USE OF MULTIVARIATE STATISTICAL TOOLS TO ASSESS AND MONITOR THE GROUNDWATER AND SEDIMENT QUALITY OF THE SURROUNDING AREA OF THE BHARALU RIVER

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DECLARATION

I hereby declare that the work presented in this report entitle "USE OF MULTIVARIATE TOOLS TO ASSES AND MONITOR THE GROUNDWATER AND SEDIMENT QUALITY OF THE SURROUNDING AREA OF THE BHARALU RIVER"in the partial fulfillment of the requirement for the award of the degree of Master of Technology in Civil Engineering with specialization in Geotechnical Engineering submittedin the Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati- 13 under Assam Science and Technology University, is an authentic work carried out in the said college under the supervision of Dr. Abinash Mahanta, Assistant Professor, Department of Civil Engineering, and Dr. Anindita Bhattacharjya (Co-guide), Assistant Professor (C), Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-3, Assam. Whatever I have presented in this report has not been submitted by me for the award of any other degree or diploma.

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This is to certify that the work presented in the project report entitled "USE OF MULTIVARIATE TOOLS TO ASSES AND MONITOR THE GROUNDWATER AND SEDIMENT QUALITY OF THE SURROUNDING AREA OF THE BHARALU RIVER" is submitted by Pirbi Ronghangpi, Roll No.:PG-C-22-14, a student of M.Tech 4th semester, Department of Civil Engineering, Assam Engineering College, to the Assam Science and Technology University in partial fulfillment of the requirement for the award of the degree of Master of Technology in Civil Engineering with specialization in Geotechnical Engineering under my guidance and supervision.

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ABSTRACT

Due to human and industrial activities, the groundwater and the sediment are contaminated. This is a serious problem nowadays. Assessment of the quality of the groundwater and sediment is important. This study aimed to apply multivariate statistical techniques, such as HCA and PCA, to analyse the significant sources impacting groundwater and sediment quality in the vicinity of the Bharalu river. Geo-accumulation index (I_{geo}), enrichment factor (EF), contamination factor (CF), and pollution load index (PLI) were used to evaluate metal contamination levels of the sediment. cadmium (Cd) is highly contaminant in comparison to other metals, indicating a contamination threat to the river ecosystem. Overall, pollution indices indicated that sediment contamination was comparatively higher at the upstream sites. HCA results were used to carry out PCA, yielding different PCs and proving information about the respective site's sources. The PCA analysis indicates the main sources of sediment contaminant originate from inorganic anthropogenic activities, whereas groundwater contamination results from both natural and anthropogenic activities.

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CHAPTER 1

INTRODUCTION

1.1 General:

Water is one of the necessary elements that supports all forms of plant and animal life, and it is received mostly from two natural sources: surface water (freshwater lakes, rivers, streams, etc.) and groundwater (borehole water, well water, tube well water, etc.). Water has unique chemical properties due to its polarity and hydrogen bonds, which means it can dissolve, absorb, adsorb, or suspend a wide range of compounds. As a result, water is not pure in nature because it picks up contaminants from its surroundings as well as those emitted by humans and animals, as well as other biological activities.

Groundwater contamination is one of the most pressing environmental challenges today, and among the many contaminants harming water supplies, heavy metals are of special concern due to their high toxicity even at low concentrations. Heavy metal can cause serious health effects with varied symptoms depending on the nature and quantity of the metal ingested. At very high concentrations trace metals can cause the malfunctions of many organs in the human body.

Heavy metal concentrations in the environment could be hazardous to living species, accumulate in the marine food chain, and harm human health through the consumption of contaminated seafood. Heavy metals settle in bottom sediments after being released into aquatic habitats., However, be released back into the water column as a result of physical, chemical, or biological processes under certain conditions. Sediments are considered as a possible risk source as well as the ultimate sink of heavy metals in aquatic settings.

Sediments preserve crucial environmental data. Sediment contamination, which is defined as the buildup of dirt, sand, and mineral particles in water bodies, is becoming an increasingly serious environmental issue. Sediment contamination, caused by both natural processes and human activity, has a global impact on rivers, lakes, reservoirs, and coastal areas. Agriculture, deforestation, construction, and mining all contribute to increased silt transport and deposition, exacerbating the problem. This thesis digs into the complexities of sediment pollution, including its causes, and consequences.

Among various contaminants, heavy metal pollution in surface water bodies has garnered special attention due to its non-biodegradable nature, capacity for bioaccumulation, and potential for food chain contamination (Kayembe et al., 2018). River sediments, often used as disposal sites for a variety of industrial and urban treated and untreated effluents, are particularly vulnerable to metal contamination (Chabukdhara et al. 2012). The contamination of surface sediments with metals in urban rivers has become a major concern recently. Urban and industrial activities have been closely linked to the presence of heavy metals in these sediments and the associated ecological risks (Suther et al. 2009, Xia F et al. 2018, Li Y et al. 2018). The migration of metals from sediments to the overlying water and other environments poses significant environmental and human health risks (Shao et al. 2020).

The Bharalu river, a minor tributary on the Brahmaputra's southern bank, originates in the Khasi hills of the Meghalaya Plateau. Known as Bahini or Bihini in its upper reaches, it flows through Guwahati and joins the Brahmaputra at Bharalumukh. The river carries substantial municipal and industrial waste, posing health risks to the community and harming aquatic life. The current condition of the Bharalu river near Pragjyotish College, Santipur, Guwahati, is depicted in Figure1. Foam forms during the monsoon season due to pollution, sewage discharge, and industrial waste, similar to the situation in the Yamuna river. These contaminants affect both groundwater, surface water, and sediment, impacting residents who rely on groundwater. Recent media reports highlight severe pollution in the vicinity of the Bharalu river.

Few literature indicates that Bharalu's water and sediment are contaminated by municipal waste and industrial waste disposal along various stretches. This pollution is seeping into the groundwater, causing health hazards for nearby inhabitants.

Fig.1: Foam formation due to effluent contaminants in Bharalu river near Pragjyotish College, Santipur, Guwahati

1.1 Physico-chemical test:

It is essential to test the water before it is used for drinking, domestic, agricultural, or industrial purposes. It is necessary to examine water using many physicochemical parameters. The selection of parameters for water testing depends entirely on the intended use of the water and the required level of quality and purity. Water does contain different types of floating, dissolved, suspended, and microbiological as well as bacteriological impurities. Some physical tests should be performed to test its physical appearance such as temperature, pH, turbidity, TDS, etc., while chemical tests should be performed for its BOD, COD, dissolved oxygen, alkalinity, hardness,and other characteristics. Drinking water should pass these entire tests and it should contentlyrequire amount of mineral level.

1.2 Heavy metal test:

Heavy metals occur naturally in the Earth's crust. They are found and distributed in living tissues of an organism and in different components of the environment. However, at low concentrations, they possess no potential risk or hazard to any living organisms or the environment. Some heavy metals are arsenic (As), chromium (Cr), cadmium (Cd), nickel (Ni), zinc (Zn), lead (Pb), manganese (Mn), etc. The high levels of the metals produce an adverse effect on plants, animals, aquatic life, and as well as also on human health. Therefore, it is important to monitor and assess the level and degree of heavy metals in the environment.

1.3 Statistical tools:

An assessment of groundwater and sediment is of maximum significance since it directly concerns public well-being and aquatic life. Water quality assessment aims to describe the nature of water quality to meet defined objectives in terms of its physical, chemical, and biological parameters. The demand for monitoring the nature of groundwater and sediment quality of a river based on various parameters increased since the last decades. To demonstrate the groundwater and sediment quality a typical monitoring scheme with maximum efficiency is very much essential for an authentic estimation of the quality since it very difficult due to spatial and temporal variations.

To achieve this goal, multivariate statistical methods such as clustering analysis (CA), and principal component analysis (PCA) have been widely used to assess the diversity of environmental subjects. According to Shiker (July 2012), a multivariate analysis is used extensively to analyze data sets and is comprised of various techniques. These techniques are nothing but methods based on mathematical statistics and can be used to solve multi-index problems.

Boyacioglu et al. (2007) highlight several advantages of using multivariate statistical techniques for ecological data, which are detailed below:

I. They reflect the multivariate Characteristics of the natural ecological systems.

II. They enable the handling of large datasets with numerous variables by summarizing redundancies.

III. They provide a means of detecting and quantifying genuinely multivariate patterns that emerge from the correlation structure within the variable set.

1.4 Some Technical Terms:

1.5.1 Hierarchical Clustering Analysis:

Hierarchical clustering analysis in short HCA, is an identification tactic to ascertain the basic form or foremost behavior from a dataset and try to form groups of clusters based on their closeness or similarity of the data matrix. The clusters are linked in sequence beginning with the most similar variables and developing higher clusters until a single cluster is attained comprising all variables.

The clustering process generates dendrogram (tree diagram) outputs, providing a visual description that determines the number of clusters and describes the essential processes that lead to spatial variation. Usually, the square Euclidean distance serves to measure the similarity between two samples, representing the disparity between analytical values obtained from these samples, as noted (Singh et al. 2004). single linkage method was adopted to cluster the sampling sites. In this study, a hierarchically agglomerative CA was executed on the groundwater and sediment quality dataset.

1.5.2 Principal Component Analysis:

Principal component analysis in short PCA is a very fruitful gadget used to diminish the amplitude of a dataset into a considerable number of independent variables, maintaining the original inconsistency in the dataset. PCA includes uncorrelated variables to reduce the number of variables and explain the same amount of variance with fewer variables (principal components). This is achieved by converting the set into a fresh array of variables, i.e., the principal components (PCs), which are orthogonal and organized in descending order of significance. Mathematically the PCs are calculated from covariance that defines the distribution of various computed parameters to obtain eigenvalues and eigenvectors. PCs are the linear groupings of fundamental variables and eigenvectors (Alberto et al. 2001).

The procedural steps of the PCA are:

- Number of components equal to the number of variables are generated
- The number of components to retain are determined
- Components are rotated (rotations is a linear transformation of the solution to make interpretation easier)
- Rotated solution is interpreted

Several researchers used this multivariate statistic method to solve a large and complex data matrix of surface water parameters which are discussed in the literature review.

1.5 Pollution indices:

In this study, we evaluate the sediment contamination levels in the marine port and their potential impact on the marine ecosystem by employing various pollution indices, as outlined by previous researchers (Abrahim G.M.S. et al. 2008 and Belaidi O. et al. 2018) given in the following:

1.6.1 Geo-accumulation index (I_{geo}):

The Geo-accumulation Index (Igeo) was developed by Muller (1969). This index (Igeo) facilitates comprehensive contamination assessment by comparing contemporary and pre-industrial values. In this research, the Igeo of sediment samples was calculated utilizing the subsequent equation. It is formulated as follows:

$$I_{geo}=\log_2(C_n/1.5B_n)$$

Where, C_n = measured content of metal "n", B_n = the metal's content in "average shale" (Turekian and Wedephol 1961), and 1.5 is the background matrix correction in factor due to lithogenic effects (Praveena et al. 2007)

This index is classified or divided into seven different grades/classes with index classes ranging from 0-6 which are given in the table.

Table 1.1: Classification of Geo-accumulation Index I_{geo} (Muller,1969):

Index class	Igeo	Level of contamination
0	Igeo<0	Uncontaminated
1	0<Igeo<1	Uncontaminated to moderately contaminated
2	1<Igeo<2	Moderately contaminated
3	2<Igeo<3	Moderately to highly contaminated
4	3<Igeo<4	Highly contaminated
5	4<Igeo<5	Highly to very highly contaminated
6	Igeo<5	Very highly contaminated

Table 1.2: Heavy metals global background values (*Turekian and Wedephol 1961*):

Heavy Metals	B_n (Background)
As	13
Cd	0.3
Cr	90
Ni	68
Pb	20
Zn	95
Mn	850

1.6.2 Enrichment factor (EF):

Enrichment factor (EF) is a useful tool in determining the degree of anthropogenic heavy metal pollution. It was developed by Ergin M et al.1991. The EF is computed using the relationship below:

$$EF = \frac{(\text{Metal/Mn})\ \text{Sample}}{(\text{Metal/Mn})\ \text{Background}}$$

Usually, Al is selected as RE (reference element) sometimes Ti, Fe, Mn, Zr, Sc, or other conservative elements (Gong et al. 2008) are selected. In this study, Manganese was used as the reference element for geochemical normalization.

Based on the EF value, the toxicity level of the sediment can be classified as follows

Table 1.3: Toxicity level of the sediment:

EF	Toxicity level
EF<1	No enrichment
EF<3	Minor
3-EF-5	Moderate
5-EF-10	Moderately to Severe
10-EF-25	Severe
25-EF-50	Very Severe
EF>50	Extremely Severe

1.6.3 Contamination factor:

The CF is the ratio obtained by dividing the concentration of each metal in the sediment by the baseline or background value.

$$CF = \frac{\text{Heavy metal in the sediment (Cn)}}{\text{Baseline level of the metal in the sediment (Cbn)}}$$

Where C_n denotes the observed level of heavy metal in the sediment, and C_{bn} represents the baseline or background level of the metal in the sediment table 1.2(Turekian and Wedephol 1961). The formula was interpreted as suggested by Hakanson L et al.1980

Table 1.4: Level of Contamination:

CF	Level of contamination
CF<1	Low Contamination
1<CF<3	Moderate Contamination
3<CF<6	Considerable Contamination
CF>6	High Contamination

1.6.4 Pollution load index (PLI):

PLI is the product of individual inputs from various heavy metals. It estimates the overall heavy metal toxicity status of a specific sample and indicates how many times the heavy metal concentration in the sediment exceeds the background concentration. It can be expressed as follows:

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \cdot\cdot\cdot \times CF_n)^{1/n}$$

where CF_n is the contamination factor of heavy metal "n," and "n" represents the number of metals. This empirical index provides a simple, comparative means for assessing the level of heavy metal pollution.

When PLI > 1, it means that pollution exists; otherwise, if PLI < 1, there is no metal pollution exists (Tomlinson D.L. et al. 1980)

1.6 Objectives:

The prime objective of the present study is to investigate the major sources of contaminants in the Bharalu river at different stretches within Guwahati. To achieve this objective, the following sub-objectives are fixed:

- To find out the various contaminants present in the groundwater and sediment in the vicinity of the Bharalu river.
- To assess the extent of contamination in terms of geo-accumulation index, Enrichment factor, Contamination factor, and Pollution load index in Sediment.
- Multivariate statistical tools were used to identify the source of contamination in the vicinity of the Bharalu river.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction:

To conduct any scientific study, a thorough understanding of the topic or place is essential. This can be achieved through an extensive literature review of noted researchers' work. Literature reviews, primarily involving secondary sources, help readers evaluate the strengths and weaknesses of existing information, forming a broad, scientifically sound concept. For the study on "USE OF MULTIVARIATE STATISTICAL TOOLS TO ASSESS AND MONITOR THE GROUNDWATER AND SEDIMENT QUALITY OF THE SURROUNDING AREA OF THE BHARALU RIVER," various researchers' literature was summarized to familiarize with established knowledge. Methods for literature review include analyzing books, journals, thesis, reports, and papers. Digital resources like e-Libraries, and Google Scholar, have greatly simplified and enhanced the process of gaining and sharing knowledge.

The major work carried out by different researchers are summarized below:

2.1 Review of Literature:

Sudhir Kumar Singh et al. (2008) To assess the groundwater quality in Bareilly district, Uttar Pradesh, India, it was monitored at 10 sites during 2005–2006. Principal component analysis (PCA) and cluster analysis (CA) were used to evaluate and interpret the data. Hierarchical cluster analysis grouped the sites into three clusters based on similar water quality characteristics, facilitating the design of an optimal sampling strategy to reduce costs. PCA identified key factors affecting water quality, including trace metals, dissolved salts, organic pollution, and nutrients. The study demonstrated the effectiveness of multivariate statistical techniques for analyzing groundwater quality, identifying pollution sources, and understanding spatial and temporal variations for better groundwater management.

Memet Varol (2011) find the heavy metal concentrations in sediment samples from the Tigris River to evaluate contamination levels. The highest concentrations were observed at the first site, attributed to metallic wastewater discharges from a copper mine plant. Pollution assessment utilized contamination factor (CF), pollution load index (PLI), geo-accumulation index (I_{geo}), and enrichment factor (EF). CF values for Co, Cu, and Zn indicated very high contamination at the first site, while PLIs suggested moderate pollution at all sites except the first. Cu, Co, Zn, and Pb showed the highest Igeo values. EF values indicated significant anthropogenic impacts on metal levels, potentially harming sediment-dwelling organisms. PCA/FA and cluster analysis identified anthropogenic sources, particularly copper mine discharges, as major contributors to metal pollution. Regulatory measures and ongoing environmental monitoring are recommended to mitigate these impacts in the Tigris river basin.

Rabee et al. (2011) studied six stations along the Tigris River in the Baghdad region, examining Mn, Ni, Pb, Cu, and Cd contamination using the Pollution Load Index (PLI) and Geo-accumulation Index (I_{geo}). Their findings indicated that Cd had the lowest concentrations, ranging from 0.3 to 1.3 µg/g dry weight, while Mn had the highest, between 166 and 426 µg/g dry weight. The Geo-accumulation Index revealed that sediments at most stations were slightly polluted (grade 1) concerning Pb and Cd, whereas all stations were unpolluted (grade 0) regarding Mn, Cu, and Ni. The PLI values, ranging from 0.301 to 0.970, also suggested that the Tigris River stations were unpolluted by the total of the studied heavy metals. This comprehensive assessment highlights the relatively low levels of heavy metal pollution in the Tigris River sediments, contributing valuable data to the field of environmental monitoring and water quality management.

Usman Nasiru Usman et al. (2014) addresses the scarcity of groundwater quality assessment efforts in Terengganu, Malaysia. It examines a six-year dataset from ten wells using multivariate statistical methods to understand spatial variability and pollution sources. Cluster analysis identified three distinct water quality clusters, while discriminant analysis revealed key parameters distinguishing these clusters, aiding in spatial variation recognition. The principal component analysis highlighted eight major factors contributing to 76.45% of the variance, linking natural processes, point-source (municipal and industrial wastewater), and non-point-source pollution (primarily from agriculture). The study showcases the efficacy of multivariate techniques in geochemistry, offering insights for decision-makers to prioritize water quality improvements amidst anthropogenic pollution.

Joseph et al. (2016) revealed heavy metal concentrations in sediments varied across sampling stations, with the control station (UAC beach) having the lowest levels. Concentrations of Cu, Zn, Fe, Cd, and Ni showed no significant variation (P>0.05), while Cr, Mn, and Pb varied significantly. Mean concentrations were Fe>Mn>Ni>Zn>Cu>Pb>Cd>Cr. Sediments from Qua Iboe river were slightly polluted with Cr, Cd, and Ni, exceeding WHO or sediment quality guidelines, and posing potential bioaccumulation risks. The geo-accumulation index indicated strong pollution with Fe, which had the highest positive loading. Regulatory agencies should monitor and enforce policies to mitigate pollution and support further environmental studies in the area.

Kunwar Raghvendra Singh et al. (2017) examined the surface water quality of Amingaon, a rapidly developing area in North Guwahati, Assam, India. Samples from 12 lakes were tested for 24 parameters, including temperature, pH, electrical conductivity, turbidity, and various ions and nutrients. Multivariate statistical techniques, including cluster analysis (CA) and principal component analysis (PCA), were employed to classify water quality parameters and identify pollution sources. CA grouped the parameters into three clusters, while PCA identified six components explaining 90.54% of the variance. The primary pollution sources were fertilizers, stormwater runoff, land development, and domestic wastewater discharge. Carlson's Trophic State Index (TSI) revealed that five lakes were hypereutrophic, three were eutrophic, and the remaining were oligotrophic. The study demonstrates the effectiveness of CA and PCA in water quality assessment and can inform policymakers in managing water resources.

Siddhant Dash et al. (2018) studied how to apply multivariate statistical techniques, including hierarchical cluster analysis (HCA), principal component analysis (PCA), and discriminant analysis (DA), to identify significant sources affecting water quality in Deepor Beel. Laboratory analyses were conducted on 20 water quality parameters from samples collected at 23 monitoring stations. HCA categorized the sampling locations into three clusters—high (HP), moderate (MP), and low pollution (LP) sites—based on water quality similarities. The HCA results informed the PCA, which identified principal components (PCs) reflecting pollution factors/sources. PCA for HP sites identified six PCs accounting for over 84% of the variance, while PCA for LP and MP sites identified two and five PCs, respectively, each accounting for 100% of the variance. DA revealed that BOD, COD, TSS, and $SO4^{2}$- accounted for significant spatial variations in water quality. The study demonstrates the effectiveness of these techniques in monitoring and managing water quality in Deepor Beel.

M. Yerima Kwaya et al. (2019) investigated the groundwater quality of Maru town and its environs, focusing on heavy metals concentration using pollution indices and multivariate statistical approaches. A total of 29 groundwater samples from dug wells and one borehole were analysed for heavy metals, temperature, and pH. The metals were found in decreasing concentrations as follows: Cr > Fe > Mn > Zn > Cu > Ni, with Cr, Fe, and Mn exceeding WHO recommended limits. Pollution indices indicated low Cd and HEI values but high HPI, classifying the area as highly polluted. No significant correlation was found between the heavy metals, but Cd, HPI, and HPI were strongly positively correlated to Cr. PCA and HCA results were consistent, indicating both geogenic and anthropogenic sources for the heavy metals. Chromium pollution was significant, with 58.62% of samples exceeding the permissible limit of 50 µg/l. The high HPI values in 65.52% of locations confirmed the pollution status. HEI was deemed the most reliable index for assessing heavy metal pollution. Multivariate analysis showed that heavy metals originated from weathering of rocks, automobile exhaust, and agricultural activities.

Das M. et al. (2020) conducted a regression-based analysis to assess the impacts of Fluoride reaching river water on the groundwater aquifer adjacent to the river: a case study in the Bharalu river basin of Guwahati, India. Fluoride is one of the parameters that is non-degradable and naturally occurring inorganic anion found in many natural streams, lakes, and groundwater. Fluoride causes serious health issues like dental and skeletal fluorosis. This study was performed to examine the level of fluoride in both Bharalu river water and groundwater within Guwahati city and to analyze the impact of fluoride-reach river water on the groundwater aquifer adjacent to the river. It was observed that the value of fluoride varied from 0.02 to 3.73 mg/l in river water and 0.04 to 4.7 mg/l in the case of groundwater. The authors find a direct relationship between the fluoride concentration of river water and groundwater which implies that groundwater is contaminated by the polluted river water.

Hamidu et al. (2021) performed a study focused on the pollution status of groundwater in the industrial areas of Challawa and Sharada in Kano City based on pollution indices, statistical and spatial analysis. Twenty samples representing groundwater of the studied areas were analyzed for the presence of Cd, Cr, Ni, Fe, Mn, and Zn using an atomic absorption spectrophotometer. The statistical evaluation gave strong and positive correlations between indices a moderate one between indices and a moderate one between metallic ions. Component analysis revealed a strongly positive loading of Fe, Ni, and Zn while Cd hada strong negative loading. Cr and Mn were positive and moderately loaded. Statistical analysis suggested both anthropogenic and geogenic sources for the heavy metals mainly from the industrial and agricultural practices and rock weathering processes respectively.

Bhuyan et al. (2023) performed a study that assessed heavy metals in the surfacesediments of the Bharalu river, India, with concentrations ranging from 6.65−54.6 mg/kg for Ni, 25.2−250.0 mg/kg for Zn, 83.3−139.1 mg/kg for Pb, and 11940.0−31250.0 mg/kg for Fe. Sediment quality guidelines, geo-accumulation index (I_{geo}), enrichment factor (EF), pollution load index (PLI), Nemerow's pollution index (PIN), and potential ecological risk index were used to evaluate contamination levels. Pb exceeded guidelines at all sites, indicating a potential ecological threat, with I_{geo} and EF showing moderate to severe enrichment. Pollution indices revealed higher contamination in downstream sites due to urban discharges and waste dumping. PCA and correlation analysis indicated both anthropogenic (urban discharges, waste dumping) and natural origins for metals. Pb was identified as the major contributor to ecological risk. The study highlights the need for detailed and regular monitoring of heavy metals to inform river management strategies aimed at mitigating heavy metal pollution and protecting river ecosystems.

Jian Zhou et al. (2007) In Yangzhon City, China, a multivariate statistical approach, including principal component analysis (PCA) and cluster analysis (CA), was used to identify the sources of heavy metals (Bi, Cd, Co, Cr, Mn, Pb, U, V, and Zn) in surface water and freshly deposited riverine sediment samples. Statistical analysis revealed significant metal-to-metal correlations, indicating common sources of variability in both water and sediment samples. The findings highlighted that Bi, Cd, Co, and Pb in both mediums (with Co only in water) are controlled by a high background lithogenic factor, while Co, Mn, U, and V (Co only in sediment) mainly originate from soil parent materials. Additionally, Cr, Zn, and Mn were identified as tracers of industrial pollution. The study's results showed a similarity in the factor loadings of both sample types, suggesting that the same sources control metal variability. This statistical analysis, corroborated by background values and field surveys, provided a convincing differentiation between natural and anthropogenic inputs of heavy metals in the region.

CHAPTER 3

EXPERIMENTAL PROCEDURE AND RESULTS

3.1 Introduction:

To achieve the project's goal, pertinent laboratory experiments were carried out according to Indian standard procedures and the corresponding IS codes. This chapter presents the test program for the various laboratory tests that were conducted as well as the related findings.

3.2 Test Program:

The phases of the complete test program are as follows:

1. Collection of water and sediment samples from different stations in the vicinity of the Bharalu river.
2. Preservation of the samples as per Indian standard.
3. Determination of physical and chemical properties of the samples.
4. Determination of heavy metal in sediment.
5. Calculation of pollution indices of the surface sediment.
6. Analysis of test results by Multivariate Statistics.

3.3 Water and sediment sampling stations:

Water samples were collected in post-monsoon season from 7 sampling stations in the vicinity of the Bharalu river.

- Station -1Bharalumukh
- Station-2 Fatasil
- Station-3 Ulubari
- Station-4 Lachit Nagar
- Station-5 Ambikagiri Nagar
- Station-6 Jonali Path
- Station-6 Ganeshguri
- Ststion-8 Dispur

Sediment samples were collected in post-monsoon season from 4 sampling stations

- Station -1Bharalumukh
- Station-2 Fatasil
- Station-3 Ulubari
- Station-4 Ambikagiri Nagar

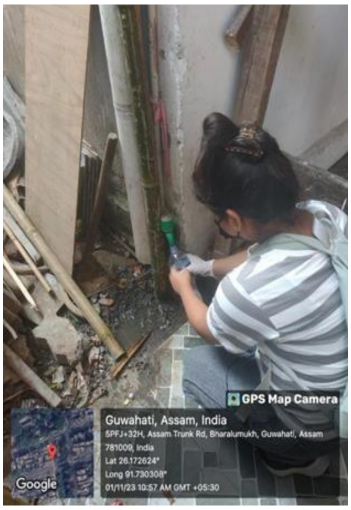
Fig.3.1: Sampling Location

Source- Google Earth

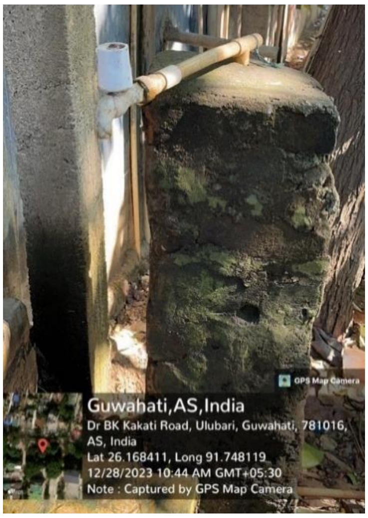
= Water Sampling

= Sediment Sampling

Groundwater:



1: Bharalumukh



2: Fatasil

3: Ulubari

Sediment:

4: Bharalumukh

5: Fatasil

6: Ulubari

Fig.3.2: Collecting samples

3.4 Collection and preparation of water sample:

Total 8 groundwater samples were collected from 8 different sampling stations, in and around the Bharalu river, State Assam, India. The water sampling was manually performed and collected samples belong to grab samples. Tape (boring), hand pumps, and ring wells were used to collect groundwater samples. The sampling was done in 2-L polyethylene bottles. The methods of sampling and collection are by standard methods for the examination of water [IS 3025 (part 1):1987].

All samples were collected, preserved, and stored for analysis as outlined in standard methods for the examination of water and wastewater. Water and wastewater sampling are done as per Indian standard IS 3025 (Part 1):1987

As per IS 3025 (Part 1):1987 for water and wastewater sampling specific guidelines should be followed which are discussed below

1. Selection of the container or bottle is done in the following ways-
    - Glass containers– It should be cleaned with water and detergents to remove dust and packing material. They should then be cleaned with chromic acid-sulphuric acid mixed before being thoroughly rinsed with distilled water.
    - Polyethylene containers - It should be cleaned by filling them with acid or hydrochloric acid. leaving for 1 to 2 days, followed by thorough rinsing with distilled or de-ionized water.
    - Sample Volume: - A two-liter sample is normally sufficient for a physicochemical Test.
    - Measures should be adopted in the following way from the place of sampling to the laboratory:
    - The sample should be collected in a leakproof glass or plastic container.
    - The sample should be transported in an ice box keeping the temperature around 4°C.
    - Undue jerking of the samples should be avoided as this may result in coagulation of the suspended matters.
    - Immediately after reaching the destination, the samples should be transferred to the refrigerator.
    - A wax pencil may be used for writing details on the labels which should be protected from wetting.

- The sample bottles should be carefully providing the following information:

    a. Place of sampling,

    b. Time and date of sampling,

    c. Types of sampling and depth of sample,

    d. Purpose of sampling.

2. Sampling Location for groundwater -The sample has to be collected from a boreholeat a desired depth.

3.4.1 Preservation of the water sample:

After sampling samples are preserved in the refrigerator by maintaining a temperature around 4 ºC-5 ºC as instructed by the in-charge of the Environmental Laboratory. For the determination of Heavy metal parameters, a part of the sample from each location are kept aside by putting Concentrated HCl acid as instructed by PCB, Guwahati.

Fig.3.3: Preservation of the water sample

3.4.2 Collection, preservation, and preparation of sediment samples:

Four stations were selected for river sediment sampling. At each station, surface sediment samples were collected using a stainless steel auger, then immediately placed in polypropylene zipped pouches and transported to the laboratory. The GPS coordinates (latitude and longitude) of each station were recorded.

The levels of metal parameters in sediment samples were determined with XRF (X-ray fluorescence spectrometer) (model- Zetium DY 2942). The samples have to be in the form of dry powder. Air-dried sediment samples were sieved through the 150-micron sieve size. For analysis of traces (up to 3 ppm), 30g of samples are required.

Fig.3.4: Zetium XRF

3.5 Determination of Physico-chemical Properties:

The parameters for water quality characterization have been used within the permissible limits prescribed by the Bureau of Indian Standards. These refer to domestic water supplies for drinking water. A few numbers of parameters have been studied in this work and these are mentioned below:

pH, conductivity, turbidity, total dissolved solid, total hardness, chemical oxygen demand (COD). biological oxygen demand (BOD), dissolved oxygen (DO), chloride, total alkalinity, acidity, calcium, magnesium, iron, fluoride, and arsenic

Physical Parameters:

pH: The pH of a solution refers to hydrogen ion activity and is expressed as the negative logarithm of hydrogen ion concentration. The pH of the various samples is measured with the help of a pH meter.

Turbidity: Turbidity in water is caused by the presence of suspended matter, such as clay, silt, colloidal organic particles, plankton, and other microscopic organisms. Turbidity is also caused by discharges of domestic and industrial wastewater containing soaps, detergent, etc. turbidity meter is used to measure the turbidity of the samples. The values are expressed in NTU.

Chemical parameters

Chloride: In nature, chloride is commonly found as calcium, potassium, and sodium salts. It is a significant component of wastewater and water. The dissolving of salt deposits is the cause of the occurrence of chloride in natural waterways. chloride levels in samples of water and wastewater are frequently measured using the argentometric method.

Total Alkalinity: Alkalinity of water is the capacity of that water to accept protons. It may be defined as the quantitative capacity of an aqueous medium to react with hydrogen ions to pH 8.3 (Phenolphthalein alkalinity) and then to Ph 4.5 (Total alkalinity or methyl orange alkalinity). apparatus pH meter, burette, pipette, etc. are used to measure Alkalinity.

Acidity: Acidity of the water is its capacity to neutralize a strong base to a fixed pH and is mostly due to the presence of strong mineral acids, weak acids, and the salts of strong acids & weak bases. Determination of acidity is significant as it causes corrosion and influences chemical and biochemical reactions. Acidity can be determined by titrating the sample with a strong base such as NaOH using methyl orange or phenolphthalein as an indicator.

Dissolved oxygen (DO): Dissolved oxygen is one of the most important parameters in water quality assessment and reflects the physical and biological processes prevailing in the waters. Its presence is essential to maintain higher forms of biological life in the water and the effects of a waste discharge in a water body are largely determined by the oxygen balance of the system. Low oxygen in water can kill fish and other organisms present in water. The concentration of oxygen will also reflect whether the processes undergoing are aerobic or anaerobic low oxygen concentrations are generally associated with heavy contamination by organic matter. In such condition oxygen, sometimes, totally disappears from the water.

COD: COD measures the oxygen needed for the chemical oxidation of organic matter using a strong chemical oxidant. High COD levels can lead to oxygen depletion due to microbial decomposition, which can harm aquatic life. The COD test is advantageous over the BOD test because it provides results in approximately 5 hours, compared to the 5 days required for the BOD test.

BOD: BOD, measured in mg/L, indicates the level of organic material contamination in water. It represents the amount of dissolved oxygen needed for the biochemical breakdown of organic compounds and the oxidation of some inorganic substances, such as iron and sulphate. The standard test for BOD is usually carried out over a period of five days.

TDS: The difference between total solids and suspended solids is used to determine filterable solids by analyzing the filtrate and following the same procedure. In a water sample, this can also be estimated through conductivity measurement. According to IS: 10500-2012, the acceptable limit for total solids is 500 mg/l, and the permissible limit is 2000 mg/l.

Total Hardness: According to IS: 10500-2012, the desirable limit for water hardness is 200 mg/l, and the permissible limit is 600 mg/l. Hardness in water can cause scale formation in utensils, hot water systems, and boilers, as well as soap scum. The primary sources of water hardness are dissolved calcium and magnesium from soil and aquifer minerals containing limestone or dolomite. Hard water can be treated using softeners, ion exchangers, and reverse osmosis processes. The degree of hardness in drinking water is classified based on the equivalent CaCO3 concentration as follows: soft (0-60 mg/l), medium (60-120 mg/l), hard (120-180 mg/l), and very hard (greater than 180 mg/l).

Calcium: Calcium is one of the most abundant substances in natural water. Being present in high quantities in the rocks, it is leached from there to contaminate the water. Disposal of sewage and industrial wastes are also important sources of calcium. The concentration of the calcium is reduced at higher pH due to its precipitation as CaCO3.It is measured by complexometric titration with a standard EDTA solution using Patton's and Reeder's indicator at a pH of over 12.0. This pH level is achieved by adding a fixed volume of 4N sodium hydroxide. The volume of the titrant (EDTA solution) used against a known volume of the sample determines the calcium concentration in the sample.

Magnesium: Magnesium occurs in all kinds of natural waters with calcium, but its concentration remains generally lower than the calcium. Sewage and industrial wastes are also important contributors of magnesium. It is supposed to be non-toxic the concentrations generally met within natural waters High concentrations may be cathartic and diuretic for the initial user. It is also measured using complexometric titration with a standard EDTA solution and Eriochrome Black T as the indicator under buffer conditions of pH 10.0. The buffer solution, composed of ammonium chloride and ammonium hydroxide, stabilizes the pH during titration.

Fluoride: Groundwater has a higher fluoride content than surface water. The primary fluoride sources in groundwater are various fluoride-containing rocks. The actual concentration of fluoride in drinking water depends on the air temperature because ambient air temperature influences the amount of water that people.

Iron: All kinds of water including groundwater have appreciable quantities of iron. Iron has a microbial significance since a few microorganisms such as crenothrix, Leptothrix, etc can utilize dissolved iron as an energy source and convert ferrous into ferric hydroxide. This gives a rusty appearance to the waters. Although iron has little concern as a health hazard, but is still considered as a nuisance in excessive quantities. Is determined by flame atomic absorption spectrometer

Arsenic: Arsenic is a heavy metal present in trace amounts, which is highly toxic even at very low concentrations, and causes serious physiological disorders. Arsenic tends to accumulate in body tissues to cause arsenosis. It is determined by a flame atomic absorption spectrometer.

Electric Conductivity: Conductivity shows a significant correlation with ten parameters such as temperature, pH value, alkalinity, total hardness, calcium, total solids, total dissolved solids, chemical oxygen demand, chloride, and iron concentration of water. It is measured with the help of an EC meter which measures the resistance offered by the water between two platinized electrodes. The instrument is standardized with known values of conductance observed with standard KCl solution.

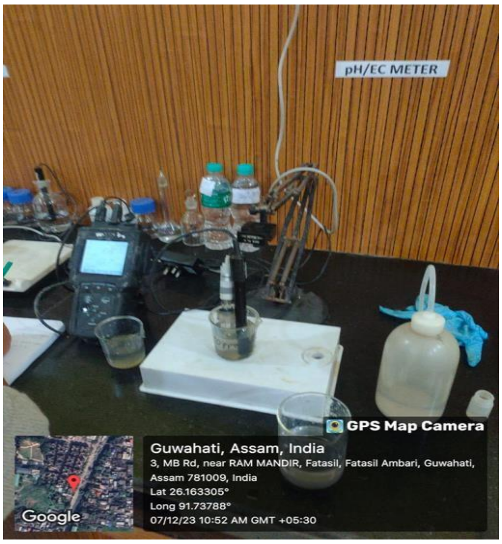


Fig.3.5: Determining of groundwater samples

3.6 Determination of heavy metals:

Determining the concentrations of cadmium, arsenic, manganese, lead, zinc, chromium, and nickel in sediment requires employing various analytical methods. Typically, sediment samples are first collected and then processed using acid digestion to extract metals from the sediment matrix. Techniques such as Inductively Coupled Plasma Mass Spectrometry (ICP-MS) or Atomic Absorption Spectroscopy (AAS) are commonly used for precise quantification due to their ability to detect trace metals with high sensitivity and specificity. Rigorous quality control procedures, including the use of certified reference materials and blank samples, are essential to ensure the accuracy and reliability of the results. Analysing these metal concentrations in sediment provides valuable insights into the sources of environmental pollution, potential ecological impacts, and risks to both human health and aquatic ecosystems.

3.7 Analysis of the test results by using multivariate statistical tools:

Microsoft Excel, SPSS 27, and Origin 2024 were used to analyse groundwater and sediment datasets in the Bharalu river's vicinity. Multivariate statistical analysis, including principal component analysis (PCA) and hierarchical cluster analysis (HCA), was performed to identify the sources and governing factors causing the contamination of the Bharalu river.

Methods to be followed for determinations of Physico-chemical parameters are summarized in tabular form which is shown in the table below

Table 3.1: Determination of physiochemical parameters:

Sl No.	Parameters	Units	Methods of test ref. to
1	pH	-	IS 3025 Part 11 (1983)
2	Turbidity	NTU	IS 3025 Part 10 (1984)
3	Chlorides	mg/L	IS 3025 Part 32 (1998)
4	Total Alkalinity (as $CaCO_3$)	mg/L	IS 3025 Part 23 (1986)
5	Acidity	mg/L	IS 3025 Part 22 (1986)
6	Dissolved oxygen	mg/L	IS 3025 Part 38 (1989)
7	Total dissolved solids	mg/L	IS 3025 Part 16 (1984)
8	COD	mg/L	IS 3025 Part 58 (2006)
9	BOD	mg/L	IS 3025 Part 44 (1993)
10	Electric conductivity	μ/cm	IS 3025 Part 14
11	Total hardness (as $CaCO_3$)	mg/L	IS 3025 Part 21 1983
12	Calcium	mg/L	IS 3025 Part 40 (1991)
13	Magnesium	mg/L	IS 3025 Part 46 (1994)
14	Flouride	mg/L	FSSAI Manual 2016 Sec A, III, B,2
15	Iron	mg/L	FSSAI Manual 2016 Sec A, III, B,2
16	Arsenic	mg/L	FSSAI Manual 2016 Sec A, III, B,2

Table 3.2: Water quality specification for drinking water (Groundwater) as per (IS 10500:2012):

Sl No.	Parameters	Units	Acceptable Limit	Permissible Limit
1.	pH	No unit	6.5-8.5	No relaxation
2	Turbidity	NTU	1	5
3	Chloride	mg/L	250	1000
4.	Total Alkalinity (as $CaCO_3$)	mg/L	200	600
5.	Acidity	mg/L	NA	NA
6.	DO	mg/L	NA	NA
7.	TDS	mg/L	500	2000
8.	COD	mg/L	NA	NA
9.	BOD	mg/L	NA	NA
10.	Electric Conductivity	mS/L	NA	NA
11.	Total Hardness (as $CaCO_3$)	mg/L	200	300
12.	Calcium	mg/L	75	200
13.	Magnesium	mg/L	30	300
14.	Flouride	mg/L	1	1.5
15.	Iron	mg/L	0.3	No relaxation
16	Arsenic	mg/L	0.01	0.05

Table 3.3: Sediment quality specification for sediment as per WHO (2012):

Sl No.	Metals	Unit	Acceptable limits
1	As	ppm	NA
2	Cd	ppm	6
3	Cr	ppm	25
4	Mn	ppm	NA
5	Ni	ppm	20
6	Pb	ppm	NA
7	Zn	ppm	123

Below table 3.4 and 3.5 are the test results of the groundwater and sediment

Table 3.4: Test results for the groundwater parameters:

Parameter	Unit	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
pH	-	7.01	6.01	7.029	7.1	7.285	7.6	7.9	7.5
Turbidity	NTU	7.4	0.1	5	0	2	5	9	8
Chloride	mg/L	177.99	124.95	72.2	6.9	58.96	105	127.8	147.68
Total Alkalinity (as CaCO3)	mg/L	168	90	153.3	148	178.5	180	188	178
Acidity	mg/L	14	146	34	144	18	14	10	16
Dissolved oxygen	mg/L	5.7	9.02	4.8	10	3.6	1.22	4.9	4.8
Total dissolved solid	mg/L	109.37	460	453	230	625	222	245	250
COD	mg/L	50	150	32	20	16	16.4	12	10
BOD	mg/L	1.2	1.22	6.2	3.98	3.4	2.2	1.5	1.6
Electric conductivity	µ/cm	211.2	890.8	574	345	663	332	385	355
Total hardness (as CaCO3)	mg/L	208	200	183.02	132	213.21	240	190	224
Calcium	mg/L	90	80	45.33	79.9	67.1	200	166	130
Magnesium	mg/L	118	120	137.69	52.1	146.11	40	24	94
Flouride	mg/L	2.9	0.8	1.9	0.7	2.1	2.6	2.75	2.4
Iron	mg/L	BDL	0.45	0.744	0.009	BDL	0.6	0.8	0.75
Arsenic	mg/L	0.0004	0.0005	0.0009	0.0055	0.0002	0.0001	0.0001	0.0001

Table 3.5: Test results of Sediment:

Heavy metals	Unit	Station 1	Station 2	Station 3	Station 4
As	ppm	8	9	8	9
Cd	ppm	3	3	86	73
Cr	ppm	101	122	3	BDL
Mn	ppm	599	642	481	695
Ni	ppm	68	82	58	50
Pb	ppm	77	40	62	56
Zn	ppm	431	272	406	328

3.8 Calculation of pollution indices of heavy metals (Sediment)

Table 3.6: Geo-accumulation index: Station 1 Bharalumukh

Heavy Metals	C_n	Constant	B_n	Constant × B_n	$\frac{C_n}{constant \times B}$	$\log \frac{C_n}{\text{Constant x } B_n}$	Igeo	Index class	Geo Accumulation Index (Pollution Level)
As	8	1.5	13	19.5	0.410	-0.387	Igeo<0	0	Uncontaminated
Cd	3	1.5	0.3	0.45	6.667	0.824	0<Igeo <1	1	Uncontaminated to moderately contaminated
Cr	101	1.5	90	135	0.748	-0.126	Igeo<0	0	Uncontaminated
Mn	599	1.5	850	1275	0.470	-0.328	Igeo<0	0	Uncontaminated
Ni	68	1.5	68	102	0.667	-0.176	Igeo<0	0	Uncontaminated
Pb	77	1.5	20	30	2.567	0.409	0<Igeo <1	1	Uncontaminated to moderately contaminated
Zn	431	1.5	95	142.5	3.025	0.481	0<Igeo <1	1	Uncontaminated to moderately contaminated

Table 3.7: Geo-accumulation index: Station 2 -Fatasil

Heavy Metals	C_n	Constant	B_n	Constant × B_n	$\frac{C_n}{constant \times B_n}$	$\log \frac{C_n}{\text{Constant x B}}$	Igeo	Index class	Geo Accumulation Index (Pollution Level)
As	9	1.5	13	19.5	0.462	-0.336	Igeo<0	0	Uncontaminated
Cd	3	1.5	0.3	0.45	6.667	0.824	0<Igeo <1	1	Uncontaminated to moderately contaminated
Cr	122	1.5	90	135	0.904	-0.044	Igeo<0	0	Uncontaminated
Mn	642	1.5	850	1275	0.504	-0.298	Igeo<0	0	Uncontaminated
Ni	82	1.5	68	102	0.804	-0.095	Igeo<0	0	Uncontaminated
Pb	40	1.5	20	30	1.333	0.125	0<Igeo <1	1	Uncontaminated to moderately contaminated
Zn	272	1.5	95	142.5	1.909	0.281	0<Igeo <1	1	Uncontaminated to moderately contaminated

Table 3.8: Geo-accumulation index: Station 3 -Ulubari

Heavy Metals	C_n	Constant	B_n	Constant × B_n	$\frac{C_n}{constant \times B_n}$	$\log \frac{C_n}{\text{Constant x}}$	I_{geo}	Index class	Geo Accumulation Index (Pollution Level)
As	8	1.5	13	19.5	0.410	-0.387	I_{geo} <0	0	Uncontaminated
Cd	86	1.5	0.3	0.45	191.111	2.281	2< I_{geo} <3	3	Moderately to highly contaminated
Cr	3	1.5	90	135	0.022	-1.653	I_{geo} <0	0	Uncontaminated
Mn	481	1.5	850	1275	0.377	-0.423	I_{geo} <0	0	Uncontaminated
Ni	58	1.5	68	102	0.569	-0.245	I_{geo} <0	0	Uncontaminated
Pb	62	1.5	20	30	2.067	0.315	0< I_{geo} <1	1	Uncontaminated to moderately contaminated
Zn	406	1.5	95	142.5	2.849	0.455	0< I_{geo} <1	1	Uncontaminated to moderately contaminated

Table 3.9: Geo-accumulation index: Station 4 -Ambikagiri Nagar

Heavy Metals	C_n	Constant	B_n	Constant × B_n	$\frac{C_n}{constant \times}$	$\log \frac{C_n}{\text{Constant x } B_n}$	Igeo	Index class	Geo Accumulation Index (Pollution Level)
As	9	1.5	13	19.5	0.462	-0.336	Igeo<0	0	Uncontaminated
Cd	73	1.5	0.3	0.45	162.222	2.210	2<Igeo <3	3	Moderately to highly contaminated
Mn	695	1.5	850	1275	0.545	-0.264	Igeo<0	0	Uncontaminated
Ni	50	1.5	68	102	0.490	-0.310	Igeo<0	0	Uncontaminated
Pb	56	1.5	20	30	1.867	0.271	0<Igeo <1	1	Uncontaminated to moderately contaminated
Zn	328	1.5	95	142.5	2.302	0.362	0<Igeo <1	1	Uncontaminated to moderately contaminated

Table 3.10: Enrichment factor: Station 1 -Bharalumukh

Heavy Metals	Cn	Bn	(Metal/Mn) Cn	(Metal/Mn) Bn	EF	Class	Degree
As	8	13	0.013	0.015	0.873	EF<1	No enrichment
Cd	3	0.3	0.005	0.0004	14.190	10-EF- 25	Severe
Cr	101	90	0.169	0.106	1.592	EF<3	Minor
Mn	599	850	1	1	1	EF<3	Minor
Ni	68	68	0.114	0.080	1.419	EF<3	Minor
Pb	77	20	0.129	0.024	5.463	5-EF- 10	Moderately severe
Zn	431	95	0.720	0.112	6.438	5-EF-10	Moderately severe

Table 3.11: Enrichment factor: Station 2 - Fatasil

Heavy Metals	Cn	Bn	(Metal/Mn) Cn	(Metal/Mn) Bn	EF	Class	Degree
As	9	13	0.014	0.015	0.917	EF<1	No enrichment
Cd	3	0.3	0.005	0.0004	13.240	10-EF-25	Severe
Cr	122	90	0.190	0.106	1.795	EF<3	Minor
Mn	642	850	1	1	1	EF<3	Minor
Ni	82	68	0.128	0.080	1.597	EF<3	Minor
Pb	40	20	0.062	0.024	2.648	EF<3	Minor
Zn	272	95	0.424	0.112	3.791	3-EF-5	Moderate

Table 3.12: Enrichment factor: Station 3 – Ulubari

Heavy Metals	C_n	B_n	(Metal/Mn) C_n	(Metal/Mn) B_n	EF	EF Class	Degree
As	8	13	0.013	0.015	0.873	EF<1	No enrichment
Cd	3	0.3	0.005	0.0004	14.190	10 - 25	Severe
Cr	101	90	0.169	0.106	1.592	EF<3	Minor
Mn	599	850	1.000	1.000	1.000	EF<3	Minor
Ni	68	68	0.114	0.080	1.419	EF<3	Minor
Pb	77	20	0.129	0.024	5.463	5 - 10	Moderately severe
Zn	431	95	0.720	0.112	6.438	5 - 10	Moderately severe

Table 3.13: Enrichment factor: Station 4 – Ambikagiri Nagar

Heavy Metals	C_n	B_n	(Metal/Mn) Cn	(Metal/Mn) Bn	EF	Class	Degree
As	9	13	0.013	0.015	0.847	EF<1	No enrichment
Cd	73	0.3	0.105	0.0004	297.602	EF>50	Extremely severe
Mn	695	850	1	1	1	EF<3	Minor
Ni	50	68	0.072	0.080	0.899	EF<1	No enrichment
Pb	56	20	0.081	0.024	3.424	3-EF-5	Moderate
Zn	328	95	0.472	0.112	4.223	3-EF-5	Moderate

Table 3.14: Contamination factor: Station 1- Bharalumukh

Heavy metal	C_n	C_{bn}	$CF=C_n/C_{bn}$	CF class	Contamination level
As	8	13	0.615	CF<1	Low contamination
Cd	3	0.3	10	CF>6	very high contamination
Cr	101	90	1.122	1<CF<3	Moderate Contamination
Mn	599	850	0.705	CF<1	Low contamination
Ni	68	68	1	1<CF<3	moderate Contamination
Pb	77	20	3.850	3<CF<6	Considerable Contamination
Zn	431	95	4.537	3<CF<6	considerable Contamination

Table 3.15: Contamination factor: Station 2- Fatasil

Heavy metal	C_n	C_{bn}	CF= Cn/Cbn	CF class	Contamination level
As	9	13	0.692	CF<1	Low contamination
Cd	3	0.3	10	CF>6	very high contamination
Cr	122	90	1.356	1<CF<3	Moderate Contamination
Mn	642	850	0.755	CF<1	Low contamination
Ni	82	68	1.206	1<CF<3	moderate Contamination
Pb	40	20	2	1<CF<3	moderate Contamination
Zn	272	95	2.863	1<CF<3	moderate Contamination

Table 3.16: Contamination factor: Station 3 – Ulubari

Heavy metal	C_n	C_{bn}	$CF=C_n/C_{bn}$	CF class	Contamination level
As	8	13	0.615	CF<1	Low contamination
Cd	86	0.3	286.667	CF>6	Very high contamination
Cr	3	90	0.033	CF<1	Low contamination
Mn	481	850	0.566	CF<1	Low contamination
Ni	58	68	0.853	CF<1	Low contamination
Pb	62	20	3.100	1<CF<3	Moderate contamination
Zn	406	95	4.274	3<CF<6	Considerable contamination

Table 3.17: Contamination factor: Station 4 - Ambikagiri Nagar:

Heavy metal	C_n	C_{bn}	$CF=C_n/C_{bn}$	CF class	Contamination level
As	9	13	0.692	CF<1	Low contamination
Cd	73	0.3	243.333	CF>6	Very high contamination
Mn	695	850	0.818	CF<1	Low contamination
Ni	50	68	0.735	CF<1	Low contamination
Pb	56	20	2.800	1<CF<3	Moderate contamination
Zn	328	95	3.453	3<CF<6	Considerable contamination

Table 3.18: Pollution load index (PLI)

Stations	As	Cd	Cr	Mn	Ni	Pb	Zn	PLI	Pollution
Bharalumukh	0.615	10	1.22	0.705	1.122	3.85	4.537	1.55	Pollution exists
Fatasil	0.692	10	1.356	0.755	1.206	2	2.863	1.521	Pollution exists
Ulubari	0.615	286.667	0.033	0.566	0.853	3.1	4.274	2.254	Pollution exists
Ambikagiri Nagar	0.692	243.333	NA	0.818	0.735	2.8	3.453	2.512	Pollution exists

All station PLI are greater than (>) 1

CHAPTER 4

ANALYSIS OF THE TEST RESULTS

4.1 INTRODUCTION:

Several approaches have been developed for assessing groundwater and sediment, including pollution indices and multivariate statistical tools. Pollution indices are essential for evaluating contamination levels in sediments, providing quantitative measures by comparing contaminant concentrations to predefined baseline levels or standards. Commonly used indices include the geo-accumulation Index (I_{geo}), contamination factor (CF), pollution load index (PLI), and enrichment factor (EF). These indices help in understanding the extent of sediment contamination and its potential ecological risks.

Multivariate statistical tools analyse complex datasets from groundwater and sediment studies, identifying patterns, relationships, and sources of pollution. These tools help decipher the multivariate nature of environmental data, enabling meaningful conclusions about contamination quality and sources. Methods such as hierarchical cluster analysis (HCA) and principal component analysis (PCA) are used in this study.

4.2. Analysis of the test results:

4.2.1 Analysis of the results of pollution indices:

Table 4.1: Geo-accumulation index classes:

Location	As	Cd	Cr	Mn	Ni	Pb	Zn
Bharalumukh	0	1	0	0	0	1	1
Fatasil	0	1	0	0	0	1	1
Ulubari	0	3	0	0	0	1	1
Ambikagiri Nagar	0	3	**NA**	0	0	1	1

Tables 4.1 present the I_{geo} classes for the four studied stations. Where arsenic (As), chromium (Cr), manganese (Mn), and nickel (Ni) indicate no contamination at any of the stations. Whereas lead (Pb) and zinc (Zn) shows uncontaminated to moderate contamination at Bharalumukh, Fatasil, Ulubari, and Ambikagiri Nagar. Cadmium (Cd) shows moderately to

high contamination at Ulubari, and Ambikagiri Nagar. And uncontaminated to moderate contamination in Bharalumukh and Fatasil.

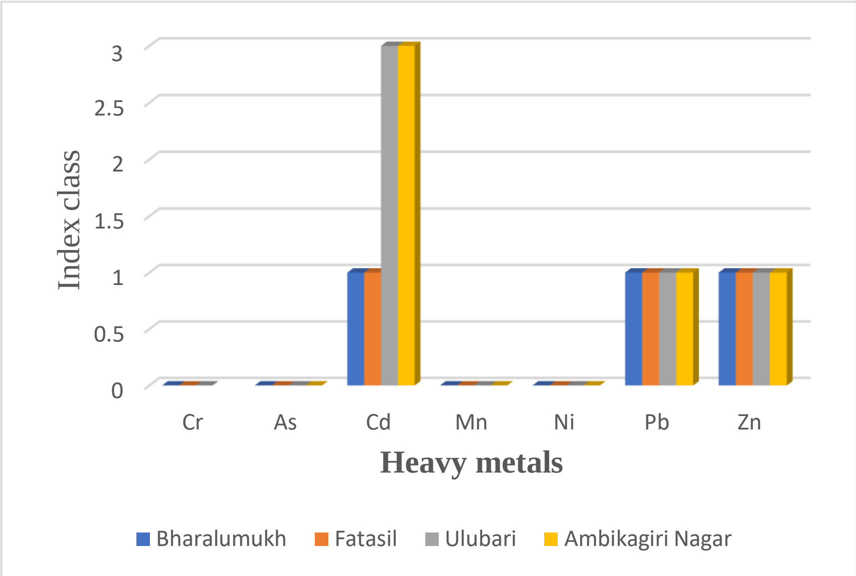


Fig. 4.1: Graphical representation of geo-accumulation index classes

Table 4.2: Toxicity level of the Enrichment factor:

Location	As	Cd	Cr	Mn	Ni	pb	Zn
Bharalumukh	No enrichment	Severe	Minor	Minor	Minor	Moderately to severe	Moderately to severe
Fatasil	No enrichment	Severe	Minor	Minor	Minor	Minor	Moderate
Ulubari	No enrichment	Severe	Minor	Minor	Minor	Moderately to severe	Moderately to severe
Ambikagiri Nagar	No enrichment	Extremely Severe	NA	Minor	No enrichment	Moderate	Moderate

Tables 4.2 present the Enrichment Factor of various metals in the four studied areas of the Bharalu River. Cadmium (Cd) shows severe enrichment at Bharalumukh, Fatasil, and Ulubari, and extremely severe enrichment at Ambikagiri Nagar. Arsenic (As) shows no enrichment at any of the stations. Chromium (Cr) and nickel (Ni) exhibit minor contamination at Bharalumukh, Fatasil, and Ulubari while showing no contamination at Ambikagiri Nagar. Manganese (Mn) remains uncontaminated in all four stations. Lead (Pb) and zinc (Zn) shows moderately to severe contamination at Bharalumukh and Ulubari, moderate contamination at Ambikagiri Nagar, and at Fatasil, zinc (Zn) shows moderate contamination while lead (Pb) shows minor contamination.

Table 4.3: Level of contamination of Contamination Factor:

Location	As	Cd	Cr	Mn	Ni	pb	Zn
Bharalumukh	Low contamination	very high contamination	Moderate Contamination	Low contamination	moderate Contamination	Considerable Contamination	considerable Contamination
Fatasil	Low contamination	very high contamination	Moderate Contamination	Low contamination	moderate Contamination	Moderate Contamination	moderate Contamination
Ulubari	Low contamination	Very High contamination	Low contamination	Low contamination	Low contamination	Moderate contamination	Considerable contamination
Ambikagiri Nagar	Low contamination	Very high contamination	NA	Low contamination	Low contamination	Moderate contamination	Considerable contamination

Table 4.3 displays the level of contamination factors across the studied areas. Arsenic (As) and manganese (Mn) indicate low contamination levels at all the studied areas. Similarly, Cr and Ni shows low to moderate contamination in Bharalumukh, Fatasil, Ulubari, and Ambikagiri Nagar. Low contamination at Ulubari and Ambikagiri Nagar. Cr remains practically uncontaminated with a CF = 0 at Ambikagiri Nagar. Pb shows moderate contamination at Fatasil, Ulubari, and Ambikagiri Nagar, while Pb shows considerable contamination in Bharalumukh. Zinc (Zn) displays moderate contamination at Fatasil and considerable contamination in Bharalumukh, Ulubari, and Ambikagiri Nagar. Cadmium (Cd) shows very high contamination across all four studied areas, with CF values exceeding 6.

The above tables (4.1, 4.2,4.3) indicate that Cadmium (Cd) has the highest values in terms of the geo-accumulation Index, contamination factor, and enrichment factor when compared to other metals across all the studied areas. This suggests that cadmium is significantly more concentrated in these regions, pointing to a high level of contamination.

The relatively higher concentrations of cadmium found in the analysed samples are reflective of anthropogenic, or human-induced, effects. These high levels of cadmium can be primarily attributed to several key sources of pollution. One major source is the burning of fossil fuels. Another significant source is the wear and tear of vehicle tires, which also contribute cadmium to the environment. These human activities result in the increased presence of cadmium in the environment, as evidenced by the high values observed in the study.

According to Fatoki et al. (2002) and Passos et al. (2010), Cadmium (Cd) is one of the most hazardous pollutants due to its highly toxic effects on both the environment and human health. Its toxicity is significant even at low concentrations, making it a critical contaminant to monitor and control.

Zhou et al. (2008) studied that the distribution of cadmium in sediment is not uniform but regional. This regional distribution is significantly influenced by inputs from upstream areas. Cadmium tends to accumulate in specific locations where it is transported by water flow from upstream sources, such as industrial discharges, agricultural runoff, and urban wastewater. These upstream inputs cause an uneven distribution of cadmium in sediment, resulting in localized areas of higher contamination.

Table 4.4: Pollution load index of different stations:

Stations	PLI	Pollution
Bharalumukh	1.55	Pollution Exist
Fatasil	1.521	Pollution Exist
Ulubari	2.254	Pollution Exist
Ambikagiri Nagar	2.512	Pollution Exist

Table 4.4 shows the PLI values for the studied areas. A PLI value greater than 1 indicates contamination, while a value less than 1 indicates that the sediment is uncontaminated. This study reveals contamination in terms of PLI in all four areas. Bharalumukh and Fatasil show less contamination compared to Ulubari and Ambikagiri Nagar. The overall ranking of sites based on PLI is Ambikagirinagar > Ulubari > Fatasil > Bharalumukh. The studied areas are highly urbanized, with densely populated residential and commercial zones, contributing to higher pollution levels due to mixed liquid and solid waste from urban discharges. The graphical representation is shown in fig.4.2

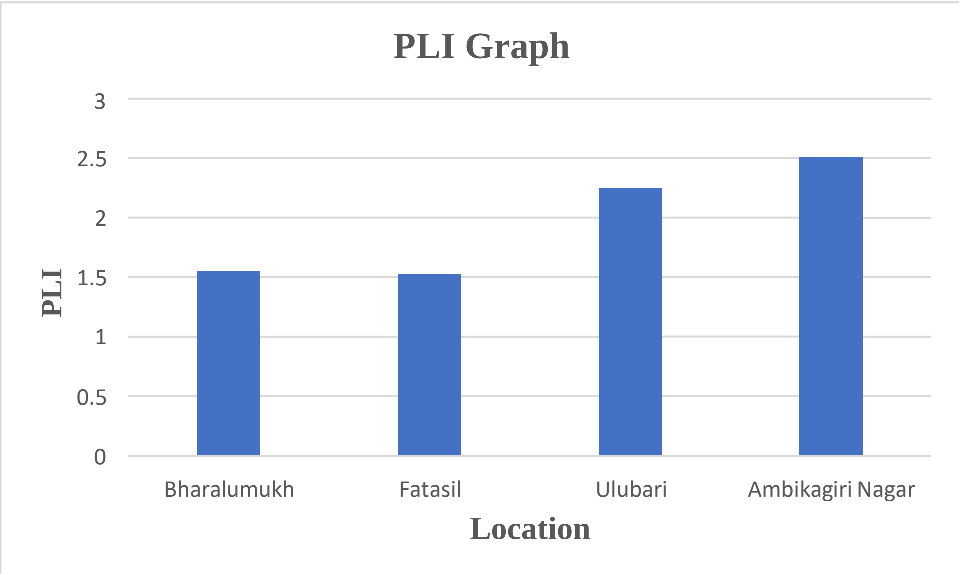


Fig.4.2: Graphical representation of pollution load index

4.2.2 Multivariate statistical tools:

4.2.2.1 Hierarchical cluster analysis (HCA):

Cluster Analysis (CA) categorizes objects into classes or clusters based on their similarities shown in tables 4.6 and 4.10 within a class and dissimilarities between different classes. The results of CA assist in interpreting the data and identifying patterns. In hierarchical clustering, clusters are created sequentially, starting with the most similar pair of objects and progressively forming higher-level clusters. Hierarchical agglomerative CA was conducted on the normalized data set (mean observations over the entire period) using a single linkage method, with squared Euclidean distances serving as the measure of similarity.

4.2.2.1.1 Descriptive statistics:

Basic statistical analyses were conducted to provide an initial overview of the data. tables 4.5 and 4.9 below present the descriptive statistics for the various water quality and sediment variables, detailing measures such as mean, median, standard deviation, and range.

First case: Sediment

Table 4.5: Descriptive statistics:

	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
As	8.333	0.577	25	8	8	9
Cd	30.667	47.920	92	3	3	86
Cr	75.333	63.516	226	3	101	122
Mn	574.000	83.361	1722	481	599	642
Ni	69.333	12.055	208	58	68	82
Pb	59.667	18.610	179	40	62	77
Zn	369.667	85.500	1109	272	406	431

Table 4.6: Similarity:

Similarity	Label
59.857	Bharalumukh
59.857	Fatasil
100	Ulubari

Below fig. 4.3 shows the dendrogram showing 3 sampling locations

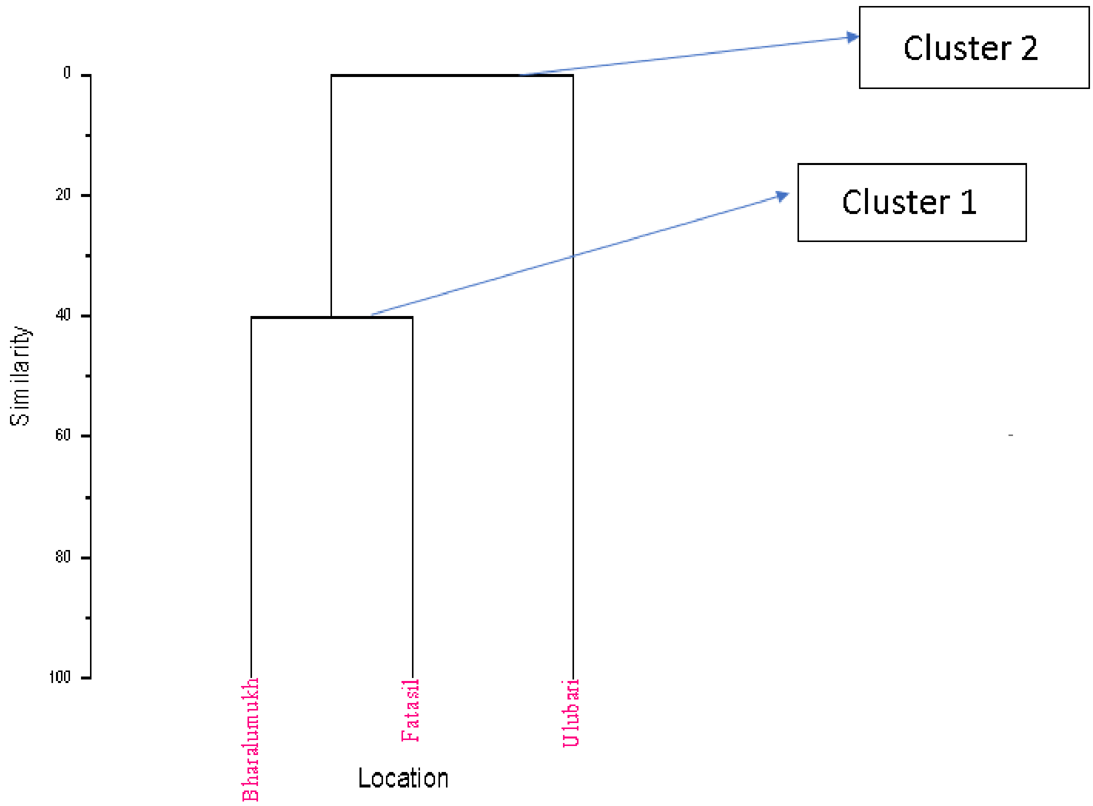


Fig.4.3: Dendrogram

In Cluster Analysis, the four monitoring stations—Bharalumukh, Fatasil, Ulubari, and Ambikagiri Nagar are classified into two statistically significant clusters based on seven different parameters. The clustering is done using squared Euclidean distance as the resemblance measure. Cluster 1 includes Bharalumukh and Fatasil, grouped due to their similarity levels (Table 4.6). Where cluster 2 includes only Ulubari because it has no similarity with Bharalumukh and Fatasil. Ambikagiri Nagar did not form a cluster due to the Cr levels being below detectable limits (BDL).

Fatasil, a commercially significant area of the city, hosts numerous commercial establishments along with small and medium-scale industries, contributing substantially to environmental pollution. Zhou et al. (2008) identified that chromium (Cr), zinc (Zn), and manganese (Mn) primarily originate from industrial wastewater extraction, designating them as "local industrial factors". Bharalumukh, where all the waste are gathered, is a densely populated old commercial district with limited industrial activity, which significantly contributes to the pollution levels of lead (Pb) and zinc (Zn), which are indicators of industrial contamination. (Alveraz et al., 2014). Xiao et al. (2021) found that the enrichment of zinc (Zn) and lead (Pb) in river sediments is associated with industrial emissions and urban pollution,

4.2.2.2 Principal component analysis (PCA):

Principal Component Analysis (PCA) is a powerful tool for recognizing patterns by reducing a large dataset of intercorrelated variables into a smaller set of independent variables. This is achieved through the extraction of eigenvalues and eigenvectors from the original variables' covariance matrix. The resulting Principal Components (PCs) are orthogonal variables derived by multiplying the original correlated variables with the eigenvectors, which contain loadings or weightings. PCs represent weighted linear combinations of the original variables, capturing the most significant parameters and describing the dataset while minimizing information loss. PCA effectively transforms a complex, intercorrelated dataset into a concise set of independent components, thereby aiding in data reduction and enhancing pattern recognition capabilities.

4.2.2.2.1 Scree plot:

Fig. 4.4 and 4.8 present the scree plot of the components plotted against their eigenvalues. The red line indicates the first two significant principal components, each with eigenvalues of 1 or above.

Below fig.4.4 and fig. 4.5 shows the scree plot and biplot

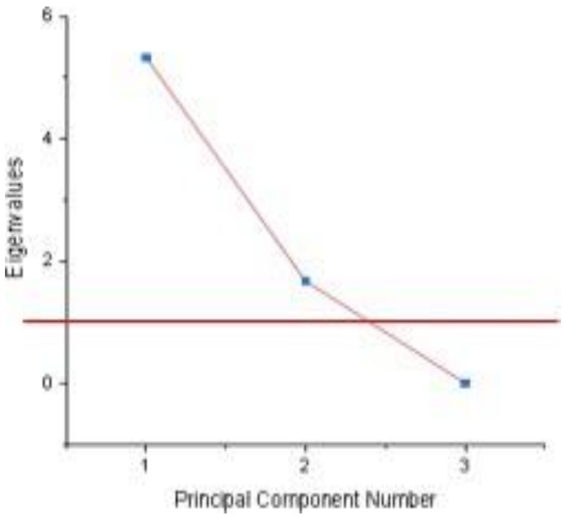


Fig. 4.4: Scree plot

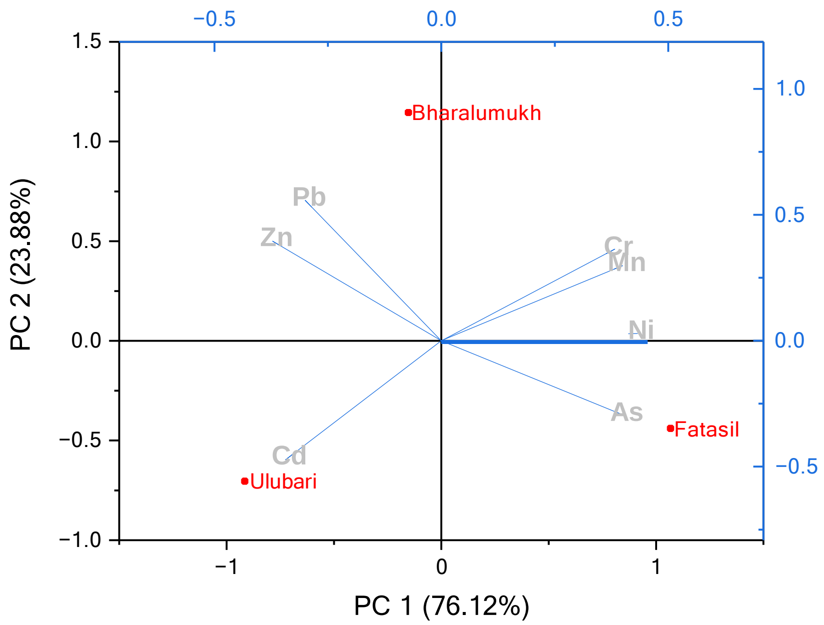


Fig. 4.6 Biplot

Table 4.7: Metal-to-metal correlation coefficient matrix:

	As	Cd	Cr	Mn	Ni	Pb	Zn
As	1						
Cd	-0.5	1					
Cr	0.636	-0.986	1				
Mn	0.706	-0.966	0.996	1			
Ni	0.910	-0.814	0.899	0.936	1		
Pb	-0.915	0.109	-0.271	-0.361	-0.666	1	
Zn	-0.989	0.368	-0.517	-0.595	-0.840	0.964	1

(Correlation is significant at the 0.05 level)

A correlation analysis was performed on the analytical data set to examine all possible correlations between the study variables. This simplified statistical tool demonstrates the degree of dependency between two variables. A correlation coefficient value up to 0.5 indicates no significant correlation, while a value of ±0.5 signifies a significant linear correlation, and a value of ±0.8 indicates a very strong linear correlation. In simple the correlation study was carried out to establish a relationship between the parameters.

The analysis identified significant correlations among four pairs, with positive correlation values ranging from 0.63 to 0.99. Table 4.7 presents the correlation matrix for the 7 variables. The correlation coefficient matrix shows a significant positive correlation of Cr, Mn, and Ni with As. Mn and Ni with Cr, and a significant positive correlation of Ni and Mn, which implies a close association with each other. Zn shows a significant positive correlation with pb indicating the same origin or source.

According to Alveraz et. al. 2014 and Xiao et al 2021, Pb and Zn are indicators of industrial pollution. Zn, Mn, Cr, Pb enrichment in river sediments are linked to industrial emissions, metropolitan pollution, and natural resources. The areas surrounding the Bharalu river are notorious for disposing of residential waste and garbage into the river. It carries a substantial portion of the city's municipal and other refuse and also functions as a drainage system for stormwater runoff. (Tang et al 2010) find that the lack of a comprehensive sewage treatment and disposal system in the city further endangers the river ecosystem. Zhou et al 2008 stated that the pattern of distribution of Mn is affected by a mixed source. Cr, Zn, and Mn have a majority of contribution from the industrial extraction of wastewater and can be concluded as a “local industrial factor”. Ni shows a strong correlation with As, Cr, and Mn which can be due to several factors like geochemical behavior, source of pollution, and

Environment conditions among them. Other shows no significant association with each other indicating different origins or sedimentological features.

Table 4.8: Principal Component Analysis with two extracted components:

Heavy metals	PC1	PC2
As	0.433	0.901
Cd	-0.997	-0.075
Cr	0.971	0.239
Mn	0.944	0.33
Ni	0.768	0.64
Pb	-0.033	-0.999
Zn	-0.297	-0.955
Eigenvalues	5.329	1.671
% of Variance	76.12	23.88
Total Variance	76.12	100

Principal Component Analysis (PCA) using the Varimax Kaiser normalized rotation method was performed on seven heavy metals—As, Cd, Cr, Mn, Ni, Pb, and Zn—from the four studied areas. The component analysis identified two significant principal components, with only components having an eigenvalue of 1 or above being considered, as described by Liu CW et al. (2003). Two major components were identified, representing 100% of the total variance (Table 4.8). Fig. 4.4 presents the scree plot of the two components plotted against their eigenvalues. The red line indicates the first two significant principal components, each with eigenvalues of 1 or above.

On PC1, Cr, Mn, and Ni exhibit high loadings, while Pb, Zn, and Cd have negative factor loadings, explaining 76.12% of the total variance. It indicates pollution from domestic and industrial waste. On PC2, As has high loading with 23.88% of the total variance indicating that pollution from the natural and inorganic sources.

Jayaprakash et al. (2014) state that the high loadings of nickel (Ni), manganese (Mn), and chromium (Cr) PC1 suggest severe sediment contamination from both home and industrial effluents in metropolitan regions. This indicates that the main sources of these heavy metals in the sediment are likely residential sources like household wastewater as well as waste discharges from industry operations like manufacturing and processing plants. The combined effects of home and industrial pollution on the quality of sediment in metropolitan areas are shown in the elevated levels of Cr, Mn, and Ni. Stanimirova et al. (1999), find that the high loading of As, Cr, Mn, and Ni indicates a “natural inorganic factor”.

Second case: Groundwater

4.2.2.3 Hierarchical Cluster Analysis (HCA):

Table 4.9: Descriptive statistics:

	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
pH	7.189	0.662	43.139	6.01	7.3	7.9
Turbidity	4.516	3.810	27.1	0	5	9
Chloride	97.421	51.174	584.53	6.9	114.975	147.68
TA	156.217	36.086	937.3	90	165.65	188
Acidity	60.666	65.844	364	10	25	146
DO	5.79	3.218	34.74	1.22	4.85	10
TDS	310	113.946	1860	222	247.5	460
COD	40.066	54.415	240.4	10	18.2	150
BOD	2.7833	1.946	16.7	1.22	1.9	6.2
EC	480.3	220.169	2881.8	332	370	890.8
TH	194.837	37.492	1169.02	132	195	240
Calcium	116.872	58.891	701.23	45.33	105	200
Magnesium	77.965	46.073	467.79	24	73.05	137.69
Flouride	1.858	0.905	11.15	0.7	2.15	2.75
Iron	0.558	0.298	3.353	0.009	0.672	0.8
Arsenic	0.0012	0.00213	0.0072	1.00E-04	3.00E-04	0.0055

Table 4.10: Similarity:

Similarities	Label
2.308	Jonali Path
2.308	Ganeshguri
2.936	Dispur
14.848	Lachit Nagar
36.525	Ulubari
100	Fatasil

Below fig. 4.3 shows the dendrogram showing 6 sampling locations

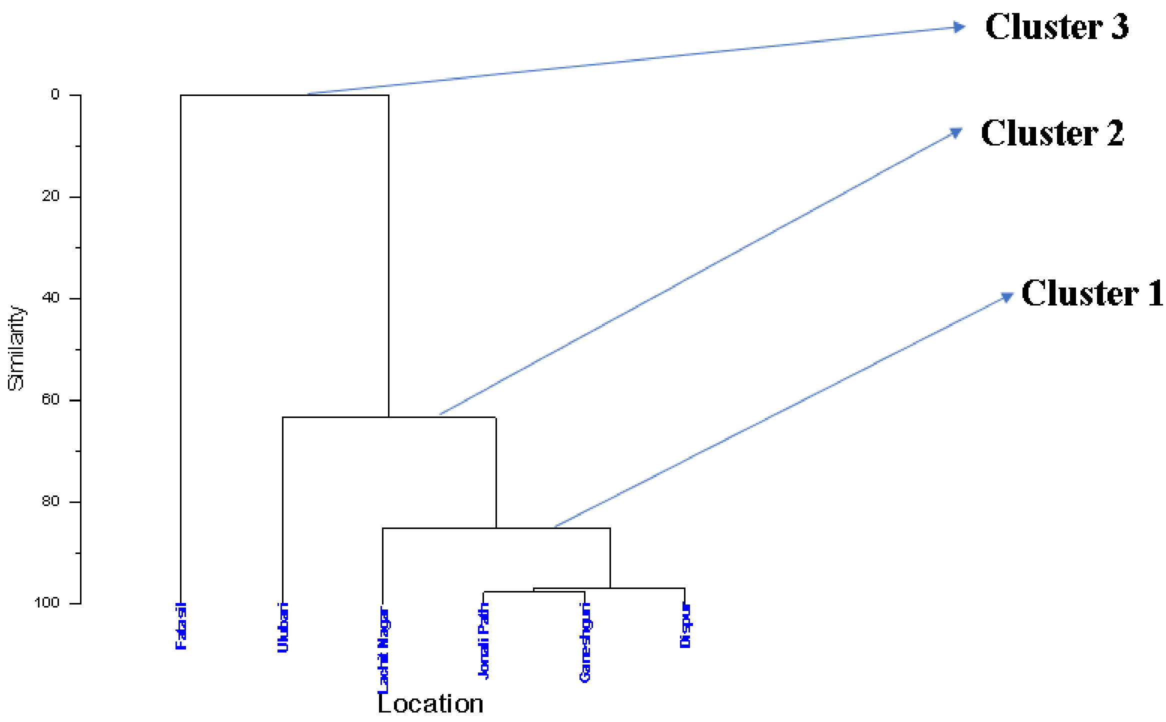


Fig.4.7: Dendrogram

It is illustrated as a dendrogram shown in Fig.4.7, grouping all seven sampling sites into three statistically significant clusters (Table 4.10)- Fatasil, Ulubari, Lachit Nagar, Jonali Path, Ganeshguri, and Dispur. Bharalumukh and Ambikagiri Nagar did not form a cluster because the iron value wasbelow the detention limit (BDL). From similarity table 4.10 we can see that Lachit Nagar, Jonali Path, Ganeshguri, and Dispur form a single group which shows as cluster 1 in dendrogram Fig. 4.7. Ulubari and Fatasil shows large dissimilarities from the other stations. So, they form into a single cluster. Cluster 2 shows Ulubari and Cluster 3 shows Fatasil. Bharalumukh and Ambikagiri Nagar did not form a cluster because the iron level was below the detention limit (BDL).

4.2.2.4 Principal component analysis (PCA):

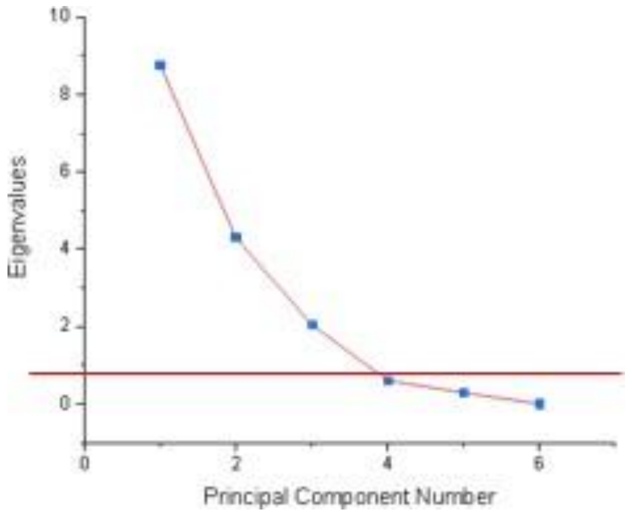


Fig 4.8: Scree plot

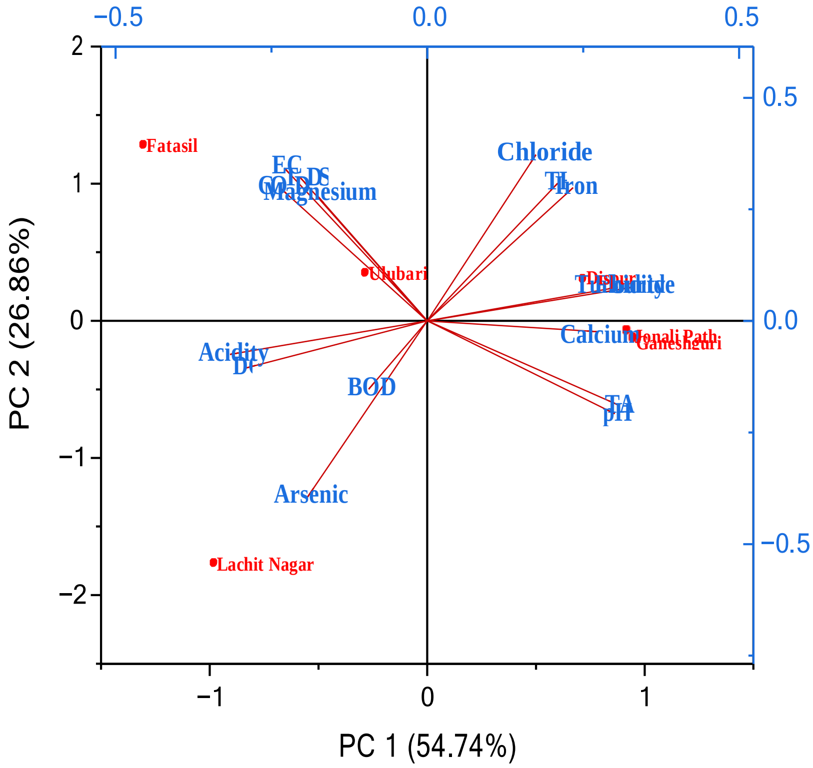


Fig. 4.9: Biplot

Table 4.11: Parameters -Parameters correlation coefficient matrix:

	pH	Turbidity	Chloride	TA	Acidity	DO	TDS	COD	BOD	EC	TH	Calcium	Magnesium	Flouride	Iron	Arsenic
pH	1															
Turbidity	0.792	1														
Chloride	0.118	0.605	1													
TA	0.991	0.812	0.134	1												
Acidity	-0.792	-0.934	-0.514	-0.838	1											
DO	-0.642	-0.708	-0.460	-0.696	0.902	1										
TDS	-0.778	-0.357	0.072	-0.737	0.331	0.287	1									
COD	-0.919	-0.618	0.180	-0.937	0.658	0.504	0.731	1								
BOD	-0.051	-0.189	-0.684	0.009	0.032	0.051	0.328	-0.261	1							
EC	-0.898	-0.499	0.193	-0.897	0.533	0.438	0.897	0.952	-0.059	1						
TH	0.206	0.500	0.812	0.261	-0.619	-0.774	-0.061	0.011	-0.489	-0.009	1					
Calcium	0.673	0.536	0.459	0.638	-0.582	-0.676	-0.718	-0.404	-0.625	-0.547	0.623	1				
Magnesium	-0.693	-0.278	0.074	-0.603	0.239	0.234	0.869	0.526	0.401	0.692	0.017	-0.771	1			
Flouride	0.817	0.937	0.581	0.840	-0.979	-0.896	-0.418	-0.618	-0.205	-0.538	0.658	0.718	-0.382	1		
Iron	0.400	0.848	0.778	0.446	-0.842	-0.717	0.138	-0.196	-0.143	-0.018	0.681	0.329	0.134	0.821	1	
Arsenic	-0.154	-0.635	-0.913	-0.190	0.660	0.678	-0.212	-0.122	0.413	-0.210	-0.868	-0.433	-0.153	-0.689	-0.901	1

(Correlation is significant at the 0.05 level)

The term correlation or covariance indicates the relationship between two variables, such as how changes in the values of one variable cause the values of the other variables to change. From table 4.11 significant positive correlations were identified among 32 pairs, with correlation values ranging positively from 0.5 to 0.952. The correlation matrix of 16 variables has been presented. In the present study, the correlation coefficient matrix shows a significant positive correlation of turbidity, Total alkalinity (TA), calcium, and flouride with pH, a significant positive correlation of turbidity, total alkalinity (TA), calcium, and flouride, which implies a close association with each other. Chloride, TA, TH, Calcium, and fluoride, and iron show a significant positive correlation with Turbidity. TH, flouride, and Iron show a significant positive correlation with Chloride. Calcium and fluoride show a significant positive correlation with TA. DO, COD, EC, and Arsenic shows a significant positive correlation with Acidity. COD, and arsenic shows a significant positive correlation with DO. COD, EC, and Magnesium shows a significant positive correlation with TDS (0.73 to 0.89). EC and magnesium show a significant positive correlation with COD. Iron shows positive significant with turbidity, chloride, TH, and fluoride.

In this study, a high correlation coefficient between TDS and EC was observed, as electrical conductance depends on dissolved salts (Agarwal et al. 2014). Consequently, Magnesium shows a positive correlation with EC. Total Hardness (TH) moderately correlates with calcium, fluoride, and iron, indicating their influence on water hardness. TH also shows a strong correlation with chloride and a moderate correlation with turbidity, indicating the influence of Chloride in TH as well as in Turbidity (Agarwal et al. 2014). The strong positive correlation of fluoride and total alkalinity (TA) with pH suggests that higher alkalinity increases fluoride levels (Adimalla, N et al. 2019). pH also correlates positively with calcium and turbidity. Turbidity correlates positively with chloride, calcium, and TH, and significantly with TA, fluoride, and iron, According to Fink, J. C., Turbidity can come from suspended sediment such as silt or clay, inorganic materials, or organic matter such as algae, plankton, and decaying material. In addition to these suspended solids, turbidity can also include coloured dissolved organic matter (CDOM), fluorescent dissolved organic matter (FDOM), and other dyes (Fink, J. C., 2005, August). This proves that turbidity of the present study area is related to the amount of chloride, calcium, fluoride, and iron which is again correlated with TA and TH. chloride shows a positive correlation with fluoride and Iron indicating a similar origin or source. chloride shows a positive correlation with fluoride and iron suggests a common source, and its significant correlation with TH indicates its impact on hardness. The high Cl contents detected in certain samples may suggest the dissolution of chloride salts (Belkhiri et al. 2011). Lowersalinity leads to higher DO concentrations as salts reduce gas solubility, and reduced microorganism activity also increases DO levels due to decreased oxygen consumption during organic matter decomposition, showing DO's strong positive correlation with acidity. Bencer et al. (2016) observed that higher TDS levels correlate strongly with increased COD, EC, and magnesium, indicating their impact on overall water or sediment salinity. Understanding these correlations is crucial for assessing water quality and environmental health, particularly in areas with high salinity affecting aquatic ecosystems and human water resources. Chen et al. (2007) found that iron strongly correlates with turbidity, total hardness (TH), and chloride, suggesting its natural occurrence in groundwater. I.A. Katsoyiannis 2006 examined that the presence of arsenic in the groundwater is thought to be geogenic, which means it occurs naturally in the earth's crust and is released through geological processes such as the weathering of arsenic-bearing minerals, volcanic activity, and the dissolution of arsenic compounds from rocks and soils. Unlike industrial pollution or agricultural runoff, this natural phenomenon is influenced by the region's geological features.

Table 4.12: Principal component Analysis with three extracted components:

Parameters	PC1	PC2	PC3
pH	-0.932	0.339	-0.028
Turbidity	-0.526	0.781	0.002
Chloride	0.203	0.817	-0.475
TA	-0.914	0.398	0.045
Acidity	0.552	-0.828	-0.096
DO	0.448	-0.786	0.022
TDS	0.883	0.138	0.417
COD	0.947	-0.137	-0.258
BOD	-0.064	-0.196	0.95
EC	0.982	0.009	-0.004
TH	0.033	0.816	-0.404
Calcium	-0.578	0.39	-0.675
Magnesium	0.766	0.166	0.534
Flouride	-0.572	0.81	-0.094
Iron	-0.05	0.976	0.079
Arsenic	-0.19	-0.949	0.238
Eigenvalues	8.759	4.297	2.048
% of Variance	54.742	26.858	12.798
Total Variance	54.742	81.6	94.398

The Principal Component Analysis identified three significant principal components, with only those with an eigenvalue of 1 or higher being evaluated, as shown in fig.4.8 considered by Liu CW et al. (2003). Principal component analysis (PCA) was performed on 16 parameters using the Varimax Kaiser normalized rotation method. A total of three components were extracted, accounting for a total variance of 94.39% (Table4.12). The first component contributed 54.74% of the total variance with an eigenvalue of 8.75 with strong positive loading for TDS, COD, EC, and Magnesium which is obvious since electrical conductance depends on dissolved salts present in the water bodies (Agarwal et al 2014) and COD due to the high organic matter concentrations. According to Usman Nasiru Usman et al. (2014), the high loading factor of conductivity is due to dissolved ions' active participation in determining groundwater quality. Magnesium, a critical variable, is linked to hydro-chemical qualities emerging from groundwater mineralization. The second principal component (PC2) has an eigenvalue of 4.29, accounting for 26.85% of the total variance. It shows strong positive loadings for Turbidity (0.781), Chloride (0.817), Total Hardness (TH) (0.816), Fluoride (0.81), and Iron (0.976). Turbidity arises from suspended sediment such as silt or clay, inorganic materials, or organic matter such as algae, plankton, and decaying material. Besides these suspended solids, turbidity can also include coloured dissolved organic matter (CDOM), fluorescent dissolved organic matter (FDOM), and other dyes (Fink, J.C 2005, Chapter 4) Furthermore, the presence of chloride could imply point source pollution from urban wastewater discharge. TH may indicate the natural origin of elements. Fluoride is a naturally occurring, non-degradable inorganic anion that can be found in many natural streams, lakes, and groundwater sources (Das et al, 2020). The third principal component (PC3) is strongly positively loaded with Biochemical Oxygen Demand (BOD) at 0.95. This component, with an eigenvalue of 2.04, explains 12.79% of the total variance. The composition of PC3 highlights the significant contribution of BOD to groundwater pollution in the area.

CHAPTER 5

CONCLUSIONS AND SCOPE FOR FUTURE STUDY

5.1 Conclusions:

The following conclusions are drawn based on the analysis and interpretation of the results obtained:

The study assessed the groundwater and sediment quality in the vicinity of the Bharalu river and investigated the heavy metal contamination in the surface sediments of urban rivers affected by human activities using various approaches. Pollution indices, including the I_{geo} index, CF, EF, and PLI, indicated moderate to high pollution levels, with cadmium (Cd) being of particular concern among all studied metals. The increased heavy metal pollution is likely due to urban discharges from the industries and commercial areas

Cluster Analysis resulted in three main clusters in groundwater and two main clusters in the sediment of the sampling stations depending upon the similarities and dissimilarities characteristic between the parameters.

PCA was employed to investigate the root of each parameter of groundwater and sediment due to nature and anthropogenic activities based on three cluster regions for groundwater and two cluster regions for sediment. Three varimax factors account for 94.39% of the total variance in the data set were found in groundwater and 100% of the total variance in the data set was found in sediment. The larger source of variance (54.72%) appears to be from water quality parameters associated with natural and anthropogenic sources and the larger source of variation (76.12%) appears to be from the sediment quality parameters associated with inorganic anthropogenic sources. Thus, it is noteworthy that PCA precisely confirms the results of CA and identifies the pollution sources.

Therefore, the results of this study demonstrate the effectiveness of multivariate statistical analysis. Furthermore, these findings can help reduce the number of samples analysed over space and time without significant loss of information. This approach will assist decision-makers in prioritizing efforts to improve water and sediment quality, which has deteriorated due to various anthropogenic activities.

5.2 Scope for Future Study:

Any comprehensive research project should include a section addressing future study scope to thoroughly explore the subject. Many rivers in Assam, such as Bhogdoi and Kolong, face daily contamination due to the absence of adequate sewage treatment plants. Moreover, urbanization, industrialization, and rapid population growth exacerbate the situation, with effluents from all domestic industries contributing to river pollution. In assessing water quality and identifying pollutant sources, multivariate statistical analysis emerges as a highly beneficial tool. This method can provide deeper insights into water quality and facilitate the development of monitoring networks or strategies for effective water resource management.

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