude. Fig. 3.4 shows the locations for water sample collection as par Table 3.2.

Table 3.2: Locations for water sample collection in Patiala and their Latitude & longitude

Sr. no.	DIFFERENT LOCATIONS	Latitude and longitude
1	Rangesha Colony	30°19'15.3"N, 76°24'49.7"E
2	ChotiRaymajra	30°19'17.6"N, 76°25'02.6"E
3	Choura Road	30°19'07.4"N, 76°25'09.6"E
4	MSW Site	30°19'11.7"N, 76°25'00.5"E
5	New Officer Colony	30°18'57.0"N, 76°22'30.6"E
6	Mohindera Complex	30°18'44.0"N, 76°22'30.2"E
7	Ghalori Gate	30°19'06.0"N, 76°24'25.9"E
8	SainiKesarBagh	30°18'40.6"N, 76°23'49.0"E

9	NIS Chok , Lower Mall	30°18'58.4"N, 76°23'42.3"E
10	New LalBagh	30°19'43.8"N, 76°23'26.2"E
11	Devigarh Road	30°19'00.8"N, 25°07'.6"E
12	BadiRaymajra	30°19'17.6"N, 76°25'05.4"E
13	TejBagh Colony	3019'19.8"N, 76°24'50.1"E
14	Mohindera Colony	30°18'49.0"N, 76°23'55.3"E
15	Urban Estate Nagar 1 PG	30°21'03.8"N, 76°26'41.4"E
16	Urban Estate Nagar2 MANDIR	30°20'58.5"N, 76°26'07.8"E
17	SST Nagar	30°20'04.3"N, 76°24'55"E
18	Old Bishan Nagar	30°20'13.5"N, 76°24'46.7"E
19	Vikas Colony	30°20'08.7"N, 76°24'27.9"E
20	Abchal Nagar	30°21'04.5"N, 76°24'17.5"E
21	Udham Nagar	30°22'05.9"N, 76°22'17.7"E
22	Ghuman Nagar	30°21'59.0"N, 76°24'10.5"E
23	Ranjeet Nagar	30°22'16.0"N, 76°22'17.7"E
24	Kartar Colony	30°21'13.1"N, 76°21'29.3"E

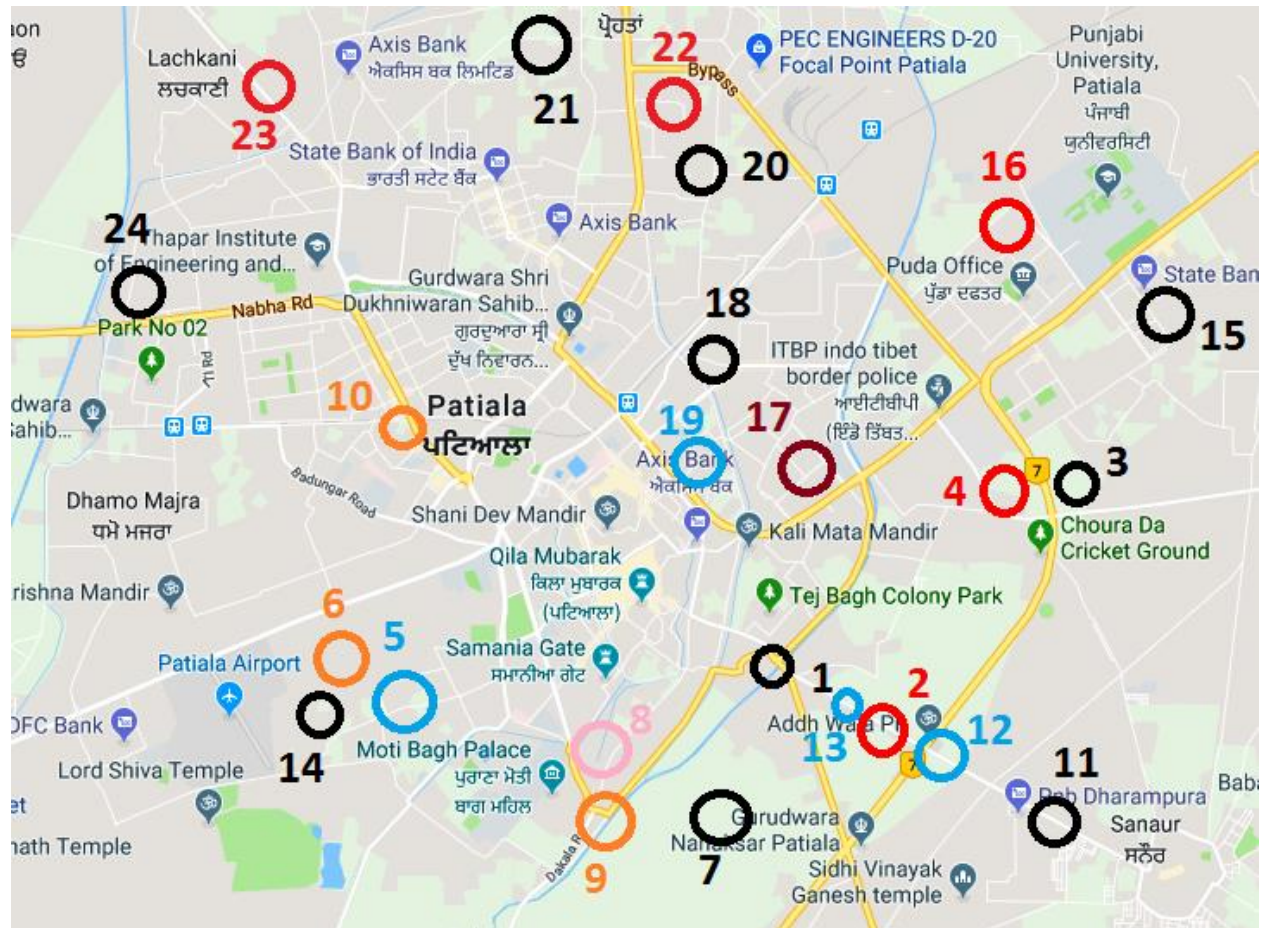


Fig. 3.4 Locations for water sample collection as per Table 3.2

### 3.4.1 Stimulated Leachate

To compare the quality of landfill runoff artificial rainfall simulator is used to generate the artificial runoff waste water. The collected runoff waste water was termed as leachate in this reported. For leachate, the Artificial Rainfall Instrument available in Water Resource lab is utilized. The dimension of this instrument is 1.5 m X 2.5 m X 30 cm. Initially, a 10 cm thick layer of sand is spread on the instrument. The average grain size of the sand used is 4.536 mm. The MSW collected from various sites was spread evenly on this sand. For generating leachate, artificial rainfall was generated from the instrument. The resultant was left for an hour to settle down. Sufficient time is given for the water to penetrate and react with the MSW.

Then, 30 different samples were collected from this resultant. These samples are collected using 30 different holes below the instrument and are marked as  $C_1, C_2, C_3, \dots, C_{30}$  in the results. This process was repeated multiple times to get aggregated data. The collected samples are further

processed and tested for their physiochemical properties. Along with this, one sample of water used for rainfall (clean water) is also tested. The data collected from these samples is compared with the drinking water quality standards as per IS10500:2012.

The complete process was repeated again including timing as additional variable. For this task, 10 cm thick layer of sand was spread. MSW was spread above this layer. The water flow from the artificial rainfall instrument is maintained at 15 liter per minute. After leaving the MSW for one hour, 14 samples are collected after 30 minutes. The process of collecting 14 samples is repeated after every 30 minutes. These samples are then taken to lab where they are tested for the physiochemical properties. Along with it, one sample of clean water used in rainfall is also tested for reference purpose.

Various tests are performed on these samples to calculate parameters like pH, turbidity, alkalinity etc. Finally, a correlation is developed between the different physiochemical parameters of the groundwater collected from the MSW sites. The statistical analysis is done by SPSS software using factor analysis as a tool. Factor analysis is a procedure used to reduce large number of variables into smaller number. It gives a common score to variables by calculating the maximum common variance. This score can be further used for analysis.

### **3.4.2 Physico-chemical Analysis**

The samples of leachate and groundwater taken from various dumpsites were taken to the laboratory where they were processed. The processing of these samples included calculation of physico-chemical parameters. The parameters analyzed in the groundwater and leachate samples include pH, temp, TDS (ppm), TH, Magnesium Hardness, Calcium Hardness, turbidity, alkalinity, sulphate, chloride, salinity (%), conductivity ( $\mu\text{s}/\text{cm}$ ), resistivity ( $\Omega.\text{cm}$ ),  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ . These parameters were calculated using standard methods given in Table 3.3. The acceptable limits of these parameters according to IS 10500:2012 standard are also given in Table 3.3.

### **3.4.3 Statistical Analysis**

The results of the data collected from different parameters are presented in Chapter 4. After the calculation of physico-chemical parameters from leachate samples, correlation was calculated from these samples. The Pearson correlation coefficients are calculated for this task. Correlation

between various parameters is calculated and plotted to get more insight into results. Statistical parameters like average, minimum, maximum and standard deviation are also calculated. These statistical parameters were processed using Univariate analysis to calculate the dependence of these parameters on each other. It also provides the variations in different samples from various dump sites. The impact of each variable on groundwater contamination is also studied along with their collective influence.

Table 3.3: Parameters, methods and their acceptable limits used in study

Parameter	Method	Acceptable limits IS 10500:2012
TDS	Conductometry	500mg/l
Electrical conductivity(ds/cm)	Conductometry	1.5-3.0
pH	Ph meter	6.5-8.5
Cl <sup>-</sup>	Argentometric method	250mg/l
Turbidity	Turbidity meter	1 NTU
Alkalinity	Titeration method	200mg/l
Sulphate	Gravimetric method	200 mg/l
Fluoride	SPADNS method	1mg/l
Nitrate	Spectrophotometer with cadmium reduction method	45 mg/l
Total hardness	EDTA	200mg/l

# CHAPTER 4

## MATERIALS AND METHODS

### 4.1 TDS calculation using TDS meter

Conductometry is related to the conductivity of electrolytes. In general, conductivity is the capability of a material to pass an electric current. The resistance of a solution is measured by applying voltage to the measuring cell. There are different parameters on which the conductivity of a solution depends. Some of them are as follows:

- ❖ number of ions
- ❖ ionic mobility
- ❖ type of ion
- ❖ solvent
- ❖ temperature
- ❖ viscosity

The TDS (Total Dissolved Solids) is the total weight of cations, anions and the dissolved particles in 1 Liter of solution. Mathematically, the TDS can be calculated as

$$\text{TDS} = \frac{\beta}{\gamma_{\text{th}}} \gamma_{\text{meas}}$$

Where TDS is the total dissolved solids in mg/L,  $\beta$  is the mass concentration of salt in mg/L,

$\gamma_{\text{meas}}$  is the measured conductivity in  $\mu\text{S}/\text{cm}$  and  $\gamma_{\text{th}}$  is the theoretical conductivity of salt in  $\mu\text{S}/\text{cm}$ . Fig. 4.1 shows the migration of ions in a solution. For clean water, the TDS should be within 0.50 to 0.70. TDS meters are used to calculate the TDS readings.

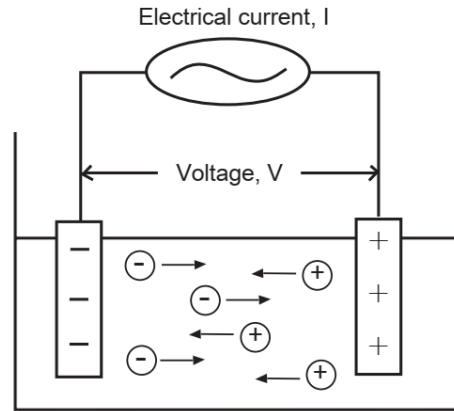


Fig. 4.1 Migration of ions in a solution

## 4.2 Electrical conductivity (ds/cm) calculation using Conductometry

The electrical conductivity also known as specific conductance is a measure to calculate the quality of water. Conductometry is used to calculate Electrical conductivity of a solution.

There are three popular methods to calculate Electrical conductivity which are the linear approach, Pseudo-linear approach and the diffusion coefficient-based approach. In this dissertation, electrical conductivity is measured using a conductivity meter. Fig. 4.2 shows the conductivity meter used in the study.

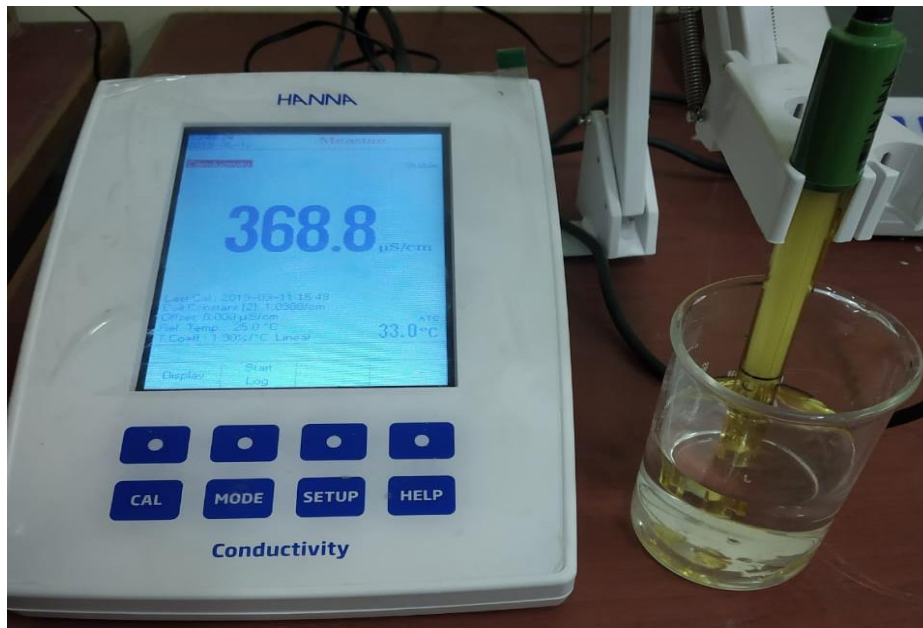


Fig. 4.2 shows the conductivity meter used in the study.

### 4.3 pH using pH meter

The term pH is also known as pondushydrogenii was proposed by S.P.L. Sorensen in 1909. Initially, pH was defined as the negative base 10 log of H ion concentration. This definition was changed later on. Based on hydrogen ion activity, pH is defined as

$$\text{pH} = -\log_{10} a_{\text{H}^+}$$

in practical applications, pH is measured using a pH meter. This meter calculates the potential difference between the electrodes and converts it to a display of pH.

Measuring probe is the central component in a pH meter. This probe is connected to the electronic meter. The pH meter is calibrated using a buffer solution whose hydrogen ion activity is already known. The pH of a solution can be very easily calculated by just sinking the electrode into the solution and interpreting the pH value on the display of the pH-meter. The typical setup for a pH calculation is shown in Fig. 4.3. In this dissertation, the pH meter used to calculate pH is shown in Fig. 4.4.

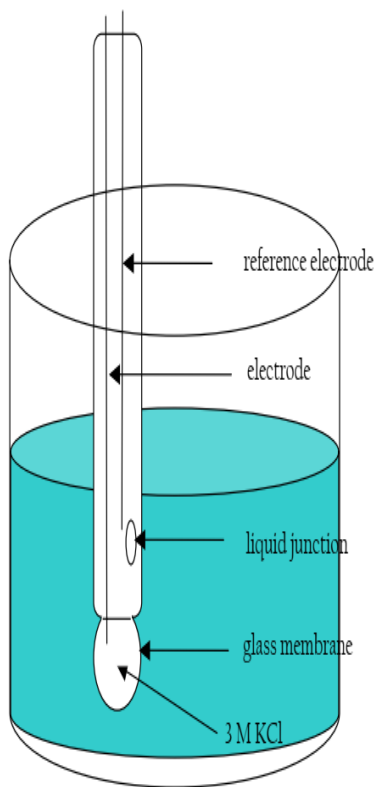


Fig. 4.3 pH calculation of a solution

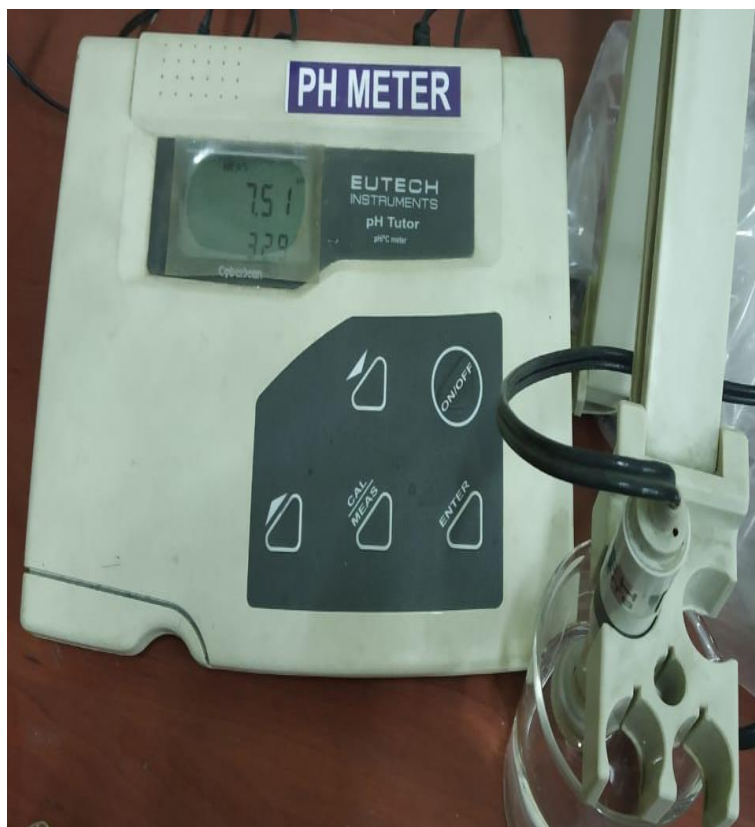
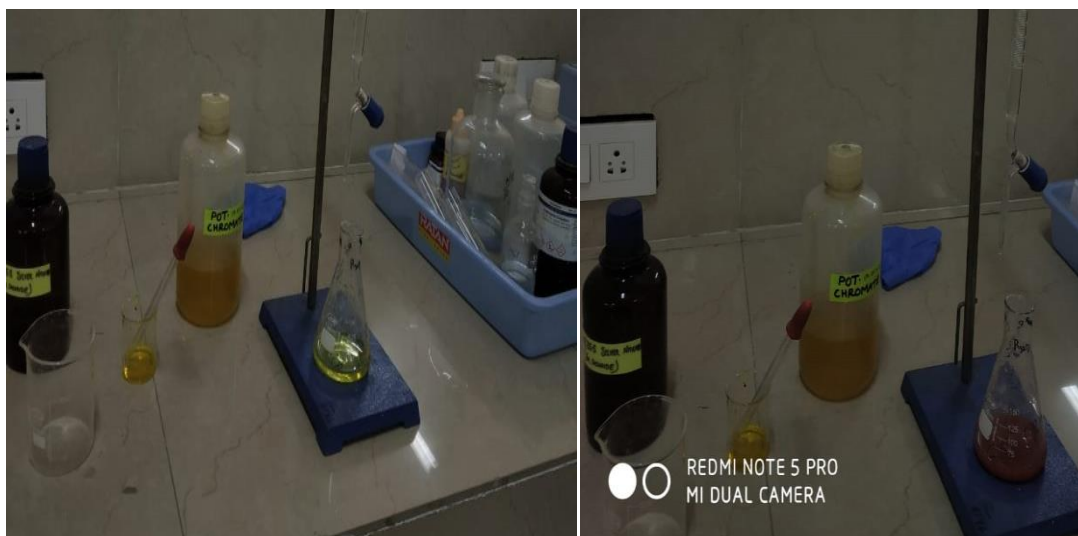


Fig. 4.4 pH meter for pH calculation

#### **4.4 Cl<sup>-</sup> calculation by using Argentometric method**

Argentometric method is used to calculate the Cl<sup>-</sup> concentration in a solution. In this method, titration is employed for the calculation of the concentration of an unidentified material in solution by adding predefined quantities of a known solution which reacts with the unknown. Then the number of moles of standard solution required to achieve endpoint is calculated to get the concentration of unknown.

For Cl<sup>-</sup> calculation, the solution is dried at 110° C for 1 hour. Then the solution is cooled using a desiccator. Then the sample is dissolved into 100 mL of distilled water. A small quantity of NaHCO<sub>3</sub> is added to the solution until effervescence is ended. Thereafter, 2 mL of K<sub>2</sub>CrO<sub>4</sub> is added until the solution becomes red. Fig. 4.5 and 4.6 demonstrate the process of Cl<sup>-</sup> calculation.



(a)

(b)

Fig. 4.5(a) Solution before adding silver nitrate (b) Solution after adding silver nitrate



Fig. 4.6 Left flask shows before titration endpoint, it shows cloudy solution after adding  $\text{Ag}^+$  ions; middle flask that all the  $\text{Cl}^-$  ions have precipitated; Right flask shows upon addition of  $\text{Ag}^+$  ions after endpoint results in red-brown color solution.

#### 4.5 Turbidity by Turbidity meter

Turbidity calculates the scattering of light due to the presence of suspended solids in a solution. Turbidity results from the presence of mud, clay, organic and inorganic substance and

microscopic organisms. Turbidity of water is a very commonly used parameter to predict the water quality of both surfaces as well as groundwater.

The units of turbidity are nephelometric turbidity units (NTU) or Formazin turbidity units (FTU). If measured in NTU, nephelometric methods are utilized whereas for FTU, absorptometric methods are used. Turbidity-free water is generated by the filtration of the given water sample using a 0.2  $\mu\text{m}$  pore-sized membrane. Usually, Turbidity meters are used for calculation of Turbidity. Fig. 4.7 shows a typical turbidity meters used in the study.



Fig. 4.7 Turbidity meters used in the study

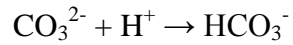
#### 4.6 Alkalinity by Titeration method

The buffering ability of water to neutralize strong acid is known as alkalinity. It is due to the bases present in natural water including  $\text{OH}^-$  and  $\text{HCO}_3^-$ .

Titration method is used to calculate the alkalinity of a solution. In this method, the solution is titrated with sulfuric acid or hydrochloric acid. The volume of the acid used in the titration can be used to calculate the alkalinity. This includes the following reactions:

For pH range above 8.3:





For pH range from 8.3 to 4.5



If the carbonate ( $\text{CO}_3^{2-}$ ) ion is present in the solution,  $\text{CO}_3^{2-}$  consumes one  $\text{H}^+$  when upon titration to pH 8.3, and another  $\text{H}^+$  during titration from pH 8.3 to pH 4.5. The alkalinity is then calculated as:

$$\begin{aligned} \text{Alkalinity} &= \text{Amount of acid used to reach pH 8.3 (ml)} * \text{Normality of acid (eq/L)} \\ &* 100,000 \text{ (mg CaCO}_3\text{/eq)} / \text{sample volume (ml)} \end{aligned}$$

where Normality =

Molarity (moles/L) \* the number of hydrogen exchanged in a reaction (eq/moles). Fig. 4.8 and 4.9 show the solution before and after titration respectively.



Fig.4.8 Solution before titration

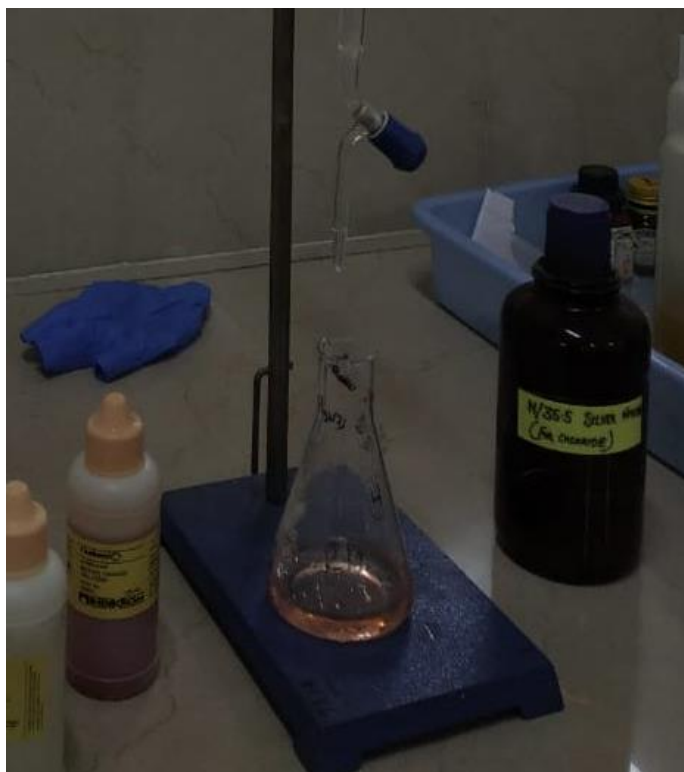
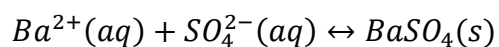


Fig. 4.9 Solution after titration

#### 4.7 Sulphate calculation by Gravimetric method

Gravimetric method is used for the calculation of Sulphate concentration. The sulfate ion in an aqueous solution has following reaction with barium:



$$K_{sp} = [\text{Ba}^{2+}][\text{SO}_4^{2-}]$$

Barium sulfate is extracted in the form of precipitate from the solution on a filter. Thereafter, it is washed, ignited and weighed. The amount of sulfate present in the original sample is calculated. Fig. 4.11 and 4.12 show the process of sulphate calculation by gravimetric method.

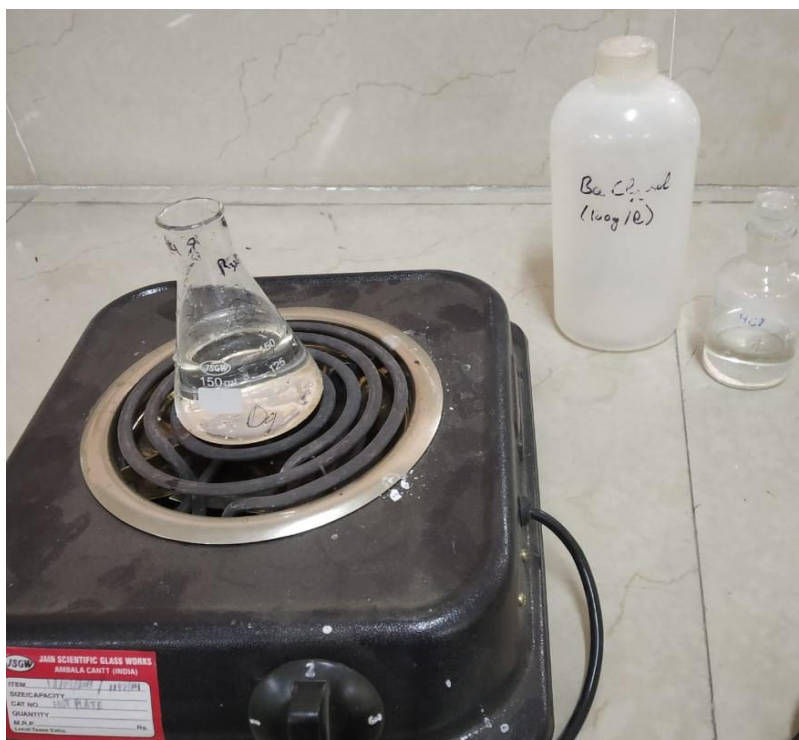


Fig. 4.10 Sulphate calculation by Gravimetric method (a)



Fig. 4.11 Sulphate calculation by Gravimetric method (b)

## 4.8 Total hardness using EDTA

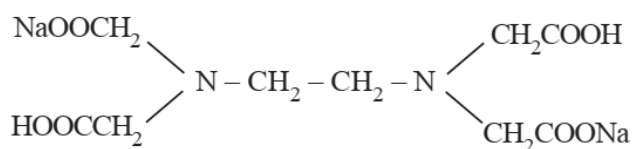
Water hardness is usually calculated as the ability of water to precipitate soap.

The hardness in a water sample is due to a composite combination of cations and anions (metallic ions) which can be calculated as the amount of CaCO<sub>3</sub> in mg/L. Table 4.1 shows the amount of CaCO<sub>3</sub> concentration for drinking water.

Table 4.1 Amount of CaCO<sub>3</sub> concentration for drinking water

Type	Amount of CaCO <sub>3</sub> in mg/L
Soft	0-60
Medium	60-120
Hard	120-180
Very hard	>180

In order to calculate the CaCO<sub>3</sub> concentration in a sample of hard water, Eriochrome Black T dye is added at pH value of ten. A wine red color appears due to the Ca<sub>2</sub><sup>+</sup> and Mg<sub>2</sub><sup>+</sup> ions. Thereafter, when titrated with EDTA, the solution changes its color back to blue which shows the endpoint of the reaction.



EDTA method has various advantages over other methods as it is more accurate, fast and convenient. Hardness is usually measured in parts per million (PPM), Milligram per liter (mg/L), Degree Clarke (°Cl) or Degree French (°Fr).

Procedure to calculate Permanent hardness

- Initially, a water sample of 250 ml is taken
- Water was boiled till 50ml is left from the solution
- Again the volume was increased to 250 ml by adding distilled water

- 2 ml of buffer solution was added to 50 ml of this solution
- Thereafter, the solution was titrated with EDTA.
- The volume used to obtain clear blue color was noted.

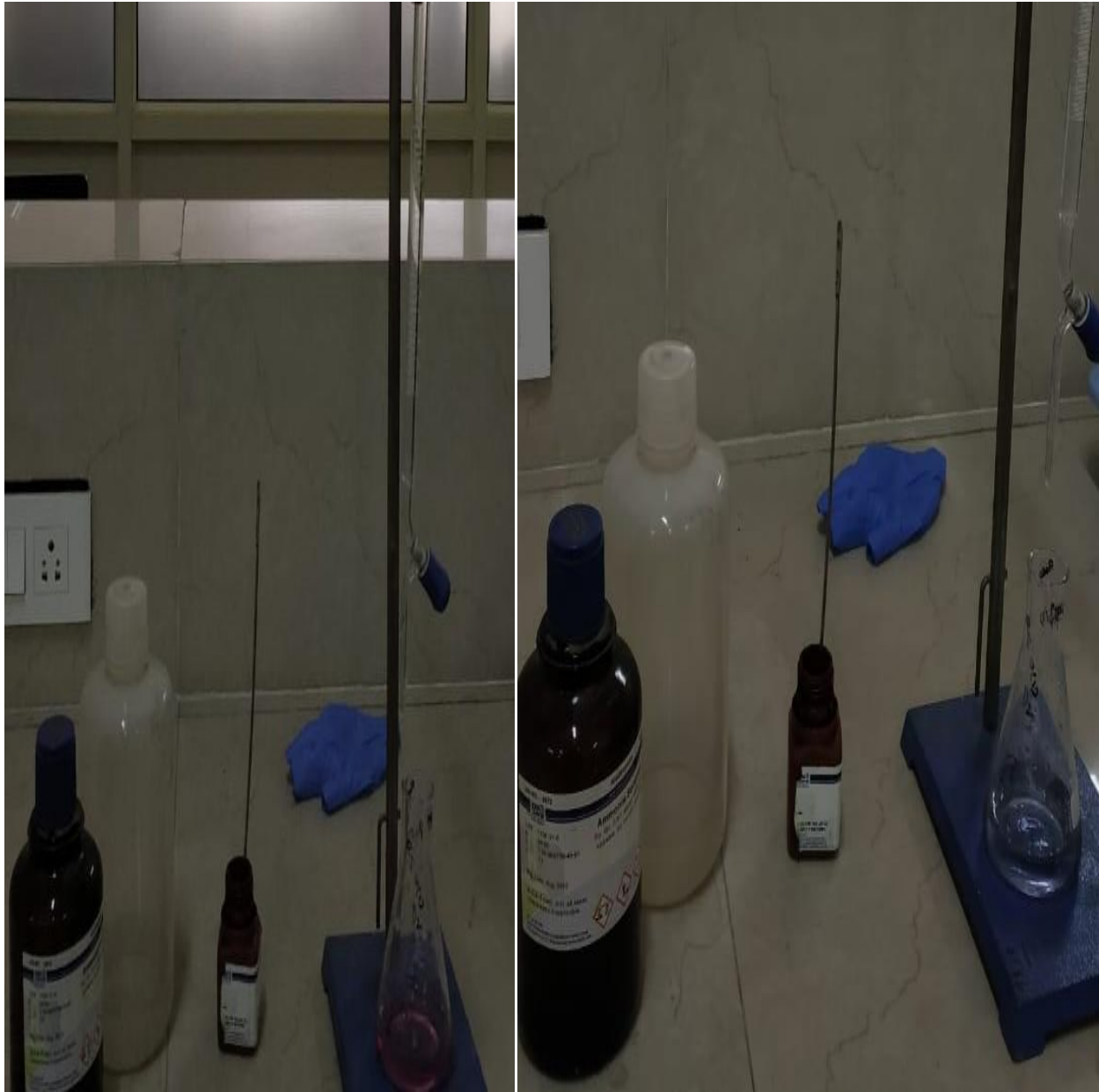


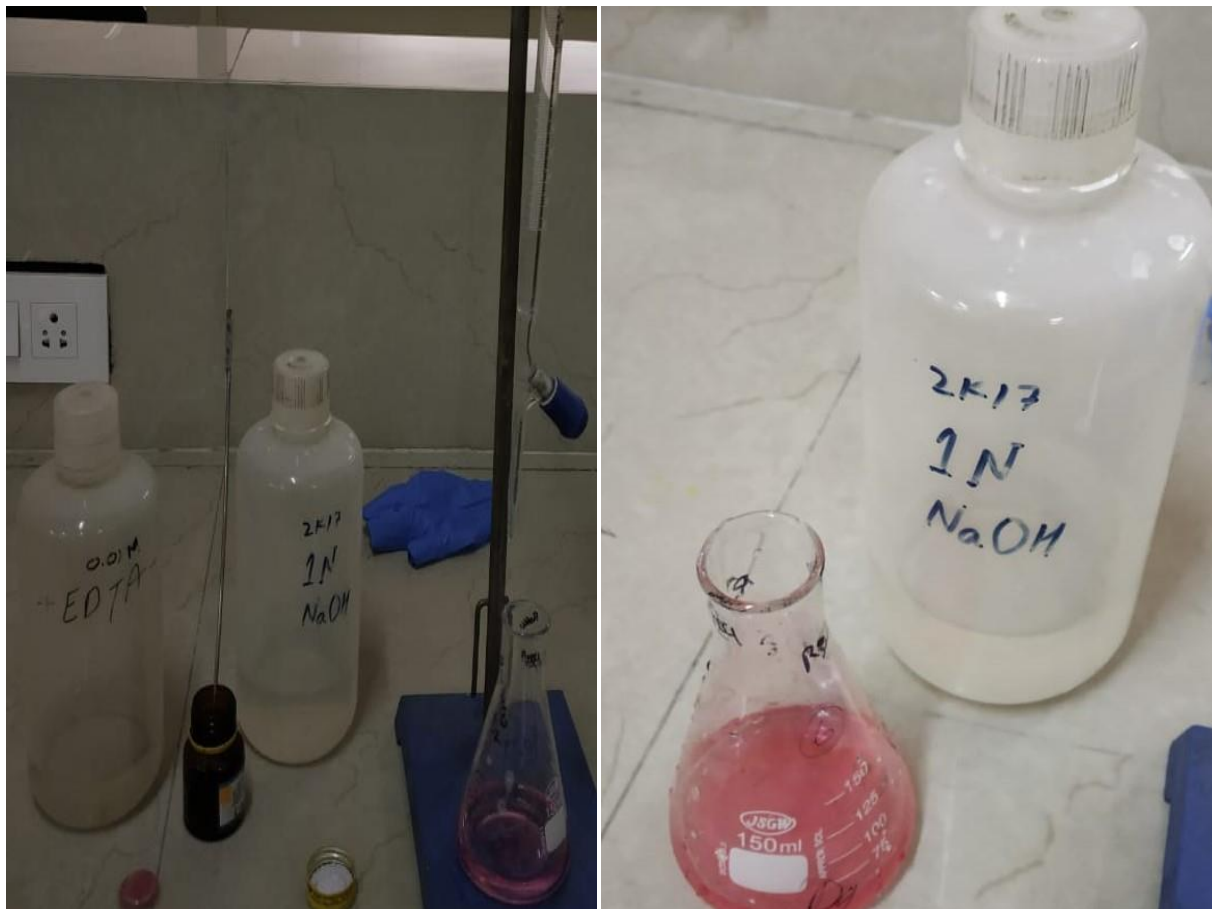
Fig. 4.12 (a) Solution before titration

(b) solution after titration

#### Procedure to calculate Calcium hardness

- To calculate Calcium hardness, 50 ml of the water sample is collected in a flask
- 1N NaOH is then mixed with the solution to increase the pH value.
- The solution was stirred after adding the murexide indicator
- Thereafter, the solution was titrated with EDTA.
- The volume used to convert red wine color to blue violet was noted.

Fig. 4.13 and 4.14 shows the solution before and after titration respectively for calculation of calcium hardness.



4.13 Solution before titration



Fig. 4.14 Solution after titration

### Concluding Remarks

In this chapter, different techniques and methods utilized to calculate physio-chemical characteristics of groundwater and leachate samples have been presented. These methods are very well known and accepted among the research fraternity. The results calculated from these techniques have been further presented in Chapter 5.

# CHAPTER 5

## RESULTS AND DISCUSSION

Various techniques used to calculate the parameters of wastewater from municipal waste on underground water are discussed in Chapter 4. Now, in Chapter 5, the results calculated from these techniques are presented. For this task, the concentration of water quality parameters is calculated for both contaminated underground water and leached water.

### 5.1 Results of Contaminated Underground Water

Fig. 5.1-5.8 shows the plots of different water quality parameters calculated from different locations at different time spans for contaminated underground water. These results show that some variables remain almost constant throughout while others vary drastically with the change in location.

It can be observed from Fig. 5.1 (a) that the values of pH vary between the ranges 6.9 to 8. The average pH value is 7.5. The graph of pH is very smooth and show very less variations. This can also be visualized from the standard deviation of pH which is calculated to be 0.23. The graph of TDS v/s location is shown in Fig. 5.1 (b). It shows a lot of fluctuations. The average value of TDS is found to be 880.1 whereas the maximum value is 1656 and minimum value is 324.4.

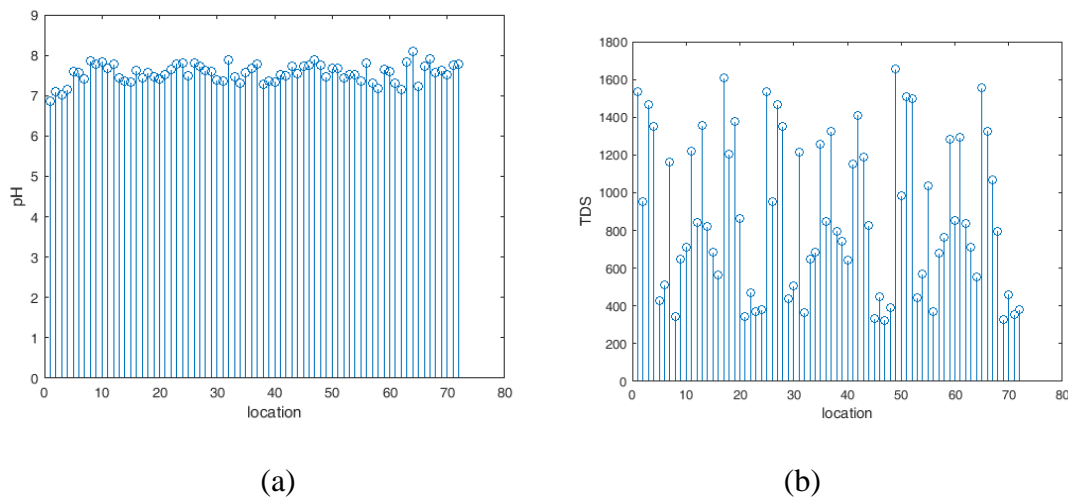
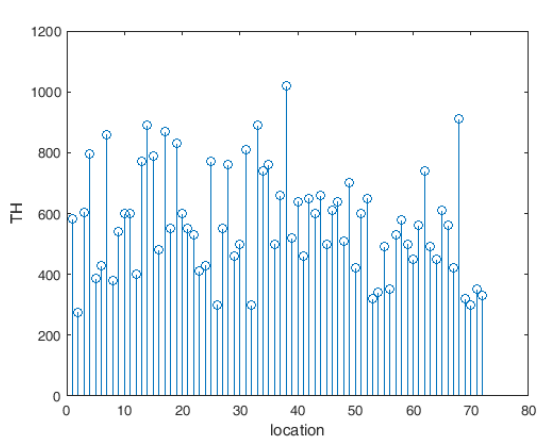
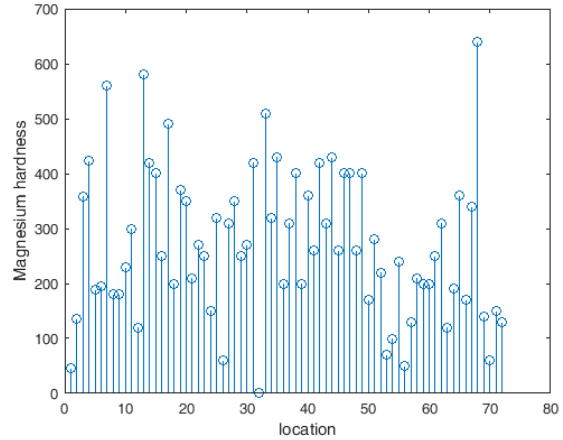


Fig. 5.1: Plot of (a) pH v/s location and (b) TDS v/s location



(a)



(b)

Fig. 5.2: Plot of (a) TH v/s location and (b) Magnesium Hardness v/s location

As in the case of Fig. 5.1, similar observations can be made in Fig. 5.2. Fig. 5.2 (a) shows the results of TH v/s location while the results of Magnesium Hardness v/s location are given in Fig. 5.2 (b). For TH, the average value is 568.5 whereas; the average for Magnesium hardness is 269.9. The standard deviations for TH and Magnesium hardness are 134.5 and 94.4 respectively. Fig. 5.3 shows the plot of Calcium hardness v/s location which shows 299.0, 80, 620 and 94.5 as the average, minimum, maximum and standard deviation values. It is important to note here that both TH and Magnesium Hardness show high standard deviations of 173.9 and 134.5. This shows that the values of TH and Magnesium Hardness vary rapidly from one location to other.

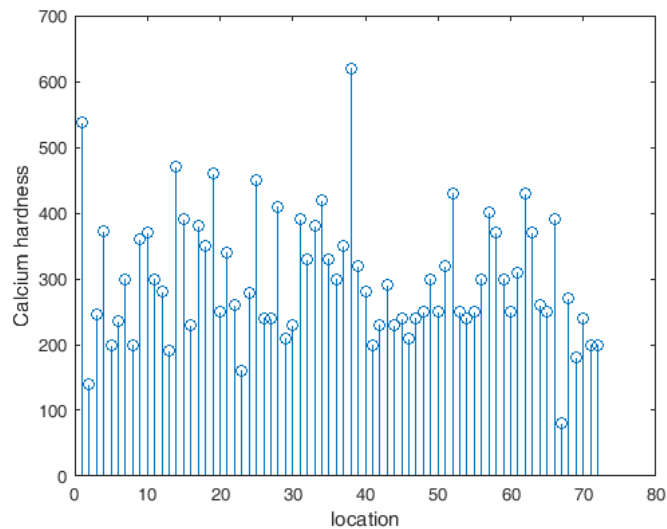


Fig. 5.3: Plot of Calcium hardness v/s location

Fig. 5.3 shows the plot of Calcium hardness v/s location which shows the results of 299.04, 80, 620, and 94.4 as their average minimum, maximum and standard deviation values. Calcium hardness also shows a higher value of standard deviation (94.4) which can also be visualized from the graph.

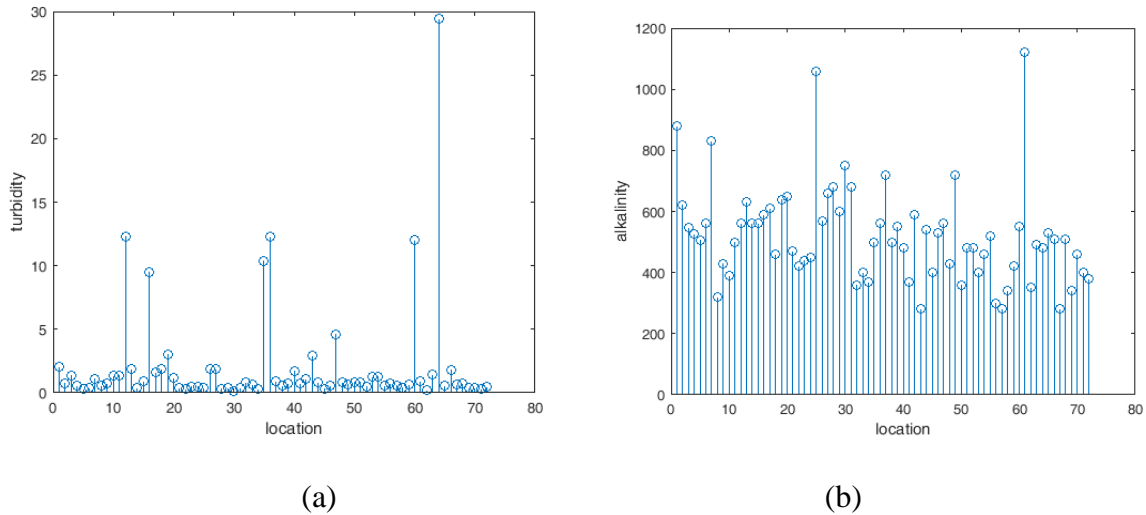
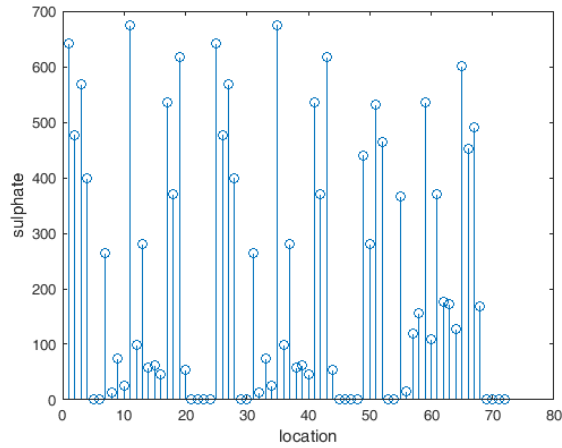


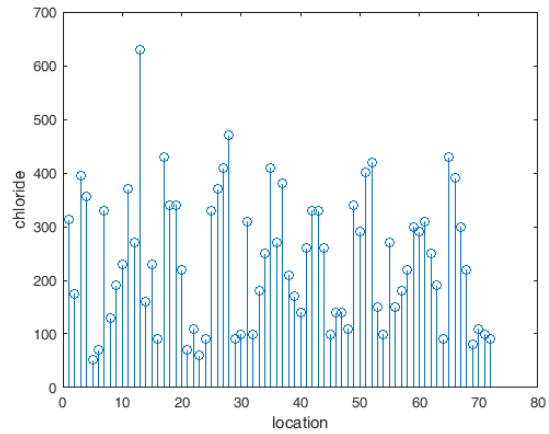
Fig. 5.4: Plot of (a) turbidity v/s location and (b) alkalinity v/s location

The results of turbidity v/s location and alkalinity v/s location are presented in Fig. 5.4 (a) and (b) respectively. It can be observed from Fig. 5.4 that, in the case of turbidity, the average value is 2.06 and it shows a standard deviation of 4.2. For alkalinity, the average and standard deviation are 520.1 and 158.7 respectively. So, alkalinity shows a much higher average values than turbidity as expected. The standard deviation in turbidity data is small (4.2) while alkalinity shows a high value of standard deviation (158.7) which can also be visualized from Fig. 5.4.

Fig. 5.5 (a) and 5.5 (b) shows the plots of sulphate v/s location and chloride v/s location respectively. In plot (a) for sulphate v/s location, the average value is 223.4 while it shows a high standard deviation of 231.7. The minimum value is 0 and maximum value was calculated to be 675.02. Similar trend can be visualized in Fig. 5.5 (b) in which the average value is calculated to be 238.6 while the minimum value is 52 with 630 as its highest value. The standard deviation for chloride is 124.4 which means that chloride values are fluctuating with locations.

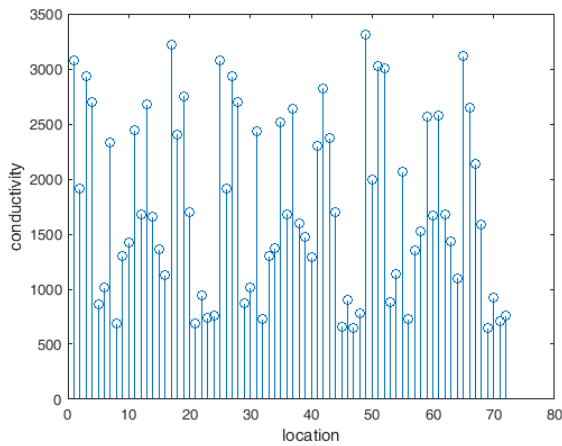


(a)

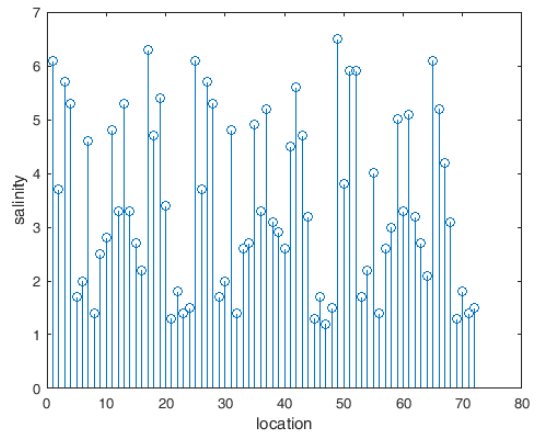


(b)

Fig. 5.5: Plot of (a) sulphate v/s location and (b) chloride v/s location



(a)



(b)

Fig. 5.6: Plot of (a) conductivity ( $\mu\text{s}/\text{cm}$ ) v/s location and (b) salinity (%) v/s location

Fig. 5.6 shows the plot of (a) conductivity v/s location and (b) salinity v/s location. The conductivity shows an average of 1759.533 while for salinity, the average is found to be 3.443056. The minimum value for the conductivity is 650.2 while the maximum value is 3314. Conductivity shows a very high standard deviation value of 823.67 which means that the results of conductivity from samples of different locations behave differently.

On the other hand, salinity shows a minimum value of 1.2 and maximum value of 6.5. the standard deviation is just 1.6 which shows that salinity does not vary much with change in locations.

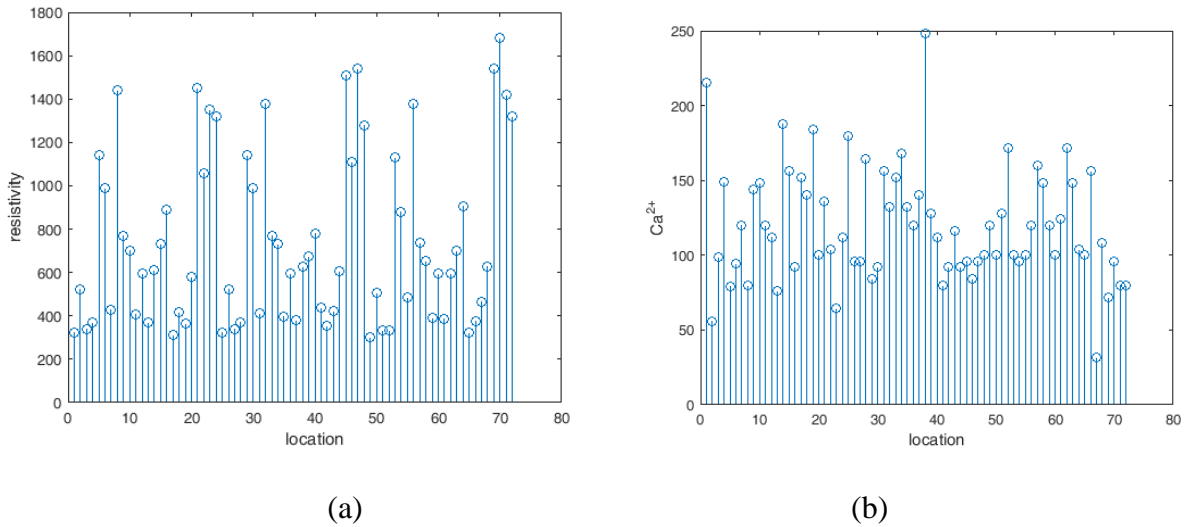


Fig. 5.7: Plot of (a) resistivity v/s location and (b) Ca<sup>2+</sup> v/s location

The results of resistivity v/s location and Ca<sup>2+</sup> v/s location are shown in Fig. 5.7. Average resistivity value is 739.3472 while Ca<sup>2+</sup> has average value of 119.6167. The maximum values of resistivity and Ca<sup>2+</sup> are 248 and 155.5 respectively. Fig. 5.8 shows the results of Mg<sup>2+</sup> v/s location which shows average values of 65.6 while the maximum and minimum values are 155.5 and 0.

Fig. 5.8 shows the results of Mg<sup>2+</sup> v/s location in which the average value is 65.6 while the minimum value is 0. It shows a maximum value of 155.5 and standard deviation of 32.7.

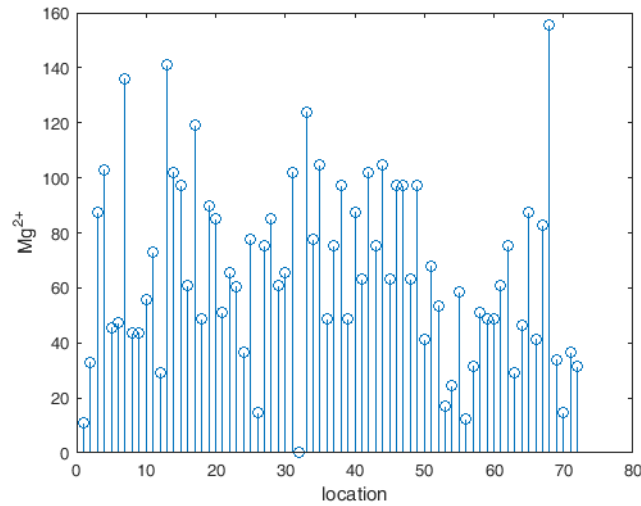


Fig. 5.8: Plot of  $Mg^{2+}$  v/s location

In order to calculate the relationship between these parameters, the correlation coefficients are calculated for contaminated underground water samples. The linear dependence between the parameters can be observed from these coefficients.

The Pearson correlation coefficient is mathematically calculated as:

$$\rho(X, Y) = \frac{1}{N - 1} \sum_{i=1}^N \left( \frac{X_i - \mu_X}{\sigma_X} \right) \left( \frac{Y_i - \mu_Y}{\sigma_Y} \right)$$

where  $\mu_X$  and  $\sigma_X$  are the mean and standard deviation of the first data variable  $X$  and  $\mu_Y$  and  $\sigma_Y$  are the mean and standard deviation of the second data variable  $Y$ .  $N$  is taken to be the number of observations. This formula can be generalized for any number of data variables. Otherwise, the correlation coefficients can also be calculated in terms of covariance of  $X$  and  $Y$  as:

$$\rho(X, Y) = \frac{cov(X, Y)}{\sigma_X \sigma_Y}$$

Table 5.1 various statistical parameters of contaminated underground water

	Average	Minimum	Maximum	Standard deviation
pH	7.5525	6.86	8.09	0.232177
TDS	880.1056	324.4	1656	411.8377
TH	568.5736	276	1020	173.9385
Magnesium hardness	269.9486	0	640	134.504
Calcium hardness	299.0417	80	620	94.48786
Turbidity	2.061111	0.17	29.4	4.280647
Alkalinity	520.1667	280	1120	158.7528
Sulphate	223.4918	0	675.024	231.709
Chloride	238.6389	52	630	124.4986
Conductivity	1759.533	650.2	3314	823.6733
Salinity	3.443056	1.2	6.5	1.624272
Resistivity	739.3472	302	1680	397.8511
Ca <sup>2+</sup>	119.6167	32	248	37.79514
Mg <sup>2+</sup>	65.62991	0	155.5968	32.70062

Table 5.2 shows the correlation coefficients of different parameters calculated from tests. The correlation coefficient matrix given in Table 5.2 gives the values of correlation coefficients. An interesting observation from Table 5.2 is that all the diagonal values are unity. The matrix for two variables A and B can be represented as:

$$R = \begin{pmatrix} \rho(A, A) & \rho(A, B) \\ \rho(B, A) & \rho(B, B) \end{pmatrix}$$

where  $\rho(A, A)$  and  $\rho(A, B)$  gives the correlation of variable A with A and A with B respectively.

As A and B are always correlated to themselves, the diagonal entries are 1. Therefore,

$$R = \begin{pmatrix} 1 & \rho(A, B) \\ \rho(B, A) & 1 \end{pmatrix}$$

Table 5.2: correlation coefficients of data for contaminated underground water

	Ph	TDS	TH	Mg Hardness	CaHardness	turbidity	Alkalinity	Sulphate	Chloride	conductivity	salinity	resistivity	Ca <sup>2+</sup>	Mg <sup>2+</sup>
pH	1	-0.4	-0.2	-0.4	0.3	-0.3	-0.3	-0.3	-0.4	-0.4	0.4	-0.4	-0.2	1
TDS	-0.4	1	0.8	0.6	-0.1	0.3	0.3	0.5	0.5	0.5	-0.5	0.6	0.8	-0.4
TH	-0.2	0.8	1	0.1	-0.1	0.3	0.2	0.4	0.4	0.4	-0.4	0.1	1	-0.2
Mg Hardness	-0.4	0.6	0.1	1	-0.1	0.2	0.2	0.3	0.3	0.3	-0.4	1	0.1	-0.4
CaHardness	0.3	-0.1	-0.1	-0.1	1	0	0	0	0	0	0	-0.1	-0.1	0.3
Turbidity	-0.3	0.3	0.3	0.2	0	1	0.3	0.3	0.5	0.5	-0.4	0.2	0.3	-0.3
Alkalinity	-0.3	0.3	0.2	0.2	0	0.3	1	0.8	0.9	0.9	-0.8	0.2	0.2	-0.3
Sulphate	-0.3	0.5	0.4	0.3	0	0.3	0.8	1	0.9	0.9	-0.8	0.3	0.4	-0.3
Chloride	-0.4	0.5	0.4	0.3	0	0.5	0.9	0.9	1	1	-0.9	0.3	0.4	-0.4
Conductivity	-0.4	0.5	0.4	0.3	0	0.5	0.9	0.9	1	1	-0.9	0.3	0.4	-0.4
salinity	0.4	-0.5	-0.4	-0.4	0	-0.4	-0.8	-0.8	-0.9	-0.9	1	-0.4	-0.4	0.4
resistivity	-0.4	0.6	0.1	1	-0.1	0.2	0.2	0.3	0.3	0.3	-0.4	1	0.1	-0.4
Ca <sup>2+</sup>	-0.2	0.8	1	0.1	-0.1	0.3	0.2	0.4	0.4	0.4	-0.4	0.1	1	-0.2
Mg <sup>2+</sup>	1	-0.4	-0.2	-0.4	0.3	-0.3	-0.3	-0.3	-0.4	-0.4	0.4	-0.4	-0.2	1

Now, in order to get more detailed results, the correlation plots of data variables are shown. It is observed from Fig. 5.9 that TDS v/s pH graphs show very low correlations i.e. -0.386. Negative correlation means that the two variables are moving in opposite directions. This shows that pH and TDS are almost uncorrelated from each other.

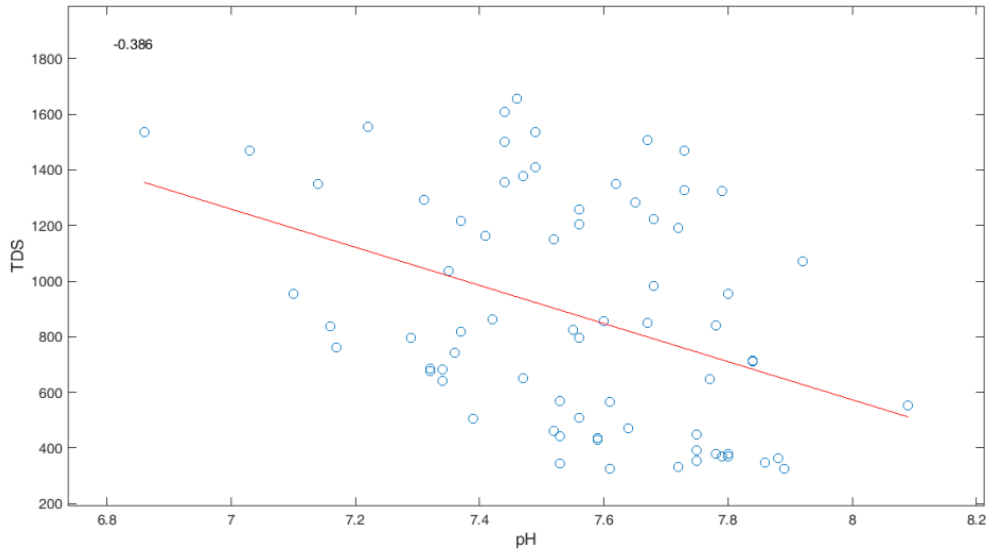


Fig. 5.9: Correlation plot between pH and TDS

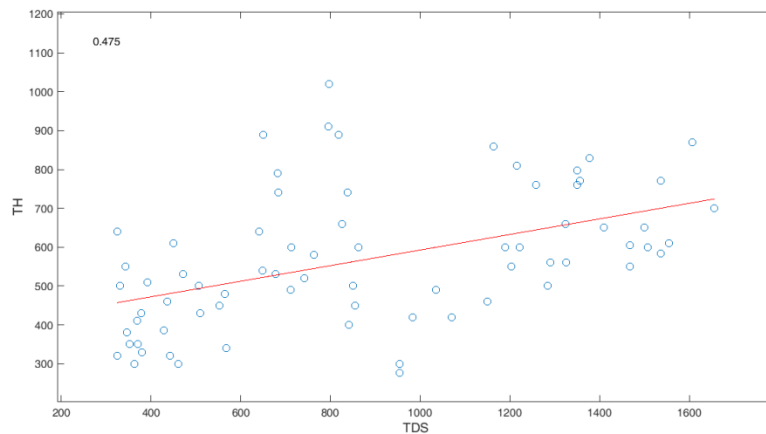


Fig. 5.10: Correlation plot between TDS and TH

Fig. 5.10 shows the correlation plots between TH & TDS. The correlation between TH and TDS is 0.47. This can also be visualized from the scatter plots of Fig. 5.10. The data in 5.10 is scattered thus having lower correlation.

Fig. 5.11 shows the correlation plot between Magnesium Hardness and TH with 0.843 as the correlation. The dots in scatter plot are very confined towards the slopes of the least-squares reference lines which also show high correlation between Magnesium Hardness and TH. In Fig. 5.12, Magnesium Hardness and Calcium Hardness show very low correlation of 0.11, thus showing no correlation between Magnesium Hardness and Calcium Hardness.

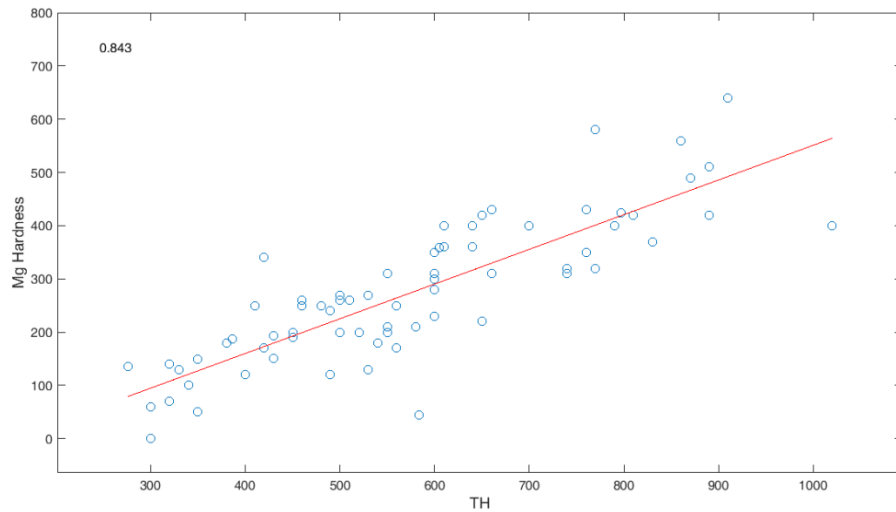


Fig. 5.11: Correlation plot between Magnesium Hardness and TH

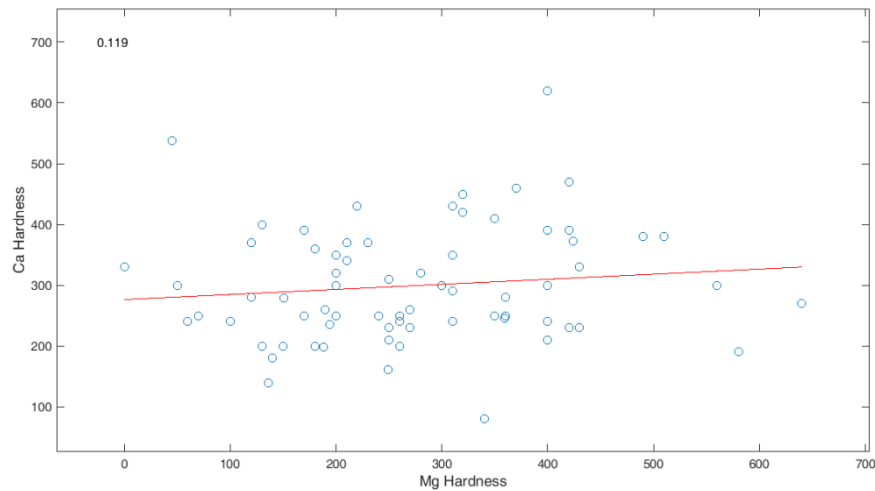


Fig. 5.12: Correlation plot between Magnesium Hardness and Calcium Hardness

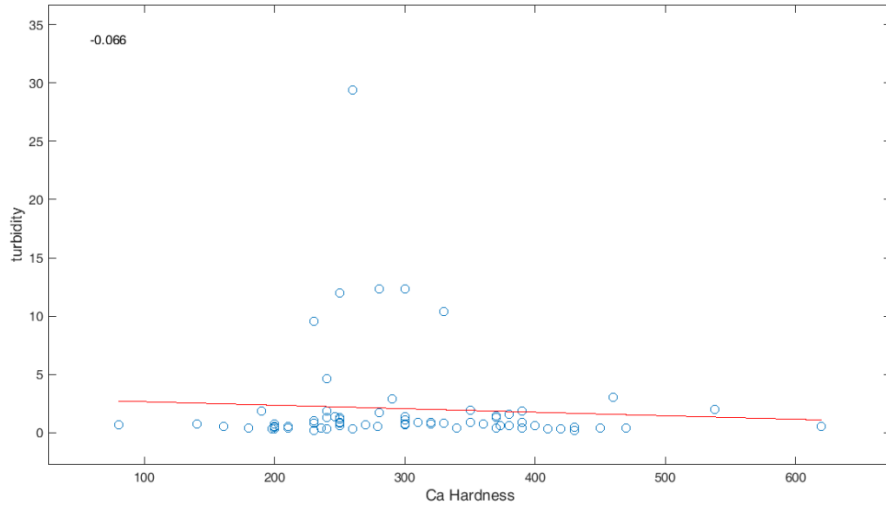


Fig. 5.13: Correlation plot between turbidity and Calcium hardness

The correlation graph shown between turbidity and Calcium hardness in Fig. 5.13 show very low correlation value of -0.06 which shows their non-dependence on each other. Fig. 5.14 shows the correlation graph between alkalinity and turbidity with 0.03 as the correlation value. Therefore, alkalinity is found to be uncorrelated from turbidity.

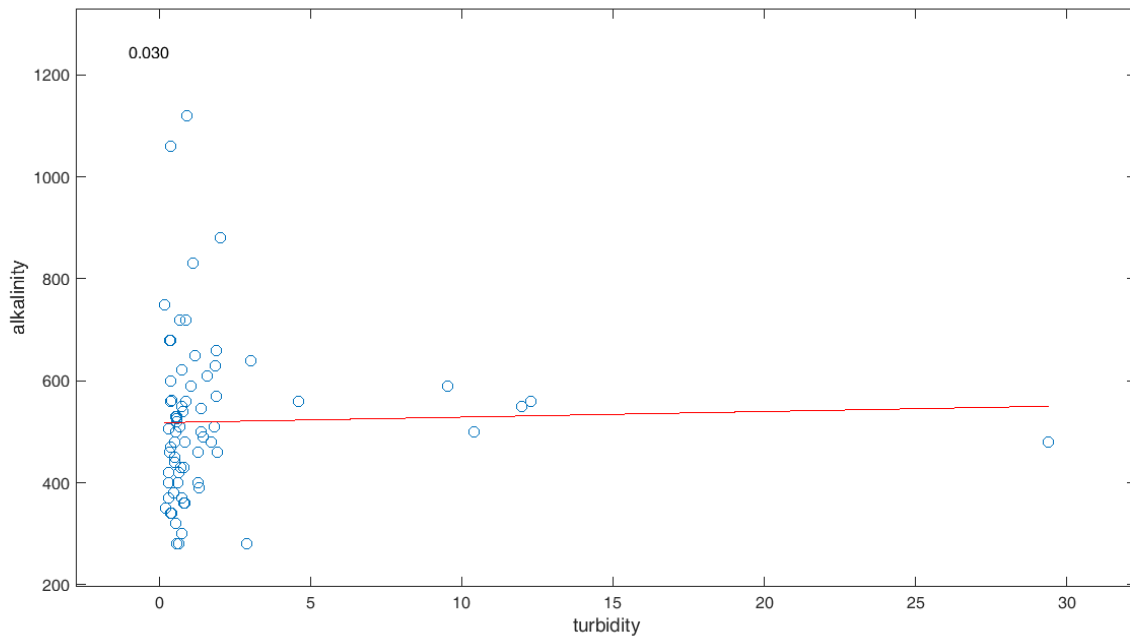


Fig. 5.14: Correlation plot between alkalinity and turbidity

Fig. 5.15 presents the correlation graph of sulphate and alkalinity which show low value of correlation (0.32). The correlation graph between chloride and sulphate given in Fig. 5.16 shows a high correlation of 0.79.

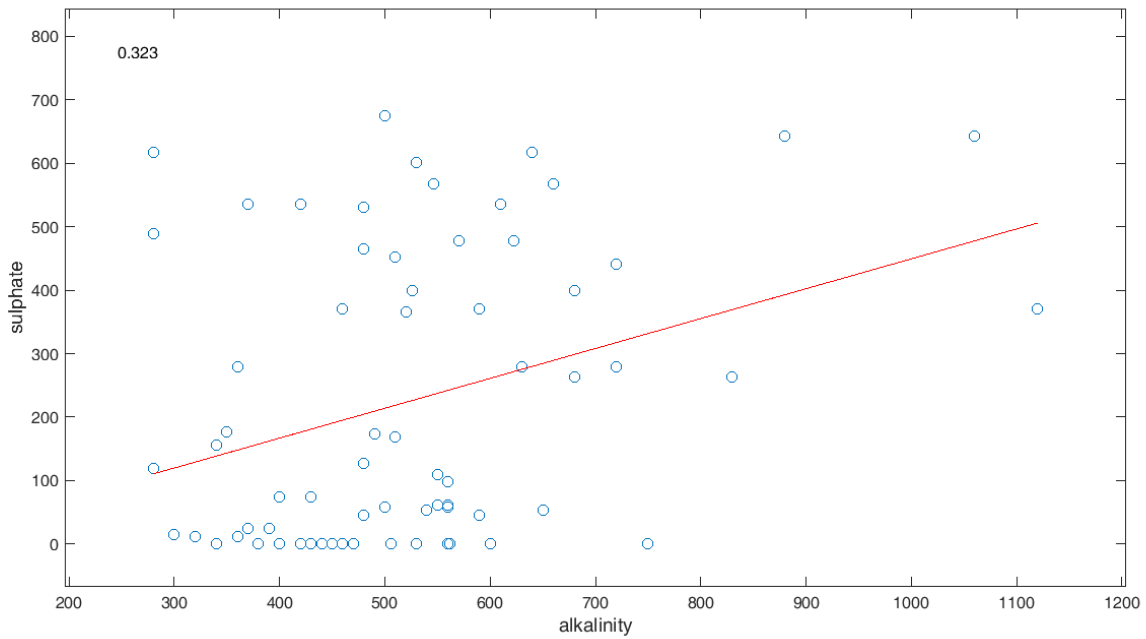


Fig. 5.15: Correlation plot between sulphate and alkalinity

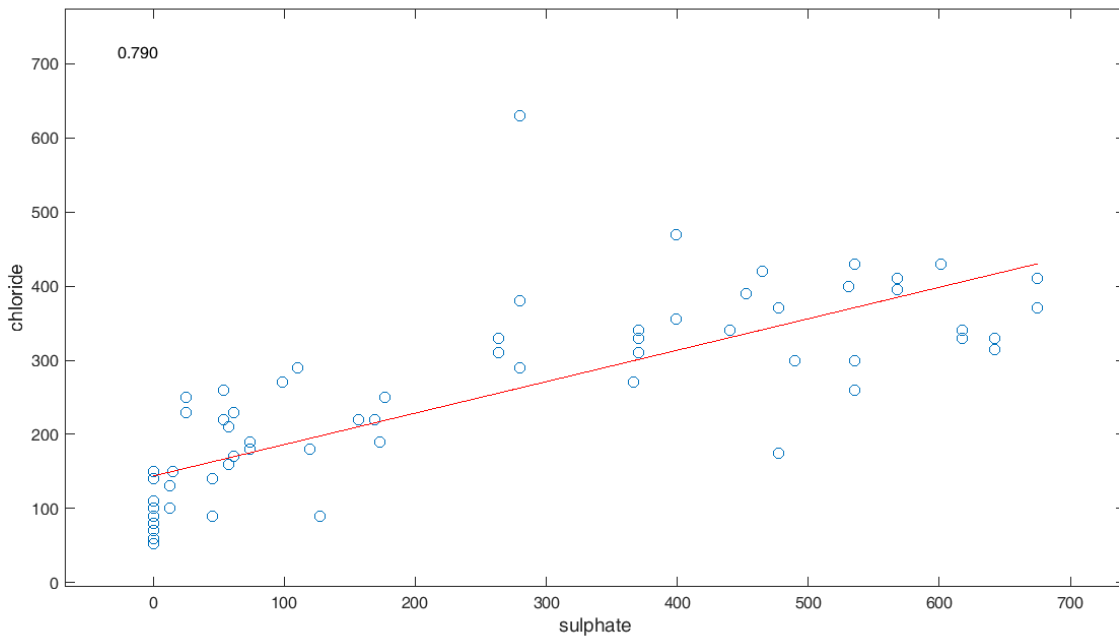


Fig. 5.16: Correlation plot between chloride and sulphate

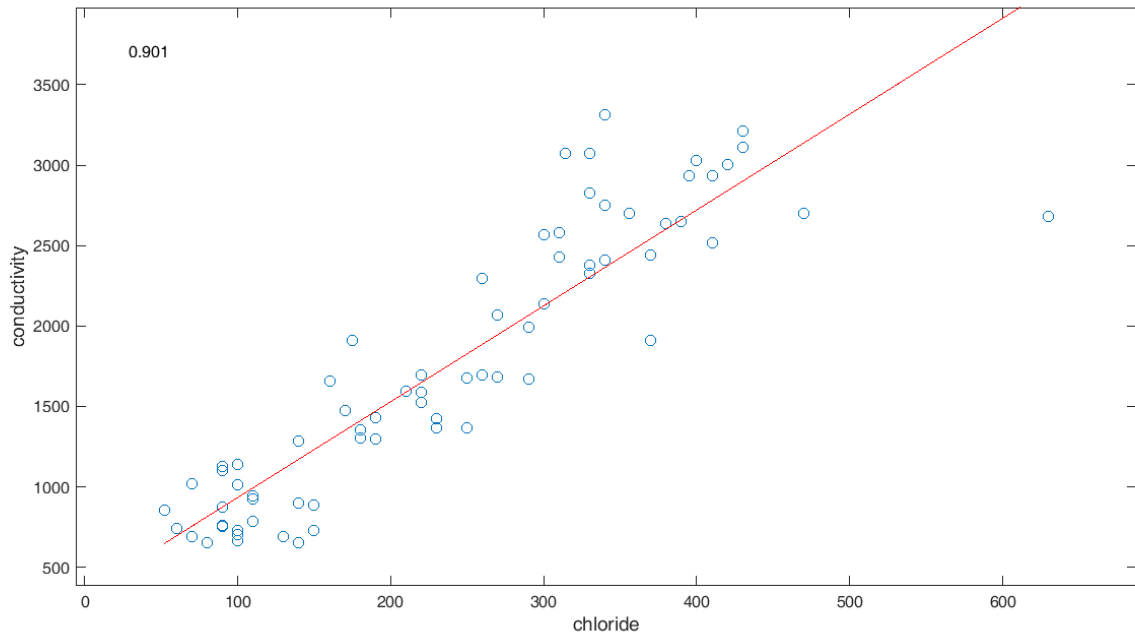


Fig. 5.17: Correlation plot between conductivity and chloride

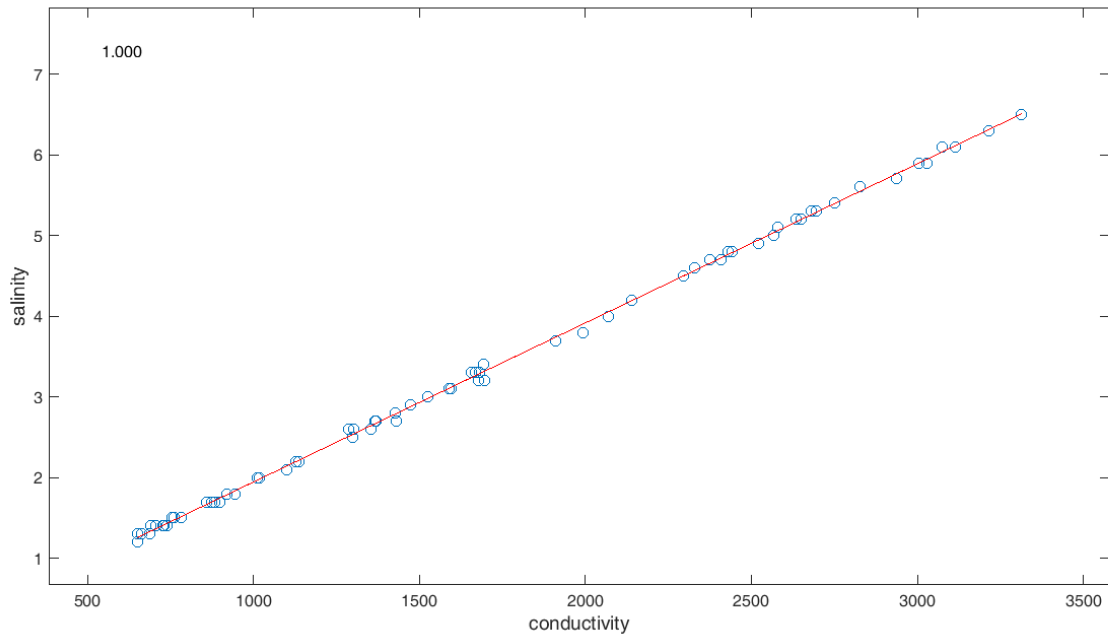


Fig. 5.18: Correlation plot between salinity and conductivity

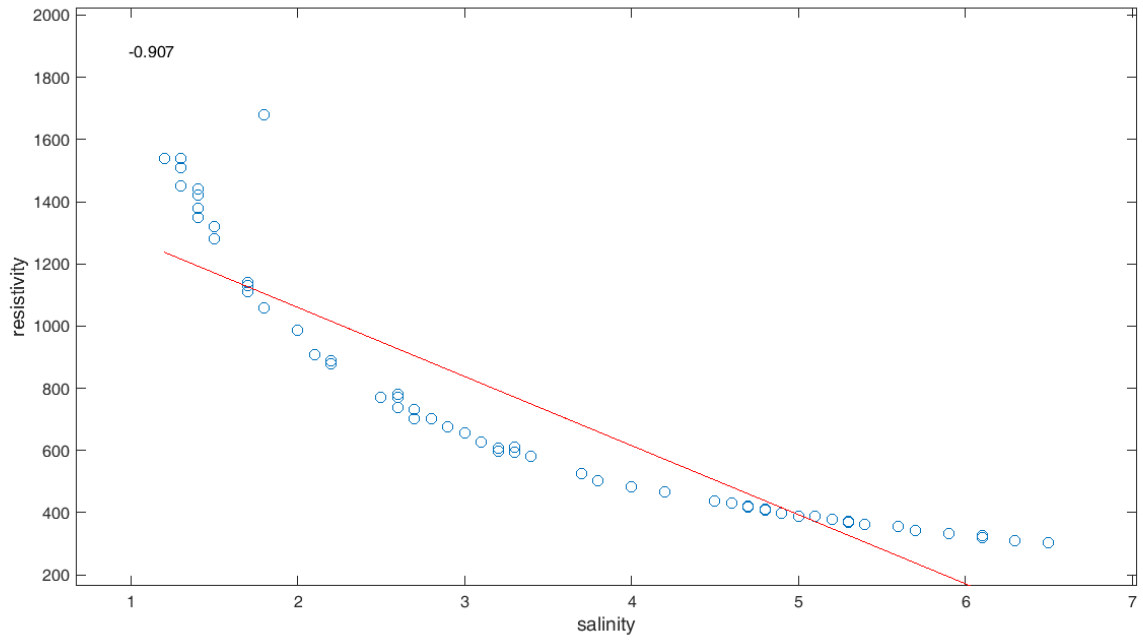


Fig. 5.19: Correlation plot between resistivity and salinity

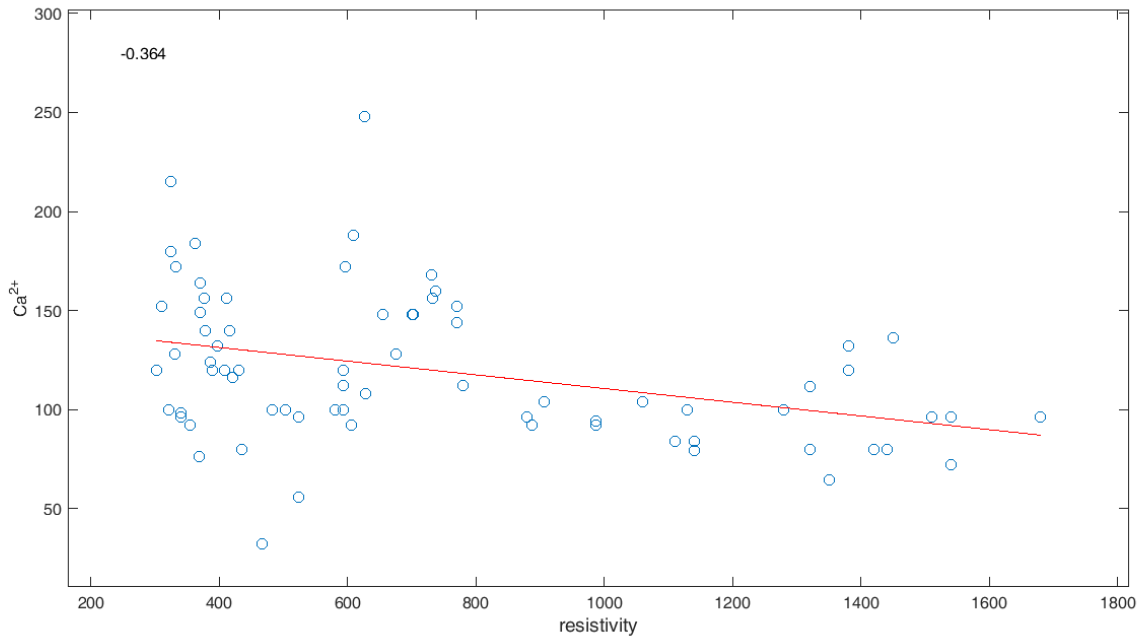


Fig. 5.20: Correlation plot between  $\text{Ca}^{2+}$  and resistivity

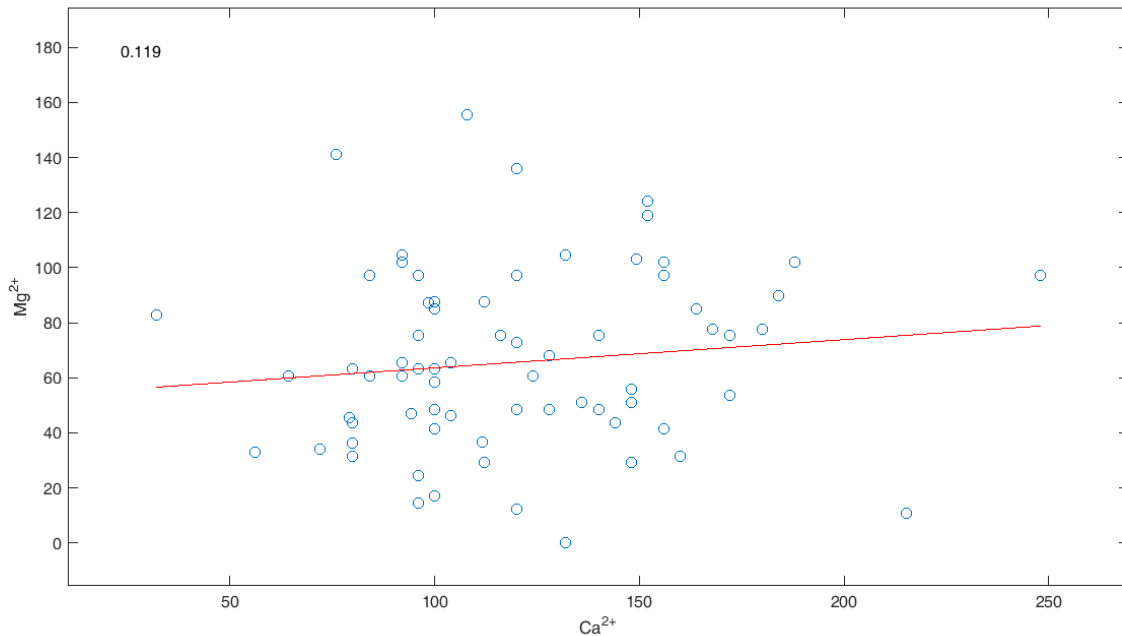


Fig. 5.21: Correlation plot between Ca<sup>2+</sup> and Mg<sup>2+</sup>

Fig. 5.17 – 5.21 shows the correlation plots of other physio-chemical parameters. The correlation between resistivity and salinity in Fig. 5.19 is found to be -0.907 which shows they are negatively correlated with each other. Apart from this, conductivity v/s chloride, chloride and sulphate and salinity v/s conductivity also show high correlation with each other.

The correlation values from Fig. 5.9 – Fig. 5.15 are used to calculate the relative dependence of the parameters on each other. The plots are in form of matrix which shows the correlation among pair of variables. The diagonal elements show the histograms of variables whereas, the scatter plots of variables are shown in the off-diagonal elements. The slopes of the least-squares reference lines are given in both the scatter plots. The graph in which the data (shown by scattered dots) lies around the pink line shows high correlation.

For example, Fig. 5.10 (b), 5.13 and 5.14 (a) show high correlation values. The plot in Fig. 5.10 (b) between TH and Magnesium hardness show a correlation of 0.84 and hence these two variables are correlated. Other graphs like salinity and resistivity; conductivity and salinity; & chloride and conductivity also show higher correlations.

## 5.2 Results of Leachate Data

Now, the results of leachate data are presented. These results are calculated from various physico-chemical parameters of leachate samples. The plots of these physico-chemical parameters v/s locations are plotted to visualize their variations with the location. Correlation coefficients are calculated between different parameters. Further, the correlation graphs are plotted to get a deeper insight into the results. Thereafter, the average, minimum, maximum and standard deviation is also calculated.

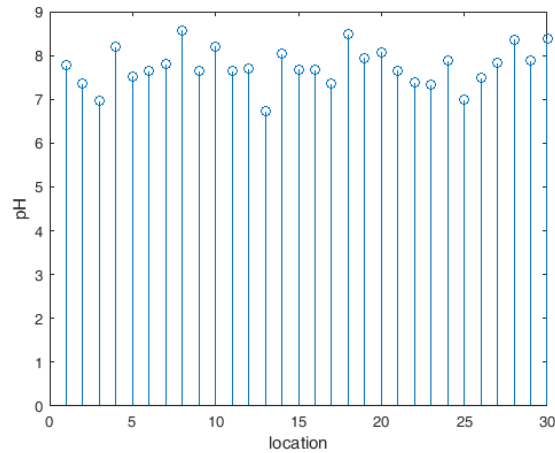


Fig. 5.16: Plot of (a) pH v/s location

The results of pH v/s location are plotted in Fig. 5.16. It can be observed from Fig. 5.16 that the maximum value of pH is 8.5 and minimum value is 6.7. It shows a standard deviation of 0.44. The value of pH for clean water is calculated to be 8.46 which is close to the calculated values.

The graph of TDS v/s location is shown in Fig. 5.17 (a). It shows a lot of fluctuations with a high standard deviation of 514.6771. The average value of TDS is found to be 1371.6 which was only 880.1 for water sample. The maximum value is 2544 which was 1656 for water samples and minimum value is 774.3 which was 324.4 for water sample. The value of TDS calculated for clean water is 355.6. Even the minimum value of TDS calculated from leachate samples is much higher than the TDS of clean water. The plot of TH v/s location is presented in Fig. 5.17 (b). the value of TH for clean water is 280 while the average value of TH from leachate samples is calculated to be 634.66. The maximum and minimum values are reported to be 970 and 300 respectively. A high standard deviation of 143.3 is observed in this data.

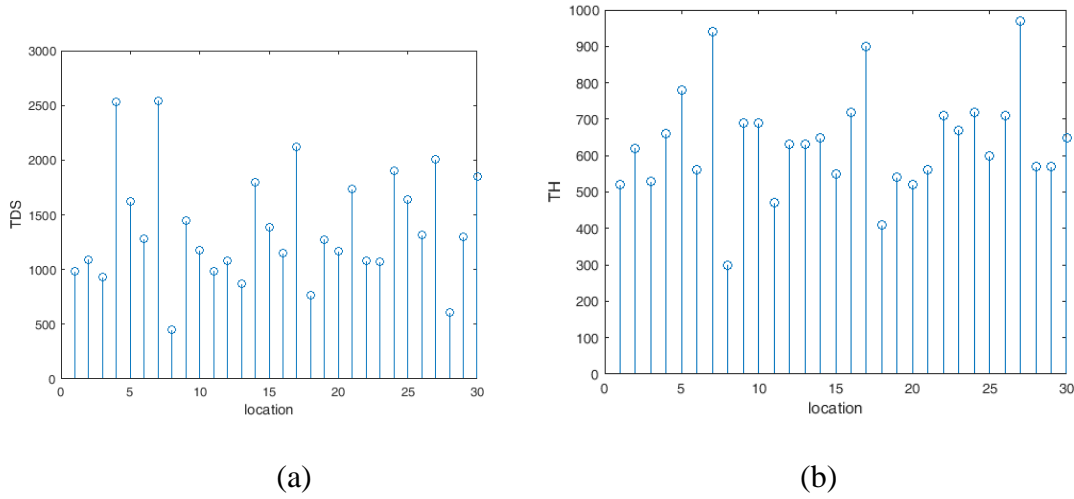


Fig. 5.17: Plot of (a) TDS (ppm) v/s location and (b) TH v/s location

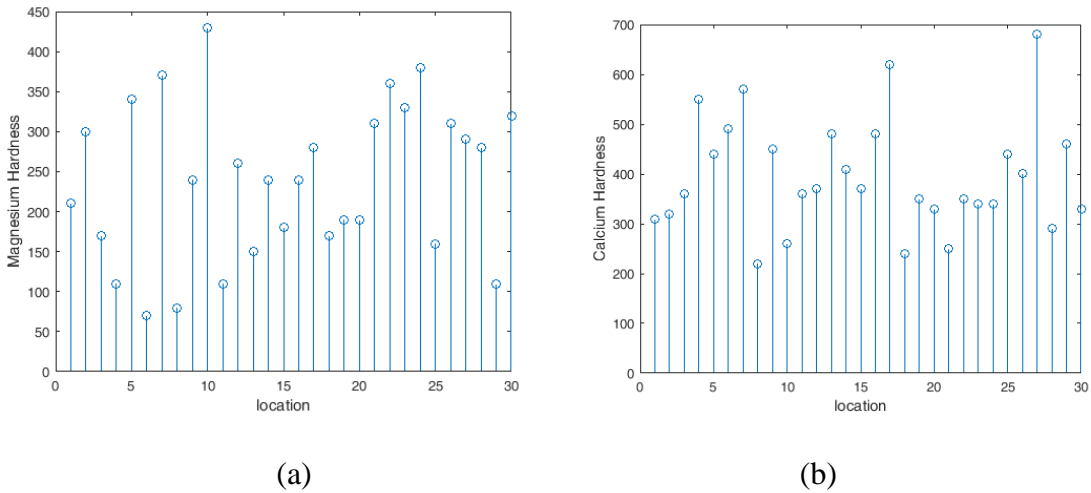
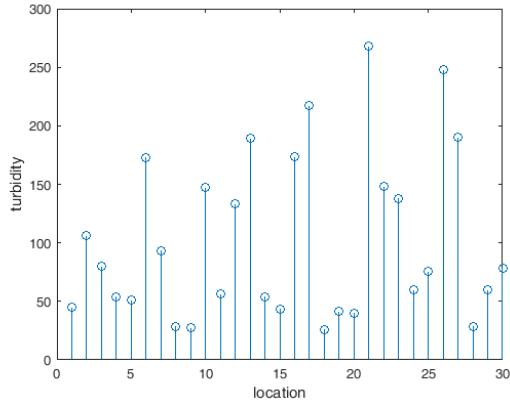
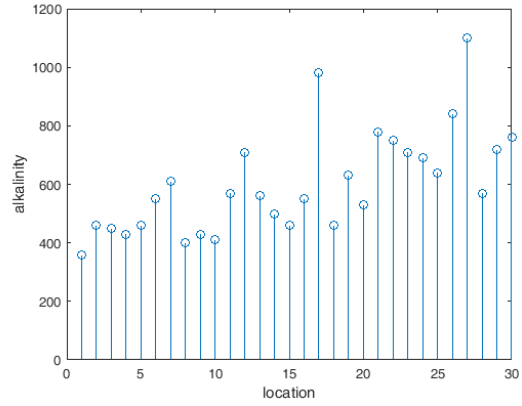


Fig. 5.18: Plot of (a) Magnesium Hardness v/s location and (b) Calcium Hardness v/s location

The plots of Magnesium Hardness v/s location and Calcium Hardness v/s location are shown in Fig. 5.18 (a) and (b) respectively. For the case of Magnesium Hardness v/s location, the maximum value is calculated to be 430 while the minimum value is 70. It shows a high standard deviation of 96.4. The value of Magnesium Hardness for clean water is calculated to be 160 which is very low than the average value of 239.3. For the case of Calcium Hardness v/s location, the value of Calcium Hardness for clean water is 120 while the average value calculated from the leachate samples is calculated to be 395.3. It shows a high standard deviation of 111.65.

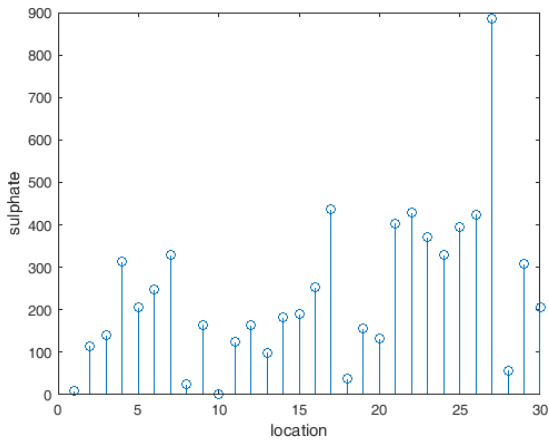


(a)

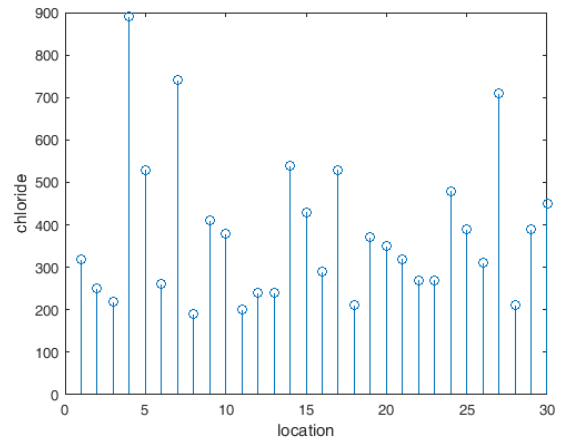


(b)

Fig. 5.19: Plot of (a) turbidity v/s location and (b) alkalinity v/s location



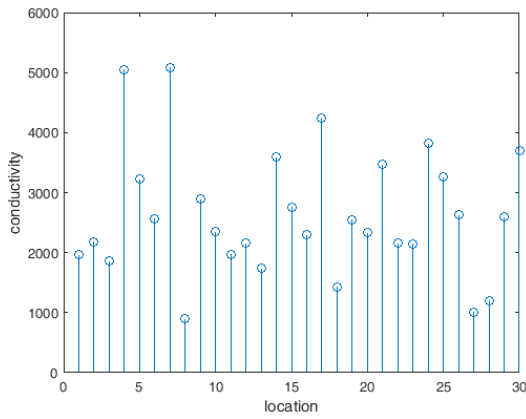
(a)



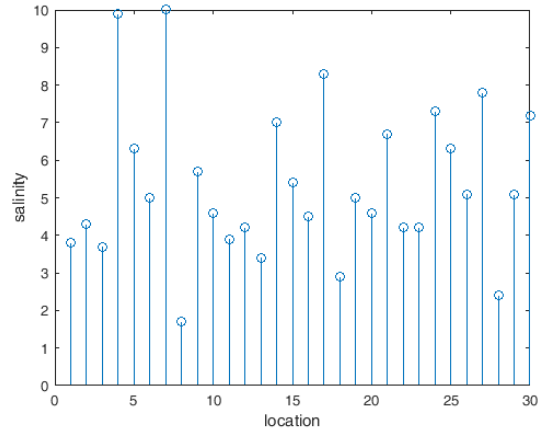
(b)

Fig. 5.20: Plot of (a) sulphate v/s location and (b) chloride v/s location

The results of turbidity v/s location and alkalinity v/s location are shown in Fig. 5.19 (a) and (b) respectively. For the case of turbidity, the value calculated for clean water is 2.02 while the leachate samples show a much higher average value of 102.52. The minimum value is calculated to be 26.2 for leachate samples. For the case of alkalinity v/s location, the value for simple water is 370 while the average value for leachate sample is calculated to be 602.3.

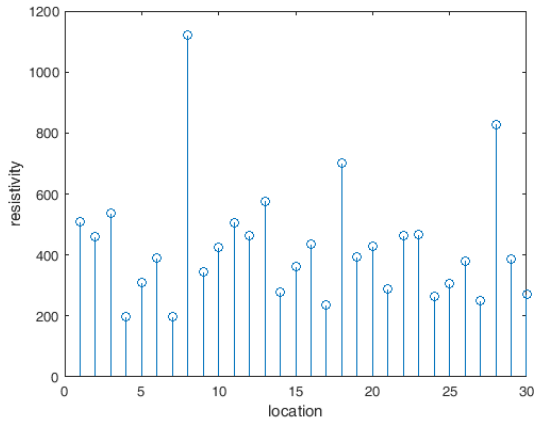


(a)

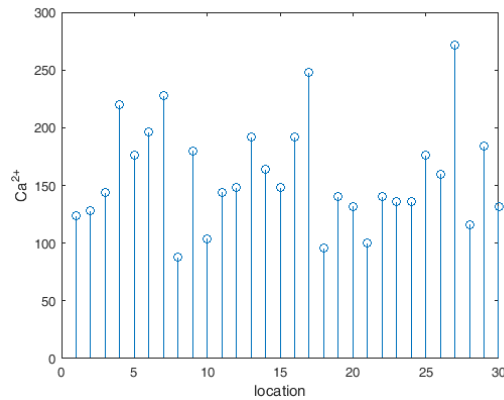


(b)

Fig. 5.21: Plot of (a) conductivity ( $\mu\text{s}/\text{cm}$ ) v/s location and (b) salinity (%) v/s location



(a)



(b)

Fig. 5.22: Plot of (a) resistivity v/s location and (b)  $\text{Ca}^{2+}$  v/s location

The results of conductivity ( $\mu\text{s}/\text{cm}$ ) v/s location and salinity (%) v/s location are shown in Fig. 5.21. It can be visualized from the Fig. 5.21 that the average value of conductivity is calculated to be 2639.3 which for clean water is just 1.4. On the other hand, for salinity, the average value for leachate sample is 5.3 while for clean water is 1.4. This shows the extent of contamination generated due to leachate.

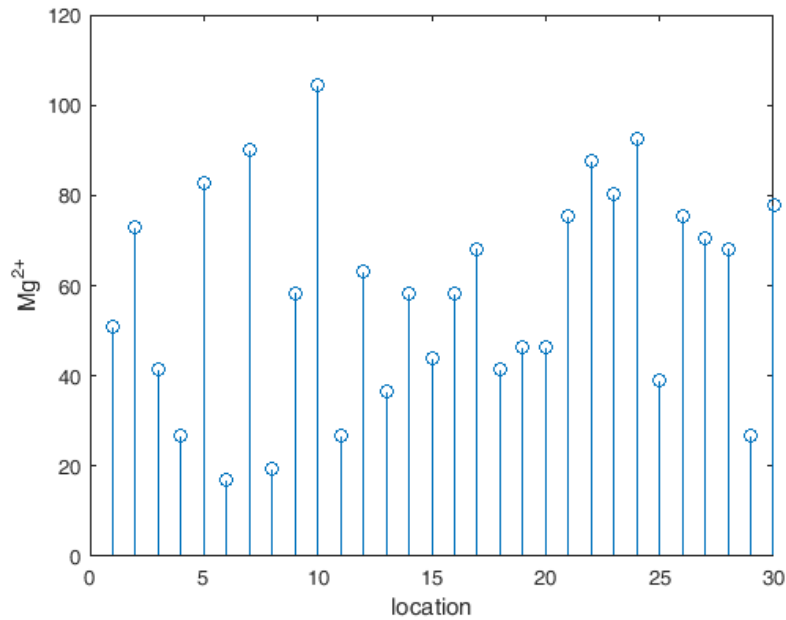


Fig. 5.23: Plot of Mg<sup>2+</sup> v/s location

Fig. 5.23 shows the plot of Mg<sup>2+</sup> v/s location for which the average value is 58.1 while the value of Mg<sup>2+</sup> calculated for clean water is 38.89. Similar inference like the one drawn from the contaminated groundwater case in Fig. 1-8 can be drawn from Fig. 16-23. In order to get a deeper insight into the variations, Table 5.3 shows the Average, Minimum, Maximum and Standard deviation values of leachate data with timing. The corresponding values of clean water are also provided. Table 5.4 presents the correlation coefficients for leachate data. The first sample in this dataset is simple water i.e. the clean water which was used for creating artificial rainfall. The results of other samples can be compared with this clean water sample.

Now, the results in the form of correlation graphs between different variables are shown in Fig. 5.24-5.36.

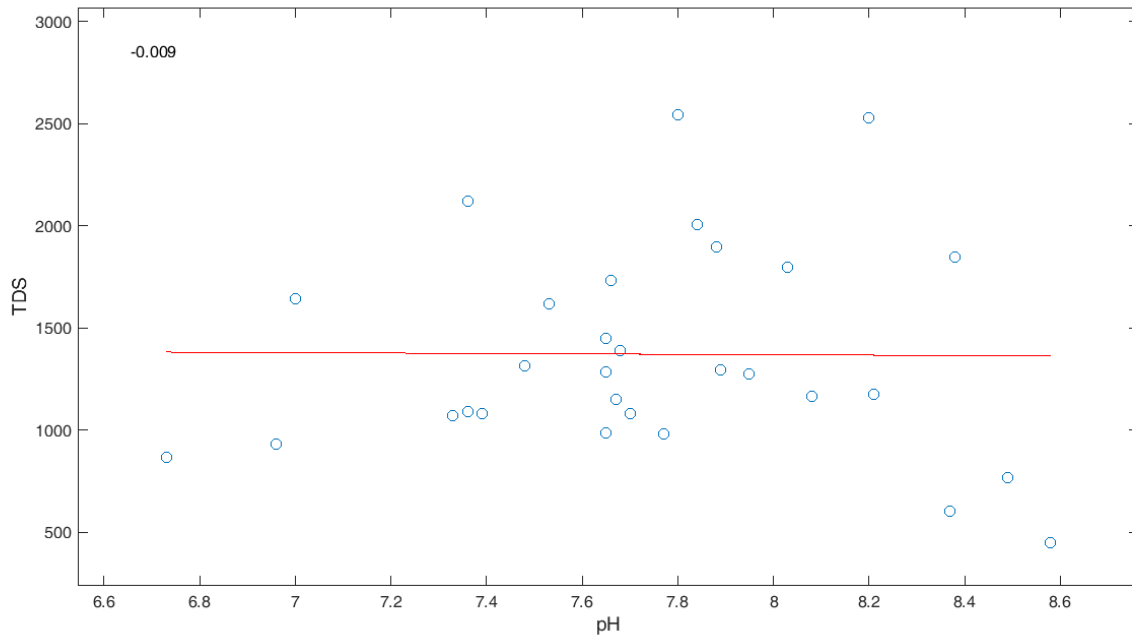


Fig. 5.24: Correlation plot between pH and TDS

It is observed from Fig. 5.24 that TDS and pH are uncorrelated variables as the correlation coefficient is -0.009. This shows that the values of pH do not depend on the TDS values of the samples.

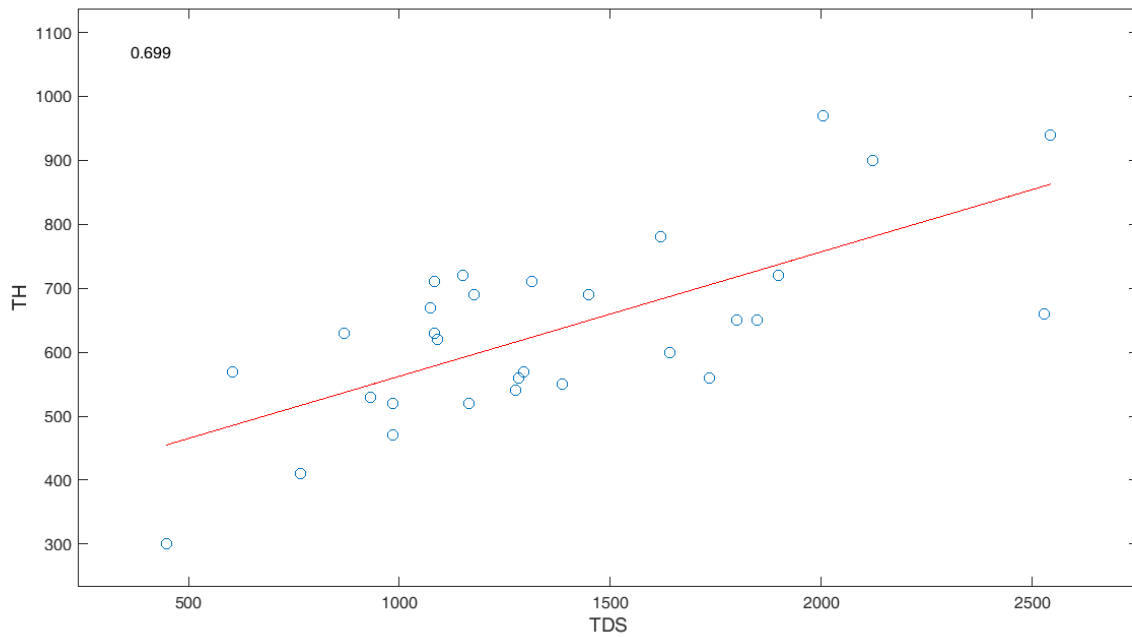


Fig. 5.25: Correlation plot between TDS and TH

The results of correlation between TDS and TH are shown in Fig. 5.25. It can be observed from Fig. 5.25 that TDS and TH show a good positive correlation value of 0.699 which shows their interdependence on each other.

Similarly, in Fig. 5.26, the results of Magnesium Hardness and TH are shown which have a correlation of 0.62. Therefore, they show a averagely high positive correlation value.

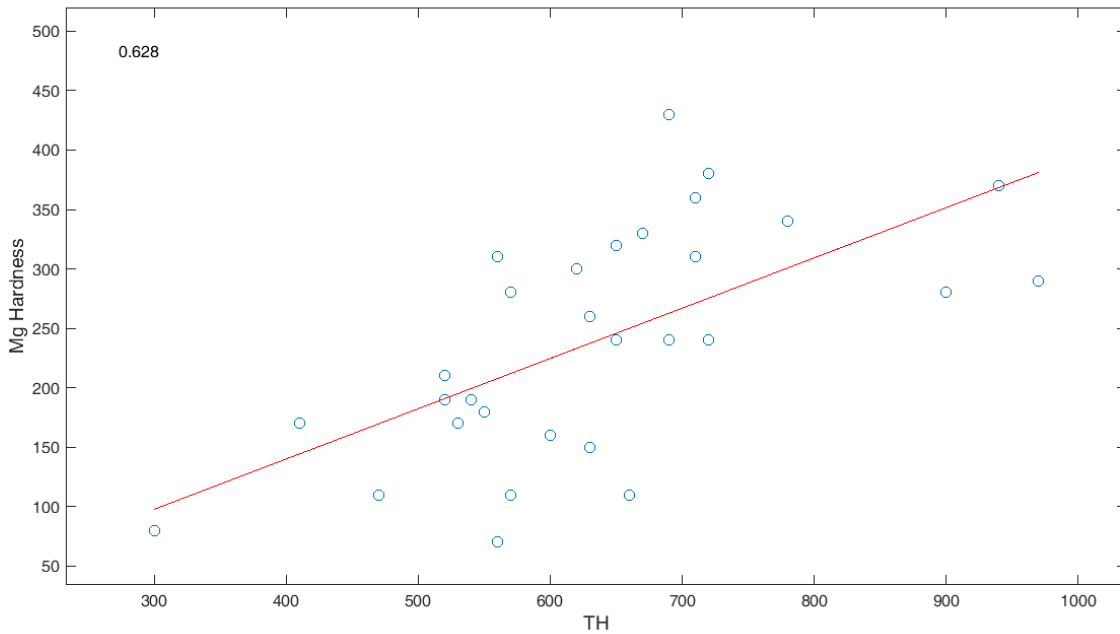


Fig. 5.26: Correlation plot between Magnesium Hardness and TH

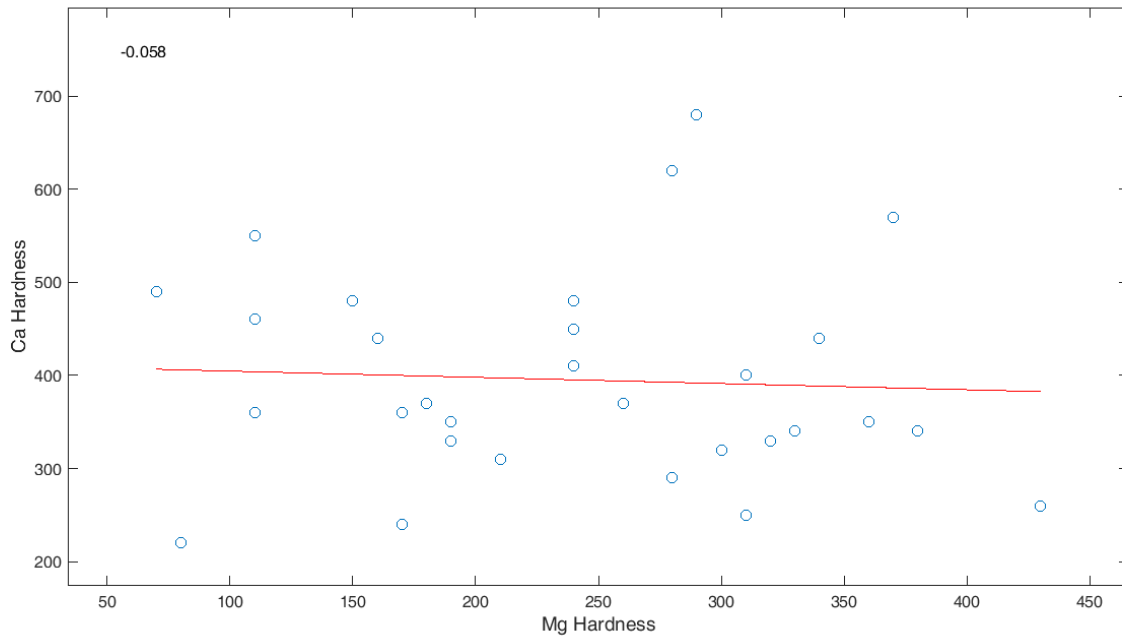


Fig. 5.27: Correlation plot between Magnesium Hardness and Calcium Hardness

Fig. 5.27 shows the correlation plot between Magnesium Hardness and Calcium Hardness which has a correlation of  $-0.058$ . Therefore, it can be concluded that Magnesium Hardness and Calcium Hardness are uncorrelated variables. Similarly, in Fig. 5.28, the plot of turbidity and Calcium hardness shows a correlation of  $0.29$  which proves that turbidity and Calcium hardness is uncorrelated variables.

The Correlation plot between alkalinity and turbidity in Fig. 5.29 show a high correlation of  $0.618$ . This shows that alkalinity and turbidity are correlated variables and depend on each other.

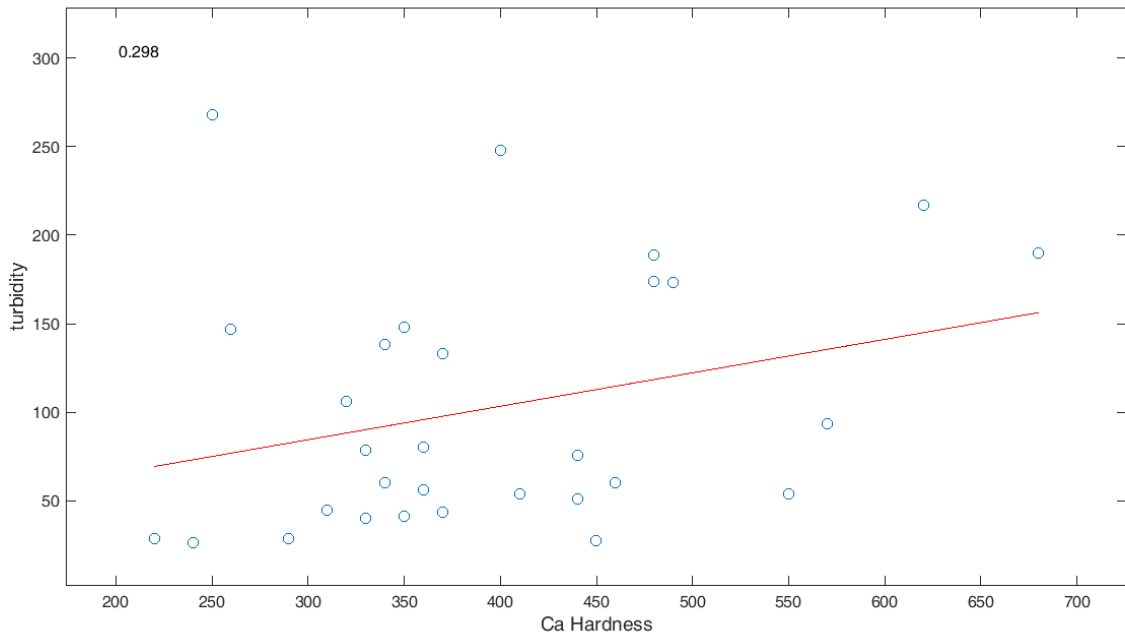


Fig. 5.28: Correlation plot between turbidity and Calcium hardness

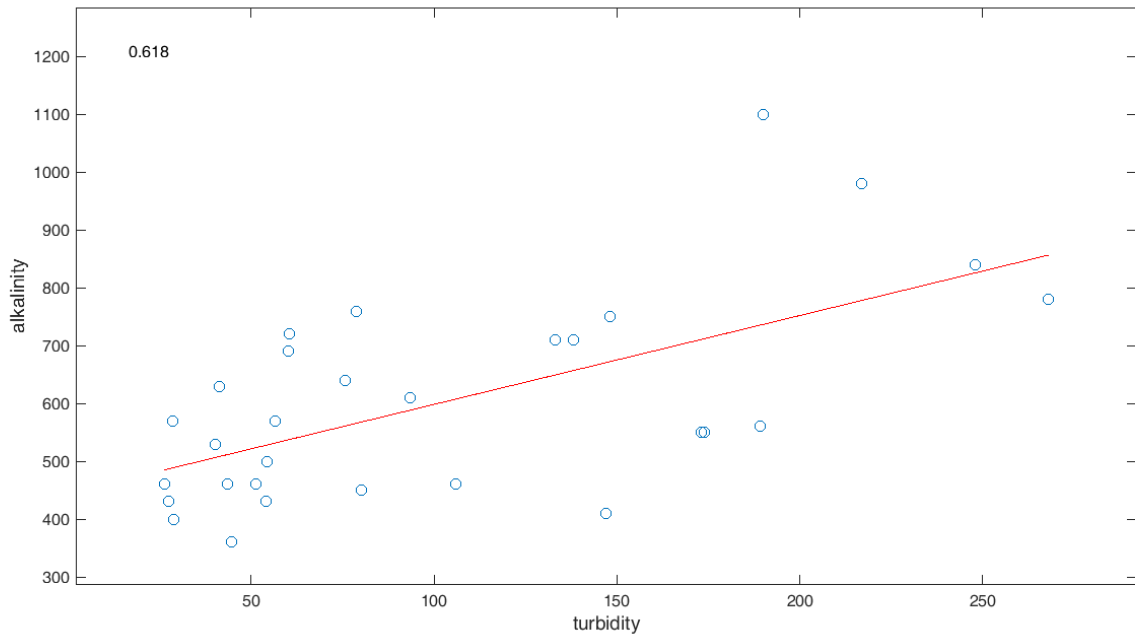


Fig. 5.29: Correlation plot between alkalinity and turbidity

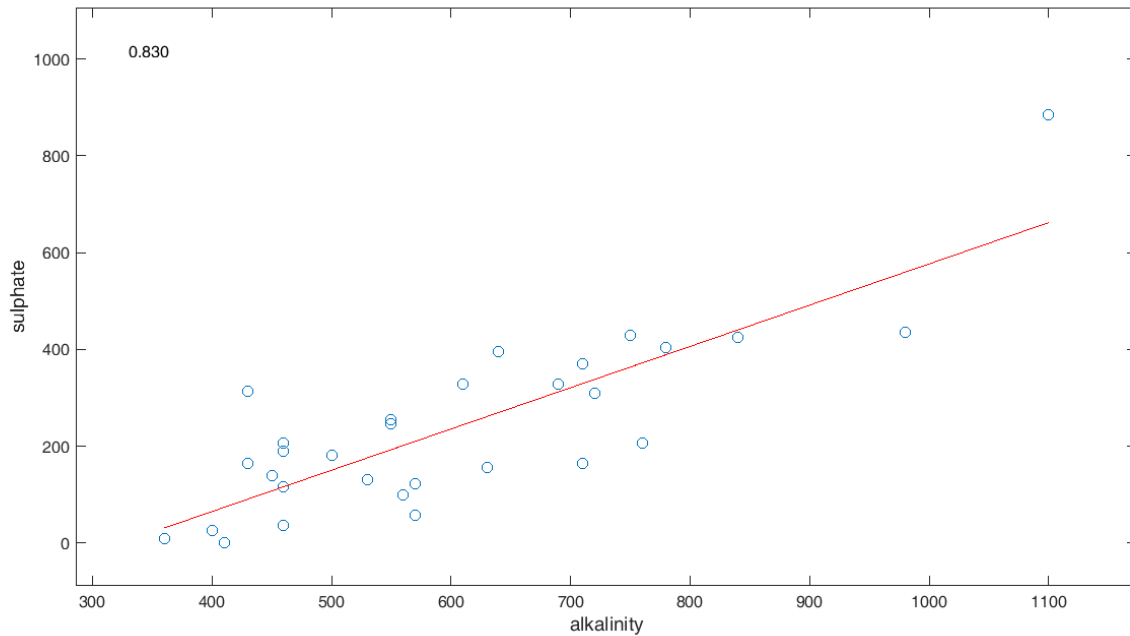


Fig. 5.30: Correlation plot between sulphate and alkanity

The results of sulphate and alkanity are shown in Fig. 5.30 which shows a high correlation of 0.830. Whereas, the correlation plot between chloride and sulphate in Fig. 5.31 shows a relatively lower correlation of 0.499.

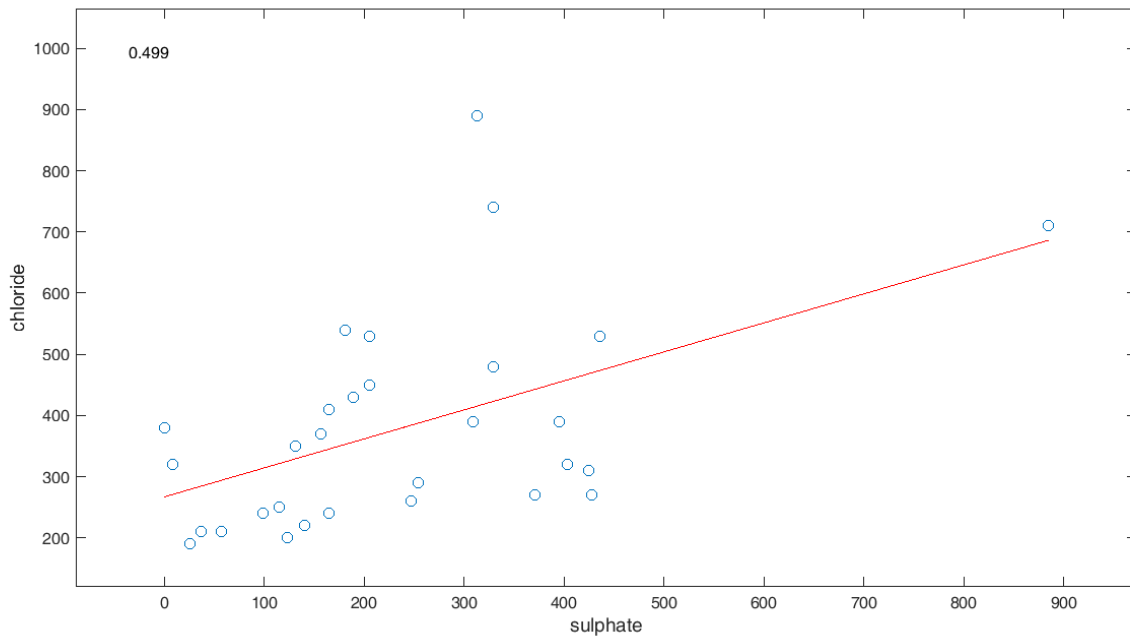


Fig. 5.31: Correlation plot between chloride and sulphate

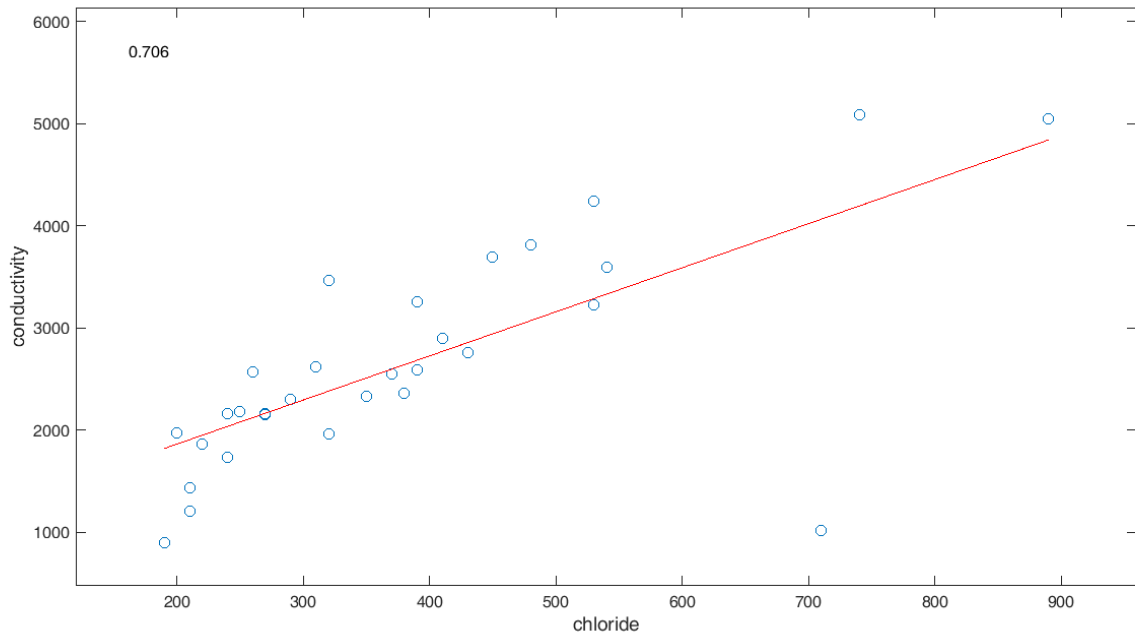


Fig. 5.32: Correlation plot between conductivity and chloride

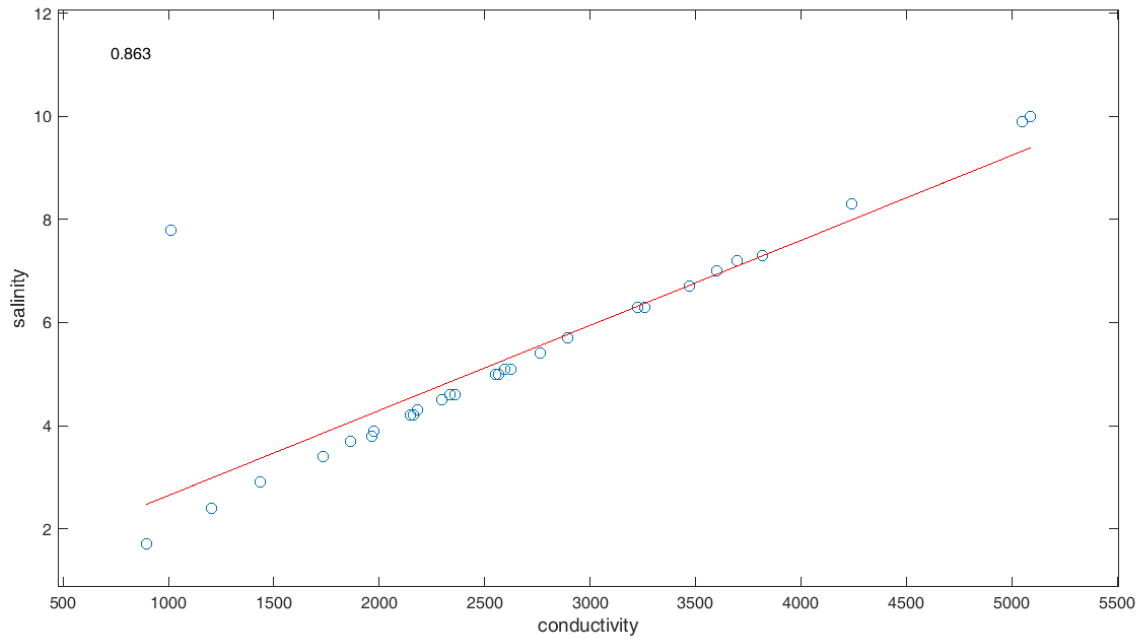


Fig. 5.33: Correlation plot between salinity and conductivity

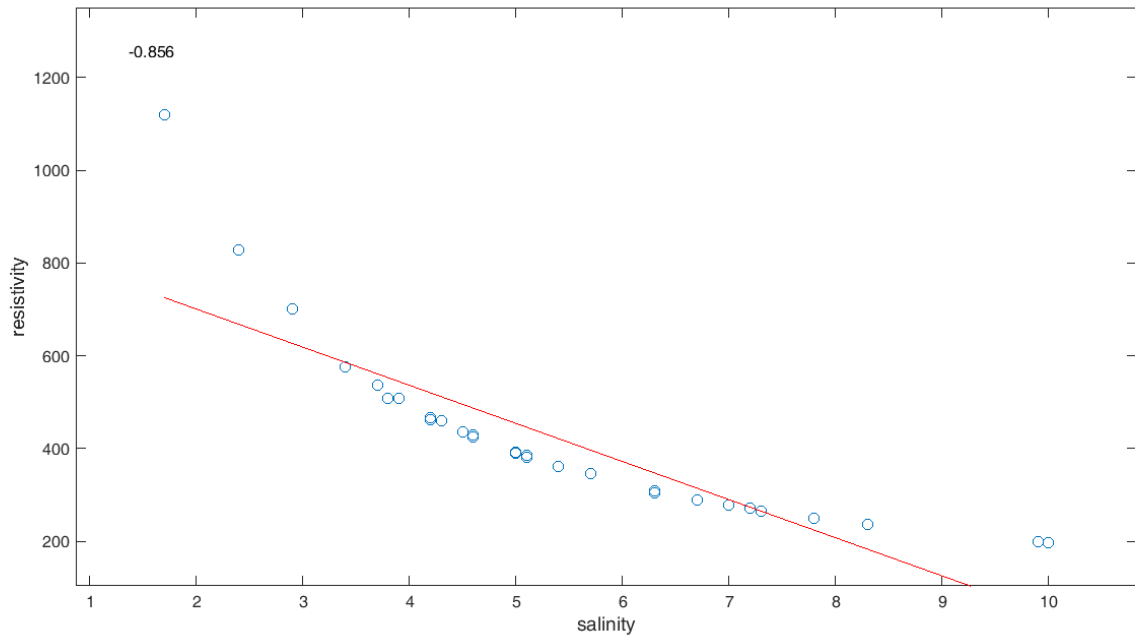


Fig. 5.34: Correlation plot between resistivity and salinity

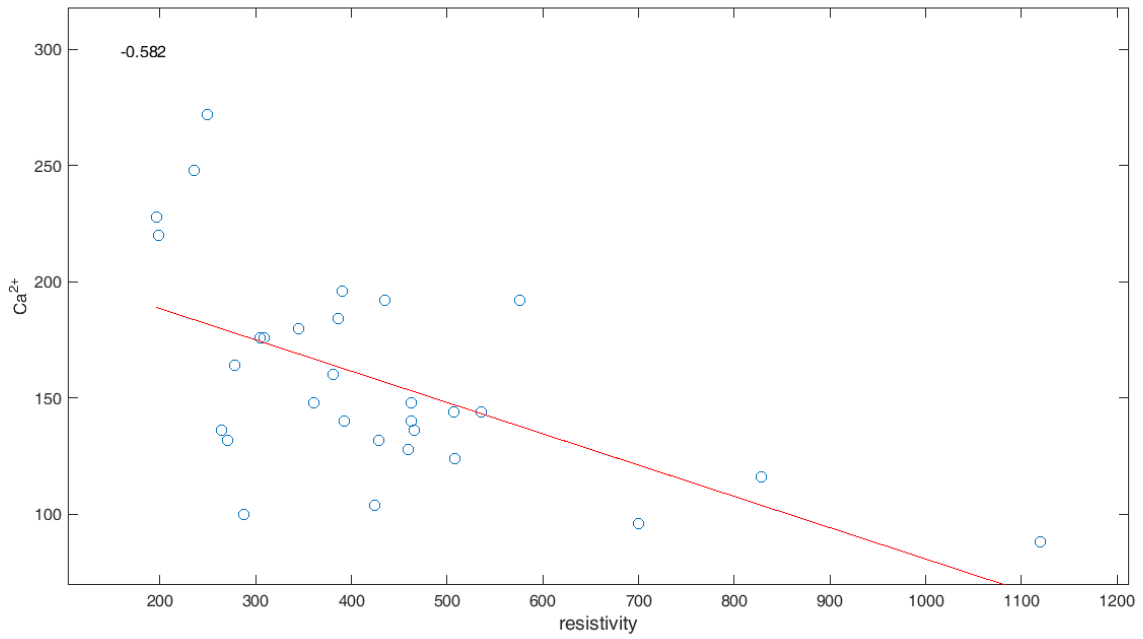


Fig. 5.35: Correlation plot between Ca<sup>2+</sup> and resistivity

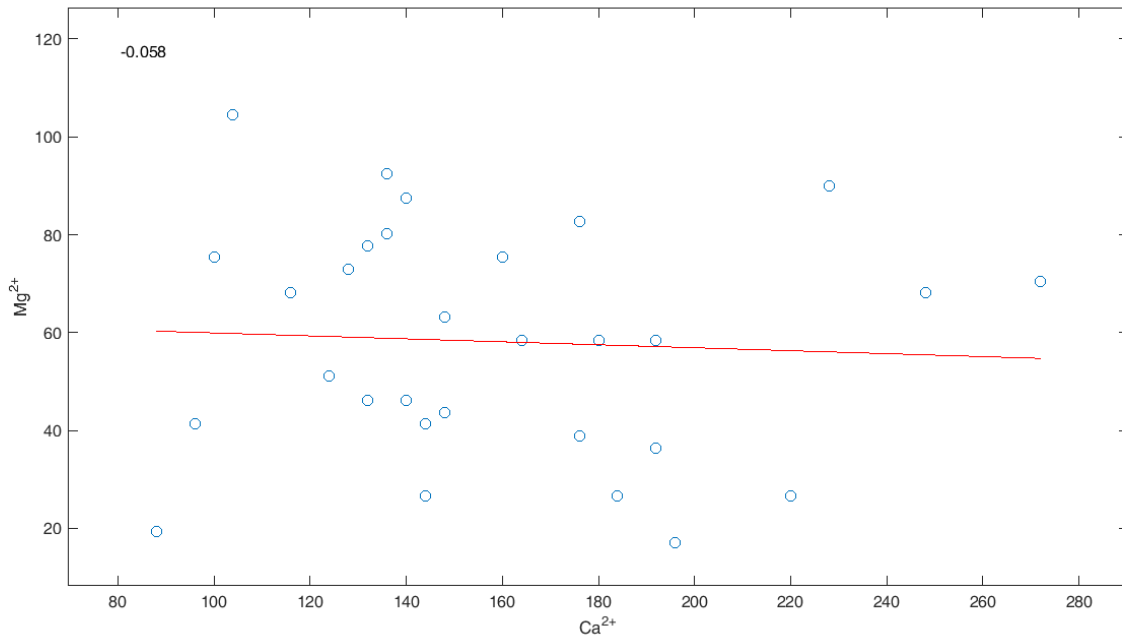


Fig. 5.36: Correlation plot between Ca<sup>2+</sup> and Mg<sup>2+</sup>

The correlation plots between conductivity and chloride for leachate show a correlation of 0.70 in Fig. 5.32. The correlation plot in Fig. 5.33 show a correlation plot between salinity and conductivity

The correlation plots for sulphate v/s chloride and chloride v/s conductivity have corresponding correlation values as 0.53 and 0.73 respectively. The conductivity and salinity for leachate shows a high correlation of 0.88 but its value is lower than the case of groundwater sample where the correlation was reported to be 1. An interesting observation can be noted that the graph between salinity and resistivity shows a high negative correlation value of -0.82. A similar trend was observed in the corresponding result of groundwater sample. Resistivity and Ca<sup>2+</sup> and (b) Ca<sup>2+</sup> and Mg<sup>2+</sup> which show a correlation of -0.67 and 0.01 respectively.

Table 5.3 Average, Minimum, Maximum and Standard deviation values of leachate data

	Clean Water	Maximum	Average	Minimum	Standard Deviation
Ph	8.46	8.58	7.742333	6.73	0.443938
TDS(ppm)	355.6	2544	1371.617	447.3	514.6771
TH	280	970	634.6667	300	143.3042
Magnesium hardness	160	430	239.3333	70	96.48775
Calcium hardness	120	680	395.3333	220	111.6563
Turbidity	2.02	268	102.52	26.2	70.67954
Alkalinity	370	1100	602.3333	360	175.9052
Sulphate	8.232	884.94	237.6586	0	180.7161
Chloride	70	890	379.6667	190	171.7553
conductivity( $\mu\text{s}/\text{cm}$ )	710.6	5090	2639.35	894.5	1051.193
salinity(%)	1.4	10	5.35	1.7	2.009246
resistivity( $\Omega.\text{cm}$ )	1410	1120	425.3667	196	193.0059
$\text{Ca}^{2+}$	48	272	158.1333	88	44.66251
$\text{Mg}^{2+}$	38.8992	104.5416	58.18672	17.0184	23.4581

Table 5.4: Correlation coefficients of leachate data

	pH	TDS	TH	MgHardness	CaHardness	Turbidity	Alkalinity	sulphate	chloride	conductivity	salinity	resistivity	Ca <sup>2+</sup>	Mg <sup>2+</sup>
pH	1	-0.3	0	-0.3	-0.4	-0.2	-0.3	0.2	0	0	0.3	-0.3	0	1
TDS	-0.3	1	0.6	0.7	0.4	0.6	0.7	0.7	0.5	0.7	-0.7	0.7	0.6	-0.3
TH	0	0.6	1	-0.1	0.3	0.3	0.2	0.2	0.2	0.3	-0.3	-0.1	1	0
MgHardness	-0.3	0.7	-0.1	1	0.3	0.5	0.6	0.7	0.4	0.7	-0.6	1	-0.1	-0.3
CaHardness	-0.4	0.4	0.3	0.3	1	0.6	0.5	0	0	0.2	-0.3	0.3	0.3	-0.4
Turbidity	-0.2	0.6	0.3	0.5	0.6	1	0.8	0.2	0.1	0.4	-0.4	0.5	0.3	-0.2
Alkalinity	-0.3	0.7	0.2	0.6	0.5	0.8	1	0.5	0.2	0.6	-0.6	0.6	0.2	-0.3
Sulphate	0.2	0.7	0.2	0.7	0	0.2	0.5	1	0.7	0.9	-0.7	0.7	0.2	0.2
Chloride	0	0.5	0.2	0.4	0	0.1	0.2	0.7	1	0.9	-0.8	0.4	0.2	0
conductivity	0	0.7	0.3	0.7	0.2	0.4	0.6	0.9	0.9	1	-0.9	0.7	0.3	0
salinity	0.3	-0.7	-0.3	-0.6	-0.3	-0.4	-0.6	-0.7	-0.8	-0.9	1	-0.6	-0.3	0.3
Resistivity	-0.3	0.7	-0.1	1	0.3	0.5	0.6	0.7	0.4	0.7	-0.6	1	-0.1	-0.3
Ca <sup>2+</sup>	0	0.6	1	-0.1	0.3	0.3	0.2	0.2	0.2	0.3	-0.3	-0.1	1	0
Mg <sup>2+</sup>	1	-0.3	0	-0.3	-0.4	-0.2	-0.3	0.2	0	0	0.3	-0.3	0	1

From the results provided using Table 5.3 and Table 5.4, the following conclusions can be drawn:

- When compared with the clean water samples, the values of parameters calculated from leachate data are found to be very deviating. This shows that the extent of contamination present in the leachate water.
- PH shows highest negative correlation with the turbidity (-0.4) which is a low negative correlation.

- TDS shows highest correlation with both chloride and conductivity (0.9).
- TH shows high correlation with all parameters apart from turbidity and pH.
- Standard deviation in results of pH is minimum i.e. 0.4 and highest in conductivity (1051.1).

### **Concluding Remarks**

In this chapter, the results calculated from various physio-chemical characteristics of groundwater and leachate samples have been provided. A thorough analysis of statistical properties of these results gives an insight into the effect of leachate on groundwater contamination.

## **CHAPTER 6**

### **CONCLUSIONS**

This research studied the degree of contamination in groundwater around the landfills and dumpsites in the city of Patiala to check the amount of various harmful substances present in groundwater with the standards. Fifteen parameters were taken in the study in which samples were collected from twenty-four locations.

#### **6.1 Conclusions**

It was found that the parameters like pH, temperature, TDS, TH, Magnesium hardness, Calcium hardness, turbidity, alkalinity, sulphate, chloride, conductivity, salinity, resistivity,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  are present in inadequate amounts as compared with the IS 10500:1991 standard.

The correlation graphs and tables revealed that when these parameters are calculated from the clean water, the values do not match with either the groundwater samples or the leachate data. This shows that the extent of contamination present in both groundwater and leachate. It was also observed that pH shows the highest correlation with the turbidity. TDS was found to show a high correlation with chloride, conductivity, resistivity, and salinity. The total hardness shows good correlation values with calcium hardness. The standard deviation data was also calculated for these variables to check the deviations with respect to locations. It was observed that the parameters like TDS, TH, Magnesium hardness, Calcium hardness, sulphate, chloride, and conductivity have shown high standard deviations. Whereas, other variables had lower values of standard deviations.

#### **6.2 Recommendations and Future Works**

In the last few years, due to rapid industrialization and improvements in the standard of living, the problem of solid waste disposal has become prominent. Patiala is one of the popular and civilized cities in India facing this problem. The old and rudimentary system of MSW disposal has been utilized in the city i.e. dumping the waste on open land. Keeping the present scenario in mind more advanced waste disposal techniques should be implemented to save the groundwater resources from contamination.

In order to control the contamination of groundwater through dumpsites and landfills, adequate and proper planning, design and construction of waste disposal systems should be done. The government should take stringent actions to outlaw the open dumpsites. New landfills away from the city water supply should be discovered. Further, continuous and real-time monitoring of groundwater contamination status has to be measured to save the most precious resource on earth.

This work can be further extended to include more physio-chemical variables in the analysis. Other statistical parameters can also be employed in future works. Further, the use of big data analysis can be utilized to calculate a similar analysis for very large areas like complete country.

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