

**BEFORE THE NATIONAL GREEN TRIBUNAL
EASTERN ZONE BENCH, KOLKATA
ORIGINAL APPLICATION (O.A.) NO. 89/2024/EZ**

IN THE MATTER OF:

GOPINATH MAJHI

...APPLICANT

VERSUS

STATE OF ODISHA AND ORS.

...RESPONDENTS

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RESPONDENT NO. 02

THROUGH

Raman yadav

RAMAN YADAV, ADVOCATE

Address: C-167, LGF, Defence Colony

New Delhi-110024

Ph: 011-45784866

Mob: 8800457781

E-mail: officeoframanyadav@gmail.com

DATED: 28.07.2025

PLACE: NEW DELHI



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BEFORE PRADEEP K. TIWARI
NOTARY JHARSUGUDA
REGD. NO. ON-01/13
SL NO. 18 DT 28.7.25

BEFORE THE NATIONAL GREEN TRIBUNAL
EASTERN ZONE BENCH, KOLKATA
ORIGINAL APPLICATION (O.A.) NO. 89/2024/EZ

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GOPINATH MAJHI

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**ADDITIONAL AFFIDAVIT ON BEHALF OF RESPONDENT NO. 02 IN
COMPLIANCE WITH ORDER DATED 09.05.2025**

I, Sri Brajabandhu Bhoi, OAS (SAG), S/o-Late Yudhistir Bhoi aged about 53 years, working as the Additional District Magistrate (General), Jharsuguda do hereby solemnly state and affirm as under:-

1. That I am authorised to file this Additional Affidavit on behalf of Respondent No. 02 in compliance with the Order dated 05.03.2025 passed by this Hon'ble Tribunal in the instant matter.
2. That pursuant to the order dated 09.05.2025 of this Hon'ble National Green Tribunal, immediate action to ensure compliance, as detailed hereinbelow, was undertaken:
 - i. By Official letter No. 8810 dated 06.06.2025, the Tahasildar, Lakhanpur was directed to ascertain and report on whether the Odisha Power Generation Corporation Limited (OPGC), IB Thermal Power Station (ITPS), Banharpali, had engaged the TERI School of Advanced Studies (TERI-SAS), New Delhi; Development and Environment Futures Trust (DEFT), Bhubaneswar; and Sambalpur University, Burla, to conduct the *Environmental Damage Assessment Study* as mandated by this Hon'ble Tribunal in three seasonal phases i.e., Pre-Monsoon, Monsoon and Post-Monsoon.
 - ii. Accordingly, the Tahasildar, Lakhanpur, visited the site and has submitted a copy of the *Environment Damage Assessment Study Report* prepared jointly

Brajabandhu Bhoi
Addl. District Magistrate
JHARSUGUDA

PART OF AFFIDAVIT

P. N. TIWARI
NOTARY, JHARSUGUDA

by TERI-SAS, New Delhi; DEFT, Bhubaneswar; and Sambalpur University, Burla, Odisha. The said report was forwarded by the Director (Operations), OPGC, Banharpali, vide his letter bearing No. ITPS/1139/WE dated 10.07.2025.

A copy of the correspondences are annexed herewith and marked as ANNEXURE - 1.

A copy of the Environmental Damage Assessment report dated 15.07.2025 is annexed herewith and marked as ANNEXURE - 2.

3. That following are the conclusions and recommendations from the report which was conducted over the period of June 2024 to June 2025, with the final submission dated 15.07.2025:

I. Conclusions:

A. On Water Quality: Seasonal water sampling from Hirakud Reservoir showed compliance with CPCB's best use standards for pH and electrical conductivity. Arsenic remained below 10 µg/L, and lead and mercury were undetected in all samples. Iron levels rose during the monsoon and declined post-monsoon.

B. On Soil Contamination: Soil samples across all seasons had element concentrations (Na, K, Ca, Mn, Co, Ni, Cu, Zn, As, Mo, Pb, Fe, Hg, F) below Upper Continental Crustal (UCC) standards. Contamination factor and geo-accumulation index indicated low to no pollution for Zn, As, Cd, Pb, and Fe. Pollution Load Index also showed no significant cumulative contamination.

C. On Metal Mobility: Seasonal trends showed mercury as the most mobile contaminant, though levels declined post-monsoon due to natural attenuation. Localized contamination from mercury and cadmium was noted, but overall pollution levels stayed within acceptable limits.



P. N. Tiwari
Addl. District Magistrate
JHARSUGUDA

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P. N. Tiwari
P. N. TIWARI
NOTARY, JHARSUGUDA

D. On Ecological Health: Control sites showed higher plankton diversity and ecological stability, reflected in favorable Shannon, Simpson's, and Evenness Index scores. However, Experimental sites showed reduced diversity, likely due to coal-based industrial activity. However, post-monsoon data showed partial recovery through runoff and dilution, with no significant statistical change observed.

E. On Environmental Damage Estimate: The total estimated damage from the Ash Pond breach is **Rs. 8,02,06,528/-** (Rupees Eight Crore Two Lakh Six Thousand Five Hundred Twenty-Eight only), comprising:

- i. Crop loss over 3 Kharif seasons: Rs. 82,82,528/-
- ii. Environmental service loss (10 years): Rs. 1,06,51,000/-
- iii. Mature trees lost: Rs. 1,19,20,000/-
- iv. Small trees/bamboo/shrubs lost: Rs. 2,43,33,000/-
- v. Private land stock loss: Rs. 2,50,20,000/-.

II. Recommendations:

- i. While compensation for crop loss and agricultural land can follow existing OPGC/ITPS procedures, the study recommends creation of a dedicated corpus fund of not less than Rs. 5 crores by the industry. This fund should be used for alternative site development such as forest creation or degraded land restoration to benefit local communities (e.g., increased green fodder availability).
- ii. The industry is advised to conduct a feasibility study for developing a green belt between the Hirakud Reservoir and existing/proposed ash ponds, using native species to establish a sustainable buffer ecosystem.
- iii. Due to the lack of recent baseline data, it is recommended that ITPS undertake fresh studies, including:
 - a. Biodiversity and ecological assessment of vegetation in and around ITPS;



Bhagyabandhu Mishra
Addl. District Magistrate
JHARSUGUDA

PART OF AFFIDAVIT

P. N. Tiwari
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- b. Analysis of metal contamination in soil, water, vegetation, and aquatic life.
- c. Socio-ecological and health surveys, especially comparing communities affected and unaffected by CSR activities, to assess quality of life.
- iv. Quarterly sampling of surface and groundwater and soil is recommended to monitor heavy metals (Cd, Hg, As, Pb, Fe) and physicochemical changes, particularly in contaminated hotspots. Seasonal studies are essential to track leaching and pH variations caused by fly ash.
- v. To avoid future breaches, it is suggested to reinforce ash pond dykes with geosynthetic liners, implement real-time structural monitoring, and enhance leachate collection systems.



vi. Implementation of biomonitoring programs (e.g., blood/urine testing) is advised to detect heavy metal exposure among residents. In addition, awareness drives should inform locals about safe agricultural practices and water safety advisories.

4. That in view of the directions given by the Hon'ble Tribunal vide order dated 09.05.2025, the exercise has been duly undertaken. It is therefore respectfully prayed that the same may kindly be taken on record by this Hon'ble Tribunal.

Brajchandra Bhi
 DEPONENT
 Addl. District Magistrate
 JHARSUGUDA

VERIFICATION

Verified at Jharsuguda on this the 25th day of July 2025, that the contents of the aforesaid Additional Affidavit and Annexures are true and correct to the best of my knowledge and have been derived from official records maintained by the Respondent No. 02. No part of it is false nor has anything material been concealed therefrom.

The Deponent Solemnly Affirms
 Before Adv. [Signature]
 Today at 5:30 am/pm
[Signature]
 P. N. TIWARI
 NOTARY, JHARSUGUDA

[Signature]
 DEPONENT Magistrate
 JHARSUGUDA
 27.7.25
 PRATAP NARAYAN TIWARI
 NOTARY JHARSUGUDA
 REGD. NO. ON-01/13
 MOB. No.- 9437345360

DISTRICT OFFICE : JHARSUGUDA.
(JUDICIAL SECTION)No. VK- 130/2025 11095 / Judl. Dated, 18/07/2025

To

Sri Raman Yadav, Government Advocate
of Odisha.

Sub :-

Submission of compliance report of order dt.09.05.2025 of Hon'ble
NGT, Kolkata in O.A.No 89/2024/EZ filed by Gopinath Majhi Vrs State of
Odisha...

Sir,

In inviting a reference to the subject cited above, I am to submit herewith
the compliance of order dt. 09.05.2025 passed by Hon'ble NGT, Kolkata in O.A.No
89/2024/EZ filed by Gopnath Majhi Vrs State of Odisha for kind information and
necessary action.

Encl: As above.

Yours faithfully,

[Handwritten Signature]
Additional District Magistrate,
Jharsuguda
Add. District Magistrate
JHARSUGUDA

COMPLIANCE REPORTIN .No 89/2024/EZ FILED BY GOPINATH MAJHI VRS STATE
OF ODISHA AS PER DIRECTION DT09.05.2025 OF HON'BLE N.G..T KOLKATA ..

That in pursuance of order dt.09.05.2025 of Hon'ble NGT,Kolkata the Tahasildar, Lakhanpur was requested to comply the order of Hon'ble NGT,Kolkata vide this office letter No. 8810/dt.06.06.2025 and submit detailed report whether the Industry has engaged TERI-SAS for carrying out Environmental Damage Assessment Study which was to be carried out in 3 seasons i.e. Pre-Monsoon, Monsoon and Post-Monsoon and final report should be available by 31.03.2025 and Pre-Monsoon Report would be available by August 2024. This report have not been filed till date before the Hon'ble NGT..

Accordingly, the Tahasildar, Lakhanpur visited the site and has submitted a copy of Environment Damage Assessment study Report prepared by TERI School of advance Study (TERI-SAS) New-Delhi Development and Environment Futures Trust, (DEFT), Bhubaneswar, Sambalpur University, Burla, Odisha in OA No.89/2024/EZ filed by Gopinath Majhi Vrs State of Odisha submitted by the Director, (Operation), O.P.G.C. Banharpali vide his letter No. ITPS /1391/WE-Dtd 10.07.2025.

This is for favour of kind information and necessary action.

Encl: As above.

Additional District Magistrate,
Jharsuguda
Addl. District Magistrate
JHARSUGUDA



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DISTRICT OFFICE OF THE TAHASILDAR, LAKHANPUR

16 JUL 2025

Email- tah.lakhan-od@nic.in, tahasildar.lakhanpur1@gmail.com

No. 5052 / Dt. 15.07.2025

JHARSUGUDA

To

The Addl. District Magistrate,
Jharsuguda.

Sub:- O.A. No. 89/2024/EZ filed by Gopinath Mahi Vrs State of Odisha.

Ref:- District Office letter no. 8810 Dtd. Judl Dtd. 06.06.2025

Sir,

With reference to the letter on the subject cited above I am to say that the Director (Operations) & Occupier, OPGC Banharpali has submitted a copy of Environment Damage Assessment Study Report conducted by TERI-SAS New Delhi pertaining to O.A. No. 89/2024/EZ filed by Gopinath Majhi Vrs State of Odisha, sub-judice before the Hon'ble NGT Kolkata vide letter no. ITPS/3391/WE Dtd. 10.07.2025. The same is enclosed herewith for favour of kind information and necessary action.

Encl:- As above

Yours faithfully,


Tahasildar, Lakhapur

**Environmental Damage Assessment of ash/slurry spread due to ash pond breach
at the IB Thermal Power Station of Banharpali, Jharsuguda District, Odisha**

Submitted to

**Ib Thermal Power Station, Banaharpali
of
Odisha Power Generation Corporation Limited (OPGCL)**

Prepared by

**TERI School of Advanced Studies (TERI-SAS), New Delhi
Development and Environment Futures Trust (DEFT), Bhubaneswar
Sambalpur University, Burla, Odisha**

Period of work

JUNE 2024 – JUNE 2025

Submission on 15th July 2025

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Scientists/Experts and Project Assistants Associated with the Project

Sl. N.	Name and Designation of the Scientists and Project Assistants
1	Prof. (Dr.) Chander Kumar Singh, Ph.D., MRSC Principal Investigator Professor and Academic Dean, Dept. Natural and Applied Sciences TERI School of Advance Studies, 10 Institutional Area, Vasant Kunj, New Delhi-110070
2	Prof. (Dr.) Arabinda Mishra, Ph.D., Chairman, Development and Environment Futures Trust N1/303, IRC Village, Bhubaneswar-751015
3	Prof. (Dr.) Malay Kumar Mahananda, M.Phil., M. Tech and Ph.D., Prof and Head, Post Graduate Department of Environmental Sciences, Sambalpur University, Jyoti Vihar – 768919, Sambalpur, Odisha
4	Prof. (Dr.) Pramod Chandra Mishra, Ph.D. and D.Sc., Advisor to the Project i. Former Prof and Head, Post Graduate Department of Environmental Sciences, Sambalpur University, Jyoti Vihar-768919 ii. Former Expert Member of National Green Tribunal, New Delhi and Kolkata. iii. Former President, Odisha Bigyan Academy (a Unit of Department of Science and Technology, Govt. of Odisha)
5	Shri Somanath Chakravorty, CEO, Development and Environment Futures Trust N1/303, IRC Village, Bhubaneswar-751015
	PROJECT ASSISTANTS
6	Shri Prasoon Dwivedy, TERI University, New Delhi
7	Shri Dibya Ranjan Behera, M.Sc., MTech, Sambalpur University
8	Shri Soumya Ranjan Barik, M.Sc., MTech, Sambalpur University
9	Shri Rakesh Mahapatra, Research Associate, DEFT

Certificate



Prof (Dr) Chander Kumar Singh
Dept. of Natural and Applied Sciences
Dean (Academics)

Date – 1 July 2025

This is to certify that the project entitled "Environmental Damage Assessment Study of ash/slurry spread due to ash pond breach at the Ib Thermal Power Station of Banaharpali, Jharsuguda District, Odisha, funded by OPGC-ITPS has been successfully completed in terms of objectives enumerated in the proposal. It is further certified that the work was undertaken by TERI-SAS, New Delhi, DEFT, Bhubaneswar, Prof (Dr) P. C. Mishra as Consultant cum Advisor and Prof (Dr.) Malay Kumar Mahananda of Sambalpur University as Associate Consultant, and that standard methods were followed for analysis of samples collected from the sites.

Chander Kumar Singh

Acknowledgement

The Scientists associated with the Project are immensely thankful to OPGC-ITPS for extending financial support for carrying out the Study. The laboratory facilities extended by TERI and Sambalpur University are highly appreciated.

Prof (Dr) Chander Kumar Singh

Professor & Dean (Academics)
Dept. of Natural and Applied Sciences,
TERI School of Advanced Studies
10, Institutional Area, Vasant Kunj
New Delhi - 110 070

**Prof. (Dr.) Malay Kumar
Mahananda**

Prof. and Head, Post Graduate
Department of Environmental
Sciences, Sambalpur University
Jyoti Vihar – 768919,
Sambalpur, Odisha

Prof. (Dr.) Arabinda Mishra

Chairman, Development and
Environment Futures Trust
N1/303, IRC Village,
Bhubaneswar-751015

**Prof. (Dr.) Pramod Chandra
Mishra, Advisor to the Project**

Former Expert Member of
National Green Tribunal, New
Delhi and Kolkata

Executive Summary

The breach of ash pond/dyke C at the IB Thermal Power Station (ITPS) in Banharpali, Jharsuguda, Odisha, on December 9, 2023, led to the spillage of fly ash and slurry into surrounding agricultural fields, grazing lands, and water bodies. Fly ash, a byproduct of coal combustion, contains trace elements and heavy metals such as arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg), and iron (Fe), which pose significant environmental and health risks. This study, conducted by TERI School of Advanced Studies, Development and Environment Futures Trust (DEFT) and Sambalpur University aimed to assess the environmental damage caused by the spillage, focusing on soil, water, plankton biodiversity impacts, and socioeconomic analysis that includes the economic valuation of environmental damage.

For Physico-chemical Analysis of water, Soil and Sediment, the assessment involved systematic sampling during pre-monsoon, monsoon, and post-monsoon seasons (2024–2025). Water samples were analysed for pH, TDS, alkalinity, major cations /anions, and heavy metals, while soil samples were tested for nutrients, pH, electrical conductivity (EC), and heavy metal concentrations. Pollution indices—Contamination Factor (CF), Geo-accumulation Index (Igeo), and Pollution Load Index (PLI)—were computed to quantify contamination levels.

Water quality analysis revealed pH levels ranging from slightly acidic (6.36) to alkaline (9.04), with seasonal variations. Heavy metals such as arsenic (As) remained below 10 µg/L, while lead (Pb) and mercury (Hg) were mostly below detection limits. Iron (Fe) concentrations peaked during the monsoon (average 559 µg/L) but decreased post-monsoon, indicating natural dilution. Soil analysis showed predominantly acidic conditions (pH 4.20–7.56), with localized elevated levels of cadmium (Cd) and mercury (Hg). Cadmium exceeded upper continental crust (UCC) averages in 14.28% of surface and 9.52% of subsurface post-monsoon samples, while Hg surpassed UCC limits in 22.72% of surface and 50% of subsurface pre-monsoon samples. Chloride (Cl) levels were also higher than UCC averages in some samples. Pollution indices indicated low contamination (CF < 1) for most metals, except moderate contamination (CF 1–3) for Hg in pre-monsoon and as/Cd in post-monsoon samples. The Geo-accumulation Index (Igeo) confirmed uncontaminated conditions for most metals, with Hg showing minor contamination in pre-monsoon. The Pollution Load Index (PLI) remained ≤1 across all locations, suggesting no significant cumulative pollution.

The study concludes that while the overall pollution load is low, localized hotspots of Cd, Hg, and Cl require attention. Natural dilution reduced Hg levels post-monsoon, but proactive measures such as phytoremediation or soil amendments may be necessary for Cd-affected areas. Long-term monitoring is recommended to track heavy metal mobility, particularly after rainfall. Strengthening ash pond infrastructure to prevent future breaches and conducting health screenings for local communities are also advised. This assessment highlights the need for sustainable ash management practices to balance power generation with environmental protection. The findings provide a baseline for regulatory actions and mitigation strategies to minimize ecological and health risks from fly ash disposal.

The abundance and diversity indices of plankton were studied during the pre-monsoon and post-monsoon seasons of 2024 in two freshwater environments at the control site (Rampela) in Jharsuguda

district and experimental site (Banharpali) in Sambalpur district. Plankton samples were collected from different designated stations and analysed to identify the species of major taxonomic groups using standardized sampling and preservation techniques. Phytoplankton communities were dominated by Chlorophyceae and cyanophyceae while zooplankton communities were represented by Copepoda, Rhizopoda and Cladocera. Diversity indices including Shannon, Simpson, evenness, and similarity revealed higher biodiversity at the control site in both seasons. Phytoplankton abundance peaked during the post-monsoon, followed by pre-monsoon, with zooplankton showing a similar seasonal trend. The control site showed higher diversity values, with Shannon indices of 3.213 for phytoplankton and 2.436 for zooplankton, compared to 2.976 and 1.809, respectively, at the experimental site. Simpson and evenness indices also supported greater species balance at the control site. Notably, similarity indices increased after the monsoon from 0.732 to 0.792 for phytoplankton and from 0.573 to 0.786 for zooplankton, indicating greater species overlap after the monsoon influence. Overall, control sites exhibit better ecological balance, while experimental sites may be slightly affected by environmental stress or anthropogenic disturbance. These results suggest that post-monsoon conditions, probably due to nutrient enrichment and environmental stabilization, increase overall plankton abundance and promote standardization of community structures in different aquatic habitats. Seasonal variations particularly during post monsoon season encourage plankton composition. However, statistical analysis of data between Pre-and Post-monsoon did not show a significant difference in result indicating that during post-monsoon months the situation has almost been restored due surface run-off and dilution.

As a direct consequence of the ash pond breach, 149.885 acres of land, including 55.6 acres of privately owned agricultural land, were impacted by ash and slurry inundation, resulting in extensive crop loss and disruption of agroecosystem services. Estimated losses include Rs 82.8 lakhs for standing and potential Kharif paddy crops and Rs 1.07 crore as the net present value of lost provisioning, regulating, and supporting ecosystem services over a 10-year horizon. The loss of mature fruit-bearing trees and tree/scrub vegetation further contributed to environmental degradation, with an estimated loss of Rs 3.62 crore in ecosystem services, that includes air pollution mitigation and carbon sequestration.

Cumulatively, the total cost of environmental damage is assessed at Rs 8.02 crore. This includes land value loss, ecosystem service disruption, and biotic resource degradation. While compensation has been provided for agricultural losses, additional measures, such as ecological restoration, long-term environmental monitoring, and the establishment of a greenbelt buffer, are recommended to address residual and long-term impacts. These findings reinforce the need for a dedicated environmental mitigation corpus and robust land-use planning to prevent future breaches and promote sustainable ash management.

Physico-Chemical Analysis of water, soil and sediment likely to be impacted during Ash Pond Breach during December 2023

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1. Introduction

Globally, most thermal power plants (about 84%) are running on coal, while the remaining 13% run on gas and 3% on oil (Sarode et al., 2010). India has over 197 coal/lignite based thermal power plants producing 133 million tons of coal fly ash annually (Yadav et al., 2022). The disposal of such large quantities of fly ash poses significant environmental challenges. Fly ash contains several of the elements found in coal, including silica, alumina, and iron, which are significant oxides, as well as minor oxides of sodium, magnesium, calcium, phosphorus and potassium (Wu et al., 2022). Coal might also incorporate one or more dangerous elements, such as arsenic, cadmium, cobalt, lead, manganese, mercury, and molybdenum in either significant or minute concentrations, based on the origin (Yuan et al., 2021; Park et al., 2021; Chen et al., 2022; Yadav et al., 2020; Yadav et al., 2021; Yadav et al., 2022). The trace elements present in coal are concentrated after combustion due to loss of carbon in the form of carbon dioxide, which gets adsorbed onto the surface of fly ash and released during the utilization of coal. Two types of ash are produced namely, fly ash and bottom ash. Bottom ash is collected from the bottom of the boiler and is coarse grained whereas fly ash is finer in size ranging from 0.5 to 200 μ m. Disposal of ash can be done by dry and wet disposal methods. In the dry disposal method, the ash is dumped into open ponds, whereas in the wet disposal method, the ash is mixed with water and transported through pipes to the ash pond. Soil and water contamination around coal ash disposal sites can occur due to atmospheric fallout and leaching. If the ash pond is unlined then trace elements and soluble ions from the surface of fly ash can leach into water and contaminate groundwater due to rainwater infiltration. The leaching potential of heavy metals from ash ponds is expected to be greater due to diurnal and seasonal variation in temperature, moisture and other parameters (Verma et. al., 2016, Mandel et. al., 2006). Leaching potential of heavy metals depends on the acidic or alkaline conditions of aqueous environment (Singh et al., 2016).

IB Thermal Power Station (ITPS), is a coal based thermal power plant situated in Jharsuguda, Odisha. Coal ash including bottom ash and fly ash produced in the plant, is disposed of, as slurry for deposition in the ash ponds. On December 9, 2023, a breach of ash pond/dyke C occurred at the Ib thermal power station. Therefore, assessment of soil, water, and biodiversity is necessary to understand spillage's effect on agricultural fields, grazing lands, and water sources. The following study was conducted to assess the holistic environment damage assessment of water, soil, aquatic biodiversity and socio-economic loss to the local population residing in the area. To estimate the extent of pollution various indices were used such as contamination factor, geo-accumulation index and pollution load index along with characterization of aquatic biodiversity.

1.1 Heavy Metals Toxicity

The heavy metals contamination has been documented in several studies to have adverse effects on human health and the ecosystem. For example, heavy metals can accumulate in living organisms and food chains, resulting in reduction in species diversity and abundance, ultimately leading to the degradation of the ecosystem. Soil is an essential part of the terrestrial ecosystem and ultimately it becomes the sink for heavy metals therefore it can spread them into water bodies, organisms and

atmosphere. Heavy metals may persist and accumulate in soil and hence can increase the toxicity of soils after combining with inorganic and organic matters. Arsenic (As) causes skin pigmentation (Rahman et al., 2001), however exposure over longer duration may result in skin, cardiovascular, respiratory, haematological, neurological and renal diseases, lack of intellectual ability of children and premature pregnancy (Palma-Lara et al., 2020). Cadmium (Cd) is carcinogenic to humans. It has been revealed that it causes lung and prostate cancers. Higher exposures to Cd may cause accumulation of fluid in the lungs, a medical emergency, with difficulty in breathing. Cd may damage the male reproductive system and can affect the female reproductive cycle. However, repeated low exposures of Cd can cause liver and kidney damage (Genchi et al., 2020). Manganese (Mn) plays an essential role in the metabolism of carbohydrates, cholesterol, and amino acids. Higher levels of Mn can cause various effects such as male infertility, neurological disorders, birth disability, and bone defects (Crossgrove & Zheng, 2004; O'Neal & Zheng, 2015). Too much concentration of Lead (Pb) in the blood can cause hypertension, skeletal injury, immune system disorders, endocrine, reduces intelligence ability in kids and among adults it affects the functioning of kidney and heart (Ara & Usmani, 2015; Kumar et al., 2020). Mercury (Hg) bind with residue of protein causes depletion of cellular antioxidants, resulting in production of reactive oxygen species (ROS). ROS play a major role in the metal induced cellular responses so it can cause damage to DNA and can initiate carcinogenic processes (Ajsuvakova et al., 2020). High-level exposure to zinc (Zn), can cause acute Zn toxicity which include headache, nausea, vomiting, diarrhoea, abdominal discomfort and, in rare cases, can also cause metabolic imbalances and severe neurological symptoms. Long term exposure of Zn can cause symptoms linked with zinc-induced copper deficiency, including impaired immune function, decreased levels of high-density lipoprotein (HDL) and increased levels of low-density lipoprotein (LDL) (Schoofs et al., 2024).



Fig.1. The spread of fly ash near the thermal power plant (photos taken on 2nd May 2024 during site visit DEFT)

2. Study Site

The power station is located on the bank of the Hirakud reservoir, in Banaharpalli village of Jharsuguda district. The plant is equipped with electrostatic precipitators and a flue-gas desulfurization system to control emissions. The water required for the operation of the power plant is sourced from the Hirakud reservoir through the existing 5.45km long intake canal. Coal is supplied by Mahanadi Coalfields (MCL) from the Lakahanpur open-cast mines in the Ib valley area, and from OPGC's own captive mines in the vicinity. There are two ash pond complexes (Ash Pond ABC & Tilia Ash Pond) for discharge of ash slurry.

Jharsuguda district has a complex geological setting. Major part of the district is occupied by consolidated formations, comprising all the rock types of Archaean and Proterozoic age. These rocks are generally hard, compact and lack primary porosity. The groundwater in the region is developed through open wells and borewells. The depth of open wells in this rock varies from 5m to 13m, and the depth of the water table varies from 2.8mbgl to 10mbgl during pre-monsoon, from 0.7mbgl to 7.2mbgl in post-monsoon (CGWB 2013).

3. Methodology

The study area was divided into several grids of 500m each as given below. A total of 42 centroid were marked for each of the grid for sampling. However, depending on the season and accessibility the number of samples were restricted to maximum possible that could be collected, the details of which are given in respective sections.



Fig 2. Sampling grids for sample collection in the study area.

3.1 Water Onsite-parameters Analysis

The physical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS) and salinity were measured on the site. The calibration of the pH meter was done using standard buffer solutions of pH 4.01, 7.0, 10.02. For EC, the probe was calibrated with $84\mu\text{S}/\text{cm}$, $1413\mu\text{S}/\text{cm}$ and $12.8\text{mS}/\text{cm}$ standard solutions then a 50 ml sample was taken in a beaker for measurement of pH, EC and TDS.

3.2 Water Sample Collection

The entire area impacted by the fly ash spread was identified from aerial photos taken after the breach and divided into grids. The geotagged samples were collected in two sets, for cation and anion analysis in high density polyethylene (HDPE) bottles from the grids with stratified random sampling approach. The bottles were acid washed followed by washing with double distilled water 2-3 times and air dried before sampling. A total 33 samples were collected in the three seasons pre-monsoon (16), monsoon (7), and post-monsoon (10). The locations of the samples were marked using the global position system (GPS). The samples for cation and trace metals analysis were acidified, while left non-acidified for anion analysis.



Fig 3. Surface water sample collection and onsite analysis of physical water quality parameters.

3.3 Water Sample Analysis

The major cations sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) analysis was performed using flame-photometer Systronics 128. The standard solutions for Na^+ , K^+ , Ca^{2+} were prepared using sodium chloride (NaCl), potassium chloride (KCl), calcium carbonate (CaCO_3) to calibrate the flame photometer. The chloride (Cl^-) analysis was performed by titration method; samples were titrated against silver nitrate (AgNO_3) with potassium chromate (K_2CrO_4) indicator. Nitrate (NO_3^-), phosphate (PO_4^{3-}) and sulphate (SO_4^{2-}) analysis were performed by spectrophotometric method (APHA, 2012). BaCl_2 turbidity method was used for the analysis of sulphate. For nitrate, samples were digested with hydrochloric acid (HCl) and then absorbance of nitrate was measured. The ammonium molybdate and stannous chloride method was used for the analysis of phosphate. The fluoride (F^-) analysis was done by the SPADNS method. The standard solutions were prepared from stock solutions, which were used for calibration. Standard addition calibration plots were made for each of the parameter analysed. The unknown sample anion concentrations were estimated from the calibration graphs based on observed absorbance. All the methods used for analysis was adopted as is described in APHA, 2012.

3.4 Heavy Metals Analysis in Water

The samples were filtered through $0.2\mu\text{m}$ filter papers and were analysed for As, Pb, Cd, and Zn using ICP-MS Agilent. Iron (Fe) was analysed by phenanthroline spectroscopic method. The mercury was analysed using the dithizone method. The ICP-MS was calibrated using a standard reference solution for heavy metals before analysis. Different concentration standard solutions were prepared and used for calibration to perform iron and mercury analysis.

3.5 Soil Sampling

A total of 62 soil samples were collected from the grids during pre-monsoon (27), monsoon (12), and post-monsoon (23). These samples were collected in polyethylene bags. The soil samples were collected from the surface and from 10cm depth using auger. The locations of the samples were marked using the global position system (GPS).

3.6 Soil Sample Preparation and Analysis

The samples were air dried in natural condition then sieved to remove the pebbles, small stones and gravels if any. The samples were digested using EPA 3050B method. Soil samples were homogenised, sieved and 1-2 gram of soil sample were taken for analysis. 10 mL of 1:1 HNO₃ (nitric acid) was added, and slurry was prepared in the digestion. Slurry was heated at 95°C +/- 5°C for 10-15 minutes. After the samples were cooled, concentrated HNO₃ was added and then heated for 30 minutes. The brown fumes indicate digestion of the soil samples with HNO₃. Addition of HNO₃ and heating repeated until the brown fumes stopped appearing, indicating completion of digestion reaction. After cooling 2 ml water and 30% H₂O₂ (hydrogen peroxide) was added and heated again. The slurry was heated with addition of H₂O₂ in intervals till the effervescence is minimised. The slurry was cooled down and then diluted to 100ml with double-distilled water. The slurry was filtered through Whatman No. 41 filter paper then centrifuged for 3000rpm for 15 minutes and filtrate was used for further analysis.



Fig 4. Soil sample collection (both surface and from 10cm depth).

3.7 pH Measurement

The naturally air dried and sieved samples were homogenised. After that, a 50g soil sample was taken and sufficient water was added to moisten the soil, stirred with a glass rod and added water till the soil became saturated. Left overnight, to get the soil fully saturated at 25°C. Next day again stirred with a glass rod, and more water added if required. The calibration of the pH meter was done using a

standard buffer solution of pH 4.01, 7.0, 10.02. After calibration, samples were tested for their pH using water saturated samples in a beaker. After every measurement the electrode was washed with distilled water and cleaned with tissue paper.

3.8 Electrical Conductivity and Total Dissolved Solids measurement

Electrical conductivity (EC) was measured using Oakton multi-parameter electrodes. Before testing, the probe was calibrated with $84\mu\text{S}/\text{cm}$, $1413\mu\text{S}/\text{cm}$ and $12.8\text{mS}/\text{cm}$ standard solutions. Once the instrument was calibrated, 50mL extracted samples were taken in a beaker and then a probe was dipped into it. EC and TDS values were recorded.

3.9 Chloride, Fluoride, Sulphate, Nitrate and Phosphate analysis

The chloride analysis was performed using the silver nitrate titration method by using a chromate indicator after extraction from soil samples. The chloride content was calculated from the amount of silver nitrate used in the titration. The SPANDS method was used for the determination of fluoride from digested soil samples. The turbidimetric method was used to perform sulphate analysis. Extracted soil sample diluted to 100mL and taken in a beaker, then conditional reagent added to it. The BaCl_2 crystals were added with stirring and stirred for 60 seconds in a magnetic stirrer. Turbid solution was then poured into a photometric cell to determine absorbance at 420nm. Extracted sample was taken in a beaker and Hanna HI98191 electrode was used for the determination of nitrate. For phosphate analysis, sodium bicarbonate extracted sample aliquot was taken into the volumetric flask and 1.5% ammonium molybdate, and distilled water added to it. After that, a working stannous chloride solution was added to it, followed by addition of distilled water to make up the volume. A blue colour solution was obtained, whose absorbance was determined by a spectrophotometer at 660nm.

3.10 Major Cation Analysis

The standard solutions were prepared for Na^+ , K^+ , Ca^{2+} using sodium chloride, potassium chloride and calcium carbonate to calibrate the flame photometer. The major cations Na^+ , K^+ and Ca^{2+} were analysed using flame-photometer Systronics 128 from a digested liquid sample of soil.

3.11 Heavy metals analysis

Aliquot of digested liquid samples were taken and analysed with ICP-MS for heavy metals As, Pb, Cd and Zn. The iron was analysed using phenanthroline spectroscopic method and mercury was analysed using dithizone method. The ICP-MS was calibrated using a standard reference solution

(Agilent) for heavy metals before analysis. For iron and mercury analysis calibration was done using different concentration standard solutions.

3.12 Pollution assessment

Comprehensive assessment of the degree of soil pollution is estimated through various pollution indices. The contamination factor (CF), geo-accumulation index (I_{geo}) pollution load index (PLI) was used to assess the status of contamination of soil and water.

3.12.1 Contamination factor (CF)

Contamination factor (CF) is an effective method for monitoring sediment pollution over time. It is the ratio of individual metal in the sample to the metal's background values

$$CF = (C_{\text{metal in sample}}/C_{\text{metal in background}})$$

3.12.2 Geoaccumulation Index

The Geo-accumulation index showing the degree of contamination is estimated using the following formula:

$$I_{geo} = \log_2[C_{\text{metal in sample}}/1.5 \times C_{\text{metal in background}}]$$

3.12.2 Pollution load index (PLI)

The pollution load index (PLI) measures the quantity of harmful heavy metals in the area. The PLI was calculated as a ratio of each heavy metal's concentration to the soil's background value.

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

3.13 Sampling Locations

Surface water and soil samples were collected around the ash ponds. The description of sampling sites and distance from breaching point are presented in table 1-6.

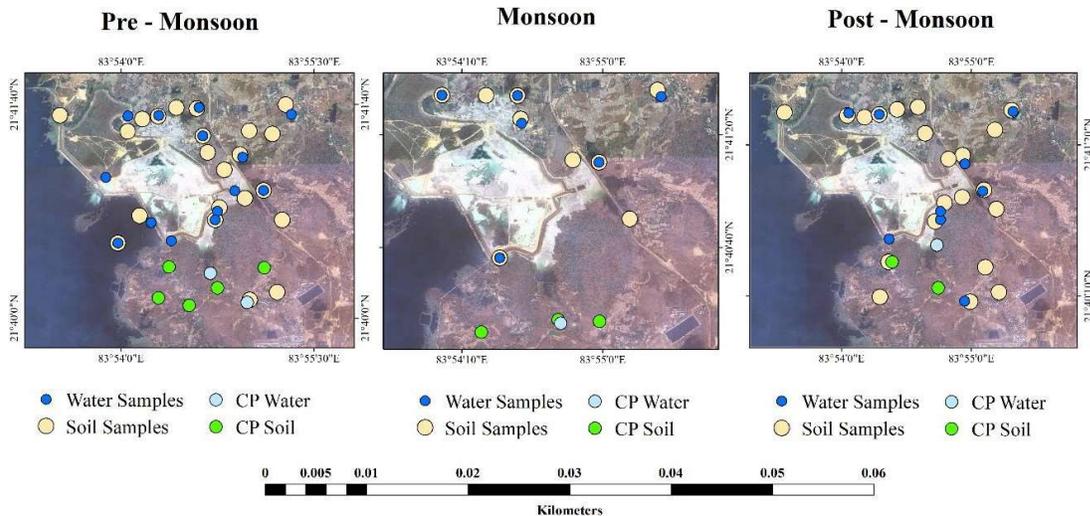


Fig 5. Map showing locations of water and soil samples in pre-monsoon, monsoon and post-monsoon seasons.

Table 1. Location of water samples collected during pre-monsoon (*prefix with C is control sample*)

S.No.	Latitude	Longitude	Distance from breach point (m)
JHWS 1	21.6791	83.90389	1158.05
JHWS 2	21.67643	83.89959	1737.02
JHWS 3	21.67673	83.9065	1104.5
JHWS 4	21.68056	83.91246	488.54
JHWS 5	21.67943	83.91218	595.77
JHWS 6	21.69292	83.90089	1627.22
JHWS 7	21.69298	83.90486	1343.83
JHWS 8	21.69405	83.91009	1105.02
JHWS 9	21.68757	83.91574	460.77
JHWS 10	21.68327	83.91844	759.14
JHWS 11	21.69314	83.92204	1324.74
JHWS 12	21.69035	83.91059	716.09
JHWS 13	21.6832	83.91472	420.38
C JHWS 14	21.66873	83.91632	1771.91
C JHWS 15	21.67252	83.91156	1324.46
JHWS 16	21.68497	83.89802	1620.73
JHGW	21.69358	83.92386	1484.58

Table 2. Location of soil samples collected during pre-monsoon (prefix with C is control sample)

S.	No.	Latitude	Longitude	Distance from breach point (m)
JHS1		21.67999	83.90239	1253.5
JHS 2		21.67643	83.89959	1737.02
C JHS 3		21.67335	83.9062	1466.69
JHS 4		21.68103	83.91272	423.08
JHS 5		21.67943	83.91218	595.77
JHS 6		21.69095	83.90084	1496.92
JHS 7		21.6929	83.90481	1343.83
JHS 8		21.69387	83.90981	1096.75
JHS 9		21.69304	83.89206	2423.83
JHS 10		21.691	83.9166	835
JHS 11		21.68793	83.91538	440.6
JHS 12		21.68327	83.91844	537.26
JHS 13		21.67943	83.92086	713.6
JHS 14		21.69441	83.92133	1390.69
JHS 15		21.67018	83.91267	946.47
JHS 16		21.69254	83.90275	1436.03
JHS 17		21.694	83.90715	1262.7
JHS 18		21.69035	83.91059	716.09
JHS 19		21.68819	83.9112	481.4
JHS 20		21.68594	83.91335	309.69
JHS 21		21.68226	83.91603	382.78
JHS 22		21.67008	83.92021	1735.26
JHS 23		21.66906	83.91665	1771.91
C JHS 24		21.67325	83.91856	1346.62
C JHS 25		21.67064	83.91246	1568.86
C JHS 26		21.668.357	83.9088	1917.34
C JHS 27		21.66932	83.90484	1888.65

Table 3. Location of water samples collected during monsoon (*prefix with C is control sample*)

S.No.	Latitude	Longitude	Distance from breach point (m)
JHWS1	21.67673	83.9065	1139.29
C JHWS2	21.67027	83.91253	1527.35
JHWS3	21.69265	83.92244	1279.05
JHWS4	21.68618	83.9163	321.84
JHWS5	21.69279	83.90083	1702.54
JHWS6	21.69275	83.90828	1156.4
JHWS7	21.69001	83.90868	888.34

Table 4. Location of soil samples collected during monsoon (*prefix with C is control sample*)

S. No.	Latitude	Longitude	Distance from breach point (m)
JHS1	21.676732	83.906498	1131.54
C JHS2	21.669392	83.904691	1888.81
C JHS3	21.670605	83.912284	1487.12
C JHS4	21.670466	83.916359	1502.83
JHS5	21.693311	83.922065	1317
JHS6	21.686176	83.9163	328.13
JHS7	21.69279	83.900828	1706.86
JHS8	21.686385	83.913716	280.86
JHS9	21.680589	83.919324	635.55
JHS10	21.692781	83.90517	1172.53
JHS11	21.692754	83.908279	1183.82
JHS12	21.690446	83.908583	933.51

Table 5. Location of water samples collected during post-monsoon (*prefix with C is control sample*)

S.No.	Latitude	Longitude	Distance from breach point (m)
JHWS 1	21.676802	83.906114	1167.86
C JHWS 2	21.670173	83.912610	1622.36
JHWS 3	21.668807	83.915801	1787.59
JHWS 4	21.693224	83.922023	1285.88
JHWS 5	21.686485	83.915844	308.19
JHWS 6	21.682966	83.91812	522.75
JHWS 7	21.679315	83.912692	612.96
JHWS 8	21.680379	83.912692	496.43
JHWS 9	21.693025	83.900915	1586.4
JHWS 10	21.69283	83.904824	1259.65

Table 6. Location of soil samples collected during post-monsoon (*prefix with C is control sample*)

Sample	Latitude	Longitude	Distance from breach point (m)
JHS 1	21.676752	83.906180	1167.54
C JHS 2	21.673867	83.906484	1410.08
JHS 3	21.669365	83.904938	1923.88
C JHS 4	21.670553	83.912397	1581.77
JHS 5	21.668773	83.916515	1802.73
JHS 6	21.673196	83.918451	1384.85
JHS 7	21.669997	83.920182	1780.58
JHS 8	21.693361	83.921819	1282.72
JHS 9	21.690863	83.919687	929.95

JHS 10	21.687595	83.915529	375.66
JHS 11	21.683121	83.91829	532.72
JHS 12	21.680674	83.91987	805.06
JHS 13	21.687085	83.913728	254.76
JHS 14	21.679093	83.912003	650.12
JHS 15	21.681459	83.91321	372.53
JHS 16	21.682189	83.915475	357.74
JHS 17	21.693071	83.892678	2338.3
JHS 18	21.69271	83.900738	1581.96
JHS 19	21.69247	83.902948	1380.54
JHS 20	21.69283	83.904824	1259.65
JHS 21	21.693481	83.907132	1164.73
JHS 22	21.690402	83.910712	682.48
JHS 23	21.693802	83.909828	1065.27

4. Result of Water Sample Analysis

4.1 Pre-monsoon Control Water Sample Cation and Anion Analysis

Table 7. Descriptive statistics (minimum, maximum and mean values) of water quality parameters in pre -monsoon control samples.

Parameter	Minimum	Maximum	Mean
pH	7.29	7.76	7.53
TDS	225.00	308.00	266.50
Alkalinity	112.00	128.00	120.00
Na (mg/L)	22.04	54.29	38.17
K (mg/L)	3.58	6.58	5.08
Ca (mg/L)	14.05	42.11	28.08
Mg (mg/L)	11.68	29.20	20.44
F (mg/L)	0.04	0.08	0.06

Cl (mg/L)	106.35	141.80	124.08
SO₄ (mg/L)	22.96	103.79	63.38
PO₄ (mg/L)	0.25	0.65	0.45
NO₃ (mg/L)	11.58	12.04	11.81

Water samples from control sites were collected and analysed for pH, TDS, alkalinity, major cations (sodium, potassium, magnesium and calcium), anions (nitrate, phosphate, sulphate, fluoride and chloride) and heavy metals. Almost all the water samples were alkaline with a pH range of 7.29- 7.76 and with an average pH of 7.53. TDS in the water samples ranges from 225- 308 with an average of 266.5. Alkalinity in the water samples ranges from 112- 128mg/L with an average of 120mg/L. The minimum, maximum and average concentration for sodium was observed 22.04mg/L, 54.29mg/L, 38.17mg/L respectively in water samples. The minimum, maximum and average concentration for potassium was found to be 3.58mg/L, 6.58mg/L, 5.08mg/L respectively. While for calcium the minimum was 14.05mg/L and maximum values observed was 42.11mg/L with a mean value of 28.08mg/L. The minimum, maximum and mean value for magnesium was observed to be 11.68mg/L, 29.2mg/L, 20.44mg/L respectively. The fluoride in control samples had a minimum value of 0.04mg/L, and a maximum value of 0.08mg/L with a mean of 0.06mg/L. Chloride was found to have 106.35mg/L, 141.8mg/L, 124.08mg/L minimum, maximum and mean concentration respectively. The sulphate varied from a minimum of 22.96mg/L to a maximum of 103.79mg/L and mean value of 63.38mg/L. Phosphate was found to vary from 0.25mg/L to a maximum of 0.65mg/L, with a mean value of 0.45mg/L. Nitrate ranged between a minimum value of 11.58 mg/L to a maximum of 12.04 mg/L, with a mean value of 11.81 mg/L.

4.2. Pre-monsoon Control Water Sample Heavy Metal Analysis

Table 8. Descriptive statistics of heavy metals in pre-monsoon control water samples.

Parameter	Minimum	Maximum	Mean
As (µg/L)	0.00	0.00	0.00
Cd (µg/L)	53.60	53.60	53.60
Pb (µg/L)	BDL	BDL	BDL
Hg (µg/L)	BDL	BDL	BDL
Fe (µg/L)	240.33	250.33	245.33

As, Cd, Pb, Hg, Fe were analysed for control water samples. The Cd Concentration was found to be 53.6 µg/L, while Fe was found to be having minimum 240.33 µg/L to a maximum of 250.33 µg/L. The arsenic, lead and mercury were found to be below detection.

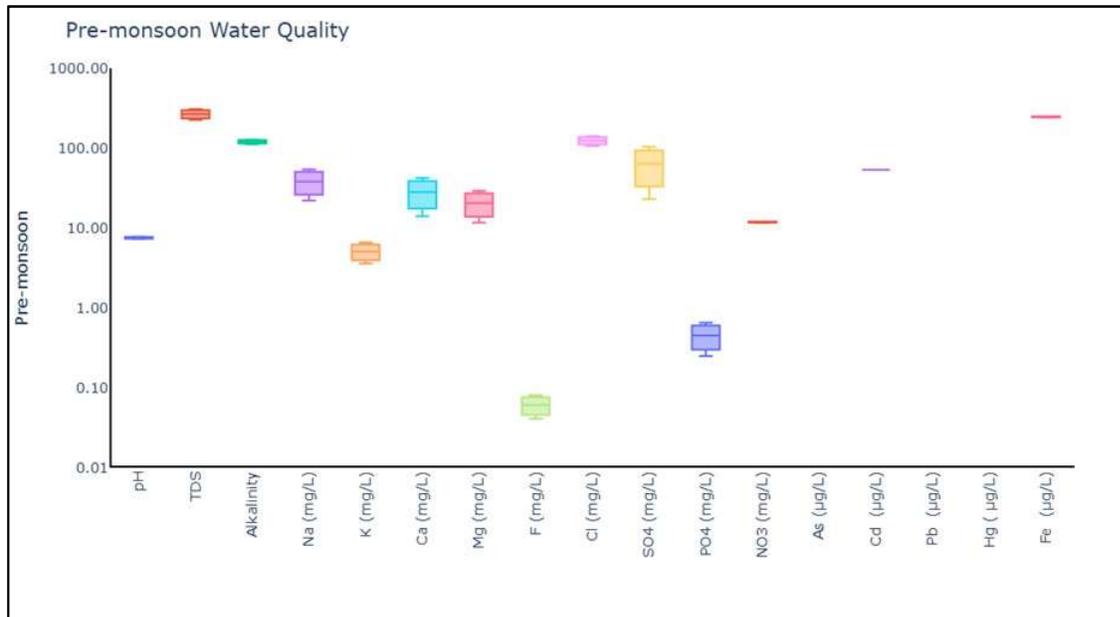


Fig 6. Water quality of pre-monsoon control samples.

4.3. Pre-monsoon Experimental Water Sample Cation and Anion Analysis

Table 9. Descriptive statistics of water quality parameters in pre-monsoon samples.

Parameter	Minimum	Maximum	Mean
pH	6.80	9.04	7.71
TDS	174.00	672.00	399.38
Alkalinity	48.00	208.00	117.71
Na (mg/L)	14.67	77.24	34.35
K (mg/L)	0.89	15.63	7.63
Ca (mg/L)	13.98	76.25	47.51
Mg (mg/L)	1.95	60.34	34.76
F (mg/L)	0.22	0.45	0.13
Cl (mg/L)	70.90	177.25	125.44
SO₄ (mg/L)	17.96	614.23	244.34
PO₄ (mg/L)	0.19	0.36	0.24
NO₃ (mg/L)	1.11	12.12	9.86

A total 16 water samples from experimental suites were collected in pre-monsoon and analysed for pH, TDS, alkalinity, major cations (sodium, potassium, magnesium and calcium) and anions (nitrate, phosphate, sulphate, fluoride and chloride) and heavy metals.

The pH of water samples was slightly acidic to alkaline having a minimum value of 6.8 to a maximum value of 13.2 with mean value of 8.06. the 78.57% of samples were found to be alkaline, whereas

21.43% were found to be acidic in nature. The TDS of samples was found to be in the range of minimum 174 and maximum 672 with a mean of 399.38. The alkalinity of analysed samples was having a minimum 48 mg/L and a maximum 208 mg/L, while mean was found to be 117.71 mg/L. The sodium was having a range of minimum concentration 14.67 mg/L to maximum concentration of 77.24 mg/L, with the mean concentration of 34.35 mg/L. The potassium concentration was found to be in the range of 0.89 mg/L minimum and 15.63 mg/L maximum, with the mean value of 7.63 mg/L. While the mean concentration of calcium was found to be 47.51 mg/L with the range of 13.98 mg/L minimum and 76.25 mg/L maximum. In the analysed samples magnesium was found to be having a minimum concentration of 1.95 mg/L and a maximum of 60.34 mg/L, while the mean was found to be 34.76 mg/L. It was found that fluoride has a minimum concentration of 0.22 mg/L and maximum concentration of 0.45 mg/L, with a mean concentration of 0.13 mg/L in the analysed samples. The phosphate concentration in the analysed water samples ranged from a minimum of 0.19 mg/L to a maximum of 0.36 mg/L, with a mean concentration of 0.24 mg/L. Nitrate levels was found to be having a minimum concentration of 1.11 mg/L, a maximum of 12.12 mg/L, and an average concentration of 9.86 mg/L

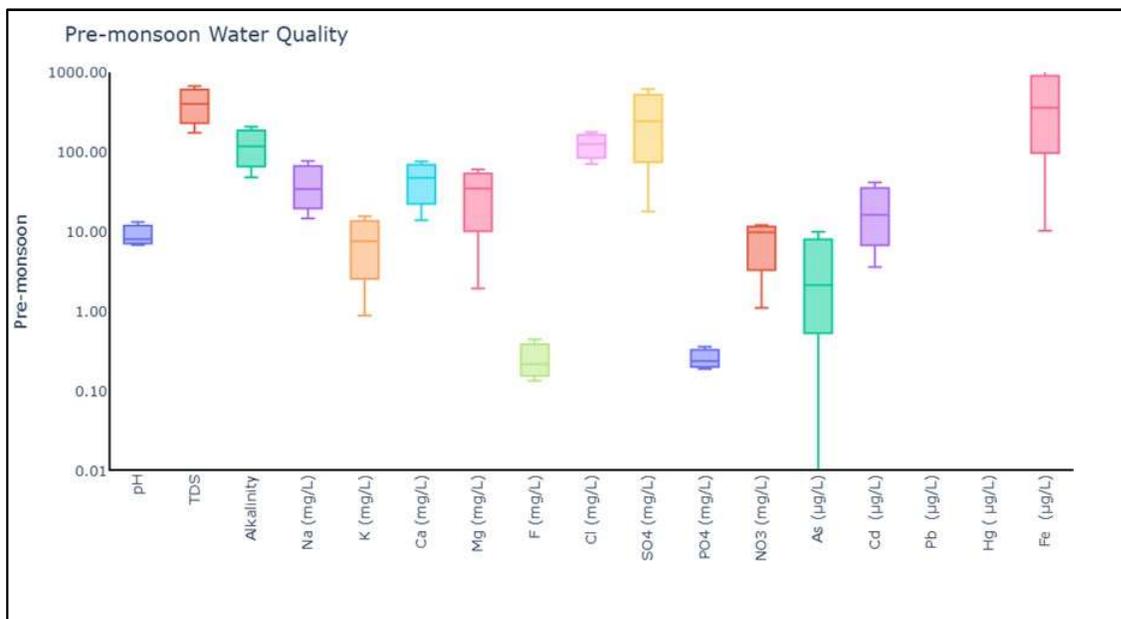


Fig 7. Water quality of pre-monsoon experimental samples

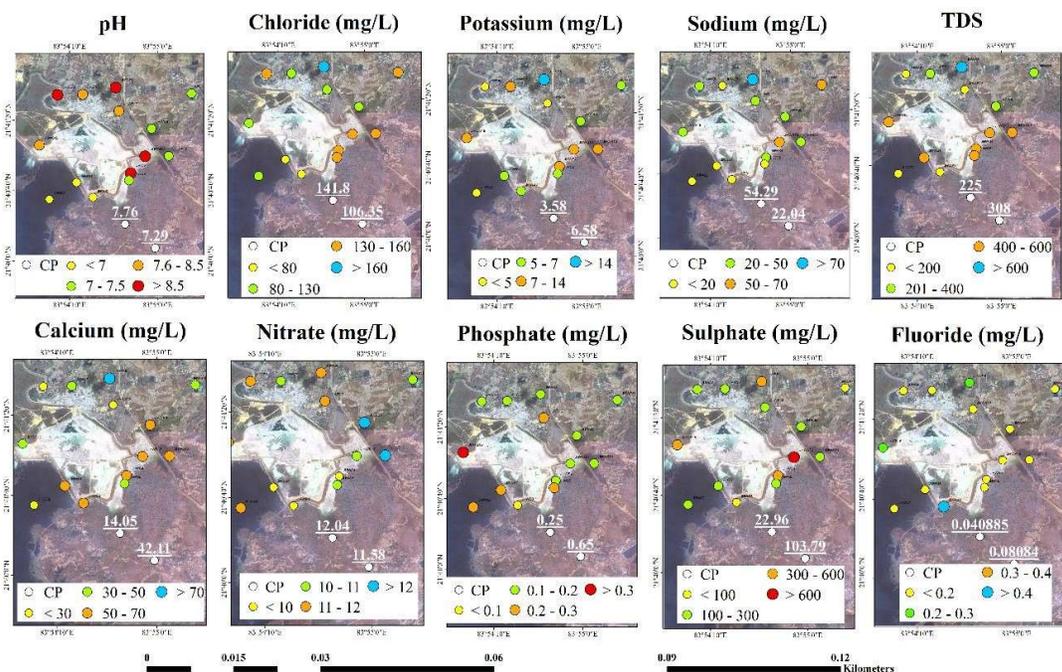


Fig 8. Spatial distribution of water quality parameters in pre-monsoon (both control and experimental). The control samples are shown by values in the map.

4.4. Pre-monsoon Experimental Water Sample Heavy Metal Analysis

Table 10. Descriptive statistics of heavy metals in pre-monsoon experimental water samples.

Parameter	Minimum	Maximum	Mean
As ($\mu\text{g/L}$)	0.00	10.00	2.14
Cd ($\mu\text{g/L}$)	3.60	41.60	16.27
Pb ($\mu\text{g/L}$)	BDL	BDL	BDL
Hg ($\mu\text{g/L}$)	BDL	BDL	BDL
Fe ($\mu\text{g/L}$)	10.33	1083.67	357.48

Water samples were analysed for heavy metal content, including arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg), and iron (Fe). The measured concentrations were found to be in the following ranges: arsenic (0–10 $\mu\text{g/L}$), cadmium (3.6–41.6 $\mu\text{g/L}$), lead (below detection limit, BDL), mercury (BDL), and iron (10.33–1083.67 $\mu\text{g/L}$). The mean concentrations that were determined in the samples were as follows: arsenic (2.14 $\mu\text{g/L}$), cadmium (16.27 $\mu\text{g/L}$), lead (BDL), mercury (BDL), and iron (357.48 $\mu\text{g/L}$).

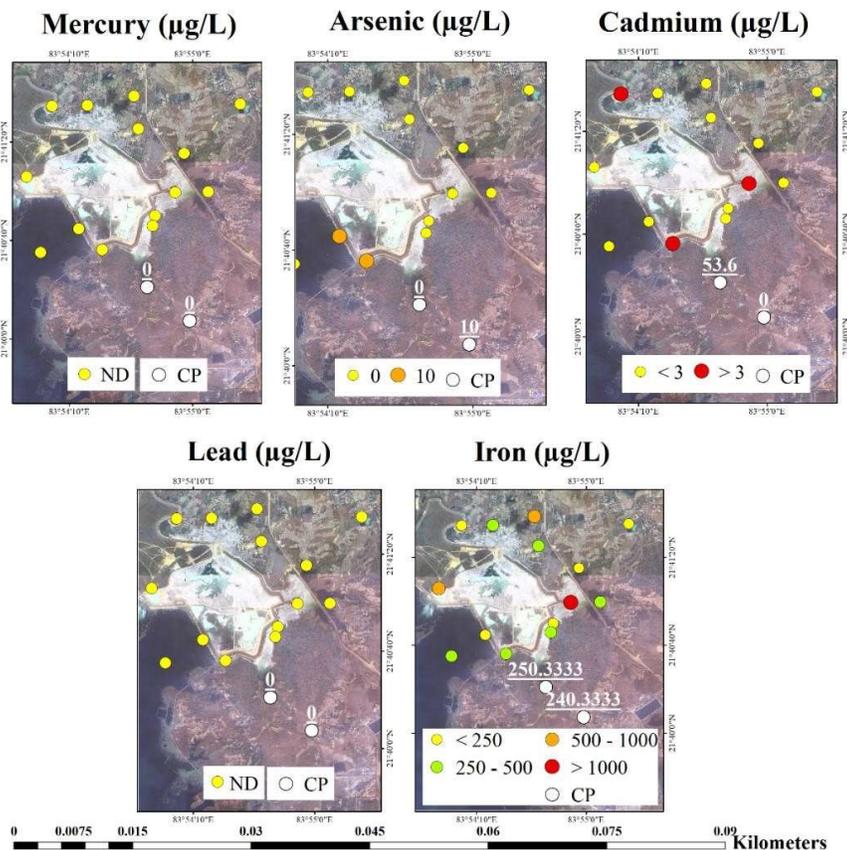


Fig 9. Spatial distribution of heavy metals in pre-monsoon experimental samples.

4.5. Monsoon Control Water Sample Cation and Anion Analysis

Table 11. Descriptive statistics of water quality parameters in monsoon control samples.

Parameter	Minimum	Maximum	Mean
pH	7.51	7.51	7.51
TDS	80.40	80.40	80.40
Alkalinity	48.00	48.00	48.00
Na (mg/L)	3.69	3.69	3.69
K (mg/L)	0.46	0.46	0.46
Ca (mg/L)	19.56	19.56	19.56
Mg (mg/L)	5.84	5.84	5.84
F (mg/L)	0.01	0.01	0.01
Cl (mg/L)	70.90	70.90	70.90
SO ₄ (mg/L)	9.00	9.00	9.00
PO ₄ (mg/L)	0.58	0.58	0.58
NO ₃ (mg/L)	0.15	0.15	0.15

The control water samples were collected and analysed for pH, total dissolved solids (TDS), alkalinity, major cations (sodium, potassium, calcium), anions (nitrate, phosphate, sulphate, fluoride, chloride), and heavy metals. The control water samples showed the following water quality: pH (7.51), TDS (80.40 mg/L), alkalinity (48 mg/L), sodium (3.69 mg/L), potassium (0.46 mg/L), calcium (19.56 mg/L), magnesium (5.84 mg/L), fluoride (0.01 mg/L), chloride (70.9 mg/L), sulphate (9 mg/L), phosphate (0.58 mg/L), and nitrate (0.15 mg/L). The pH of the control sample was alkaline in nature.

4.6. Monsoon Control Water Sample Heavy Metal Analysis

Table 12. Descriptive statistics of heavy metals in monsoon control water samples.

Parameter	Minimum	Maximum	Mean
As ($\mu\text{g/L}$)	0.00	0.00	0.00
Cd ($\mu\text{g/L}$)	13.60	13.60	13.60
Pb ($\mu\text{g/L}$)	BDL	BDL	BDL
Hg ($\mu\text{g/L}$)	BDL	BDL	BDL
Fe ($\mu\text{g/L}$)	987.00	987.00	987.00

The water samples collected from control sites were analysed for heavy metal content, including arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg), and iron (Fe). The analysed control sample was found to be having concentrations as the following: arsenic (0 $\mu\text{g/L}$ minimum, 13.6 $\mu\text{g/L}$ maximum), cadmium (BDL), lead (BDL), and iron (987 $\mu\text{g/L}$).

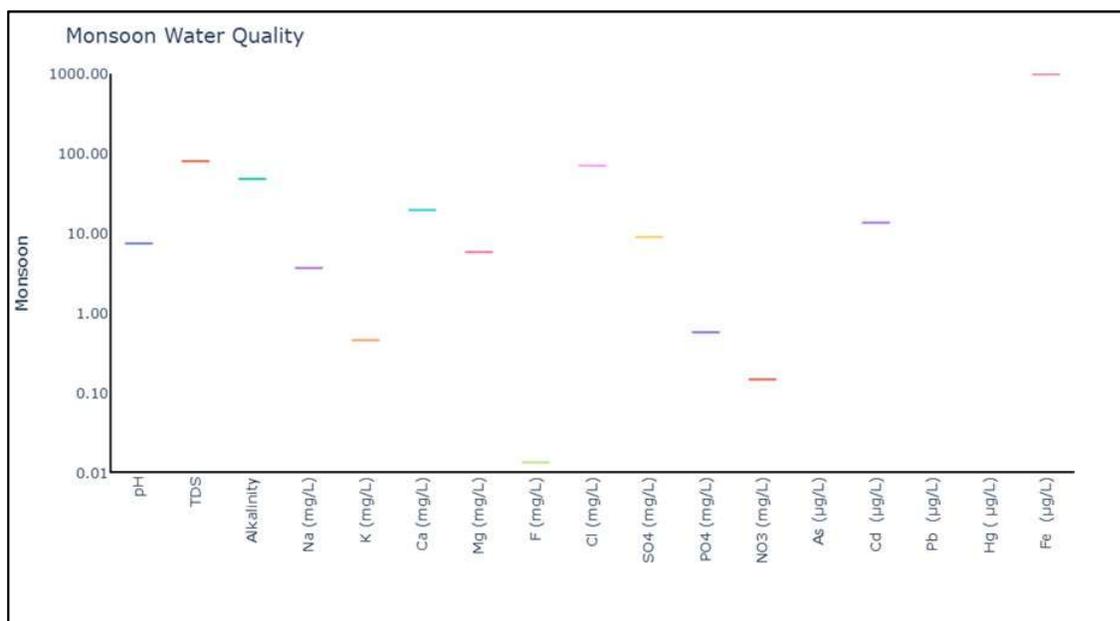


Fig 10. Water quality of monsoon control sample.

4.7. Monsoon Experimental Water Sample Cation and Anion Analysis

Table 13. Descriptive statistics of water quality parameters in monsoon samples.

Parameter	Minimum	Maximum	Mean
pH	7.54	7.75	7.63
TDS	172.00	313.00	222.17
Alkalinity	112.00	200.00	146.67
Na (mg/L)	3.08	24.82	9.39
K (mg/L)	0.03	2.12	0.76
Ca (mg/L)	27.54	64.30	43.00
Mg (mg/L)	15.57	25.30	21.74
F (mg/L)	0.00	0.05	0.03
Cl (mg/L)	70.90	106.35	94.53
SO ₄ (mg/L)	15.81	91.55	36.16
PO ₄ (mg/L)	0.75	0.96	0.84
NO ₃ (mg/L)	0.13	0.67	0.46

The pH of experimental water samples was alkaline, having a minimum value of 7.54 to a maximum value of 7.75 with a mean value of 7.63. The TDS of samples was found to be in the range of minimum 172 and maximum 313, with a mean of 222.17. The alkalinity of analysed samples was having a minimum 112 mg/L and a maximum 200 mg/L, while mean was found to be 146.67 mg/L. The sodium was having a range of minimum concentration 3.08 mg/L to maximum concentration of 24.82 mg/L, with the mean concentration of 9.39 mg/L. The potassium concentration was found to be in the range of 0.03 mg/L minimum and 2.12 mg/L maximum, with the mean value of 0.76 mg/L. While the mean concentration of calcium was found to be 43 mg/L with the range of 27.54 mg/L minimum and 64.3 mg/L maximum. In the analysed samples magnesium was found to be having a minimum concentration of 15.57 mg/L and a maximum of 25.3 mg/L, while the mean was found to be 21.74 mg/L. It was found that fluoride has a minimum concentration of 0 mg/L and maximum concentration of 0.05 mg/L, with a mean concentration of 0.03 mg/L in the analysed samples. The chloride was having 70.9 mg/L minimum concentration, 106.35 mg/L maximum concentration and 94.53 mg/L mean concentration in the analysed samples. The Sulphate in analysed samples was found to be in the range of 15.81 mg/L minimum, 91.55 mg/L maximum, while mean was found to be 36.16 mg/L. The phosphate concentration in the analysed water samples ranged from a minimum of 0.75 mg/L to a maximum of 0.96 mg/L, with a mean concentration of 0.84 mg/L. Nitrate levels was found to be having a minimum concentration of 0.13 mg/L, a maximum of 0.67 mg/L, and an average concentration of 0.46 mg/L.

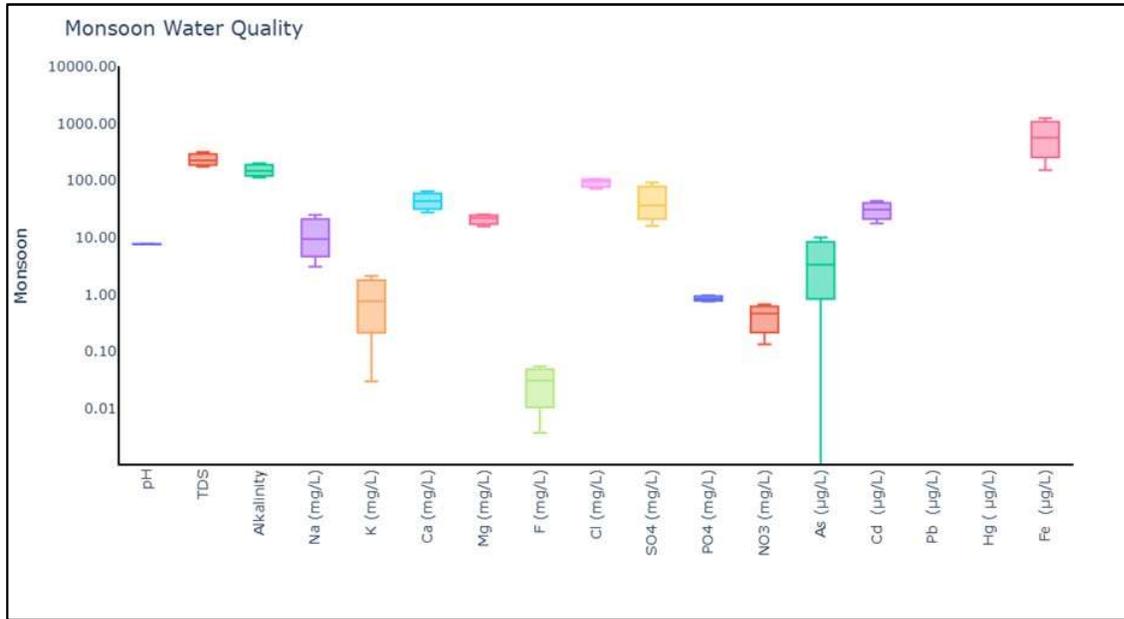


Fig 11. Water quality of monsoon samples.

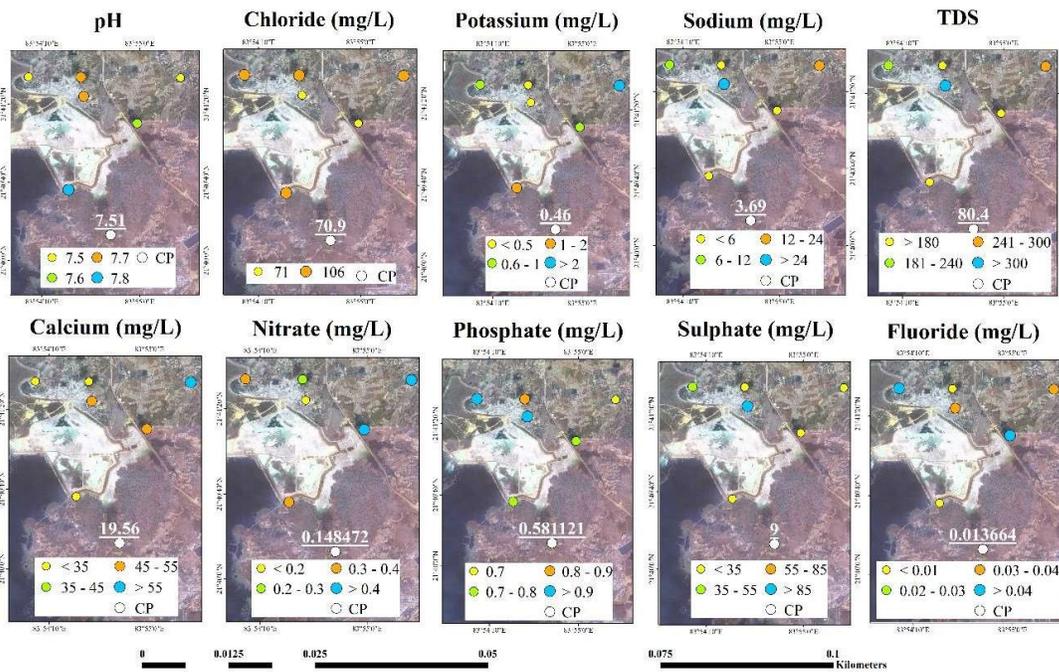


Fig 12. Spatial distribution of Water Quality parameters in monsoon

4.8. Monsoon Experimental Water Sample Heavy Metal Analysis

Table 14. Descriptive statistics of heavy metals in monsoon water samples.

Parameter	Minimum	Maximum	Mean
As ($\mu\text{g/L}$)	0.00	10.00	3.33
Cd ($\mu\text{g/L}$)	17.60	43.60	30.60
Pb ($\mu\text{g/L}$)	BDL	BDL	BDL
Hg ($\mu\text{g/L}$)	BDL	BDL	BDL
Fe ($\mu\text{g/L}$)	150.33	1223.67	559.22

The experiment water samples were analysed for heavy metal content including arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg), and iron (Fe). The concentration ranges of heavy metals in the experimental water samples were found to be, arsenic (0-10 $\mu\text{g/L}$), cadmium (17.6-43.6 $\mu\text{g/L}$), lead (below detection limit, BDL), mercury (BDL), and iron (150.33-1229.67 $\mu\text{g/L}$). The average concentrations were determined to be, arsenic (3.33 $\mu\text{g/L}$), cadmium (30.67 $\mu\text{g/L}$), lead (BDL), mercury (BDL), and iron (559.22 $\mu\text{g/L}$).

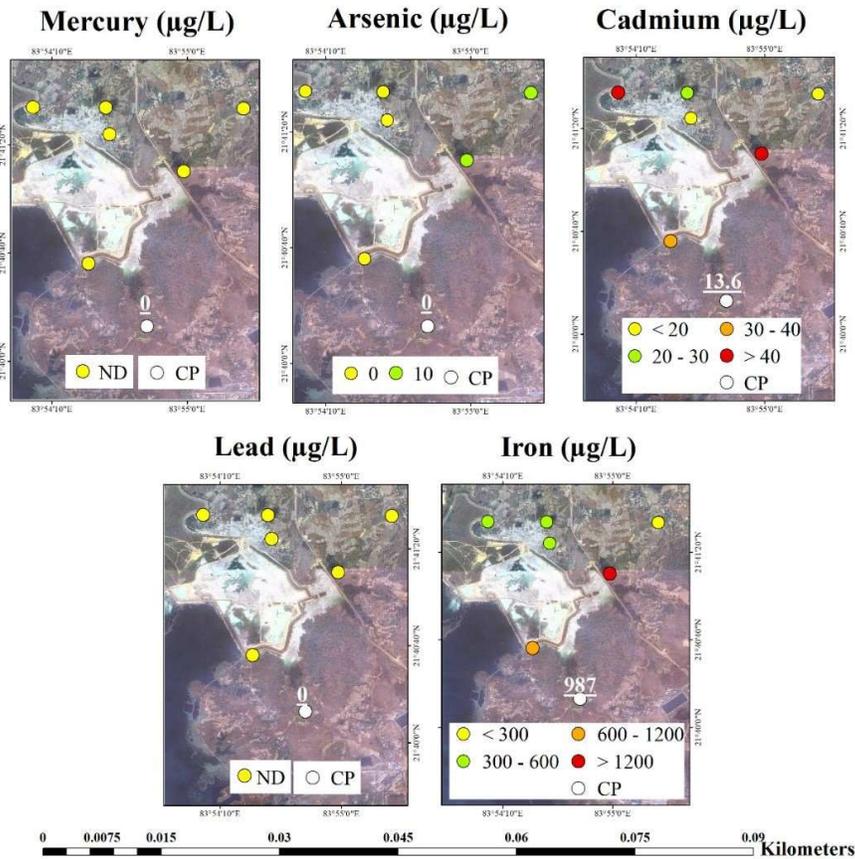


Fig 13. Spatial distribution of heavy metals in monsoon.

4.9. Post-monsoon Control Water Sample Cation and Anion Analysis

Table 15. Descriptive statistics of water quality parameters in post-monsoon control samples.

Parameter	Minimum	Maximum	Mean
pH	6.36	6.36	6.36
TDS	162.00	162.00	162.00
Alkalinity	88.00	88.00	88.00
Na (mg/L)	9.45	9.45	9.45
K (mg/L)	42.72	42.72	42.72
Ca (mg/L)	33.05	33.05	33.05
Mg (mg/L)	7.79	7.79	7.79
F (mg/L)	0.01	0.01	0.01
Cl (mg/L)	70.90	70.90	70.90
SO ₄ (mg/L)	26.45	26.45	26.45
PO ₄ (mg/L)	0.37	0.37	0.37
NO ₃ (mg/L)	8.16	8.16	8.16

The control water sample was analysed for major cations and anions during post-monsoon season. Sodium concentration was found to be having a minimum concentration of 3.69 mg/L, maximum of 3.69 mg/L, with a mean concentration of 3.69 mg/L. Potassium levels was found in the range of 0.46 mg/L minimum to 0.46 mg/L maximum, with average 0.46 mg/L. Calcium concentration was determined to be in the range of 19.56 mg/L minimum and 19.56 mg/L maximum, with mean value of 19.56 mg/L. Magnesium was found to be having 5.84 mg/L minimum and 5.84 mg/L maximum concentration, while mean was found to be 5.84 mg/L. The fluoride concentration ranged from 0.01 mg/L minimum to 0.01 mg/L maximum, while the mean concentration was found 0.01 mg/L in the analysed control samples. The chloride was having 70.9 mg/L minimum, 70.9 mg/L maximum and 70.9 mg/L mean concentration. The sulphate levels were found to be in the range of 9 mg/L minimum and 9 mg/L maximum, while mean was found to be 9 mg/L. the phosphate concentration was determined to be 0.58 mg/L minimum, 0.58 mg/L maximum, with average concentration of 0.58 mg/L. The nitrate was found to be having 0.15 mg/L minimum, 0.15 mg/L maximum, and mean concentration of 0.15 mg/L.

4.10. Post Monsoon Control Water Sample Heavy Metal Analysis

Table 16. Descriptive statistics of heavy metals in post- monsoon control water samples.

Parameter	Minimum	Maximum	Mean
As ($\mu\text{g/L}$)	0.10	0.10	0.10
Cd ($\mu\text{g/L}$)	2.90	2.90	2.90
Pb ($\mu\text{g/L}$)	6.40	6.40	6.40
Hg ($\mu\text{g/L}$)	BDL	BDL	BDL
Fe ($\mu\text{g/L}$)	444.40	444.40	444.40

The control water sample was analysed for heavy metals including arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg) and iron (Fe). Arsenic concentration was found to be having a minimum concentration of 0.1 $\mu\text{g/L}$, maximum of 2.9 $\mu\text{g/L}$, with a mean concentration of 6.4 $\mu\text{g/L}$. Cadmium levels was found in the range of BDL minimum to BDL maximum, with average BDL. Lead concentration was determined to be in the range of BDL minimum and BDL maximum, with mean value of BDL. Mercury was found to be having BDL minimum and BDL maximum concentration, while mean was found to be BDL. The iron concentration ranged from 444.4 $\mu\text{g/L}$ minimum to 444.4 $\mu\text{g/L}$ maximum, while the mean concentration was found 444.4 $\mu\text{g/L}$ in the analysed control samples.

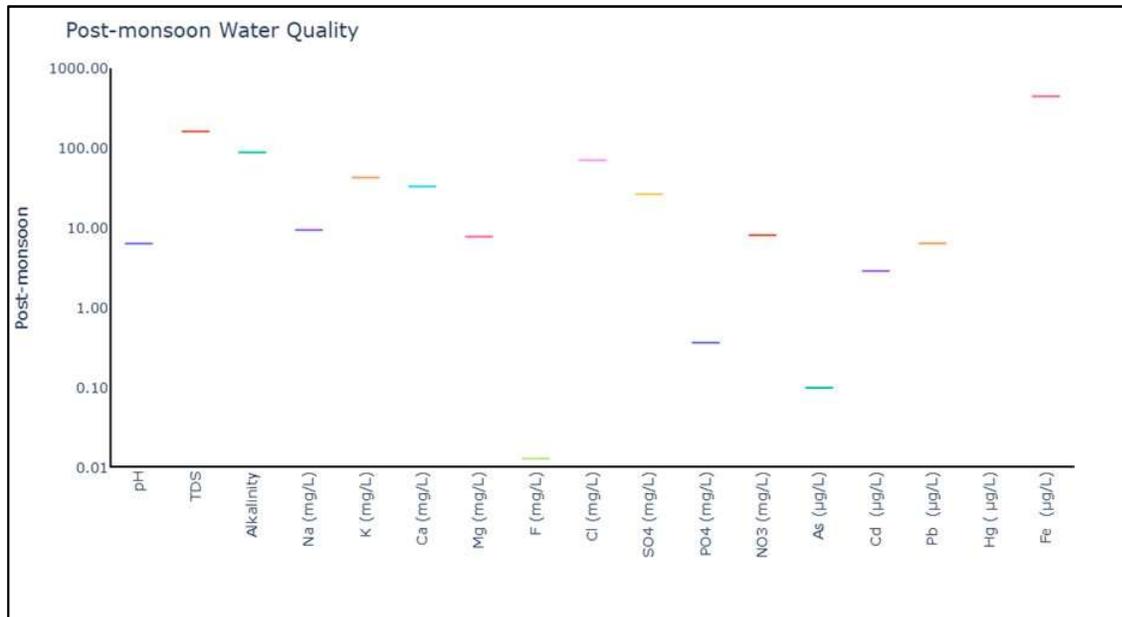


Fig 14. Water quality of post-monsoon control samples.

4.11. Post-monsoon Experimental Water Sample Cation and Anion Analysis

Table 17. Descriptive statistics of water quality parameters in post-monsoon samples.

Parameter	Minimum	Maximum	Mean
pH	6.43	7.32	6.82
TDS	253.00	519.00	362.89
Alkalinity	88.00	208.00	163.56
Na (mg/L)	6.91	14.10	9.55
K (mg/L)	60.60	289.95	132.10
Ca (mg/L)	41.90	62.36	51.20
Mg (mg/L)	21.41	66.18	44.34
F (mg/L)	0.01	0.13	0.07
Cl (mg/L)	35.45	141.80	82.72
SO ₄ (mg/L)	33.47	269.21	134.70
PO ₄ (mg/L)	0.29	0.68	0.43
NO ₃ (mg/L)	1.54	10.98	4.89

The pH of water samples was slightly acidic to alkaline, having a minimum value of 6.43 to a maximum value of 7.32 with mean value of 6.82. The 77.78% of samples were found to be alkaline, whereas 22.22% were found to be acidic in nature. The TDS of samples was found to be in the range of minimum 253 and maximum 519 with a mean of 362.89. The alkalinity of analysed samples was having a minimum 88 mg/L and a maximum 208 mg/L, while mean was found to be 163.56 mg/L. The sodium was having a range of minimum concentration 6.91 mg/L to maximum concentration of

14.1 mg/L, with the mean concentration of 9.55 mg/L. The potassium concentration was found to be in the range of 60.6 mg/L minimum and 289.95 mg/L maximum, with the mean value of 132.1 mg/L. While the mean concentration of calcium was found to be 51.2 mg/L with the range of 41.9 mg/L minimum and 62.36 mg/L maximum. In the analysed samples magnesium was found to be having a minimum concentration of 21.41 mg/L and a maximum of 66.18 mg/L, while the mean was found to be 44.34 mg/L. It was found that fluoride has a minimum concentration of 0.01 mg/L and maximum concentration of 0.13 mg/L, with a mean concentration of 0.07 mg/L in the analysed samples. The chloride was having 35.45 mg/L minimum concentration, 141.8 mg/L maximum concentration and 82.72 mg/L mean concentration in the analysed samples. The sulphate in analysed samples was found to be in the range of 33.47 mg/L minimum, 269.21 mg/L maximum, while mean was found to be 134.7 mg/L. The phosphate concentration in the analysed water samples ranged from a minimum of 0.29 mg/L to a maximum of 0.68 mg/L, with a mean concentration of 0.43 mg/L. Nitrate levels was found to be having a minimum concentration of 1.54 mg/L, a maximum of 10.98 mg/L, and an average concentration of 4.89 mg/L.

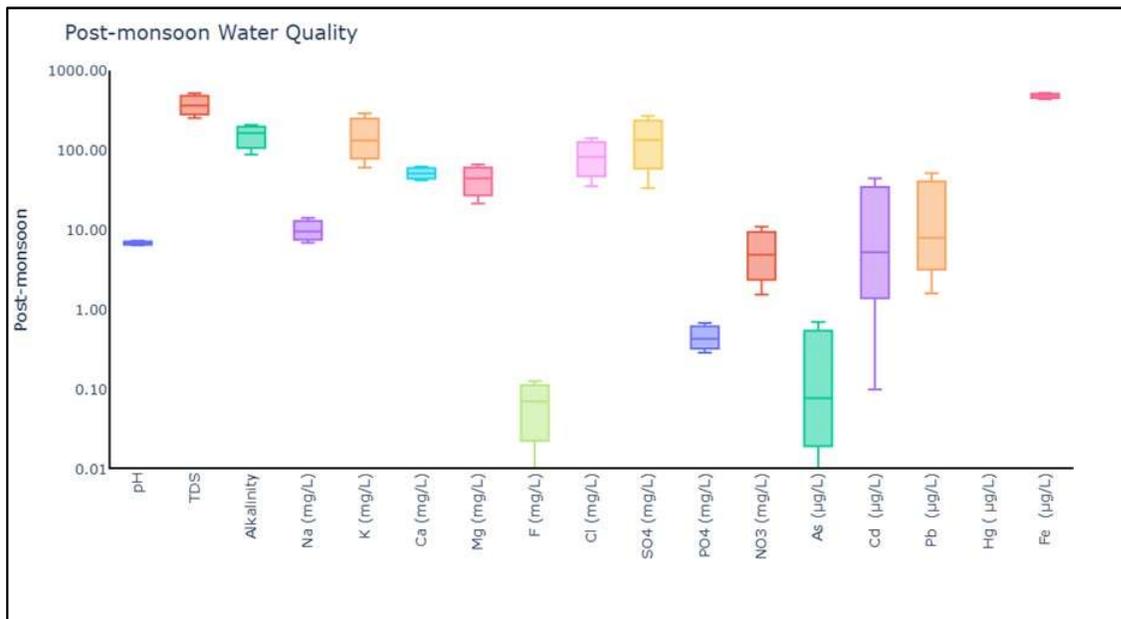


Fig 15. Water quality of post-monsoon samples.

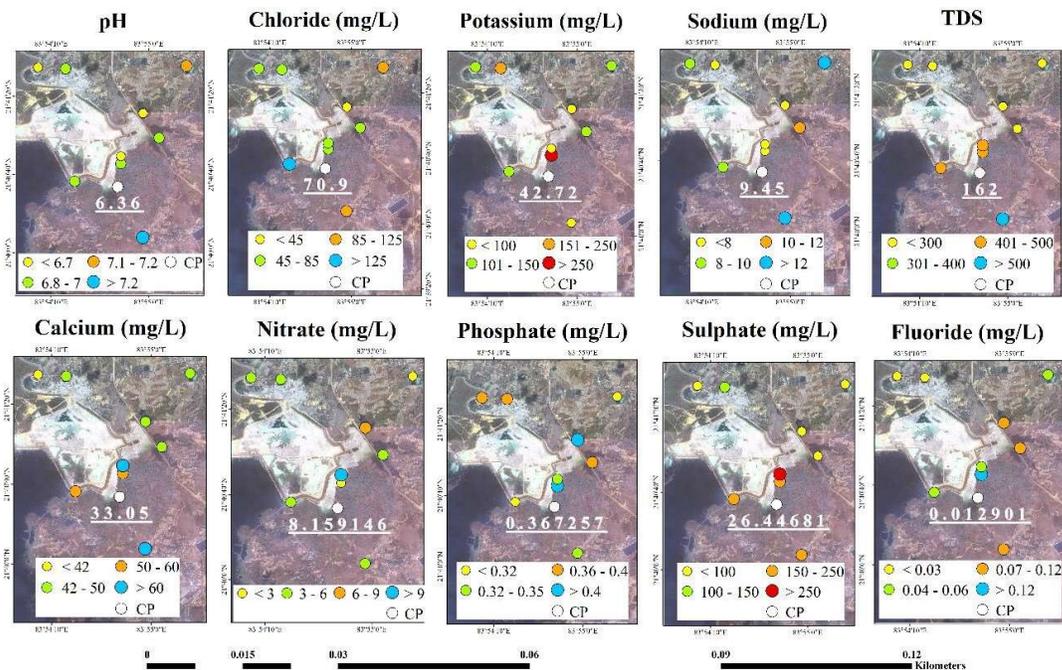


Fig 16. Spatial distribution of Water Quality parameters in post-monsoon

4.12. Post-monsoon Experimental Water Sample Heavy Metal Analysis

Table 18. Descriptive statistics of heavy metals in post- monsoon water samples.

Parameter	Minimum	Maximum	Mean
As ($\mu\text{g/L}$)	0.00	0.70	0.08
Cd ($\mu\text{g/L}$)	0.10	44.30	5.28
Pb ($\mu\text{g/L}$)	1.60	51.50	7.96
Hg ($\mu\text{g/L}$)	BDL	BDL	BDL
Fe ($\mu\text{g/L}$)	439.10	521.60	479.98

The water samples were analysed for heavy metal content including arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg), and iron (Fe). The arsenic concentration was found to be having a minimum concentration of 0 $\mu\text{g/L}$ and maximum of 0.7 $\mu\text{g/L}$, with a mean concentration of 0.08 $\mu\text{g/L}$. Cadmium levels were found in the range of 0.1 $\mu\text{g/L}$ minimum to 44.3 $\mu\text{g/L}$ maximum, with average 5.28 $\mu\text{g/L}$. Lead concentration was determined to be in the range of 1.6 $\mu\text{g/L}$ minimum and 51.5 $\mu\text{g/L}$ maximum, with mean value of 7.96 $\mu\text{g/L}$. Mercury was found to be having BDL minimum and BDL maximum concentration, while mean was found to be BDL. The iron concentration ranged from 439.1 $\mu\text{g/L}$ minimum to 521.6 $\mu\text{g/L}$ maximum, while the mean concentration was found to be 479.98 $\mu\text{g/L}$ in the analysed samples.

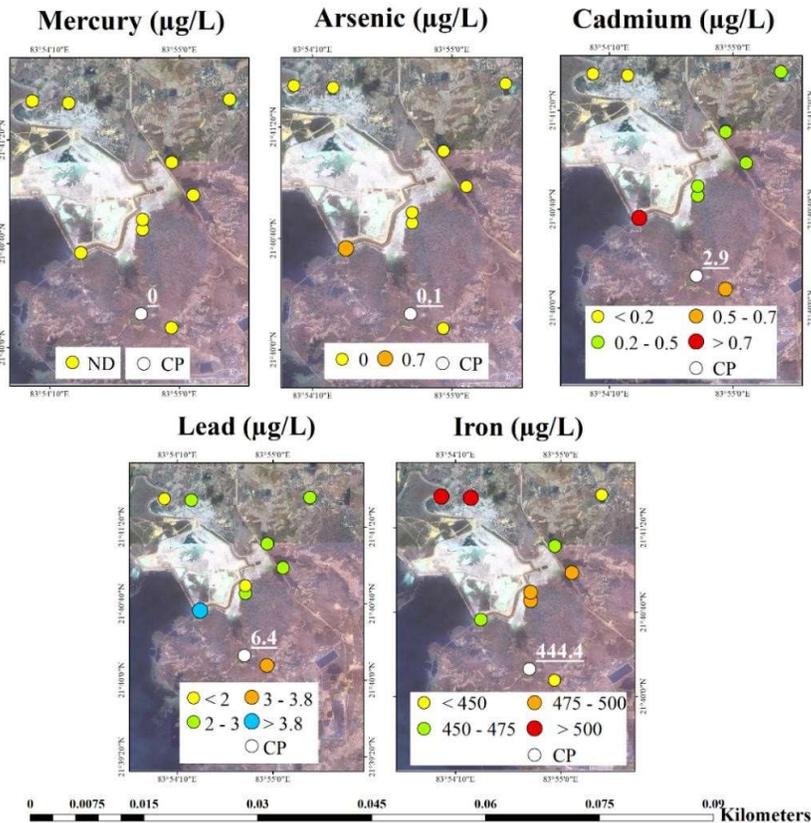


Fig 17. Spatial distribution of heavy metals in post-monsoon

4.13. Percentage of samples exceeding permissible limit for surface water

However, these are surface water samples and comparison to drinking water would not be appropriate, however, based on water quality analysis the water seems to be meeting drinking water quality standards. Since there are no Indian standards for surface water quality to be followed so no comparison was made for water quality parameters. However, water samples collected from Hirakud reservoir satisfactorily fulfil the designated best use (DBU) criteria of CPCB for pH and EC. Highly alkaline water (>8.5) can cause gastrointestinal irritation; acidic water (<6.5) may corrode pipes. Low TDS indicates minimal salinity; high TDS affects taste and may indicate contamination. No risk of dental/skeletal fluorosis. Safe for infants and adults; no risk of methemoglobinemia based on nitrate concentrations. High sulphate may cause laxative effects or taste issues, whereas high iron may cause aesthetic issues (colour/taste) and potential liver toxicity at very high levels but not at current observed levels in water. Few samples show localized high cadmium and lead which might lead to kidney and bone fragility, this should be treated with disclaimer that it is not drinking water but still satisfies most of the drinking water criteria.

The water quality was also evaluated for bathing water suitability and was found to be in full compliance of bathing classification as per CPCB, 2019 except for pH.

Table 19. Bathing Water Suitability (CPCB Standards, 2019)

Parameter	Observed Range	CPCB Limit (Class B: Bathing)	Compliance Status	Implications
pH	6.36 – 9.04	6.5 – 8.5	Non-compliant (21.43% samples)	Skin irritation possible in alkaline/acidic water.
TDS (mg/L)	80.4 – 672	500	Compliant (mostly)	No significant risk.
Arsenic (µg/L)	0.0 – 10.0	100	Compliant	Safe for dermal contact.
Lead (µg/L)	BDL – 51.5	100	Compliant	No acute dermal risk.
Cadmium (µg/L)	0.1 – 53.6	10	Compliant (all ≤ 10 except 1 sample at 53.6)	Low risk for short-term exposure.

5. Result of Soil Sample Analysis

5.1 Pre-monsoon Control Surface Soil Sample Cation and Anion Analysis

Table 20. Descriptive statistics of soil quality parameters in pre-monsoon surface control samples.

Parameter	Minimum	Maximum	Mean
pH	5.36	6.67	5.91
EC	108.80	1089.00	398.84
Na (mg/Kg)	17.21	35.10	23.62
K (mg/Kg)	37.09	198.83	84.42
Ca (mg/Kg)	151.54	388.01	226.82
F (mg/Kg)	0.01	0.02	0.02
Cl (mg/Kg)	26.59	106.35	85.08
SO ₄ (mg/Kg)	14.53	77.03	46.22
PO ₄ (mg/Kg)	0.02	0.06	0.04
NO ₃ (mg/kg)	2.74	25.05	12.35

The soil samples were collected from the surface and analysed for pH, electrical conductivity (EC), major cations (sodium, potassium, calcium), anions (nitrate, phosphate, sulphate, fluoride, chloride), and heavy metals. The pH of soil samples was acidic, having a minimum value of 5.36 to a maximum value of 6.67 with a mean value of 5.91. The EC of samples was found to be in the range of minimum 108.8 mS/cm and maximum 1089 mS/cm, with a mean of 398.84 mS/cm. The sodium concentration was found to be having a minimum concentration of 17.21 mg/kg to maximum concentration of 35.1 mg/kg, with the mean concentration of 23.62 mg/kg. The potassium concentration was found to be in the range of 37.09 mg/kg minimum and 198.83 mg/kg maximum, with the mean value of 84.42 mg/kg. While the mean concentration of calcium was found to be 226.82 mg/kg with the range of 151.54 mg/kg minimum and 388.01 mg/kg maximum.

It was found that fluoride has a minimum concentration of 0.01 mg/kg and maximum concentration of 0.02 mg/kg, with a mean concentration of 0.02 mg/kg in the analysed samples. The chloride was having 26.59 mg/kg minimum concentration, 106.35 mg/kg maximum concentration, and 85.08 mg/kg mean concentration in the analysed samples. The sulphate in analysed samples was found to be in the range of 14.53 mg/kg minimum, 77.03 mg/kg maximum, while mean was found to be 46.22 mg/kg. The phosphate concentration in the analysed soil samples ranged from a minimum of 0.02 mg/kg to a maximum of 0.06 mg/kg, with a mean concentration of 0.04 mg/kg. Nitrate levels were found to be having a minimum concentration of 2.74 mg/kg, a maximum of 25.05 mg/kg, and an average concentration of 12.35 mg/kg.

5.2 Pre-monsoon Control Surface Soil Sample Heavy Metal Analysis

Table 21. Descriptive statistics of heavy metals in pre-monsoon surface control samples.

Parameter	Minimum	Maximum	Mean
Mn (mg/kg)	5.33	68.53	31.13
Co (mg/kg)	0.34	1.69	0.92
Ni (mg/kg)	0.43	2.59	1.23
Cu (mg/kg)	0.32	2.04	0.87
Zn (mg/kg)	0.65	4.42	1.67
As (mg/kg)	0.04	0.36	0.20
Mo (mg/kg)	0.00	0.02	0.01
Cd (mg/kg)	0.00	0.01	0.00
Pb (mg/kg)	0.36	1.63	1.12
Fe (mg/kg)	4.41	10.23	6.25
Hg (mg/kg)	0.07	0.12	0.10

The soil samples were analysed for heavy metal content, including cadmium (Cd), zinc (Zn), lead (Pb), iron (Fe), arsenic (As), molybdenum (Mo), manganese (Mn), nickel (Ni), copper (Cu), cobalt (Co), and mercury (Hg). The results indicated the following concentration ranges and mean values (in mg/kg): manganese (Mn) ranged from 5.33 to 68.53 with a mean of 31.13; cobalt (Co) ranged

from 0.34 to 1.69 with a mean of 0.92; nickel (Ni) ranged from 0.43 to 2.59 with a mean of 1.23; copper (Cu) ranged from 0.32 to 2.04 with a mean of 0.87; and zinc (Zn) ranged from 0.65 to 4.42 with a mean of 1.67. Arsenic (As) concentrations ranged from 0.04 to 0.36 with a mean of 0.20, while molybdenum (Mo) ranged from below detection limit (BDL) to 0.02 with a mean of 0.01. Cadmium (Cd) levels were between BDL and 0.01, with a mean below detection. Lead (Pb) concentrations ranged from 0.36 to 1.63 with a mean of 1.12, iron (Fe) ranged from 4.41 to 10.23 with a mean of 6.25, and mercury (Hg) ranged from 0.07 to 0.12 with a mean of 0.10.

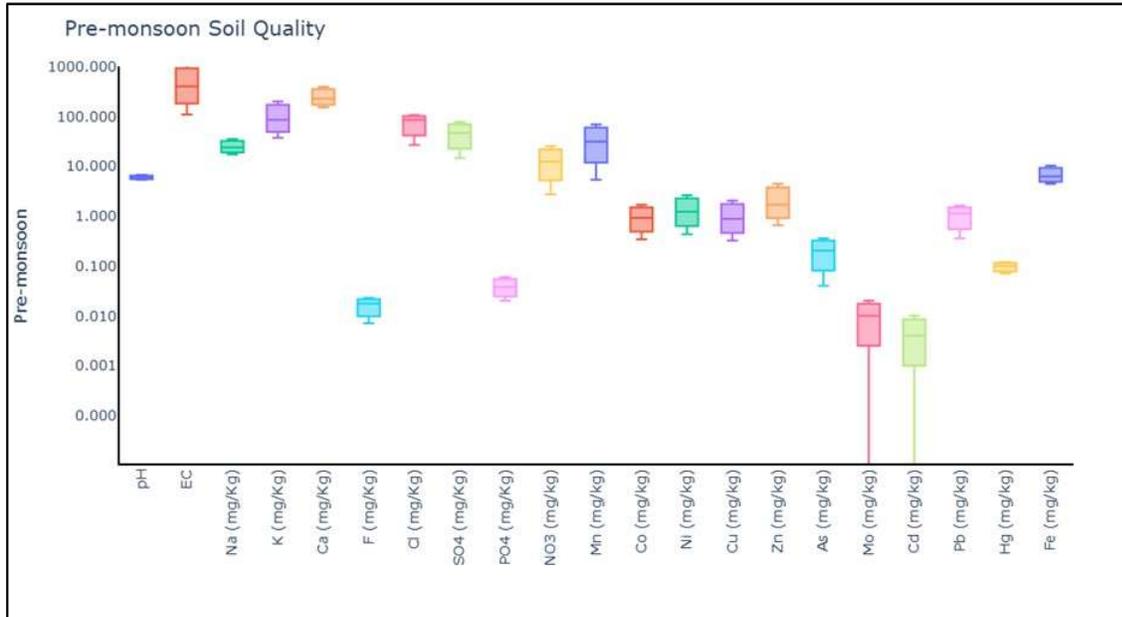


Fig 18. Soil quality of pre-monsoon surface control samples.

5.3 Pre-monsoon Experimental Surface Soil Sample Cation and Anion Analysis

Table 22. Descriptive statistics of soil quality parameters in pre-monsoon surface samples.

Parameter	Minimum	Maximum	Mean
pH	4.81	7.39	5.93
EC	69.2	2041	604.59
Na (mg/Kg)	9.34	36.9	22.65
K (mg/Kg)	7.24	118.13	63.38
Ca (mg/Kg)	26.66	523.01	185.49
F (mg/Kg)	0.011	0.022	0.018
Cl (mg/Kg)	53.18	212.7	102.72
SO ₄ (mg/Kg)	14.53	505.81	78.88
PO ₄ (mg/Kg)	0.02	0.16	0.04
NO ₃ (mg/kg)	4.95	25.4	14.65

A total of 27 surface soil samples were collected and analysed for pH, electrical conductivity (EC), major cations (sodium, potassium, calcium), anions (nitrate, phosphate, sulphate, fluoride, chloride), and heavy metals. The pH of soil samples was predominantly acidic, having a minimum value of 4.81 to a maximum value of 7.39 with a mean value of 5.93. The 90.91% of samples were found to be acidic, whereas 9.09% were found to be alkaline in nature. The EC of samples was found to be in the range of minimum 69.2 mS/cm and maximum 2041 mS/cm, with a mean of 604.59 mS/cm. The sodium concentration was found to be having a minimum concentration of 9.34 mg/kg to maximum concentration of 36.9 mg/kg, with the mean concentration of 22.65 mg/kg. The potassium concentration was found to be in the range of 7.24 mg/kg minimum and 118.13 mg/kg maximum, with the mean value of 63.38 mg/kg. While the mean concentration of calcium was found to be 185.49 mg/kg with the range of 26.66 mg/kg minimum and 523.01 mg/kg maximum. It was found that fluoride has a minimum concentration of 0.011 mg/kg and maximum concentration of 0.022 mg/kg, with a mean concentration of 0.018 mg/kg in the analysed samples. The chloride was having 53.18 mg/kg minimum concentration, 212.7 mg/kg maximum concentration, and 102.72 mg/kg mean concentration in the analysed samples. The sulphate in analysed samples was found to be in the range of 14.53 mg/kg minimum, 505.81 mg/kg maximum, while mean was found to be 78.88 mg/kg. The phosphate concentration in the analysed soil samples ranged from a minimum of 0.02 mg/kg to a maximum of 0.16 mg/kg, with a mean concentration of 0.04 mg/kg. Nitrate levels were found to be having a minimum concentration of 4.95 mg/kg, a maximum of 25.4 mg/kg, and an average concentration of 14.65 mg/kg.

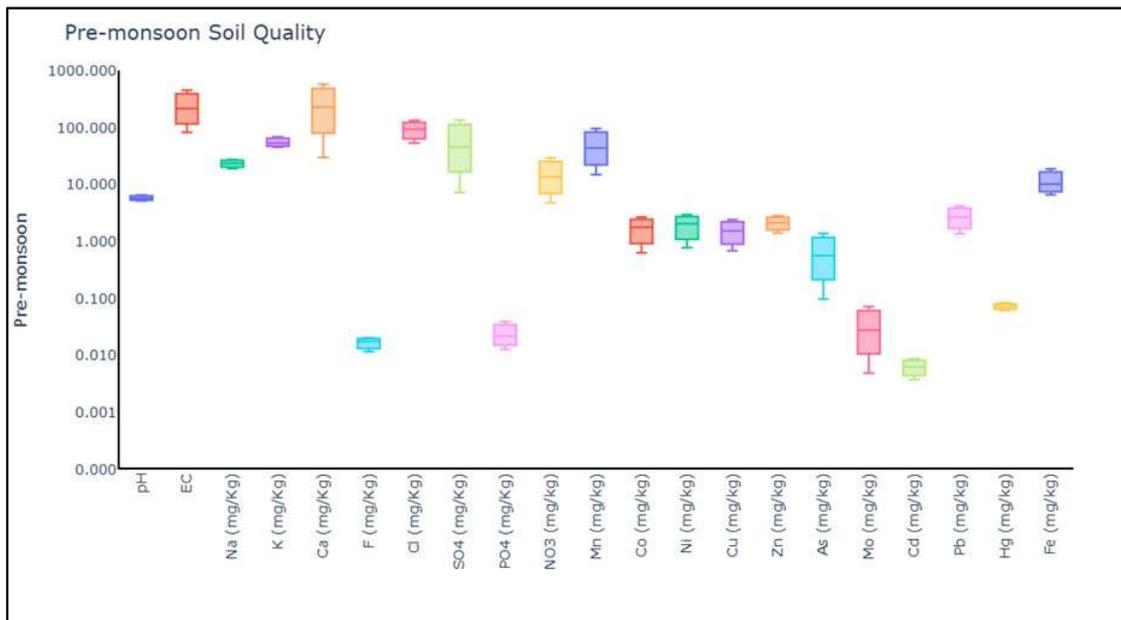


Fig 19. Soil quality of pre-monsoon surface samples.

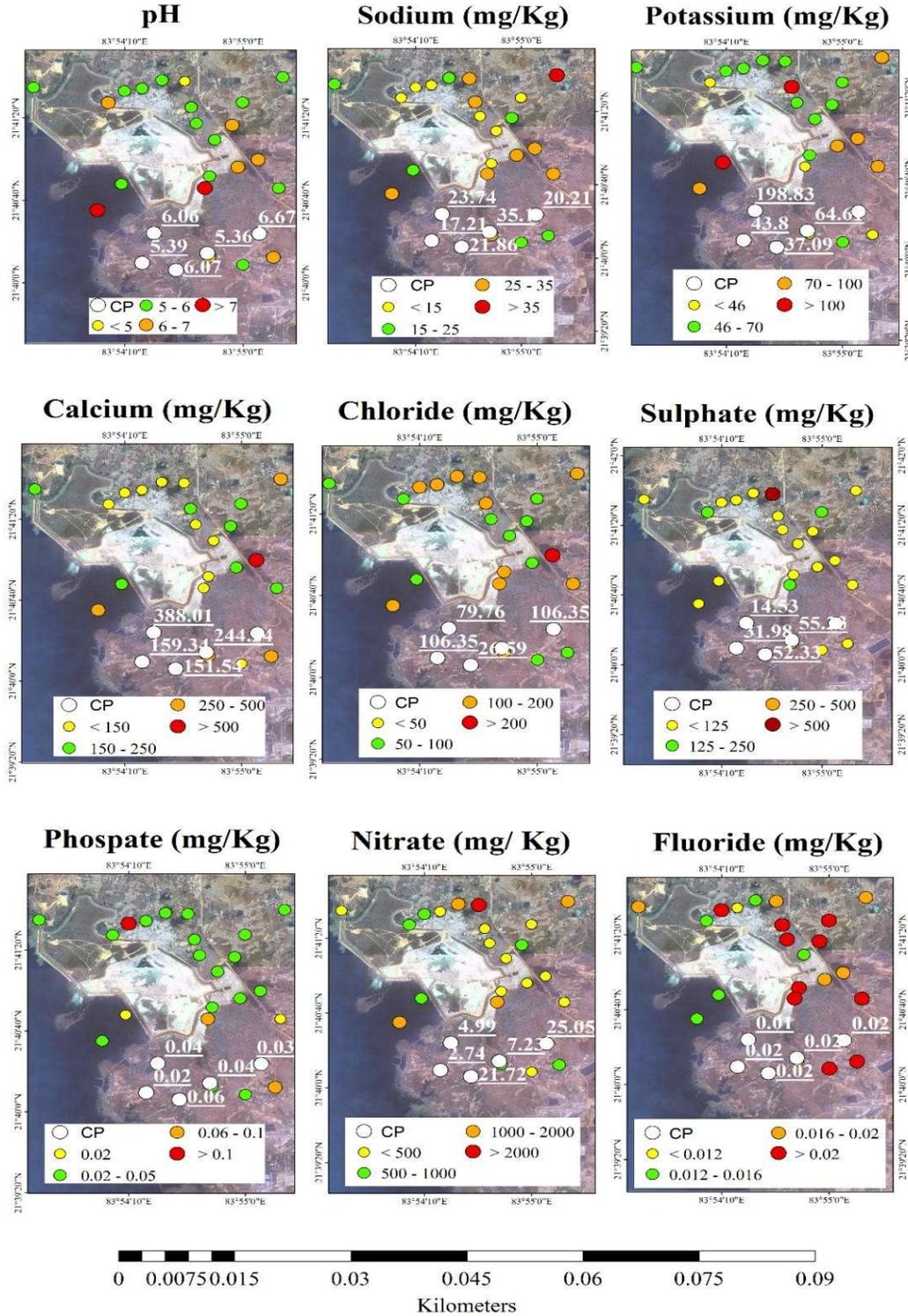


Fig 20. Spatial distribution of soil quality parameters in pre-monsoon surface samples.

5.4 Pre-monsoon Experimental Surface Soil Sample Heavy Metal Analysis

Table 23. Descriptive statistics of heavy metals in pre-monsoon surface soil.

Parameter	Minimum	Maximum	Mean
Mn (mg/kg)	1.69	89.04	24.43
Co (mg/kg)	0.08	2.87	0.72
Ni (mg/kg)	0.11	3.36	1.03
Cu (mg/kg)	0.08	2.45	0.67
Zn (mg/kg)	0.14	2.61	1.20
As (mg/kg)	0.02	1.29	0.27
Mo (mg/kg)	0	0.83	0.08
Cd (mg/kg)	0	0.01	0.00
Pb (mg/kg)	0.07	2.6	0.74
Fe (mg/kg)	1.51	20.83	8.07
Hg (mg/kg)	0.06	0.13	0.09

Soil samples from the experimental site were analysed for heavy metal contamination, quantifying eleven elements: cadmium (Cd), zinc (Zn), lead (Pb), iron (Fe), arsenic (As), molybdenum (Mo), manganese (Mn), nickel (Ni), copper (Cu), cobalt (Co), and mercury (Hg). Analytical results showed copper concentrations ranging from 0.08 to 2.45 mg/kg with a mean of 0.67 mg/kg, while zinc exhibited concentrations between 0.14 and 2.61 mg/kg (mean: 1.20 mg/kg). Arsenic levels varied from 0.02 to 1.29 mg/kg (mean: 0.27 mg/kg), with molybdenum ranging from below detection limit to 0.83 mg/kg (mean: 0.08 mg/kg). Cadmium concentrations were minimal, ranging from non-detectable to 0.01 mg/kg (mean below detection), whereas lead showed a wider distribution from 0.07 to 2.6 mg/kg (mean: 0.74 mg/kg). Iron demonstrated the greatest variability, with concentrations spanning 1.51 to 20.83 mg/kg (mean: 8.07 mg/kg), while mercury maintained relatively consistent levels between 0.06 and 0.13 mg/kg (mean: 0.09 mg/kg). Manganese concentrations averaged 24.43 mg/kg, with cobalt and nickel showing mean values of 0.72 mg/kg and 1.03 mg/kg respectively.

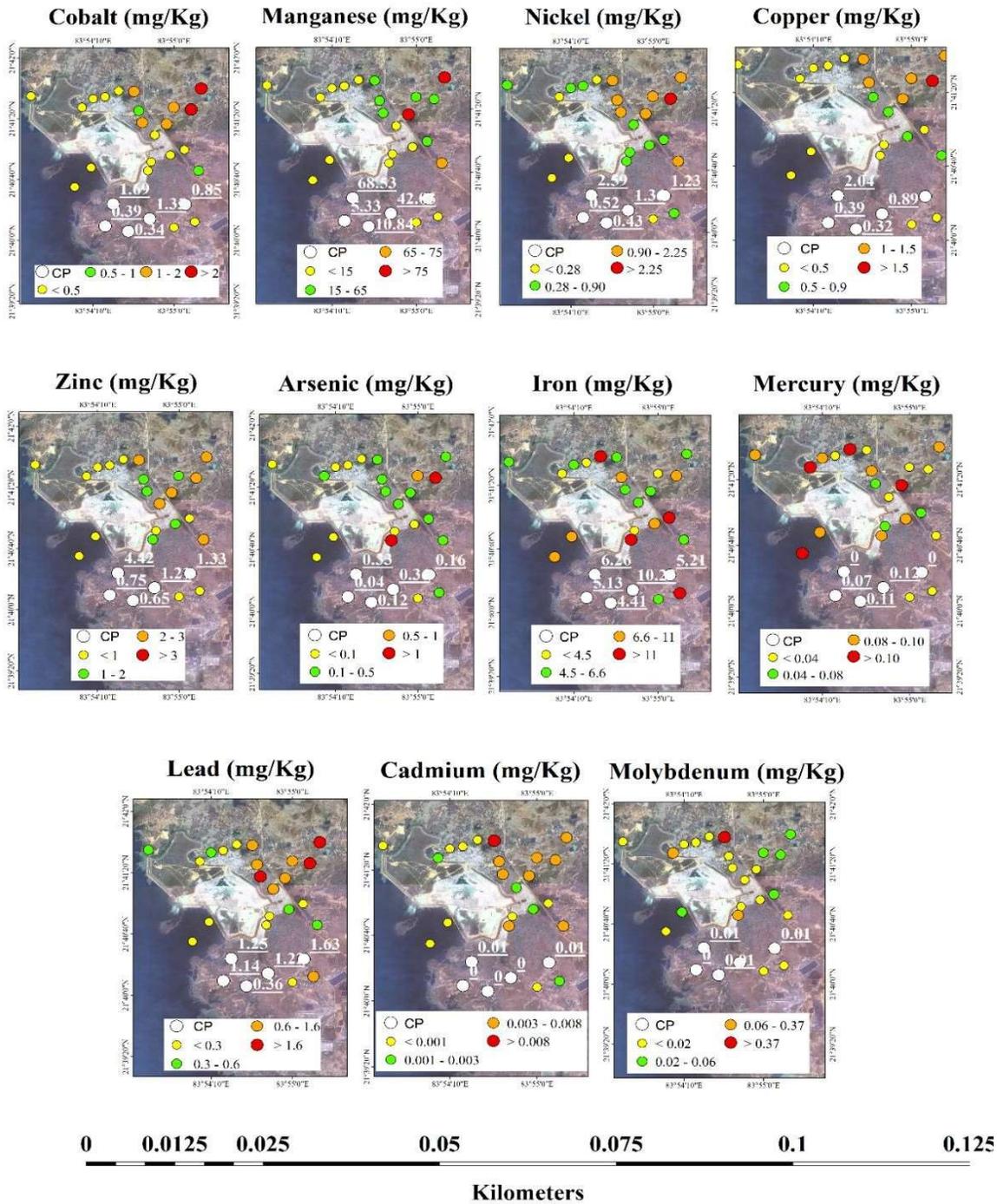


Fig 21. Spatial distribution of heavy metals in pre-monsoon surface soil.

5.5 Pre-monsoon sub-surface (10 cm) Control Soil Sample Cation and Anion Analysis

Table 24. Descriptive statistics of soil quality parameters in pre-monsoon sub- surface (10 cm) control samples.

Parameter	Minimum	Maximum	Mean
pH	5.14	6.53	5.71
EC	81.70	450.00	214.98
Na (mg/Kg)	18.98	27.53	23.54
K (mg/Kg)	45.08	68.78	53.18
Ca (mg/Kg)	29.93	570.86	227.54
F (mg/Kg)	0.01	0.02	0.02
Cl (mg/Kg)	53.18	132.94	93.06
SO ₄ (mg/Kg)	7.27	135.17	45.35
PO ₄ (mg/Kg)	0.01	0.04	0.02
NO ₃ (mg/kg)	4.75	29.14	13.54

Twenty-seven soil samples were collected from a depth of 10 cm and analysed for pH, electrical conductivity (EC), major cations (sodium, potassium, calcium), anions (nitrate, phosphate, sulphate, chloride), and heavy metals. The pH of soil samples was acidic, having a minimum value of 5.14 to a maximum value of 6.53 with a mean value of 5.71. The EC of samples was found to be in the range of minimum 81.70 mS/cm and maximum 450 mS/cm, with a mean of 214.98 mS/cm. The sodium concentration was found to be having a minimum concentration of 18.98 mg/kg to maximum concentration of 27.53 mg/kg, with the mean concentration of 23.54 mg/kg. The potassium concentration was found to be in the range of 45.08 mg/kg minimum and 68.78 mg/kg maximum, with the mean value of 53.18 mg/kg. While the mean concentration of calcium was found to be 227.54 mg/kg with the range of 29.93 mg/kg minimum and 570.86 mg/kg maximum. It was found that fluoride has a minimum concentration of 0.01 mg/kg and maximum concentration of 0.02 mg/kg, with a mean concentration of 0.02 mg/kg in the analysed samples. The chloride was having 53.18 mg/kg minimum concentration, 132.94 mg/kg maximum concentration, and 93.06 mg/kg mean concentration in the analysed samples. The sulphate in analysed samples was found to be in the range of 7.27 mg/kg minimum, 135.17 mg/kg maximum, while mean was found to be 45.35 mg/kg. The phosphate concentration in the analysed soil samples ranged from a minimum of 0.01 mg/kg to a maximum of 0.04 mg/kg, with a mean concentration of 0.02 mg/kg. Nitrate levels were found to be having a minimum concentration of 4.75 mg/kg, a maximum of 29.14 mg/kg, and an average concentration of 13.54 mg/kg.

5.6 Pre-monsoon sub-surface (10 cm) Control Soil Sample Heavy Metal Analysis

Table 25. Descriptive statistics of heavy metals in pre- monsoon sub- surface (10 cm) control soil samples.

Parameter	Minimum	Maximum	Mean
Mn (mg/kg)	14.89	95.94	43.77
Co (mg/kg)	0.63	2.69	1.77

Ni (mg/kg)	0.78	2.98	2.05
Cu (mg/kg)	0.69	2.42	1.53
Zn (mg/kg)	1.42	2.82	2.15
As (mg/kg)	0.10	1.38	0.56
Mo (mg/kg)	0.00	0.07	0.03
Cd (mg/kg)	0.00	0.01	0.01
Pb (mg/kg)	1.37	4.18	2.66
Fe (mg/kg)	6.61	18.76	10.16
Hg (mg/kg)	0.06	0.08	0.07

The soil analysis revealed manganese concentrations ranging from 14.89 to 95.94 mg/kg, with a mean value of 43.77 mg/kg. Cobalt levels were detected between 0.63 and 2.69 mg/kg, averaging 1.77 mg/kg across samples. Nickel concentrations spanned from 0.78 to 2.98 mg/kg, while demonstrating a mean concentration of 2.05 mg/kg. Copper levels varied from 0.69 to 2.42 mg/kg, with an average content of 1.53 mg/kg observed in the samples. Zinc showed a relatively narrow distribution ranging from 1.42 to 2.82 mg/kg and maintained a mean concentration of 2.15 mg/kg. Arsenic contamination was measured between 0.10 and 1.38 mg/kg, averaging 0.56 mg/kg throughout the sampled area. Molybdenum concentrations ranged from below detection limit to 0.07 mg/kg, with samples showing a mean value of 0.03 mg/kg. Cadmium levels were minimal, ranging from non-detectable to 0.01 mg/kg and averaging 0.01 mg/kg. Lead contamination was particularly notable, with concentrations varying from 1.37 to 4.18 mg/kg and a mean value of 2.66 mg/kg. Iron exhibited substantial variability across samples, ranging from 6.61 to 18.76 mg/kg while maintaining an average concentration of 10.16 mg/kg. Mercury concentrations were consistently low throughout the study area, ranging from 0.06 to 0.08 mg/kg with a mean value of 0.07 mg/kg.

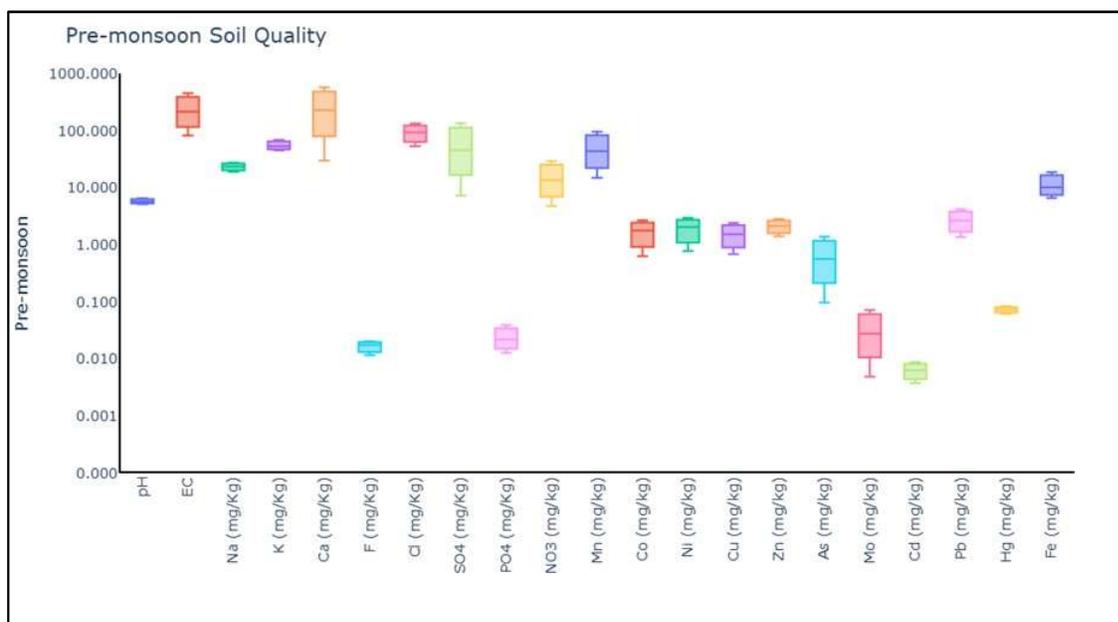


Fig 22. Soil Quality of Pre-monsoon Subsurface (10cm) Control Samples

5.7 Pre-monsoon Experimental sub-surface (10 cm) Soil Sample Cation and Anion Analysis

Table 26. Descriptive statistics of soil quality parameters in pre-monsoon sub- surface (10 cm) samples.

Parameter	Minimum	Maximum	Mean
pH	4.20	7.56	6.10
EC	59.80	539.00	240.07
Na (mg/Kg)	5.33	38.70	22.67
K (mg/Kg)	4.73	200.51	65.07
Ca (mg/Kg)	40.43	732.04	224.25
F (mg/Kg)	0.01	0.02	0.02
Cl (mg/Kg)	53.18	159.53	96.68
SO ₄ (mg/Kg)	8.72	979.65	74.33
PO ₄ (mg/Kg)	0.01	0.04	0.02
NO ₃ (mg/kg)	3.38	29.14	11.20

Soil samples were collected from a 10 cm depth and analysed for pH, electrical conductivity (EC), major cations (sodium, potassium, calcium), anions (nitrate, phosphate, sulphate, chloride), and heavy metals. The pH of soil samples was predominantly acidic, having a minimum value of 4.2 to a maximum value of 7.56 with a mean value of 6.10. The 90.91% of samples were found to be acidic, whereas 9.09% were found to be alkaline in nature. The EC of samples was found to be in the range of minimum 59.8 mS/cm and maximum 539 mS/cm, with a mean of 240.07 mS/cm. The sodium concentration was found to be having a minimum concentration of 5.33 mg/kg to maximum concentration of 38.7 mg/kg, with the mean concentration of 22.67 mg/kg. The potassium concentration was found to be in the range of 4.73 mg/kg minimum and 200.51 mg/kg maximum, with the mean value of 65.07 mg/kg. While the mean concentration of calcium was found to be 224.25 mg/kg with the range of 40.43 mg/kg minimum and 732.04 mg/kg maximum. It was found that fluoride has a minimum concentration of 0.01 mg/kg and maximum concentration of 0.02 mg/kg, with a mean concentration of 0.02 mg/kg in the analysed samples. The chloride was having 53.18 mg/kg minimum concentration, 159.53 mg/kg maximum concentration, and 96.68 mg/kg mean concentration in the analysed samples. The sulphate in analysed samples was found to be in the range of 8.72 mg/kg minimum, 979.65 mg/kg maximum, while mean was found to be 74.33 mg/kg. The phosphate concentration in the analysed soil samples ranged from a minimum of 0.01 mg/kg to a maximum of 0.04 mg/kg, with a mean concentration of 0.02 mg/kg. Nitrate levels were found to be having a minimum concentration of 3.38 mg/kg, a maximum of 29.14 mg/kg, and an average concentration of 11.2 mg/kg.

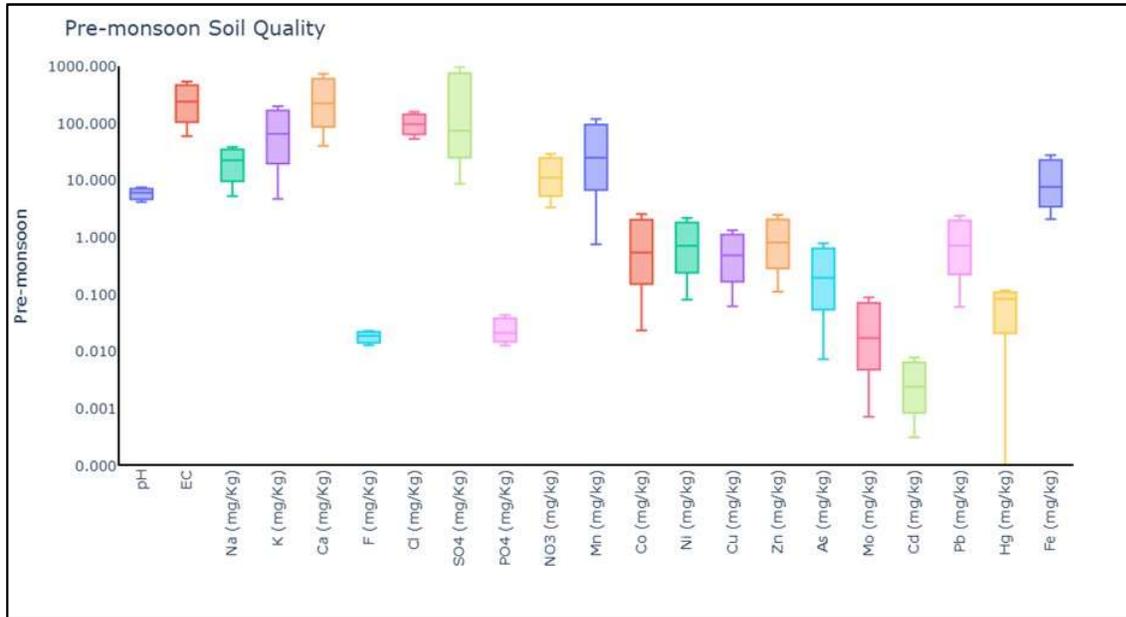


Fig 23. Soil quality of pre-monsoon subsurface (10 cm) soil samples.

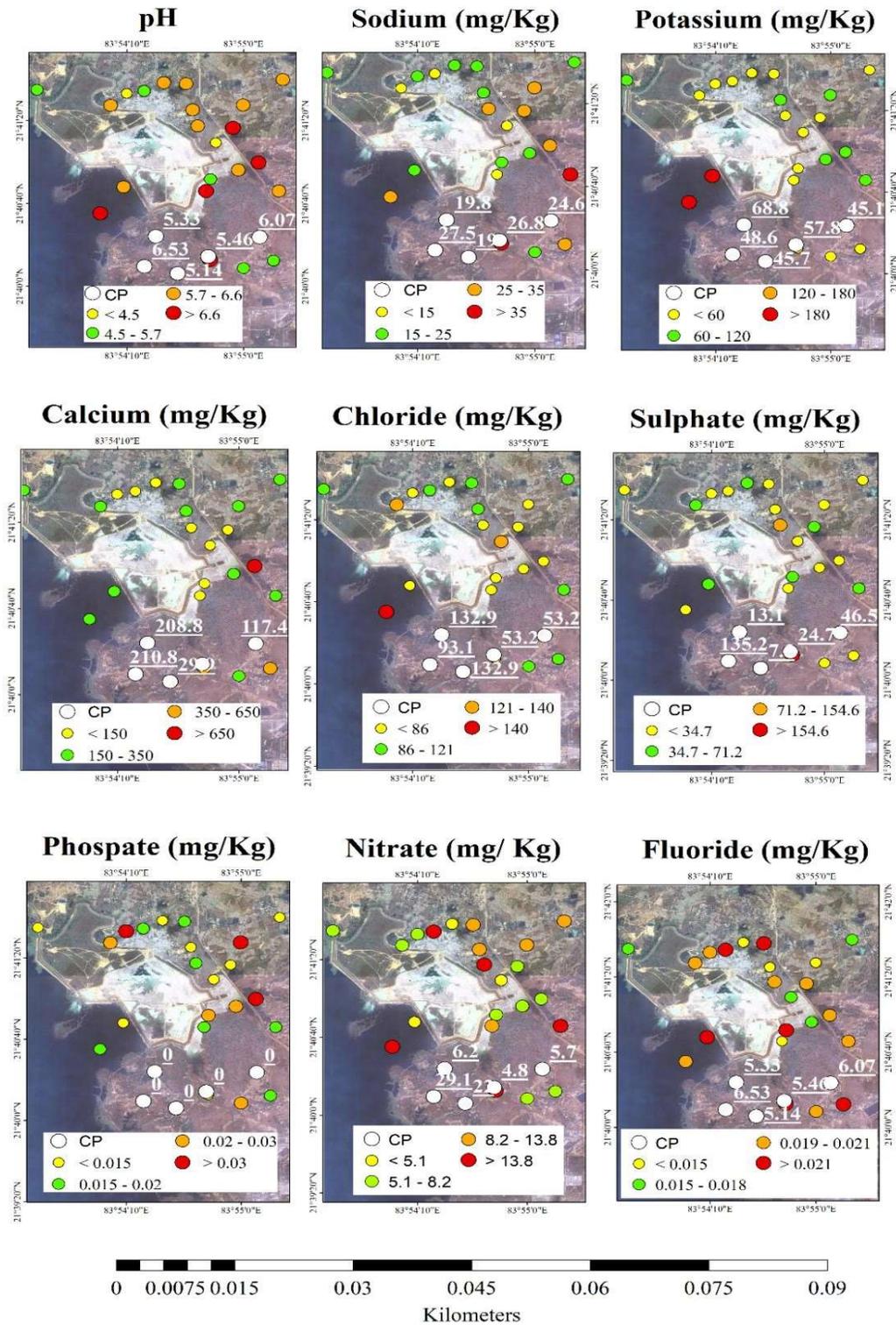


Fig 24. Spatial distribution of soil quality parameters in pre-monsoon subsurface (10cm).

5.8 Pre-monsoon Experimental sub-surface (10 cm) Soil Sample Heavy Metal Analysis

Table 27. Descriptive statistics of heavy metals in pre- monsoon sub- surface (10 cm) soil samples.

Parameter	Minimum	Maximum	Mean
Mn (mg/kg)	0.76	118.77	24.94
Co (mg/kg)	0.02	2.56	0.55
Ni (mg/kg)	0.08	2.20	0.72
Cu (mg/kg)	0.06	1.34	0.49
Zn (mg/kg)	0.11	2.50	0.82
As (mg/kg)	0.01	0.79	0.20
Mo (mg/kg)	0.00	0.09	0.02
Cd (mg/kg)	0.00	0.01	0.00
Pb (mg/kg)	0.06	2.43	0.72
Fe(mg/kg)	2.09	27.83	7.71
Hg(mg/kg)	0.00	0.12	0.08

The soil samples exhibited a wide range of heavy metal concentrations, with manganese showing the most substantial variation from 0.76 to 118.77 mg/kg and averaging 24.94 mg/kg. Cobalt levels ranged from 0.02 to 2.56 mg/kg with a mean concentration of 0.55 mg/kg, while nickel was detected between 0.08 and 2.20 mg/kg, averaging 0.72 mg/kg. Copper concentrations varied from 0.06 to 1.34 mg/kg with a mean value of 0.49 mg/kg, and zinc levels spanned 0.11 to 2.50 mg/kg with an average of 0.82 mg/kg. Arsenic contamination ranged from 0.01 to 0.79 mg/kg, showing a mean concentration of 0.20 mg/kg. Molybdenum was present in trace amounts, ranging from non-detectable to 0.09 mg/kg with an average of 0.02 mg/kg. Cadmium concentrations were minimal, not exceeding 0.01 mg/kg and averaging below detection limits. Lead showed moderate contamination levels, ranging from 0.06 to 2.43 mg/kg with a mean of 0.72 mg/kg. Iron concentrations demonstrated significant variability across samples, from 2.09 to 27.83 mg/kg with an average of 7.71 mg/kg. Mercury was detected at trace levels up to 0.12 mg/kg, averaging 0.08 mg/kg.

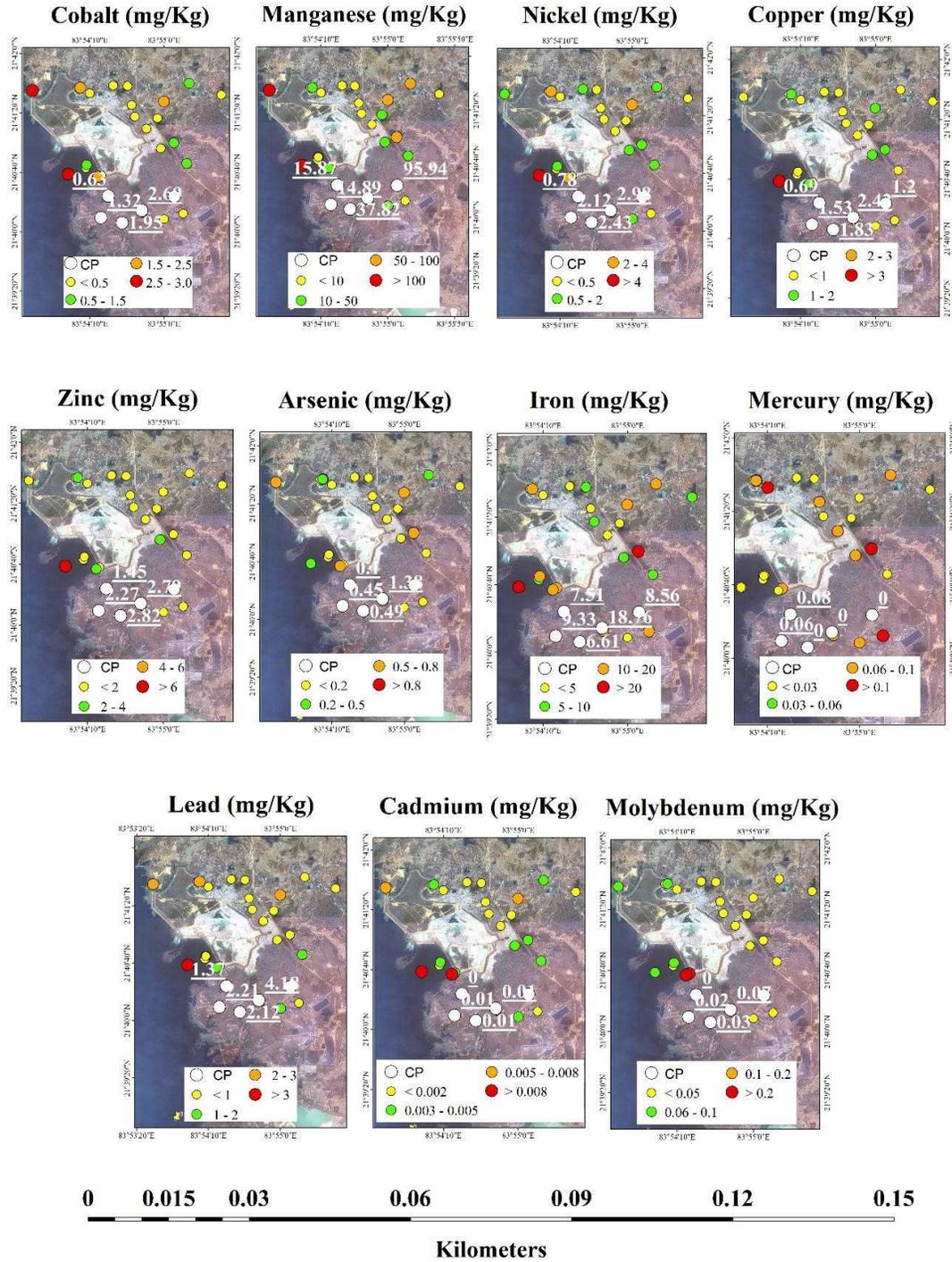


Fig 25. Spatial distribution of heavy metals in pre-monsoon subsurface (10cm).

5.9 Monsoon Surface Control Soil Sample Cation and Anion Analysis

Table 28. Descriptive statistics of soil quality parameters in monsoon control surface samples.

Parameter	Minimum	Maximum	Mean
pH	5.34	6.30	5.70
EC	150.60	198.00	174.10
Na (mg/Kg)	6.19	8.96	7.69
K (mg/Kg)	15.19	43.24	30.64
Ca (mg/Kg)	175.28	389.03	253.97
F (mg/Kg)	0.02	0.02	0.02
Cl (mg/Kg)	70.90	106.35	82.72
SO ₄ (mg/Kg)	32.56	112.50	66.96
PO ₄ (mg/Kg)	0.03	0.08	0.06
NO ₃ (mg/kg)	13.35	16.31	15.30

The surface soil samples collected for analysis exhibited acidic characteristics with pH values ranging from 5.34 to 6.3 and averaging 5.70, while electrical conductivity measurements showed moderate salinity levels varying between 150.60 and 198 mS/cm with a mean value of 174.10 mS/cm. Sodium concentrations were found to range from 6.19 to 8.96 mg/kg with an average of 7.69 mg/kg, whereas potassium displayed greater variability with levels spanning 15.19 to 43.24 mg/kg and a mean concentration of 30.64 mg/kg. Calcium emerged as the most abundant cation in the soil samples, showing concentrations from 175.28 to 389.03 mg/kg and averaging 253.97 mg/kg, indicating its dominant presence in the soil matrix. Fluoride levels remained remarkably consistent across all samples at 0.02 mg/kg, demonstrating uniform distribution of this anion throughout the study area. Chloride concentrations varied between 70.90 and 106.35 mg/kg with an average of 82.72 mg/kg, while sulphate exhibited the widest variation among anions ranging from 32.56 to 112.50 mg/kg and averaging 66.96 mg/kg. Phosphate levels were relatively low across samples, ranging from 0.03 to 0.08 mg/kg with a mean value of 0.06 mg/kg, suggesting limited phosphorus availability in the soil environment. Nitrate concentrations showed moderate variation between 13.35 and 16.31 mg/kg with an average of 15.30 mg/kg, reflecting relatively stable nitrogen levels in the analysed soils. The comprehensive analysis revealed distinct patterns in ionic distribution, with calcium and sulphate showing the greatest variability among the measured parameters. The consistent fluoride levels across all samples suggest homogeneous geochemical processes governing its distribution in the soil profile. The electrical conductivity values indicate moderate salinity conditions that could influence nutrient availability and plant growth in the studied soils. The acidic pH range observed may affect the solubility and bioavailability of various nutrients and heavy metals in the soil system. The relative abundance of calcium compared to other cations highlights its importance in the soil's cation exchange capacity and structural stability. The variation in sulphate concentrations likely reflects differences in organic matter decomposition and atmospheric deposition patterns across sampling locations.

5.10 Monsoon Surface Control Soil Sample Heavy Metal Analysis

Table 29. Descriptive statistics of heavy metals in monsoon control surface soil samples.

Parameter	Minimum	Maximum	Mean
Mn (mg/kg)	1.66	34.75	13.58
Co (mg/kg)	0.06	0.85	0.36
Ni (mg/kg)	0.08	0.84	0.42
Cu (mg/kg)	0.08	0.47	0.27
Zn (mg/kg)	0.11	1.21	0.67
As (mg/kg)	0.02	0.17	0.08
Mo (mg/kg)	0.00	0.01	0.00
Cd (mg/kg)	0.00	0.00	0.00
Pb (mg/kg)	0.27	1.54	0.73
Fe(mg/kg)	5.11	20.49	10.97
Hg(mg/kg)	0.01	0.02	0.02

The soil analysis revealed detectable levels of eleven heavy metals, with manganese (Mn) showing the highest concentration range (1.66-34.75 mg/kg) and an average of 13.58 mg/kg, followed by iron (Fe) which ranged from 5.11-20.49 mg/kg with a mean concentration of 10.97 mg/kg. Lead (Pb) contamination was observed between 0.27-1.54 mg/kg, averaging 0.73 mg/kg, while zinc (Zn) concentrations varied from 0.11-1.21 mg/kg with a mean of 0.67 mg/kg. Cobalt (Co) levels ranged from 0.06-0.85 mg/kg (mean: 0.36 mg/kg) and nickel (Ni) showed similar variation (0.08-0.84 mg/kg) with a slightly higher average of 0.42 mg/kg. Copper (Cu) concentrations were relatively low, ranging 0.08-0.47 mg/kg and averaging 0.27 mg/kg, whereas arsenic (As) was detected in the range of 0.02-0.17 mg/kg with a mean of 0.08 mg/kg. Mercury (Hg) showed minimal presence (0.01-0.02 mg/kg) with an average of 0.02 mg/kg. Both molybdenum (Mo) and cadmium (Cd) were either below detection limits or present only in trace amounts, with Mo ranging from non-detectable to 0.01 mg/kg and Cd completely non-detectable in all samples. The results demonstrate a distinct hierarchy of metal concentrations, with Mn and Fe being the most abundant, followed by Pb and Zn, while other metals were present in significantly lower quantities.

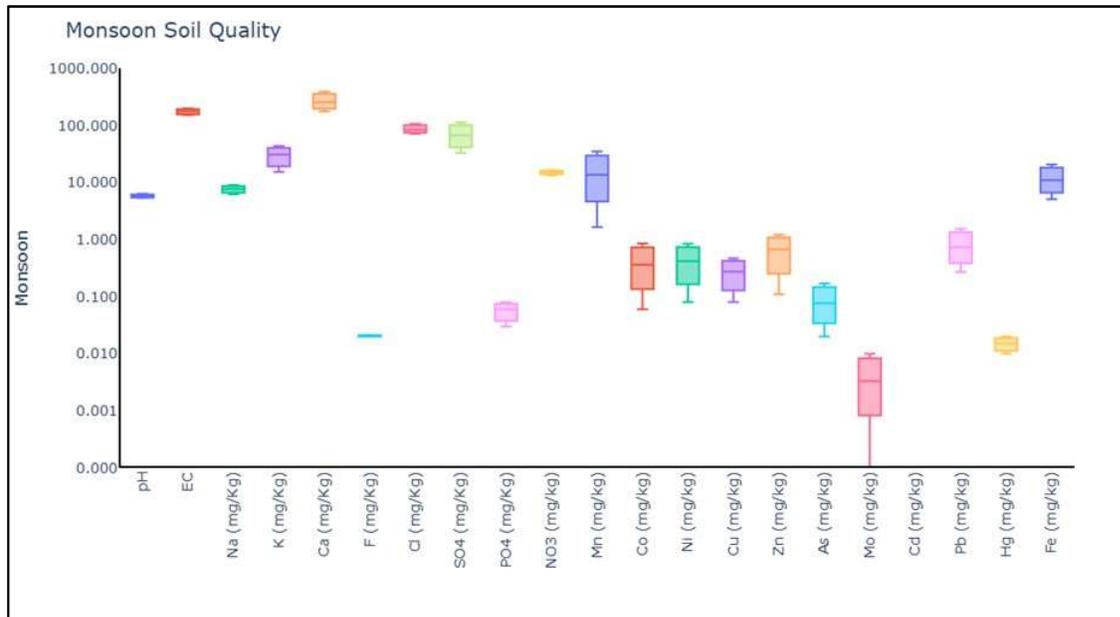


Fig 26. Soil quality of monsoon surface control samples

5.11 Monsoon Experimental Surface Soil Sample Cation and Anion Analysis

Table 30. Descriptive statistics of soil quality parameters in monsoon surface samples.

Parameter	Minimum	Maximum	Mean
pH	5.11	7.49	6.18
EC	110.6	329	199.41
Na (mg/Kg)	0.64	9.11	5.45
K (mg/Kg)	5.96	70.16	38.54
Ca (mg/Kg)	65.06	387.71	216.28
F (mg/Kg)	0.02	0.02	0.02
Cl (mg/Kg)	35.45	106.35	78.78
SO ₄ (mg/Kg)	0.87	24.13	8.95
PO ₄ (mg/Kg)	0.04	0.11	0.06
NO ₃ (mg/kg)	8.42	26.63	16.59

A total of twelve surface soil samples were collected and analysed for pH, electrical conductivity (EC), major cations (sodium, potassium, calcium), anions (nitrate, phosphate, sulphate, chloride), and heavy metal content. The soil pH ranged from 5.11 to 7.49, with a mean value of 6.18, indicating predominantly acidic conditions, as 66.67% of samples fell below neutral pH, while 33.33% exhibited alkaline properties. Electrical conductivity measurements revealed moderate to high salinity, with values spanning 110.6 to 329 mS/cm and an average of 199.41 mS/cm, suggesting potential variability in soil salinity across sampling sites.

Among the major cations, sodium concentrations varied from 0.64 to 9.11 mg/kg, averaging 5.45 mg/kg, while potassium displayed a broader range of 5.96 to 70.16 mg/kg, with a mean concentration of 38.54 mg/kg. Calcium was the most dominant cation, with levels ranging from 65.06 to 387.71 mg/kg and an average of 216.28 mg/kg, reflecting its significant contribution to soil cation exchange capacity.

Anion analysis demonstrated distinct distribution patterns, with chloride exhibiting concentrations between 35.45 and 106.35 mg/kg (mean: 78.78 mg/kg), and sulphate showing lower but variable levels from 0.87 to 24.13 mg/kg (mean: 8.95 mg/kg). Phosphate concentrations were relatively low, ranging from 0.04 to 0.11 mg/kg (mean: 0.06 mg/kg), while nitrate levels displayed moderate variability, spanning 8.42 to 26.63 mg/kg (mean: 16.59 mg/kg). Fluoride concentrations remained consistently low across all samples at 0.02 mg/kg, indicating uniform distribution and minimal anthropogenic influence.

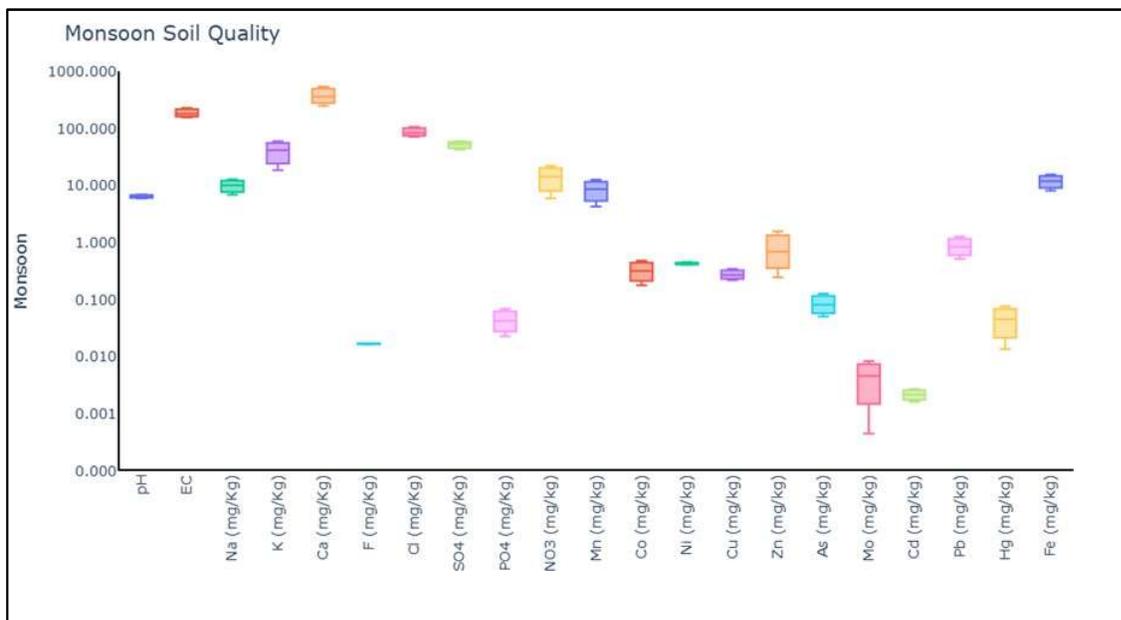


Fig 27. Soil quality of monsoon surface soil samples.

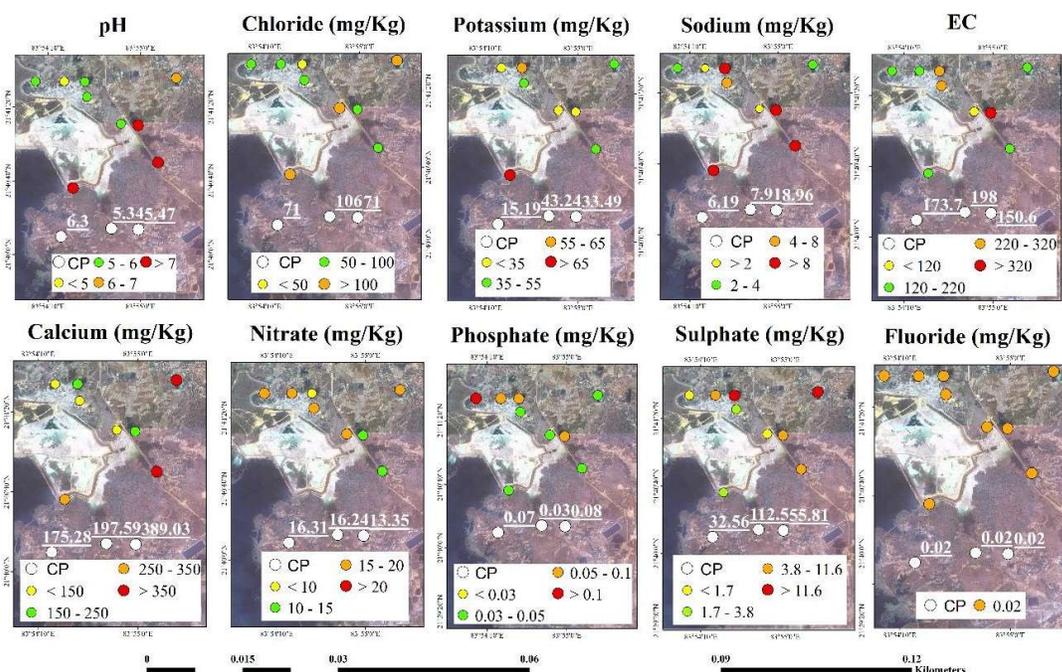


Fig 28. Spatial distribution of soil quality in monsoon in surface.

5.12 Monsoon Experimental Surface Soil Sample Heavy Metal Analysis

Table 31. Descriptive statistics of heavy metals in monsoon surface soil samples.

Parameter	Minimum	Maximum	Mean
Mn (mg/kg)	0.22	9.81	3.83
Co (mg/kg)	0.01	0.33	0.12
Ni (mg/kg)	0.03	0.31	0.17
Cu (mg/kg)	0.01	0.33	0.14
Zn (mg/kg)	0.05	0.75	0.29
As (mg/kg)	0.01	0.14	0.07
Mo (mg/kg)	0	0.01	0.00
Cd (mg/kg)	0	0	0.00
Pb (mg/kg)	0.06	0.77	0.38
Fe(mg/kg)	2.01	15.1	7.69
Hg(mg/kg)	0.01	0.07	0.04

The soil analysis revealed manganese concentrations ranging from 0.22 to 9.81 mg/kg with a mean value of 3.83 mg/kg, while cobalt levels varied between 0.01 and 0.33 mg/kg averaging 0.12 mg/kg. Nickel concentrations spanned 0.03 to 0.31 mg/kg with a mean of 0.17 mg/kg, and copper showed a similar range of 0.01 to 0.33 mg/kg with an average concentration of 0.14 mg/kg. Zinc was detected at levels from 0.05 to 0.75 mg/kg with a mean value of 0.29 mg/kg, whereas arsenic concentrations

ranged from 0.01 to 0.14 mg/kg averaging 0.07 mg/kg. Molybdenum was either non-detectable or present at trace levels up to 0.01 mg/kg, while cadmium was completely absent in all analysed samples. Lead contamination ranged from 0.06 to 0.77 mg/kg with a mean concentration of 0.38 mg/kg, and iron showed the highest accumulation levels between 2.01 and 15.1 mg/kg averaging 7.69 mg/kg. Mercury concentrations were consistently low, ranging from 0.01 to 0.07 mg/kg with a mean value of 0.04 mg/kg.

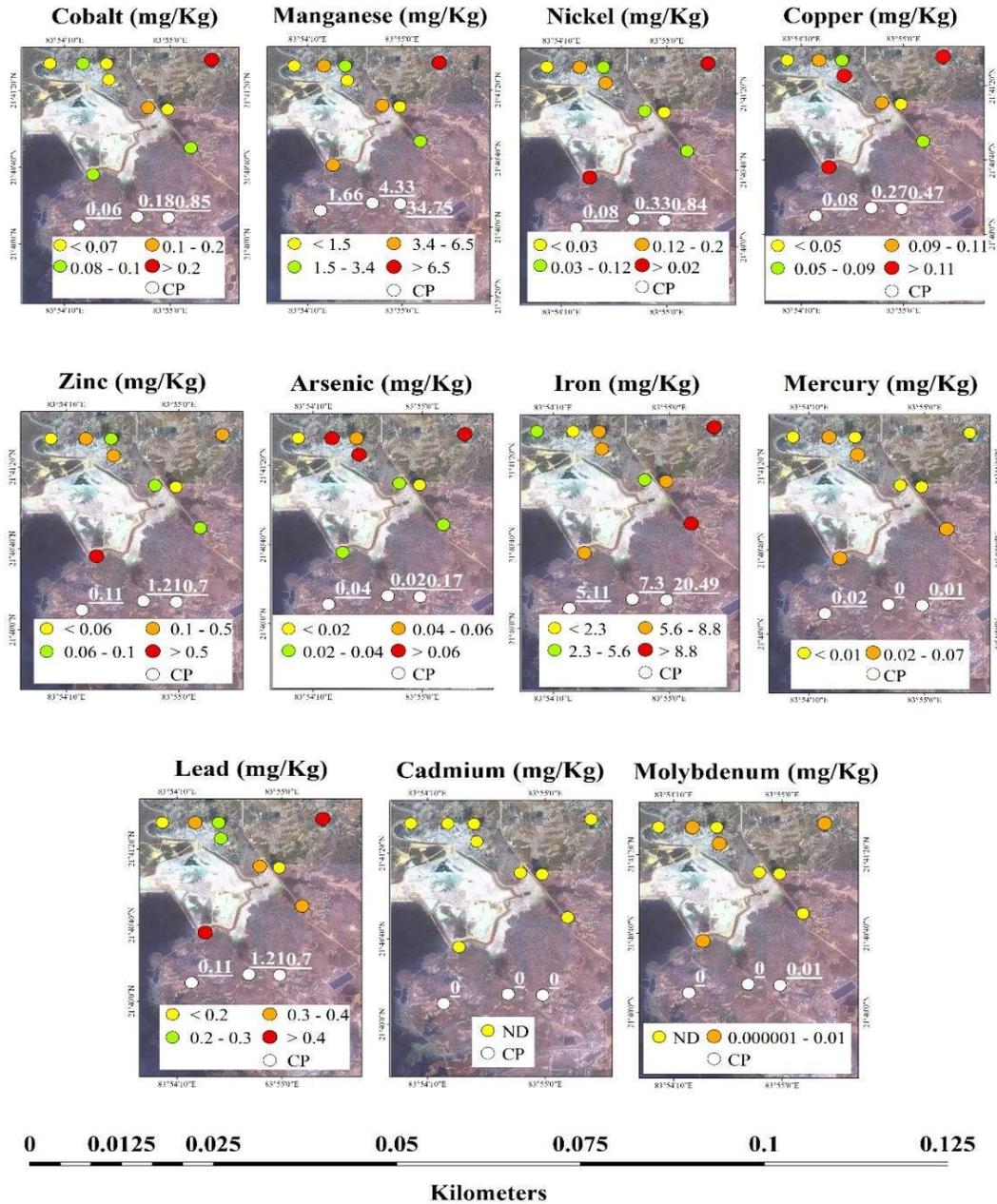


Fig 29. Spatial distribution of heavy metals in monsoon in surface.

5.13 Monsoon sub-surface (10 cm) Control Soil Sample Cation and Anion Analysis

Table 32. Descriptive statistics of soil quality parameters in monsoon Sub- surface (10 cm) control samples.

Parameter	Minimum	Maximum	Mean
pH	5.93	6.94	6.38
EC	155.20	228.00	180.07
Na (mg/Kg)	6.90	12.75	10.10
K (mg/Kg)	18.60	59.85	41.35
Ca (mg/Kg)	249.08	539.03	360.53
F (mg/Kg)	0.02	0.02	0.02
Cl (mg/Kg)	70.90	106.35	82.72
SO ₄ (mg/Kg)	42.44	59.30	52.52
PO ₄ (mg/Kg)	0.02	0.07	0.04
NO ₃ (mg/kg)	5.96	22.13	14.38

The soil exhibited acidic characteristics with pH values ranging from 5.93 to 6.94 and averaging 6.38 across all samples. Electrical conductivity measurements showed moderate salinity levels varying between 155.20 and 228 mS/cm, with a mean value of 180.07 mS/cm. Sodium concentrations ranged from 6.90 to 12.75 mg/kg, averaging 10.10 mg/kg throughout the sampled area. Potassium levels displayed greater variability, spanning from 18.60 to 59.85 mg/kg with a mean concentration of 41.35 mg/kg. Calcium emerged as the dominant cation, showing concentrations between 249.08 and 539.03 mg/kg and averaging 360.53 mg/kg in the soil profile. Fluoride concentrations remained consistently low at 0.02 mg/kg across all sampling locations. Chloride levels varied from 70.90 to 106.35 mg/kg, with an average concentration of 82.72 mg/kg observed in the samples. Sulphate concentrations showed moderate variation, ranging from 42.44 to 59.30 mg/kg and averaging 52.52 mg/kg throughout the study area. Phosphate levels were relatively low, measuring between 0.02 and 0.07 mg/kg with a mean value of 0.04 mg/kg. Nitrate concentrations exhibited the widest variation among anions, ranging from 5.96 to 22.13 mg/kg and averaging 14.38 mg/kg across sampling sites. The comprehensive analysis revealed calcium as the most abundant cation, followed by potassium and sodium in the soil matrix. Anion distribution patterns showed sulphate as the predominant anion, followed by chloride and nitrate, while phosphate and fluoride were present in minimal quantities.

5.14 Monsoon sub-surface (10 cm) Control Soil Sample Heavy Metal Analysis

Table 33. Descriptive statistics of heavy metals in monsoon control sub- surface (10 cm) soil samples.

Parameter	Minimum	Maximum	Mean
Mn (mg/kg)	4.28	12.67	8.64
Co (mg/kg)	0.18	0.48	0.32
Ni (mg/kg)	0.41	0.45	0.43
Cu (mg/kg)	0.22	0.35	0.27
Zn (mg/kg)	0.25	1.56	0.69

As (mg/kg)	0.05	0.13	0.08
Mo (mg/kg)	0.00	0.01	0.00
Cd (mg/kg)	0.00	0.00	0.00
Pb (mg/kg)	0.52	1.27	0.84
Fe(mg/kg)	8.10	15.55	11.86
Hg(mg/kg)	0.01	0.08	0.05

The analysed soil samples showed manganese concentrations averaging 8.64 mg/kg (range: 4.28-12.67 mg/kg), while cobalt levels averaged 0.32 mg/kg (0.18-0.48 mg/kg). Nickel concentrations averaged 0.43 mg/kg (0.41-0.45 mg/kg), and copper showed a mean of 0.27 mg/kg (0.22-0.35 mg/kg). Zinc levels averaged 0.69 mg/kg (0.25-1.56 mg/kg), with arsenic demonstrating a mean concentration of 0.08 mg/kg (0.05-0.13 mg/kg). Molybdenum was either undetectable or present in trace amounts (0-0.01 mg/kg), while cadmium was completely absent from all samples. Lead contamination averaged 0.84 mg/kg (0.52-1.27 mg/kg), and iron showed the highest mean concentration at 11.86 mg/kg (8.10-15.55 mg/kg). Mercury levels averaged 0.05 mg/kg (0.01-0.08 mg/kg), completing the heavy metal profile. The results indicate iron and manganese as the predominant metals, with other elements present at significantly lower concentrations. Most measured heavy metals fell within typical background ranges, suggesting minimal anthropogenic influence. The consistent absence of cadmium and negligible molybdenum levels further confirm the relatively uncontaminated nature of the sampled soils.

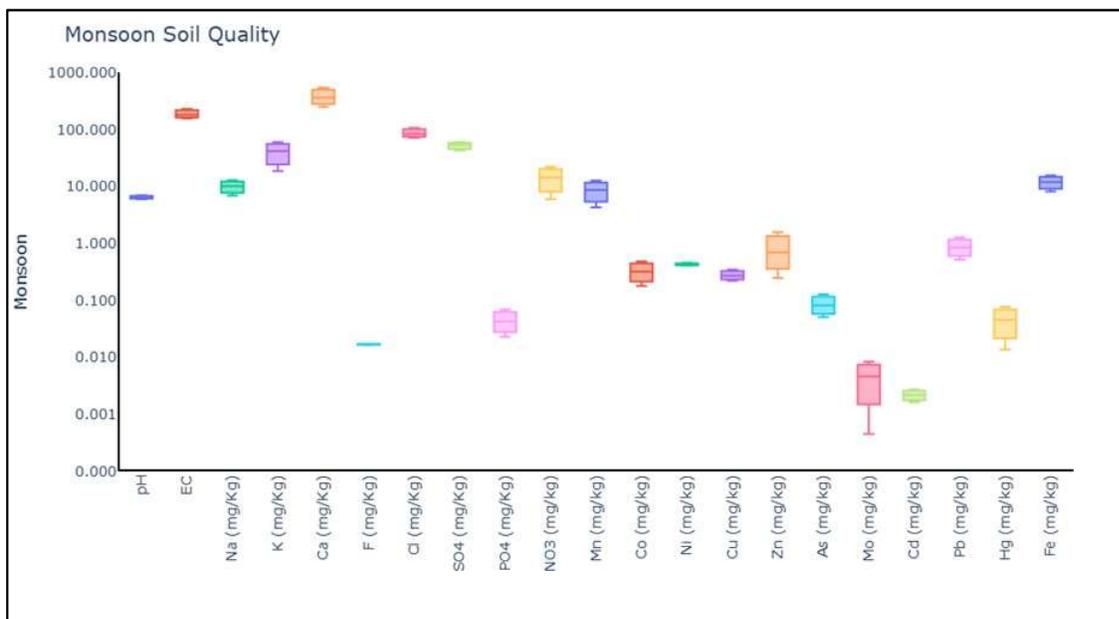


Fig 30. Soil quality of monsoon subsurface (10cm) control samples.

5.15 Monsoon Experimental sub-surface (10 cm) Soil Sample Cation and Anion Analysis

Table 34. Descriptive statistics of soil quality parameters in pre-monsoon Sub- surface (10 cm) samples.

Parameter	Minimum	Maximum	Mean
pH	5.35	7.12	6.21
EC	104.40	287.00	201.04
Na (mg/Kg)	2.74	12.75	6.85
K (mg/Kg)	10.31	59.85	31.92
Ca (mg/Kg)	77.55	547.69	245.73
F (mg/Kg)	0.01	0.02	0.02
Cl (mg/Kg)	35.45	141.80	79.76
SO ₄ (mg/Kg)	2.03	59.30	22.09
PO ₄ (mg/Kg)	0.02	0.08	0.05
NO ₃ (mg/kg)	5.96	29.06	15.36

Twelve soil samples collected from a 10 cm depth were analysed for physicochemical properties and showed predominantly acidic characteristics with pH values ranging from 5.35 to 7.12 and averaging 6.21, where 88.89 percent of samples were acidic while 11.11 percent exhibited alkaline conditions. Electrical conductivity measurements indicated moderate salinity levels varying between 104.4 and 287 mS/cm with a mean value of 201.04 mS/cm across all samples. Sodium concentrations ranged from 2.74 to 12.75 mg/kg with an average of 6.85 mg/kg, while potassium levels showed greater variability from 10.31 to 59.85 mg/kg and averaged 31.92 mg/kg. Calcium emerged as the dominant cation with concentrations spanning 77.55 to 547.69 mg/kg and a mean value of 245.73 mg/kg, demonstrating significant spatial variability in the soil profile. Fluoride concentrations remained consistently low at 0.02 mg/kg in most samples, with a minimum detection of 0.01 mg/kg. Chloride levels varied from 35.45 to 141.8 mg/kg with an average concentration of 79.76 mg/kg, whereas sulphate exhibited more pronounced variation ranging from 2.03 to 59.3 mg/kg and averaging 22.09 mg/kg. Phosphate concentrations were relatively low throughout the study area, measuring between 0.02 and 0.08 mg/kg with a mean value of 0.05 mg/kg. Nitrate levels displayed moderate variability from 5.96 to 29.06 mg/kg and averaged 15.36 mg/kg, potentially reflecting differential organic matter decomposition or fertilizer inputs across sampling locations.

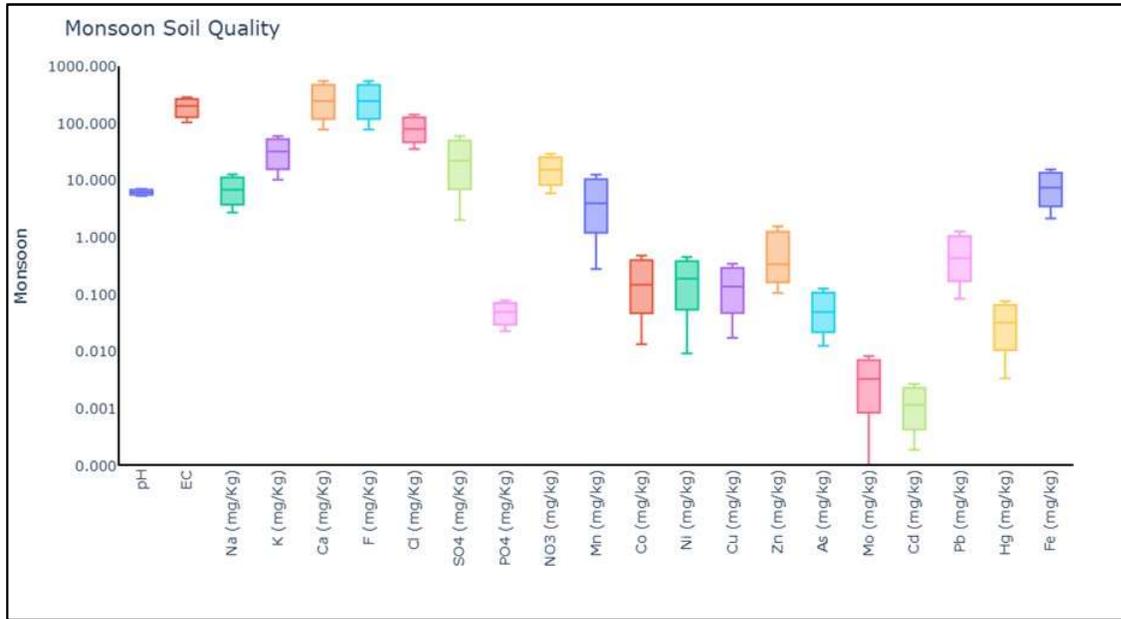


Fig 31. Soil quality of monsoon subsurface (10cm) samples

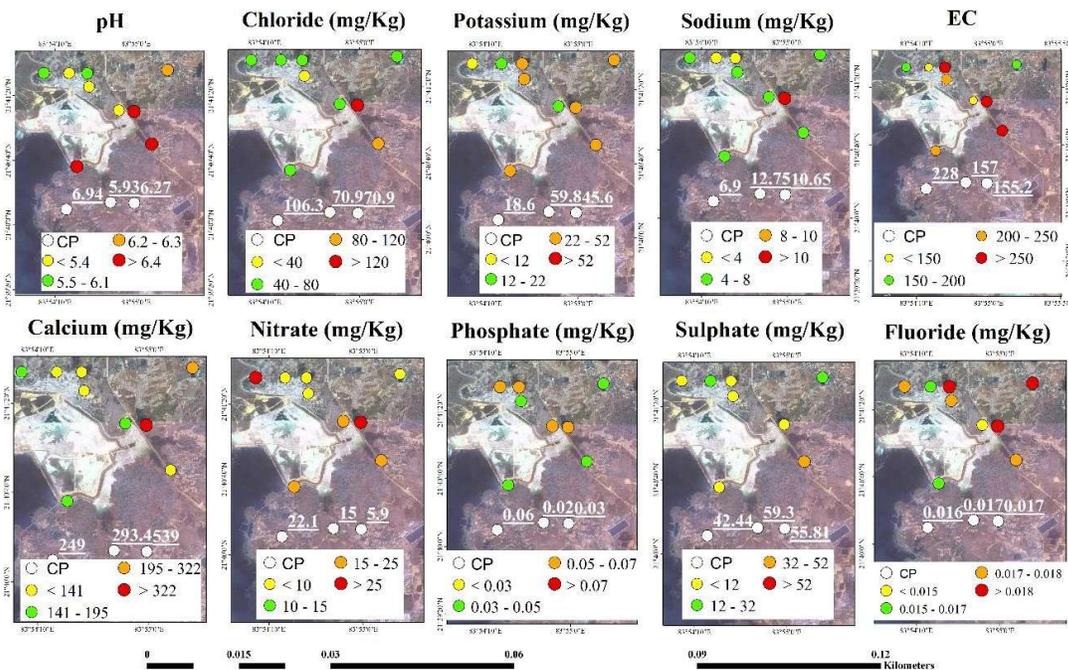


Fig 32. Spatial distribution of soil quality in monsoon in subsurface (10cm).

5.16 Monsoon Experimental sub-surface (10 cm) Soil Sample Heavy Metal Analysis

Table 35. Descriptive statistics of heavy metals in monsoon sub- surface (10 cm) soil samples.

Parameter	Minimum	Maximum	Mean
Mn (mg/kg)	0.28	12.67	3.99
Co (mg/kg)	0.01	0.48	0.15
Ni (mg/kg)	0.01	0.45	0.19
Cu (mg/kg)	0.02	0.35	0.14
Zn (mg/kg)	0.11	1.56	0.34
As (mg/kg)	0.01	0.13	0.05
Mo (mg/kg)	0.00	0.01	0.00
Cd (mg/kg)	0.00	0.00	0.00
Pb (mg/kg)	0.09	1.27	0.43
Fe(mg/kg)	2.16	15.55	7.49
Hg(mg/kg)	0.00	0.08	0.03

The soil analysis revealed distinct concentration patterns for eleven heavy metals, with iron showing the highest accumulation ranging from 2.16 to 15.55 mg/kg and averaging 7.49 mg/kg. Manganese concentrations varied from 0.28 to 12.67 mg/kg with a mean value of 3.99 mg/kg, while lead levels ranged between 0.09 and 1.27 mg/kg and averaged 0.43 mg/kg. Zinc was detected at concentrations of 0.11 to 1.56 mg/kg with a mean of 0.34 mg/kg, and copper showed lower levels ranging from 0.02 to 0.35 mg/kg with an average of 0.14 mg/kg. Cobalt and nickel exhibited similar concentration ranges, with cobalt measuring 0.01 to 0.48 mg/kg and averaging 0.15 mg/kg, while nickel ranged from 0.01 to 0.45 mg/kg with a mean of 0.19 mg/kg. Arsenic concentrations were relatively low, varying between 0.01 and 0.13 mg/kg and averaging 0.05 mg/kg. Mercury showed minimal presence with levels from undetectable to 0.08 mg/kg and a mean concentration of 0.03 mg/kg. Notably, molybdenum was either absent or present only in trace amounts up to 0.01 mg/kg, while cadmium was completely undetectable in all analysed samples. The results demonstrate iron and manganese as the predominant heavy metals, with other elements present at significantly lower concentrations. Most measured heavy metals fell within typical background ranges, suggesting minimal anthropogenic influence in the sampled soils. The consistent absence of cadmium and negligible molybdenum levels further indicate an uncontaminated soil environment.

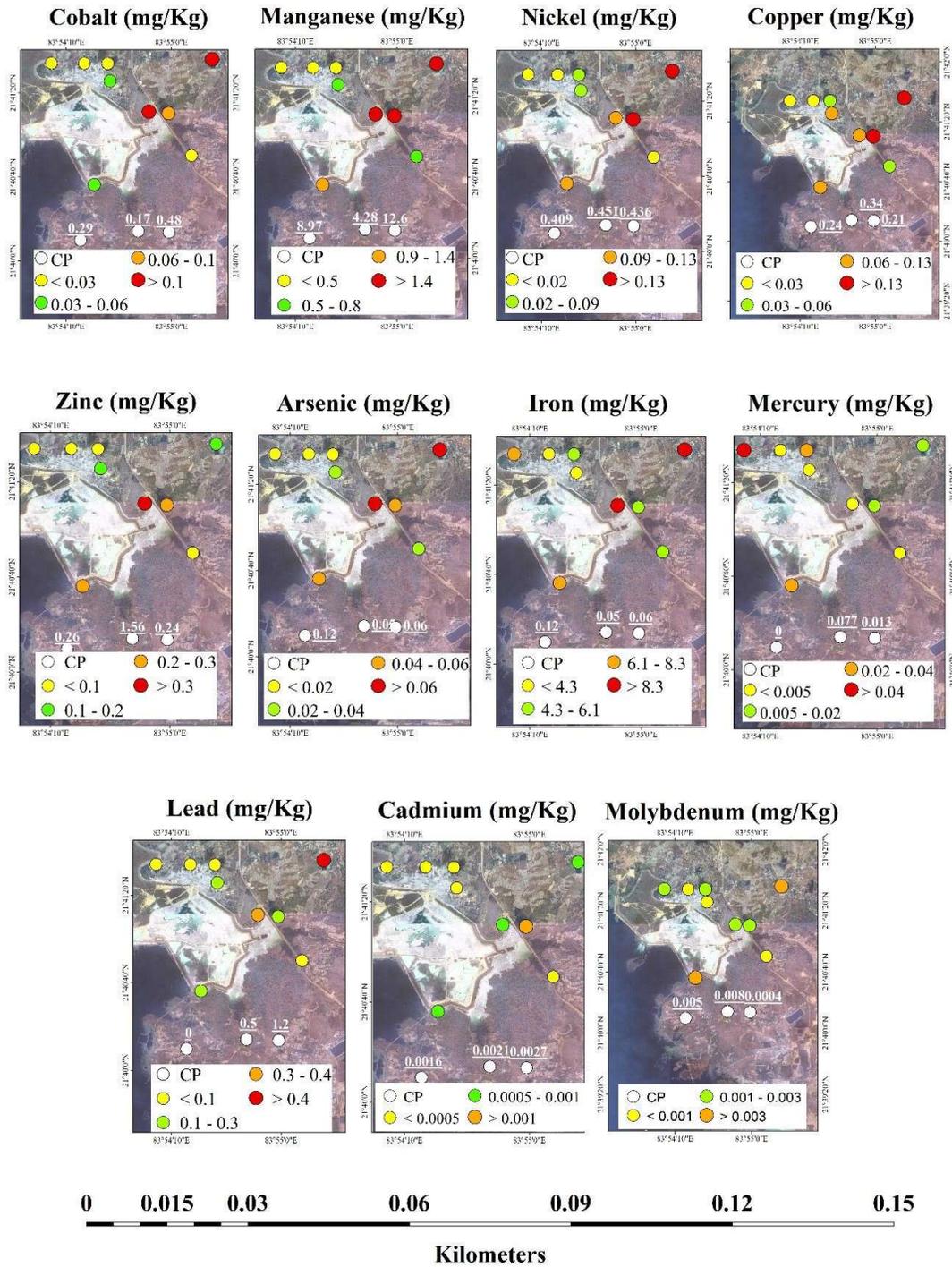


Fig 33. Spatial distribution of heavy metals in monsoon in subsurface (10cm).

5.17 Post-monsoon Surface Control Soil Sample Cation and Anion Analysis

Table 36. Descriptive statistics of soil quality parameters in post- monsoon control surface samples.

Parameter	Minimum	Maximum	Mean
pH	5.23	6.26	5.75
EC	182.80	246.00	214.40
Na (mg/Kg)	18.15	24.53	21.34
K (mg/Kg)	90.00	343.13	216.57
Ca (mg/Kg)	290.06	365.85	327.96
F (mg/Kg)	0.01	0.02	0.02
Cl (mg/Kg)	70.90	70.90	70.90
SO ₄ (mg/Kg)	3.80	7.05	5.43
PO ₄ (mg/Kg)	0.02	0.02	0.02
NO ₃ (mg/kg)	12.89	18.37	15.63

The surface soil samples exhibited acidic characteristics with pH values ranging from 5.23 to 6.26 and averaging 5.75, while electrical conductivity measurements showed moderate salinity levels varying between 182.8 and 246 mS/cm with a mean value of 214.4 mS/cm. Sodium concentrations ranged from 18.15 to 24.53 mg/kg with an average of 21.34 mg/kg, whereas potassium displayed greater variability with levels spanning 90 to 343.13 mg/kg and a mean concentration of 216.57 mg/kg. Calcium emerged as the most abundant cation, showing concentrations between 290.06 and 365.85 mg/kg and averaging 327.96 mg/kg, indicating its dominant presence in the soil matrix. Fluoride levels remained consistently low across all samples, ranging from 0.01 to 0.02 mg/kg with a mean of 0.02 mg/kg, while chloride concentrations showed uniform distribution at 70.9 mg/kg throughout the study area. Sulphate concentrations exhibited moderate variation from 3.8 to 7.05 mg/kg with a mean value of 5.43 mg/kg, and phosphate levels were stable at 0.02 mg/kg in all analysed samples. Nitrate concentrations demonstrated relatively consistent values ranging from 12.89 to 18.37 mg/kg with an average of 15.63 mg/kg, reflecting stable nitrogen levels in the soil environment. The comprehensive analysis revealed calcium as the predominant cation followed by potassium and sodium, while among anions, chloride showed uniform distribution followed by sulphate and nitrate. These findings provide valuable insights into the soil's chemical characteristics, with calcium dominance suggesting good cation exchange capacity and the consistent chloride levels indicating homogeneous distribution patterns. The moderate nitrate concentrations may reflect balanced nitrogen cycling processes in the studied soils, while the stable phosphate levels suggest limited phosphorus availability in the soil system.

5.18 Post-monsoon Surface Control Soil Sample Heavy Metal Analysis

Table 37. Descriptive statistics of heavy metals in post-monsoon control surface soil samples.

Parameter	Minimum	Maximum	Mean
Mn (mg/kg)	0.15	20.46	10.31
Co (mg/kg)	0.01	0.65	0.33

Ni (mg/kg)	0.53	0.53	0.53	The soil
Cu (mg/kg)	0.01	0.38	0.20	
Zn (mg/kg)	0.01	0.99	0.50	
As (mg/kg)	0.00	0.14	0.07	
Mo (mg/kg)	0.01	0.01	0.01	
Cd (mg/kg)	0.00	0.00	0.00	
Pb (mg/kg)	0.03	1.05	0.54	
Fe(mg/kg)	4.14	9.85	7.00	
Hg(mg/kg)	0.00	0.00	0	

analysis revealed varying concentrations of heavy metals, with manganese showing the widest range from 0.15 to 20.46 mg/kg and averaging 10.31 mg/kg, while iron concentrations ranged from 4.14 to 9.85 mg/kg with a mean of 7 mg/kg. Lead was detected between 0.03 and 1.05 mg/kg, averaging 0.54 mg/kg, and zinc levels varied from 0.1 to 0.99 mg/kg with a mean concentration of 0.5 mg/kg. Nickel maintained a consistent level of 0.53 mg/kg across all samples, whereas cobalt ranged from 0.01 to 0.65 mg/kg and averaged 0.33 mg/kg. Copper concentrations showed a range of 0.01 to 0.38 mg/kg with a mean value of 0.2 mg/kg, and arsenic was present in quantities ranging from undetectable to 0.14 mg/kg, averaging 0.07 mg/kg. Molybdenum was either absent or present in trace amounts up to 0.01 mg/kg, averaging 0.01 mg/kg where detected, while cadmium was completely absent from all samples. Mercury was not detected in any of the analysed soil samples. The results demonstrate that manganese and iron were the most abundant heavy metals, with other elements present at significantly lower concentrations, suggesting natural geochemical processes as the primary source of these metals in the soil environment. The consistent absence of cadmium and mercury, along with the low levels of other potentially toxic elements, indicates minimal anthropogenic contamination in the studied soils.

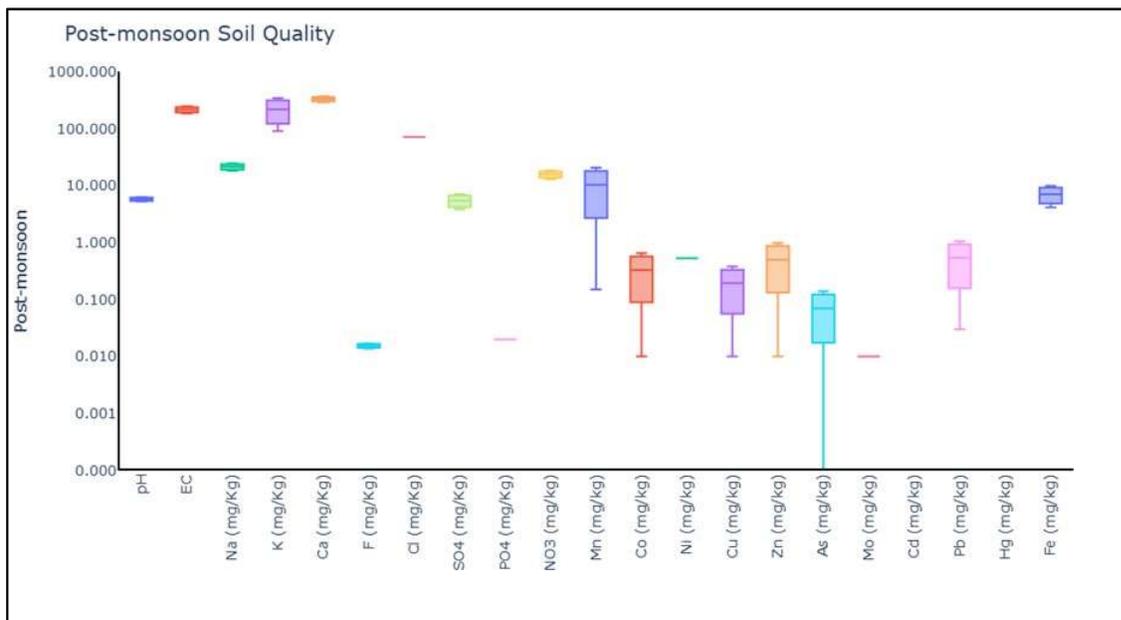


Fig 34. Soil quality of post-monsoon surface control samples.

5.19 Post-monsoon Experimental Surface Soil Sample Cation and Anion Analysis

Table 38. Descriptive statistics of soil quality parameters in post- monsoon surface samples.

Parameter	Minimum	Maximum	Mean
pH	4.9	7.09	5.72
EC	56.2	1068	365.65
Na (mg/Kg)	8.66	30.08	16.14
K (mg/Kg)	56.7	362.4	149.52
Ca (mg/Kg)	68.36	3750.83	388.43
F (mg/Kg)	0.01	0.02	0.02
Cl (mg/Kg)	35.45	177.25	74.28
SO ₄ (mg/Kg)	1.94	25.43	9.38
PO ₄ (mg/Kg)	0.01	0.05	0.02
NO ₃ (mg/kg)	7.47	29.83	18.54

Analysis of 23 surface soil samples revealed predominantly acidic conditions, with pH values ranging from 4.9 to 7.09 and averaging 5.72, where 95.24% of samples were acidic and only 4.76% showed alkaline characteristics. Electrical conductivity measurements indicated highly variable salinity levels across the sampling sites, ranging from 56.2 to 1068 mS/cm with a mean value of 365.65 mS/cm. Sodium concentrations varied from 8.66 to 30.08 mg/kg with an average of 16.14 mg/kg, while potassium levels showed greater variability, spanning 56.7 to 362.4 mg/kg and averaging 149.52 mg/kg. Calcium exhibited the most dramatic concentration range among cations, from 68.36 to 3750.83 mg/kg with a mean of 388.43 mg/kg, suggesting significant spatial heterogeneity in soil mineral composition. Fluoride levels remained consistently low throughout the study area, ranging from 0.01 to 0.02 mg/kg with an average of 0.02 mg/kg. Chloride concentrations varied moderately from 35.45 to 177.25 mg/kg and averaged 74.28 mg/kg, while sulphate levels ranged from 1.94 to 25.43 mg/kg with a mean concentration of 9.38 mg/kg. Phosphate concentrations were consistently low across all samples, measuring between 0.01 and 0.05 mg/kg and averaging 0.02 mg/kg. Nitrate levels showed moderate variation from 7.47 to 29.83 mg/kg with a mean value of 18.54 mg/kg, potentially reflecting differential nitrogen inputs or mineralization rates across sampling locations. The comprehensive analysis revealed calcium as the dominant cation despite its extreme variability, followed by potassium and sodium, while among anions, chloride showed the highest concentrations followed by sulphate and nitrate. These findings highlight the complex spatial variability of soil properties in the studied area, with particularly remarkable differences in calcium content and salinity levels that may significantly influence soil fertility and plant growth conditions.

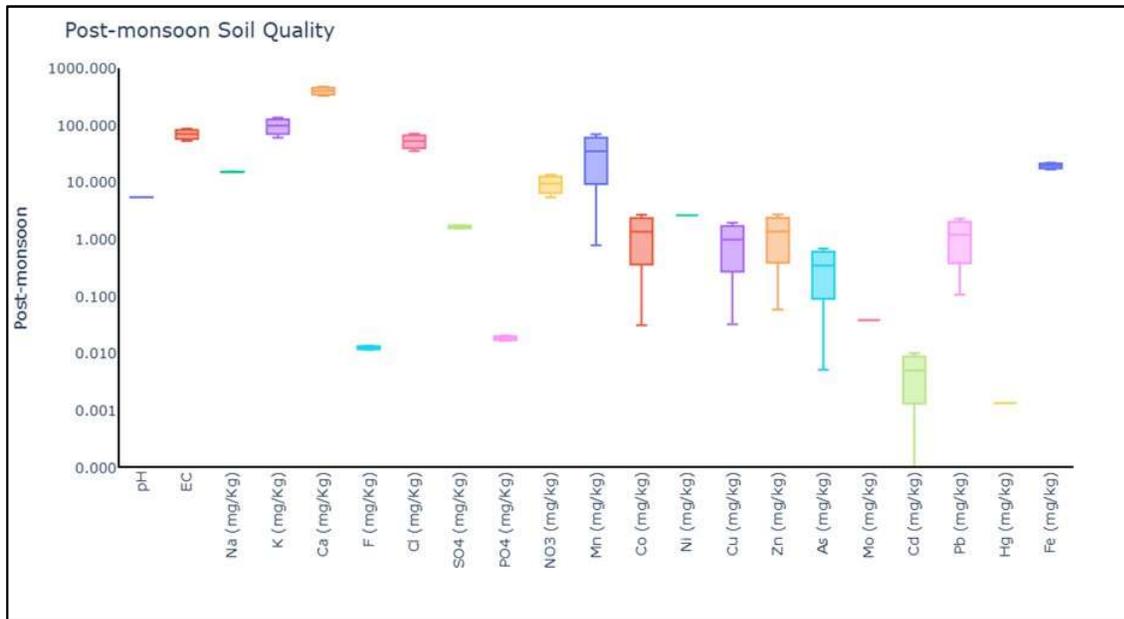


Fig 35. Soil Quality of Post-monsoon Surface Samples

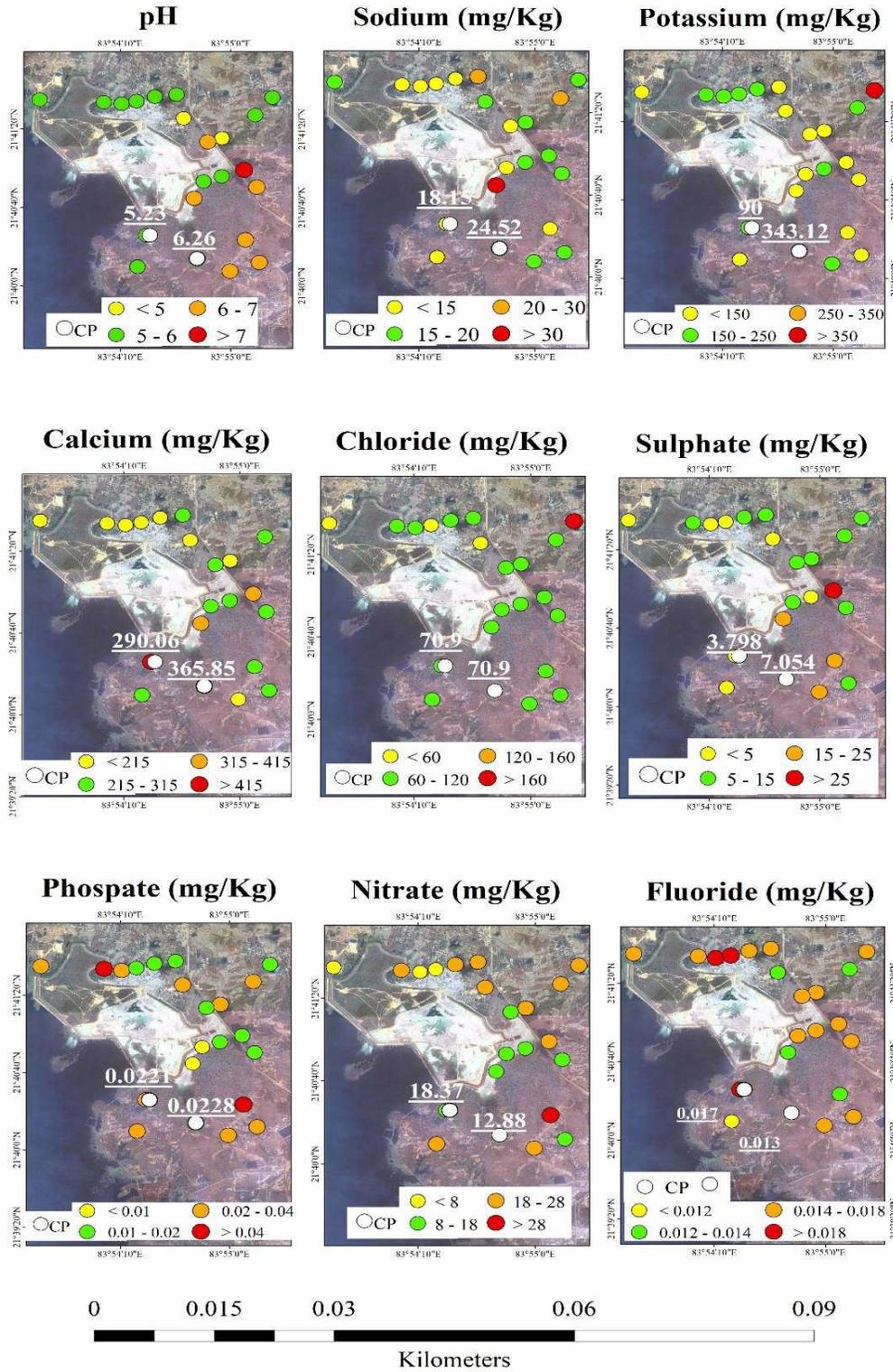


Fig 36. Spatial distribution of soil quality in post-monsoon in surface.

5.20 Post-monsoon Experimental Surface Soil Sample Heavy Metal Analysis

Table 39. Descriptive statistics of heavy metals in post-monsoon surface soil samples.

Parameter	Minimum	Maximum	Mean
Mn (mg/kg)	0.03	46.27	7.74
Co (mg/kg)	0	1.44	0.35
Ni (mg/kg)	0.01	2.85	0.89
Cu (mg/kg)	0	1.54	0.39
Zn (mg/kg)	0	6.3	1.10
As (mg/kg)	0	6.47	0.91
Mo (mg/kg)	0	1.49	0.33
Cd (mg/kg)	0	2.61	0.36
Pb (mg/kg)	0.01	1.41	0.44
Fe(mg/kg)	0.68	20.83	8.74
Hg(mg/kg)	0	0	0.00

The soil samples were analysed for eleven heavy metals including cadmium (Cd), zinc (Zn), lead (Pb), iron (Fe), arsenic (As), molybdenum (Mo), manganese (Mn), nickel (Ni), copper (Cu), cobalt (Co), and mercury (Hg). Manganese showed the widest concentration range from 0.03 to 46.27 mg/kg with an average of 7.74 mg/kg, while iron concentrations varied between 0.68 and 20.83 mg/kg averaging 8.74 mg/kg. Lead levels ranged from 0.01 to 1.41 mg/kg with a mean concentration of 0.44 mg/kg, and zinc was detected from non-detectable levels up to 6.3 mg/kg averaging 1.1 mg/kg. Nickel concentrations spanned 0.01 to 2.85 mg/kg with an average of 0.89 mg/kg, whereas cobalt ranged from non-detectable to 1.44 mg/kg and averaged 0.35 mg/kg. Copper levels varied between non-detectable and 1.54 mg/kg with a mean value of 0.39 mg/kg, and arsenic showed concentrations from non-detectable to 6.47 mg/kg averaging 0.91 mg/kg. Molybdenum was present in quantities ranging from non-detectable to 1.49 mg/kg with an average of 0.33 mg/kg, while cadmium ranged from non-detectable to 2.61 mg/kg averaging 0.36 mg/kg. Mercury was not detected in any of the analysed soil samples. The results demonstrate that iron and manganese were the most abundant heavy metals, with other elements generally present at lower concentrations, though several metals including arsenic and zinc showed instances of elevated levels in some samples. The detection of various heavy metals across the samples indicates potential multiple sources of these elements in the soil environment, while the absence of mercury suggests no significant contamination from this element in the studied area.

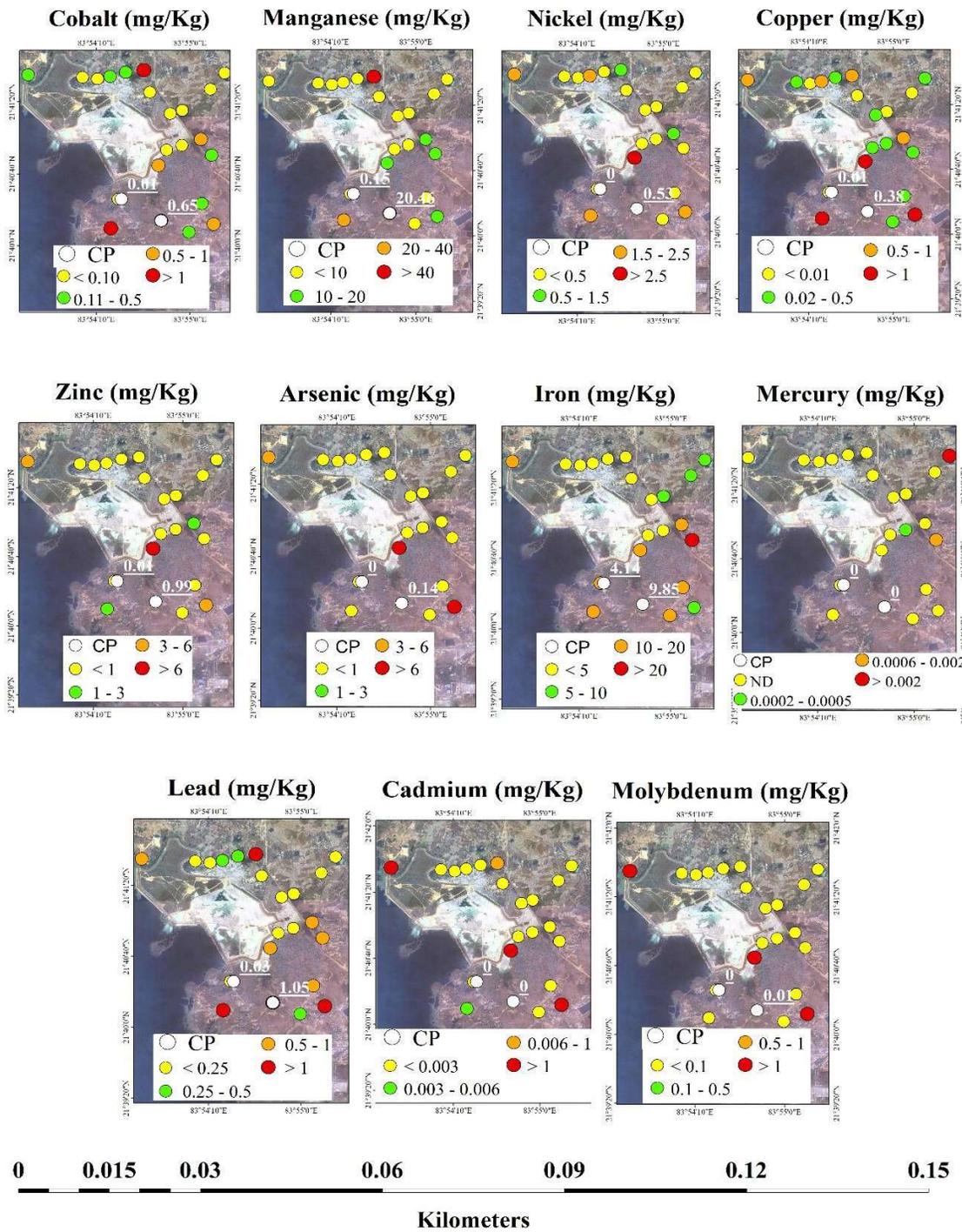


Fig 37. Spatial distribution of heavy metals in post-monsoon in surface.

5.21 Post-monsoon Sub- Surface (10 cm) Control Soil Sample Cation and Anion Analysis

Table 40. Descriptive statistics of soil quality parameters in post-monsoon Sub- surface (10 cm) control samples.

Parameter	Minimum	Maximum	Mean
pH	5.46	5.52	5.49
EC	53.30	86.90	70.10
Na (mg/Kg)	15.08	15.49	15.28
K (mg/Kg)	61.05	136.73	98.89
Ca (mg/Kg)	326.63	476.96	401.79
F (mg/Kg)	0.01	0.01	0.01
Cl (mg/Kg)	35.45	70.90	53.18
SO ₄ (mg/Kg)	1.55	1.78	1.67
PO ₄ (mg/Kg)	0.02	0.02	0.02
NO ₃ (mg/kg)	5.47	13.67	9.57

Surface soil samples were analysed for various physicochemical parameters, revealing consistently acidic conditions with pH values ranging narrowly from 5.46 to 5.52 and averaging 5.49. Electrical conductivity measurements showed moderate salinity levels varying between 53.3 and 86.9 mS/cm with a mean of 70.1 mS/cm. Sodium concentrations remained remarkably stable across samples, ranging from 15.08 to 15.49 mg/kg and averaging 15.28 mg/kg, while potassium levels exhibited greater variability from 61.05 to 136.73 mg/kg with a mean concentration of 98.89 mg/kg. Calcium concentrations ranged from 326.63 to 476.96 mg/kg, averaging 401.79 mg/kg, establishing it as the dominant cation in the soil profile. Fluoride levels were consistently low at 0.01 mg/kg in all samples, and chloride concentrations varied from 35.45 to 70.9 mg/kg with an average of 53.18 mg/kg. Sulphate levels showed minimal variation, ranging from 1.55 to 1.78 mg/kg and averaging 1.67 mg/kg, while phosphate concentrations remained constant at 0.02 mg/kg throughout all analysed samples. Nitrate levels demonstrated moderate variability, ranging from 5.47 to 13.67 mg/kg with a mean concentration of 9.57 mg/kg. The comprehensive analysis revealed calcium as the most abundant cation followed by potassium and sodium, while among anions, chloride showed the highest concentrations followed by nitrate, sulphate, and phosphate. These findings characterize a soil environment with stable acidity and salinity parameters, relatively uniform sodium distribution, but notable variability in potassium and calcium concentrations that may influence nutrient availability and soil fertility in the studied area.

5.22 Post-monsoon Sub- Surface (10 cm) Control Soil Sample Heavy Metal Analysis

Table 41. Descriptive statistics of heavy metals in post-monsoon control sub- surface (10 cm) soil samples.

Parameter	Minimum	Maximum	Mean
Mn (mg/kg)	0.79	69.72	35.26
Co (mg/kg)	0.03	2.71	1.37
Ni (mg/kg)	2.64	2.64	2.64

Cu (mg/kg)	0.03	1.96	1.00
Zn (mg/kg)	0.06	2.73	1.39
As (mg/kg)	0.01	0.70	0.35
Mo (mg/kg)	0.04	0.04	0.04
Cd (mg/kg)	0.00	0.01	0.01
Pb (mg/kg)	0.11	2.32	1.21
Fe(mg/kg)	16.90	21.99	19.45
Hg(mg/kg)	0.00	0.00	0.00

The soil analysis examined eleven heavy metals, revealing distinct concentration patterns across the samples. Manganese showed the widest variation, ranging from 0.79 to 69.72 mg/kg with a notably high average of 35.26 mg/kg, while iron concentrations remained consistently elevated between 16.9 and 21.99 mg/kg, averaging 19.45 mg/kg. Nickel maintained a stable presence at 2.64 mg/kg across all samples, and lead concentrations varied from 0.11 to 2.32 mg/kg with a mean of 1.21 mg/kg. Zinc levels ranged from 0.06 to 2.73 mg/kg, averaging 1.39 mg/kg, slightly higher than cobalt which spanned 0.03 to 2.71 mg/kg with a mean of 1.37 mg/kg. Copper concentrations showed moderate levels between 0.03 and 1.96 mg/kg, averaging 1 mg/kg, while arsenic was detected in lower quantities ranging from 0.01 to 0.7 mg/kg with a mean of 0.35 mg/kg. Molybdenum appeared consistently at 0.04 mg/kg throughout the samples, and cadmium was nearly undetectable, present only in trace amounts up to 0.01 mg/kg with an average matching this detection limit. Mercury was completely absent from all analysed samples. The results demonstrate manganese and iron as the predominant metals, with manganese showing particularly high accumulation in certain samples, while other elements generally occurred at lower concentrations. The consistent presence of nickel at 2.64 mg/kg and the near absence of cadmium and mercury suggest specific geochemical conditions in the sampled area.

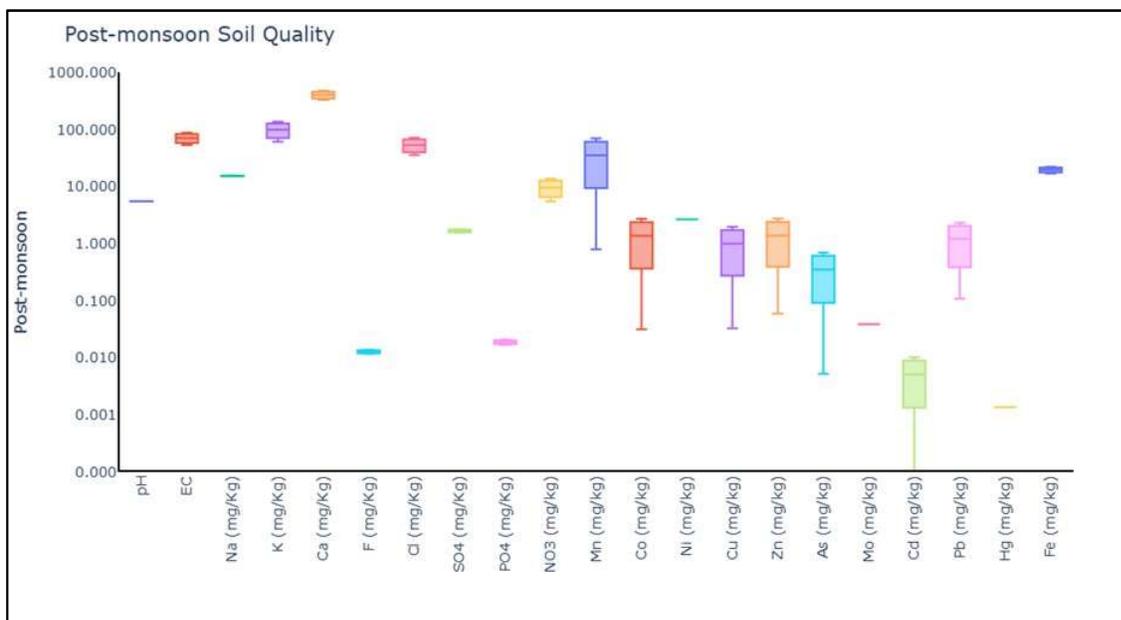


Fig 38. Soil quality of post-monsoon subsurface (10cm) control samples

5.23 Post-monsoon Experimental sub-Surface (10 cm) Soil Sample Cation and Anion Analysis

Table 42. Descriptive statistics of soil quality parameters in post-monsoon Sub- surface (10 cm) samples.

Parameter	Minimum	Maximum	Mean
pH	4.97	7.26	5.71
EC	43.90	362.00	177.98
Na (mg/Kg)	7.58	25.13	13.69
K (mg/Kg)	37.76	340.01	148.95
Ca (mg/Kg)	49.61	371.06	218.45
F (mg/Kg)	0.01	0.02	0.02
Cl (mg/Kg)	35.45	141.80	65.84
SO ₄ (mg/Kg)	2.48	11.01	5.50
PO ₄ (mg/Kg)	0.01	0.24	0.03
NO ₃ (mg/kg)	3.32	26.79	16.79

Analysis of 23 soil samples collected from 10 cm depth revealed predominantly acidic conditions, with pH values ranging from 4.97 to 7.26 and averaging 5.71, where 95.24% of samples were acidic while 4.76% exhibited alkaline properties. Electrical conductivity measurements indicated variable salinity levels spanning 43.9 to 362 mS/cm with a mean value of 177.98 mS/cm. Sodium concentrations ranged from 7.58 to 25.13 mg/kg with an average of 13.69 mg/kg, while potassium levels demonstrated greater variability from 37.76 to 340.01 mg/kg and averaged 148.95 mg/kg. Calcium concentrations varied substantially from 49.61 to 371.06 mg/kg with a mean of 218.45 mg/L, establishing it as the dominant cation despite measurement units differing from other parameters. Fluoride levels remained consistently low across all samples, ranging from 0.01 to 0.02 mg/kg and averaging 0.02 mg/kg. Chloride concentrations showed moderate variation between 35.45 and 141.8 mg/kg with a mean of 65.84 mg/kg, while sulphate levels ranged from 2.48 to 11.01 mg/kg and averaged 5.5 mg/kg. Phosphate concentrations varied from 0.01 to 0.24 mg/kg with a mean of 0.03 mg/kg, whereas nitrate demonstrated the widest variation among anions, ranging from 3.32 to 26.79 mg/kg and averaging 16.79 mg/kg.

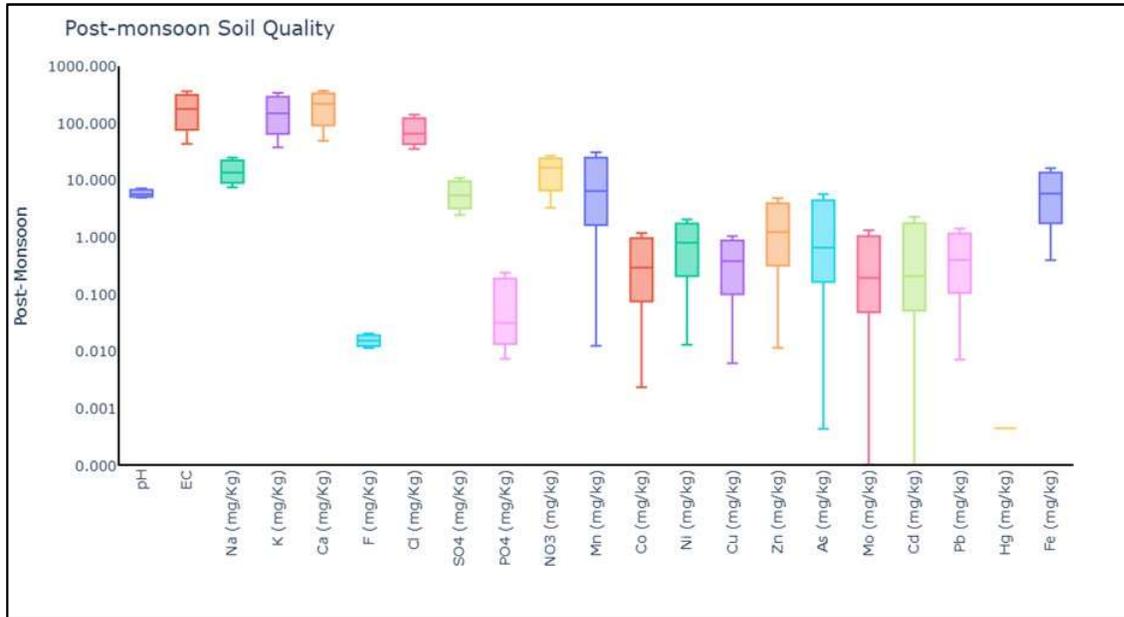


Fig 39. Soil quality of post-monsoon subsurface (10cm) samples.

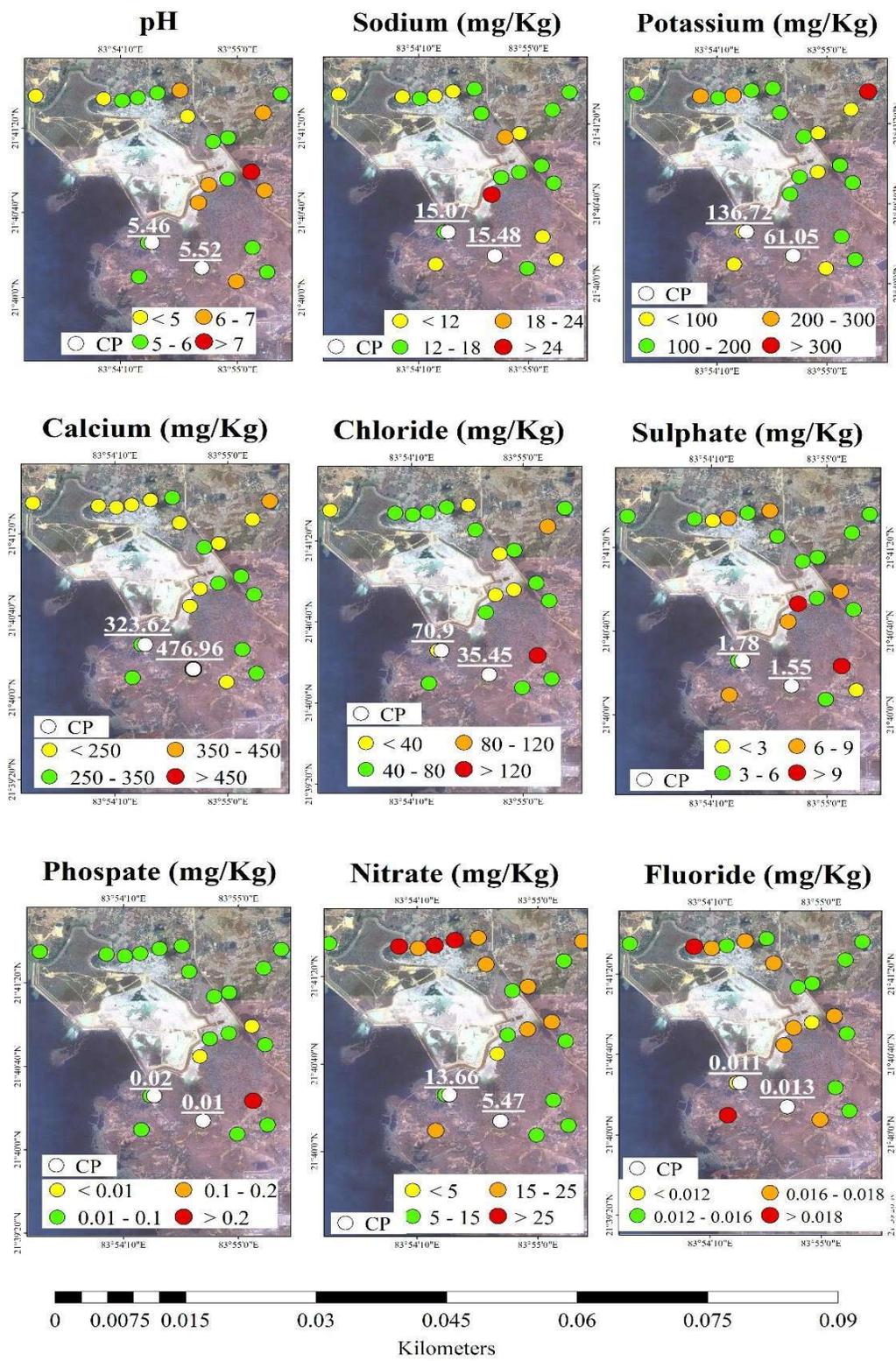


Fig 40. Spatial distribution of soil quality in post-monsoon in subsurface (10cm).

5.24 Post-monsoon Experimental sub-Surface (10 cm) Soil Sample Heavy Metal Analysis

Table 43. Descriptive statistics of heavy metals in post-monsoon sub- surface (10 cm) soil samples.

Parameter	Minimum	Maximum	Mean
Mn (mg/kg)	0.01	31.01	6.55
Co (mg/kg)	0.00	1.20	0.30
Ni (mg/kg)	0.01	2.06	0.81
Cu (mg/kg)	0.01	1.06	0.39
Zn (mg/kg)	0.01	4.89	1.26
As (mg/kg)	0.00	5.77	0.67
Mo (mg/kg)	0.00	1.34	0.20
Cd (mg/kg)	0.00	2.31	0.21
Pb (mg/kg)	0.01	1.43	0.40
Fe(mg/kg)	0.40	16.36	5.90
Hg(mg/kg)	0.00	0.00	0.00

The soil analysis examined eleven heavy metals, with manganese showing concentrations ranging from 0.01 to 31.01 mg/kg and averaging 6.55 mg/kg, while iron levels varied between 0.4 and 16.36 mg/kg with a mean of 5.9 mg/kg. Zinc concentrations spanned 0.1 to 4.89 mg/kg and averaged 1.26 mg/kg, and lead was detected from 0.01 to 1.43 mg/kg with a mean of 0.4 mg/kg. Nickel levels ranged from 0.01 to 2.06 mg/kg averaging 0.81 mg/kg, and cobalt showed concentrations of 0 to 1.2 mg/kg with a mean of 0.3 mg/kg. Copper was present at 0.01 to 1.06 mg/kg with an average of 0.39 mg/kg, while arsenic concentrations varied more substantially from 0 to 5.77 mg/kg and averaged 0.67 mg/kg. Molybdenum was detected between 0 and 1.34 mg/kg with a mean of 0.2 mg/kg, and cadmium showed trace levels from 0 to 2.31 mg/kg averaging 0.21 mg/kg. Mercury was not detected in any samples. The results indicate iron and manganese as the most abundant metals, with zinc and arsenic showing occasional elevated concentrations, while other elements generally occurred at lower levels. The consistent absence of mercury and generally low cadmium levels suggest minimal contamination from these particularly toxic elements.

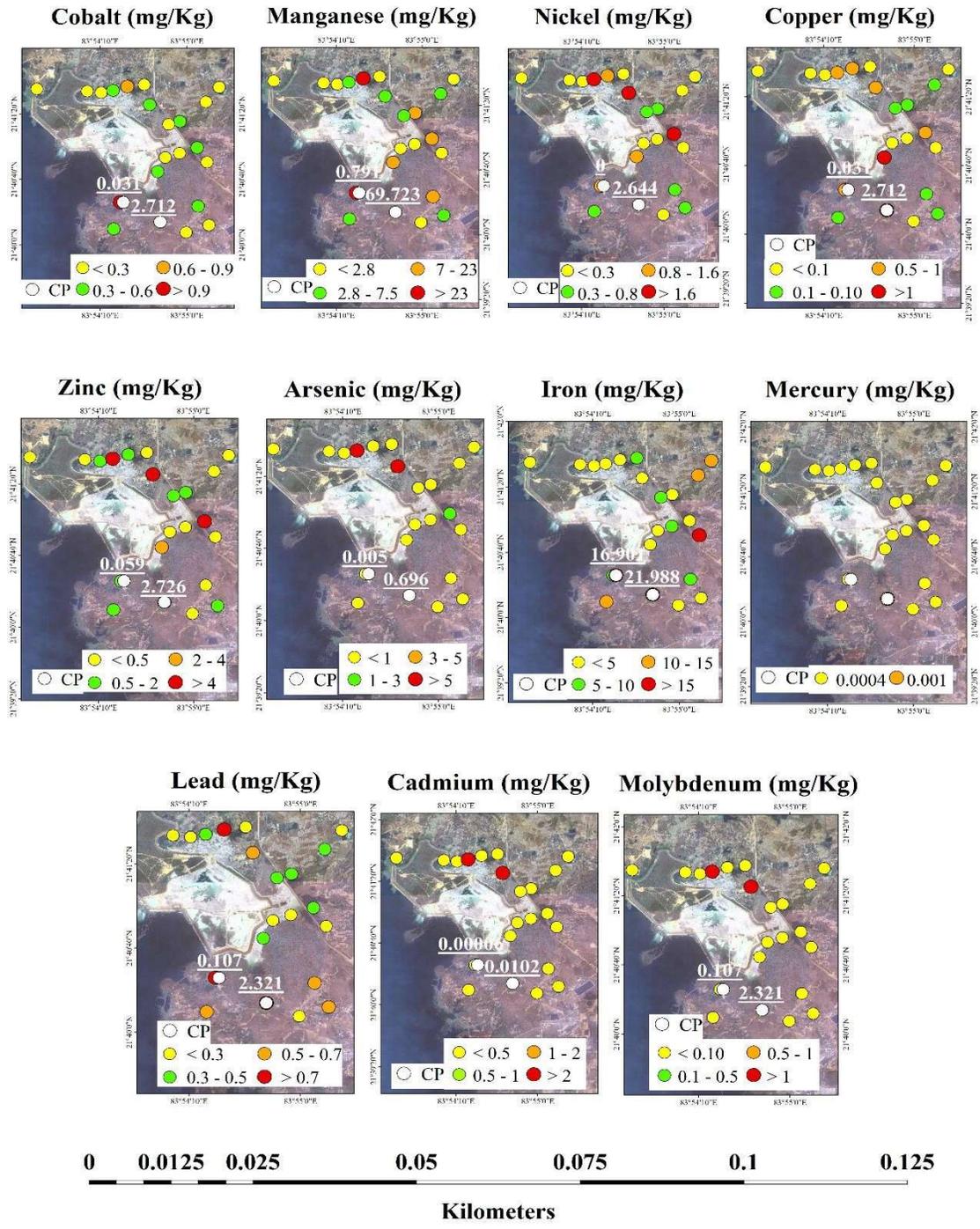


Fig 41. Spatial distribution of heavy metals in post-monsoon in subsurface (10cm).

5.25 Percentage of soil samples exceeding average crustal values

Table 44. Percentage of control soil samples exceeding average concentration in upper continental crust/ crustal values

Element	UCC/Crustal Avg (mg/Kg)	Soil Surface Control Sample			Soil Sub surface (10 cm) Control Sample		
		Pre (%)	Monsoon (%)	Post (%)	Pre (%)	Monsoon (%)	Post (%)
Na	23600	0	0	0	0	0	0
K	20900	0	0	0	0	0	0
Ca	41500	0	0	0	0	0	0
Cl	130	0	0	0	40	0	0
Mn	950	0	0	0	0	0	0
Co	25	0	0	0	0	0	0
Ni	75	0	0	0	0	0	0
Cu	55	0	0	0	0	0	0
Zn	70	0	0	0	0	0	0
As	1.8	0	0	0	0	0	0
Mo	1.5	0	0	0	0	0	0
Cd	0.2	0	0	0	0	0	0
Pb	12.5	0	0	0	0	0	0
Fe	56300	0	0	0	0	0	0
Hg	0.08	40	0	0	60	0	0
F	625	0	0	0	0	0	0

The control soil analysis revealed nearly all tested elements were undetectable in both surface and subsurface samples across pre-monsoon, monsoon, and post-monsoon periods, with concentrations below detection limits for sodium, potassium, calcium, manganese, cobalt, nickel, copper, zinc, arsenic, molybdenum, cadmium, lead, iron, and fluoride. Chloride showed limited detection at 40% occurrence in subsurface samples during pre-monsoon but was absent in all other seasons and surface

samples. Mercury exhibited seasonal and depth-specific patterns, detected in 40% of surface samples and 60% of subsurface samples during pre-monsoon but completely absent during monsoon and post-monsoon periods. The data suggest most elements remain tightly bound in soil matrices or exist at concentrations too low for detection under current analytical methods. The exclusive pre-monsoon detection of chloride and mercury indicates potential seasonal mobilization or deposition prior to monsoon rains. Mercury's higher detection frequency in subsurface samples may reflect downward leaching or accumulation patterns. The complete absence of elements during monsoon and post-monsoon suggests rainfall effectively flushes or dilutes mobile species. These findings demonstrate the control site's overall geochemical stability but highlight mercury as requiring special attention due to its sporadic presence. The results establish important baseline data showing minimal elemental mobility under normal conditions. Seasonal variations appear limited to chloride and mercury, with other elements remaining non-detectable year-round.

Table 45. Percentage of soil samples exceeding average concentration in upper continental crust/ crustal values

Element	UCC/Crustal Avg (mg/Kg)	Soil Surface Sample			Soil Subsurface (10 cm) Sample		
		Pre (%)	Monsoon (%)	Post (%)	Pre (%)	Monsoon (%)	Post (%)
Na	23600	0	0	0	0	0	0
K	20900	0	0	0	0	0	0
Ca	41500	0	0	0	0	0	0
Cl	130	22.72	0	4.76	13.63	11.11	4.76
Mn	950	0	0	0	0	0	0
Co	25	0	0	0	0	0	0
Ni	75	0	0	0	0	0	0
Cu	55	0	0	0	0	0	0
Zn	70	0	0	0	0	0	0
As	1.8	0	0	0	0	0	0
Mo	1.5	0	0	0	0	0	0
Cd	0.2	0	0	14.28	0	0	9.52
Pb	12.5	0	0	0	0	0	0

Fe	56300	0	0	0	0	0	0
Hg	0.08	22.72	0	0	50	0	0
F	625	0	0	0	0	0	0

The assessment of soil samples revealed that while most elements remained within natural crustal background levels, chloride, cadmium, and mercury exhibited significant seasonal mobility patterns. Surface soil samples showed elevated chloride concentrations exceeding the 130 mg/kg threshold in 22.72% of pre-monsoon samples and 4.76% of post-monsoon samples, indicating surface runoff contributions during these periods. Subsurface samples at 10 cm depth demonstrated more persistent chloride mobility, with exceedances observed in 13.63% of pre-monsoon, 11.11% of monsoon, and 4.76% of post-monsoon samples. Cadmium mobilization became particularly evident during post-monsoon conditions, with 14.28% of surface and 9.52% of subsurface samples surpassing the 0.2 mg/kg limit, suggesting wetting-front induced displacement of this metal. Mercury displayed the most pronounced transport behaviour, with 22.72% of pre-monsoon surface samples and 50% of subsurface samples exceeding the 0.08 mg/kg.

6. Pollution Indices

The sediment samples were collected in the pre-monsoon, monsoon and post-monsoon season from the study site and analysed for heavy metals. To investigate the extent of soil pollution three indices were used: contamination factor, geo - accumulation index and pollution load index which were calculated using concentration of heavy metals in sediment samples.

6.1 Contamination Factor (CF)

The contamination factor shows the extent of pollution of sediment. It is the ratio of concentration of metal in the samples to the average background value of the sediment. The CF value of < 1 means low, > 1 to < 3 indicates moderate, > 3 to < 6 considerable, and > 6 is considered very high concentration. Figure 20 shows spatial distribution of contamination factor of soil samples analysed in all the three seasons. The Cf value for Zn, As, Cd, Pb and Fe is less than 1 in pre-monsoon samples at all the locations, which suggests low contamination of these HMs at all the locations. The CF value for Hg is greater than 1 and less than 3 in 9 locations of pre-monsoon, suggesting moderate pollution due to Hg at these locations. The Cf value for Zn, As, Cd, Pb and Fe is less than 1 in monsoon at all the locations, which suggests low contamination of these HMs at all the locations. The CF value for Hg is > 1 to < 3 in 2 locations in monsoon suggesting moderate contamination at these two locations. The Cf value for Zn, Pb, Fe and Hg is < 1 in post-monsoon at all the locations suggesting low contamination. 3 locations have CF value > 1 to < 3 for As and Cd in the post-monsoon season suggesting moderate contamination at these locations due to As and Cd.

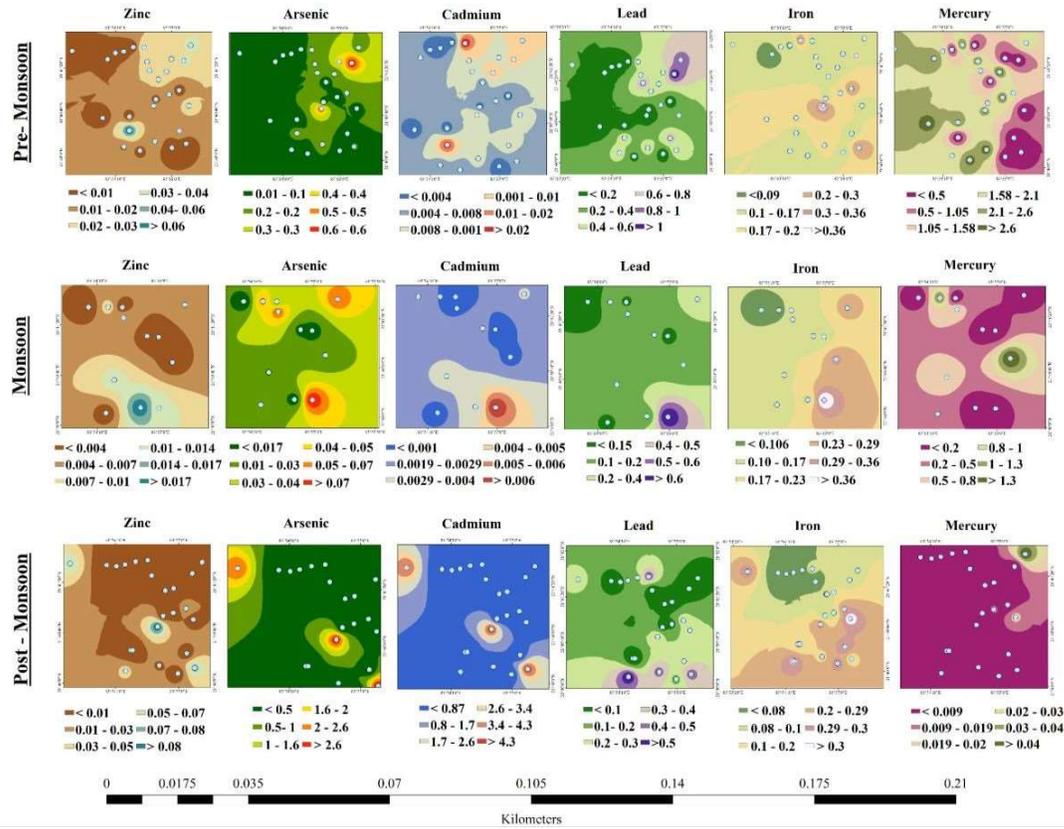
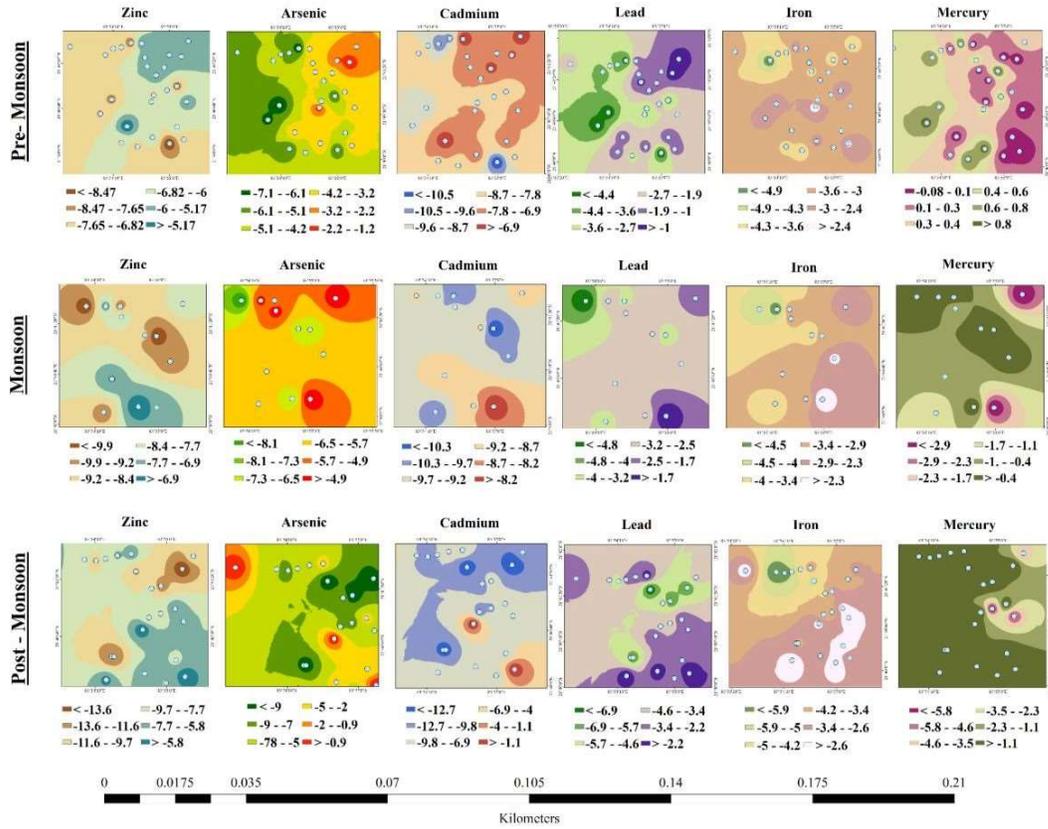


Fig 42. Spatial distribution of Contamination Factor (CF) of soil samples analysed in the three seasons.

6.2 Geo-accumulation Index (I_{geo})

The geo-accumulation index was calculated for the heavy metals in sediment samples taken from the study site. The geo-accumulation index is divided into seven categories (i) practically uncontaminated ≤ 0 , (ii) uncontaminated to moderately contaminated =0-1, (iii) moderately contaminated = 1-2, (iv) moderately to heavily contaminated = 2-3 (v) heavily contaminated = 3-4, (vi) heavily to extremely contaminated = 4-5, (vii) extremely contaminate ≥ 5 . Figure 21 shows spatial distribution of geo-accumulation index of soil samples analysed in all the three seasons. The I_{geo} index value is ≤ 0 for Zn, As, Cd, Pb and Fe in all the three seasons suggesting all the locations are uncontaminated from these HMs. The I_{geo} index value of Hg is between 0 to 1 in 11 locations of pre-monsoon, suggesting these locations are uncontaminated to moderately contaminated. While the I_{geo} index value of Hg is ≤ 0 in monsoon and post-monsoon in all locations suggesting these locations are un-contaminated.



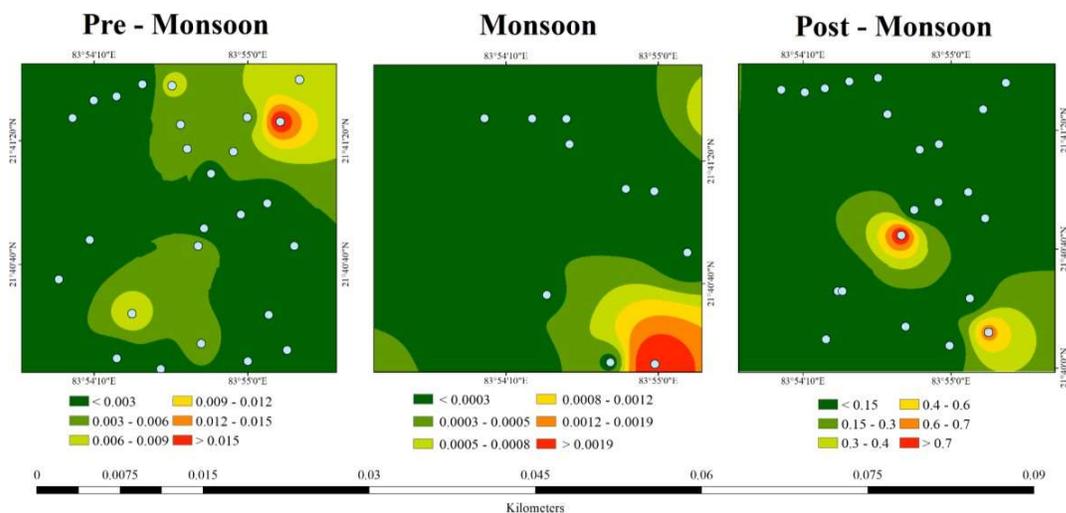


Fig 44. Spatial distribution of pollution load index of soil samples analysed in the three seasons.

7. Conclusions

An environmental damage assessment was conducted following the ash pond dike breach at IB Thermal Power Station in Banharpali, Jharsuguda, analysing surface water and soil samples. Water samples were evaluated for physicochemical parameters and heavy metals, while soil samples were tested for nutrients and heavy metal content. Pollution indices including contamination factor (CF), geo-accumulation index (Igeo), and pollution load index (PLI) were employed to assess soil contamination levels. Water quality analysis showed samples from Hirakud reservoir met CPCB's designated best use standards for pH and electrical conductivity, though no Indian surface water standards were available for comprehensive comparison. Seasonal water pH variations were observed, ranging from slightly acidic to alkaline in pre-monsoon, near neutral during monsoon, and slightly acidic post-monsoon. All water samples contained arsenic below $10\mu\text{g/L}$ across seasons, with lead and mercury remaining below detection limits. Iron concentrations exhibited seasonal fluctuations, increasing during monsoon and decreasing post-monsoon. Soil analysis revealed most elements (Na, K, Ca, Mn, Co, Ni, Cu, Zn, As, Mo, Pb, Fe, Hg, F) maintained concentrations below upper continental crustal (UCC) averages in both surface and subsurface samples across all seasons. Cadmium exceeded UCC values in 14.28% of surface and 9.52% of subsurface post-monsoon samples, while mercury surpassed thresholds in 22.72% of surface and 50% of subsurface pre-monsoon samples. Control samples showed elevated mercury in 40% of surface and 60% of subsurface pre-monsoon collections. Chloride concentrations exceeded UCC averages in 22.72% of surface and 13.63% of subsurface pre-monsoon samples, with 11.11% of subsurface monsoon samples and 4.76% of post-monsoon samples also showing elevated levels. Contamination factor analysis indicated low pollution for Zn, As, Cd, Pb and Fe during pre-monsoon and monsoon periods at all locations. Mercury displayed moderate contamination at 9 pre-monsoon and 2 monsoon locations but showed natural dilution by post-monsoon. Post-monsoon samples revealed low

contamination for Zn, Pb and Fe, but moderate contamination for As and Cd at 3 locations. Geo-accumulation index values confirmed uncontaminated conditions for Zn, As, Cd, Pb and Fe across all seasons and locations. Mercury showed variable Igeo values ranging from uncontaminated to moderately contaminated at 11 pre-monsoon locations but remained uncontaminated during monsoon and post-monsoon periods. Pollution load index calculations suggested no significant cumulative contamination at any location throughout the study period. The findings demonstrate seasonal variations in metal mobility, with mercury showing the most pronounced contamination that naturally attenuates by post-monsoon. The study concludes that while localized heavy metal contamination exists, particularly for mercury and cadmium, overall pollution levels remain within acceptable limits across most monitored parameters and locations.

8. Recommendations

The environmental damage assessment following the ash pond breach at the IB Thermal Power Station in Banharpali, Jharsuguda, highlights several critical follow-up actions to mitigate risks and prevent future incidents. Long-term environmental monitoring should be implemented, with quarterly sampling of water (surface and groundwater) and soil (surface and subsurface) to track heavy metals (Cd, Hg, As, Pb, Fe) and physicochemical parameters, particularly in hotspots where contamination exceeded permissible limits. Seasonal assessments—pre-monsoon, monsoon, and post-monsoon—are essential to evaluate leaching and dilution effects, especially given the observed pH fluctuations in soil and water due to fly ash interactions. For remediation and mitigation, phytoremediation using metal-accumulating plants (e.g., *Brassica juncea* for Cd, *Pteris vittata* for As) should be deployed in contaminated zones, supplemented by soil amendments like lime (Ca(OH)_2) or organic compost to neutralize acidity and reduce metal mobility. Capping fly ash-affected soil with geotextiles or clean soil can prevent erosion, while constructed wetlands and adsorbents. Infrastructure upgrades are critical to prevent future breaches, including strengthening ash pond dykes with geosynthetic liners, implementing real-time structural monitoring systems, and improving leachate collection. Transitioning to dry ash disposal and promoting fly ash utilization in construction (per MoEF&CC guidelines) can minimize environmental risks. Community health and engagement must be prioritized through biomonitoring programs to screen residents for heavy metal exposure (blood/urine tests) and associated health disorders (skin, respiratory, neurological). Awareness campaigns should educate farmers on safe agricultural practices and distribute health advisories on drinking water safety.

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10. Field Photographs











Biological and Ecological enumeration of
surface water samples, with reference to
Phyto planktons and Zooplanktons in
response to Ash Pond Breach

Keywords: Phytoplankton, Zooplankton, Species diversity, Community structure, Ecological balance, Environmental stress, Seasonal variations.

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Introduction

Water is essential for life on Earth, serving as the foundation upon which all living organisms depend. Ponds, as vital water sources, which support a diverse range of aquatic organisms and hold significant importance for humanity. These bodies of water may have originated as natural resources that humans have utilized over time to fulfil various needs, or they may have been artificially created for numerous purposes, such as domestic or agricultural use, transportation, defence, rituals, industrial activities, social enhancement, recreational swimming, fish farming, or to enhance the aesthetic appeal of the landscape (Ress, 1997; Narayan et al., 2007; Bishnoi and Malik, 2008). As dynamic ecosystems, ponds undergo continuous interactions between biotic and abiotic components, where factors such as water quality, nutrient availability, and climatic conditions influence their structure and function.

Water Pollution

Water pollution can be analysed by the changes in physical, chemical and biological properties like colour, organic / inorganic contents and microbial load. Water quality is affected by a wide range of natural and human influences. The most important of the natural influences are geological, hydrological and climatic, since these affect the quantity and the quality of water available. (Singh et al. (2015).

Water pollution significantly impacts plankton diversity by altering aquatic ecosystems. Excess nutrients from sewage and agriculture cause eutrophication, leading to harmful algal blooms that reduce phytoplankton diversity and create oxygen-depleted zones, harming zooplankton. Toxic pollutants like heavy metals and pesticides accumulate in plankton, disrupting food webs. Industrial discharge and acid rain lower pH levels, making water inhospitable for many plankton species. Increased turbidity from sediment runoff limits light penetration, reducing phytoplankton photosynthesis. Thermal pollution from industries raises water temperatures, altering plankton metabolism and species composition. Organic pollution from sewage promotes microbial growth, leading to oxygen depletion and a decline in zooplankton populations. These disruptions affect fish and higher organisms, leading to biodiversity loss and poor water quality. Since plankton are key indicators of environmental health, studying their diversity helps assess pollution levels and ecosystem stability in freshwater bodies.

Planktons

Among the many life forms present in pond ecosystems, plankton play a fundamental role in maintaining ecological balance. Planktons are microscopic aquatic life forms with little or no resist to current movement and thus, live free-floating(suspended) in natural waters.

Water contamination is a global issue, with varying levels across regions and countries. It has a significant impact on the floating community, which includes plankton. Changes in the freshwater ecology can impact plankton diversity and abundance. Examining the physical, chemical, and biological properties of the water including plankton is necessary to determine its quality. The connection between these variables and plankton diversity offers information on how the ecosystem functions.

“Plankton” has been variously defined by many authorities. Hensen (1887) originally defined the term as denoting all that floats in water, “Alles was in Wasser treibt.” Kolkwitz (1912) defined the term as the natural community of those organisms that are normally living in water and are passively carried along by currents. According to Rylov (1922), “pelagic organisms” are not the same as “planktons,” since planktons can be both pelagic and littoral. Rylov also uses the terms “obligoplankton,” which refers to true planktons only, and “facultative planktons,” which refers to those forms found in both limnetic and littoral regions.

The term “plankton,” which comes from the Greek word “drifter,” refers to microscopic creatures that float or drift in watery environments. These essential aquatic food web creatures are divided into several size groups, including picoplankton (less than 2 μm), nanoplankton (2–20 μm), microplankton (20–200 μm), macroplankton (200–2000 μm), and mega plankton (more than 2000 μm). Planktons are very sensitive to the environment they live in and any alteration in the environment leads to the change in the plankton communities in terms of tolerance, abundance, diversity and dominance in the habitat. They react fast to the pollution in the aquatic environment. Therefore, plankton population observation may be used as a reliable tool for biomonitoring studies to assess the pollution status of aquatic bodies Mathivanan and Jayakumar (1995).

Plankton are classified into two main types: phytoplankton (plant-like microorganisms) and zooplankton (animal-like microorganisms). These organisms are essential in aquatic food webs and contribute significantly to nutrient cycling, oxygen production, and energy transfer within the ecosystem.

Phytoplankton

Phytoplankton (derived from the Greek words *Phyto*, meaning plant, and *planktos*, meaning wandering) are single-celled marine algae. Some species can move using flagella, while others passively drift with water currents. These microscopic plants vary in size, ranging from as small as 0.001 millimetres to up to 2 millimetres.

Standing at the bottom level of the food chain, phytoplanktons bear a significant importance in respect of their role in aquatic ecosystems and their relations with other organisms at top levels. According to Sukumaran et al. (2008), phytoplanktons are the main primary producers in many aquatic environments and serve as a significant source of food for other creatures. Phytoplankton represents the microscopic algal communities of water bodies and the pioneer of aquatic food chain. The productivity of an aquatic system is directly related to diversity of phytoplankton. They are source of food for zooplankton, fishes and other aquatic organisms. Phyto planktons not only serve as food for aquatic animals but also play a crucial role by maintaining the biological balance and quality of water as revealed by Pandey et al. (1998).

Zooplankton

Zooplankton (derived from the Greek words *zoon*, meaning animal, and *planktos*, meaning drifting) are a diverse group of floating or drifting aquatic organisms with limited movement capability. Most zooplankton are microscopic, either unicellular or multicellular, with sizes ranging from a few

microns to over a millimetre. They play a crucial role in assessing the biodiversity of aquatic ecosystems. Representing nearly every major animal phylum, zooplankton can be classified into holoplankton, which remain planktonic throughout their life cycle, and meroplankton, which exist as plankton only during their egg or larval stages before developing into larger, free-swimming organisms.

By sheer abundance of both types and their presence at varying depths, the zooplankton are utilized to assess energy transfer at secondary trophic level. They feed on phytoplankton and facilitate the conversion of plant material into animal tissue and in turn constitute the basic food for higher animals including fishes, particularly their larvae. Zooplankton is subdivided, according to size, into microzooplankton, mesozooplankton and 43 microzooplankton. Microzooplankton are the smallest organisms, consisting of flagellates, ciliates and rotifers, mostly detritivorous and bacterivorous, though rotifers also consume small algae. Mesozooplankton is comprised of cladocerans and 3 microzooplankton of copepods (or cladocerans and copepods). The dietary range of zooplankton organisms is often wider (Declince 1992).

Plankton Diversity as a Bioindicator of Water Quality

Today, organic pollution of water resources has become a crucial concern. Increasing human population and activities imposes great burden on freshwater resources. Among freshwater resources, ponds are small but attributed with profuse aquatic macrophytes development (Penny et al, 2003). Phytoplankton are microscopic plants containing chlorophyll A, that float or swim on the upper surfaces of water or are suspended in the water column, where they are dependent on sunlight for photosynthesis (Penny et al, 2003). Carbon dioxide is the main source for providing carbon to phytoplankton that in turn serve as food for zooplankton and fish (Arya et al, 2011). Phytoplankton, being primary producers, holds a significant place in aquatic food chain and all the life forms including zooplanktons are dependent on them (Pace et al, 2004).

Phytoplankton and zooplankton retort rapidly to any alterations in nutrient changes in water bodies indicating the growing nutrient pollution. Effect of pollutants on aquatic life and a reduction in biotic diversity can be easily understood by analysing phytoplankton. Phytoplankton analysis gives an overall idea of the environmental condition of the water body both at the time of growing and sampling. Although phytoplankton is present in water bodies, their supply as food supplement can be increased through external supply from cultures or by development of prevailing algae through fertilization (Boyd, 2004).

On one hand where phytoplankton serves as food source, on the other hand some forms cause fish poisoning due to release of toxins during blooms (Boyd, 2004). Thus, these reasons make it very essential to estimate the levels of planktons in each pond samples which will in turn indicate its water quality.

Coal mining and its impacts

Coal mining and thermal power plants are significant sources of environmental pollution, particularly through the release of coal dust and fly ash. These pollutants often enter nearby water bodies,

impacting aquatic ecosystems. Among the most vulnerable organisms are plankton, which play a critical role in aquatic food webs. Both phytoplankton (plant-like microorganisms) and zooplankton (animal-like microorganisms) are essential for nutrient cycling and energy transfer in water bodies, and any disruption to their populations can have widespread ecological consequences.

Impact of Fly Ash and Heavy Metals

Fly ash, a by-product of coal combustion in thermal power plants, is rich in toxic heavy metals such as mercury, arsenic, lead, and cadmium. These substances can leach into water bodies, contaminating them and posing serious threats to planktonic organisms. Heavy metals can interfere with cell division, enzyme activity, and reproductive functions in plankton. Phytoplankton exposed to these contaminants often exhibit reduced photosynthetic efficiency, while zooplankton may suffer from developmental deformities and lower survival rates.

Effect of Coal Dust from Mining Activities

Coal dust generated from mining operations can be transported to aquatic environments through runoff or atmospheric deposition. Once in water, coal dust increases turbidity, which limits sunlight penetration, a key requirement for photosynthesis in phytoplankton. Reduced light availability diminishes the primary productivity of the ecosystem, weakening the base of the aquatic food web. Additionally, coal dust can physically clog the filtering apparatus of zooplankton, making it difficult for them to feed and survive.

Thermal Pollution and Its Consequences

Thermal power plants frequently discharge hot water into rivers, lakes, or reservoirs, raising the temperature of these water bodies. Elevated temperatures can reduce the dissolved oxygen content in water, stressing aquatic life, including plankton. Thermal stress can speed up metabolic processes in plankton, disrupting normal growth and reproduction cycles. Sensitive species may be eliminated, while more heat-tolerant or opportunistic organisms may dominate, leading to a loss in biodiversity and changes in ecosystem dynamics.

The combined effects of coal dust, fly ash, and thermal pollution from coal mining and power generation severely disrupt the survival and diversity of planktonic organisms. These pollutants alter water chemistry, increase turbidity, introduce toxic substances, and raise temperatures, creating an inhospitable environment for plankton. Protecting aquatic ecosystems requires stringent regulation of coal-related pollutants, effective waste management practices, and environmentally responsible thermal power operations. Safeguarding plankton is essential for maintaining the ecological balance and health of freshwater systems.



Figure 1: Photographs Of Sample Collection During Pre-Monsoon

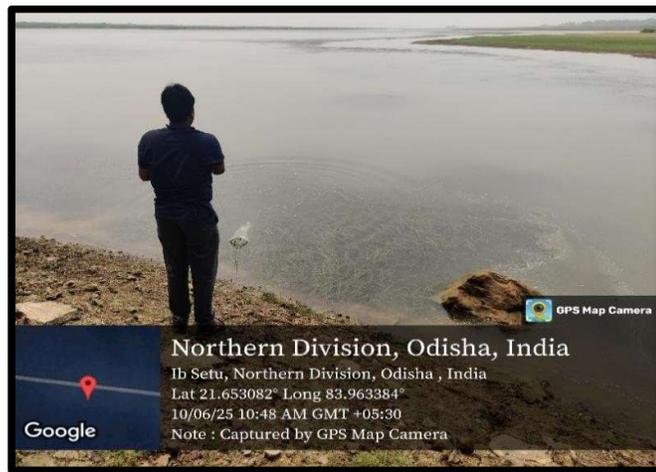
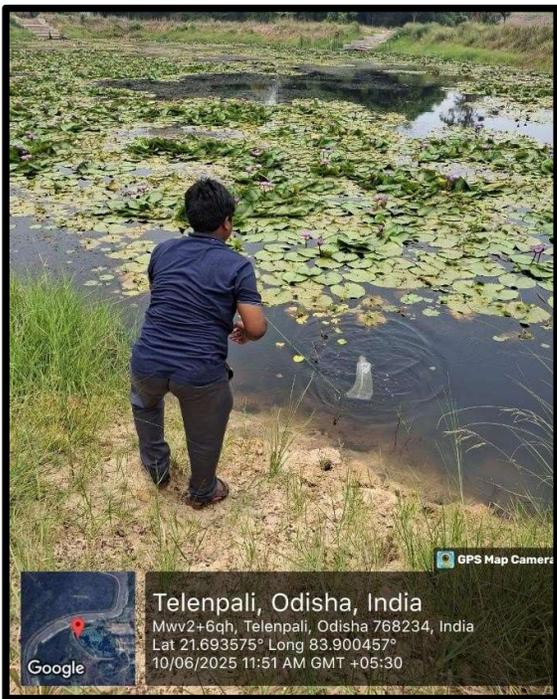
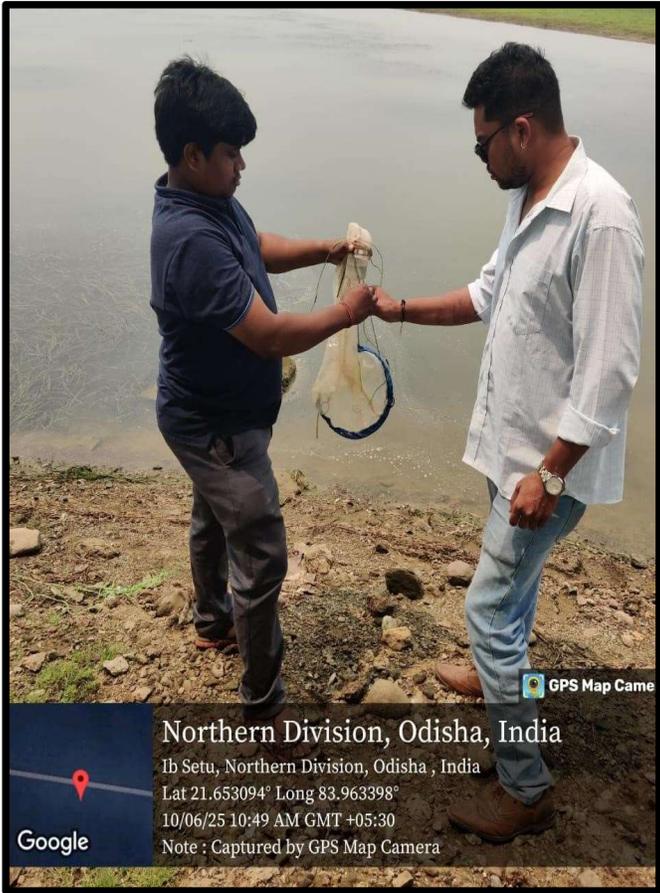


Figure 2: Photographs Of Sample Collection During Post-Monsoon

Materials and Methods

Sample collection

Plankton samples were collected from sampling stations normally at the early morning. plankton samples were collected by means of a bucket (50 litre) and filtered through plankton net of 50 μ . The filtrate was transferred to 50ml plastic bottle and preserved immediately in 4% formalin.

The sample was thereafter taken to the laboratory for qualitative and quantitative analysis. With the help of electrical centrifuge 5-20ml of water sample is centrifuge for 10-20 min at 1500-2000 rpm. Supernatant plankton was removed from by decanting.

Counting Procedure

Sedimentary plankton was counted by Sedgewick rafter counting cell (1 ml capacity) and then the planktons were identified under compound microscope.

A Sedgwick Rafter (S-R) cell is commonly used for counting phytoplankton because it is easily manipulated and provides reasonably reproducible data when used with a calibrated microscope equipped with computer. The S-R cell is about 50mm long 20mm wide 1mm deep. Its total bottom area is about 1000mm², and volume is about 1000mm³ (1 mL).

To count cells using a Sedgwick-Rafter counting chamber, the sample was first prepared and mixed well. The chamber was carefully filled, ensuring no air bubbles were trapped, and the cells were allowed to settle for 15–30 minutes. It was then placed under a compound microscope and focused on low magnification up to 200x. The chamber's grid system helped in counting cells systematically.

Diversity indices analysis

To assess the diversity indices of plankton, species were calculated by respective formula/equation as Shannon Diversity Index, Simpson Diversity Index, Evenness Index and Similarity index. The indices are as follows:

Shannon Diversity Index

Shannon Diversity Index measures species diversity, the Shannon diversity index (H) accounts for both abundance and evenness of species present.

It is calculated as:

$$H = - \sum P_i \times \ln (P_i)$$

Where,

H = the Shannon diversity index

P_i = fraction of the entire population made up of species

S = numbers of species encountered

\sum = sum from species 1 to species S

Simpson Index

Simpson Index Measures the probability that two individuals randomly selected from a sample belong to the same species.

$$D = \sum (n - 1) / (N - 1)$$

Where ,

n= Number of individuals of species

N=Total number of individuals

Evenness Index

Evenness Index measures how equal the abundances of different species are in a community. It is calculated as:

$$J = H / \ln(S)$$

Where, J= Evenness index

H=Shannon index

S= max is the maximum possible value of H, and it is equivalent to lnS

Similarity Index (S)

Similarity Index measures the similarity between two communities based on the number of shared species.

It is calculated as :

$$S = 2C / (A + B)$$

Where,

A= Total no of species in Control Site

B=Total no of species in Experimental site

2C=Total no of common species in both site

Results and Discussion

Distribution, Abundance and Diversity of Planktons During Pre-Monsoon Seasons

Distribution of phytoplankton in each station of the control sites

The consistent presence of specific phytoplankton species across all control sampling stations highlights their ecological resilience and adaptability to stable environmental conditions. In this study, *Anabaena* sp., *Nostoc* sp., *Gloecapsa*, *Synedra* sp., *Euglena* sp., and *Diatom* sp. were observed in every control sample, suggesting their fundamental role in the aquatic ecosystem. *Anabaena* sp. and *Nostoc* sp., members of Cyanophyceae (blue-green algae), are known for their nitrogen-fixing abilities, which contribute to nutrient cycling and ecosystem productivity. The presence of *Gloecapsa*, another cyanobacterium, further underscores the dominance of nitrogen-fixing species, which are often associated with stable and nutrient-rich environments. *Synedra* sp. and *Diatom* sp., both belonging to Bacillariophyceae (diatoms), indicate a sustained diatom presence, which is essential for

primary productivity and bioindication of water quality. Additionally, the presence of *Euglena* sp., a member of Euglenophyceae, highlights its adaptability as a mixotrophic organism capable of surviving in various environmental conditions. The omnipresence of these species in all control samples suggests their ecological importance in maintaining aquatic ecosystem stability and serves as a reference for understanding phytoplankton distribution in experimental conditions.

Table 1: Presence phytoplankton in each station of the control sites							
Species	Control 1	Control 2	Control 3	Control 4	Control 5	Control 6	Control 7
Chlorophyceae							
<i>Actinastrum</i> sp.	+	+	-	-	+	-	+
<i>Chlorella</i> sp.	+	+	+	+	-	-	-
<i>Chlamydomonas</i> sp.	-	-	-	+	+	+	-
<i>Cladophora</i> sp.	+	+	+	+	+	+	+
<i>Closterium</i> sp.	+	+	+	+	+	-	+
<i>Cosmarium</i> sp.	-	+	+	+	+	+	+
<i>Cylindrocapsa</i> sp.	+	-	-	+	+	-	+
<i>Desmidium</i> sp.	+	+	-	+	+	+	+
<i>Golenkinia</i> sp.	+	-	-	+	-	-	-
<i>Mougeotia</i> sp.	+	+	+	+	+	+	+
<i>Scenedesmus</i> sp.	-	+	-	-	+	-	-
<i>Sphaeroszoma</i> sp.	+	+	+	+	+	+	+
<i>Spirogyra</i> sp.	+	+	+	+	+	+	+
<i>Triploceras</i> sp.	+	-	+	-	-	+	-
<i>Zygnema</i> sp.	+	+	+	+	+	+	+
Cyanophyceae							
<i>Anabaena</i> sp.	+	+	+	+	+	+	+
<i>Aulosira fertilissima</i>	-	+	-	-	-	+	-
<i>Chlorococcus</i> sp.	-	-	+	+	-	-	+
<i>Microcoleus acutissimus</i>	-	+	-	-	+	-	+
<i>Lyngbya</i> sp.	+	+	+	+	+	+	+
<i>Nostoc</i> sp.	+	+	+	+	+	+	+
<i>Oscillatoria</i> sp.	-	-	+	-	+	-	-
<i>Rivularia</i> sp.	+	-	-	+	-	-	+
<i>Scytonema</i> sp.	-	-	+	-	+	-	+
<i>Spirulina</i> sp.	+	-	+	-	+	-	+

<i>Aphanizomenon</i>	-	-	-	-	+	+	-
<i>Gloecapsa</i>	+	+	+	+	+	+	+
Bacillariophyceae							
<i>Cymbella sp.</i>	+	+	+	+	-	+	+
<i>Fragillaria sp.</i>	+	+	-	-	+	+	+
<i>Gyrosigma sp.</i>	+	+	+	+	-	-	-
<i>Navicula sp.</i>	+	+	+	+	-	-	-
<i>Nitzschia sp.</i>	-	+	+	-	+	+	-
<i>Synedra sp.</i>	+	+	+	+	+	+	+
Euglenophyceae							
<i>Euglena sp.</i>	+	+	+	+	+	+	+
Chrysophyceae							
<i>Diatom sp.</i>	+	+	+	+	+	+	+
Vaculariaceae							
<i>Gonyostomum sp.</i>	+	-	-	+	-	-	-

Distribution of phytoplankton in each station of the experimental sites

The presence of specific phytoplankton species across all experimental sampling stations indicates their ecological significance and adaptability to varying environmental conditions. In this study, *Desmidium sp.*, *Sphaerosozma sp.*, *Spirogyra sp.*, *Anabaena sp.*, *Lyngbya sp.*, *Nostoc sp.*, *Gloecapsa*, *Synedra sp.*, *Euglena sp.*, and *Diatom sp.* were consistently observed in every sample. These species belong to different taxonomic groups, including Chlorophyceae (green algae), Cyanophyceae (blue-green algae), Bacillariophyceae (diatoms), and Euglenophyceae, highlighting their widespread distribution and potential role in aquatic ecosystems. The dominance of *Desmidium sp.*, *Sphaerosozma sp.*, and *Spirogyra sp.* among green algae suggests a preference for nutrient-rich environments, while the presence of *Anabaena sp.*, *Lyngbya sp.*, *Nostoc sp.*, and *Gloecapsa* within Cyanophyceae underscores their resilience and nitrogen-fixing capabilities. Additionally, *Synedra sp.* and *Diatom sp.*, as members of Bacillariophyceae, indicate a stable presence of diatoms, which are crucial for primary productivity and bioindication of water quality. The persistent occurrence of *Euglena sp.* further supports its role as a euglenoid algae capable of surviving in diverse environmental conditions. The ubiquity of these species across all samples suggests their adaptability to the prevailing physicochemical parameters, making them essential indicators for assessing aquatic ecosystem health and stability.

Species	Experimental 1	Experimental 2	Experimental 3	Experimental 4	Experimental 5	Experimental 6	Experimental 7
Chlorophyceae							
<i>Actinastrum sp.</i>	-	+	+	-	-	-	-
<i>Chlorella sp.</i>	-	+	-	+	-	-	-

<i>Chlamydomons sp.</i>	-	-	-	+	+	+	-
<i>Cladophora sp.</i>	+	+	+	+	-	+	+
<i>Closterium sp.</i>	+	-	-	-	-	-	-
<i>Cosmarium sp.</i>	-	-	+	+	+	-	+
<i>Cylindrocapsa sp.</i>	+	-	+	+	+	+	+
<i>Desmidium sp.</i>	+	+	+	+	+	+	+
<i>Golenkinia sp.</i>	+	-	-	+	-	-	-
<i>Mougeotia sp.</i>	+	+	+	+	+	+	+
<i>Scenedesmus sp.</i>	-	+	-	-	-	-	-
<i>Sphaeroszoma sp.</i>	+	+	+	+	+	+	+
<i>Spirogyra sp.</i>	+	+	+	+	+	+	+
<i>Triploceras sp.</i>	+	-	+	-	-	-	-
<i>Zygnema sp.</i>	+	+	+	+	+	+	+
Cyanophyceae							
<i>Anabaena sp.</i>	+	+	+	+	+	+	+
<i>Aulosira fertilissima</i>	-	+	-	-	-	-	-
<i>Chlorococcus sp.</i>	-	-	+	+	-	-	-
<i>Microcoleus acutissimus</i>	-	-	+	-	+	-	+
<i>Lyngbya sp.</i>	+	+	+	+	+	+	+
<i>Nostoc sp.</i>	+	+	+	+	+	+	+
<i>Oscillatoria sp.</i>	-	-	+	-	+	-	-
<i>Rivularia sp.</i>	-	-	+	-	-	-	-
<i>Scytonema sp.</i>	-	-	-	-	+	-	+
<i>Spirulina sp.</i>	+	-	+	-	-	-	-
<i>Gloecapsa</i>	+	+	+	+	+	+	+
Bacillariophyceae							
<i>Cymbella sp.</i>	+	+	+	+	-	-	+
<i>Fragillaria sp.</i>	+	+	-	-	+	+	+
<i>Gyrosigma sp.</i>	+	-	-	-	-	-	-
<i>Navicula sp.</i>	+	+	+	+	-	-	-
<i>Nitzschia sp.</i>	-	+	+	-	+	+	-
<i>Synedra sp.</i>	+	+	+	+	+	+	+
Euglenophyceae							
<i>Euglena sp.</i>	+	+	+	+	+	+	+
Chrysophyceae							
<i>Diatom sp.</i>	+	+	+	+	+	+	+

Distribution of Zooplankton in each station of the control sites

The presence of *Paramecium* sp. in all control sampling stations highlights its ecological significance and adaptability to stable aquatic environments. As a member of Rizopoda (protozoa), *Paramecium* sp. is a unicellular ciliate that thrives in freshwater ecosystems with abundant organic matter and microbial communities. Its consistent occurrence across all control sites suggests that the environmental conditions, including nutrient availability and water quality, remained favourable for its survival. *Paramecium* sp. plays a crucial role in microbial food webs by feeding on bacteria and detritus, while also serving as a key food source for higher trophic organisms. Its omnipresence in all control samples indicates its resilience to environmental fluctuations and its potential use as a bioindicator for assessing aquatic ecosystem stability. The findings suggest that *Paramecium* sp. is a dominant component of the zooplankton community, contributing to nutrient cycling and energy transfer within the studied water bodies.

Species	Control 1	Control 2	Control 3	Control 4	Control 5	Control 6	Control 7
Rotifer							
<i>Anuraaeopsis</i> sp.	-	-	+	+	-	-	+
<i>Polyarthra</i> sp.	-	+	-	+	+	-	+
<i>ascomorpha</i>	+	+					
Cladoceran							
<i>Polyphemus</i> sp.	+	-	-	-	-	-	-
<i>Alona affinis</i> sp.	-	+	-	-	-	+	-
<i>Leptodora</i> sp.	-	+	-	+	-	+	-
<i>Diaphanosoma</i> sp.	-	-	-	+	-	-	-
<i>Monia</i> sp.	-	-	-	+	-	-	
<i>Bosmina</i> sp.	-	-	-	-	-	-	+
Copepoda							
<i>Diaptomus</i> sp.	+	-	+	-	+	+	+
<i>Phyllodiaptomus</i> sp.	-	-	+	-	+	-	+
<i>Paradipatomus</i> sp.	+	-	+	-	+	+	-
<i>Cyclops</i> sp.	-	+	-	+	+	-	+
Rizopoda							
<i>Paramecium</i> sp.	+	+	+	+	+	+	+
<i>Arcella</i> sp.	-	-	+	+	-	-	-
Protozoa						-	-

<i>Volvox sp.</i>	+	-	-	-	-	+	-
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Distribution of Zooplankton in each station of the experimental sites

The presence of *Paramecium sp.* in all experimental sampling stations highlights its ecological resilience and adaptability to diverse aquatic conditions. As a member of Rizopoda (protozoa), *Paramecium sp.* is a unicellular ciliate known for its ability to thrive in a wide range of environmental conditions, particularly in freshwater ecosystems with sufficient organic matter. Its omnipresence across all experimental sites suggests that the prevailing physicochemical conditions, including nutrient availability and water quality, are conducive to its survival and proliferation. *Paramecium sp.* plays a crucial role in microbial food webs by consuming bacteria and detritus while also serving as a food source for higher trophic organisms, such as small invertebrates. Its continuous presence in all samples suggests that it may serve as a reliable bioindicator of ecosystem stability and organic matter decomposition within the study area. The findings indicate that *Paramecium sp.* is a key component of the zooplankton community and contributes significantly to nutrient cycling and energy transfer within aquatic ecosystems.

Species	Experimental 1	Experimental 2	Experimental 3	Experimental 4	Experimental 5	Experimental 6	Experimental 7
Rotifer							
<i>Anuraaeopsis sp.</i>	-	-	+	+	-	-	+
<i>Polyarthra sp.</i>	-	+	-	+	+	-	+
Cladoceran							
<i>Polyphemus sp.</i>	+	-	-	-	-	-	-
<i>Alona affinis sp.</i>	-	+	-	-	-	+	-
Copepoda							
<i>Diaptomus sp.</i>	+	-	-	-	+	+	
<i>Phyllodiaptomus sp.</i>	-	-	+	-	-	-	+
<i>Paradipatomu s sp.</i>	+		+	-	-	+	-
<i>Cyclops sp.</i>	-	+	-	+	-	-	+
Rizopoda							
<i>Paramecim sp.</i>	+	+	+	+	+	+	+

Abundance of phytoplankton in the control site

Comprehensive quantitative distribution of phytoplankton in the control site, systematically categorized into six major taxonomic groups: Chlorophyceae, Cyanophyceae, Bacillariophyceae,

Euglenophyceae, Chrysophyceae, and Vacuolariaceae. The rows represent individual species within each phytoplankton group, while the columns display their numerical abundance across seven control samples. This structured format allows for a clear comparison of phytoplankton presence and variability across different sampling stations. Among the taxonomic groups, Chlorophyceae exhibits the highest total abundance, particularly species such as *Cladophora* sp., *Spirogyra* sp., and *Mougeotia* sp., indicating their dominance in the aquatic environment. Cyanophyceae, which includes *Anabaena* sp., *Nostoc* sp., and *Lyngbya* sp., also shows significant representation, with *Nostoc* sp. reaching its peak abundance of 19 in Control 5, highlighting the role of blue-green algae in nitrogen fixation. Bacillariophyceae (diatoms), represented by *Synedra* sp., *Navicula* sp., and *Cymbella* sp., demonstrates a relatively stable distribution, reinforcing their importance as bioindicators of water quality. Euglenophyceae, consisting solely of *Euglena* sp., exhibits moderate abundance, reflecting its adaptability to diverse environmental conditions. Chrysophyceae, primarily represented by *Diatom* sp., maintains a consistent presence across all samples, further emphasizing the significance of diatoms in aquatic ecosystems. Lastly, Vacuolariaceae, represented by *Gonyostomum* sp., appears sporadically with minimal abundance, indicating its limited role in the phytoplankton community. The total abundance row at the bottom of the table summarizes the overall phytoplankton population per sample, with fluctuations that may be influenced by environmental factors such as nutrient availability, temperature, and water quality. This structured dataset provides valuable insights into the phytoplankton community structure, ecological stability, and potential environmental changes in the control site.

Table 5: Abundance of phytoplankton in control site							
Species	Control 1	Control 2	Control 3	Control 4	Control 5	Control 6	Control 7
Chlorophyceae							
<i>Actinastrum</i> sp.	4	2	0	0	2	0	1
<i>Chlorella</i> sp.	2	2	2	1	0	0	0
<i>Chlamydomonas</i> sp.	0	0	0	6	8	4	0
<i>Cladophora</i> sp.	9	10	8	9	2	8	7
<i>Closterium</i> sp.	4	1	5	1	2	0	1
<i>Cosmarium</i> sp.	0	4	3	4	5	5	2
<i>Cylindrocapsa</i> sp.	5	0	0	5	6	0	4
<i>Desmidiium</i> sp.	7	6	0	5	6	4	7
<i>Golenkinia</i> sp.	2	0	0	3	0	0	0
<i>Mougeotia</i> sp.	8	4	6	4	5	3	5
<i>Scenedesmus</i> sp.	0	3	0	0	2	0	0
<i>Sphaeroszma</i> sp.	4	6	7	9	3	4	2
<i>Spirogyra</i> sp.	5	7	4	6	8	3	4
<i>Triploceras</i> sp.	3	0	2	0	0	1	0
<i>Zygnema</i> sp.	8	5	4	7	8	3	4
Total	61	50	41	60	57	35	37

Cyanophyceae							
<i>Anabaena sp.</i>	16	12	14	15	11	9	12
<i>Aulosira fertilissima</i>	0	2	0	0	0	1	0
<i>Chlorococcus sp.</i>	0	0	3	3	0	0	1
<i>Microcoleus acutissimus</i>	0	1	0	0	4	0	2
<i>Lyngbya sp.</i>	8	6	7	5	7	8	4
<i>Nostoc sp.</i>	14	16	10	5	19	12	9
<i>Oscillatoria sp.</i>	0	0	1	0	2	0	0
<i>Rivularia sp.</i>	2	0	0	1	0	0	1
<i>Scytonema sp.</i>	0	0	3	0	1	0	2
<i>Spirulina sp.</i>	6	0	1	0	2	0	5
<i>Aphanizomenon</i>	2	0	1	0	4	6	0
<i>Gloecapsa</i>	6	2	8	3	3	5	2
Total	54	39	48	32	53	41	38
Bacillariophyceae							
<i>Cymbella sp.</i>	3	4	2	6	0	6	7
<i>Fragillaria sp.</i>	2	3	0	0	2	3	3
<i>Gyrosigma sp.</i>	6	2	5	3	0	0	0
<i>Navicula sp.</i>	5	2	1	5	0	0	0
<i>Nitzschia sp.</i>	0	6	2	0	1	2	0
<i>Synedra sp.</i>	8	6	9	4	6	4	5
Total	24	23	19	18	9	15	15
Euglenophyceae							
<i>Euglena sp.</i>	12	9	11	10	9	4	7
Total	12	9	11	10	9	4	7
Chrysophyceae							
<i>Diatom sp.</i>	10	8	12	14	9	12	6
Total	10	8	12	14	9	12	6
Vaculariaceae							
<i>Gonyostomum sp.</i>	2	0	0	3	0	0	0
Total	2	0	0	3	0	0	0

Phytoplankton abundance (Nos./Litres) in 50 litre volume of water sample in control site.

The table presents data on phytoplankton abundance (Nos./Litres) in a 50-litre water sample from a control site, categorizing the abundance into six major phytoplankton groups: Chlorophyceae, Cyanophyceae, Bacillariophyceae, Euglenophyceae, Chrysophyceae, and Vaculariaceae. Each row represents a control sample, labelled from Control 1 to Control 7, with a total count of phytoplankton recorded for each sample. Chlorophyceae shows the highest abundance with a total of 341 individuals,

contributing 37.60% of the total phytoplankton population, followed by Cyanophyceae with 305 individuals (33.62%). Bacillariophyceae accounts for 123 individuals (13.56%), while Euglenophyceae and Chrysophyceae have 62 (6.84%) and 71 (7.83%) individuals, respectively. Vaculariaceae exhibits the lowest abundance with only 5 individuals, contributing 0.55% to the total count. Among the control samples, Control 1 has the highest total count (163), while Control 7 has the lowest (103). The sum of all phytoplankton in the study is 907 individuals, providing an overview of the community structure in the given water sample.

	Chlorophyceae	Cyanophyceae	Bacillariophyceae	Euglenophyceae	Chrysophyceae	Vaculariaceae	Total
Control 1	61	54	24	12	10	2	163
Control 2	50	39	23	9	8	0	129
Control 3	41	48	19	11	12	0	131
Control 4	60	32	18	10	14	3	137
Control 5	57	53	9	9	9	0	137
Control 6	35	41	15	4	12	0	107
Control 7	37	38	15	7	6	0	103
Total	341	305	123	62	71	5	907
Percent Value (%)	37.60%	33.62%	13.56%	6.84%	7.83%	0.55%	100%

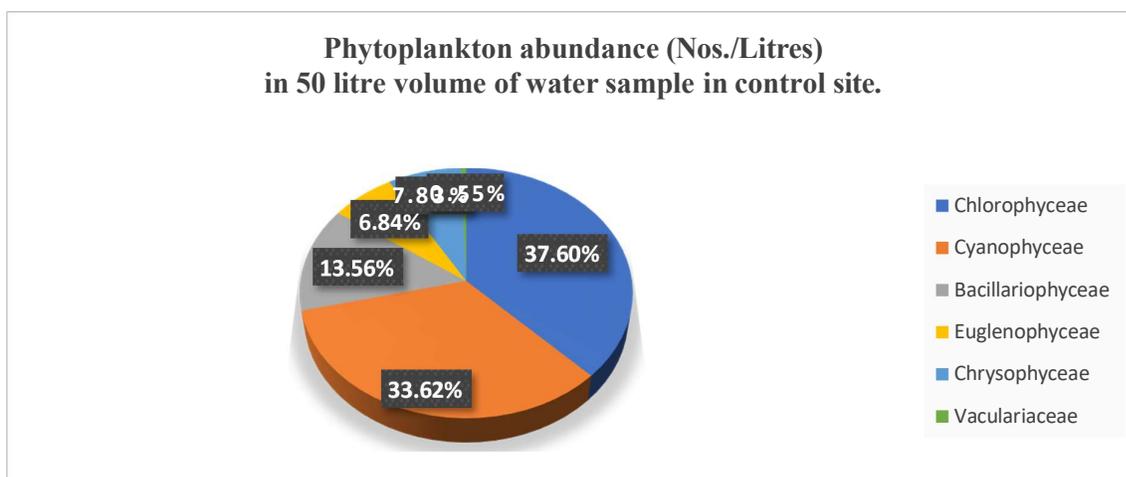


Figure 3: Graphical representation of Phytoplankton abundance in control site

Abundance of phytoplankton in experimental site

The table systematically presents the abundance of phytoplankton in the experimental site, categorizing species across different taxonomic groups and detailing their distribution across seven

sampling stations. The rows represent individual species, grouped under five major phytoplankton classes: Chlorophyceae (green algae), Cyanophyceae (blue-green algae), Bacillariophyceae (diatoms), Euglenophyceae, and Chrysophyceae. The columns indicate the numerical abundance of each species in Samples 1 to 7, reflecting their presence and variation across the experimental sites. The Chlorophyceae group, which includes species like *Cladophora* sp., *Spirogyra* sp., and *Zygnema* sp., displays fluctuating abundance across samples, suggesting site-specific environmental influences. Cyanophyceae, comprising *Nostoc* sp., *Gloecapsa*, and *Lyngbya* sp., shows higher abundance, particularly *Nostoc* sp., which recorded the highest count (18) in Sample 1, emphasizing its role in nitrogen fixation and ecosystem productivity. Bacillariophyceae (diatoms), including *Synedra* sp. and *Navicula* sp., are present at moderate levels, serving as bioindicators of water quality. Euglenophyceae, represented by *Euglena* sp., maintains a stable but moderate presence across samples, indicating its adaptability to variable conditions. Lastly, Chrysophyceae, represented by *Diatom* sp., maintains a relatively stable abundance, reinforcing the essential role of diatoms in aquatic food webs. The total abundance values at the bottom of each column summarize the overall phytoplankton count per sample, showing variation that may be attributed to environmental factors such as nutrient availability, temperature, and water quality. This tabular representation provides an insightful overview of phytoplankton diversity and abundance, allowing for the assessment of ecological stability and productivity across the sampled locations.

Species	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
Chlorophyceae							
<i>Actinastrum sp.</i>	0	3	2	0	0	0	0
<i>Chlorella sp.</i>	0	1	0	1	0	0	0
<i>Chlamydomonas sp.</i>	0	0	0	4	2	2	0
<i>Cladophora sp.</i>	6	8	5	6	0	7	3
<i>Closterium sp.</i>	2	0	0	0	0	0	0
<i>Cosmarium sp.</i>	0	0	3	2	2	0	3
<i>Cylindrocapsa sp.</i>	4	0	3	1	4	2	4
<i>Desmidium sp.</i>	2	4	2	3	4	2	3
<i>Golenkinia sp.</i>	1	0	0	1	0	0	0
<i>Mougeotia sp.</i>	6	4	2	4	3	4	3
<i>Scenedesmus sp.</i>	0	1	0	0	0	0	0
<i>Sphaeroszoma sp.</i>	1	2	2	1	2	1	1
<i>Spirogyra sp.</i>	3	4	5	2	2	3	3
<i>Triploceras sp.</i>	1	0	1	0	0	0	0
<i>Zygnema sp.</i>	4	3	2	1	3	2	1
Cyanophyceae							
<i>Anabaena sp.</i>	11	8	7	10	9	3	4
<i>Aulosira fertilissima</i>	0	1	0	0	0	0	0
<i>Chlorococcus sp.</i>	0	0	2	1	0	0	0
<i>Microcoleus acutissimus</i>	0	0	3	0	1	0	1
<i>Lyngbya sp.</i>	6	4	7	2	4	1	1
<i>Nostoc sp.</i>	18	14	17	15	12	11	9
<i>Oscillatoria sp.</i>	0	0	1	0	1	0	0
<i>Rivularia sp.</i>	0	0	1	0	0	0	0
<i>Scytonema sp.</i>	0	0	0	0	2	0	1
<i>Spirulina sp.</i>	3	0	4	0	0	0	0
<i>Gloecapsa</i>	3	2	3	2	4	1	1
Bacillariophyceae							
<i>Cymbella sp.</i>	2	3	2	2	0	0	1
<i>Fragillaria sp.</i>	1	1	0	0	2	1	1
<i>Gyrosigma sp.</i>	2	0	0	0	0	0	0
<i>Navicula sp.</i>	2	2	4	3	0	0	0
<i>Nitzschia sp.</i>	0	3	2	0	4	1	0
<i>Synedra sp.</i>	6	5	2	4	8	2	2

Euglenophyceae							
<i>Euglena sp.</i>	8	3	4	4	3	2	2
Chrysophyceae							
<i>Diatom sp.</i>	7	4	10	4	7	3	2

Phytoplankton abundance (Nos./Litres) in 50 litre volume of water sample in experimental site

	Chlorophyceae	Cyanophyceae	Bacillariophyceae	Euglenophyceae	Chrysophyceae	Total
Experimental 1	30	41	13	8	7	99
Experimental 2	32	29	14	3	4	82
Experimental 3	27	45	10	4	10	96
Experimental 4	26	30	9	4	4	73
Experimental 5	22	33	14	3	7	79
Experimental 6	23	16	4	2	3	48
Experimental 7	21	17	4	2	2	46
TOTAL	181	211	68	26	37	523
Percent Value (%)	34.61%	40.34%	13%	4.97%	7.07%	100%

The table

presents the phytoplankton abundance (Nos./Litres) in a 50-litre volume of water sample across different taxonomic groups in the experimental site. The rows represent the phytoplankton counts from seven different samples, while the columns categorize the data into five major phytoplankton groups: Chlorophyceae, Cyanophyceae, Bacillariophyceae, Euglenophyceae, and Chrysophyceae. The total abundance for each sample is recorded in the last column, showing variations ranging from a maximum of 99 in Sample 1 to a minimum of 46 in Sample 7. Among the phytoplankton groups, Cyanophyceae exhibits the highest overall abundance (211), accounting for 40.34% of the total phytoplankton population. This suggests the dominance of blue-green algae in the aquatic environment, which may indicate eutrophic conditions. Chlorophyceae ranks second (181, 34.61%), reflecting the presence of green algae, which contribute significantly to primary production. Bacillariophyceae (68, 13%) and Chrysophyceae (37, 7.07%) show moderate contributions, highlighting the role of diatoms and golden algae in aquatic ecosystems. Euglenophyceae (26, 4.97%) has the lowest abundance, suggesting that euglenoids are present in relatively smaller numbers in the studied samples. The total phytoplankton count across all samples is 523, providing an estimate of the community structure within the aquatic ecosystem. The percent values at the bottom summarize the proportional distribution of each phytoplankton group, offering insights into their ecological significance. This data is crucial for assessing water quality, trophic status, and phytoplankton dynamics within the experimental site.

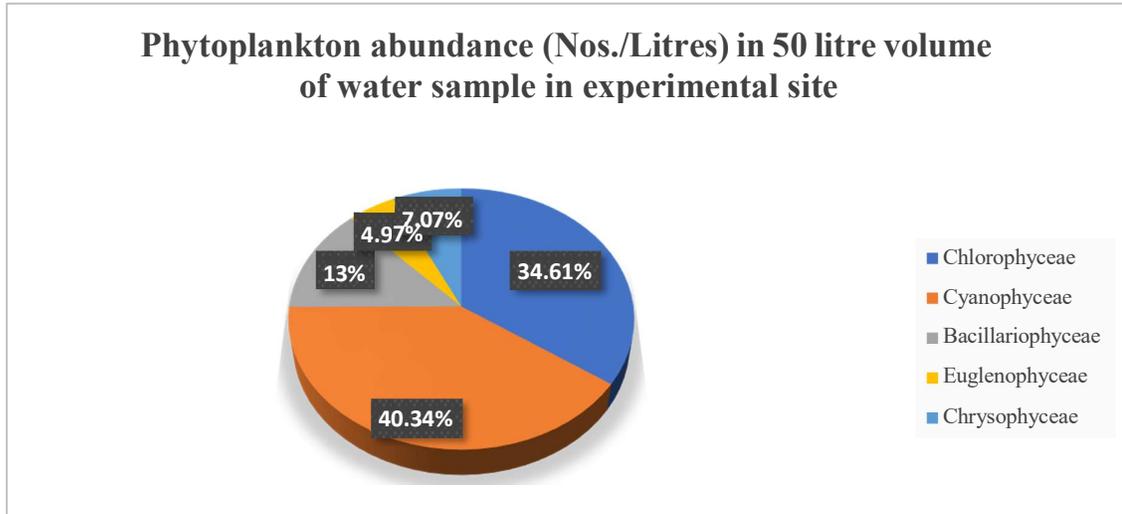


Figure 4: Graphical representation of Phytoplankton abundance in experimental site

Abundance of zooplankton in control site

It categorizes the species into five major groups: Rotifer, Cladoceran, Copepoda, Rizopoda, and Protozoa. Within the Rotifer group, Anuraeopsis sp., Polyarthra sp., and Ascomorpha sp. are recorded, with the highest total abundance observed in Control 2 (7) due to Polyarthra sp. (6). The Cladoceran group consists of Polyphemus sp., Alona affinis sp., Leptodora sp., Diaphanosoma sp., Monia sp., and Bosmina sp., with the highest total count in Control 6 (11), mainly contributed by Alona affinis sp. (6) and Leptodora sp. (5). The Copepoda group, comprising Diaptomus sp., Phyllodiaptomus sp., Paradiaptomus sp., and Cyclops sp., exhibits the highest total abundance in Control 5 (23), primarily driven by Diaptomus sp. (7) and Cyclops sp. (7). The Rizopoda category includes Paramecium sp. and Arcella sp., with the highest count in Control 4 (12), largely attributed to Arcella sp. (7). Lastly, the Protozoa category consists of Volvox sp., which is only recorded in Control 1 and Control 6, with a peak count of 4 in Control 6. The data highlight variations in species composition and abundance across the control site, offering insight into the zooplankton community structure under natural conditions.

Species	Control 1	Control 2	Control 3	Control 4	Control 5	Control 6	Control 7
Rotifer							
<i>Anuraeopsis sp.</i>	0	0	2	2	0	0	2
<i>Polyarthra sp.</i>	0	6	0	5	6	0	4
<i>ascomorpha</i>	1	1	0	0	0	0	0
Total	1	7	2	7	6	0	6
Cladoceran							
<i>Polyphemus sp.</i>	3	0	0	0	0	0	0

<i>Alona affinis sp.</i>	0	4	0	0	0	6	0
<i>Leptodora sp.</i>	0	4	0	3	0	5	0
<i>Diaphanosoma sp.</i>	0	0	0	2	0	0	0
<i>Monia sp.</i>	0	0	0	2	0	0	0
<i>Bosmina sp.</i>	0	0	0	0	0	0	4
Total	3	8	0	7	0	11	4
Copepoda							
<i>Diaptomus sp.</i>	5	0	4	0	7	6	4
<i>Phyllodiaptomus sp.</i>	0	0	3	0	4	0	5
<i>Paradipatomus sp.</i>	6	0	3	0	5	4	0
<i>Cyclops sp.</i>	0	3	0	4	7	0	4
Total	11	3	10	4	23	10	13
Rizopoda							
<i>Paramecium sp.</i>	6	4	4	5	8	9	7
<i>Arcella sp.</i>	0	0	4	7	0	0	0
Total	6	4	8	12	8	9	7
Protozoa							
<i>Volvox sp.</i>	3	0	0	0	0	4	0
Total	3	0	0	0	0	4	0

Zooplankton abundance (Nos./Litres) in 50 litre volume of water sample of control site.

Zooplankton abundance (Nos./Litres) in a 50-litre water sample from a control site. It categorizes zooplankton into five groups: Rotifer, Cladoceran, Copepoda, Rizopoda, and Protozoa, with values recorded across seven control samples. The Rotifer population varies between 0 and 7 across controls, summing to 29 individuals (14.72%). Cladocerans range from 0 to 11, totalling 33 individuals (16.75%). Copepods have the highest count, ranging between 0 and 23, contributing 74 individuals (37.56%). Rizopoda populations fluctuate between 4 and 12, totalling 54 (27.41%). Protozoa have the lowest count, appearing only in three controls, summing to 7 individuals (3.55%). The total zooplankton count across all categories and control samples is 197, with relative abundances detailed as percentages. These variations indicate differences in zooplankton distribution across sampling points, with Copepoda being the dominant group and Protozoa the least abundant.

Table10: Zooplankton abundance (Nos./Litres) in 50 litre volume of water sample of control site.						
	Rotifer	Cladoceran	Copepoda	Rizopoda	Protozoa	Total
Control 1	1	3	11	6	3	24
Control 2	7	8	3	4	0	22
Control 3	2	0	10	8	0	20
Control 4	7	7	4	12	0	30

Control 5	6	0	23	8	0	37
Control 6	0	11	10	9	4	34
Control 7	6	4	13	7	0	30
TOTAL	29	33	74	54	7	197
Percent Value (%)	14.72%	16.75%	37.56%	27.41%	3.55%	100%

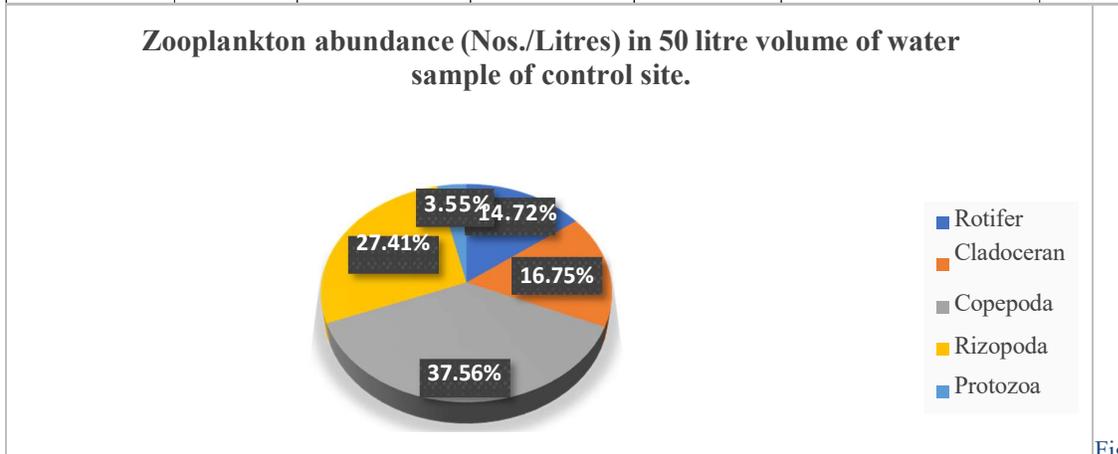


Figure 5:

Graphical representation Zooplankton abundance in control site

Abundance of zooplankton in experimental site

It categorizes the species into four major groups: Rotifer, Cladoceran, Copepoda, and Rizopoda. Within the Rotifer group, *Anuraeopsis sp.* and *Polyarthra sp.* are recorded, with their highest abundance in Sample 7 (3 and 4, respectively), contributing to a total count of 7 in that sample. Cladocerans include *Polyphemus sp.* and *Alona affinis sp.*, with the highest total abundance observed in Sample 1 and Sample 2 (both at 2). The Copepoda group consists of *Diatomus sp.*, *Phyllodiaptomus sp.*, *Paradiaptomus sp.*, and *Cyclops sp.*, showing the highest abundance in Sample 7 with a total count of 6, particularly contributed by *Cyclops sp.* (4) and *Phyllodiaptomus sp.* (2). The Rizopoda category includes only *Paramecium sp.*, which demonstrates relatively consistent distribution across samples, with the highest count in Sample 2 (8) and the lowest in Sample 5 (4). The data illustrate variations in species abundance across different samples, providing insight into the zooplankton community structure in the experimental site.

Species	Experimental 1	Experimental 2	Experimental 3	Experimental 4	Experimental 5	Experimental 6	Experimental 7
Rotifer							
<i>Anuraeopsis sp.</i>	0	0	2	3	0	0	3
<i>Polyarthra sp.</i>	0	4	0	2	1	0	4

Total	0	4	2	5	1	0	7
Cladoceran							
<i>Polyphemus sp.</i>	2	0	0	0	0	0	0
<i>Alona affinis sp.</i>	0	2	0	0	0	1	0
Total	2	2	0	0	0	1	0
Copepoda							
<i>Diaptomus sp.</i>	1	0	0	0	1	2	0
<i>Phyllodiaptomus sp.</i>	0	0	3	0	0	0	2
<i>Paradiptomus sp.</i>	2	0	2	0	0	3	0
<i>Cyclops sp.</i>	0	1	0	2	0	0	4
Total	3	1	5	2	1	5	6
Rizopoda							
<i>Paramecium sp.</i>	6	8	3	5	4	6	3
Total	6	8	3	5	4	6	3

Zooplankton abundance (Nos./Litres) in 50 litre volume of water sample in experimental site

"Zooplankton Abundance (Nos./Litres) in 50 Litre Volume of Water Sample in Experimental Site" presents the distribution of four major zooplankton groups—Rotifer, Cladoceran, Copepoda, and Rizopoda—across seven different water samples. The total zooplankton count is 82, with the highest contribution from Rizopoda (35 individuals, 42.68%), followed by Copepoda (23 individuals, 28.05%), Rotifer (19 individuals, 23.17%), and Cladoceran (5 individuals, 6.10%). Among the samples, Sample 7 has the highest overall abundance (16), primarily due to Copepoda (6) and Rotifer (7). Sample 2 follows with 15 individuals, with a notable presence of Rizopoda (8) and Rotifer (4). The lowest abundance is recorded in Sample 5 (6 individuals), where Copepoda (1) and Cladoceran (0) are minimally represented. The data suggest a dominance of Rizopoda and Copepoda in the experimental site, indicating their potential ecological significance in the water body.

Table12: Zooplankton abundance (Nos./Litres) in 50 litre volume of water sample in experimental site.

	Rotifer	Cladoceran	Copepoda	Rizopoda	Total
Experimental 1	0	2	3	6	11
Experimental 2	4	2	1	8	15
Experimental 3	2	0	5	3	10

Experimental 4	5	0	2	5	12
Experimental 5	1	0	1	4	6
Experimental 6	0	1	5	6	12
Experimental 7	7	0	6	3	16
TOTAL	19	5	23	35	82
Percent Value (%)	23.17%	6.10%	28.05%	42.68%	100%

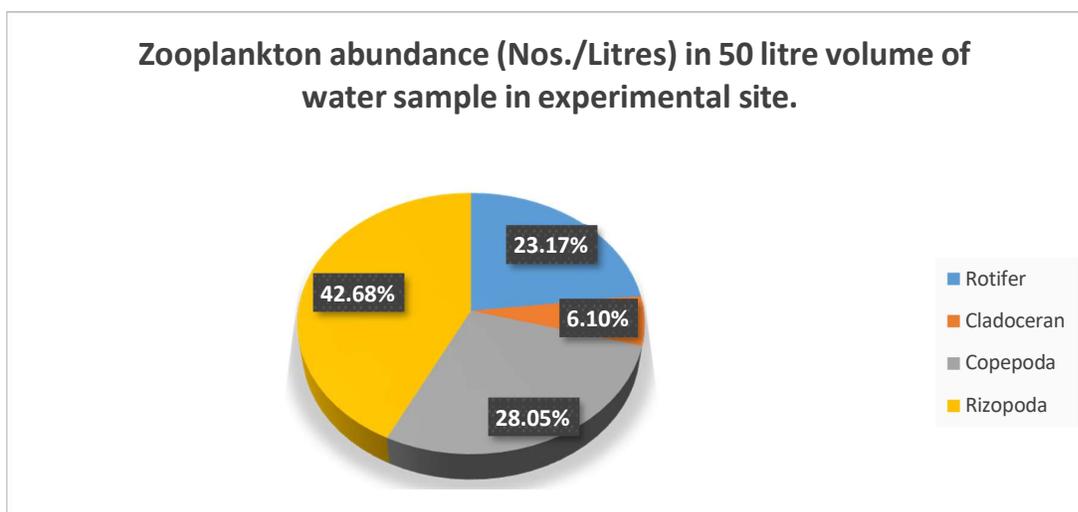


Figure 6: Graphical representation Zooplankton abundance in experimental site

Comparative Analysis of Plankton Distribution Using Two-Way ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Control and experimental sites	62250.25	1	62250.25	3.441094	0.314757	161.4476
Planktons	331200.3	1	331200.3	18.30822	0.146161	161.4476
Error	18090.25	1	18090.25			
Total	411540.8	3				

The results of the two-way ANOVA indicate that there was no statistically significant variation with respect to the control and experimental sites ($F_1 = 3.44$, $p > 0.05$). However, the F-value suggests some variation, the p-value exceeds the 0.05 significance level, and the F critical value (161.45) is much higher than the calculated F, confirming that the difference is not statistically significant. This implies that site differences (control vs. experimental) did not have a considerable impact on overall

plankton abundance. Similarly, the variation observed among plankton types ($F_2 = 18.31$, $p > 0.05$) was also not statistically significant, indicating that the differences in abundance across plankton groups were not strong enough to be meaningful. Overall, the findings suggest that neither the sampling location nor the plankton type had a significant effect on abundance patterns, possibly due to uniform environmental conditions or low ecological variability at the time of sampling.

Diversity Indices of Phyto planktons in the Pre-Monsoon Seasons

Shannon diversity index of phytoplankton

Table-14: Shannon diversity index	
Control	Experimental
3.213	2.976

In the above, the Shannon index of diversity of phytoplankton values was 3.213 for the control site and 2.976 for the experimental site in during the month of June in 2024. This suggests that the control site supports a more diverse and balanced phytoplankton community. The lower value at the experimental site indicates reduced diversity, likely due to environmental factors or disturbances that limit species richness or cause uneven species distribution.

Simpsons diversity index of phytoplankton.

Table-15: Simpsons diversity Index	
Control	Experimental
0.050	0.071

In the results presented, the Simpson's Diversity Index values for phytoplankton were recorded as 0.050 for the control site and 0.071 for the experimental site during the month of June in 2024. The Simpson's Index is inversely related to diversity the lower the value, the higher the diversity. The control site has a lower index compared to the experimental site, indicating that the control site has greater species diversity. The higher value at the experimental site suggests reduced diversity, possibly due to environmental stress or disturbance.

Evenness index of phytoplankton.

Table 16: Evenness index	
Control	Experimental
0.896	0.844

In the results we have, the evenness index phytoplankton values in the figure above were measured at 0.896 for the control site and 0.844 for the experimental site during the month of June in 2024. The Evenness Index shows a higher value at the control site compared to the experimental site, indicating a more balanced distribution of phytoplankton species in the control site. The lower evenness in the experimental site suggests that a few species dominate, likely due to environmental stress or disturbance.

Similarity Index of phytoplankton

Table 17: Similarity Index of phytoplankton	
Total species in experimental site	521
Total species in Control site	907
Total species common to both sites	521
Similarity Index	0.730

The

results indicate that the similarity index for phytoplankton was 0.732 at both the experimental and control sites. The greater number of species in the control site reflects a higher level of biodiversity. This suggests that the control site supports a more diverse and stable phytoplankton community. However, the lower species diversity at the experimental site may be due to environmental disturbances or stress factors, which could be limiting species variety even though many of the same species are still present.

Diversity Indices of Zooplanktons in the Pre-Monsoon Seasons

Shannon diversity index of zooplanktons

Table 18: Shannon diversity index	
Control	Experimental
2.436	1.809

According to our data, during the month of June in 2024, the experimental site's Shannon diversity index was 1.809, whereas the control sites was 2.436 for the zooplankton values shown in the above table. The value of the control site was higher than the experimental site which indicates greater species diversity and a more even distribution of phytoplankton in the control site. The lower value at the experimental site suggests reduced diversity, likely due to environmental stress or disturbance.

Simpsons diversity index of zooplanktons

Table 19: Simpsons diversity index		Our data
Control	Experimental	
0.104	0.222	

indicates that the Simpson's index for zooplankton values at the experimental site was 0.104 during the month of June in 2024, while the control site had a value of 0.222 as shown in the table above. This indicates that the value of control site was lower as compared to the experimental site. Since lower values indicate higher diversity, this suggests that the control site has greater phytoplankton diversity, while the higher index at the experimental site points to reduced diversity, likely due to ecosystem imbalance and human interference.

Evenness index of zooplanktons

Table 20: Evenness index	
Control	experimental
0.878	0.823

According to our data, the experimental site's evenness index for zooplankton values during the month of June in 2024 period was 0.878, whereas the control site's value was 0.823, as shown in the above table. The Evenness Index was higher at the control site than at the experimental site, indicating a more balanced distribution of phytoplankton species in the control site. The slightly lower evenness at the experimental site suggests that certain species dominate, likely due to ecological pressure or habitat disruption.

Similarity Index of zooplankton

Table 21: Similarity Index of zooplankton	
Total species in experimental site	82
Total species in Control site	197
Total species common to both sites	80
Similarity index	0.573

The results indicate that the similarity index for Zooplankton was 0.573 at both the experimental and control sites. This may reflect the lower diversity at the experimental site due to environmental stress, human impact, or altered habitat conditions that limit the presence of certain species.

Distribution, Abundance and Diversity of Planktons during Post-Monsoon Seasons

Distribution of Phytoplankton in Control sites

The presence of phytoplankton species at the control site reveals a diverse and rich community spanning across several major algal groups, Chlorophyceae, Bacillariophyceae, Cyanophyceae, Euglenaceae, and Chrysophyceae. Among the Chlorophyceae (green algae), *Zygnema sp.* and *Closterium sp.* were consistently found across all seven control samples, indicating their wide distribution and adaptability to the environmental conditions at the site. Other species such as *Pediastrum sp.*, *Eurodina sp.*, *Spirogyra sp.*, and *Mougeotia sp.* showed varied presence, suggesting fluctuations in local microhabitats or seasonal influences. The sporadic appearance of species like *Tetraedron sp.* and *Golenkinia sp.* may point to more specific ecological requirements or transient colonization. The Bacillariophyceae group also showed a high level of representation and persistence. Species such as *Leptocylindrus sp.*, *Synedra sp.*, and *Gyrosigma sp.* were found in all samples, highlighting their tolerance to a broad range of conditions and their potential importance as primary producers in the ecosystem. Others like *Naviculla sp.*, *Nitzschia sp.*, and *Cymbella sp.* appeared frequently, indicating a robust diatom community. The presence of several diatom species in most or all samples signifies good water quality, as diatoms are often used as bioindicators due to their sensitivity to pollutants and environmental changes. In the Cyanophyceae (blue-green algae) group, *Nostoc sp.* was universally present, suggesting its dominance and ecological importance at the site. *Chlorococcus sp.*, *Merismopedia sp.*, and *Gloeocapsa sp.* were present in multiple samples, though not consistently across all, possibly reflecting spatial variability or different tolerance levels to light and nutrient availability. Within the Euglenaceae, *Euglena sp.* was widely distributed, present in six out of seven samples. This genus often thrives in nutrient-rich or organic-rich waters, suggesting a moderate level of organic input at the site. Lastly, the Chrysophyceae representative, *Diatom sp.*, was found consistently across all samples, underscoring the ecological stability and productivity of the habitat. The phytoplankton community at the control site is diverse and balanced, with multiple species showing consistent presence. This richness in phytoplankton suggests a healthy aquatic ecosystem with good water quality and ecological stability, supporting various trophic levels and contributing to overall biodiversity.

Table 22: Presence Of Phyto planktons in Control Site							
Species	Control 1	Control 2	Control 3	Control 4	Control 5	Control 6	Control 7
Chlorophyceae							
<i>Pediastrum sp.</i>	+	+	-	+	+	+	-
<i>Eurodina sp.</i>	-	+	+	-	+	+	-
<i>Cylindrocapsa sp.</i>	+	-	+	+	-	+	-
<i>Spirogyara sp.</i>	+	+	-	+	-	+	+
<i>Zygnema sp.</i>	+	+	+	+	+	+	+
<i>Golenkinia sp.</i>	-	+	-	+	-	-	-
<i>Desmidium sp.</i>	-	+	+	-	+	-	+
<i>Mougeotia sp.</i>	-	+	-	+	-	+	+
<i>Oscillatoria sp.</i>	+	+	+	+	+	+	+
<i>Cosmarium sp.</i>	-	+	+	-	+	-	-
<i>Tetraedron sp.</i>	-	-	-	+	-	+	-
<i>Cladophora sp.</i>	+	+	+	-	-	+	+
<i>Closterium sp.</i>	+	+	+	+	+	+	+
Bacillariophyceae							
<i>Cymbella sp.</i>	+	+	-	+	+	+	+
<i>Naviculla sp.</i>	+	-	+	+	+	-	+
<i>Leptocylindrus sp.</i>	+	+	+	+	+	+	+
<i>Nitzschia sp.</i>	+	+	+	-	+	+	+
<i>Fragillaria sp.</i>	-	+	+	+	+	-	+
<i>Synedra sp.</i>	+	+	+	+	+	+	+
<i>Bacillaria sp.</i>	+	-	+	-	+	+	+
<i>Coscinodiscaceae sp.</i>	-	+	-	+	-	+	+
<i>Gyrosigma sp.</i>	+	+	+	+	+	+	+
Cyanophyceae							
<i>Nostoc sp.</i>	+	+	+	+	+	+	+
<i>Chlorococcus sp.</i>	+	+	+	-	-	+	
<i>Merismopedia sp.</i>	-	+	-	+	+	+	+
<i>Gloeocapsa sp.</i>	+	+	-	-	-	-	+
Euglenaceae							
<i>Euglena sp.</i>	+	+	-	+	+	+	+
Chrysophyceae							
<i>Diatom sp.</i>	+	+	+	+	+	+	+

Distribution of Phyto planktons in Experimental sites

The phytoplankton community observed at the experimental site demonstrates a high degree of diversity and widespread distribution across multiple algal groups, including Chlorophyceae, Bacillariophyceae, Cyanophyceae, and Euglenaceae. Among the Chlorophyceae (green algae), several species such as *Spirogyra sp.*, *Mougeotia sp.*, and *Gonatozygon sp.* were found consistently in all seven samples, indicating their dominance and adaptability to the experimental conditions. These taxa are often associated with clean, nutrient-rich waters and are efficient primary producers. Other species like *Pediastrum sp.*, *Eudorina sp.*, and *Closterium sp.* showed moderate to high frequency, being present in five or more samples. Some taxa, such as *Chlamydomonas sp.*, *Tetraedron sp.*, and *Gloeocystis sp.*, had a more scattered presence, suggesting they may respond to specific microhabitat conditions or fluctuating environmental variables such as light, nutrients, or pH.

The Bacillariophyceae (diatoms) group was particularly well-represented and consistently present. *Cymbella sp.*, *Synedra sp.*, *Leptocylindrus sp.*, and *Nitzschia sp.* appeared in all samples, underscoring their ecological importance and tolerance to the experimental site's conditions. These species are often considered indicators of good water quality and play a vital role in aquatic food webs. Other diatom species like *Naviculla sp.*, *Pinnularia sp.*, and *Guinadia sp.* showed more variable occurrence but still contributed to the overall diversity. In the Cyanophyceae (blue-green algae) category, *Nostoc sp.* and *Lyngbya sp.* were present in all seven samples, indicating a strong capacity for survival and possibly an ability to fix atmospheric nitrogen, which can be beneficial in nutrient-limited environments. Other cyanobacteria like *Chlorococcus sp.*, *Merismopedia sp.*, and *Gloeocapsa sp.* were observed intermittently, reflecting ecological variability and potentially different nutrient or light preferences. In the Euglenaceae group, *Euglena sp.* was consistently present in every sample, suggesting stable environmental conditions conducive to its growth. *Euglena* species are often associated with organic-rich or moderately polluted waters, indicating that the experimental site may have a higher organic load compared to the control. The phytoplankton profile of the experimental site suggests a robust and diverse algal community. The consistent presence of key species across all major groups indicates a relatively stable and nutrient-supportive environment, with signs of mild organic enrichment. This diverse assemblage reflects a healthy but possibly moderately impacted aquatic system.

Table 23: Presence Of Phyto planktons in Experimental Site

Species	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
Chlorophyceae							
<i>Pediastrum sp.</i>	+	-	+	+	+	-	+
<i>Cylindrocapsa sp.</i>	+	+	+	-	-	-	-
<i>Tetraedron sp.</i>	-	+	-	+	-	-	-
<i>Eudorina sp.</i>	+	+	-	+	-	+	+
<i>Chlamydomonas sp.</i>	-	-	+	-	+	-	-
<i>Spirogyara sp.</i>	+	+	+	+	+	+	+

<i>Zygnema sp.</i>	-	+	-	-	+	+	+
<i>Desmidiium sp.</i>	+	-	+	-	+	+	-
<i>Mougeotia sp.</i>	+	+	+	+	+	+	+
<i>Cosmarium sp.</i>	+	+	+	+	-	-	+
<i>Gonatozygon sp.</i>	+	+	+	+	+	+	+
<i>Gloeocystis sp.</i>	+	+	-	-	+	-	+
<i>Closterium sp.</i>	+	-	+	+	+	-	+
Bacillariophyceae							
<i>Cymbella sp.</i>	+	+	+	+	+	+	+
<i>Naviculla sp.</i>	-	+	+	-	+	+	+
<i>Synedra sp.</i>	+	+	+	+	+	+	+
<i>Guinadia sp.</i>	+	-	+	-	-	-	-
<i>Pinnularia sp.</i>	+	+	-	-	+	+	+
<i>Leptocylindrus sp.</i>	+	+	+	+	+	+	+
<i>Nitzschia sp.</i>	+	+	+	+	+	+	+
Cyanophyceae							
<i>Nostoc sp.</i>	+	+	+	+	+	+	+
<i>Chlorococcus sp.</i>	-	+	+	-	+	-	-
<i>Merismopedia sp.</i>	+		-	-	+	-	+
<i>Lyngbya sp.</i>	+	+	+	+	+	+	+
<i>Gloeocapsa sp.</i>	-	+	-	+	-	+	+
Euglenaceae							
<i>Euglena Sp.</i>	+	+	+	+	+	+	+

Distribution of Zooplanktons in Control sites

The presence of zooplankton species across all seven control sites, provides valuable insights into the biodiversity and ecological condition of the aquatic environment. The recorded zooplankton species represent several taxonomic groups, including Cladoceran, Copepoda, Rhizopoda, Branchionidae, Rotifera, Crustacea, and Protozoa, indicating a diverse and functionally rich ecosystem. Species such as *Diaphanosoma sp.*, *Bosmania sp.*, *Alona affinis sp.*, *Daphnia sp.*, *Paramecium sp.*, *Monostyla sp.*, *Amuraeopsis sp.*, and *Nauplius sp.* were consistently observed across multiple sites, suggesting their wide distribution and adaptability to the environmental conditions of the pond. Some species were present in almost all the samples, while others appeared only a few times. This shows that the water body has stable conditions but still experiences small changes that affect the presence of different species.

Among the Cladoceran, species like *Diaphanosoma sp.* were seen in five out of seven samples, showing they are well-suited to the environment. *Bosmania sp.* and *Daphnia sp.* were found in four samples, while *Alona affinis sp.* and *Monia sp.* also appeared regularly. This group is important because they feed on small algae and help control the balance in the water. The Copepoda group had less frequent appearances. *Phylloidiaptomus sp.* and *Paradiptomus sp.* were each found in four samples, while *Cyclops sp.* and *Diaptomus sp.* were seen in just two or three. These organisms are small crustaceans that feed on algae and are food for larger animals.

A key species in the Rhizopoda group was *Paramecium sp.*, found in all samples. This shows that conditions at the site are good for basic microscopic life. In the Branchionide group, *Keratella cochlearis sp.* was found in six samples, and among the Rotifers, *Monostyla sp.* also appeared six times. These are tiny animals that feed on bacteria and algae, playing an important role in the food chain. *Volvox sp.*, a Protozoan, was found in only two samples, suggesting it needs very specific conditions to grow. *Nauplius sp.* from the Crustacea group was found five times but was not a dominant species. This widespread presence of zooplankton signifies healthy water quality, adequate nutrient availability, and a well-supported aquatic food web. Their diversity and distribution serve as bioindicators of ecological stability and the productive status of the control sites within the pond. The findings indicate that *Paramecium sp.* is a key component of the zooplankton community and contributes significantly to nutrient cycling and energy transfer within aquatic ecosystems.

Species	Control 1	Control 2	Control 3	Control 4	Control 5	Control 6	Control 7
Cladoceran							
<i>Diaphanosoma sp.</i>	+	-	+	+	-	+	+
<i>Bosmania sp.</i>	-	+	+	-	+	-	+
<i>Alona affins sp.</i>	+		+	+	-	+	-
<i>Monia sp.</i>	+	+	-	-	-	+	-
<i>Daphnia sp.</i>	-	+	+	-	+	-	+
<i>Polyphemus sp.</i>	-		+	-	-	+	-
Copepoda							
<i>Diaptomus sp.</i>	-	+	-	-	-	-	+
<i>Phyllodiaptomus sp.</i>	+	-	+	-	+	+	-
<i>Paradipatomus sp.</i>	+	+	-	-	-	+	+
<i>Cyclops sp.</i>	-	-	+	-	+	-	+
Rhizopoda							
<i>Paramecium sp.</i>	+	+	+	+	+	+	+
Branchionide							
<i>Karatella cochlearis sp.</i>	+	+	-	+	-	+	+
Rotifer							
<i>Monostyla sp.</i>	+	+	+	+	-	+	+
<i>Anuraaeopsis sp.</i>	-	-	+	-	-	+	-
Crustacea							

<i>Nauplius sp.</i>	+	+	-	+	+	-	+
Protozoa							
<i>Volvox sp.</i>	-	+	-	-	+	-	-

Distribution of Zooplanktons in Experimental sites

The presence of zooplankton species across the seven experimental site samples, offers important insight into the ecological conditions and biodiversity of the tested water body. The observed species span major taxonomic groups such as Cladoceran, Copepoda, Rhizopoda, Crustacea, and Protozoa, reflecting a functionally diverse and ecologically active environment. Notable species like *Diaphanosoma sp.*, *Bosmania sp.*, *Alona affinis sp.*, *Daphnia sp.*, *Paramecium sp.*, and *Nauplius sp.* were consistently present across most sampling points, indicating their adaptability and stable presence under experimental site conditions. The frequent occurrence of these species suggests favourable water quality and sufficient nutrient levels, supporting a healthy aquatic food web. Their distribution also serves as a biological indicator of the site's productivity and ecological resilience, making this data valuable for environmental assessment and water quality monitoring in the experimental area.

Among the Cladoceran, *Daphnia sp.* was the most frequently observed, indicating its adaptability and resilience under experimental conditions. Other cladocerans such as *Bosmania sp.*, *Alona affinis sp.*, and *Moina sp.* showed moderate occurrence. *Diaphanosoma sp.* and *Leptodora sp.* appeared less frequently, suggesting that these species might be more sensitive to altered environmental conditions or less competitive under the experimental setup. The Copepoda group shows a scattered distribution. *Cyclops sp.* indicating a moderate tolerance to the conditions. *Paradipatomus sp.* *Phyllodiaptomus sp.* Highlighting variability in habitat suitability and perhaps competition among species.

In the Rhizopoda group, *Paramecium sp.* highlights fairly consistent member of the community and reflecting stable micro-conditions that favour protozoan activity. The Crustacea, represented by *Nauplius sp.*, showing a lower occurrence compared to the control, which may suggest environmental stress or predation pressure affecting its population. The Protozoa group, represented by *Volvox sp.*, showed moderate frequency, occurring in four of the seven samples. This suggests that while *Volvox* can adapt to the experimental site, its presence is somewhat influenced by specific environmental factors such as light, nutrient levels, or competition.

Several taxa appear less frequently than in the control site, suggesting that experimental conditions may have selectively influenced zooplankton presence and diversity. Still, the site maintains a functional community structure, indicating a degree of ecological balance despite potential environmental shifts.

Table 25: Presence of Zooplankton in Experimental Site							
Species	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
Cladoceran							
<i>Diaphanosoma sp.</i>	-	+	+	-	+	-	-
<i>Bosmania sp.</i>	+	-	-	+	-	-	+
<i>Alona affins sp.</i>	+	+	-	-	+	-	-
<i>Moina sp.</i>	-	+	+	-	-	+	-
<i>Daphnia sp.</i>	+	-	+	+	+	-	+
<i>Leptodora sp.</i>	-	-	+	-	-	+	-
Copepoda							
<i>Phyllodiaptomus sp.</i>	+	-	+	-	-	-	-
<i>Paradipatomus sp.</i>	-	-	+	-	+	-	+
<i>Cyclops sp.</i>	+	+	-	-	+	-	+
Rhizopoda							
<i>Paramecium sp.</i>	-	+	+	+	+	-	+
Crustacea							
<i>Nauplius sp.</i>	+	+	-	-	-	-	+
Protozoa							
<i>Volvox sp.</i>	-	+	+	-	+	+	-

Abundance of Phyto planktons in Control sites

Table 26: Abundance of Phytoplankton in Control Site								
Species	Control 1	Control 2	Control 3	Control 4	Control 5	Control 6	Control 7	Total
Chlorophyceae								
<i>Pediastrum sp.</i>	3	5	0	6	4	0	8	26
<i>Eurodina sp.</i>	0	7	6	0	5	2	0	20
<i>Cylindrocapsa sp.</i>	6	0	9	8	0	4	0	27
<i>Spirogyara sp.</i>	5	7	7	6	8	3	4	40
<i>Zygnema sp.</i>	10	8	4	7	5	6	9	49
<i>Golenkinia sp.</i>	5	4	0	8	0	7	0	24
<i>Desmidium sp.</i>	0	3	5	0	6	0	4	18
<i>Mougeotia sp.</i>	5	8	0	4	7	9	8	41
<i>Oscillatoria sp.</i>	8	9	10	12	6	8	9	62
<i>Cosmarium sp.</i>	4	5	6	0	5	0	7	27
<i>Tetraedron sp.</i>	0	7	0	6	5	3	0	21
<i>Cladophora sp.</i>	5	3	2	0	0	4	4	18
<i>Closterium sp.</i>	12	8	15	9	17	11	10	82
Bacillariophyceae								
<i>Cymbella sp.</i>	6	5	0	6	8	7	2	34
<i>Naviculla sp.</i>	8	0	9	7	10	0	8	42
<i>Leptocylindrus sp.</i>	11	9	12	8	7	10	9	66
<i>Nitzschia sp.</i>	9	6	8	12	5	8	7	55
<i>Synedra sp.</i>	10	8	9	7	13	8	12	67
<i>Fragillaria sp.</i>	0	7	5	4	5	0	3	24
<i>Bacillaria sp.</i>	6	0	6	0	3	7	4	26
<i>Coscinodiscaceae sp.</i>	0	6	0	4	0	2	1	13
<i>Gyrosigma sp.</i>	5	8	4	6	2	4	6	35
Cyanophyceae								
<i>Nostoc sp.</i>	10	12	8	14	16	9	11	80
<i>Chlorococcus sp.</i>	3	5	6	0	0	8	0	22
<i>Merismopedia sp.</i>	0	0	3	2	5	2	4	16
<i>Gloeocapsa sp.</i>	5	4	0	0	5	8	3	25
Euglenaceae								
<i>Euglena sp.</i>	4	6	0	8	4	3	5	30
Chrysophyceae								
<i>Diatom sp.</i>	9	7	6	5	8	2	10	47
								1037

	Chlorophyceae	Bacillariophyceae	Cyanophyceae	Euglenaceae	Chrysophyceae	Total
Control 1	63	55	18	4	9	149
Control 2	74	49	21	6	7	157
Control 3	64	53	17	0	6	140
Control 4	66	54	16	8	5	149
Control 5	68	53	26	4	8	159
Control 6	57	46	27	3	2	135
Control 7	63	52	18	5	10	148
Total	455	362	143	30	47	1037
% Value	43.88%	34.91%	13.79%	2.89%	4.53%	100%

The table illustrates the distribution of phytoplankton species across seven control sites, categorized under major algal groups including Chlorophyceae, Bacillariophyceae, Cyanophyceae, Euglenaceae, and Chrysophyceae. Among these groups, Chlorophyceae showed the greatest diversity and dominance, with species like *Closterium sp.*, *Spirogyra sp.*, and *Pediastrum sp.* being highly prevalent across all sites. In the Cyanophyceae group, *Chlorococcus sp.* was the most abundant, indicating favourable conditions for blue-green algae. Bacillariophyceae also had a strong presence, particularly species such as *Nitzschia sp.* and *Navicula sp.*, reflecting the ecological importance of diatoms in the control site. Conversely, species like *Gyrosigma sp.* and *Coscinodiscaceae sp.* appeared less frequently, suggesting more specific environmental preferences or limited adaptability. Overall, the distribution reflects a balanced and diverse phytoplankton community, indicative of a healthy and productive aquatic ecosystem in the control area.

The table provides the relative abundance of zooplankton community across seven control sites, highlighting both numerical and percentage contributions of different taxonomic groups. Cladoceran species were the most dominant, comprising 37.67% of the total zooplankton population, followed by Copepoda at 24.22%, indicating their strong presence and ecological role in the freshwater system. Rhizopoda accounted for 13.45%, while Rotifers contributed 8.97%, showing moderate distribution across the sites. Branchionide made up 7.62%, reflecting relatively limited presence. The least represented groups were Crustacea and Protozoa, constituting only 4.48% and 3.59% respectively.

This distribution suggests a zooplankton community dominated by filter feeders and herbivores, with Cladocerans playing a particularly key role in maintaining the ecological balance in the control sites.

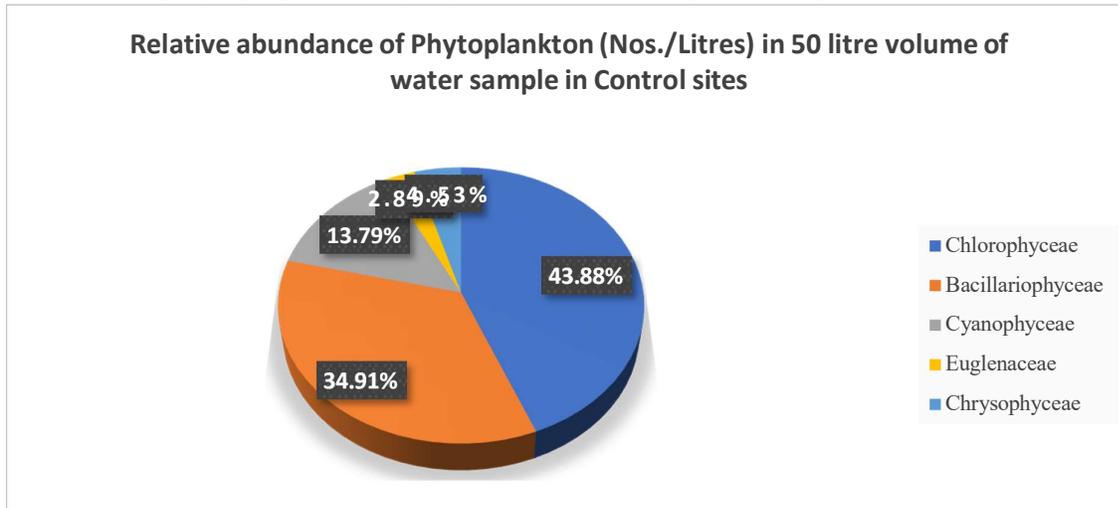


Figure 7: Graphical Representation of Phytoplankton abundance in Control sites

Abundance of Phyto planktons in Experimental sites

The table presents the abundance of phytoplankton species across seven experimental sites, revealing a diverse and ecologically balanced aquatic system. Phytoplankton groups represented include Chlorophyceae (green algae), Bacillariophyceae (diatoms), Cyanophyceae (blue-green algae), and Euglenaceae. Among the groups, Chlorophyceae displayed significant species richness, with genera like Spirogyra, Closterium, and Zygnema showing high abundance, indicating favourable growth conditions and nutrient availability. Bacillariophyceae also contributed substantially to the phytoplankton community, with Navicula sp., Nitzschia sp., and Coscinodiscus sp. being prominent, reflecting the stability and oxygenation of the aquatic environment. Cyanophyceae species such as Nostoc sp. and Oscillatoria sp. were moderately abundant, suggesting their adaptability to varying light and nutrient conditions. Euglena sp., representing Euglenaceae, had lower but consistent presence, indicating some organic enrichment. Overall, the experimental sites support a diverse phytoplankton assemblage, with green algae and diatoms dominating, suggesting relatively healthy water quality with varied ecological niches.

	Chlorophyceae	Bacillariophyceae	Cyanophyceae	Euglenaceae	Total
Sample 1	50	40	19	5	114
Sample 2	47	38	25	4	114
Sample 3	49	40	20	5	114
Sample 4	43	28	24	2	97

Sample 5	46	36	24	6	112
Sample 6	36	40	21	3	100
Sample 7	34	38	24	4	100
Total	305	260	157	29	751
% Value	40.61%	34.62%	20.91%	3.86%	100%

The relative abundance of phytoplankton in the experimental site provides insight into the ecological condition of the water body. Among the four major groups recorded, Chlorophyceae (green algae) were the most dominant, accounting for 40.61% of the total phytoplankton population. Their high abundance indicates favourable environmental conditions such as sufficient light and moderate nutrient levels that support their growth. Bacillariophyceae (diatoms) followed closely, contributing 34.62%, which is a positive indicator of water quality, as diatoms are typically associated with clean and well-oxygenated environments. Cyanophyceae (blue-green algae) made up 20.91% of the population. While this is a significant proportion, it does not suggest excessive nutrient enrichment or eutrophication, which could lead to algal blooms. Lastly, Euglenaceae represented only 3.86% of the phytoplankton community, indicating a minor presence and possibly reflecting lower levels of organic pollution. The overall composition suggests a balanced phytoplankton community structure with good species diversity. The co-existence of various algal groups, without the dominance of harmful cyanobacteria, points to a relatively healthy aquatic ecosystem at the experimental site. This phytoplankton profile can serve as a useful biological indicator for monitoring water quality and assessing the ecological impact of environmental or anthropogenic changes.

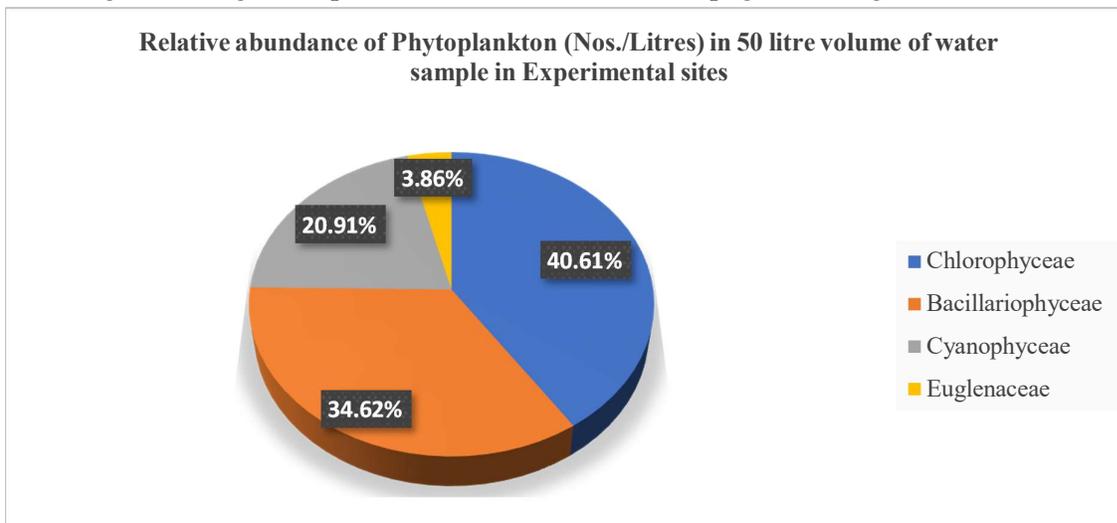


Figure 8: Graphical representation of Phytoplankton abundance in Experimental sites

Table 29: ABOUNDANCE OF ZOOPLANKTONS IN CONTROL SITE								
Species	Control 1	Control 2	Control 3	Control 4	Control 5	Control 6	Control 7	Total
Cladoceran								
<i>Diaphanosoma sp.</i>	4	0	3	2	0	5	1	15
<i>Bosmania sp.</i>	0	4	1	0	4	0	3	12
<i>Alona affins sp.</i>	5	0	4	3	0	3	0	15
<i>Monia sp.</i>	4	3	0	0	0	2	0	9
<i>Daphnia sp.</i>	0	4	6	0	5	0	3	18
<i>Polyphemus sp.</i>	0	3	0	4	0	3	5	15
Copepoda								
<i>Diaptomus sp.</i>	3	0	4	0	2	5	0	14
<i>Phyllodiaptomus sp.</i>	3	5	0	1	0	2	4	15
<i>Paradiptomus sp.</i>	0	0	4	0	5	0	3	12
<i>Cyclops sp.</i>	6	2	0	0	0	5	0	13
Rhizopoda								
<i>Paramecium sp.</i>	5	3	4	4	3	6	5	30
Branchionide								
<i>Karatella cochlearis sp.</i>	0	4	3	5	0	0	5	17
Rotifer								0
<i>Monostyla sp.</i>	2	0	3	0	1	3	0	9
<i>Anuraeopsis sp.</i>	5	2	0	0	4	0	0	11
Crustacea								
<i>Nauplius sp.</i>	0	4	0	1	2	0	3	10
Protozoa								
<i>Volvox sp.</i>	0	4	0	0	3	3	0	8
								223

Abundance of Zooplankton in Control sites

The table shows the abundance of various zooplankton species across seven control sites, categorized into major groups: Cladoceran, Copepoda, Rhizopoda, Branchionide, Rotifer, Crustacea, and Protozoa. Among the Cladocerans, *Alona affins*, *Moina sp.*, and *Diaphanosoma sp.* exhibited the highest and equal total abundance, indicating they are the dominant taxa in this group. In the Copepoda category, *Phyllodiaptomus sp.* and *Diaptomus sp.* had significant representation, while *Paradiptomus sp.* showed slightly lower but consistent occurrence. *Paramecium sp.* (Rhizopoda) was the most abundant individual species overall, reflecting a strong presence across all control samples.

Karatella cochlearis (Branchionide) and Monostyla sp. (Rotifer) also contributed to the zooplankton diversity, though in smaller numbers. The Crustacean Nauplius sp. and the Protozoan Volvox sp. had limited presence, indicating they were minor contributors to the community. Overall, the total abundance of zooplankton reached 223, with a noticeable dominance of Cladoceran and Rhizopoda species, highlighting a rich and varied zooplankton population in the control site ecosystem.

	Cladoceran	Copepoda	Rhizopoda	Branchionide	Rotifer	Crustacea	Protozoa	Total
Control 1	13	12	5	0	7	0	0	37
Control 2	14	7	3	4	2	4	4	38
Control 3	14	8	4	3	3	0	0	32
Control 4	9	1	4	5	0	1	0	20
Control 5	9	7	3	0	5	2	3	29
Control 6	13	12	6	0	3	0	3	37
Control 7	12	7	5	5	0	3	0	32
Total	84	54	30	17	20	10	8	223
% Value	37.67%	24.22%	13.45%	7.62%	8.97%	4.48%	3.59%	100%

The relative abundance of zooplankton in the control site water samples reveals a diverse community structure with noticeable group-wise dominance. Cladocerans were the most dominant group, comprising 37.67% of the total zooplankton population. Their prevalence reflects stable environmental conditions, as cladocerans are often indicators of good water quality and play a key role in aquatic food webs. Copepods followed, contributing 24.22% to the total population, suggesting a healthy and balanced ecosystem, since copepods are efficient grazers of phytoplankton and serve as a vital food source for higher trophic levels like fish. Rhizopods, mainly protozoans like Paramecium, formed 13.45% of the population, indicating microbial activity and organic matter recycling. Rotifers contributed 8.97%, often considered indicators of eutrophic or organically enriched waters, though their moderate numbers here reflect a balanced environment. Branchionids (7.62%) and crustacean larvae (4.48%) were present in smaller numbers but still play a supporting ecological role. Protozoans made up 3.59% of the total, pointing to natural biological diversity.

Overall, the composition and relative abundance of zooplankton in the control site suggest a well-functioning aquatic ecosystem with a healthy balance between various zooplankton groups, indicative of stable physicochemical conditions and moderate nutrient levels in the environment.

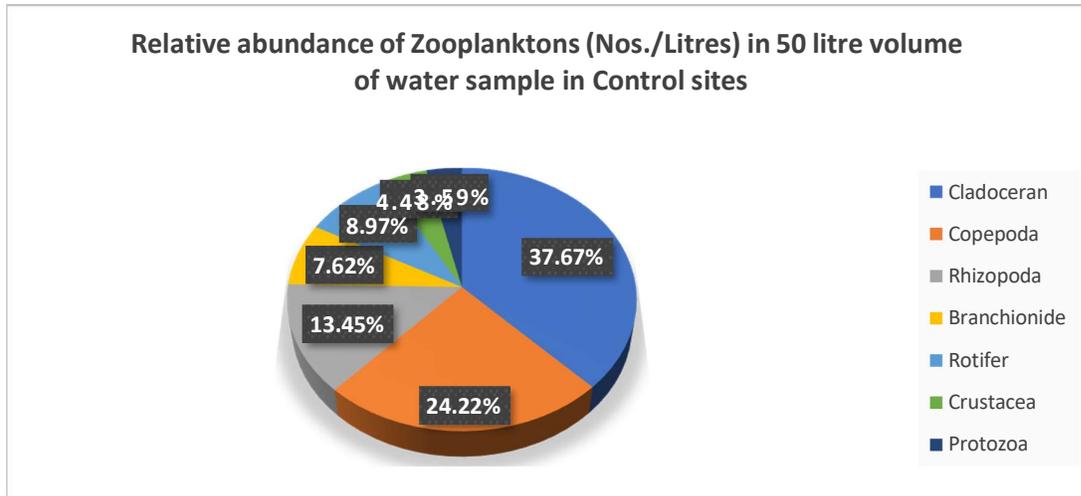


Figure 9: Graphical representation of zooplankton abundance in Control sites

Abundance of Zooplankton in Experimental sites

Species	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Total
Cladoceran								
<i>Diaphanosoma sp.</i>	0	2	3	0	4	0	0	9
<i>Bosmania sp.</i>	4	0	0	2	0	0	4	10
<i>Alona affins sp.</i>	3	2	0	0	4	0	0	9
<i>Moina sp.</i>	0	3	5	0	0	2	0	10
<i>Daphnia sp.</i>	5	0	3	3	2	0	1	14
<i>Leptodora sp.</i>	0	0	4	0	0	3	0	7
Copepoda								
<i>Phyllodiaptomus sp.</i>	1	0	2	0	0	0	0	3
<i>Paradipatomus sp.</i>	0	0	5	0	3	0	3	11
<i>Cyclops sp.</i>	2	1	0	0	3	0	2	8
Rhizopoda								

<i>Paramecium sp.</i>	2	4	6	7	4	0	5	28
Crustacea								
<i>Nauplius sp.</i>	3	2	0	0	0	0	4	9
Protozoa								
<i>Volvox sp.</i>	0	5	2	0	2	4	0	13
								131

The table presents the distribution of zooplankton species across seven experimental sites. The data reveals a diverse range of species, with some being more abundant than others. *Daphnia sp.* and *Paramecium sp.* are among the most prevalent species, while others like *Bosmina sp.*, *Alona affinis sp.*, and *Cyclops sp.* are also present in significant numbers. The total number of zooplankton individuals across all sites indicates a thriving aquatic ecosystem. The distribution of species suggests a balanced food web, with various zooplankton species playing important roles as primary consumers and intermediate predators. The data provides valuable insights into the composition and abundance of zooplankton in the experimental sites, which can inform further research on aquatic ecology and conservation.

	Cladoceran	Copepoda	Rhizopoda	Crustacea	Protozoa	Total
Sample 1	12	3	2	3	0	20
Sample 2	7	1	4	2	5	19
Sample 3	15	7	6	0	2	30
Sample 4	5	0	7	0	0	12
Sample 5	10	6	4	0	2	22
Sample 6	5	0	0	0	4	9
Sample 7	5	5	5	4	0	19
Total	59	22	28	9	13	131
%Value	45.04%	16.79%	21.37%	6.87%	9.92%	100%

The relative abundance of zooplankton in the experimental site, based on samples from a 50-litre water volume, reveals a notable shift in community composition compared to control conditions. Cladocerans dominate the zooplankton population, accounting for 45.04% of the total, indicating their strong adaptability or potential proliferation under altered environmental conditions. Their dominance suggests they may be more resilient to stressors introduced in the experimental site, possibly due to better reproductive strategies or reduced predation. Rhizopods, such as *Paramecium*, represent 21.37% of the population, reflecting increased microbial and organic activity, which may have been influenced by nutrient enrichment or other experimental variables. Copepods make up 16.79%, suggesting a moderate but reduced presence, possibly due to competition or environmental

stress. Protozoa contribute 9.92%, indicating their role in microbial food webs remains significant under experimental conditions. Crustacean larvae, comprising 6.87%, maintain a minor but stable role in the ecosystem. Overall, the data shows a shift towards increased abundance of Cladocera and Rhizopoda, potentially highlighting changes in water quality, food availability, or ecological dynamics. The reduced presence of copepods and crustaceans may suggest sensitivity to the environmental conditions imposed in the experimental site. This zooplankton composition offers insights into how aquatic communities respond to varying ecological pressures.

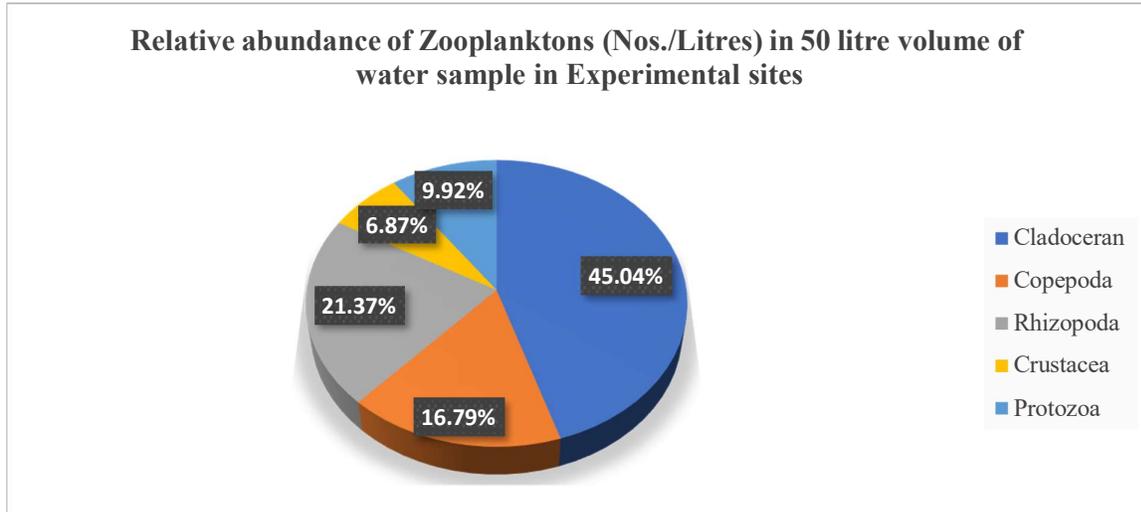


Figure 10: Graphical representation of Zooplanktons abundance in Experimental sites

Comparative Analysis of Plankton Distribution Using Two-Way ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Control and experimental sites	514089	1	514089	54.63801	0.085606	161.4476
Planktons	35721	1	35721	3.796471	0.301868	161.4476
Error	9409	1	9409			
Total	559219	3				

The results of two-way ANOVA, indicate that there was no statistically significant variation with respect to the control and experimental sites ($F_1 = 54.64$, $p = 0.086 > 0.05$). Although the F-value appears high, the p-value exceeds the 0.05 Significance level, and the F critical value (161.45) is much higher than the calculated F, indicating the difference is not statistically significant. This suggests that site differences (control vs. experimental) did not have a meaningful influence on overall plankton abundance. Similarly, the variation observed among plankton types ($F_2 = 3.80$, $p = 0.302 > 0.05$) was also not statistically significant, implying that the differences in abundance between different plankton groups were not strong enough to be considered meaningful in this context.

Overall, the results indicate that neither the sampling location nor the plankton group had a significant effect on the observed abundance. This reflects uniform environmental conditions or limited variability in plankton distribution at the time of sampling.

Diversity Indices of Phyto planktons in the Post Monsoon Seasons Shannon Index of Phyto planktons

Table 34: Shannon Index	
Control	Experimental
3.20708	3.11335

In the table above, the Shannon index of diversity of phytoplankton values was 3.20708 for the Control Sites and 3.11335 for the experimental sites. The value is slightly higher at the control site compared to the experimental site, indicating slightly greater phytoplankton diversity at the control site. The small difference suggests that both sites have relatively high diversity, but the control site maintains a more balanced and varied species composition.

Simpson index of Phyto planktons

Table 35: Simpson Index	
Control	Experimental
0.04442	0.04924

According to our data, the Simpsons index value for phytoplankton was 0.04442 for the Control Sites and 0.04924 for Experimental sites. The value is lower at the control site than the experimental site. Since lower values indicate higher biodiversity, this suggests that the control site has slightly greater phytoplankton diversity. The slightly higher value at the experimental site points to reduced diversity, possibly due to mild ecological stress or habitat disruption.

Evenness index of Phytoplankton

Table 36: Evenness Index	
Control	Experimental
0.46184	0.47109

In the table above, the Evenness index of phytoplankton values was 0.46184 for the Control Sites and 0.47109 for the experimental sites. This shows a slightly higher Evenness Index at the experimental site compared to the control site. This indicates that species at the experimental site are more uniformly distributed, with less dominance by any single species, suggesting a more balanced community structure despite possible differences in overall diversity.

Similarity index of Phytoplankton

Table 37: Similarity Index of Phytoplankton	
Total no. of species in Control	28
Total no. of species in Experimental	25
Total no. of common species	21
Similarity Index	0.792453

The results indicate that the similarity index phytoplankton value was 0.792453 at both the sites. This indicates a high degree of similarity in phytoplankton species composition this showing significant overlap. This suggests that both sites share a largely similar phytoplankton community, although the control site has slightly higher species richness.

Diversity Indices of Zooplanktons in the Post Monsoon Seasons

Shannon index of Zooplanktons

Table 38: Shannon Index	
Control	Experimental
2.7156	2.3645

In the table above, the Shannon index of diversity for Zooplankton was 2.7156 for the Control Sites and 2.3645 for experimental sites. The value was higher at the control site than the experimental site, which indicates greater phytoplankton diversity in the control site. The lower value at the experimental site suggests reduced species richness or uneven distribution, likely due to environmental factors.

Simpson index of Zooplanktons

Table 39: Simpson Index	
Control	Experimental
0.066457	0.10005

In the table above, the Simpson index for Zooplankton was 0.066457 for the Control Sites and 0.10005 for Experimental sites. The value was lower at the control site as compared to the experimental site. Since lower values indicate higher diversity, this means the control site has greater phytoplankton diversity, while the higher value at the experimental site suggests reduced diversity, possibly due to environmental stress or habitat disturbance.

Evenness index of Zooplanktons

Table 40: Evenness Index	
Control	Experimental
0.50222	0.485

In the table above, the Evenness index of diversity of Zooplankton values was 0.50222 for the Control Sites and 0.485 for Experimental sites. The value was slightly higher at the control site as compared to experimental site. This indicates that zooplankton species are more evenly distributed in the control site, while the experimental site shows slightly less balance, suggesting that a few species may be more dominant there.

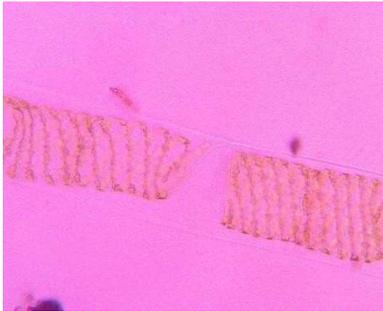
Similarity index of Zooplanktons

Table 41: Similarity Index of Zooplanktons	
Total no. of species in control sites	16
Total no. of species in experimental sites	12
Total no. of common species	11
Similarity index	0.785714

The results indicate that the similarity index Zooplankton value was 0.785714 at both the sites. This indicates a high overlap in zooplankton species between control and experimental sites, The slight difference in total species may be due to environmental stress or reduced habitat quality at the

experimental site, while the high similarity suggests shared conditions or close proximity between the two sites.

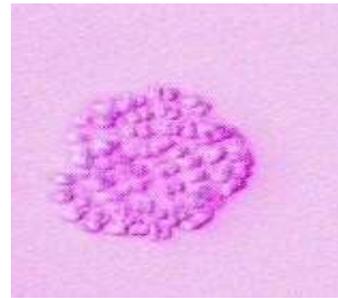
Species Abundant of the Phytoplankton during Pre Monsoon Seasons



Spirogyra sp.



Actinastrum sp.



Chlorella sp.



Cladophora sp.



Closterium sp.



Cosmarium sp.



Cylindrocapsa sp.



Desmidium sp.



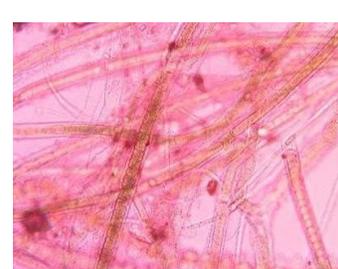
Mougeotia sp.



Scenedesmus sp.



Sphaerososma sp.



Zygnema sp.



Anabaena sp.



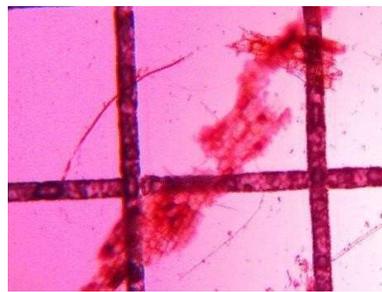
Microcoleus acutissimus



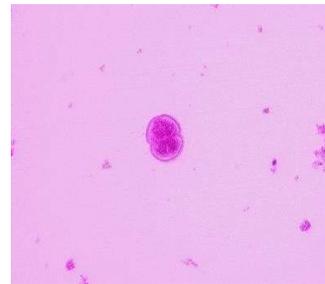
Nostoc sp.



Rivularia sp.



Aphanizomenon



Gloeocapsa



Cymbella sp.



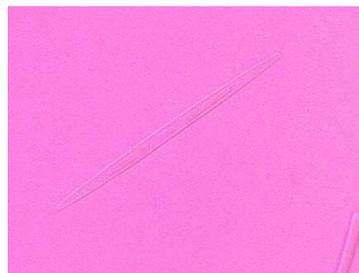
Fragillaria sp.



Gyrosigma sp.



Navicula sp.



Nitzschia sp.



Synedra sp.

Figure 11: Species Abundant of the Phytoplankton during Pre Monsoon Seasons

Species Abundant of the Zooplankton during Pre-Monsoon Seasons

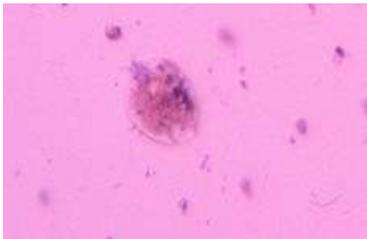
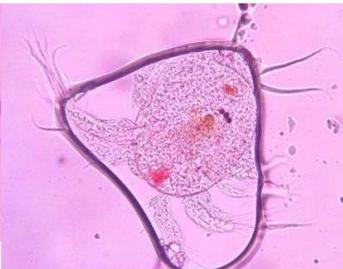
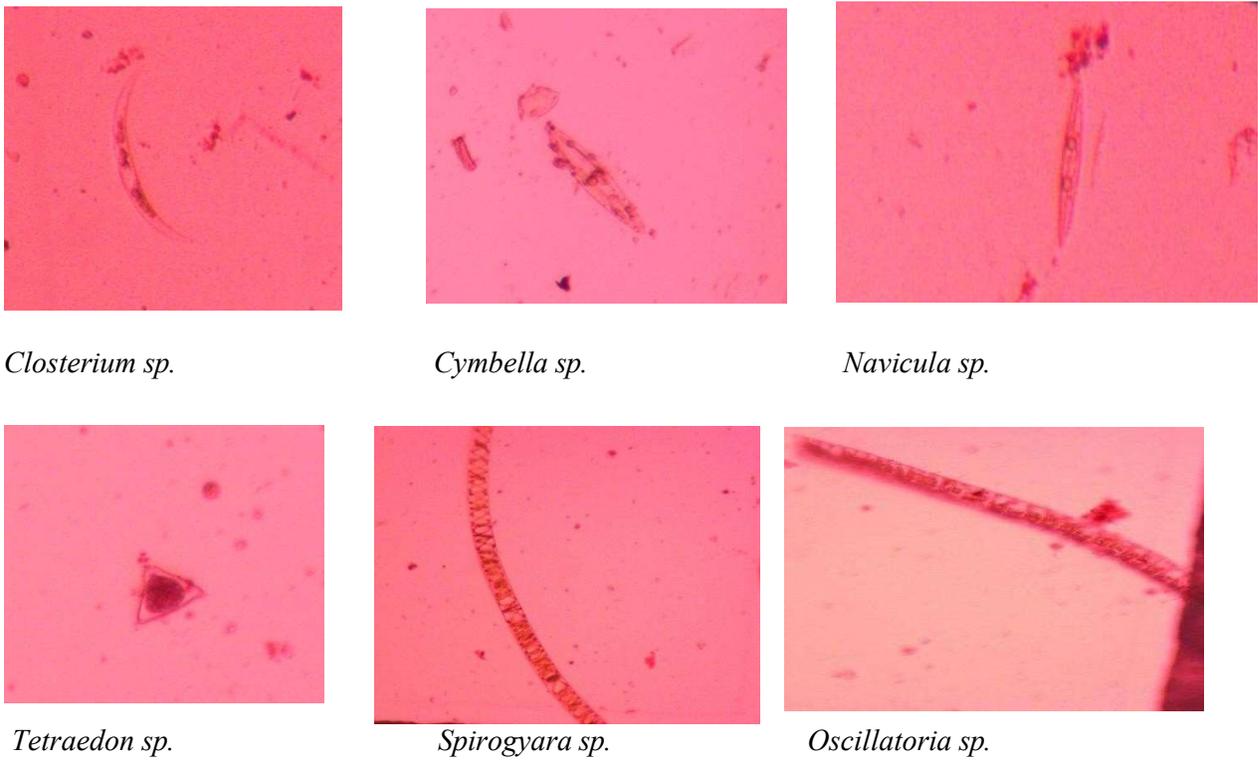
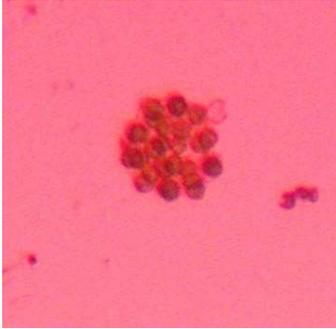
*Phyllodiaptomus sp.**Polyphemus sp.**Paradiaptomus sp.**Alona affinis sp.**Cyclops sp.**Ascomorpha sp.**Monia sp.**Diaptomus sp.**Paramesium sp.**Anuraaeopsis sp.**Leptodora sp.**Diaphanosoma sp.*



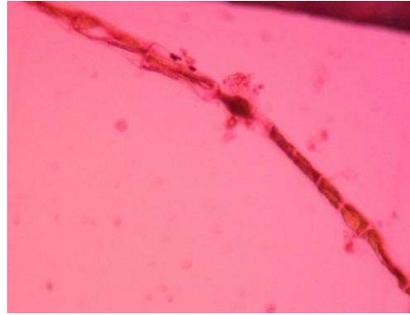
Figure 12: Species Abundant of the Zooplankton during Pre Monsoon Seasons

Species Abundant of the Phytoplankton during Post-Monsoon Period

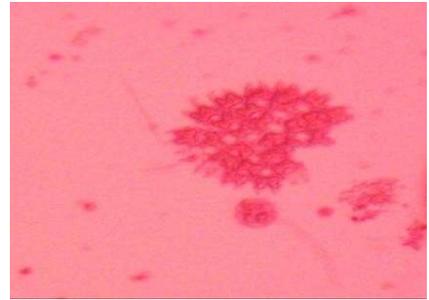




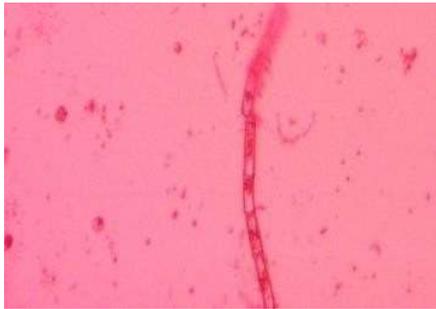
Eudorina sp.



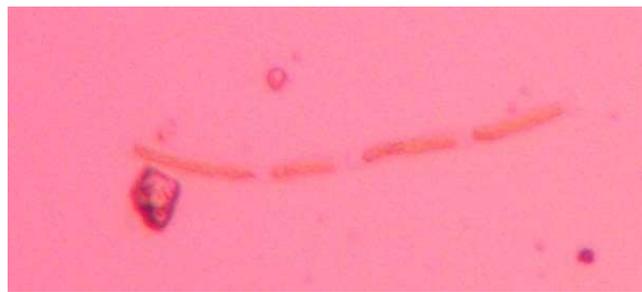
Gonatozygon sp



Pediastrum sp



Zygnema sp.



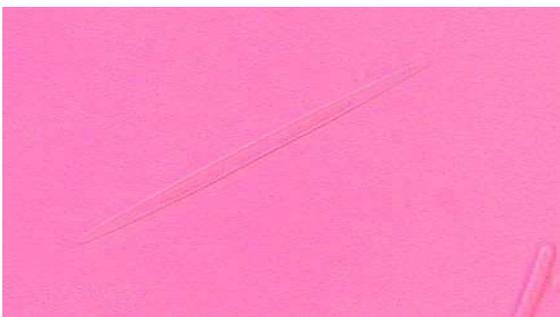
Mougeotia sp.



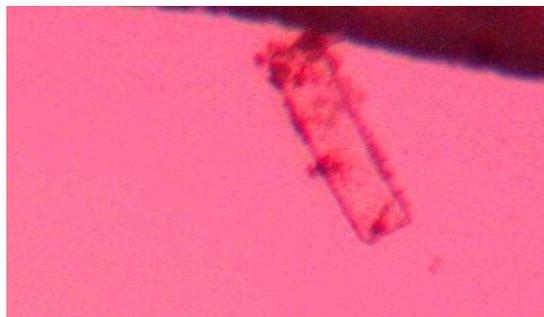
Chlamydomonas sp



Euglena sp.



Nitzszia sp.



Guinardias sp.



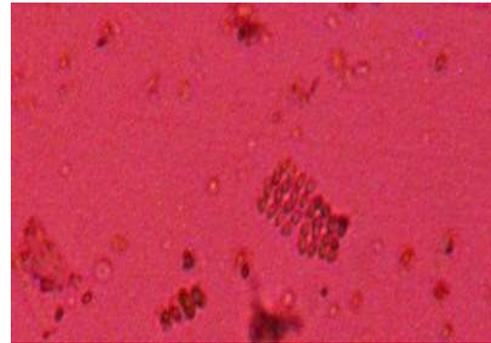
Nostoc sp.



Synedra sp.



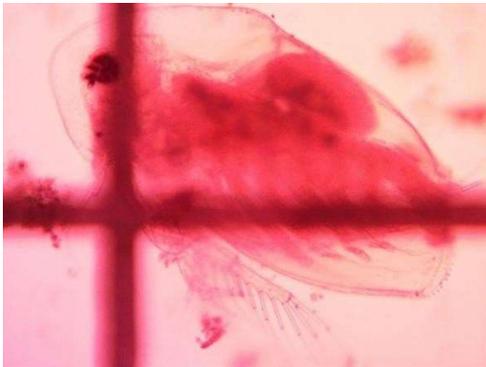
Cosmarium sp.



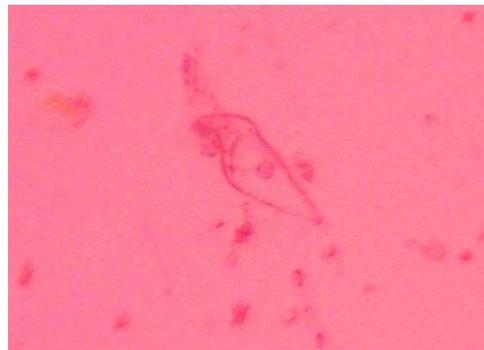
Merismopedia sp.

Figure 13: Species Abundant of the Phytoplankton during Pre Monsoon Seasons

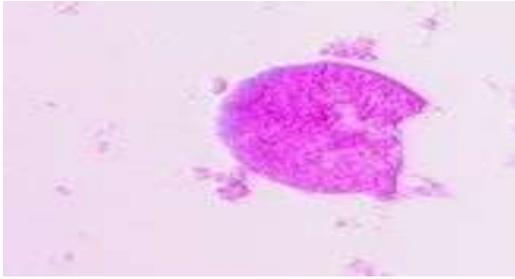
Species Abundant of the Zooplankton during Post Monsoon Seasons



Diaphanosoma sp.



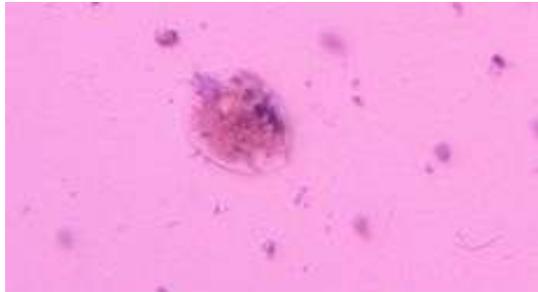
Paramecium sp.



Moina sp.



Paradiaptomus sp.



Volvox sp.



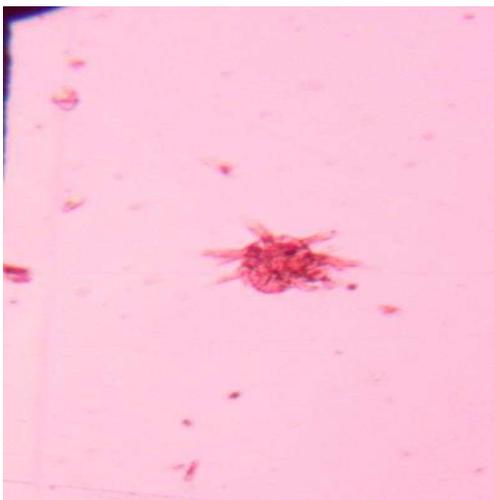
Karatella sp.



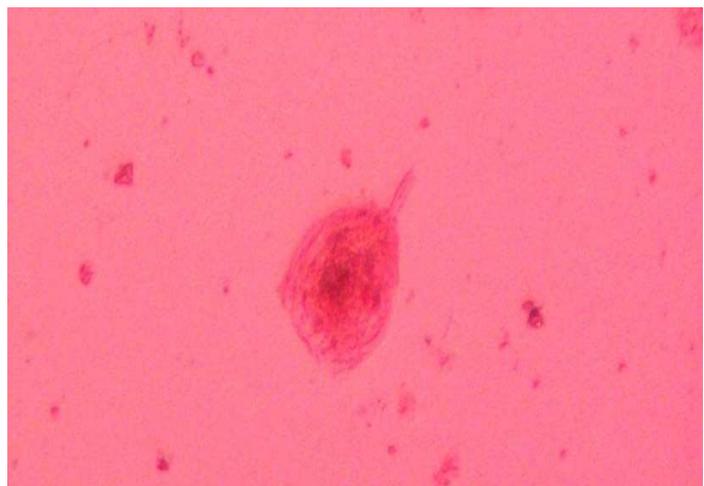
Leptodora sp.



Phyllodiaptomus sp.



Nauphillus sp.



Monostyla sp.

Figure 14: Species Abundant of the Zooplankton during Pre Monsoon Seasons

Conclusion

This study highlights the diversity and ecological significance of plankton communities across control and experimental sites during pre- and post-monsoon seasons, highlighting the influence of anthropogenic activities on aquatic biodiversity. The control site consistently demonstrated higher species richness, evenness, and ecological stability for both phytoplankton and zooplankton, supported by diversity indices such as the Shannon Index (3.213 for phytoplankton and 2.436 for zooplankton), lower Simpson's Index values (0.050 and 0.104, respectively), and higher Evenness Index scores (0.896 and 0.878). In contrast, the experimental site showed reduced diversity and increased dominance of a few species, with higher Simpson's Index values (0.071 for phytoplankton and 0.222 for zooplankton) and lower evenness (0.844 and 0.823, respectively), indicating ecological stress likely induced by coal-related industrial activities. The Similarity Index values (0.732 for phytoplankton and 0.573 for zooplankton) reflect partial overlap in species composition, with more pronounced differentiation in zooplankton communities. Post-monsoon observations continued to support the trend of greater ecological balance in the control site, although limited data constrained a full seasonal comparison. Overall, the diversity indices suggest that environmental stress likely resulting from anthropogenic activities near the experimental site has contributed to decreased diversity and evenness in plankton communities, with the effects being more evident during the pre-monsoon season. Statistical analysis of data between Pre-and Post-monsoon did not show a significant difference in result indicating that during post-monsoon months the situation has almost been restored due surface run-off and dilution. This emphasizes the value of using plankton as effective indicators for assessing the health of aquatic ecosystems and detecting environmental disturbances. Observations from the post-monsoon period further reinforced the pattern of higher phytoplankton diversity and ecological stability at the control site.

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Socio-Economic analysis of
environmental damage caused by ITPS'
ash pond breach & spillage

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Introduction

The contamination of land and water resources caused by coal ash pond breach and spillage can potentially cause significant socioeconomic damage in terms of farm-based livelihood losses, risk to human and animal health, and large-scale displacement of affected communities. The environmental damage to soil, land and water has direct and immediate adverse impacts on livelihoods of local farmers, herders, and fisher folk. Some of these impacts can last a long time with inter-generational consequences for people's health and incomes. Loss of soil fertility and groundwater contamination caused by leaching of heavy metals are often irreversible impacts that can leave the affected people with no other choice but to relocate. The economic burden of coal ash pond breaches is compounded when farmers face a lack of compensation for damaged crops, and communities most likely incur costs for water purification and land remediation.

In the present study, the socioeconomic analysis is focused on establishing a monetary value of the environmental damage and loss of livelihoods resulting from the breach incident. Given the local geophysical as well as agroecological context and considering the nature of environmental damage caused by ITPS' ash pond breach and spillage, our socio-economic analysis covers the following natural resource components: (a) agriculture crop; (b) total land stock; (c) tree and shrub vegetation; (d) grazing land; and (e) ponds and open wells. Our field queries at different time points during the study period revealed no significant decline in the catch of major fish varieties from the reservoir and small fish collections from nearby village ponds in the aftermath of the breach incident. Thus, the major livelihood loss considered in the study is that related to single paddy crop cultivation.

It was also confirmed during field investigation that there has been no distress labour outmigration from the affected villages following the loss of agriculture land. The constant availability of wage-based employment for various Plant activities of the ITPS has ensured that none of the affected villagers have been pushed down to the abject poor status. However, the loss of access to tree products, bamboo, fodder material, and land for vegetables cultivation appeared to have adversely impacted the poorer households and some of the women self-help groups (WSHGs) who were dependent on the locally available natural resources for their productive activities.

ITPS' ash pond breach incident

According to the very first Inspection Report (dated 11.12.2023) prepared by officials of the Odisha State Pollution Control Board (OSPCB), the breach of Ash Pond C occurred on the morning (8.30AM) of 09.12.2023, at north side of the ash dyke. The inspection had happened on 9.12.2023 and 10.12.2023, and it is reported that approximately 30 ft depth and 40 ft width of the ash dyke collapsed, spilling around 4.0 to 4.5 lakh tons of ash and water to the nearby agricultural land of villages Saradhapali and Kantatikira. The report mentions that about 420 acres of agricultural land along with one village pond in Saradhapali village were affected by the ash slurry spread. Since the villages are situated at a higher elevation, no houses of villagers were affected. Subsequently, as per the compliance letter dated 16.12.2023 from ITPS side, the breach was arrested by constructing a temporary earthen bund and slurry discharge had stopped. A survey carried out by the Revenue Department resulted in a more precise estimate of 154.24 acres of agriculture land area getting affected by the ash spillage/flow.

The presence of the backwaters of Hirakud reservoir in close proximity to the ash pond is a factor not to be ignored. There is a natural channel connecting the affected ash spread area to the reservoir, thereby creating the risk of flow of surface runoff from affected area containing ash into the reservoir. Fortunately, as evident from the observations made by earlier inspection teams and our own sample-based damage assessment, the spillage of ash and slurry into the dam backwaters was not of significant scale to cause damage to water and sediment quality, aquatic life and biodiversity.

Land area and type affected by the ash pond breach

Table 1: Affected land details

Sl. No.	Land in acres	Village	Type of Land	Land Kisam	Remarks
1.	46.390	Rengali	Private	Agriculture	
2.	9.205	Kumarbandh	Private	Agriculture	
3.	34.6	Rengali	Government	Agriculture	Encroachment
4.	14.69	Kumarbandh	Government	Pathar Chatana	
Total [A]	104.885	OPGC in process of acquiring 104.885-acre land for Ash Pond-D			
5.	10	Rengali	Government	Jalasya	Beyond HFL of Hirakud Reservoir
6.	35	Kumarbandh	Government	Pathar Chatana	
Total [B]	45	Additional 45 acres of land affected due to Ash Pond Breach			
[A] + [B]	149.885	Total land affected due to Ash Pond Breach (A+B)			

Data source: ITPS

Crop Loss

At the time of the ash pond breach and consequent spillage of ash and slurry there was Kharif paddy crop standing on many of the agriculture fields. Information regarding the exact number of acres which had unharvested standing crop at the time of breach was not available. Hence, we have taken the upper bound estimate of all 90.195 acres of cultivated land (including encroached government land of 34.6 acres) as having suffered loss of standing paddy crop because of breach and ash deposit.

The average per acre paddy yield was estimated as 15 quintals based on consultation with local farmers. Thus the loss of standing Kharif paddy crop of 2023 over 90.195 acres @15 quintals /acre average yield and with prevailing paddy Minimum Support Price (MSP) @Rs 2300 /quintal is estimated to be **Rs 31,11,727.5** (i.e. Rs 34,500 per acre). We were informed that ITPS has paid compensation @35000 /acre in 2023 and 2024.

The potential crop loss is the result of non-availability of privately held cultivable land of 55.6 acres for the Kharif seasons of 2024 and 2025. In the calculation of potential crop loss, the encroached 34.6 acres of government land is excluded. With the revised MSP @ 3100 /quintal, the economic value of potential Kharif crop loss from both the years is estimated to be **Rs 51,70,800¹**.

We have not taken potential crop loss beyond 2025 because it was informed by ITPS that the plant is already in the process of acquiring the entire 55.6 acres of privately owned agricultural land along with 49.29 acres of government land for Ash Pond – D.

Loss of Flow of Environmental Services from Affected Agricultural Land

Rath et al (2024) have done a meta-analysis of published literature and identified the various environmental services flowing from agroecosystems as follows:

Table 2: Environmental services of agroecosystems

Provisioning services	Regulating services	Cultural services	Supporting services
Food	Soil retention	Recreation and tourism	Soil carbon
Raw materials	Water augmentation	Inspiration for art, culture and design	Soil nutrients
Timber/wood/fuelwood	Soil formation	Aesthetic value	Carbon sequestration
Straw	Water holding capacity / Water infiltration		Micronutrients (iron, zinc)
Non-timber forest products (bamboo)	Flood mitigation		Nitrogen fixation
Byproducts	Groundwater recharge		Mineralization of soil nutrients

¹ (55.6 acres x 15 quintal/acre x 3100) X 2

Playground	Soil erosion prevention		Biodiversity maintenance
Fodder / Fibre	GHG emissions		
Genetic diversity	Biocontrol of pests		
Water supply	Soil fertility		

In the context of the study area, the key environmental services impacted because of contamination of land would include most of the provisioning, regulating and supporting services listed in the above table. Cultural services are excluded; also excluded from economic valuation is the land area listed in Table 1 as ‘pathar chatana’ (14.69 acres + 35 acres) and as ‘jalasaya’ (10 acres).

The meta-analysis by Rath et al (2024) provides mean value estimates of provisioning services, regulating services and supporting services from agroecosystems to be Rs 22,306, Rs 9021 and Rs 4613 respectively per hectare per year.² Thus the total economic value (TEV) of environmental services lost from the affected 90.195 acres (i.e. 36.529 hectares) of land is estimated to be **Rs 13,12,852.3 per year**.

Considering land use change from agriculture to industrial use of affected area in future, due to acquisition plan, the loss of environmental services will be permanent. Hence, as mitigation measure, it is suggested pooling of the TEV over a period of 10 years with NPV estimate and using this corpus for alternative site development or degraded land remediation for social benefit. Assuming a social discount rate of 4%- and 10-years duration for pooling of a fixed stream of Rs 32.42 lakhs annual flow of monetized benefits, the NPV estimate would be around **Rs 1,06,51,000 (Rs 1.07 crores)**.

Loss of Tree Vegetation

Our field team identified 8 matured trees completely damaged because of the ash spillage, that included fruit bearing trees (mango, jackfruit, tamarind) and one *mahula/mahua* (*Madhuca longifolia*) tree which has local cultural significance as well. The damaged trees were open access for people belonging to the nearest village as far as their fruit produce and fallen biomass were concerned.

Trees deliver a host of ecosystem services such as mitigating pollution, improving air quality, providing oxygen, storing carbon, managing stormwater runoff, providing shade and enhancing aesthetic beauty. They play an important role in climate regulation by helping to mitigate extreme weather events such as floods and heatwaves. Trees also contribute to mitigating climate change by sequestering carbon, helping to protect soils, and by supporting biodiversity, acting as a refuge for avian and arboreal life forms. The existing legal framework does not take into account the intrinsic and instrumental value of trees as public assets.

² Rath, S., Kiran Kumara, T.M., Das, A. and Sarangi, K.K. (2024). Economic Valuation of Ecosystem Services in Indian Agricultural Landscape: A Meta-analysis. *Econ. Aff.*, **69**(02): 939-950.

The Supreme Court (SC) of India had appointed a Centrally Empowered Committee (CEC) in March 2021 to fix the value of trees considering the intrinsic as well as instrumental value of trees based not only on their timber worth but their age, girth and environmental contribution. The 25th of March 2021 order of the SC Bench specifically states: “The guidelines shall prescribe a mechanism for assessment of both intrinsic and instrumental value of the trees, based not only on the value of timber, but also the ecosystem services rendered by the trees and its special relevance, if any, to the habitat of other living organisms, soil, flowing and underground water³.”

The guideline established by the Committee allows for estimating an economic value to trees in India by multiplying the tree's age by Rs 74,500. This valuation methodology considers the economic value of a tree, including approximately Rs 45,000 for the oxygen it produces annually and Rs 20,000 for the bio-fertilizers it generates. A heritage tree with a lifespan of over 100 years can even be worth over Rs one crore. In the case of our study, we have taken an average age of 20 years for the 8 damaged trees. Accordingly, the cost to society because of the damage to the trees is valued at **Rs 1,19,20,000 (Rs 1.19 crore)**.

Other tree vegetation in the affected area was mostly scrubs and occasional bamboo clumps. Bamboo has special ecological significance because of the role it plays in soil binding. Bamboo thickets provide a unique habitat to birds, insects, and animals. In an earlier study, Mishra et al (2011) have established significant dust pollution mitigation occurring because of tree and scrub vegetation in and around the ITPS complex⁴. According to the study, the dust collection mostly happens by tree vegetation outside the ITPS complex and amounts to 2345 to 4691 tonnes per annum: this collection matches with the total dust emitted from the ITPS plant. For our economic valuation of this environmental service provided by tree vegetation in the affected area, we have considered the cost to industry for controlling fugitive ash and dust pollution due to presence of ash pond. As per the information provided by ITPS, this pollution control activity happens during the 3 months of summer and involves hiring of 3 water tankers (@Rs 60,000 per month) and employment of 4 skilled labour in daily 3 shifts. The total expenditure incurred by ITPS on this activity is around Rs 30,00,000 per year and we have taken this amount to be the value of the pollution mitigation service provided by tree vegetation in the affected area. Again, once the acquisition of this land happens for another ash pond, the environmental service from tree vegetation is lost for ever. Assuming that it will take another 10 years at least to recreate the lost vegetation in another site, and with a social discount rate of 4%, the NPV estimate of the total damage cost would be **Rs 2,43,33,000**.

³ Expert committee (2022). Compensatory Conservation in India: An Analysis of the Science, Policy and Practice, Report submitted to the Hon'ble Supreme Court by the 7-Member Expert Committee pursuant to the directions dated 25th March 2021 in Special Leave Petition (Civil) No. 25047 Of 2018, New Delhi, India.

⁴ Mishra P.C., N. Behera, S.P. Mishra and K. Meher (2011). Ecological Enumeration of Tree Vegetation and Their Contribution in Removal of Atmospheric Pollution Load: A Case Study in an Industrial Complex of Western Orissa, India. *Asian Journal of Water, Environment and Pollution*, Vol. 8, No. 3 (2011), pp. 19-28.

Loss of the privately owned agriculture land stock

The 55.6 acres of privately owned agricultural land can be valued at prevailing market price for such land type. The District Administration has fixed the cost at Rs 4,50,000 per acre, basing their pricing on last 5 land sale registrations. The total cost for the 55.6 acres of affected land thus comes to **Rs 2,50,20,000**.

Common grazing area and village ponds

We have already accounted for the loss of grazing services from land in the TEV estimation. Further, we have considered the fact that open access grazing of goats and cattle is not restricted solely to the affected area.

Regarding village ponds, the study team found that there is limited livelihood dependence of villagers on the ponds that are there in the affected area. The use of ponds for bathing and non-drinking purpose was not affected.

Total cost of environmental damage

1. The total cost estimate of environmental damage caused by the ash pond breach is Rs 8,02,06,528, (or roughly Rs 8.02 crores) consisting of the following components:
 - a. Loss of crop (standing and potential) over 3 kharif seasons: Rs 82,82,528
 - b. Loss of annual flow of environmental services from affected agricultural land over a period of 10 years: Rs 1,06,51,000
 - c. Loss of tree vegetation (mature trees): Rs 1,19,20,000
 - d. Loss of tree vegetation (other small trees, bamboo and shrubs): Rs 2,43,33,000
 - e. Loss of privately owned land stock: Rs 2,50,20,000

Other observations

1. In the aftermath of the pond breach there was a significant increase in the movement of heavy vehicles in the affected area, which caused high levels of dust and ash pollution of the air, thus adversely affecting people's health, food intake and labour productivity. Most of the villagers consulted by the field team complained of itching of skin and irritation of eyes. The village women complained of cooked food getting spoilt in an instant because of ash carried indoors by sudden

gusts of wind (especially during summer afternoons) blown into kitchens, food that has been just served for eating, and even storage spaces.

2. During our discussions with villagers an issue that was of common concern related to physical safety of the villagers and specially that of school children due to movement of heavy vehicles throughout day and night. The bad condition of the roads increased the risk of accidents.
3. Villagers recalled that immediately after the breach, there was sudden appearance of large number of snakes who most likely were driven out of their shelters in the affected area. Many these creatures got killed since they entered village houses and posed a risk to life.
4. Fortunately, the spillage caused no damage to social infrastructure like schools, community buildings, water supply systems, and distribution of electricity.
5. The power plant is a source of wage-based employment for a significant number of people belonging to the affected villages. Following the breach household income from daily wage employment in ITPS continues to be significant.

Photographs from the field







General Conclusions and Recommendations

General Conclusions

1. Water quality analysis showed samples from Hirakud reservoir met CPCB's designated best use standards for pH and electrical conductivity. All water samples contained arsenic below 10µg/L across seasons, with lead and mercury remaining below detection limits. Iron concentrations exhibited seasonal fluctuations, increasing during monsoon and decreasing post-monsoon.
2. Soil analysis revealed most elements (Na, K, Ca, Mn, Co, Ni, Cu, Zn, As, Mo, Pb, Fe, Hg, F) maintained concentrations below upper continental crustal (UCC) averages in both surface and subsurface samples across all seasons. Contamination factor analysis indicated low pollution for Zn, As, Cd, Pb and Fe during pre-monsoon and monsoon periods at all locations. Geo accumulation index values confirmed uncontaminated conditions for Zn, As, Cd, Pb and Fe across all seasons and locations. Pollution load index calculations suggested no significant cumulative contamination at any location throughout the study period.
3. The findings demonstrate seasonal variations in metal mobility, with mercury showing the most pronounced contamination that naturally attenuates by post-monsoon. The study concludes that while localized heavy metal contamination exists, particularly for mercury and cadmium, overall pollution levels remain within acceptable limits across most monitored parameters and locations.
4. The control sites consistently demonstrated higher species richness, evenness, and ecological stability for both phytoplankton and zooplankton, supported by diversity indices such as the Shannon Index, lower Simpson's Index values, and higher Evenness Index scores. In contrast, the experimental site showed reduced diversity and increased dominance of a few species, with higher Simpson's Index values and lower evenness, indicating ecological stress likely induced by coal related industrial activities. However, statistical analysis of data between Pre-and Post-monsoon did not show a significant difference in result indicating that during post-monsoon months the situation has almost been restored due surface run-off and dilution.
5. The total cost estimate of environmental damage caused by the ash pond breach is Rs 8,02,06,528, (or roughly Rs 8.02 crores) consisting of the following components:
 - a. Loss of crop (standing and potential) over 3 kharif seasons: Rs 82,82,528
 - b. Loss of annual flow of environmental services from affected agricultural land over a period of 10 years: Rs 1,06,51,000
 - c. Loss of tree vegetation (mature trees): Rs 1,19,20,000
 - d. Loss of tree vegetation (other small trees, bamboo and shrubs): Rs 2,43,33,000
 - e. Loss of privately owned land stock: Rs 2,50,20,000

Recommendations

1. Whereas the compensation for loss of crop and privately owned agriculture land to the affected land cultivators can follow the established modalities of OPGC / ITPS, this study recommends that to compensate for loss of environmental services the industry should set aside a fund not less than Rs 5 crores and use this corpus for alternative site development as a 'forest' or degraded

land remediation for social benefit (e.g. increase availability of green fodder for cattle owned by local villagers).

2. The industry may also like to commission a feasibility study to explore the creation of a 'green belt' between the Hirakud reservoir and the ash ponds (both existing and proposed). Such a green belt can hope to create a suitable ecosystem with native tree species.
3. The current assessment faced challenges on account of absence of baseline data for comparability purpose. We were informed by Prof P C Mishra that 20-25 years back Sambalpur University undertook following 3 projects in ITPS: (i) Flyash utilization in agriculture; (ii) ecological and taxonomical enumeration of tree vegetation in and around ITPS of OPGC at Banaharpali and strategy for future plantation program with emphasis on carbon sequestration and dust collecting capacity; and (iii) socio-economic and health status survey around ITPS of OPGC at Banaharpali. These studies were done long back, and it is time that the data is refreshed. Hence, we propose ITPS to carry out the following studies to generate baseline data for future impact assessment studies.
 - a. Biodiversity & Ecological Enumeration of tree vegetation in and around ITPS
 - b. Metal components and ecological magnification in soil, water, grass, trees and aquatic animals in and around ITPS
 - c. Socio-ecological studies, nutritional anthropometry and health status of people living in and around ITPS that would help evaluate Quality of Life of people, especially communities benefitting from ITPS' CSR activities versus communities who are not covered under such activities.
4. Long-term environmental monitoring should be implemented, with quarterly sampling of water (surface and groundwater) and soil (surface and subsurface) to track heavy metals (Cd, Hg, As, Pb, Fe) and physicochemical parameters, particularly in hotspots where contamination exceeded permissible limits. Seasonal assessments—pre-monsoon, monsoon, and post-monsoon—are essential to evaluate leaching and dilution effects, especially given the observed pH fluctuations in soil and water due to fly ash interactions.
5. Infrastructure upgrades are critical to prevent future breaches, including strengthening ash pond dykes with geosynthetic liners, implementing real-time structural monitoring systems, and improving leachate collection.
6. Community health and engagement must be prioritized through biomonitoring programs to screen residents for heavy metal exposure (blood/urine tests) and associated health disorders (skin, respiratory, neurological). Awareness campaigns should educate farmers on safe agricultural practices and distribute health advisories on drinking water safety.

BEFORE THE NATIONAL GREEN TRIBUNAL EASTERN ZONE BENCH,
KOLKATA

Original Application 89/2024/EZ

IN THE MATTER OF:

Gopinath Majhi

...Applicant

VERSUS

State Of Odisha & Ors.

...Respondent(s)

VAKALATNAMA

KNOW ALL to whom those present that I, Sri Brajabandhu Bhoi, OAS (SAG), S/o- Late Yudhistir Bhoi, Additional District Magistrate, Jharsuguda, At-/Po Dist-Jharsugua, 752056, Odisha on behalf of Respondents No. 2, do hereby appoint:

MR. RAMAN YADAV (D/5326/2019), ADVOCATE

C-167, LGF, DEFENCE COLONY, NEW DELHI – 110024

M- 8800457781 E-mail- officeoframanyadav@gmail.com

(hereinafter called the Advocate(s) to be my/our Advocate(s) in the above-noted case authorized them:

To act, appear and plead in the above-noted case in this court or in any other court in which the same may be tried or heard and also in the appellate court including High Court subject to payment of fees separately for each court by me/us.

To sign, file verify and present pleadings, appeals cross-objections or petitions for executions review, revision, withdrawal, compromise or other petitions or affidavits or other documents as may be deemed necessary or proper for the prosecution of the said case in all its stages subject to payment of fees of each stage.

To file and take back documents, to admit and/or deny the documents of opposite party. To withdraw or compromise the said case or subject to arbitration any differences or disputes that may arise touching or in any manner relating to the said case. To take execution proceedings.

To deposit, draw and receive money, cheques, cash and grant receipts hereof and to do all other acts and things which may be necessary to be done for the progress and in the course of prosecution of the said case.

To appoint and instruct any other legal practitioner authorizing him to exercise the power and authority hereby conferred upon the advocate whenever he may think fit to do so and to sign the power of attorney on our behalf.

And I/we the undersigned do hereby agree to ratify and confirm all acts done by the Advocate(s) or his/their substitute in the matter as my/our own acts, as if done by me/us to all intents and purposes.

And I/we undertake that I/we or my/our duly authorized agent would appear in court on all hearing and will inform the Advocate(s) for appearance when the case is called. I/we undersigned to hereby agree not to hold the Advocate or his substitute responsible for the result of the said case. The appointment costs whenever ordered by the court shall be of the Advocates(s) which he shall receive and retain for themselves.

And I/we the undersigned do hereby agree that in the event of the whole or part of the fee agreed by me/us to be paid to the Advocate(s), remaining unpaid he shall be entitled to withdraw from the prosecution of the said case until the same is paid up. The fee settled is only for the above case and above court. I/we hereby agree that once the fees is paid I/we will not be entitled for the refund of the same in any case whatsoever and if the case prolongs for more than 3 yrs. The original fee shall be paid again by me/us.

IN WITNESS WHEREOF I/we do hereunto set my/our hand to these presents the content of which have been understood by me/us on this 28th day of July, 2025

Raman yadav
Advocate(s)

Client

Brajchandra Bhoi

Addl. District Magistrate
JHARSUGUDA

Service of Additional Affidavit on behalf of Respondent No. 02 in OA No. 89 of 2024 titled Gopinath Majhi vs. State of Odisha & Ors.

1 message

Office of Raman Yadav <officeoframanyadav@gmail.com>

Mon, Jul 28, 2025 at 7:05 PM

To: Sankar Pani <sankarprasadpani@gmail.com>, fsec.ora@nic.in, paribesh1@ospcboard.org, rdcbsp@nic.in, revsec.od@nic.in, mscb.cpcb@nic.in, ee_mddburla@rediffmail.com, msobb@rediffmail.com, secy-moef@nic.in, dfo.hirakudwl@odisha.gov.in, "direnvodisha@gmail.com" <direnvodisha@gmail.com>

Cc: dm-jharsuguda@nic.in

Dear All,

This is to inform you that the Additional Affidavit on behalf of Respondent No. 2, in the captioned matter has been filed before the Hon'ble National Green Tribunal, Kolkata.

A copy of the same is being attached herewith for your reference.

This email serves as an advance service.

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Office of Raman Yadav
Advocate, Supreme Court of India
C-167, LGF Defence Colony, New Delhi -110024
Mobile: +91 88004 57781

**Additional Affidavit-R2_Gopianth Majhi.pdf**

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