Assessment of Water Pollution Indices and Distribution of Heavy Metals in Yamuna River Water in Delhi, India

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Approval Sheet

This thesis report entitled Assessment of water Pollution Indices and Distribution of Heavy Metals in Yamuna River Water in Delhi, India by Mahipal Singh Sankhla approved for the degree of Doctor of Philosophy in Forensic Science.

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis, entitled **"Assessment of water Pollution Indices and Distribution of Heavy Metals in Yamuna River Water in Delhi, India"** in fulfillment of the requirements for the award of the degree of Doctor of Philosophy in School of Basic and Applied Sciences and submitted in Galgotias University, Greater Noida is an authentic record of my own work carried out during a period from January 2018 to September 2023 under the supervision of Prof. (Dr.) Rajeev Kumar and Prof. (Dr.) Lalit Prasad.

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

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ABSTRACT OF THESIS

India's Yamuna River, the second-largest tributary of the Ganga, holds not only historical and cultural significance but also a crucial role in the ecosystem. Regrettably, the river's prominence has been overshadowed by the dire issue of pollution, particularly the alarming presence of heavy metals like lead, nickel, Chromium and zinc. Beyond the ecological concern, the pollution of the Yamuna River carries profound forensic implications that demand immediate attention and comprehensive remediation. The pollution of the Yamuna River is a complex problem with multiple sources, including rapid urban expansion, unchecked industrial growth, and the escalating demands of a growing population. The consequence of this pollution is not limited to ecological damage alone; it poses a severe threat to human health, aquatic life, and even has implications in forensic investigations. To assess the magnitude of this crisis, a year-long study was conducted throughout 2019. Water samples were meticulously collected from various locations along the river, with a gap of 20–25 days between collections, factoring in climate variations. Cutting-edge analytical techniques, such as Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Atomic Absorption Spectroscopy (AAS), were employed to scrutinize the water samples for heavy metal content. The results of this study are undeniably concerning. Heavy metals such as Pb, Ni, Zn, and Cr, known to be toxic to both humans and the environment, were consistently identified at concentrations exceeding the permissible limits set by the World Health Organization (WHO). What's particularly noteworthy is that these concentrations were notably elevated during the drier months, indicating a potential link between lead levels and climatic conditions. This is particularly forensically significant as it indicates that environmental factors might contribute to the distribution and concentration of heavy metals in the river. The study also brought to light disturbing levels of nickel chromium and zinc, both of which are well-known for their toxicity. These metals consistently exceeded WHO limits, with their peak concentrations occurring during the summer season. The repercussions of exposure to these toxic metals through water are grave, posing chronic health risks to humans and threatening the intricate aquatic ecosystem. From a forensic perspective, the presence of these toxic

metals in the river's waters can complicate investigations involving potential poisoning cases, unintentional heavy metal exposure, or even identifying the origin of pollutants. The cultural and spiritual significance of the Yamuna River adds another layer of complexity to the pollution crisis. This revered river is not only used for drinking, agriculture, and aquaculture but also holds a spiritual value deeply embedded in Hindu mythology. However, the contamination jeopardizes these multifaceted uses. The water's compromised quality renders it unsuitable for consumption, irrigation, and maintaining aquatic life. Furthermore, the pollution disrupts the equilibrium of aquatic ecosystems, thereby affecting the biodiversity of the river. The forensic significance of this pollution becomes evident when considering cases involving waterborne illnesses, poisoning, or even deaths resulting from heavy metal exposure. In such scenarios, identifying the presence and origin of heavy metals in the victims' bodies becomes crucial. Understanding the temporal and spatial distribution of these toxic elements in the river can provide valuable insights into their potential sources and routes of exposure. Forensic scientists can use this information to build a comprehensive picture of the events leading to an individual's exposure and subsequent health complications. The gravity of the pollution crisis compels immediate action. Remediation efforts must encompass pollution source control, efficient water treatment, and stringent regulations to mitigate further contamination. The collaboration of governmental agencies, industries, and local communities is essential to ensure the success of these initiatives. Establishing measures to reduce industrial emissions, proper waste disposal, and enhanced wastewater treatment are critical steps in this journey. Moreover, raising public awareness about the ecological, health, and forensic implications of the pollution is essential. Education and advocacy can drive behavioral change and create a culture of environmental responsibility. By empowering individuals to take action in their communities, a collective effort can be established to protect the Yamuna River's integrity. In conclusion, the pollution crisis in India's Yamuna River holds not only ecological and health implications but also profound forensic significance. The study's findings underscore the urgency of addressing this issue, not only for the sake of the river's health but also for the safety and well-being of the communities it serves. By taking immediate and concerted action, a multi-faceted approach can be adopted to reverse the damage, restore the river's vitality, and prevent the forensic complexities arising from heavy metal contamination. The Yamuna River deserves nothing less than meticulous care and swift action to preserve its sanctity and safeguard the lives it touches.

Dedicated

To

My Parents

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LIST OF ABBREVIATIONS

CR	Citation References
CPCB	Central Pollution Control Board
HDL	High-Density Lipoprotein
Zn	Zinc
Pb	Lead
Ni	Nickel
Cr	Chromium
GSH	Glutathione
DNA	De-oxy ribose nucleic acid
HNO_3	Nitric acid
H_2SO_4	Sulfuric
ICP-MS	Inductively coupled plasma mass spectrometry
AAS	Atomic Absorption Spectroscopy

LIST OF PUBLICATIONS

S.No	Title of the Paper	Journal/Conference	Year of Publication	GU-ID
1.	Impact of Variation in Climatic Changes in Concentration of Lead & Nickel in Yamuna River Water, Delhi, India	Materials Today Proceedings (Scopus), Volume 69.	2022	G-02867
2.	Estimation of Zinc Concentration in Yamuna River (Delhi) Water Due to Climatic Changes	Journal of Punjab Academy of Forensic Medicine & Toxicology (Scopus)	2021	G-01765
3.	Seasonal Variation of Lead and Chromium Concentration in Water of Yamuna River (Delhi)	Iranian Journal of Toxicology (Scopus), Volume 15.	2021	N-4328
4.	Seasonal Variation of Nickel and Zinc Concentration in Water of Yamuna River (Delhi)	Journal of Punjab Academy of Forensic Medicine & Toxicology, (Scopus), Volume 21.	2021	X-0233
5.	Zinc Impurity in Drinking Water and its Toxic Effect on Human Health	Indian Internet Journal of Forensic Medicine & Toxicology , (UGC Approved)	2019	G-1071
6.	Analysis of Monthly Site-Wise Differences in Lead Pollution in the Yamuna River Water, Delhi: Implications for Environmental Forensics and Human Health	Journal of Forensic Science and Medicine, (Scopus)	Submitted	

Chapter 1

Introduction

Introduction

1.1. Environmental Forensics

In our ongoing efforts to understand and mitigate the impacts of pollution on the environment, the field of environmental forensics has emerged as an invaluable tool (Johnson et al., 2015). In today's era of heightened environmental awareness, combating pollution and its far-reaching consequences has never been more crucial (Megson *et al.,* 2016). Environmental forensics is a multidisciplinary field with the objective of systematically researching, interpreting, and presenting information related to pollution sources, timing, quantity, and culpability (Morrison & Murphy, 2010). This discipline draws upon scientific expertise from diverse domains, including chemistry, geology, biology, physics, and law. It sheds light on the intricate facets of the ecological milieu, encompassing soil, water, air, and living organisms—a complex mosaic of environmental pollution (Sanganyado *et al.,* 2020). The services provided by environmental forensics span a wide spectrum, from pinpointing pollution sources and reconstructing contamination timelines to predicting the movement of pollutants and offering critical support in legal and regulatory matters (Yim *et al.*, 2012). As challenges and technologies evolve, environmental forensics continues to exemplify scientific precision, guiding us toward a more sustainable and accountable future for safeguarding the health of our planet (Lal *et al.*, 2021).

1.2. Water

Water, which is the most abundant material on Earth, is essential to all living forms. Its accessibility, both in terms of quantity and quality, is of utmost importance for all types of communities, from the smallest hamlets to the largest metropolitan centres (Gleick, 2014). Due to its deep connections to both social welfare and the support of life itself, water quality plays a crucial role in determining the wellbeing of mankind (Wutich *et al.*, 2020; Edokpayi *et al.*, 2018). The importance of water cannot be understated in the context of India, a country with a long history of cultural, economic, and ecological development (Tilt, 2018). Indigenous cultures frequently refer to the nation's waterways as goddesses, representing not just the nation's physical sources of life but also its spiritual and cultural ties (Katyaini & Barua, 2015). However, a number of causes throughout time have degraded the integrity of these rivers. Unintentional urban growth, unrestricted suburbanization, quick industrialisation, rising population density, and pervasive agricultural practises have all played a part in the long-term contaminating of these holy water sources (Goel *et al.*, 2020). Finding sustainable methods to protect these essential water sources is of the utmost significance as India struggles with the complicated interaction between development and environmental protection (Swamy *et al.*, 2018). India can work to maintain its history of social and economic prosperity while encouraging ecological harmony and assuring a healthy future for both its people and the many ecosystems that depend on these waterways by tackling the problems at the root of pollution. (Mishra S. *et. al*. 2006).

(Malik, A. 2004) Water is one of nature's essential necessities for supporting life in its fullness, as the adage "No water, no life" concisely states. Water acts as the principal solvent for all metabolic processes in living things, highlighting its crucial function in sustaining life itself (Gull & Pasek, 2021). Unpolluted water is made up of two hydrogen atoms and one oxygen atom at its purest state. This results in a colourless, pleasant liquid that is cold, well-aerated, free of infectious agents and dangerous impurities (Malik *et al.*, 2020). Rainwater is pure until it comes into contact with outside elements during its descent or the collection devices (Yannopoulos *et al.*, 2019). Impressively, water covers around 73% of Earth's surface, and of the 97% of water that is available, a substantial amount is found in the huge seas (Hutchison et al., 2017). Less than 1% of the water on Earth may be accessed as freshwater, and only around 2% is trapped in icebergs (Enderlin et al., 2016). In the case of India, a country gifted with a variety of landscapes, the entire country receives yearly precipitation on over 370 million hectares of land (Pathak et al., 2018). However, a sizeable fraction of this water—roughly 30%—experiences direct evaporation, whereas only around 22% penetrates into the earth to recharge aquifers (Merino et al., 2016). Through different drainage systems, the residual water eventually enters bigger water bodies. This complicated water cycle emphasises how vital it is to protect water resources since they support not just human existence but also the intricate web of life that thrives on our planet (Kansoh *et al.*, 2020).

(D.S. Rathore. *et. al.* 2014). Water contamination can result from a number of biological and chemical processes, making the water unsafe for human consumption. An worrying data from India shows that pollution has a negative impact on over 70% of water sources (Ghuman & Sharma, 2019). The main cause of this pollution is the incorrect disposal of home and industrial garbage. Manufacturing waste and domestic sewage are frequently dumped straight into connecting streams and aquatic bodies without any kind of treatment, especially in underdeveloped nations (Sharma *et al.,* 2017). Local wastewater frequently degrades the quality of the water by including a substantial amount of biological matter, nitrates, phosphates, chlorides, detergents, inorganic salts, and oils (Sarker *et al.,* 2021). In contrast, manufacturing wastes introduce a wide range of pollutants, such as coliform bacteria, heavy metals, pesticides, fertilisers, detergents, organic and inorganic salts, and oils (Bhardwaj *et al.*, 2020). Both the intended target of industrial operations as well as non-target animals within aquatic environments face significant hurdles as a result of these contaminants (Dhamodharan *et al.,* 2019). The serious consequences of water pollution highlight the urgent need for all-encompassing measures to control and lessen the impact of pollutants, protecting the integrity of our water resources and the wellbeing of both natural and human populations (Sol et al., 2020).

(Martin, 1982). The primary cause of environmental degradation is water pollution. Water is a vital element, and the purity of that element is directly related to healthy human life. Water of high quality is needed due to industrialization and a wide range of human activities, but its pollution is getting worse every day. (Aradpour *et al.,* 2021). On the basis of the current situation, it is assumed that good quality water will soon become scarce due to the ever-growing population and industrialization, making it very difficult for people to live their normal lives. Due to this, it is now crucial to have a reliable technology for purifying water. (Rashmi *et al.,* 2020).

Pollutants entering water sources are classified broadly into local waste & oxygen requiring water, pathogenic agents, plant nutrients, chemical like insecticide, herbicides & detergent minerals and chemical, sediments from terrestrial erosions, dangerous materials, and temperature from energy and industrial plants (Akpomie & Conradie, 2020). India is wealthy in ground water sources. There is a huge system of waterways and sedimentary deposits. Conditions, though, differ from one region to another. Some areas have exaggerated scarcity, while others frequently flood. Water resources are being depleted as a result of rising population and increased demand for water for irrigation, human consumption, and industrial use.Conditions, though, differ from one region to another. Some areas have exaggerated scarcity, while others frequently flood. Water resources are being depleted as a result of rising population and increased demand for water for irrigation, human consumption, and industrial use (Shu *et al.,* 2021).

1.3. Pollution

Unwanted changes to our environment lead to contamination, which has a negative impact on both humans and animals as well as plants. When short-term economic profits take precedence over the long-term ecological benefits essential for humanity's well-being, this tragic scenario occurs (Speight, 2020). Compared to any natural occurrence, man's activities have had a bigger impact on environmental dynamics. As a result of human activities in recent years, a variety of unneeded and abandoned items have polluted the very soil, air, and water that support life (Zamora-Ledezma *et al.,* 2021). We have unwittingly threatened the delicate balance that sustains our planet and its inhabitants in our pursuit of momentary convenience, highlighting the urgent need to reevaluate our methods and switch to a more sustainable strategy that ensures the coexistence of environmental preservation and human advancement. (Canli *et al.,* 2003).

(Duruibe *et al.,* 2007). A wide range of liquid, gaseous, or solid chemicals that are present in more than normal quantities, are the result of human activity, and have negative effects on the environment are classified as contaminants. The intensity of these pollutants' harmful effects on human health directly depends on their type and concentration (Dharwal *et al.,* 2022). Unbelievably, the average person needs about 12 kilograms of air per day, which is about 12 to 15 times more volume than we take in through meals. As a result, even minute amounts of pollutants in the air are more significant than equal levels found in our diet (Joshi *et al.,* 2021). It should be noted that toxins have an effect on more than just the air; pollutants that enter water bodies have the ability to spread across great distances, especially within ocean ecosystems, emphasising the interconnectivity of our planet's natural systems (Cheng *et al.,* 2020). This highlights the urgent need for awareness and all-encompassing action to stop the spread of toxins, protecting the health of our environment and, therefore, our personal wellbeing.

From an environmental viewpoint pollutant can be categorized as following:

1.3.1. **Non-Persistent or Degradable Pollutants**: This pollutant can be quickly fragmented by the naturally occurring processes e.g., domestic sewage, discarded vegetables, etc. (Hernández *et al.,* 2022)

1.3.2. **Persistent or Slowly Degradable Pollutants**: Contaminants which endure in the situation for many ages in an unaffected situation and take years or greater to decompose e.g., DDT and Plastics (Li *et al.,* 2023).

1.3.3. Non-Degradable Pollutants: Such pollutants can't be decomposed by naturally occurring process. As they are liberated in the atmosphere, they are problematic to eliminate and endure to collect e.g., poisonous constituents like lead, chromium, nickel, etc. (Gebre *et al.,* 2021)

1.4. Water Pollution

Over recent times, the heavy metal poisoning of Earth's water and atmosphere has become a ubiquitous and lasting issue. Due to the persistent and unyielding nature of these metals and their deep and sometimes fatal effects on diverse types of life, this situation has attracted the attention of scientists, environmentalists, and politicians alike (Agarwal & Xue, 2019). Due to their ability to have hazardous effects and their worrisome propensity to accumulate within aquatic ecosystems, heavy metals stand out as a particularly serious worry among the variety of ecological contaminants that plague our world (Zeng *et al.,* 2020).

(Goldstein, 1990). Heavy metal pollution of Earth's oceans and atmosphere has recently become a pervasive and long-lasting problem. This issue has grabbed the attention of scientists, environmentalists, and politicians alike because of the persistent and unyielding nature of toxic metals and their profound and occasionally fatal consequences on many sorts of life. Among the many ecological pollutants that afflict our planet, heavy metals stand out as a particularly severe concern due to their potential for harmful consequences and their alarming propensity to accumulate inside aquatic ecosystems (Yang *et al.,* 2020). Recent investigations have illuminated the significant environmental effects that human activities have had on the watery ecosystems that fish and other aquatic life forms call home. The result of these efforts has increased attention on the problem of aquatic pollution and its harmful effects. This worrying situation has been exacerbated by a number of causes, including fast population growth, concentrated urbanisation, greater industrial activity, and increased exploitation of natural resources, such as arable land (Bird *et al.,* 2019).

The increased waste discharge from industrial activities is to blame for the growing pollution of aquatic environments. Notably, significant amounts of organic matter are released into water bodies, frequently as a result of industrial operations like pulp mills and sugar processing facilities. These operations produce finely split organic waste products that easily degrade due to microbial activity, causing oxygen levels to drop in the area around these discharges (Quesada *et al.,* 2019). As significant amounts of organic matter decompose in aquatic habitats, inorganic nutrients like nitrate, phosphate, and ammonia are released in addition to the immediate decrease in oxygen concentrations. This high nutrient enrichment of the water encourages the growth of algae, or what is known as an algal bloom. Intense oscillations in oxygen levels, which are necessary for the survival of aquatic creatures like fish, might result from this fast algal development. When these variations are significant, they can reach critical levels, which can lead to fish mortality and other negative effects (Sikder *et al.,* 2019). A decrease in water quality may result from the worsening of these problems, which is brought on by high organic loads. Eutrophication is the term used to describe this occurrence, which is characterised by elevated nitrogen levels and excessive algae growth. The equilibrium of aquatic ecosystems is upset when nutrient levels rise, resulting in imbalances that might be harmful to aquatic life.

In conclusion, the increased interest in the toxicological effects of numerous pollutants, particularly heavy metals, has been sparked by the widespread concern about the quality of food items. Aquatic habitats have suffered the most from contamination within the larger context of environmental deterioration, which has been fueled by elements such rapid urbanisation, industrialisation, and mismanagement of natural resources. The effects, which include oxygen deprivation, nutrient overabundance, and algal blooms, are severe and endanger aquatic creatures, particularly fish. To guarantee the continued health and resilience of these sensitive ecosystems, it is crucial that coordinated efforts are directed towards reversing these trends and minimising the causes of water pollution.

1.5. River Basin Degradation and Pollution

The Indian economy has seen a remarkable shift over the past five decades, one that has been characterised by strong growth, intense agricultural practises, quick urbanisation, and industrialisation. Increasing globalisation and a paradigm change in economic policy have sped up this trajectory even further. India's economy is now the third biggest in Asia and the 12th largest in the world, behind Japan and China (Giri, 2021). Numerous predictions predict that by the year 2050, India would grow to become the third-largest economic powerhouse on the world arena, with a total GDP of about 1 trillion US dollars (Evans *et al.,* 2019). The Ganga River and its tributaries, which include Betwa, Tonnes, Ken, Chambal, and Sindh, have played a key part in the backdrop of this economic history. Together, these tributaries produce around 71% of the catchment area for the Ganga basin, with the drainage from major rivers and minor streams making up the remaining 29%. More specifically, the catchment basin of the Yamuna River contains 10.7% of the country's total land area and 40.2% of the Ganga basin (Matta *et al.,* 2022).

The economic expansion waves have not spared this complex network of rivers, as a number of variables have had varying effects on how well it functions and is maintained. Numerous multipurpose projects have been started in various Indian river basins in an effort to advance the economy. These initiatives have a wide range of uses, including irrigation, fisheries development, hydropower generating, and water diversion (Ghosh *et al.,* 2019). These projects not only helped the economy expand and thrive, but they also significantly altered the river systems. In addition, the introduction of municipal, industrial, and agricultural waste into the environment is a different source of pollution, having a negative impact on rivers. River sources are especially important among these (Xue *et al.,* 2020). The importance of river sources, especially surface waterways like streams, in supplying water to people, animals, and industry makes it imperative to protect these crucial resources from contamination. A variety of organic and biochemical contaminants, including heavy metals, are introduced into river sources when urban, industrial, and agricultural effluents make their way into rivers. The quality of waterbodies is significantly hampered by this flood of contaminants, which also has an impact on the ecology and the communities' way of life. In conclusion, India's economy has experienced tremendous expansion over the past 50 years, which has been characterised by urbanisation, industrialisation, and intensification of agriculture (Sarker *et al.,* 2021b). These patterns have spread across its river systems, changing their courses in a variety of complex ways. These economic advancements have been accompanied by the problem of pollution, as a result of the influence of urban, industrial, and agricultural waste on river sources and, consequently, on the entire aquatic ecosystem. The sustainability of India's economy and its ecosystems depends on the protection of these key resources and the recovery of their health (Wan & Wang, 2021; Loi *et al.,* 2022). Figure 1.1 shows the sources of water pollution.

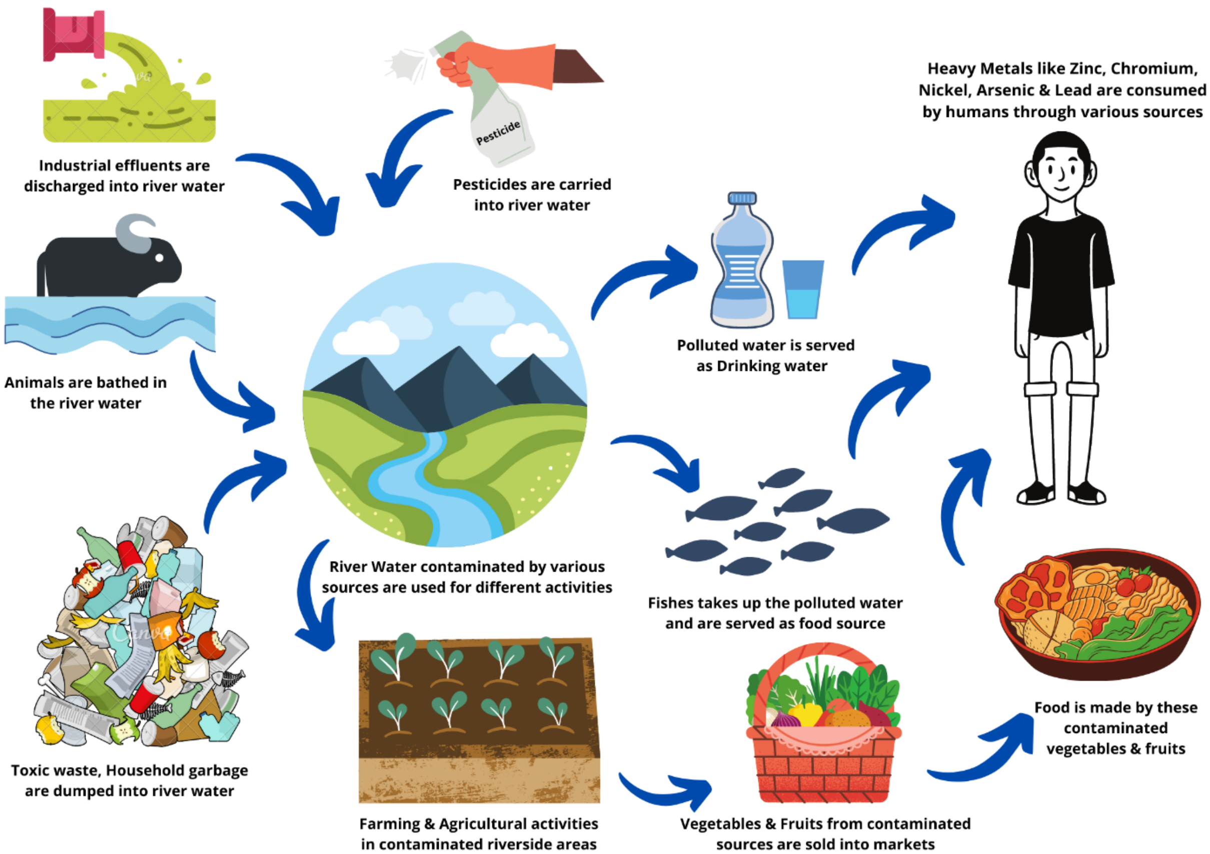

Figure 1.1: Major Source of Water Pollution & Food Chain

1.6. Heavy Metals

The term "heavy metal" refers to a group of metallic and metalloid elements with atomic densities exceeding 4g/cm3 or at least five times denser than water. These heavy metals, also known as trace elements, are present in minuscule quantities within biological systems. What sets heavy metals apart from other hazardous chemicals is that they are neither produced nor broken down by human activities. However, their interaction with humans can significantly affect well-being through two primary pathways (Kim et al., 2019).

First, anthropogenic activities that have an impact on the environment might cause heavy metals to have an impact on human health. This can entail the intentional or unintentional discharge of heavy metals into the land, air, food, or water supply (Nyambura *et al.*, 2020). Heavy metals are dispersed into numerous environmental compartments through processes including industrial activities, trash disposal, and vehicle emissions. Once in the environment, these heavy metals have the potential to infiltrate the food chain, where they might then have an impact on human health through eating (Zhou *et al.*, 2019).

Second, heavy metals may vary their chemical speciation or form to produce their effects. The particular arrangement of atoms inside a molecule or compound is referred to as chemical speciation (Awasthi *et al.*, 2022). According on the chemical form they take, the toxicity of heavy metals can change. The toxicity of the same metal might vary depending on its chemical state. As an illustration, some heavy metals may be more readily absorbed by the body or have a stronger affinity for adhering to cellular components, amplifying their negative effects on health (Sankhla & Kumar, 2019).

Exposure to heavy metals can have serious effects. They may eventually build up in numerous tissues and cause persistent health problems. These negative health impacts can range from interference with biological functions to more serious consequences including organ damage, aberrant development, and even cancer. As a result, the danger of exposure to heavy metals goes beyond short-term toxicity and includes long-term consequences for environmental sustainability and public health (Parihar K., 2019).

1.6.1. Toxic Effect of Heavy Metals on Living Beings

Depending on their concentration, heavy metals can have either good or bad impacts on humans, animals, and plants. While certain heavy metals are harmful even at low quantities, others are necessary for human health and can be fatal when ingested at high amounts (Zaynab *et al.*, 2022). Metal exposure has been a continual factor in human evolution, and as a result, different quantities of necessary and non-essential metals have been found in different people (CR et al., 2022). Through food ingestion and environmental exposure, these metals can enter the body and eventually accumulate in several organs, including the liver, kidneys, and brain. The capacity of these metals to interact with biological structures will determine how they behave inside the body (Sankhla *et al.,* 2016). Extra metals in the body can either accumulate in different tissues or be eliminated through the urine and faeces. However, some metals can become dangerous when present in high concentrations. When present together, certain metals have additive effects, whereas others work separately, even antagonistically or synergistically.

Various levels of essential and non-essential metals have been detected in various persons as a result of the ongoing role that metal exposure has had in human evolution. These metals may enter the body through food consumption and environmental exposure, eventually accumulating in a number of organs, including as the liver, kidneys, and brain (Sankhla *et al.*, 2019). How these metals behave within the body will depend on their ability to interact with biological structures. Additional metals in the body can either build up in various tissues or be excreted in the urine and faeces. However, when present in large quantities, some metals can become hazardous. Some metals act additively when combined, but others act alone, even antagonistically or synergistically (Chopade *et al.,* 2022).

In conclusion, there are numerous and intricate interactions between heavy metals and biological systems. These metals have a variety of effects that can be both beneficial and harmful to health, from vital contributions to normal body processes. The implications of exposure to heavy metals depend significantly on the quantity of exposure, the particular metal involved, and the biological setting. For addressing the dangers associated with heavy metal exposure and ensuring the health of ecosystems and human populations, it is crucial to comprehend these processes.

1.6.2. Heavy Metal Contamination of Aquatic System

Aquatic systems get contaminated for a number of reasons, including both natural and human-caused variables that are frequently linked. Anthropogenic sources—human activities—contribute greatly to the decline of these vulnerable ecosystems. These sources include a wide range of factors, such as waste management, chemical use, and industrial operations. Natural occurrences can also contribute to them, although human actions frequently have the biggest influence. The release of effluents from local industrial processes and industries is one of the main anthropogenic sources of aquatic pollution (Komijani *et al.,* 2021). These effluents, which are full of contaminants, end up in water bodies where they change the chemistry and have a negative impact on the aquatic ecosystem. The use of pesticides and inorganic fertilisers in agricultural practises can also result in runoff, which can introduce dangerous compounds into adjacent water systems (Häder *et al.,* 2020). Pollutants from different sources can also be transported into aquatic environments by water overflow, whether from severe rain or flood occurrences. A additional factor in water contamination is the discharge of garbage from landfills and dumping sites, which can introduce poisons and pollutants (Vardhan *et al.,* 2019). Transport-related activities can also bring pollutants into water bodies, affecting aquatic life and water quality, such as shipping and harbour operations. Additionally, the environmental persistence of some compounds, including heavy metals in the soil, over an extended period of time can result in their progressive leaching into water systems. Another way that toxins enter aquatic ecosystems is by atmospheric deposition, in which pollutants from the air descend into water bodies (Bashir *et al.,* 2020).

1.6.3. Destiny of heavy metals in water system (heavy metal buildup)

Water ecosystems often retain low levels of heavy metals in their natural condition. These substances have a tendency to build up, combine, or bind in sediments, marine ecosystems, and aquatic species because they are not biodegradable. As a result, this event causes heavy metal pollution of aquatic organisms. Metals may be ingested by aquatic creatures through a variety of processes after entering water systems. The influence of biomass, which occurs when metals are absorbed and integrated into the tissues of aquatic creatures, is one such process (Alam *et al.*, 2020). Bioaccumulation, in which metals accumulate over time in organisms as a result of repeated exposure, makes this process much worse. Metals can travel up the aquatic food chain as it develops, accumulating at higher trophic levels and eventually building up to potentially dangerous levels. When their concentration reaches noticeably high levels, heavy metal buildup in aquatic creatures becomes very troublesome. At these high concentrations, the deposited metals can become poisonous, endangering the wellbeing of aquatic animals as well as the environments they live in (Karaouzas *et al.,* 2021).

1.7. Yamuna River

The Yamuna River, depicted in Figure 1.2, is a prominent and revered waterway in India, often likened to the mighty River Ganga. It holds a significant place in Indian mythology and is home to numerous religious sites. Paonta Sahib in Himachal Pradesh, Yamunotri in Uttaranchal, Vrindavan, Mathura, Allahabad, and Bateshwar in Uttar Pradesh are some of the sacred places located along its banks. Additionally, major urban centers such as Sonipat, Yamuna Nagar, Delhi, Faridabad, Gautam Buddha Nagar, Mathura, Etawah, and Agra are situated on its riverbanks. The river basin of the Yamuna is highly productive in agriculture, particularly in Haryana and western districts of Uttar Pradesh, making it a vital contributor to the nation's economy. However, like many other river systems, the Yamuna River faces challenges due to industrialization, urbanization, and rapid agricultural expansion. Its entire course spans approximately 1376 kilometers, traversing five states. The river originates from the Yamunotri glaciers, known as Saptrishi Kund, near the Bander Punch mountains, located at approximately 380º 59’ N and 780º 27’E in the Mussoorie range of the lesser Himalayas, at an elevation of approximately 6320 meters above mean sea level in Uttarkashi District, Uttarakhand. The primary stream of the Yamuna River is fed by numerous meltwater channels, with the main one emerging from the hills at a height of 3250 meters, 8 kilometers northwest of Yamunotri. Hot springs further contribute to its flow at the coordinates 310º 2’12” N and 780º 26’ 10”. As the river descends from its source, it meanders through bends and cascades for around 120 kilometers before reaching the Indo-Gangetic plains at Dak Patthar in Uttarakhand. At Dak Patthar, the river's flow is regulated by a dam and diverted into a channel for irrigation and energy generation. From Dak Patthar, the river proceeds toward the revered Sikh pilgrimage site of Paonta Sahib in Himachal Pradesh and then to Hathni Kund in Haryana, where a significant portion of its waters is diverted through the Eastern and Western Yamuna Canals for agricultural purposes. During dry periods, no water is allowed to flow downstream of Hathni Kund dam. Consequently, the riverbed downstream of Hathni Kund may be nearly dry in some stretches. Downstream of Hathni Kund, the river's flow is sustained through groundwater seepage and contributions from various tributaries and smaller streams. It continues its journey and reaches Delhi at Palla, covering a distance of approximately 224 kilometers. At Wazirabad, a dam intercepts the river's flow for water supply to the urban population of Delhi. In the summer, the river is often blocked at Wazirabad due to inadequate water availability to meet the city's demands. Downstream of Wazirabad, the river's flow is again hindered and diverted into the Agra Canal for irrigation through an additional dam at Okhla. Similar to the situation downstream of Wazirabad, the water in the river at Okhla primarily consists of municipal and industrial effluents channeled through multiple sewage drains connecting to the Yamuna River. After flowing approximately 22 kilometers downstream from the Okhla dam, the Yamuna River merges with the Ganga River at Allahabad, having traveled a distance of about 790 kilometers through towns such as Bateshwar, Agra, Hamirpur, Pratapgarh, and Etawah. In essence, the Yamuna River is a major tributary of the sacred Ganga River and holds a vital place in Indian culture and geography. Its significance extends beyond its cultural and religious importance, as it also plays a crucial role in the nation's economy. However, like many river systems, it faces challenges arising from industrialization, urbanization, and rapid agricultural expansion (CPCB, 2016).

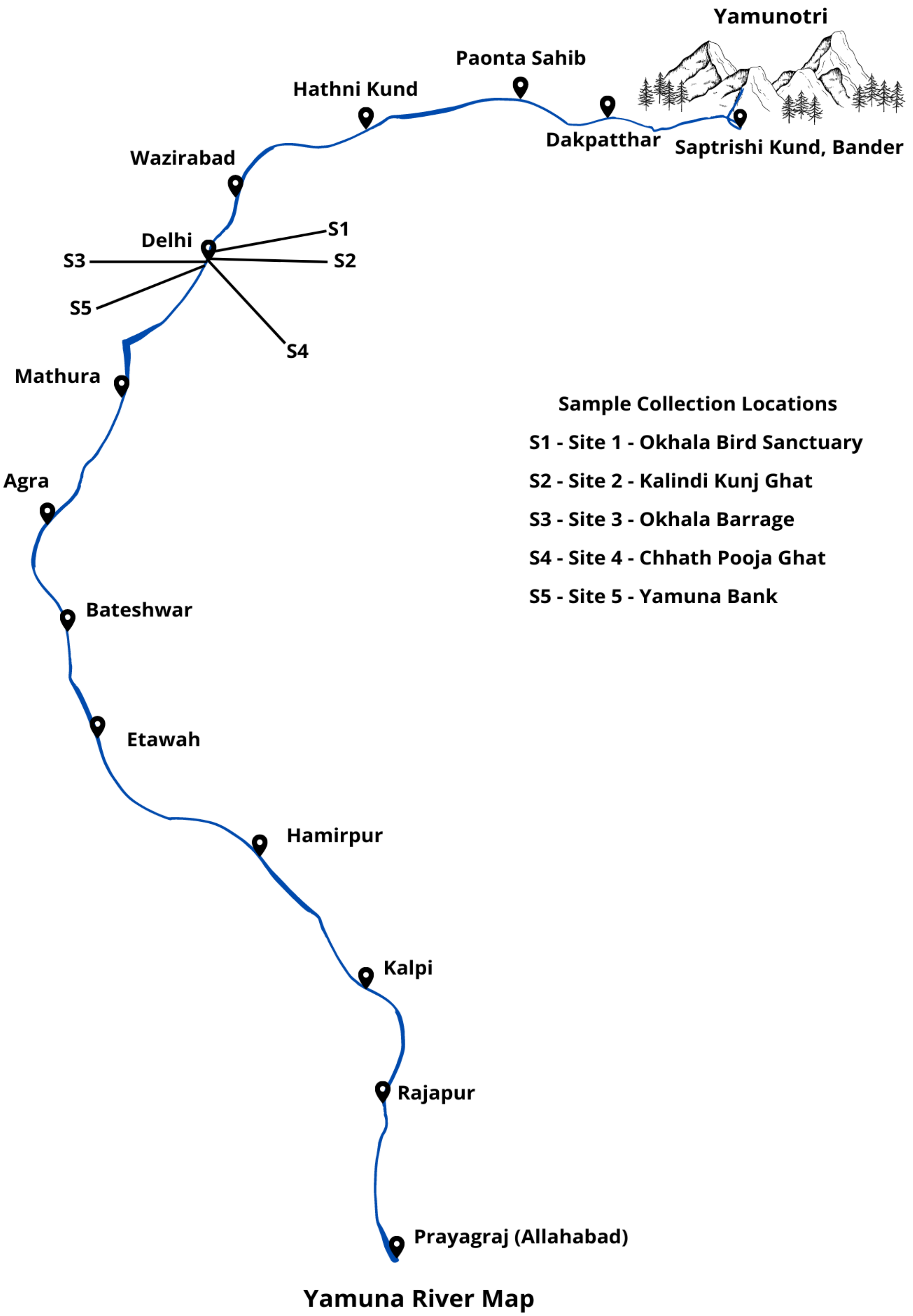

Figure 1.2: Yamuna River Map with Site Location

1.8. Objectives of The Study

1.5.1. General Objective

1. The primary objective of this study is to assess the water quality and investigate the distribution of heavy metals within the waters of the Yamuna River.

1.5.2. Specific Objective

1. To figure out the levels of major heavy metals in the Yamuna River's water.
2. To investigate whether variations in temperature and humidity influence the concentrations of water pollutants within the Yamuna River.
3. To assess the seasonal fluctuations in the concentrations of major heavy metals in the waters of the Yamuna River, aiming to understand potential patterns and trends.
4. To evaluate the potential toxic effects of heavy metals, present in the river water, with a focus on their relevance for forensic considerations.

Chapter 2

Review

Of

Literature

Review of Literature

Highly contaminated food and water consumption can be fatal to people and can cause genetic disorders. As a result of Allahabad's rapid industrialization, toxic heavy metals are continuously released into the waterways. Metals pose a significant and widespread ecological problem due to their high toxicity and ability to accumulate in living organisms. Numerous toxicologists have dedicated their efforts to studying and identifying heavy metals in various environmental components, including water bodies, soil, sediments, plankton, and fish organs. This paper aims to conduct a comprehensive examination of heavy metal concentrations in water, fish, sediments, and agricultural products like vegetables grown in areas adjacent to riverbeds. Furthermore, it strives to offer recommendations for mitigating the health hazards associated with the consumption of these contaminated resources, particularly in light of technological advancements and the industrial expansion near water bodies, which have become prominent sources of pollution, potentially endangering public health through tainted food and water supplies (Suciu *et al.,* 2008). There are numerous publications about heavy metal detection that are available all over the world and have been covered in this chapter. Some gaps or omissions are possible due to the volume of references gathered from the range of sources. The following are a few of the authors' efforts to cover as much information as possible: Nanotechnology is a cutting-edge scientific discipline that modifies materials at a microscopic scale to address environmental problems. Due to their security, extensive surface area, simplicity in breakdown, and potential for resolving environmental problems, carbon nanomaterials are unique. Heavy metals in water, which are harmful to human health, are one major issue. Because of their small size and unique properties, carbon nanomaterials like nanotubes, fullerenes, graphene, and activated carbon are becoming more significant. Heavy metals from water wells can be eliminated by them. In this review, we examine recent developments in the use of these carbon materials to purify water contaminated with heavy metals as well as their environmental benefits. We also discuss how safe these materials are. Typically, elements with metallic properties and an atomic number >20 are considered heavy metals. Cd, Cr, Cu, Hg, and Zn are the most typical heavy metal contaminants. Metals are organic elements of soil. Zn, Cu, Mn, Ni, and Co are a few of these metals that are essential micronutrients for plant growth, whereas Cd, Pb, and Cr have unknown biological functions. Typically, metals with an atomic number of 22 to 92 in all groups from periods 3 to 7 of the periodic table are thought of as heavy metals. Some of the metals such as Cu, Zn, Cd, Pb, Fe, Cr, Co, Ni, Mn, Mo, Se are essential in trace quantities for the general well-being of living organism but an excess of these can be lethal (Sharma and Rehman, 2009).

According to Suciu et al. (2008), heavy metals have been attributed various definitions, but they can generally be regarded as a group of elements with metallic characteristics, encompassing actinides, certain metalloids, lanthanides, and transition metals. Additionally, heavy metals are often defined by their specific density, typically exceeding 5 g/cm3, making density a defining characteristic. Adelekan and Abegunde (2011) expand on this definition, stating that heavy metals are chemical elements with densities greater than 4 g/cm3, commonly found in various soils, rocks, and water within terrestrial and freshwater ecosystems. They may also refer to chemical substances with densities surpassing 4 g/cm3 present in these environmental contexts.

Lenntech (2010) provides a concise characterization, describing any metallic element with relatively high density that can be toxic or poisonous even at low concentrations as a heavy metal.

(Saha, P. K. *et.al.,* 2011) Due to their toxicity and accumulation in aquatic habitats, heavy metal contamination in the environment is a serious concern. Contrary to most pollutants, trace metals are not biodegradable, and they go through a global ecological cycle with natural water being the main pathways. Since heavy metals are not biodegradable, they can accumulate along the food chain and have their toxic effects at locations that are far from the pollution source.

(Ayandiran T.A. *et al.,* 2009) The ecological balance of the aquatic environment may be severely impacted by heavy metal contamination of a river, and the diversity of aquatic organisms is constrained as contamination levels rise.

(Obaroh *et al*., 2012) When a river is contaminated with heavy metals, the ecological balance of the aquatic environment may be severely disrupted, and the variety of aquatic organisms is constrained as the contamination level increases. (Kane, S. *et.al.* 2012) Even though some of these metals are necessary as micronutrients, their high concentration in the food chain can have negative effects on the environment and aquatic ecosystems, putting users and the ecosystems at risk.

(Singh, J. *et al.* 2011) Agricultural runoff that contains heavy metals enters the aquatic environment and can be toxic to aquatic plants and animals. Heavy metal contamination in compostable waste, including sewage sludge, municipal solid waste, and pig manure, may alter the composting process by inhibiting bacterial growth. The earth worm life cycle is impacted by heavy metals during the vermicomposting process. Therefore, the current study's objective was to assess the effects of compost containing heavy metals on soil, plants, human health, aquatic life, as well as the effects of compostable materials containing heavy metals on the composting process. Through the processes of organic matter decomposition and mineralization, microbial activities were the primary factor in increasing the amount of nutrients that were available to plants in agricultural soil. Because these metals inhibit physiological metabolism, they cause crops to produce less when they are absorbed by plants from the soil. Concerns about both human health and the environment arise from the uptake of heavy metals by plants, their subsequent accumulation in human tissues, and their biomagnification through the food chain. Aquifers become contaminated with heavy metals from agricultural runoff, harming aquatic life. So, if the compost is going to be used in agriculture, it needs to be pathogen- and heavy metal-free.

(Saha, P. K. *et al.*, 2011) Heavy metal exposure has been linked to a number of human diseases, including kidney damage, cancer, abortion, effects on intelligence and behaviour, and in some cases, death due to exposure to extremely high concentrations of heavy metals.

(Conama, 2010) It has been established that heavy metals are toxic to both human and environmental health. High levels of nutrients, organic matter, and a nearly neutral pH were present in sewage sludge, making it suitable for use in agriculture. Additionally, heavy metal concentrations were below the legal limits set by Brazilian law.

2.1.1. Sources of Heavy Metal Contamination in Water

2.1.2. **Natural sources**

In the natural world, elevated concentrations of trace metals can result from geological events such as volcanic eruptions, rock weathering, and the leaching of metals into rivers, lakes, and oceans due to water-induced processes (Bagul et al., 2015; Armah et al., 2014). Additionally, small quantities of heavy metals are released into the environment during mining activities and the unregulated smelting of large quantities of metal ores using open flames. Furthermore, the industrial revolution contributed to the release of heavy metals into the atmosphere through mining and the processing of metals from natural resources. Similar to the discharge of domestic, agricultural, and automotive exhaust waste, trace amounts of heavy metals are introduced into the environment. The following list highlights various human activities that contribute to heavy metal contamination in the environment:

1. Smelting and processing of metal ores.
2. Mining operations.
3. Emissions from automotive exhaust systems.
4. Combustion of fossil fuels such as coal, gasoline, and kerosene.
5. Discharge of agricultural waste.
6. Release of industrial waste.
7. Use of pesticides containing heavy metal compounds (salts).
8. Disposal of domestic waste.

2.1.3. Industrial Effluent

Some of the main sources of pollution include municipal waste, domestic sewage, and industrial waste that is discharged directly into the natural water system. Water contamination results from the discharge of untreated waste. The primary cause of surface and groundwater contamination is the untreated discharge of manufacturing effluents into water bodies (Afzal, M.S. *et al*,. 2018). Wastewater, which contains a variety of microorganisms, heavy metals, nutrients, radionuclides, pharmaceuticals, and personal care products, makes its way to surface water resources, where it damages the aesthetic value of the water and causes irreparable harm to both humans and the aquatic ecosystem. These toxins contaminate aquatic resources, reduce the amount of usable water available, raise the price of water purification, and have an impact on food supplies (Edokpayi, J *et al.*, 2017). Water pollution is brought on by contaminants such as acid, a toxic metal, agrochemicals, dyes, and other untreated waste discharged from industries. Discharged products, which frequently cause pollution, also lead to a loss of biodiversity in the aquatic ecosystem and may put humans at risk for cholera, diarrhoea, and other illnesses (Sonone, S.S., *et al.,* 2020).

2.1.4. Dumping of Holy Materials

The Yamuna is regarded as a holy river in India. Devotees throw poly bags filled with various sacred objects into rivers, increasing the amount of suspended and floating materials (organic, inorganic, and toxic), adding to the ugliness (Bhargava, D.S. 2006).

2.1.5. Mass bathing by devotees

At Mathura (on the Yamuna's right bank), mass bathing occurs frequently throughout the year during various religious occasions and festivals. Unfortunately, there are no sanitary facilities along the river's banks. As a result, a sizable portion of the floating population uses river catchments for open defecation. As a result, pathogenic and organic contaminants from the river catchments frequently enter the river due to rain, sudden releases of water from the upstream side, and overflow of drains (Bhargava, D.S. 2006).

2.1.6. Mineral extraction

Mineral processing operations have the potential to significantly increase heavy metal pollution through both direct extraction processes and leaching from ore and tailings stockpiles (which frequently involve size reduction, greatly increasing the surface area for mass transfer (Sankhla, M.S. *et al*.,2016a).

2.1.7. Electronic waste

Manufacturers of electronic products are legally obligated to provide disposal instructions in their user manuals. Proper management and disposal of electronic waste (e-waste) are essential to prevent a range of health issues affecting the skin, respiratory system, gastrointestinal system, immune system, endocrine system, nervous system, and even the development of cancer. E-waste is a significant source of heavy metals, hazardous chemicals, and carcinogens. Improper disposal of information and communication technology (ICT) waste can have alarming consequences on both the environment and human health, especially given the exponential growth in the use of electrical and electronic equipment (EEE) aimed at bridging the digital divide (Sankhla, M.S. et al., 2016b).

2.1.8. Power generation plants

Coal-fired power generation is a significant non-point source of heavy metal pollution, and mercury emissions from boiler flues can contaminate water sources through aerial deposition.

Additionally, the industry produces a lot of ash, which itself contains heavy metals like uranium (Mustapha, O.M. *et. al.,* 2014).

2.1.9. Fertilizers petroleum Industry

Due to the presence of these metals in the raw ore, cadmium is a by-product of zinc (and occasionally lead) refining that cannot be avoided. However, recycling cadmium is not too difficult once it has been collected. Cadmium is primarily used in nickel/cadmium batteries, which are secondary or rechargeable power sources with high output, long lifespans, low maintenance requirements, and high resistance to mechanical and electrical stress. In high stress environments like marine and aerospace applications where high safety or reliability are required, cadmium coatings offer good corrosion resistance; however, the coating corrodes more quickly if damaged. Cadmium is also used in electronic compounds, PVC stabilisers, alloys, and pigments. Several products, such as phosphate fertilisers, detergents, and refined petroleum products, all contain cadmium as an impurity (Mustapha, O.M. *et. al.,* 2014).

2.1.10. Biological Practices

The main natural sources of mercury are volcanic emissions, evaporation from natural bodies of water, and crustal degassing. The metal is mined all over the world, which results in indirect atmospheric discharges. Mercury is frequently used in industrial processes and in a variety of products (e.g. batteries, lamps and thermometers). It is also widely used by the pharmaceutical industry and in dentistry as an amalgam for fillings (Honglei *et. al*., 2008).

2.1.11. Other Sources

The ongoing issues with siltation and bank erosion, the pollution load from the upper segment of the river, which is highly polluted, and the excessive use of fresh water from the river, which prevents the availability of proper dilution, all contribute to more aesthetic problems. More aesthetically problematic is the direct disposal of dead bodies of people and animals that have been mauled and dispersed by stray dogs and birds that are only partially burned and/or not burned. (Bhargava, D.S. 2006).

2.2. Heavy Metal Contamination, Detection and Remediation in Water

Water contaminated with heavy metals is a serious environmental problem that has negative effects on human health. Heavy metals like lead, cadmium, arsenic, and mercury have been the subject of in-depth research in recent years due to their harmful effects. Numerous scientific studies have concentrated on locating contamination sources, determining pollution levels, and creating efficient remediation strategies. The findings from numerous research articles are synthesised in this review of the literature to offer information on the degree of heavy metal contamination, its effects on ecosystems and human health, and cutting-edge methods for water purification. (Naik and Jujjavarapu, 2021) developed a self-powered microbial fuel cell biosensor that can identify heavy metal toxicity in water to address the need for real-time water pollution detection. This ground-breaking biosensor provides a reusable and economical way to keep track of heavy metal pollution, especially in areas with diminishing supplies of clean water.

In a study in lead-zinc mining communities, (Obasi and Akudinobi, 2020) emphasised the grave health risks posed by heavy metals in water. According to their investigation, unsafe drinking limits were exceeded for metals like lead, chromium, manganese, and others at elevated levels. These metals can cause cancer and neurological disorders, among other health problems, when present in water. Heavy metal removal is a promising application of nanotechnology. The use of carbon nanomaterials, such as nanotubes, fullerenes, and graphene, for efficient heavy metal removal from water was discussed by Baby, (Saifullah, and Hussein, 2019). These substances are effective adsorbents because of their high surface area and distinctive qualities. In addition, Baby, (Saifullah, and Hussein, 2019) investigated the use of palm oil kernel shells as an economical and environmentally friendly heavy metal removal technique. This waste material proved to be very effective at removing metals from water, including chromium, lead, cadmium, and zinc.

In the removal of heavy metals, electrochemical techniques have also shown promise. A novel electrochemical technique was created by (Liu *et al.*, 2019) that effectively removes heavy metal ions even at high pollution levels. This technique has the benefit of recovering particular metals separately, expanding its applicability in various situations.

It has been suggested that microbeads made of metal-organic frameworks and nanoparticles are effective adsorbents for removing heavy metals from water (Boix *et al.*, 2020). These microbeads demonstrated exceptional performance in simultaneously removing multiple heavy metals, offering a flexible and affordable solution for water filtration (El Awady *et al.*, 2021) investigated the potential of silver nanoparticle-modified aquatic plant powders for heavy metal phytoremediation. Their study demonstrated the selective absorption of different heavy metals by various aquatic plants. The incorporation of silver nanoparticles enhanced the absorption efficiency of these plants, showcasing their potential for water purification.

2.3. Heavy Metal in different water bodies

(Dogra *et al.*, 2023) evaluated whether groundwater in an agricultural region was suitable for irrigation. The study assessed heavy metal contamination, physico-chemical parameters, and indicators of water quality. The need for treatment prior to irrigation was highlighted by the research, which identified copper, lead, and chromium as major contaminants (**Shree, K., and** Nishikant 2019) looked into heavy metal contamination in Maharashtra's Ulhas River estuary. Their research showed significant Pb, Ni, Cr, Cu, Zn, Hg, and Cd pollution, especially close to populated areas and industrial facilities. The study emphasised the need for specialised management plans to safeguard the estuarine ecosystem. The Tuticorin industrial area's groundwater quality was assessed by Karthikeyan et al. in 2021. According to their research, there were higher-than-required levels of heavy metals in the drinking water. In order to enhance the quality of groundwater and reduce health risks, the study emphasised the need for sustainable water management strategies (Karunanidhi *et al.,* 2022) evaluated the Noyyal River's heavy metal pollution. They identified pollution levels, ecological risk, and health risks for humans in their study. The study highlighted the requirement for efficient pollution mitigation and river water quality improvement strategies. Ponds, which are important sources of water in rural India, were studied by (Goyal *et al.,* 2022) for heavy metal contamination. According to their research, there may be health risks due to elevated metal concentrations in sludge, soil, and groundwater. The study made clear the importance of testing heavy metal toxicity before pond rejuvenation. Heavy metal contamination in industrial wastewater and natural water sources was addressed by (Sankhla & Kumar 2019). The study focused on India's quick industrial development, how it affected groundwater quality, and the health risks it brought with it. The Yamuna River's heavy metal concentrations were studied by (Asim *et al.,* 2021). The heavy metal pollution index approach was used in the study's analysis of water samples. The study emphasised the severity of pollution and the need to address heavy metal contamination to safeguard both urban and riverside communities. The Yamuna River's heavy metal concentrations, as well as the sources of contamination and health risks, were evaluated by (Jaiswal *et al.* 2022). Based on the seasons, geographic distribution, and human activities, their study discovered variations in metal concentrations. The study emphasised health risks, particularly for kids. Heavy metal bioaccumulation in edible fish species from the Adyar estuary was studied by (Rubalingeswari *et al.,* 2021). The study focused on the bioaccumulation of metals in fish tissues after metal enrichment in sediment. The study emphasised the dangers of fish heavy metal bioaccumulation. The hydrochemistry of groundwater from the Ramganga aquifer was evaluated by (Mazhar & Ahmad, 2020). The study highlighted the connection between land use and seasonal changes and elevated levels of heavy metal contamination in groundwater, particularly in semi-urban areas.

2.4. Heavy Metal Contamination and Risk associated

The heavy metal content of wastewater from Delhi's irrigation-related Najafgarh and Loha Mandi drains was evaluated in the study by (Gola *et al.,* 2020). The study emphasised contamination from untreated industrial effluents that exceeded FAO-permitted limits for irrigation, particularly in the Punjabi Bagh site. The study highlights the need for quick, efficient action to reduce heavy metal contamination in drain water. Heavy metal concentrations in the Teesta River in the Eastern Himalayas were examined by (Chettri *et al.,* 2022). Their study uncovered downstream contamination that exceeded the legal limits for lead, zinc, cadmium, and chromium. The study revealed pollution patterns, common sources, and specific pollution origins, providing insights into effective pollution management strategies. Using GIS and risk assessment tools, (Rizwan *et al.,* 2021) evaluated the groundwater quality in the Gadilam River basin. They found several heavy metals to have elevated concentrations and highlighted their sources, which included geogenic and anthropogenic factors. The study emphasised the requirement for continuing groundwater monitoring and the application of suitable management techniques. (Supriya *et al.,* 2020) assessed the levels of heavy metals in seafood from Chennai's fish landing centres, highlighting potential risks to the food chain and the general public's health. The study emphasised the significance of ongoing monitoring and interventions to ensure food safety while highlighting the presence of heavy metals in seafood. In the Upper Bhima Basin sediments, (Kalekar *et al.,* 2022) evaluated the accumulation and contamination of heavy metals. Their study outlined contamination hotspots, uncovered pollution sources, and evaluated ecological risks. The study emphasised how crucial it is to comprehend sediment contamination for managing water resources and taking socioeconomic factors into account. Aluminum, arsenic, lead, and other heavy metals have been linked to health risks, according to (Vig *et al.,* 2023) investigation .'s into heavy metal pollution in groundwater near coal thermal power plants in 2023. The study emphasised the unfitness of groundwater for drinking because of potential health risks and called for ongoing observation.

2.5. Toxicity of Heavy Metals

2.5.1. Lead

Even minute amounts of lead can be harmful, making it a dangerous element. There are many ways that lead can enter the body. Leaded paint dust and waste gases from leaded gasoline can both be inhaled. Several foods, most notably fish, which are heavily impacted by industrial pollution, contain trace amounts of it. Lead water pipes may be present in some older homes, which can contaminate drinking water. Urine removes the majority of the lead we consume, but there is still a chance of buildup, especially in young children. Lead exposure builds up over time. High levels of lead in the body can result in demise or long-term harm to the kidneys, brain, and central nervous system (USGAO, 2000).

As a result of human activities, such as fossil fuel burning, mining, and manufacturing, lead and lead compounds can be found in all parts of our environment. Water, soil, and air are included in this. There are numerous ways to release lead. Batteries, ammunition, metal goods like solder and pipes, and X-ray shielding equipment are all made with it. Lead is a highly toxic metal, and its use in many goods, including gasoline, paints, and pipe solder, has been significantly reduced recently due to health concerns (see below). Lead-based paint, possibly water pipes in older homes, contaminated soil, household dust, drinking water, lead crystal, lead in some cosmetics and toys, and lead-glazed pottery are currently the most common sources of lead exposure in the United States (Martin *et. al.*, 2009).

(Nazir *et al.*, 2015) The earth's crust contains trace amounts of lead, an element that is naturally occurring and bluish-gray in colour. Although lead naturally occurs in the environment, human activities like burning fossil fuels, mining, and manufacturing cause high concentrations to be released. The permissible limit for lead in water is 0.05 mg/l, and all of the water samples that were collected had lead concentrations that were higher than this. Lead concentrations in all the water samples that were collected ranged from 0.167 to 0.723 mg/l. Age-related accumulation occurs in the bones, aorta, kidney, liver, and spleen. It can enter the body through the ingestion of food (65%), water (20%), and air (15 percent).

Common side effects from this damage include memory and concentration issues, high blood pressure, hearing loss, headaches, slowed growth, reproductive issues in both men and women, digestive issues, and muscle and joint pain. Due to its dangerous effects, lead has been the subject of numerous studies. Lead is regarded as the leading health risk to children, and lead poisoning can have long-lasting effects. In addition to stunting a child's growth, harming their nervous system, and resulting in learning disabilities, lead poisoning is now known to contribute to crime and antisocial behaviour in kids (Kumar, R. *et. al.,* 2013).

(SJS Flora *et al.*, 2007) Lead is substituted for calcium in the mineral within the skeleton. Lead binds to biological molecules, preventing them from functioning properly through a variety of mechanisms. Lead alters the configuration and activity of enzymes by binding to their sulfhydryl and amide groups. Lead may also compete with necessary metallic cations for binding sites, reducing enzyme activity or changing how necessary cations like calcium are transported. Numerous studies have shown that lead poisoning causes cellular damage that is mediated by the formation of reactive oxygen species (ROS).

(Yedjou G. C. *et al.*, 2008) Recent research conducted in our lab has shown that toxicity and apoptosis caused by lead in human cancer cells were caused by a number of cellular and molecular processes, including the induction of cell death and oxidative stress.

2.5.1.1. Potential for Human Exposure of Lead

(Duruibe, J *et. al.*, 2007) Human exposure to such heavy metals comes from industrial products used in homes that contain heavy metals in their production. Antifungal medications, toiletries, creams, disinfectants (like mercurochrome), and organometallics are other sources of mercury exposure.

(CDC, 2001). Through drinking water, adults absorb 35 to 50 percent of lead, and children may absorb more than 50 percent. Age and physiological state are two factors that affect lead absorption. The kidney absorbs the most lead in the human body, followed by the liver and other soft tissues like the heart and brain, but the majority of the body's lead is found in the skeleton.

(Flora, *et. al.,* 2006) Lead poisoning's most vulnerable victim is the nervous system. Early signs of lead exposure's effects on the central nervous system include headache, poor attention span, irritability, drowsiness, memory loss, and dullness.

(Pateriya *et al.,* 2020) Lead is toxic to human physiology and neurological system (Pb). The kidney, reproductive system, liver, and brain can all be damaged by acute Pb poisoning, which can result in both illness and death. Pb outranks the risks even at incredibly low concentrations. Teratogenicity is a particularly harmful side effect of lead toxicity. Additionally, lead poisoning impairs the synthesis of haemoglobin and causes both acute and long-term damage to the cardiovascular, central, and peripheral nervous systems (PNS). Other long-term effects include anoxia, anaemia, exhaustion, digestive problems, and fatigue. Lead can result in high blood pressure, joint and muscle pain, and issues during pregnancy.

2.5.2. Chromium (Cr)

Chromium contaminates a number of environmental systems as a result of its pervasive use in numerous industrial processes. Commercial applications for chromium compounds include industrial welding, chrome plating, dyes and pigments, leather tanning, and wood preservation. Chromium is used as an anticorrosive in both boilers and kitchen appliances (Wang XF, *et al.*, 2006)

(Velma V *et al.*, 2009) Depending on its oxidation state, chromium's toxicity varies from the low toxicity of the metal form to the high toxicity of the hexavalent form. It was once believed that all compounds containing Cr (VI) were man-made, with only Cr (III) existing naturally in large quantities in the air, water, soil, and biological materials. However, recently, naturally occurring Cr (VI) has been discovered in ground and surface waters at levels higher than the WHO drinking water limit of 50 g of Cr (VI) per litre.

Steel grey, extremely hard, cubic crystals make up the d-block metal chromium (Cr). It is a transition metal that is a member of group 6 and period 4. Chromium (Cr) has an atomic mass of 52, an atomic number of 24, a density of 7.19 g/cm3, a melting point of 2130 K, and a boiling point of 2755 K. It doesn't naturally occur in elemental form; only compounds do (Wuana and Okieimen, 2011). The primary ore product of chromite, a mineral with the chemical formula FeCr2O4, is chromium (Cr) (Hardy et. al., 2008).

Chromium (Cr), a naturally occurring element with oxidation states (or valence states) ranging from chromium (II) to chromium (III), is found in the earth's crust (VI) (Jacobs, JA *et. al.,* 2005). (Patlolla A, et al., 2009) Trivalent [Cr (III)] chromium compounds are stable and can be found naturally in ores like ferrochromite. The second most stable state is hexavalent [Cr (VI)].

(Lenntech, 2010; Asio, 2009). Metal alloys and pigments for paints, cement, paper, rubber, and other materials contain chromium. Chromium is necessary for the metabolism of carbohydrates, lipids, and amino acids.

(Asio *et al.*, 2009) Releases from electroplating procedures and the disposal of waste containing chromium (Cr) are two sources of contamination. Chromium (VI) is the form of Cr that is frequently found at contaminated sites, and soils treated with sewage sludge frequently contain toxic levels of the metal.

(Hardy *et al.*, 2008, Lenntech, 2010; Bhagure G.R. *et al.*, 2010) Organic matter in the soil can reduce it to Cr (III). Surface runoff can carry it in either a soluble or precipitated form to surface waters. The majority of the chromium (Cr) released into natural waters is particle-associated and eventually deposition into the sediment. Chromium (Cr) is necessary for the metabolism of carbohydrates, lipids, and amino acids as well as for the production of pigments for paints, cement, paper, rubber, metal plating to prevent corrosion, leather tanning, and textile colourants.

In the studied areas, chromium pollution of the water is caused by industrial sources and agricultural activities. When other metals like cobalt, copper, iron, and zinc are present in drinking water, it becomes more toxic. There have been a lot of studies done on human nickel sensitivity. The relationships between nickel exposure and dermal irritation have been investigated in a large number of additional studies. For the first time, the connection between nickel and hair loss is reported in this study (Sankhla M.S. *et. al.*, 2019).

(Zhitkovich A *et al.*, 2001) However, recent research suggests that non-oxidative mechanisms play a biologically significant role in Cr carcinogenesis. It appears that inhaling the less soluble/insoluble Cr compounds is linked to carcinogenicity. The elemental does not hold the toxicology of Cr. It varies significantly between a wide range of extremely diverse Cr compounds.

(De Mattia G et al., 2004) Under physiological circumstances, hydrogen peroxide (H2O2), glutathione (GSH) reductase, ascorbic acid, and GSH can reduce Cr to produce reactive intermediates, including Cr, Cr, thiylradicals, hydroxyl radicals, and ultimately, Cr. Cr enters a variety of cell types. Any of these species could damage proteins, membrane lipids, DNA, and other components, impairing cellular integrity, among other things.

(Gambelunghe A *et al.*, 2003) The presence of lipid peroxidation products in the urine of workers exposed to chromium and DNA strand breaks in peripheral lymphocytes support the hypothesis that Cr (VI) causes human toxicity.

(Dayan AD, 2001) Humans have also been reported to experience negative health effects brought on by Cr (VI). Respiratory cancers have been linked to occupational exposure to Cr (VI)-containing compounds, according to epidemiological studies.

(Adelekan *et al.*, 2011) Humans who are exposed to chromium (Cr) may develop allergic dermatitis, gastrointestinal bleeding, respiratory tract cancer, and skin ulcers. Additionally, the liver and kidney damage, as well as mucus membrane damage.

2.5.2.1. Potential for Human Exposure of Chromium

The high risk of diseases caused by Cr in industrial workers who are exposed to Cr at work has made occupational exposure a major concern. Additionally, the general human population as well as some wildlife may be in danger. 33 tonnes of total Cr are thought to be released into the environment each year. More than 300,000 employees are reportedly exposed to chromium and compounds containing chromium each year at work. Cr is a necessary nutrient for both humans and animals. It influences how glucose, fats, and proteins are metabolised by enhancing the effects of insulin (Guertin, J. *et al.*, 2005).

(Jacobs. *et al.,* 2005) In soil, seawater, and rivers and lakes, chromium concentrations range from 1 to 3000 mg/kg, 5 to 800 g/L, and 26 g/L to 5.2 mg/L, respectively. The amount of chromium in food varies significantly and is influenced by processing and preparation. Chromium levels in most fresh foods typically range from 10 to 1,300 g/kg in general. Workers in 15 industries that use chromium today may be exposed to levels of chromium that are two orders of magnitude higher than those found in the general population.

(Chen TL *et al.,* 2009) High levels of chromium (VI) in the air can irritate the nose's lining and lead to nose ulcers. Anemia, sperm damage, male reproductive system damage, irritation and ulcers in the stomach and small intestine, and anaemia are the main health issues observed in animals after consuming chromium (VI) compounds. Compounds containing chromium (III) are significantly less toxic and don't seem to lead to these issues. Some people are extremely sensitive to chromium (VI) or chromium (III), and allergic reactions have been reported that cause extreme skin redness and swelling. Both humans and animals exposed to chromium (VI) in drinking water showed an increase in stomach tumours. Humans have experienced severe respiratory, cardiovascular, gastrointestinal, haematological, hepatic, renal, and neurological effects as a result of unintentional or intentional ingestion of extremely high doses of chromium (VI) compounds.

These effects have also occurred in patients who survived thanks to medical intervention. Chromium appears to be carcinogenic to humans and other terrestrial mammals, but the exact mechanism by which it causes cancer is not fully understood.

2.5.3. Nickel (Ni)

Additionally, nickel (Ni) is a d-block metal, cubic crystal, and silvery. This transition metal is a member of group 10 and period 4. It has a density of 8.9 g/cm3, an atomic mass of 58.7, an atomic number of 28, a melting point of 1726 K, and a boiling point of 3005 K. It is a substance that only very rarely occurs in the environment and is necessary in very small doses, but when used in excess, it can be hazardous (Wuana *et al.,* 2011).

(Asio, 2009) Metal plating businesses, the burning of fossil fuels, nickel mining, and electroplating are all sources of nickel contamination in the soil. Nickel (Ni) can also be ingested, inhaled, and present in contaminated food and water.

(ATSDR, 2005) Hard and silvery-white in colour, pure nickel has properties that make it a very attractive metal to combine with other metals to create alloys. Nickel can be alloyed with a variety of metals, including iron, copper, chromium, and zinc. These alloys are used to create metal jewellery, coins, and other industrial products like valves and heat exchangers. Stainless steel is the primary application for nickel. Nickel can also be combined with a variety of other elements, such as chlorine, sulphur, and oxygen, to form various compounds. Power plants, waste incinerators, and the stacks of big furnaces used to make alloys all have the potential to release nickel into the environment. For plants and animals, nickel is also a necessary element. In small quantity, nickel is necessary for the regulation of lipid contents in tissues and for the formation of red blood cells. But at high level, it becomes toxic and causes severe diseases like loss of body weight, loss of vision, and heart and liver failures, as well as skin irritation (Shah, *et al.,* 2013). (Adelekan *et al.,* 2011, Asio, 2009, Lenntech, 2010). Nickel (Ni) exposure can harm the kidneys, liver, and lungs. Additionally, Ni can lead to cancer, heart failure, respiratory failure, birth defects, allergies, dermatitis, and eczema when consumed in large doses. (Haber L.T *et al.,* 2000) Intake is thought to be the most significant route of exposure in the general population, with contributions to the body burden from inhaling nickel from the air and drinking water typically being less significant than dietary intake. The physicochemical form of nickel affects how readily it is absorbed, with water-soluble forms like chloride, nitrate, and sulphate being more readily absorbed. The gastrointestinal tract of animals absorbs 1–10% of the dietary nickel. It is significant to note that nickel's bioavailability may be significantly impacted by the way it is consumed.

(IRIS. Nickel 2005). The bioavailability of nickel is significantly influenced by food intake, gastric emptying, and intestinal peristalsis because absorption of ingested nickel is decreased when it is administered in food or water along with a meal. The bioavailability of nickel salts is significantly changed by food in the stomach. (Kasprzak K.S, 2003, IRIS. Nickel 2005) Human exposure to highly nickel-polluted environments has the potential to produce a variety of pathological effects. Among them are skin allergies, lung fibrosis, cancer of the respiratory tract and iatrogenic nickel poisoning. (Young R.A. 2005) The metabolism of nickel involves conversion to various chemical forms and binding to various ligands. The organ distribution of nickel has been documented by a number of investigators. (Cavani A. 2005, Kitaura H. *et al.*, 2003, IRIS. Nickel 2005) According to positive dermal patch tests, nickel is a common metal that frequently causes allergic skin reactions and is one of the most common causes of allergic contact dermatitis.

(Gawkrodger *et al.,* 2000, Kitaura H. *et al.*, 2003,) suggested that the higher number of antigens, or perhaps the larger nickel load, in the extended metal series resulted in a larger proportion of patients reacting. In clinical cases, allergic contact hypersensitivity to nickel develops much more readily in inflamed skin than normal skin. (IRIS. Nickel 2005) While nickel has long been known to be a contact irritant, numerous studies have also shown that nickel ingestion can have dermal effects in sensitive people. Due to a lack of data, the U.S. EPA has not assessed the potential human carcinogenicity of soluble salts of nickel as a class of compounds. However, nickel carbonyl and nickel subsulphide have both been studied, as well as nickel refinery dust and other specific nickel compounds. (JENSEN C.S. *et. al.,* 2003) It is debatable whether oral nickel exposure can cause clinically significant systemic reactions, particularly when this metal is consumed regularly. Although a dose-response relationship is difficult to establish, several studies have shown that oral exposure to nickel may cause an eruption or worsening of eczema in nickelsensitive individuals. The nickel exposure dose that was used in the majority of these studies was significantly higher than the amount of nickel found in a person's typical daily diet. (HABER L.T. *et. al.,* 2000) Nickel salts that are soluble in water do not easily enter cells. As a result, these substances are typically not carcinogenic to animals and, to a large extent, have not been considered to be highly potent human carcinogens. However, recent studies have suggested an increase in cancer in areas of nickel refineries where workers are exposed to water-soluble nickel salts.

2.5.4. Zinc (Zn)

Zinc is used in dry cell batteries, as a rust-prevention coating, and in the creation of alloys like bronze and brass by combining it with other metals. In the US, pennies are made of an alloy of zinc and copper. In the manufacturing of paint, rubber, dye, wood preservatives, and ointments, zinc compounds are frequently used. Additionally used for galvanising sheet iron, as an ingredient in alloys like bronze, brass, Babbitt metal, German silver, and special alloys for die-casting, as a corrosion-resistant coating for other metals, for building materials, railroad car linings, automobile equipment, electrical apparatus, particularly dry cell batteries, household utensils, castings, printing plates, and deoxit. It naturally occurs in soil, but anthropogenic additions are increasing the concentrations. Most additions are from industrial activities such as mining, coal, waste combustion and steel processing (Wuana *et al.,* 2011). One of the most prevalent elements in the crust of the earth is zinc. All foods contain it, and it can be found in the water, soil, and air. bluish-white and shiny, pure zinc is a metal. One of the crucial trace elements, zinc is crucial for many organisms' physiological and metabolic processes. Nevertheless, an organism may become toxic from higher zinc concentrations (Rajkovic *et al.,* 2008). (Hardy *et al.,* 2008) The d-block metal zinc (Zn) is a hexagonal crystal that is bluish-white in colour. It is a transition metal that belongs to group 12 and period 4. Additionally, it has an atomic mass of 65.4, atomic number 30, a melting point of 693 K, and a boiling point of 1180 K. In reality, all foods, including air, soil, and water, contain the element zinc (Zn) (Bhagure *et al.,* 2010). additionally from the application of fertilisers, pesticides, composted materials, and liquid manure in agriculture. In the manufacturing process, it is used to create ointments, paint, rubber, dye, and wood preservatives. Due to the high concentrations of zinc (Zn) in industrial plant wastewater and the possibility of water-soluble forms of zinc in the soil contaminating groundwater, zinc pollutes water. It might make the waters more acidic. Thus, it may have a negative impact on earthworm and microbial activity, delaying the breakdown of organic matter.

(B. A. Adelekan *et al.,* 2011) It serves as the fundamental building block of numerous different enzymes and has catalytic, structural, and regulatory roles. Additionally, it plays a critical role in the synthesis of DNA, healthy development, brain function, bone formation, and wound healing. Zinc is a neurotoxin at high concentrations.

2.5.4.1. Potential for Human Exposure of Zinc

A healthy body needs zinc to function properly, but too much zinc can be toxic and harmful. A healthy immune system, cell division, protein and collagen synthesis, which is great for wound healing and healthy skin, are all dependent on zinc. But too much can result in nausea, vomiting, and cramps in the stomach. Long-term exposure can result in anaemia, pancreas damage, and decreased levels of HDL cholesterol. Additionally, inhaling high concentrations of zinc can result in metal fume fever, a short-term illness. It is thought that the lungs and body temperature are being affected by immune responses (Lenntech Water Treatment & Air Purification Holding, 2005).

ATSDR (2005) The condition known as metal fume fever may result from inhaling excessive amounts of zinc dust or fumes during mining or smelting. However, as soon as zinc exposure is stopped, this symptom will go away. Additionally, there may be pancreas damage, anaemia, nausea, vomiting, stomach cramps, and a decrease in high-density lipoprotein cholesterol levels. The difficulties and complexity of heavy metal contamination were highlighted by numerous case studies that were narrowly focused on particular areas. Industrial waste and sewage canal pollution plagued the East Kolkata Wetlands (Kumar et al., 2023). The study highlighted the requirement for ongoing supervision and control of heavy metal contamination in delicate ecosystems.

(Ahmed *et al.*, 2022) analysed the state of a region's groundwater that was affected by industrial waste, agricultural practices, and municipal waste. The study found rising levels of heavy metals, highlighting the urgent need for pollution mitigation techniques.

Chapter 3

Material

&

Methodology

Material & Methodology

3. Study Area

3.1. The Yamuna River Basin

The Yamuna River, originating from the Yamunotri glacier (Saptarishi Kund) near the Bander poonch peaks at coordinates 30° 59' N and 78° 27' E, is a significant Himalayan river with glacial origins. It holds the distinction of being the largest tributary of the Ganga River. This river emerges at an elevation of approximately 6.387 kilometers above mean sea level in the Uttarakhand district, as described by (Rai et al. 2012) Spanning a vast length of 1380 kilometers from its source, the Yamuna River flows through several regions, including Uttarakhand, Uttar Pradesh, Himachal Pradesh, Haryana, Rajasthan, Madhya Pradesh, and the entire state of Delhi. Its journey concludes when it merges with the Ganga River at Allahabad (Prayag), Uttar Pradesh. The Yamuna River boasts several notable tributaries, including the Tons, Giri, Hindon, Chambal, Betwa, Sind, and Ken. Among these, the Tons, situated in the hills, and the Chambal, located in the plains, are particularly significant due to the substantial volume of water they contribute to the Yamuna. The Yamuna River's catchment area encompasses a vast expanse of 366,223 square kilometers, as documented by the Central Pollution Control Board (CPCB) in 2006. To put this into perspective, the catchment area of the Yamuna River basin constitutes 42.5% of the entire Ganga basin, and it represents 10.7% of the overall geographical landmass of the country. Within this extensive catchment area, the sub-basin tributaries of the Yamuna play a crucial role, accounting for a significant portion. These tributaries collectively contribute 70.9% of the total catchment area. Meanwhile, the remaining 29.1% is comprised of direct drainage into the Yamuna River through various smaller tributaries, as highlighted in the research conducted by (Rai *et al.*, 2012).

3.1.1 The Course of the Yamuna River

The journey of the Yamuna River commences in the lower Himalayas, embarking on a course of approximately 178 kilometers from the Yamunotri group of glaciers. It meanders through a series of valleys before it transitions into the Indo-Gangetic plains at Dak Pathar near Dehradun. Along its path, the river is nourished by various streams originating from the Shivalik range in Himachal

Pradesh and Uttarakhand. At Dak Pathar, the flow of the river is controlled by a weir, and its waters are directed into a canal for both power generation and irrigation purposes. Continuing on its course, the Yamuna River passes the revered Sikh religious shrine of Poanta Sahib and eventually reaches Hathnikund/Tajewala in the Yamuna Nagar district of Haryana. At this point, the river's water is channeled into the Western Yamuna Canal (WYC) and Eastern Yamuna Canal (EYC) for irrigation and the supply of drinking water to Delhi. During the non-monsoon season, minimal to no water is allowed to flow downstream of the Hathnikund barrage, resulting in some stretches of the river running dry between Hathnikund/Tajewala and Delhi. However, the river regains water through contributions from a feeding canal via the Som Nadi (a seasonal stream) upstream of Kalanaur in Haryana. After traveling approximately 224 kilometers from Hathni kund, the Yamuna River enters Delhi near Palla village. Here, the river's water is once again controlled by the Wazirabad barrage, primarily to provide drinking water to the capital city of Delhi. Especially during the summer months, very little water is released downstream of the barrage. During its passage through Delhi, the Yamuna River becomes a repository for untreated or partially treated domestic and industrial wastewater from various drains. Around 22 kilometers downstream of the Wazirabad barrage, the Yamuna's water is further redirected into the Agra canal for irrigation purposes upstream of the Okhla barrage. The water that continues to flow in the river beyond the Okhla barrage is primarily composed of domestic and industrial wastewater generated by East Delhi, NOIDA, and Sahibabad. As the river continues its course, it eventually reaches Mathura in Uttar Pradesh, about 166 kilometers from Okhla. At Gokul barrage in Mathura, a significant portion of the river's water is harnessed for the supply of drinking water. Moving onward from the Gokul barrage, the Yamuna River receives additional water from important tributaries like the Chambal. Ultimately, after traversing a distance of approximately 790 kilometers and passing through cities such as Agra, Bateshwar, Etawah, Hamirpur, and Pratapgarh in Uttar Pradesh, the Yamuna River merges with the Ganga River at Allahabad, as described by the (Central Pollution Control Board (CPCB) 2006 and Rai et al. in 2012).

3.1.2. Yamuna River Water Flow Characteristics

The flow characteristics of the Yamuna River basin exhibit significant heterogeneity, with a wide spatial variation in rainfall patterns, ranging from 200 to 2350 millimeters. The majority of rainfall occurs during the monsoon period, spanning from July to September. Occasionally, the intensity of rainfall during this period exceeds the river's conveyance capacity, leading to flooding. In contrast, during the non-monsoon period, the river's water availability is primarily attributed to the melting of glaciers. Consequently, the river experiences a substantial reduction in water flow, resulting in stretches of dry riverbeds along its entire length. Furthermore, the limited water available during the lean period is extensively diverted from the river for irrigation and drinking purposes, often resulting in minimal to no flow in the river itself, as reported by the Central Pollution Control Board (CPCB) in 2010.

3.1.3. Utilization of Yamuna River Water for Key Purposes

The waters of the Yamuna River undergo substantial abstraction as it traverses through seven states in Northern India, facilitated by five key barrages strategically placed along its course. These barrages, their distances from the river's origin, and their respective locations are as follows:

i) Dak Patthar (approximately 160 kilometers from the river's origin in Uttarakhand)

ii) Hathnikund (located 172 kilometers from the origin, at the foothills in Haryana)

iii) Wazirabad (situated in the National Capital Territory of Delhi, at a distance of 396

kilometers from the river's source)

iv) Okhla (also in the National Capital Territory of Delhi, 418 kilometers from the river's origin)

v) Mathura (near Gokul village in Uttar Pradesh, roughly 570 kilometers from the river's origin).River water is drawn for diverse purposes at various locations along its course. Hathnikund/Tajewala and Okhla, in particular, experience substantial water extraction, typically with limited to no downstream discharge, except during periods of river flooding, as previously noted

The predominant use of the abstracted river water is for irrigation, accounting for 94% of the total usage. Domestic water supply represents 4% of the usage, while the remaining 2% is allocated for industrial purposes (power generation) and other miscellaneous uses, as documented by the Central Pollution Control Board (CPCB) in 2006. Irrigation holds particular significance in the utilization of Yamuna river water. In fact, out of the 12.3 million hectares of irrigated land across the entire Yamuna basin, 49% relies exclusively on surface water for irrigation, according to Rai et al. in 2012. Additionally, the Yamuna River serves as the primary source of domestic water supply in Delhi, Mathura, and Agra. It's important to note that the Yamuna River lacks significant tributaries along its course, with the exception of the Som Nadi and the highly polluted River Hindon, which extends for approximately 750 kilometers in the plains until it converges with the Yamuna River at Bawah near Etawah. Consequently, the water found downstream of the Hathni kund barrage is primarily sourced from groundwater recharge and wastewater drains originating from various towns and urban centers, as highlighted by (Rai *et al.* in 2012).

3.2. Climatic Conditions in the Delhi Region During the Study Period

Delhi, positioned at coordinates ranging from 28º24´17" to 28º53'00" N Latitude and 76º50´24" to 77º20'37" E Longitude, rests approximately 160 kilometers south of the Himalayas. The city's elevation stands at 216 meters above sea level, as documented in the Delhi Statistical Handbook of 2020. Delhi's climate is characterized by its unique blend of monsoon-influenced humid subtropical conditions, marked by significant fluctuations in both temperature and precipitation between the summer and winter seasons. For a detailed examination of the ambient air temperature and rainfall patterns in Delhi during the study period show in **Table 3.6**.

Months	Min Minimum Temp.	Min Max. Temp.	Total Raifall in MMS	Min Humiity
January	7	22.2	54.1	63
February	11.2	26.3	23.9	55
March	16.9	32.8	12.2	47
April	22.4	37.2	9.5	34
May	25.6	40.4	26.9	33
June	29.6	39.9	11.2	46
July	27.4	35.6	199.2	70
August	27.3	34.3	119.8	73
September	24.6	32.7	74.1	62
October	18.6	33.3	47.3	52
November	13.4	28.5	1.1	55
December	6.7	23	33.9	62

Table 3.1.: Ambient Air Temperature and Rainfall Patterns in Delhi, Study Period 2019. (***Source:*** Delhi Statistical Handbook, 2020).

3.3. Sampling Period

Throughout the entirety of the year 2019, comprehensive water sampling was collected at five specific sites along the Yamuna River in Delhi. Sampling took place consistently over a span of 20-25 days each month, covering all twelve months from January to December. These diligent efforts aimed to gather representative water samples and capture the seasonal variations and dynamics of the river's water quality at these strategic locations. Each of these designated sampling sites underwent a thorough and comprehensive collection of water samples. Figure 2-8 provides a visual representation of the geographical distribution of these sampling sites along the Yamuna River. To thoroughly understand the impact of changing seasons on contaminant levels and their behavior within the river ecosystem, samples were gathered during various seasons. This systematic approach allowed for a comprehensive assessment of how contaminants fluctuate seasonally within the Yamuna River.

3.3.1 Selection of Study Locations

"For Our Research Endeavor: Exploring the Significance of Five Sacred Ghats Along the Yamuna River in Delhi" In the pursuit of our research study, we exercised great care in selecting five sacred and revered locations, commonly known as "Ghats." These Ghats hold a central role in shaping the spiritual and cultural tapestry of the region. They are strategically positioned within the Delhi region, demarcating the path of the Yamuna River as it meanders toward Mathura, the sacred confluence point with the Ganga River. These Ghats are deeply embedded in the religious and cultural fabric, serving as the hallowed backdrop for pilgrims who partake in an array of religious rituals and ceremonies. In contrast, the Yamuna Bank predominantly functions as an agricultural hub, highlighting the river's multifaceted roles in the lives of local communities. Among these Ghats, the "Chaat Pooja Ghat & Kalindi Kunj Ghat" holds a special distinction. Located across Delhi and in close proximity to the Yamuna River confluence, this particular Ghat is renowned for its use by bathers and for hosting elaborate pooja ceremonies. It bursts with fervor, particularly during the auspicious Chaat Pooja festival, celebrated with great enthusiasm annually. Our selection of these specific locations was purposeful, driven by their close proximity to one another, as well as the heightened levels of human activity and interaction with the aquatic life of the River Yamuna. Additionally, the Okhla Barrage, Okhla Bird Sanctuary, and the entire Yamuna Bank are in close proximity to these Ghats. These areas also serve as focal points for various industries, including pulp and paper manufacturing, textile production, paint production, steel plants, thermal power plants, chemical factories, pharmaceuticals, tanneries, mechanical workshops, and battery manufacturing. These industries stand as major contributors to heavy metal pollution in the Yamuna River in Delhi, thereby presenting environmental challenges and potential health risks to the communities reliant on the waters of the Yamuna. Moreover, agriculture activities are also actively practiced in some of these Ghats, further underscoring the river's significance in sustaining local livelihoods.

3.3.2. Sample Collection Sites

The five meticulously chosen sites for water sample collection, each carrying immense significance in our research, are thoughtfully delineated in Figure 3.1-3.5. These sites have been strategically selected to offer a comprehensive assessment of water quality and conditions within the Yamuna River. Our scientific expedition leads us to these specific locations, each characterized by unique attributes and interactions with the river's aquatic ecosystem. As we immerse ourselves in the intricacies of water sampling and analysis, these sites function as indispensable landmarks, guiding our exploration of the ever-changing environmental terrain of the Yamuna. With our unwavering commitment to collecting and analyzing data at these pivotal sites, our objective is to unearth valuable insights into the river's well-being and ecological significance. This endeavor contributes to an enhanced understanding of the challenges that confront this vital watercourse.

Site 1 Okhla Bird Sanctuary

Site 2 Kalindi Kunj Ghat

Site 3 Okhla Barrage

Site 4 Chat Pooja Ghat (Mayur Vihar)

Site 5 Yamuna Bank

Figure 3.1: Sample Collection Site 1 - Okhla Bird Sanctuary, Yamuna River, Delhi

Figure 3.2: Sample Collection Site 2 - Kalindi Kunj Ghat, Yamuna River, Delhi

Figure 3.3: Sample Collection Site 3- Okhla Barrage, Yamuna River, Delhi

Figure 3.4.: Sample Collection Site 4 –Chaat Pooja Ghat, Yamuna River, Delhi

Figure 3.5: Sample Collection Site 5 - Yamuna Bank, Yamuna River, Delhi

3.3.3. Water Sample Collection

To gather samples effectively, 1-liter pre-cleaned polyethylene bottles were employed, and country boats were utilized as transportation means. The sampling process involved obtaining grab water samples at different intervals across the river width, precisely at 1/4, 1/2, and 3/4 points, all at a consistent depth ranging from 0.20 to 0.30 meters from the water surface. This sampling approach was consistently applied across all sampling points during each sampling event, as outlined in **(Sehgal *et al.* 2012).** Clearly label each sample bottle with essential information, including site name, date, time, and any other relevant details. For robust data collection, samples were acquired in triplicate at each location, and these replicates were subsequently combined to create a composite sample for analysis.

3.3.4. Water Sample Preservation

Preserving water samples for heavy metal analysis is a critical step in ensuring the accuracy and reliability of the results. The procedure outlined here provides a systematic approach to sample preservation to maintain sample integrity and prevent contamination. Additionally, work in a well-ventilated area or under a fume hood to minimize exposure to potentially harmful fumes. However, for heavy metal analysis, we utilized 0.5-liter high-grade polyethylene bottles. To ensure the integrity of the samples, these bottles were pre-treated by soaking and rinsing them in 10% HNO_3 overnight. Additionally, to prevent the precipitation of heavy metals, we acidified the collected unfiltered samples by adding 2ml of concentrated HNO_3 per liter of the sample. (Singh et al., 2005; Sehgal et al., 2012). To prevent contamination or evaporation, cap the sample bottles tightly. It's essential to store the preserved samples in a cool, dark place to minimize chemical reactions and sample degradation. Throughout this process, maintain comprehensive records of sample collection, preservation, and storage conditions. These records are essential for traceability and quality control. Finally, analyze the preserved samples for heavy metal content using the appropriate analytical techniques. Always adhere to the specific guidelines and requirements of your laboratory or regulatory agency to ensure that the preservation and analysis of water samples are conducted accurately and reliably.

3.4. Water Sample Analysis Procedures for Hydrobiological Property

The analysis of water samples adhered to established standard methodologies outlined in the 22nd Edition of the Handbook of the American Public Health Association (APHA), the American Water Works Association (AWWA), and the Water Environment Federation (WEF) in 2012, ensuring accuracy and reliability. As recommended by APHA (2012), certain key parameters such as temperature, pH, and dissolved oxygen were promptly analyzed immediately following sample collection using a portable multiparameter meter (HACH-HQ30d) onsite. Additionally, the same meter was utilized for the onsite recording of Electrical Conductivity. For comprehensive hydrobiological analyses, the collected water samples were transported to the laboratory. There, crucial parameters such as hardness, alkalinity, and acidity were meticulously analyzed using titrimetric and volumetric analysis protocols outlined by the American Public Health Association (APHA, 2012). The variations of these hydrobiological parameters in river Yamuna water were recorded on a monthly basis, providing valuable data for biostatistical applications and establishing correlations with heavy metal concentrations. This comprehensive approach ensures the robustness and relevance of the data collected for environmental and health assessments.

3.5. Analysis of Heavy Metals in Water Samples

For the estimation of heavy metals, the methods outlined by (Singh *et al.*, 2005) and (Sehgal *et al.*, 2012) were rigorously adhered to in our study. It's essential to highlight that deionized water played a pivotal role in maintaining the integrity of various water quality protocols throughout our research. To begin the process, we meticulously measured 50 ml of well-mixed, acid-preserved water samples, which were then carefully placed into acid-washed beakers. Subsequently, 10 ml of concentrated nitric acid (HNO3) was judiciously added to each sample. The acidified mixtures were subjected to digestion on a hot plate, maintaining a temperature of 90°C, until the volume significantly reduced to approximately 10-20 ml. The final volume of each sample was meticulously adjusted to 50 ml through the addition of deionized water. To eliminate any solid particles or impurities, the digested samples underwent filtration using Whatman no. 42 filter paper, ensuring that only the liquid fraction was retained for further Instrumentation analysis.

3.5.1. Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

The analytical method employed to assess the levels of heavy metals in all the samples was ICP-MS, which stands for inductively coupled plasma-mass spectrometry. The ICP-MS 7900 technique is exceptionally adept at determining concentrations, including low concentrations within the parts per billion (ppb) range, equivalent to micrograms per liter (µg/l), as well as ultra-low concentrations within the parts per trillion (ppt) range, equivalent to nanograms per liter (ng/l). In ICP-MS, atomic elements are introduced into a plasma source, where they undergo ionization. Subsequently, these ions are meticulously separated based on their respective mass-to-charge ratios. ICP mass spectrometry serves as an indispensable analytical method, especially in the realm of high-purity material quality control, where its demand continues to rise in sync with the evolving requirements of the times. Moreover, this technique holds the promise of analyzing minute quantities of hazardous metals, making it invaluable in environmental contexts. In recent times, as a response to increasingly stringent environmental and regulatory standards, ICP-MS has found extensive use in meeting these more rigorous criteria.In comparison to ICP-MS, other analytical methods like inductively coupled plasma optical emission spectrometry (ICP-OES) and Atomic Absorption Spectroscopy (AAS) fall short in terms of their capabilities for the following reasons: Extremely low detection limits

- A large linear range
- Possibilities to detect isotope composition of elements
- Can determine quality and quantity quickly.
- Simultaneous multi-element analysis possible.
- High sensitivity analysis - lower detection limits of most elements are in ppt to ppq-order.

Figure 3.6: Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

3.5.1.1. Principle

Inductively coupled plasma mass spectrometry (ICP-MS) is a highly sensitive mass spectrometry technique capable of detecting metals and various non-metals at astonishingly low concentrations, even as low as one part in 10^15 (part per quadrillion, ppq) for isotopes that are not subject to interference from background signals. ICP Optical Emission Spectrometry, abbreviated as ICP-OES, represents another facet of this analytical method. In ICP-OES, an external source of energy is applied to the sample under analysis, leading to the excitation of its constituent elements or atoms. The ICP source itself facilitates the transformation of these atoms into ions. Subsequently, these ions are meticulously separated and then detected by the mass spectrometer. The schematic depiction of an ICP source within an ICP-MS system reveals the intricate channels through which argon gas flows, showcasing the intricate process by which this technique achieves its remarkable levels of sensitivity and precision.

3.5.2. Analysis Heavy Metals in Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

Heavy metal analysis is a critical component of environmental monitoring and various industrial applications due to the potential health and environmental risks associated with these elements. Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is a powerful analytical technique widely employed for the accurate quantification of heavy metals in various matrices. This standardized procedure outlines the steps involved in sample preparation and analysis for heavy metal determination using ICP-MS. Homogenize solid samples to ensure uniform distribution of the analytes. For liquid samples, filter them through a suitable filter paper to remove particulate matter. Acidify the samples using high-purity acids (e.g., nitric acid) to facilitate analyte solubility and preservation. Transfer a representative portion of the prepared sample into a digestion vessel. Use a microwave or hot plate to digest the sample in the presence of acid. Follow established digestion procedures and safety precautions to ensure complete digestion of the sample. Prepare multi-element standard solutions of known concentrations covering the analyte range of interest. Use certified reference materials (CRMs) for calibration and quality control purposes to validate the accuracy of the method. Transfer the digested samples into appropriate autosampler vials. Load the samples onto the ICP-MS instrument. Calibrate the instrument using the standard solutions and ensure stability and sensitivity. Run the samples, monitoring the intensities of specific mass-to-charge ratios for the target heavy metals. Quantify the heavy metal concentrations in the samples using calibration curves. Implement quality control measures, including the analysis of blanks and CRMs to verify instrument performance and data accuracy. Prepare a comprehensive report including sample information, analysis methods, results, and quality control data. Present the results in the appropriate units, typically expressed in µg/L or mg/kg. Comply with relevant regulatory guidelines and standards Method. This standardized procedure for heavy metal analysis using ICP-MS is based on established methodologies and best practices. It ensures the reliable quantification of heavy metals in various sample matrices, contributing to environmental monitoring, regulatory compliance, and safeguarding public health (USEPA, 2018, ASTM, 2018).

3.5.3. Atomic Absorption Spectrometer

The analysis of heavy metal concentrations in all the samples was carried out using Atomic Absorption Spectroscopy (AAS4141), a widely utilized laboratory technique for metal analysis. This method is founded on the fundamental principle of atoms' capacity to absorb electromagnetic radiation.The heavy metals under investigation in this study had detection limits as low as 0.001 parts per million (ppm) and absorption wavelengths centered around 217.0 nanometers (nm). A key feature of AAS4141 is the generation of free, ground state atoms from the sample after exposure to a light beam emitted by the hollow cathode lamp. The absorption of radiation in this process often adheres to Beer's law, represented as A = abc, where A signifies the absorbance, a represents the absorptivity, b denotes the path length of absorption, and c stands for the concentration of the absorbing species. This empirical law establishes a direct relationship between the absorption of the analyte and its concentration, necessitating the calibration of the instrument for accurate quantification.

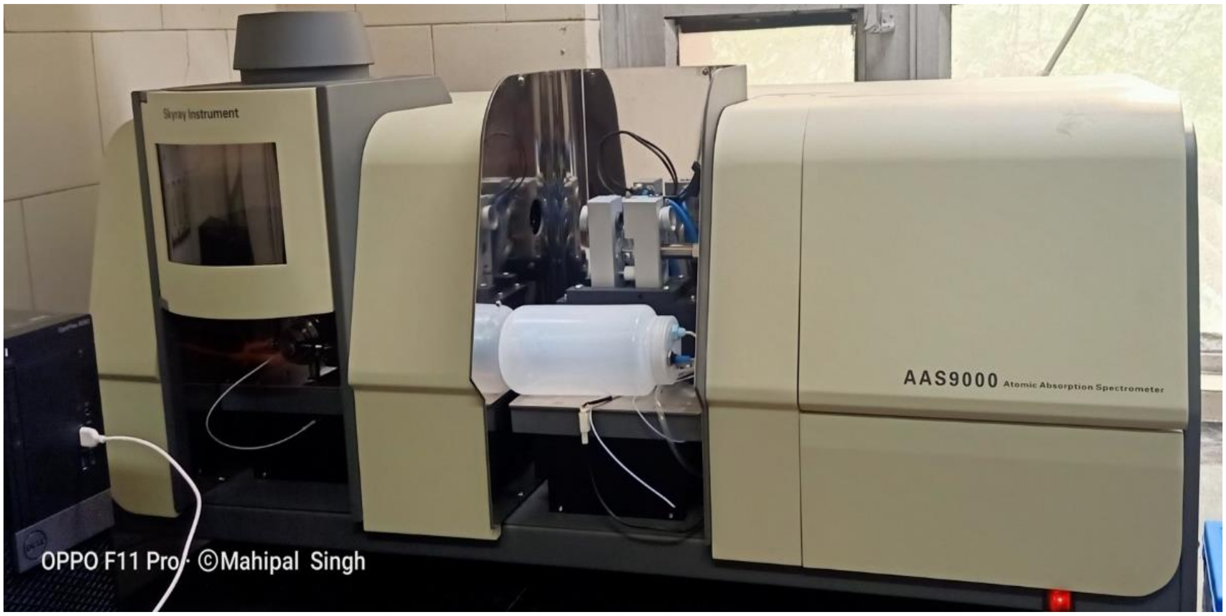

Figure 3.7. Atomic Absorption Spectrophotometer

3.5.3.1. Principle

The use of absorption spectrometry to determine an analyte's concentration in a sample. To establish the relationship between the measured absorbance and the analyte concentration based on Beer-Law, Lambert's standards with known analyte contents were required. In essence, by absorbing a specific quantum of energy, the atoms in the atomizer can have their electrons promoted to higher orbitals (excited state) for a brief period of time (nanoseconds) (radiation of a given wavelength). A specific electron transition in a particular element corresponds to this amount of energy, or wavelength. Typically, each wavelength only corresponds to one element per wavelength, and an absorption line's width is only a few picometers (pm), giving the technique its name. A detector was used to measure the radiation flux with and without a sample in the atomizer. The ratio between the two values (the absorbance) was then converted to analyte concentration or mass using the Beer-Lambert Law.

3.5.1. Analysis Heavy Metals in Atomic Absorption Spectrophotometer

The quantification of heavy metals, we employed an Atomic Absorption Spectrophotometer. This advanced instrument allowed us to set different characteristic wavelengths corresponding to the specific metals of interest, utilizing hollow cathode lamps. The digested samples were directly aspirated into an air-acetylene flame for precise analysis. To ensure the accuracy of our analysis, the instrument underwent meticulous calibration. Known concentrations of heavy metals were utilized to create standard solutions with a concentration of 1,000 mg L-1. These solutions were then serially diluted to achieve the desired concentrations for each metal of interest. A multi-point calibration graph was thoughtfully prepared for each metal. Quality control measures were diligently implemented throughout the analysis process. After every 10 samples, a blank run was performed to assess the instrument's performance and minimize potential errors. It's crucial to note that each sample underwent the determination of heavy metal concentrations three times, and the reported results represent the mean concentration of heavy metals in the respective samples. Standard Procedure for Heavy Metal Analysis and Sample Preparation for ICP-MS Instrument.

3.6. Statistic Evaluation

In our comprehensive analysis, all the parameters we investigated for heavy metal concentration, underwent a thorough assessment to discern their significance in the context of seasonal variations and wastewater contamination. This evaluation was conducted through a rigorous statistical approach, employing a two-way analysis of variance (ANOVA), supplemented by the F-test and Tukey's test, with a significance threshold set at $p < 0.005$. Additionally, we applied these statistical methods, namely the two-way ANOVA, the Tukey's test, to scrutinize the statistically significant disparities in heavy metal concentrations. The threshold for significance in this aspect was also set at $p = 0.005$. All of these statistical analyses were conducted using the powerful R Programming language, ensuring the robustness and reliability of our findings.

CHAPTER 4

RESULT & DISCUSSION

Result & Discussion

4.1. Impact of Water Quality Parameters on Heavy Metal Contamination in the Yamuna River

The comprehensive investigation, spanning from January to December 2019, aimed to discern the monthly oscillations in hydrobiological parameters within the Yamuna River in Delhi. To achieve this, bi-weekly water samples were meticulously collected from five strategically chosen sites along the river. The study incorporated on-site thermal assessments using digital thermometers, complemented by volumetric estimations of the collected water samples. The findings unearthed pronounced seasonal fluctuations in hydrobiological parameters, a phenomenon of paramount importance in understanding and addressing heavy metal contamination in the Yamuna River. These variations are not only indicative of the river's ecological health but also serve as crucial factors influencing the presence and impact of heavy metals in this vital water body. Heavy metals, which include elements like lead, chromium, nickel, and zinc, are of significant concern due to their potential toxicity and adverse effects on aquatic ecosystems and human health. Understanding how these heavy metals interact with the dynamic hydrobiological conditions of the river throughout the year is essential for effective environmental management and protection. Here, we present an analysis of four key hydrobiological parameters – water temperature, pH, dissolved oxygen, and water hardness – and explore their implications on the presence and behavior of heavy metals in the Yamuna River throughout 2019.

4.1.1. Influence of Water Temperature Fluctuations on Heavy Metal Contamination in the Yamuna River

Throughout the year 2019, the water temperature at the study site exhibited pronounced fluctuations, following a distinct seasonal pattern shown in Figure 4.1. The recorded data revealed a noteworthy range of water temperatures, with the lowest temperature occurring in January at 12.61±2.87°C and the highest in July at 30.28±4.7°C. On average, across the twelve months, the water temperature stabilized at approximately 23.01°C. These findings highlight the significant disparity between the coldest and warmest periods, with a consistent trend of gradual increase observed, commencing in the chilly winter month of January and steadily ascending through the spring season. The peak of this temperature progression was reached during the scorching heat of July. Subsequently, there was a gradual decline in temperature as the year advanced towards December, reaching its lowest point at 18.69±3.9°C, as detailed in Table 1. This seasonal temperature pattern aligns with typical climatic variations experienced in many regions, with the warmest conditions occurring during the middle months of the year and the coldest temperatures observed at both the beginning and end of the annual cycle. The fluctuations in water temperature hold considerable significance in the context of heavy metal contamination within aquatic ecosystems. Changes in temperature can influence the solubility and mobility of heavy metals in water, potentially affecting their bioavailability to aquatic organisms. Additionally, temperature variations can impact the metabolic rates of aquatic organisms, potentially altering their sensitivity to heavy metal exposure. Therefore, understanding these temperature-related fluctuations is crucial for assessing the ecological implications of heavy metal contamination in aquatic environments. Furthermore, variations in water temperature can influence the physicochemical properties of water, such as pH and oxygen solubility, which, in turn, can affect the chemical speciation and behavior of heavy metals. Therefore, the observed seasonal temperature trends provide valuable insights into the dynamics of heavy metal contamination and its potential ecological consequences within the studied water body.

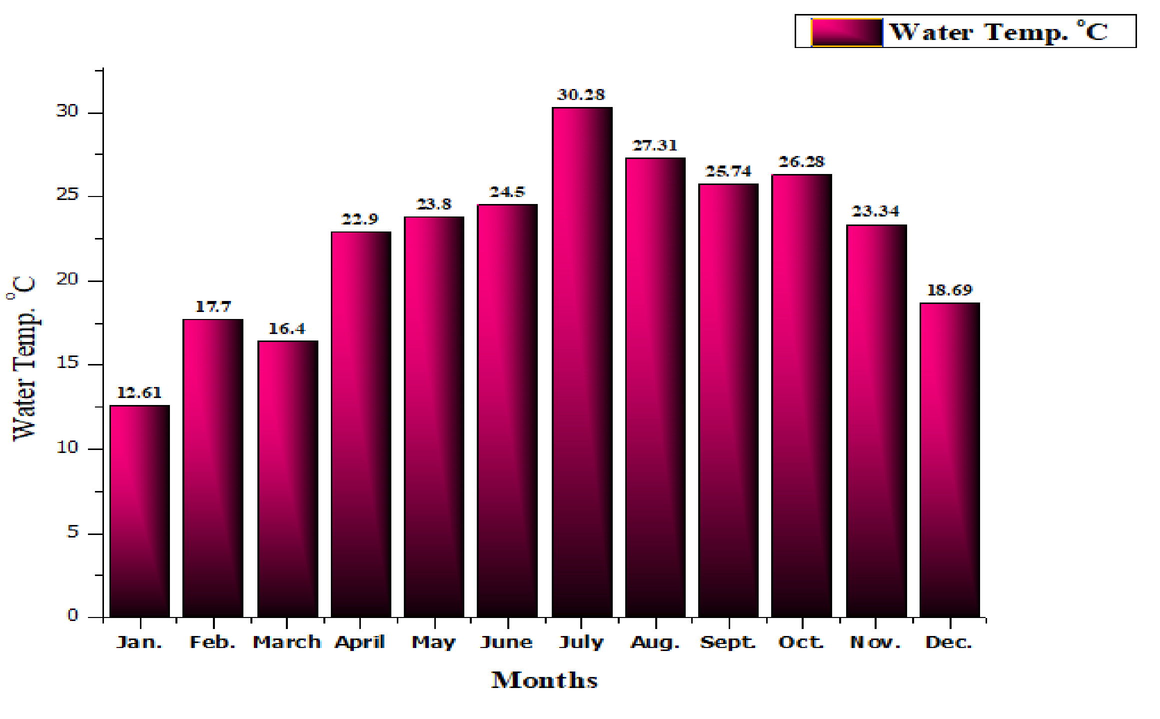

Figure 4.1: Monthly Influence of Water Temperature Fluctuations on Heavy Metal Contamination in the Yamuna River.

4.1.2. Influence of pH Fluctuations on Heavy Metal Contamination Water in the Yamuna River

The pH levels of the water samples collected throughout the year 2019 displayed significant variations, highlighting a dynamic trend in the water's acidity or alkalinity. These pH values covered a range from 5 to 8, spanning the entire pH scale. The monitoring began in January with a pH reading of 6, indicating a slightly acidic nature of the water. As February progressed in pH to 6, although the water still remained within the acidic range. March witnessed a notable in pH to 6. This trend continued into April, which registered a pH of 6. May marked a decrease in pH levels, reaching 5, signifying a slightly acidic nature of the water during this period. The subsequent months introduced changes in the opposite direction. June displayed a slight increase in pH to 8, continuing into July, which saw a consistent increase in pH to 8, indicating a return to slightly alkaline conditions. August recorded a increase in pH to 8, while September witnessed a further stable to 8. October experienced another shift, with pH levels decreasing to 6, maintaining an overall slightly acidic nature. The final two months of the year, November and December, exhibited relatively stable pH levels at 6 and 6, respectively. These substantial fluctuations in pH values throughout the year provide important insights into the dynamic nature of the water body and its potential impact on aquatic ecosystems and the environment. pH levels are crucial indicators of water quality, and these observations hold significant environmental significance. These pronounced fluctuations in pH values throughout the year provide valuable insights into the dynamic nature of the water body and its potential impact on aquatic ecosystems and the environment. pH levels are crucial indicators of water quality and can influence the health and survival of aquatic organisms, making these observations of significant environmental relevance. pH levels are crucial indicators of water quality and can influence the health and survival of aquatic organisms, making these observations of significant environmental relevance. These fluctuations in pH levels bear ecological significance, as they can profoundly influence the health and behavior of aquatic organisms within the ecosystem. pH is a critical parameter that can affect the speciation, solubility, and toxicity of heavy metals in aquatic environments. Changes in pH can alter the chemical forms of heavy metals, potentially making them more or less available to aquatic organisms. Consequently, monitoring pH variations is essential for understanding how heavy metal contamination may impact the aquatic ecosystem, as pH can influence the bioavailability and toxicity of these contaminants. Furthermore, shifts in pH levels can impact the overall water quality, affecting the survival and reproduction of aquatic organisms. Maintaining a suitable pH range is crucial for sustaining a healthy aquatic ecosystem and mitigating the adverse effects of heavy metal contamination. Therefore, the observed pH fluctuations provide valuable insights into the potential ecological consequences of heavy metal contamination in the studied water body.

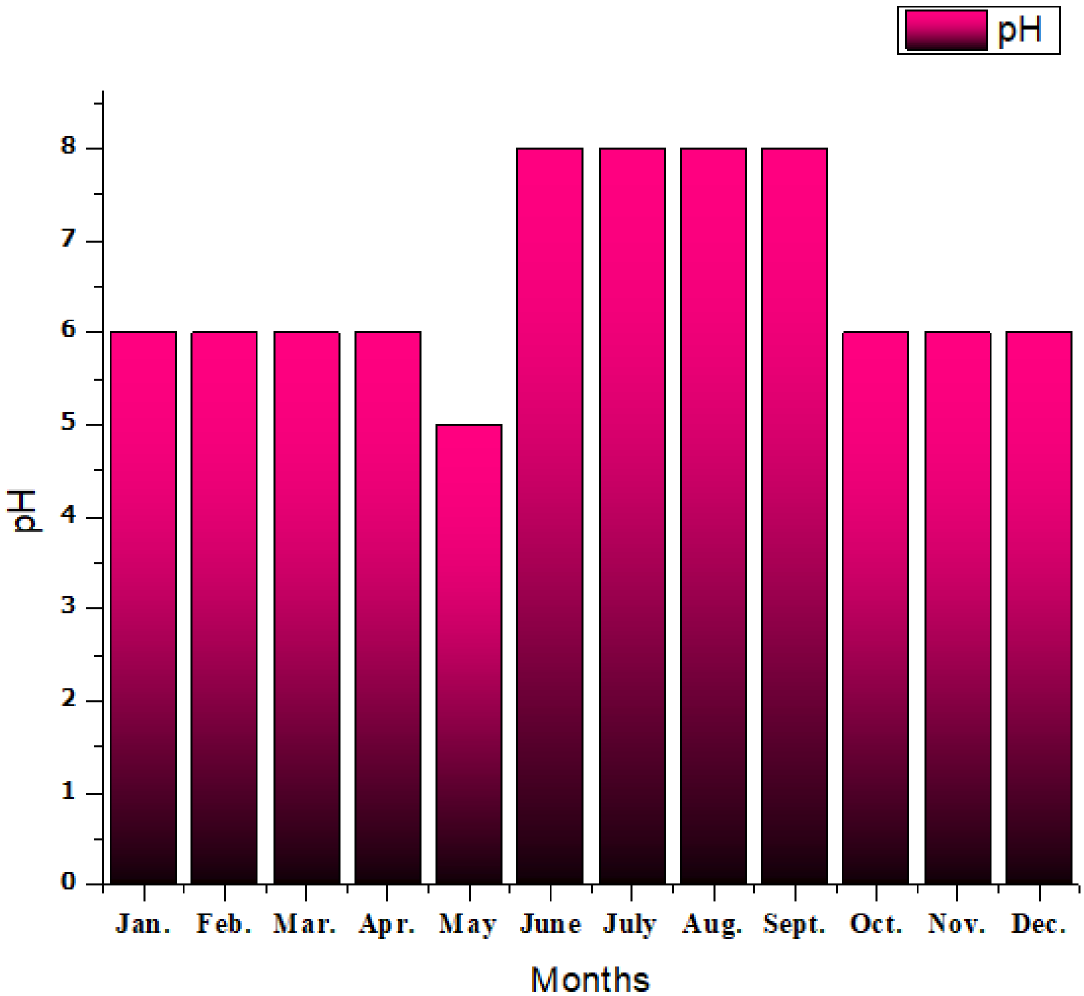

Figure 4.2: Monthly Influence of pH Fluctuations on Heavy Metal Contamination Water in the Yamuna River

4.1.3. Influence of Dissolved Oxygen (DO) Levels Fluctuations on Heavy Metal Contamination Water in the Yamuna River

The study conducted continuous monitoring of dissolved oxygen (DO) levels in the Yamuna River throughout 2019, revealing significant fluctuations in oxygen concentration. The highest recorded DO concentration occurred in May 2019, reaching 6.83±0.27 mg/L, indicating a healthy oxygen supply for aquatic organisms. Conversely, the lowest recorded DO concentration was in February 2019, at 3.40±1.52 mg/L, signaling a significant decrease in oxygen levels. These observations highlight the dynamic nature of DO content in the river (Table 1). In January, the recorded DO level was 4.48±1.60 mg/L, indicating relatively lower oxygen concentration. February witnessed a further decrease in DO to 3.55±0.65 mg/L, marking a notable decline in dissolved oxygen levels. However, as March arrived, DO levels experienced a significant increase, reaching 4.72±0.69 mg/L, signifying improved oxygen availability. April continued this positive trend, with DO levels reaching 6.06±1.22 mg/L. May represented the peak, recording DO at 6.83±0.27 mg/L, highlighting a healthy oxygen supply. June witnessed a slight decrease to 5.18±0.42 mg/L, while July saw a modest rise to 5.38±0.33 mg/L. August marked a noticeable increase, with DO levels at 6.09±0.98 mg/L, indicating improved oxygen levels. September maintained this positive trend, with DO levels at 6.55±0.72 mg/L. October showed a slight decrease to 5.78±0.68 mg/L, while November remained similar, with DO at 5.39±0.59 mg/L. In December, DO levels settled at 4.84±1.23 mg/L, indicating a relatively lower oxygen concentration. These fluctuations in DO levels are of paramount importance for aquatic ecosystems as they significantly influence the health and survival of aquatic life. Adequate DO levels are essential for sustaining aquatic organisms, and variations in oxygen content can impact the distribution and behavior of these species. Additionally, DO levels can affect the bioavailability and toxicity of heavy metals in the water, further emphasizing the ecological significance of these fluctuations. Monitoring and understanding DO dynamics in the context of heavy metal contamination provide critical insights into the potential ecological consequences of such pollution in the studied water body.

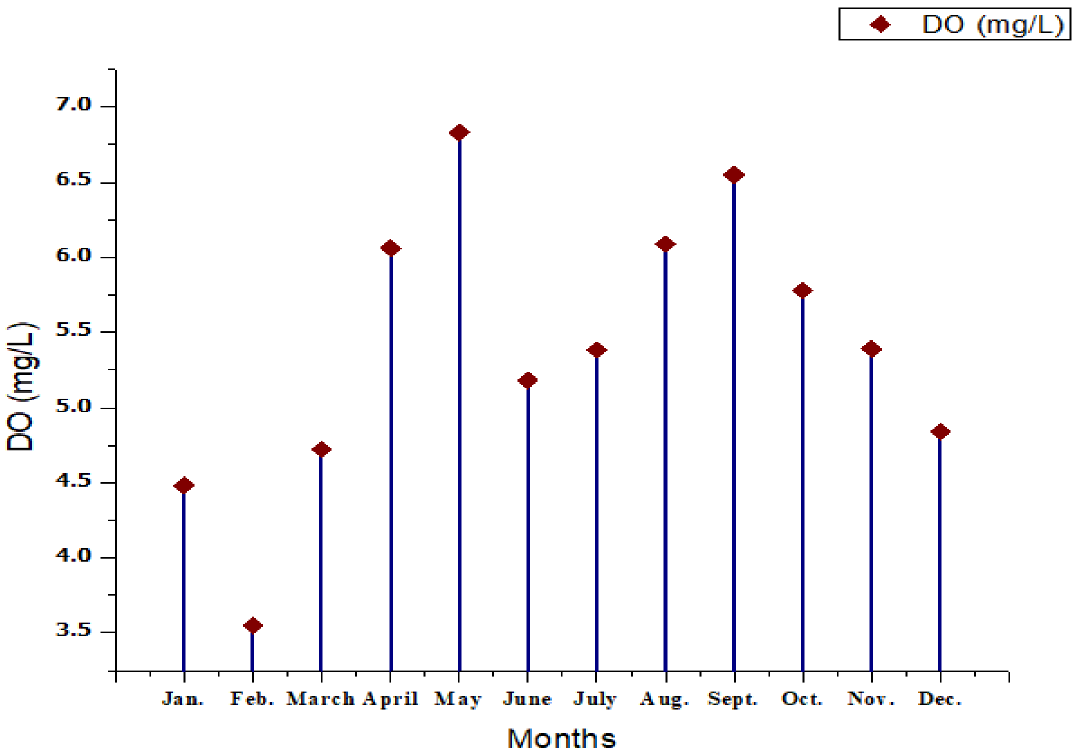

Figure 4.3: Influence of Dissolved Oxygen (DO) Levels Fluctuations on Heavy Metal Contamination Water in the Yamuna River

4.1.4. Influence of Hardness Fluctuations on Heavy Metal Contamination Water in the Yamuna River

The investigation into water hardness along the Yamuna River during the hydrobiological study for 2019 revealed intriguing trends. Water hardness fluctuated within the range of 111.30±27.60 to 170.88±6.95 mg/L, with an average hardness of 148.63±11.51 mg/L (Table 1). These variations in water hardness throughout the year are indicative of changes in mineral content and water quality. In January, water hardness was measured at 148.10±20.93 mg/L, signifying a relatively high mineral content in the water. February marked a decrease in hardness to 111.30±27.60 mg/L, reflecting a decrease in mineral concentration. March maintained a moderate mineral content with hardness recorded at 124.78±24.96 mg/L. April saw an increase in hardness to 154.82±6.90 mg/L, indicating a higher mineral concentration. May exhibited the highest hardness level at 170.88±6.95

mg/L, suggesting a pronounced mineral presence. June witnessed a decrease in hardness to 149.86±12.89 mg/L, followed by further reductions in July to 130.75±16.61 mg/L and August with hardness at 120.28±9.55 mg/L. September showed a slight rise in hardness to 138.24±7.52 mg/L. October maintained moderate hardness levels at 126.76±11.08 mg/L, while November displayed a slight increase to 143.53±30.25 mg/L. December recorded hardness at 138.28±20.78 mg/L, indicating a moderate mineral content. These fluctuations in water hardness can have multifaceted implications for the aquatic ecosystem. Water hardness affects the availability of essential ions, such as calcium and magnesium, which are crucial for various biological processes in aquatic organisms. Additionally, variations in hardness can impact the bioavailability and toxicity of heavy metals, which is of particular importance in the context of heavy metal contamination. Understanding the seasonal patterns of water hardness alongside heavy metal levels contributes to a comprehensive assessment of water quality and its potential ecological effects.

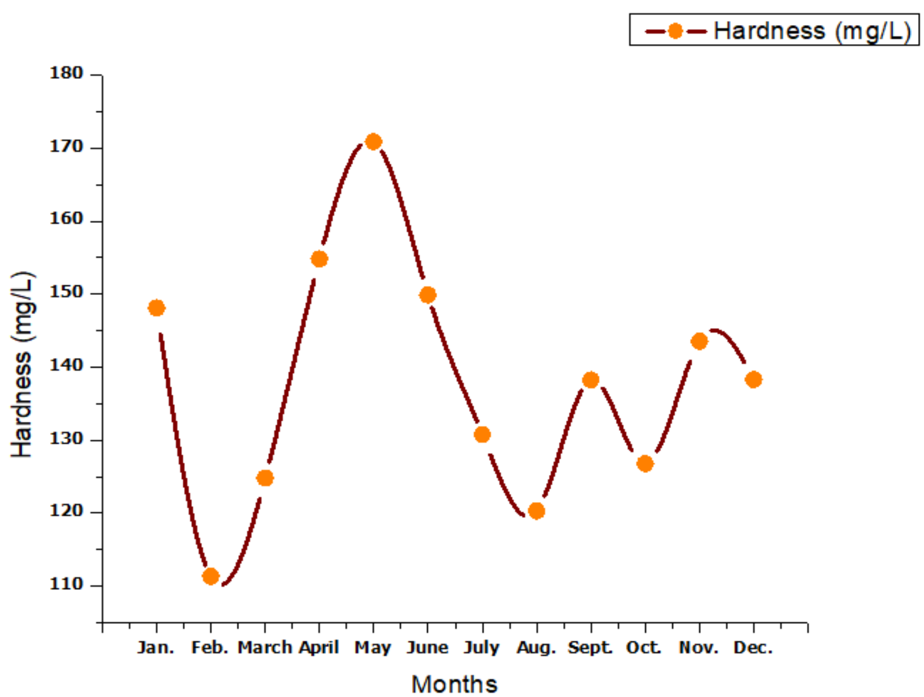

Figure 4.4: Monthly Influence of Hardness Fluctuations on Heavy Metal Contamination Water in the Yamuna River

4.1.5. Influence of Alkalinity Fluctuations on Heavy Metal Contamination Water in the Yamuna River

The hydrobiological investigations conducted throughout 2019 unveiled remarkable variations in the alkalinity levels of the Yamuna River. Alkalinity, a crucial parameter, plays a significant role in shaping the water chemistry and overall stability of aquatic ecosystems. Understanding the seasonal patterns in alkalinity is instrumental in comprehending its influence on heavy metal contamination within the river. The recorded data highlighted pronounced fluctuations in alkalinity levels, with a peak value of 123.21±18.58 mg/L observed in January 2019, indicative of a higher presence of alkaline chemicals in the river water during this period. However, this peak was followed by a consistent decrease in alkalinity levels throughout the year. In February, alkalinity dropped to 97.89±9.65 mg/L, marking a noticeable decline in alkaline concentration. This trend continued into March, with alkalinity recorded at 96.84±10.35 mg/L, signifying a continuation of relatively low alkaline content. April witnessed a further reduction in alkalinity to 76.78±14.20 mg/L, indicating a diminishing alkaline presence. The lowest alkalinity level was observed in May, at 69.48±15.99 mg/L, highlighting minimal alkaline content during this period. June displayed a slight increase in alkalinity to 65.07±18.99 mg/L, which was followed by a modest rise in July to 95.18±17.55 mg/L, indicating a return to moderate alkaline conditions. August sustained this upward trend, with alkalinity measured at 89.38±10.18 mg/L. September showed alkalinity levels at 79.80±13.12 mg/L, maintaining a moderate alkaline content. October experienced a slight increase in alkalinity to 106.73±15.50 mg/L, while November remained relatively stable at 100.78±7.88 mg/L. December marked alkalinity at 122.92±26.43 mg/L, signifying a moderate alkaline content. These fluctuations in alkalinity levels hold significant implications for heavy metal contamination in the Yamuna River. Alkalinity plays a pivotal role in water chemistry, particularly in buffering against sudden pH changes. This buffering capacity can impact the speciation, solubility, and mobility of heavy metals. At higher alkalinity levels, the river water tends to resist dramatic changes in pH, potentially reducing the dissolution of certain heavy metals and their subsequent availability to aquatic organisms. Conversely, lower alkalinity levels may render the water more susceptible to pH fluctuations, potentially enhancing the mobility and bioavailability of heavy metals. Understanding the interplay between alkalinity and heavy metal dynamics is crucial for assessing and managing heavy metal contamination in the Yamuna River.

These findings underscore the complex nature of the river's ecosystem and the need for holistic approaches to safeguard its ecological integrity and protect human health.

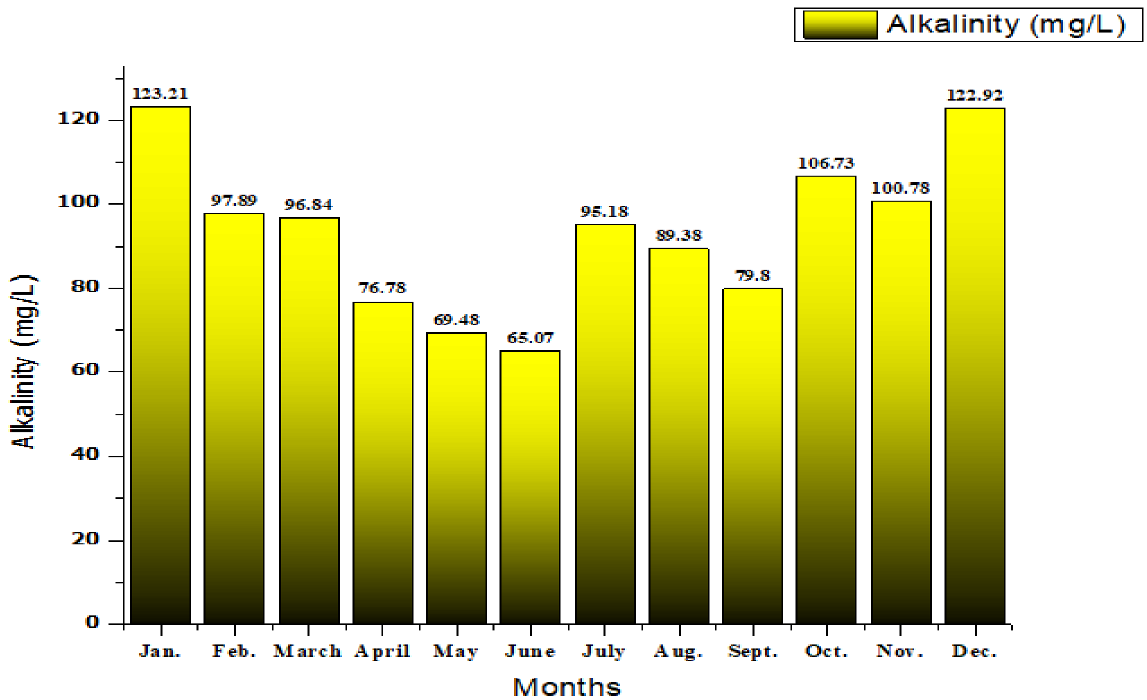

Figure 4.5: Influence of Alkalinity Fluctuations on Heavy Metal Contamination Water in the Yamuna River

4.1.6. Influence of Acidity Fluctuations on Heavy Metal Contamination Water in the Yamuna River

The hydrobiological analysis conducted throughout 2019 unveiled notable variations in the acidity levels of the Yamuna River. Acidity, a crucial parameter, has a significant influence on water chemistry, pH balance, and the overall health of aquatic ecosystems. Understanding the seasonal patterns in acidity is essential for comprehending its role in heavy metal contamination within the river. The recorded data revealed pronounced fluctuations in acidity levels, with the highest recorded acidity of 25.31±5.08 mg/L observed in May 2019, indicating a pronounced acidic content in the river water during this period. However, this peak was followed by consistent fluctuations in acidity levels throughout the year. In January, acidity was measured at 21.20±4.90

mg/L, indicating a moderate acidic content in the water. February saw a decrease in acidity to 14.22±2.41 mg/L, reflecting a decrease in acidic concentration. March recorded acidity at 15.38±3.12 mg/L, maintaining a relatively low acidic content. April witnessed a further increase in acidity to 24.20±2.18 mg/L, signifying a higher acidic presence. June exhibited a slight decrease in acidity to 24.65±3.80 mg/L. July recorded a significant drop in acidity to 11.92±1.82 mg/L, indicating a return to low acidic conditions. August continued this trend with acidity at 13.30±1.33 mg/L. September saw acidity levels at 16.56±3.09 mg/L, maintaining a moderate acidic content. October recorded a slight increase in acidity to 19.88±2.62 mg/L, while November remained relatively stable at 19.05±3.66 mg/L. December marked acidity at 23.18±2.07 mg/L, signifying a moderate acidic content shown in figure 4.6. Fluctuations in acidity levels have significant implications for heavy metal contamination in the Yamuna River. Acidity plays a pivotal role in regulating pH, which, in turn, influences heavy metal speciation, solubility, and bioavailability. Higher acidity levels can lead to lower pH values, potentially increasing the solubility of certain heavy metals and their availability to aquatic organisms. Conversely, reduced acidity can result in higher pH values, potentially reducing the mobility and bioavailability of heavy metals. Understanding the intricate relationship between acidity and heavy metal dynamics is vital for assessing and managing heavy metal contamination in the Yamuna River. These findings emphasize the need for comprehensive approaches to protect both the river's ecosystem and human health from the detrimental effects of heavy metal pollution.

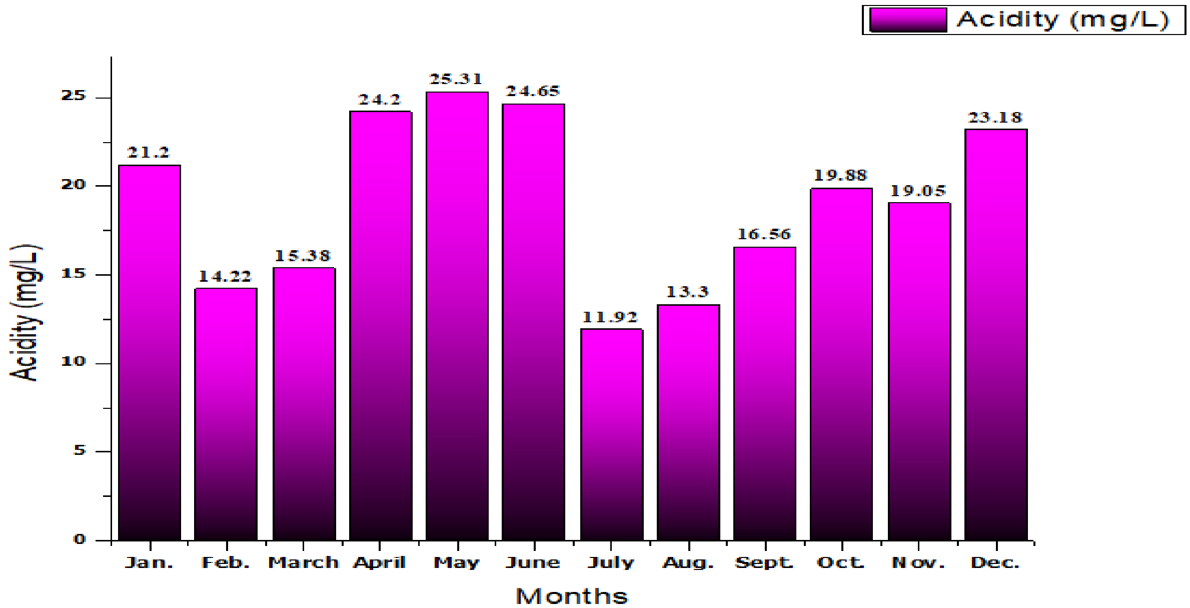

Figure 4.6: Influence of Acidity Fluctuations on Heavy Metal Contamination Water in the Yamuna River

Months	Water Temp. (ºC)	pH	DO (mg/L)	Hardness (mg/L)	Alkalinity (mg/L)	Acidity (mg/L)
January	12.61±2.87	6	4.48±1.60	148.10±20.93	123.21±18.58	21.20±4.90
February	17.7±1.8	6	3.55±0.65	111.30±27.60	97.89±9.65	14.22±2.41
March	16.4±1.6	6	4.72±0.69	124.78±24.96	96.84±10.35	15.38±3.12
April	22.9±2.8	6	6.06±1.22	154.82±6.90	76.78±14.20	24.20±2.18
May	23.8±1.7	5	6.83±0.27	170.88±6.95	69.48±15.99	25.31±5.08
June	24.5±1.9	8	5.18±0.42	149.86±12.89	65.07±18.99	24.65±3.80
July	30.28±4.7	8	5.38±0.33	130.75±16.61	95.18±17.55	11.92±1.82
August	27.31±4.8	8	6.09±0.98	120.28±9.55	89.38±10.18	13.30±1.33
September	25.74±4.3	8	6.55±0.72	138.24±7.52	79.80±13.12	16.56±3.09
October	26.28±2.6	6	5.78±0.68	126.76±11.08	106.73±15.50	19.88±2.62
November	23.34±3.6	6	5.39±0.59	143.53±30.25	100.78±7.88	19.05±3.66
December	18.69±3.9	6	4.84±1.23	138.28±20.78	122.92±26.43	23.18±2.07

Table 4.1: Monthly Water Quality Parameters in the Yamuna River

4.2. Heavy Metals

The presence of heavy metals in the Yamuna River, originating from various industrial processes, wastewater discharge, and urban runoff, exacerbates the contamination issue. Industrial pollution, including emissions from factories and manufacturing units along the riverbanks, contributes significantly to the elevated levels of heavy metals in the water. Additionally, runoff from urban areas carries pollutants like heavy metals into the river, further intensifying the problem. These multiple sources of contamination underscore the complexity of the issue and the urgent need for comprehensive remediation measures. The results obtained from the analysis of heavy metal concentrations in the Yamuna River water and the agricultural produce offer compelling evidence of the extent of pollution and its ramifications. High concentrations of heavy metals not only jeopardize the health of the river ecosystem but also pose a substantial threat to human well-being. The profound impact of heavy metal contamination in the Yamuna River extends beyond agricultural practices and human health, delving into the realm of industrial pollution and other significant sources of contamination. The industrial landscape along the Yamuna's banks encompasses a wide array of activities, including pulp and paper manufacturing, textile production, paint production, steel plants, thermal power plants, chemical factories, pharmaceuticals, tanneries, mechanical workshops, and battery manufacturing, among others. In the context of environmental forensics, the identification and quantification of heavy metals in the Yamuna River water and agricultural and industries produce provide crucial evidence in the pursuit of responsible parties. This evidence helps authorities trace the origins of contamination back to specific industries and facilities, facilitating legal action against polluters. Moreover, the findings underscore the pressing need for stringent regulations and remediation efforts aimed at curbing industrial pollution and protecting the fragile ecosystem of the Yamuna River. By addressing these issues, we can work towards mitigating the harmful effects of heavy metal contamination and ensuring the long-term sustainability of this vital water resource.

4.2.1. Seasonal Variation of Chromium Concentrations in Yamuna River Water and its Forensic Implications

The study investigated the seasonal variations in chromium concentrations within the water of Yamuna River, as depicted in Figure 4.7. These findings were subsequently evaluated in the context of WHO-recommended standard values for chromium content in water. Remarkably, the study unveiled significant fluctuations in chromium concentrations influenced by seasonal factors, such as temperature and precipitation. Of particular note was the substantially higher chromium concentration recorded during the summer season, with a p-value of <0.005, compared to the relatively lower concentrations observed during the winter and monsoon seasons. The table presents the results of the Tukey test, which was conducted to assess the differences in Cr concentrations across various seasons. Multiple comparisons of means were conducted, and the table illustrates the outcomes of these comparisons spanning the summer, monsoon, and winter seasons. The objective was to ascertain whether statistically significant variations in chromium concentrations exist among these seasons, providing valuable insights into the seasonal trends of chromium contamination in Yamuna River water. This figure visually communicates the seasonal variations in chromium concentrations at various sampling sites along the Yamuna River. The data highlights the dynamic nature of chromium levels across the summer, monsoon, and winter seasons at multiple sampling locations along the river. The figure contributes to a comprehensive comprehension of water quality dynamics in the Yamuna River, shedding light on both seasonal patterns and location-specific disparities in chromium contamination. Multiple comparisons of means, facilitated by the Tukey test, offered a clearer understanding of these seasonal disparities. The results indicated that the summer season exhibited the highest mean square value for chromium content, followed by the winter and monsoon seasons (refer to Table 4.2). The primary sources of chromium contamination in river water were identified as sewage water, anthropogenic activities, and wastewater discharge. Notably, the concentration of heavy metals in the water exhibited an upward trend during the summer season, coinciding with a decrease in the river's water level.

Season	Difference	Lower	Upper	P-Value
Summer-Monsoon	0.86755	0.642479182	1.0926208	0.0000000
Winter-Monsoon	0.20956	0.005648865	0.4247689	0.0578548
Winter-Summer	-0.65799	-0.855671965	-0.4603080	0.0000000

Table 4.2: Tukey Test for Chromium: Multiple Comparisons of Means for Different Seasons

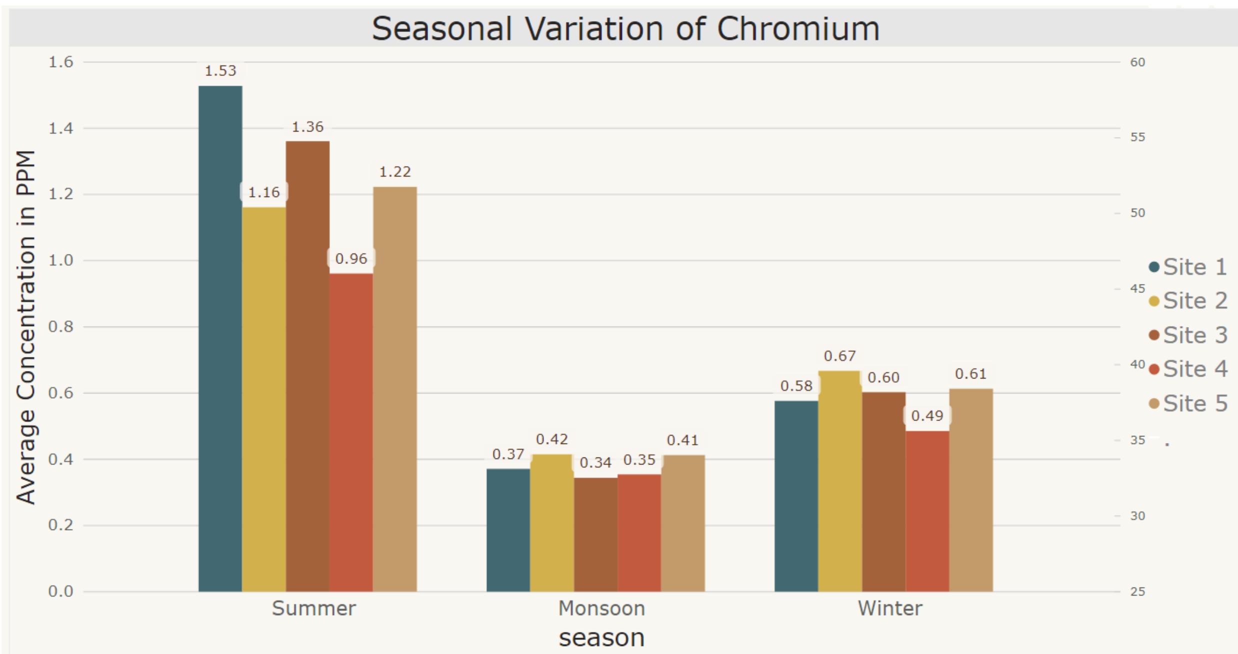

Figure 4.7: Seasonal Variation of Chromium in Yamuna River Water: Changes in Lead Concentrations Across Sites

4.2.1.1. Forensic Significance

These findings hold paramount forensic significance, particularly within the domain of environmental forensics. The observed seasonal variations in chromium concentrations in Yamuna River water can serve as pivotal evidence for tracing the sources and origins of heavy metal pollution. By scrutinizing these fluctuations and establishing connections with specific seasons, investigators can gain valuable insights into the timing and potential causes of contamination incidents. Furthermore, this data underscores the urgency of monitoring and regulating anthropogenic activities and wastewater discharge into the river, particularly during the summer months when chromium levels significantly escalate. By addressing these concerns, authorities can mitigate the environmental repercussions and potential health hazards associated with heavy metal contamination in the Yamuna River.

4.2.2. Seasonal Variation of Lead Concentrations in Yamuna River Water and its Forensic Implications

The study conducted a comprehensive analysis of seasonal variations in lead concentrations in Yamuna River water, as depicted in Figure 4.8. These findings were meticulously compared with the recommended standards set by the World Health Organization (WHO). The results revealed notable disparities in lead concentrations across different seasons, with summer registering a significantly higher concentration ($p<0.005$) compared to the winter and monsoon seasons, which exhibited lower concentrations. This observed variation is closely linked to seasonal factors such as temperature and precipitation. Upon employing multiple means comparisons in various seasons, it was established that the summer season consistently exhibited the highest mean square value for lead content, followed by the winter and monsoon seasons, as outlined in the Tukey test (Table 4.3). These variations underscore the dynamic nature of lead contamination in river water, with the summer season serving as a critical period of concern due to elevated lead levels. The source of lead contamination in the Yamuna River primarily stems from sewage and wastewater discharges. As the river's water levels recede during the summer months, the concentration of heavy metals, including lead, experiences a surge. This phenomenon amplifies the risk of lead exposure through water consumption and agricultural practices.

Season	Difference	Lower	Upper	P-Value
Summer-Monsoon	1.15060	0.83442891	1.4667711	0.0000000
Winter-Monsoon	0.21004	0.09227739	0.5123574	0.2241085
Winter-Summer	-0.94056	1.21825625	0.6628637	0.0000000

Table 4.3: Tukey Test for Lead: Multiple Comparisons of Means for Different Seasons

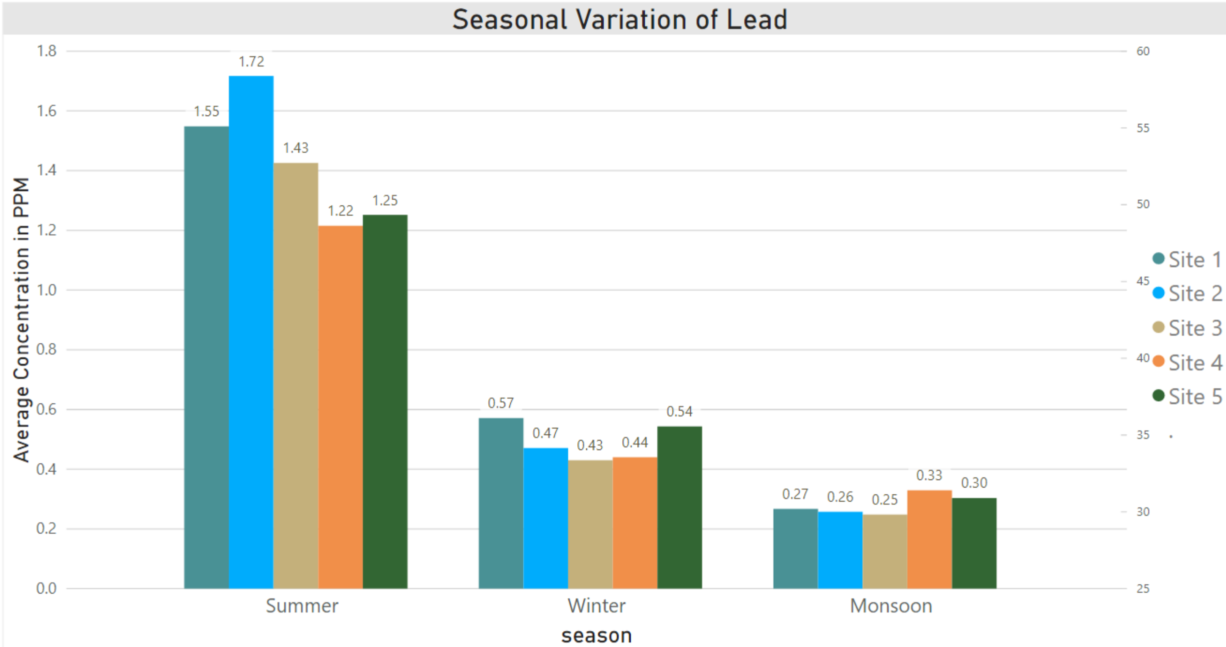

Figure 4.8: Seasonal Variation of Lead in Yamuna River Water: Changes in Lead Concentrations Across Sites

4.2.2.1. Forensic Significance

The observed seasonal variations in lead concentrations hold paramount importance in the realm of environmental forensics. They serve as valuable evidence for understanding the dynamics of pollution sources and their impacts on the river ecosystem. By pinpointing the summer season as a high-concentration period, investigators can potentially trace the sources of lead contamination back to specific activities, such as increased industrial and agricultural discharges during this time. Furthermore, these findings underscore the urgency of implementing effective pollution control measures, particularly during the summer season, to mitigate the detrimental effects of lead contamination on both environmental and human health. The data generated from this study can aid authorities in formulating targeted strategies to curtail pollution sources, safeguard water quality, and protect the well-being of community's dependent on the Yamuna River.

4.2.3. Seasonal Variation of Nickel Concentrations in Yamuna River Water and its Environmental Significance

This study delved into the seasonal variations in nickel concentrations within the Yamuna River, as elucidated in Figure 4.9. The outcomes were meticulously compared against the World Health Organization's (WHO) permissible limits for nickel content in water. The findings underscored the impact of seasonal factors, such as temperature and rainfall, on nickel concentrations. Significantly, the research unveiled distinct seasonal variations in nickel concentrations within the Yamuna River, with the summer season exhibiting notably higher levels ($p<0.005$) compared to other seasons. The Tukey test results, as presented in Table 4.4, further elucidated these differences, showcasing that the mean square value of nickel content was highest during the summer, followed by winter and monsoon seasons. The primary sources of nickel contamination in the river water were traced back to sewage water and wastewater discharges. Intriguingly, as the river's water level receded during the summer, heavy metal concentrations, including nickel, exhibited an upward trajectory. This figure visually communicates the seasonal variations in nickel concentrations at various sampling sites along the Yamuna River. The data highlights the dynamic nature of nickel levels across the summer, monsoon, and winter seasons at multiple sampling locations along the river. The figure contributes to a comprehensive comprehension of water quality dynamics in the Yamuna River, shedding light on both seasonal patterns and location-specific disparities in nickel contamination.

Season	Difference	Lower	Upper	P-Value
Summer-Monsoon	0.8689333	0.4496586	1.2882080	0.0000198
Winter-Monsoon	0.1681733	-0.2327300	0.5690766	0.5729503
Winter-Summer	-0.7007600	-1.0690132	-0.3325068	0.0000813

Table 4.4: Tukey Test for Nickel: Multiple Comparisons of Means for Different Seasons

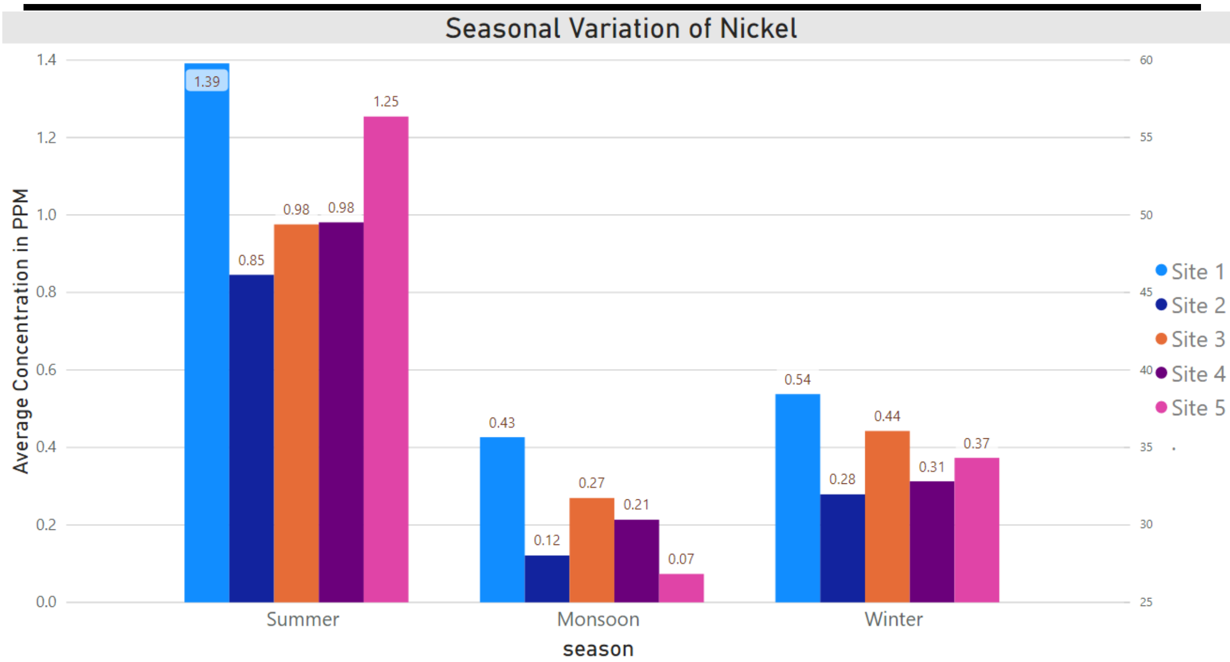

Figure 4.9: Seasonal Variation of Nickel in Yamuna River Water: Changes in Lead Concentrations Across Sites

4.2.3.1. Forensic Significance

These findings hold significant forensic importance within the purview of environmental forensics. The observed seasonal variations in nickel concentrations provide critical evidence for understanding the sources and dynamics of heavy metal pollution in the Yamuna River. By examining these fluctuations and their correlation with specific seasons, investigators can gain insights into the timing and potential causes of contamination events. Furthermore, this data underscores the urgency of monitoring and regulating anthropogenic activities, particularly sewage and wastewater discharge, into the river. The significant increase in nickel levels during the summer months highlights the need for targeted pollution control measures to mitigate environmental consequences and potential health risks associated with heavy metal contamination in the Yamuna River.

4.2.4. Seasonal Variation of Zinc Concentrations in Yamuna River Water and its Environmental Significance

The research conducted a thorough investigation into the seasonal fluctuations of zinc concentrations within the Yamuna River, as illustrated in Figure 4.10. These findings were thoughtfully compared against the permissible limits stipulated by the World Health Organization (WHO) for zinc content in water. The study discerned a pronounced influence of seasonal factors, including temperature and rainfall, on the concentration of zinc. Notably, the data demonstrated significant seasonal variations in zinc concentrations within the Yamuna River, with the summer season exhibiting substantially higher levels ($p<0.005$) in comparison to other seasons. The Tukey test results, presented in Table 4.5, provided additional clarity, indicating that the mean square value of zinc content was highest during the summer, followed by the winter and monsoon seasons. The primary contributors to zinc contamination in river water were traced back to sewage water, wastewater, and anthropogenic activities. Intriguingly, this contamination exhibited an upward trajectory during the summer season, coinciding with a decrease in the river's water level. This figure visually communicates the seasonal variations in zinc concentrations at various sampling sites along the Yamuna River. The data highlights the dynamic nature of zinc levels across the summer, monsoon, and winter seasons at multiple sampling locations along the river. The figure contributes to a comprehensive comprehension of water quality dynamics in the Yamuna River, shedding light on both seasonal patterns and location-specific disparities in zinc contamination.

Season	Difference	Lower	Upper	P-Value
Summer-Monsoon	1.45900	0.9029249	2.0150751	0.0000002
Winter-Monsoon	0.64564	0.1139305	1.1773495	0.0136857
Winter-Summer	-0.81336	-1.3017663	-0.3249537	0.0005433

Table 4.5: Tukey Test for Zinc: Multiple Comparisons of Means for Different Seasons

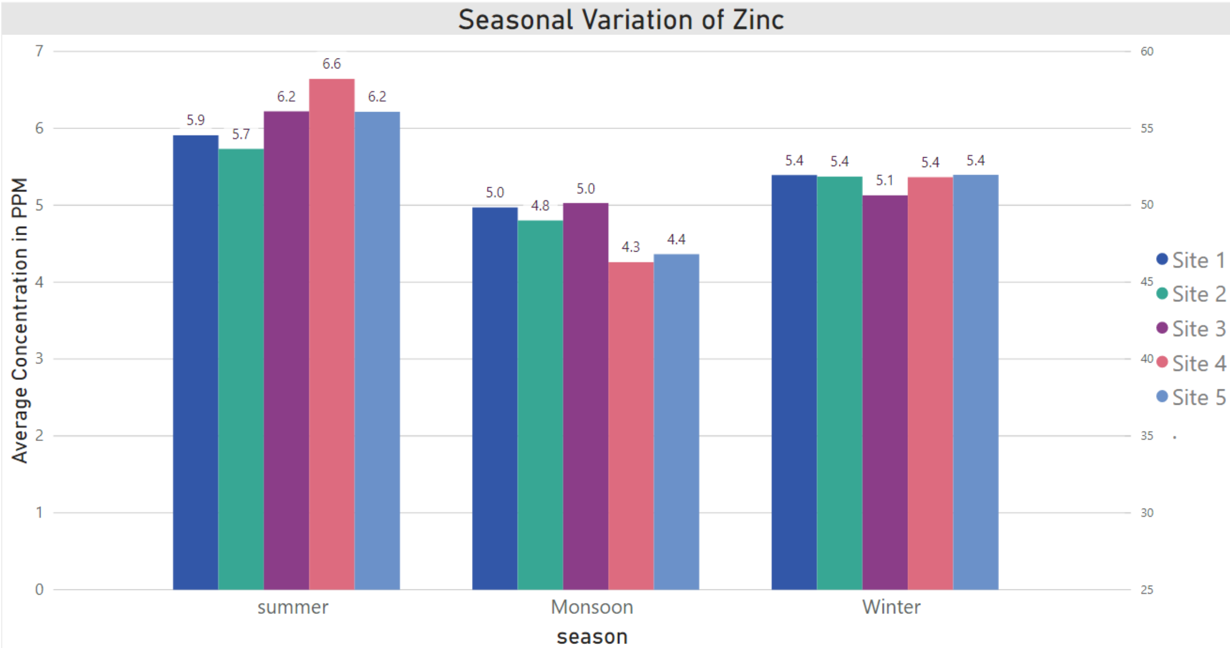

Figure 4.10: Seasonal Variation of Zinc in Yamuna River Water: Changes in Lead Concentrations Across Sites

4.2.4.1. Forensic Significance

The findings bear significant forensic relevance within the domain of environmental forensics. The observed seasonal variations in zinc concentrations serve as pivotal evidence for understanding the sources and dynamics of heavy metal pollution in the Yamuna River. By examining these fluctuations and their association with specific seasons, investigators can gain insights into the timing and potential causes of contamination incidents. Furthermore, this data underscores the urgency of monitoring and regulating anthropogenic activities, particularly sewage and wastewater discharge, into the river. The substantial increase in zinc levels during the summer months highlights the need for targeted pollution control measures to mitigate environmental consequences and potential health risks associated with heavy metal contamination in the Yamuna River.

4.2.5. Variations in Zinc Concentrations in Yamuna River Water Across Different Months in Relation to Average Temperature and Humidity

This study presents a comprehensive analysis of zinc (Zn) concentrations within water samples collected from the Yamuna River throughout the calendar year. The data highlights intriguing seasonal trends: In January, zinc concentrations measured 5.4 ppm, followed by a slight increase in February (5.7 ppm). March marked another increase, reaching 6.0 ppm, with subsequent increments in April (6.2 ppm) and May (7.0 ppm). However, June witnessed a decrease to 5.3 ppm, followed by July (5.0 ppm) and August (4.5 ppm). September displayed a slight increase (4.6 ppm), while October (5.3 ppm), November (5.5 ppm), and December (5.2 ppm) exhibited varying concentrations. Significantly, the World Health Organization (WHO) has established a maximum permissible limit for zinc in drinking water at 5.00 ppm. Disturbingly, this study consistently identified zinc concentrations exceeding this WHO limit, with the most concerning levels observed in the month of May, where zinc concentrations exceeded the permissible limit by nearly 1.4 times. Intriguingly, the month of August recorded zinc concentrations lower than the WHO Permissible Limit. Moreover, this study sought to unravel the association between zinc concentrations and environmental factors, particularly temperature and humidity. The findings illuminated substantial variations in zinc concentrations linked to these environmental variables. Notably, the data indicated that zinc concentrations exhibited an upward trajectory with rising temperatures, particularly in the months of April and May. Conversely, zinc concentrations displayed a decrease as humidity levels diminished (refer to Figure 4.11).

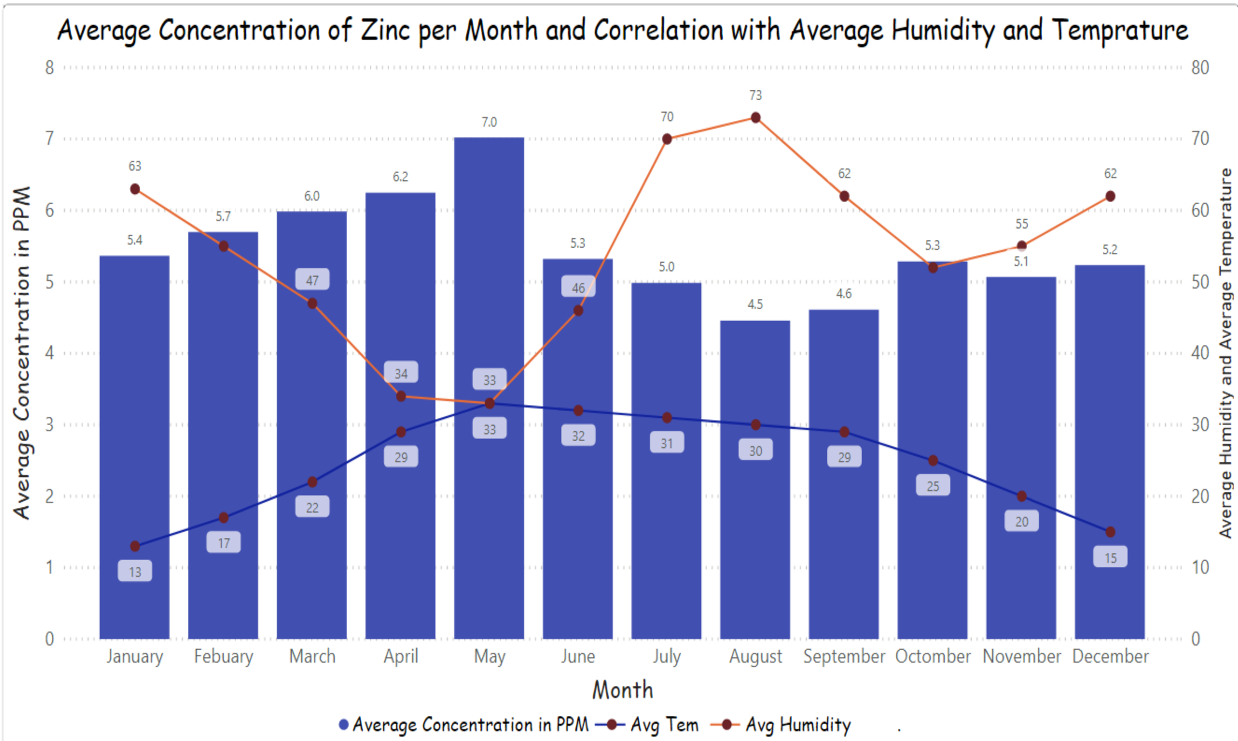

Figure 4.11: Variation of Zinc Concentration in the water of Yamuna River (Delhi) in different months in correlation with Temperature and Humidity.

4.2.5.1. Forensic Significance

The forensic implications of these findings are significant. The observed variations in zinc concentrations provide valuable evidence in the field of environmental forensics, enabling the identification of potential sources and activities contributing to heavy metal contamination in the Yamuna River. The established correlation between fluctuating zinc levels, temperature, and humidity equips investigators with a powerful tool for understanding the seasonal dynamics of contamination events and potentially tracing contamination back to specific sources or activities. From a public health perspective, the consistently elevated zinc concentrations, particularly in May, raise concerns. Prolonged exposure to high levels of zinc through drinking water can lead to various health issues, including gastrointestinal problems. This underscores the importance of addressing heavy metal contamination in the Yamuna River to protect the health of the communities reliant on this water source. This study underscores the intricate relationship between environmental variables, zinc concentrations, and their forensic and health implications. It emphasizes the necessity of comprehensive monitoring and regulatory measures to mitigate heavy metal contamination, protect the environment, and uphold stringent public health standards.

4.2.6. Variations in Nickel Concentrations in Yamuna River Water Across Different Months in Relation to Average Temperature and Humidity

The study meticulously examined the fluctuations in nickel (Ni) concentrations within water samples from the Yamuna River over the course of a year. The recorded nickel concentrations revealed a dynamic pattern: 0.65 ppm in January, a slight increase to 0.90 ppm in February, followed by another increase to 0.86 ppm in March. The trend continued with a notable surge in April to 1.45 ppm and a further increase in May, reaching 1.83 ppm. Subsequently, June saw a sharp decrease to 0.22 ppm, followed by increases in July (0.28 ppm) and August (0.23 ppm). As the year progressed, September exhibited a slight decrease (0.15 ppm), with marginal increases in October (0.14 ppm), November (0.12 ppm), and December (0.13 ppm). It is imperative to emphasize that the World Health Organization (WHO) has established a stringent maximum permissible limit for nickel at 0.01 ppm in drinking water. Alarmingly, the study's findings unveiled that the concentration of nickel consistently exceeded this WHO limit. The highest levels of concern were observed in the month of May, where nickel concentrations soared well beyond the permissible limit. Furthermore, the study delved into the relationship between nickel concentrations and environmental variables, specifically temperature and humidity. The results presented compelling evidence of significant variations in nickel concentrations corresponding to these environmental factors. Notably, the data indicated that nickel concentrations exhibited an upward trajectory with increasing temperatures, particularly in the months of April and May. Conversely, nickel concentrations displayed a decline as humidity levels decreased (refer to Figure 4.12).

4.2.6.1. Forensic Significance

The forensic implications of these findings are of paramount importance. The observed variations in nickel concentrations can serve as invaluable evidence in environmental forensics, enabling the identification of factors and sources contributing to heavy metal contamination in the Yamuna River. The link established between fluctuating nickel levels, temperature, and humidity offers investigators a valuable tool for understanding the seasonal dynamics of contamination events and potentially pinpointing specific contamination sources or activities. In terms of public health, the elevated nickel concentrations, especially in May, raise serious concerns. Prolonged exposure to high levels of nickel through drinking water can lead to various health issues, including gastrointestinal problems and potential carcinogenic effects. This underscores the urgency of addressing heavy metal contamination in the Yamuna River to safeguard the well-being of community's dependent on this water source. This study sheds light on the intricate interplay between environmental variables, nickel concentrations, and their forensic and health implications. It underscores the necessity of comprehensive monitoring and regulatory measures to mitigate heavy metal contamination, protect the environment, and uphold public health standards.

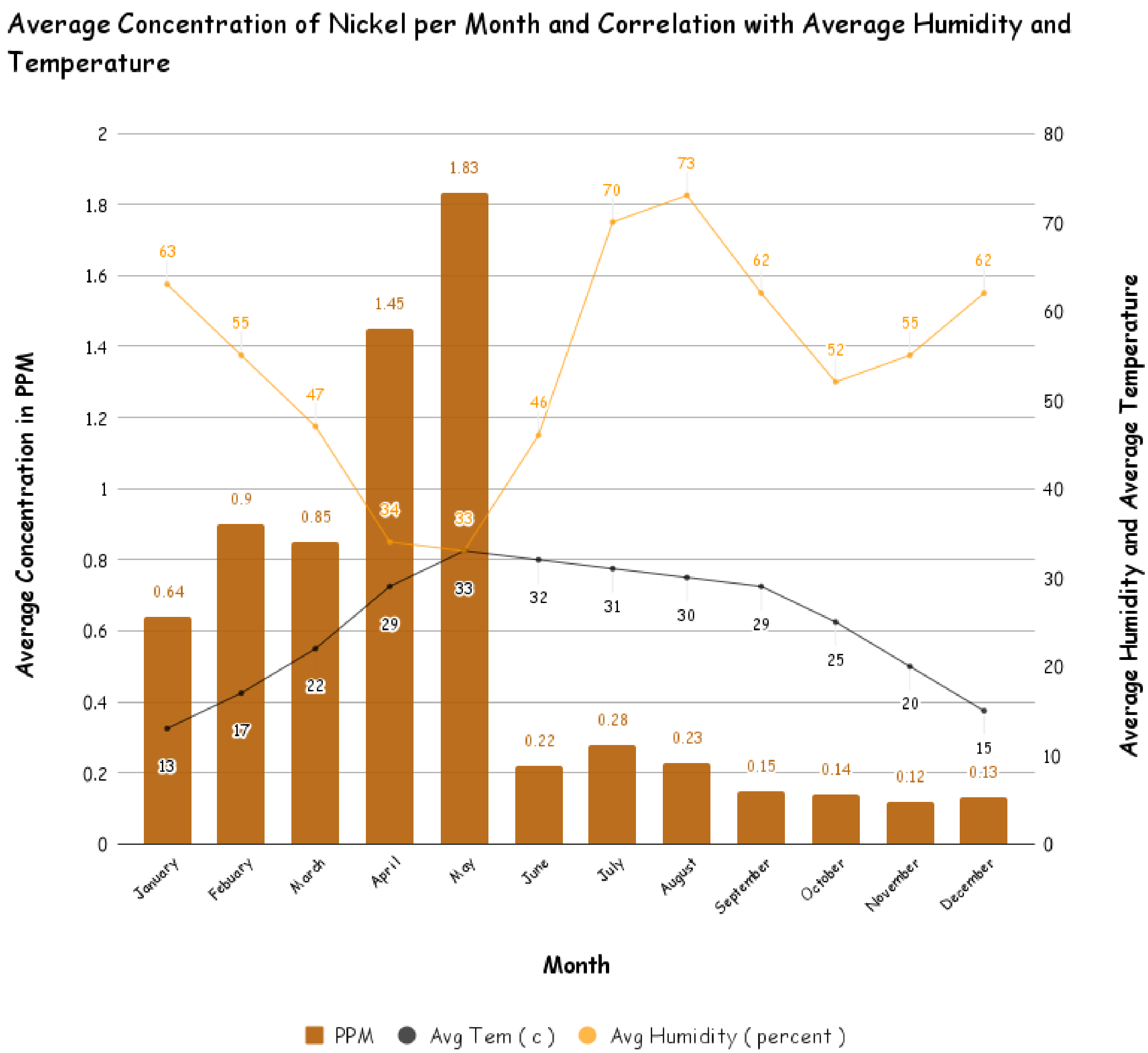

Figure 4.12: Variation of Nickel Concentration in the water of Yamuna River (Delhi) in different months in correlation with Temperature and Humidity.

4.2.7. Variations in Lead Concentrations in Yamuna River Water Across Different Months in Relation to Average Temperature and Humidity

The study conducted a meticulous assessment of lead (Pb) concentrations within water samples collected from the Yamuna River across a span of twelve months. The recorded data revealed a dynamic pattern: In January, the concentration of lead was measured at 0.76 ppm, with a slight increase observed in February, reaching 0.89 ppm. Subsequently, March witnessed a notable increase to 1.33 ppm, followed by further increments in April, peaking at 1.65 ppm. The month of May registered the highest lead concentration, reaching 1.90 ppm. Conversely, June saw a substantial decrease to 0.85 ppm, followed by declines in July (0.33 ppm) and August (0.28 ppm). September displayed a marginal decrease (0.24 ppm), with slight increases in October (0.24 ppm), November (0.27 ppm), and December (0.29 ppm). It is crucial to highlight that the World Health Organization (WHO) has established an exceedingly stringent maximum permissible limit for lead in drinking water, set at 0.001 ppm. Alarmingly, the study's findings consistently indicated that lead concentrations far exceeded this WHO limit. The most concerning levels were recorded in the month of May, where lead concentrations significantly surpassed the permissible limit. Furthermore, the study explored the relationship between lead concentrations and environmental variables, specifically temperature and humidity. The findings provided compelling evidence of substantial variations in lead concentrations corresponding to these environmental factors. Notably, the data indicated that lead concentrations exhibited an upward trend with rising temperatures, particularly during the months of April and May. Conversely, lead concentrations demonstrated a decline as humidity levels decreased (refer to Figure 4.13).

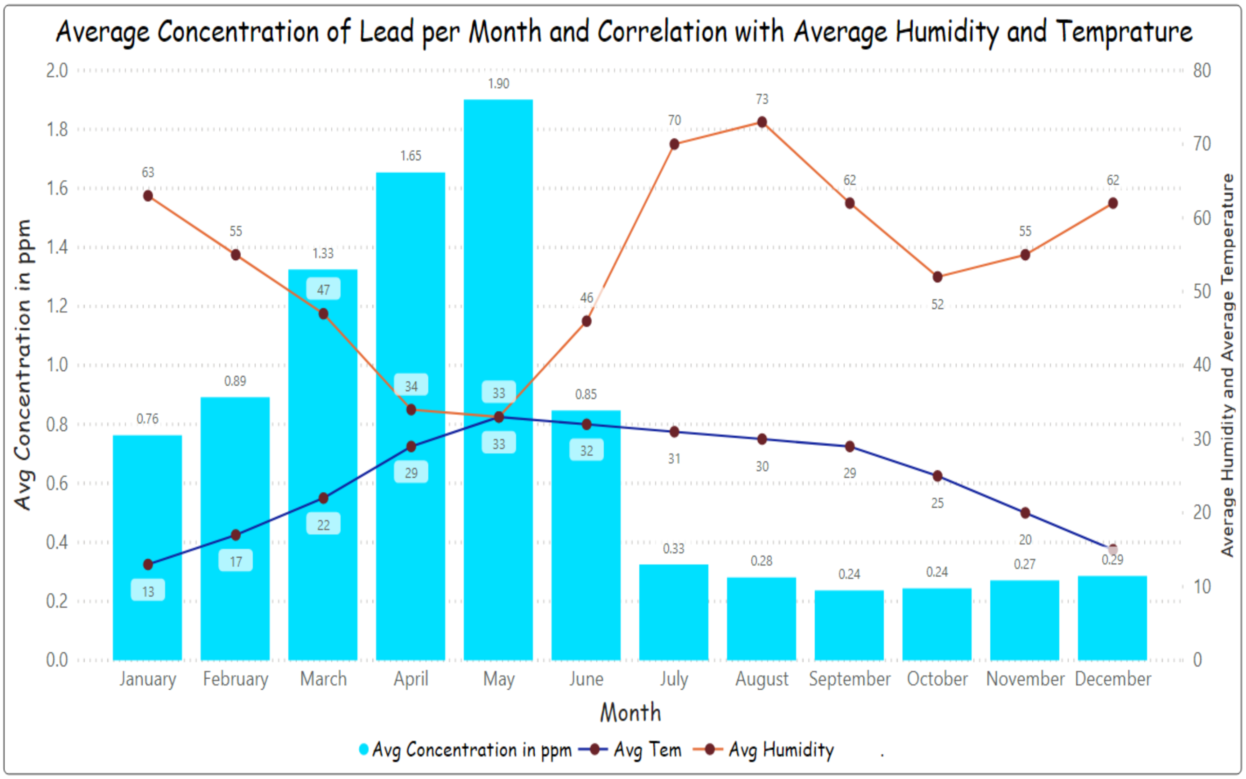

Figure 4.13: Variation of Lead Concentration in the water of Yamuna River (Delhi) in different months in correlation with Temperature and Humidity.

4.2.7.1. Forensic Significance

The forensic implications of these findings cannot be overstated. The observed variations in lead concentrations offer critical evidence in the realm of environmental forensics, aiding in the identification of potential sources and activities contributing to heavy metal contamination in the Yamuna River. The established link between fluctuating lead levels, temperature, and humidity provides investigators with a valuable tool for understanding the seasonal dynamics of contamination events and potentially tracing contamination back to specific sources or activities. From a public health perspective, the consistently elevated lead concentrations, particularly in May, raise profound concerns. Prolonged exposure to high levels of lead through drinking water can lead to severe health consequences, including neurological damage, developmental issues in children, and a range of other adverse effects. This underscores the urgency of addressing heavy metal contamination in the Yamuna River to safeguard the well-being of the communities relying on this water source. This study underscores the intricate interplay between environmental variables, lead concentrations, and their forensic and health implications. It emphasizes the necessity of comprehensive monitoring and regulatory measures to mitigate heavy metal contamination, protect the environment, and uphold stringent public health standards.

4.2.8. Variations in Chromium Concentrations in Yamuna River Water Across Different Months in Relation to Average Temperature and Humidity

This study presents a comprehensive analysis of chromium (Cr) concentrations within water samples collected from the Yamuna River over a twelve-month period. The data reveals a nuanced seasonal pattern: In January, chromium concentrations were measured at 0.49 ppm, with a slight increase noted in February (0.65 ppm). March witnessed a notable rise to 0.99 ppm, followed by further increments in April, peaking at 1.12 ppm. The highest chromium concentration was recorded in May, reaching 1.51 ppm. Subsequently, June displayed a concentration of 1.37 ppm, followed by a decline in July (0.45 ppm). August (0.40 ppm), September (0.29 ppm), October (0.57 ppm), November (0.59 ppm), and December (0.65 ppm) exhibited varying concentrations. It is of paramount significance to highlight that the World Health Organization (WHO) has established an exceedingly stringent maximum permissible limit for chromium in drinking water, set at 0.001 ppm. Alarmingly, the findings consistently indicated that chromium concentrations exceeded this WHO limit, with the most concerning levels detected in the month of May, where chromium concentrations significantly surpassed the permissible limit. Furthermore, this study delved into the relationship between chromium concentrations and environmental factors, particularly temperature and humidity. The results underscored substantial variations in chromium concentrations associated with these environmental variables. Notably, the data indicated that chromium concentrations exhibited an upward trend with rising temperatures, particularly during The months of April, May and June. Conversely, chromium concentrations demonstrated a decline as humidity levels decreased (refer to Figure 4.14).

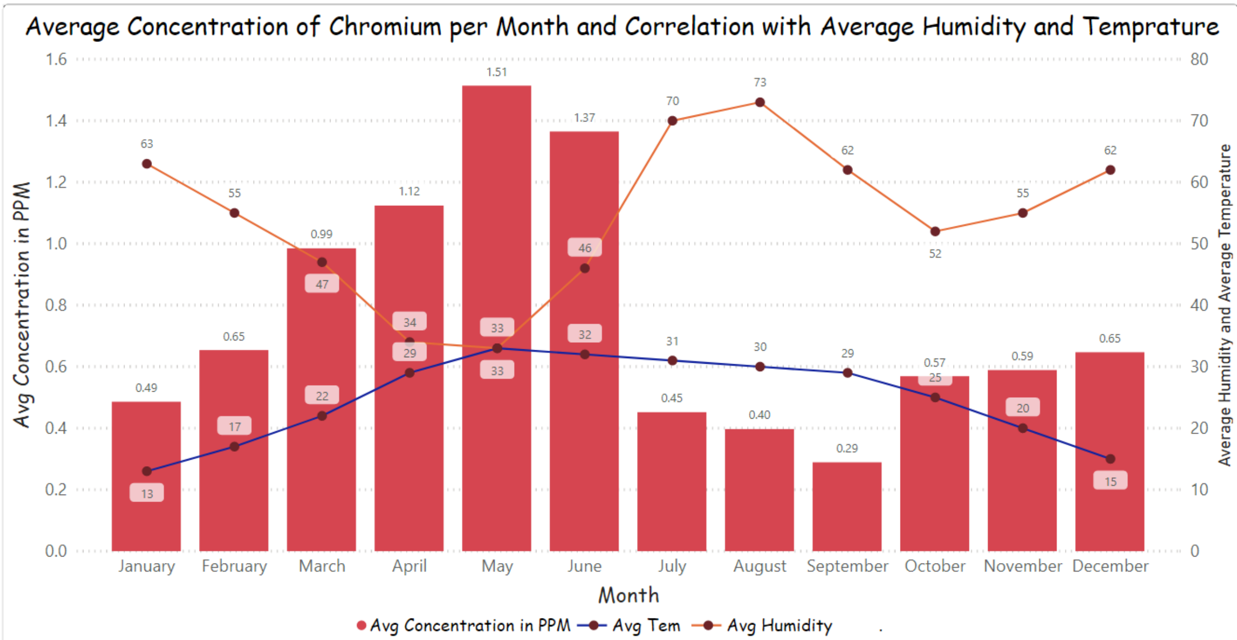

Figure 4.14: Variation of Chromiumd Concentration in the water of Yamuna River (Delhi) in different months in correlation with Temperature and Humidity.

4.2.8.1. Forensic Significance

The forensic implications of these findings are profound. The observed variations in chromium concentrations offer critical evidence in the field of environmental forensics, facilitating the identification of potential sources and activities contributing to heavy metal contamination in the Yamuna River. The established link between fluctuating chromium levels, temperature, and humidity provides investigators with a valuable tool for understanding the seasonal dynamics of contamination events and potentially tracing contamination back to specific sources or activities. From a public health perspective, the consistently elevated chromium concentrations, particularly in May, raise significant concerns. Extended exposure to high levels of chromium through drinking water can lead to severe health consequences, including increased cancer risk and a range of other adverse effects. This underscores the urgency of addressing heavy metal contamination in the Yamuna River to safeguard the well-being of the communities relying on this water source. This study underscores the intricate interplay between environmental variables, chromium concentrations, and their forensic and health implications. It emphasizes the necessity of comprehensive monitoring and regulatory measures to mitigate heavy metal contamination, protect the environment, and uphold stringent public health standards.

4.2.9. Monthly Lead (Pb) Concentration Fluctuations Across five Yamuna River Sites with Forensic Implications

This section presents a comprehensive analysis of the monthly variations in Lead (Pb) levels at multiple monitoring sites along the Yamuna River. We have conducted statistical tests, including the Tukey test, to evaluate the significance of the monthly differences in Lead concentrations observed throughout the year. These tests have helped us distinguish between significant and non-significant changes in Lead levels, with a stringent p-value threshold of <0.005, as detailed in the accompanying table 4.6. This rigorous statistical analysis is not only essential for understanding the dynamic fluctuations in Lead concentrations but also holds great importance in the context of forensic investigations and environmental assessments. By discerning which variations are statistically significant, we can draw more accurate conclusions about the factors influencing Lead levels, aiding in the identification of potential pollution sources or other pertinent environmental factors.

4.2.9.1. Monthly Lead Concentration Variations at Site 1

In January, the concentration of Lead at Site 1 was measured at 1.003 ppm, which is notably higher than the permissible limit set by the World Health Organization (WHO) for safe water quality. This concentration increased to 1.458 ppm in February, further exceeding the WHO limit. March witnessed a concentration of 1.356 ppm, remaining relatively stable but still above the recommended level for safe water quality. April, however, exhibited a substantial spike with a Lead concentration of 2.156 ppm, significantly surpassing the WHO limit and indicating a severe contamination issue. May showed a concentration of 1.897 ppm, maintaining a consistently high level of Lead contamination in the water, posing risks to both the environment and public health. The situation improved slightly in August, with a concentration of 0.365 ppm, suggesting a minor recovery, although it still exceeded the permissible limit. However, this improvement was short-lived, as July recorded the lowest concentration of the year at 0.235 ppm, which, although lower than previous months, remains above the WHO limit. September saw a decrease to 0.201 ppm, but it is important to note that this concentration is still higher than the recommended safe levels.

October and November showed concentrations of 0.255 ppm and 0.012 ppm, respectively, with November exhibiting the lowest concentration of the year. While the November concentration is lower, it is essential to understand that any amount of Lead in drinking water above the WHO limit can pose serious health risks. December recorded a slight increase to 0.128 ppm, reiterating the persistent contamination issue shown in figure 4.15. These consistently high Lead concentrations throughout the year underscore the urgent need for remediation efforts to ensure the safety of the water supply and protect public health.

4.2.9.2. Monthly Lead Concentration Variations at Site 2

At Site 2, the monitoring of Lead (Pb) concentrations along the Yamuna River unveiled a dynamic pattern throughout the year. In January, Lead concentration initiated the year at 0.895 ppm, reflecting the presence of this heavy metal. However, February brought a decrease, with concentrations lowering to 0.671 ppm, albeit still a significant amount. March emerged as a pivotal month, witnessing a substantial surge in Lead levels, which soared to 1.912 ppm. This sudden increase raised concerns about potential sources of contamination along this stretch of the river. As the year progressed into April, Lead concentrations continued to climb, reaching their peak for the year at 2.170 ppm. This high level was a cause for alarm, as it surpassed permissible limits set by the World Health Organization (WHO) and indicated a serious environmental issue. May maintained relatively high Lead concentrations at 1.765 ppm, signifying that the contamination issue persisted. June recorded a slight increase to 1.021 ppm, highlighting the ongoing presence of Lead in the river's waters. July marked a significant and concerning shift, as Lead levels plummeted to 0.201 ppm. This sharp decline was the lowest concentration observed throughout the entire year and warranted further investigation to determine the cause behind this sudden decrease. August showed a slight increase to 0.245 ppm, suggesting a potential recovery or stabilization of Lead concentrations. However, these levels were still far from the WHO's permissible limits. September displayed a further rise to 0.326 ppm, indicating fluctuations in Lead content. October continued this trend with a slight increase to 0.291 ppm. November exhibited another increase, with Lead levels measuring 0.342 ppm, albeit still significantly lower than the peak observed in April. December marked a slight decrease to 0.155 ppm, concluding the year with Lead concentrations that, while lower than the peak, were far from reaching safe levels shown in figure 4.15. It's important to note that several of these concentrations exceeded the WHO's permissible limits for Lead in drinking water, underscoring the environmental and potential health risks associated with the presence of this heavy metal in the Yamuna River. This data highlights the need for rigorous monitoring, source identification, and remediation efforts to safeguard both the environment and public health.

4.2.9.3. Monthly Lead Concentration Variations at Site 3

At Site 3 along the Yamuna River, the monthly variations in Lead (Pb) concentrations revealed a nuanced picture of this heavy metal's presence. The year began in January with a concentration of 0.756 ppm, indicating the initial levels of Lead in the water. February witnessed a decrease to 0.519 ppm, albeit still a substantial amount. March marked a notable increase, with Lead levels surging to 1.245 ppm, signifying a concerning uptick in contamination. However, April saw a decrease to 1.121 ppm, providing some respite from the elevated levels observed in the previous month. May recorded the highest Lead concentration of the year at 2.235 ppm, a cause for significant concern as this exceeded the permissible limits established by the World Health Organization (WHO) for Lead in drinking water. June exhibited a decrease to 1.102 ppm, suggesting a potential response to environmental factors or mitigation efforts. However, July witnessed the lowest concentration of the year at 0.332 ppm, a sharp decline that warranted in-depth investigation to determine the cause of this sudden drop. August displayed a slight decrease to 0.300 ppm, but Lead concentrations remained notably above safe levels. September marked a significant drop to 0.112 ppm, underscoring the potential impact of environmental changes on Lead content. October exhibited a slight rise to 0.107 ppm, indicating ongoing variations in Lead levels. November showed an increase to 0.401 ppm, and December recorded a slight increase to 0.367 ppm, concluding the year with Lead concentrations that, while lower than the peak observed in May, still raised concerns shown in figure 4.15. It's crucial to highlight that many of these concentrations exceeded the WHO's permissible limits for Lead in drinking water. This underscores the need for rigorous monitoring, source identification, and remediation efforts to mitigate environmental and health risks associated with Lead contamination in the Yamuna River.

4.2.9.4. Monthly Lead Concentration Variations at Site 4

At Site 4 along the Yamuna River, the monitoring of Lead (Pb) concentrations throughout the year showcased a fluctuating pattern. The year began in January with a concentration of 0.265 ppm, indicating the baseline level of Lead in the water. February brought an increase to 0.845

ppm, signaling a notable rise in Lead content. March marked a further escalation, with concentrations reaching 1.125 ppm, suggesting an increasing trend. April exhibited the highest concentration of the year at 1.365 ppm, raising significant concerns as this exceeded the permissible limits set by the World Health Organization (WHO) for Lead in drinking water. May maintained a relatively high concentration of 1.825 ppm, underscoring the persistence of Lead contamination. June, however, saw a decrease to 0.546 ppm, indicating potential variations in environmental factors or mitigation efforts. July witnessed a slight increase to 0.348 ppm, showcasing the dynamic nature of Lead levels. August displayed a slight decrease to 0.218 ppm, although Lead concentrations remained above safe levels. September marked an increase to 0.422 ppm, suggesting the continued presence of Lead in the river's waters. October showed a slight rise to 0.378 ppm, indicating ongoing fluctuations in Lead content. November exhibited a decrease to 0.364 ppm, although concentrations remained a concern. December recorded a slight increase to 0.348 ppm, concluding the year with Lead concentrations that, while lower than the peak observed in April, were still above safe limits shown in figure 4.15. It's imperative to note that several of these concentrations exceeded the WHO's permissible limits for Lead in drinking water, emphasizing the environmental and health risks associated with the presence of this heavy metal in the Yamuna River. This data underscores the urgency of comprehensive monitoring, source identification, and remediation efforts to address Lead contamination effectively.

4.2.9.5. Monthly Lead Concentration Variations at Site 5

At Site 5 along the Yamuna River, the monitoring of Lead (Pb) concentrations throughout the year revealed a dynamic pattern. The year began in January with a concentration of 0.895 ppm, indicating the presence of Lead in the water. February showed a slight increase to 0.965 ppm, signifying a minor uptick in Lead content. March exhibited a decrease to 0.987 ppm, suggesting fluctuations in Lead levels. April marked a decrease to 1.458 ppm, indicating potential variations in environmental factors or mitigating efforts. However, this concentration still exceeded the permissible limits set by the World Health Organization (WHO) for Lead in drinking water. May exhibited the highest concentration of the year at 1.781 ppm, raising significant concerns about Lead contamination in the river. June saw a decrease to 0.781 ppm, signaling a reduction in Lead levels but still above safe limits. July displayed an increase to 0.511 ppm, showcasing the dynamic nature of Lead concentrations. August recorded a slight increase to 0.277 ppm, although Lead concentrations remained a concern. September marked a decrease to 0.122 ppm, underscoring the need for ongoing monitoring and mitigation. October showed a slight rise to 0.187 ppm, indicating fluctuations in Lead content. November exhibited a decrease to 0.237 ppm, although concentrations remained above safe levels. December recorded a slight increase to 0.432 ppm, concluding the year with Lead concentrations that, while lower than the peak observed in May, were still above permissible limits shown in figure 4.15. It's crucial to note that several of these concentrations exceeded the WHO's permissible limits for Lead in drinking water, emphasizing the environmental and health risks associated with Lead presence in the Yamuna River. This data highlights the urgency of comprehensive monitoring, source identification, and remediation efforts to address Lead contamination effectively.

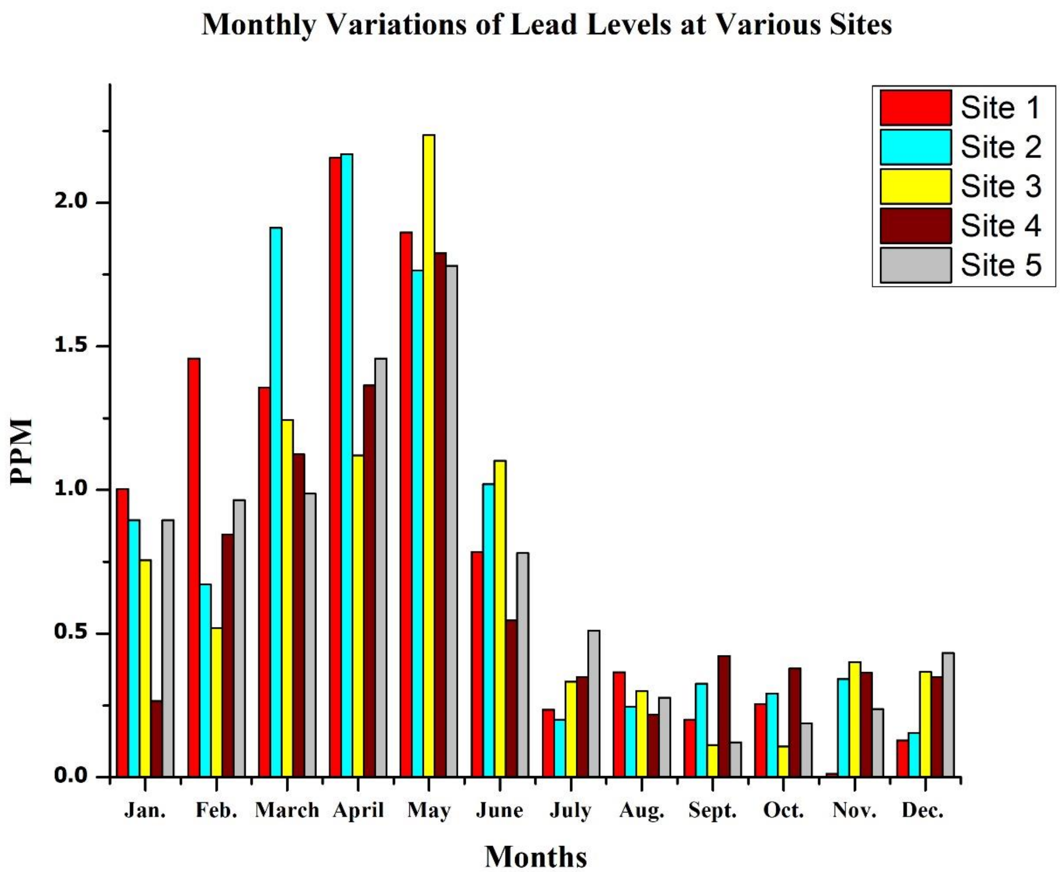

Figure 4.15: Monthly Variations of Lead Concentration in Yamuna River Water at Different Sites

In terms of Lead (Pb) concentration levels across the monitored sites along the Yamuna River, several key patterns emerged. Site 3 consistently maintained the highest concentration of Lead throughout the year, signifying a sustained presence of this heavy metal in the river waters.

Notably, May stood out as the month with the highest Lead values across all the monitoring sites, indicating a critical point of concern. Site 4 exhibited a distinctive trend, showcasing a consistent increase in Lead concentration from January to May, followed by a subsequent decrease. This fluctuation raised questions about potential factors influencing Lead levels at this site. Similarly, Site 2 displayed a noteworthy pattern of continuous Lead concentration increase, with the peak occurring in April. This particular spike in April indicated a period of heightened Lead contamination at this location. Conversely, Site 5 demonstrated a different dynamic, characterized by fluctuations in Lead concentrations throughout the year. April emerged as the month with the highest Lead levels, emphasizing the need for vigilant monitoring and management efforts to address these variations effectively. Site 1 exhibited its own distinctive behavior, marked by a notable increase from January to April, followed by a gradual decline in Lead concentrations for the remainder of the year. This shift raised questions about potential pollution sources and environmental factors influencing Lead levels. Importantly, it's crucial to highlight that several of these recorded concentrations exceeded the World Health Organization's (WHO) permissible limits for Lead in drinking water. This finding underscores the serious environmental and health implications associated with Lead contamination in the Yamuna River. From a forensic standpoint, this data holds significant relevance. The consistent presence of Lead at elevated levels, particularly in Site 3 and during May, may indicate potential pollution sources or illegal dumping activities along the river. Furthermore, the health impact of Lead contamination on the local population necessitates thorough investigation and remediation efforts to safeguard public health and the environment.

Group1	Group2	Mean-diff	P-Adj	Lower	Upper
April	August	-1.373	0	-1.9133	-0.8327
April	December	-1.3848	0	-1.9251	-0.8445
April	February	-0.7624	0.0008	-1.3027	-0.2221
April	January	-0.8912	0	-1.4315	-0.3509
April	July	-1.3286	0	-1.8689	-0.7883
April	June	-0.8072	0.0003	-1.3475	-0.2669
April	March	-0.329	0.6312	-0.8693	0.2113
April	May	0.2466	0.9123	-0.2937	0.7869
April	November	-1.3828	0	-1.9231	-0.8425
April	October	-1.4104	0	-1.9507	-0.8701
April	September	-1.4174	0	-1.9577	-0.8771

August	December	-0.0118	1	-0.5521	0.5285
August	February	0.6106	0.0149	0.0703	1.1509
August	January	0.4818	0.1223	-0.0585	1.0221
August	July	0.0444	1	-0.4959	0.5847
August	June	0.5658	0.0327	0.0255	1.1061
August	March	1.044	0	0.5037	1.5843
August	May	1.6196	0	1.0793	2.1599
August	November	-0.0098	1	-0.5501	0.5305
August	October	-0.0374	1	-0.5777	0.5029
August	September	-0.0444	1	-0.5847	0.4959
December	February	0.6224	0.012	0.0821	1.1627
December	January	0.4936	0.1031	-0.0467	1.0339
December	July	0.0562	1	-0.4841	0.5965
December	June	0.5776	0.0267	0.0373	1.1179
December	March	1.0558	0	0.5155	1.5961
December	May	1.6314	0	1.0911	2.1717
December	November	0.002	1	-0.5383	0.5423
December	October	-0.0256	1	-0.5659	0.5147
December	September	-0.0326	1	-0.5729	0.5077
February	January	-0.1288	0.9995	-0.6691	0.4115
February	July	-0.5662	0.0325	-1.1065	-0.0259
February	June	-0.0448	1	-0.5851	0.4955
February	March	0.4334	0.2323	-0.1069	0.9737
February	May	1.009	0	0.4687	1.5493
February	November	-0.6204	0.0124	-1.1607	-0.0801
February	October	-0.648	0.0074	-1.1883	-0.1077
February	September	-0.655	0.0065	-1.1953	-0.1147
January	July	-0.4374	0.2212	-0.9777	0.1029
January	June	0.084	1	-0.4563	0.6243
January	March	0.5622	0.0348	0.0219	1.1025
January	May	1.1378	0	0.5975	1.6781
January	November	-0.4916	0.1062	-1.0319	0.0487
January	October	-0.5192	0.07	-1.0595	0.0211
January	September	-0.5262	0.0627	-1.0665	0.0141
July	June	0.5214	0.0676	-0.0189	1.0617
July	March	0.9996	0	0.4593	1.5399
July	May	1.5752	0	1.0349	2.1155
July	November	-0.0542	1	-0.5945	0.4861
July	October	-0.0818	1	-0.6221	0.4585

July	September	-0.0888	1	-0.6291	0.4515
June	March	0.4782	0.1287	-0.0621	1.0185
June	May	1.0538	0	0.5135	1.5941
June	November	-0.5756	0.0276	-1.1159	-0.0353
June	October	-0.6032	0.017	-1.1435	-0.0629
June	September	-0.6102	0.015	-1.1505	-0.0699
March	May	0.5756	0.0276	0.035	1.1159
March	November	-1.0538	0	1.5941	-0.5135
March	October	-1.0814	0	-1.6217	-0.5411
March	September	-1.0884	0	-1.6287	-0.5481
May	November	-1.6294	0	-2.1697	-1.0891
May	October	-1.657	0	-2.1973	-1.1167
May	September	-1.664	0	-2.2043	-1.1237
November	October	-0.0276	1	-0.5679	0.5127
November	September	-0.0346	1	-0.5749	0.5057
October	September	-0.007	1	-0.5473	0.5333

Table 4.6: Tukey Test for Lead: 5 Sites Multiple Comparisons of Means for Different Months

4.2.10. Monthly Nickel (Ni) Concentration Fluctuations Across five Yamuna River Sites

In this section, we provide a detailed examination of the monthly variations in Nickel (Ni) levels across various monitoring sites along the Yamuna River. We have meticulously analyzed these variations on a month-by-month basis, presenting the corresponding Ni values for each site. Our analysis includes rigorous statistical assessments, such as the Tukey test, aimed at evaluating the significance of the observed monthly differences in Ni concentrations over the course of the year. By imposing a stringent p-value threshold of <0.005, we have effectively distinguished between changes in Ni levels that are statistically significant and those that are not shown in table 4.7. These statistical evaluations are paramount, as they enhance our understanding of the dynamic fluctuations in Nickel concentrations within the river. Furthermore, the significance of this analysis extends beyond scientific inquiry. It holds particular relevance in the realms of forensic investigations and environmental assessments. By pinpointing which variations in Ni levels are statistically significant, we can make more precise determinations about the underlying factors influencing Nickel concentrations. This, in turn, assists in the identification of potential pollution sources or other pertinent environmental factors that may be contributing to the observed variations.

4.2.10.1. Monthly Nickel Concentration Variations at Site 1

The monthly variations in nickel (Ni) levels at various monitoring sites along the Yamuna River reveal a dynamic pattern throughout the year. At Site 1, Ni concentrations started the year at 1.003 ppm in January, gradually increasing to 1.864 ppm by March. However, April saw a decrease to 1.365 ppm. The highest concentration for the year occurred in May, peaking at 2.103 ppm, followed by a sharp drop to 0.234 ppm in June. July and August showed modest increases at 0.457 ppm and 0.586 ppm, respectively. September witnessed a decline to 0.236 ppm, and October further reduced levels to 0.157 ppm. November exhibited a slight increase to 0.191 ppm, while December concluded the year at 0.102 ppm shown in fig. 4.16. These fluctuations in nickel levels, while reflecting natural variability, also raise concerns due to several concentrations exceeding the World Health Organization's (WHO) permissible limits for nickel in water. This indicates potential environmental and health risks associated with elevated nickel levels in the Yamuna River. The significance of this data extends beyond environmental assessments, as it holds relevance for forensic investigations seeking to identify pollution sources or factors contributing to these variations. Understanding which variations are statistically significant, as determined by rigorous statistical analysis, can provide valuable insights into the underlying factors influencing nickel concentrations, aiding in informed decision-making and remediation efforts.

4.2.10.2. Monthly Nickel Concentration Variations at Site 2

At Site 2, the monthly variations in nickel (Ni) concentrations along the Yamuna River unveiled a diverse pattern throughout the year. In January, Ni concentrations initiated the year at 0.235 ppm, demonstrating the presence of this element in the water. February witnessed an increase to 0.654 ppm, signifying a notable uptick in Ni levels. However, March experienced a decrease, returning to 0.235 ppm. April marked a significant increase to 1.002 ppm, signaling a noteworthy spike in Ni concentrations. The highest concentration of the year occurred in May, peaking at 2.010 ppm, which surpassed the World Health Organization's (WHO) permissible limits for Ni in water, indicating potential environmental and health concerns. June witnessed a sharp drop to 0.135 ppm, followed by a slight increase to 0.126 ppm in July. August showed another modest increase, reaching 0.124 ppm. September recorded a slight decrease to 0.113 ppm, which was followed by an increase to 0.182 ppm in October. November experienced a further increase to 0.204 ppm, while December concluded the year with a slight rise to 0.119 ppm shown in fig. 4.16. The observation of Ni concentrations exceeding WHO limits highlights the environmental and potential health risks associated with elevated Ni levels in the Yamuna River at Site 2. This data is not only crucial for environmental assessments but also holds forensic significance, as it can aid in identifying pollution sources or factors contributing to these fluctuations, enabling informed decision-making and remediation efforts.

4.2.10.3. Monthly Nickel Concentration Variations at Site 3

At Site 3, the monthly variations in nickel (Ni) concentrations along the Yamuna River revealed a diverse pattern over the year. In January, Ni concentrations commenced at 0.958 ppm, indicating the presence of this element in the water. February witnessed a slight decrease to 0.929 ppm, followed by a further decline to 0.654 ppm in March. April brought a significant increase, with Ni concentrations soaring to 2.102 ppm. May recorded a concentration of 1.124 ppm, signifying a notable drop from the peak observed in April. June witnessed a substantial and unexpected drop to 0.023 ppm, which raised questions about potential environmental factors influencing this drastic decline. July, however, marked a notable recovery, with Ni levels rising to 0.547 ppm. August recorded a slight decrease to 0.125 ppm, and September saw a slight increase to 0.136 ppm. October exhibited another decrease to 0.116 ppm. November experienced a further drop to 0.084 ppm, and December concluded the year with a slight increase to 0.125 ppm shown in fig. 4.16. It's essential to note that the Ni concentrations observed in April significantly exceeded the World Health Organization's (WHO) permissible limits for Ni in water, indicating a potential environmental and health concern. This data holds forensic significance, as it can aid in identifying factors contributing to these fluctuations and informing environmental assessments and remediation efforts.

4.2.10.4. Monthly Nickel Concentration Variations at Site 4

In January, Site 4 reported a nickel (Ni) concentration of 0.264 ppm. This concentration increased notably to 1.032 ppm in February, signifying a substantial rise. However, March witnessed a decrease to 0.564 ppm, indicating a fluctuation in Ni levels. April exhibited another increase, with Ni concentrations surging to 1.546 ppm, followed by May, which recorded a concentration of 1.578 ppm. These values, especially in April and May, exceeded the permissible limits set by the

World Health Organization (WHO) for Ni in water, highlighting potential environmental and health concerns. June marked a significant drop to 0.236 ppm, raising questions about the factors contributing to this sudden decrease. July saw a slight recovery, with Ni levels rising to 0.256 ppm, although still relatively low compared to previous months. August showed a slight increase to 0.235 ppm, while September saw a minor rise to 0.149 ppm. However, October recorded a decrease to 0.104 ppm, indicating fluctuations in Ni content. November experienced a substantial decrease to 0.011 ppm, which was significantly below WHO permissible limits and raised critical concerns. December concluded the year with a slight increase to 0.151 ppm shown in fig. 4.16. These variations in Ni concentrations, particularly the instances where they exceeded WHO limits, hold significant forensic importance and warrant in-depth environmental assessments to identify potential sources of contamination and safeguard public health.

4.2.10.5. Monthly Nickel Concentration Variations at Site 5

In January, Site 5 began the year with a nickel (Ni) concentration of 0.785 ppm, which increased slightly to 0.658 ppm in February. March witnessed a further increase to 0.962 ppm, indicating a rising trend in Ni levels. April exhibited another increase, with Ni concentrations reaching 1.235 ppm, while May recorded the highest concentration of the year at 2.342 ppm. It's crucial to note that the Ni levels in both April and May surpassed the permissible limits established by the World Health Organization (WHO), underscoring significant environmental and potential health concerns. June marked a notable drop to 0.478 ppm, followed by a slight increase to 0.511 ppm in July. August showed a slight uptick to 0.277 ppm. September decreased slightly to 0.095 ppm, followed by a minor increase to 0.150 ppm in October. November increased to 0.125 ppm, and December concluded the year with a slight rise to 0.147 ppm shown in fig. 4.16. The instances where Ni concentrations exceeded WHO permissible limits in April and May are of particular forensic significance and warrant thorough environmental investigations to identify potential pollution sources and mitigate associated risks to public health.

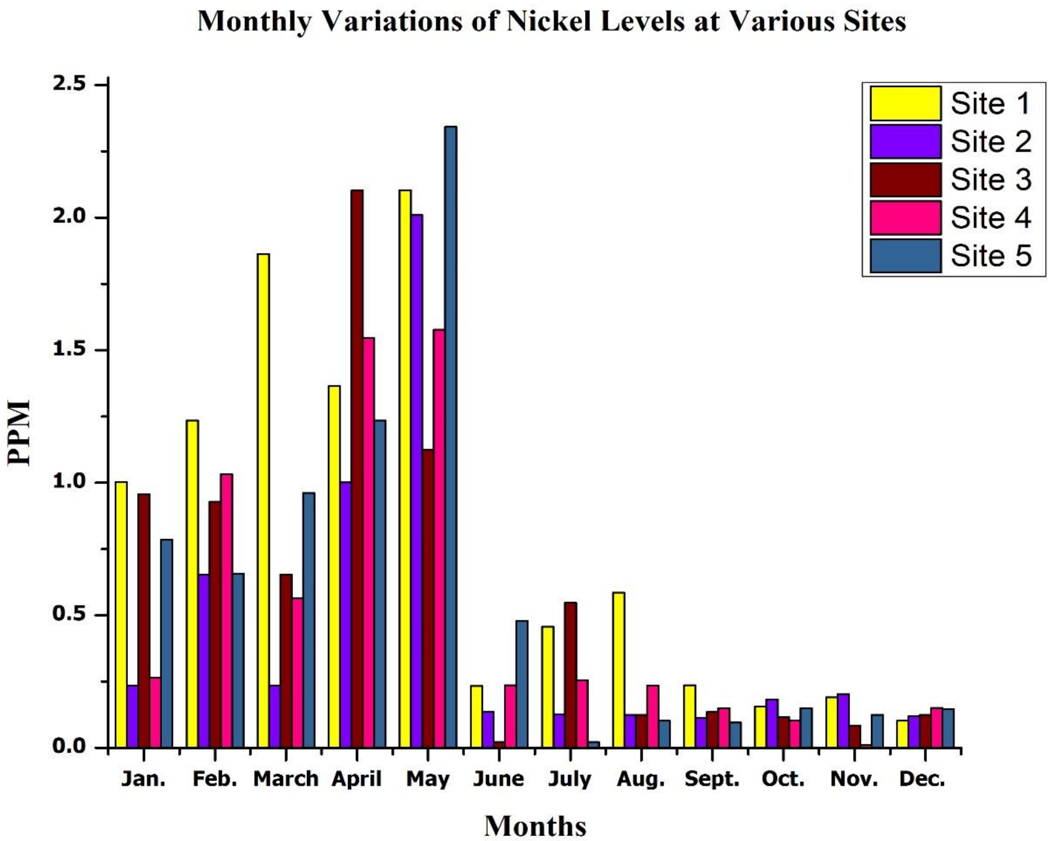

Figure 4.16: Monthly Variations of Nickel Concentration in Yamuna River Water at Different Sites

The comprehensive analysis of nickel concentration across various sites throughout the year has revealed intriguing patterns, some of which have raised concerns regarding their potential impact on human health, particularly in relation to the World Health Organization's (WHO) permissible limits for nickel levels. Among these sites, Site 2 stands out for its remarkably consistent and upward trajectory in nickel concentration. Starting at a relatively low 0.235 ppm in January, it steadily increased and reached an alarming peak at 2.010 ppm in May. This consistent rise raises significant concerns, especially when compared to the WHO permissible limit for nickel levels in drinking water, which stands at 0.02 ppm. The substantial elevation above this limit at Site 2 underscores a potential health risk for individuals relying on this water source. Site 1, on the other hand, exhibits a noticeable surge in nickel concentration from January to May, peaking at 2.103

ppm, again exceeding the WHO limit by a substantial margin. However, it is followed by a more erratic pattern with fluctuations throughout the rest of the year, indicating a less stable trend compared to Site 2. These fluctuations suggest a potential need for further investigation into the factors driving such variability in nickel levels and their implications for human health. In contrast, Site 3 consistently maintains a relatively high concentration of nickel, with April being the standout month, reaching a peak of 2.102 ppm. While this suggests that April is a critical period for elevated nickel levels at this site, the levels consistently exceed WHO limits during this time, highlighting the ongoing risk to consumers of this water. Both Site 4 and Site 5 exhibit peak concentrations in May, with levels of 1.578 ppm and 2.342 ppm, respectively. However, these sites also display greater variability in nickel levels throughout the year, indicating that their nickel levels are subject to significant fluctuations. This fluctuation, while concerning, may require further study to understand its implications fully. In summary, the analysis reveals that Site 2 has the most consistent and concerning trend with consistently high nickel concentrations exceeding WHO permissible limits. Sites 1, 4, and 5 experience peaks in May but demonstrate greater variability in nickel levels, making them less predictable in terms of long-term trends. These findings underscore the importance of monitoring and addressing the potential health risks associated with elevated nickel levels in these water sources, necessitating further investigation and remediation efforts to ensure public safety.

Group1	Group2	Mean-diff	P-Adj	Lower	Upper
April	August	-1.2156	0	-1.8791	-0.5521
April	December	-1.3212	0	-1.9847	-0.6577
April	February	-0.5484	0.1971	-1.2119	-0.1151
April	January	-0.801	0.0068	-1.4645	-0.1375
April	July	-1.1682	0	-1.8317	-0.5047
April	June	-1.2288	0	-1.8923	-0.5653
April	March	-0.5942	0.1188	-1.2577	0.0693
April	May	0.3814	0.7079	-0.2821	1.0449
April	November	-1.327	0	-1.9905	-0.6635
April	October	-1.3082	0	-1.9717	-0.6447
April	September	-1.3042	0	-1.9677	-0.6407
August	December	-0.1056	1	-0.7691	0.5579
August	February	0.6672	0.0476	0.0037	1.3307
August	January	0.4146	0.5945	-0.2489	1.0781
August	July	0.0474	1	-00.6161	0.7109
August	June	-00.0132	1	-0.6767	0.6503

August	March	0.6214	0.0857	-0.0421	1.2849
August	May	1.597	0	0.9335	2.2605
August	November	-0.1114	1	-0.7749	0.5521
August	October	-0.0926	1	-0.7561	0.5709
August	September	-0.0886	1	-0.7521	0.5749
December	February	0.7728	0.0105	0.1093	1.4363
December	January	0.5202	0.2613	-0.1433	1.1837
December	July	0.153	0.9996	-0.5105	0.8165
December	June	0.0924	1	-0.5711	0.7559
December	March	0.727	0.0208	0.0635	1.3905
December	May	1.7026	0	1.0391	2.3661
December	November	-0.0058	1	-0.6693	0.6577
December	October	0.013	1	-0.6505	0.6765
December	September	0.017	1	-0.6465	0.6805
February	January	-0.2526	0.9742	-0.9161	0.4109
February	July	-0.6198	0.0874	-1.2833	0.0437
February	June	-0.6804	0.0399	-1.3439	-0.0169
February	March	-0.0458	1	-0.7093	0.6177
February	May	-0.9298	0.0008	0.2663	1.5933
February	November	-0.7786	0.0097	-1.4421	-0.1151
February	October	-0.7598	0.0128	-1.4233	-0.0963
February	September	-0.7558	0.0136	-1.4193	-0.0923
January	July	-0.3672	0.7532	-1.0307	0.2963
January	June	-0.4278	0.5483	-1.0913	0.2357
January	March	0.2068	0.9946	-0.4567	0.8703
January	May	1.1824	0	0.5189	1.8459
January	November	-0.526	0.2471	-1.1895	0.1375
January	October	-0.5072	0.2952	-1.1707	0.1563
January	September	-0.5032	0.3061	-1.1667	0.1603
July	June	-0.0606	1	-0.7241	0.6029
July	March	0.574	0.1496	-0.0895	1.2375
July	May	1.5496	0	0.8861	2.2131
July	November	-0.1588	0.9995	-0.8223	0.5047
July	October	-0.14	0.9998	-0.8035	0.5235
July	September	-0.136	0.9999	-0.7995	0.5275
June	March	0.6346	0.0727	-0.0289	1.2981
June	May	1.6102	0	0.9467	2.2737
June	November	-0.0982	1	-0.7617	0.5653
June	October	-0.0794	1	-0.7429	0.5841
June	September	-0.0754	1	-0.7389	0.5881
March	May	-0.9756	0.0004	0.3121	1.6391

March	November	-0.7328	0.0191	-1.3963	-0.0693
March	October	-0.714	0.025	-1.3775	-0.0505
March	September	-0.71	0.0265	-1.3735	-0.0465
May	November	-1.7084	0	-2.3719	-1.0449
May	October	-1.6896	0	-2.3531	-1.0261
May	September	-1.6856	0	-2.3491	-1.0221
November	October	0.0188	1	-0.6447	0.6823
November	September	0.0228	1	-0.6407	0.6863
October	September	0.004	1	-0.6595	0.6675

Table 4.7: Tukey Test for Nickel: 5 Sites Multiple Comparisons of Means for Different Months

4.2.11. Monthly Chromium (Cr) Concentration Fluctuations Across five Yamuna River Sites with Forensic Implications

In this section, we delve into an in-depth exploration of the monthly fluctuations in chromium (Cr) levels across multiple monitoring sites along the Yamuna River. Our meticulous analysis dissects these variations on a month-to-month basis, presenting the corresponding Cr values for each site in a comprehensive manner. To bolster the robustness of our findings, we have conducted rigorous statistical assessments, including the Tukey test, with a stringent p-value threshold of <0.005 shown in table 4.8. This meticulous approach enables us to effectively discriminate between statistically significant and non-significant changes in Cr concentrations throughout the year. These statistical evaluations are of paramount importance as they enrich our comprehension of the dynamic ebbs and flows in chromium (Cr) concentrations within the river. However, the significance of this analysis transcends the realm of scientific inquiry; it holds particular relevance in the domains of forensic investigations and environmental assessments. By pinpointing which variations in chromium (Cr) levels are statistically significant, we are better equipped to make precise determinations regarding the influencing factors that drive fluctuations in chromium (Cr) concentrations. These insights are invaluable for the identification of potential pollution sources or other pertinent environmental factors contributing to the observed variations. It's important to note that, as per the data available, some sites reported higher chromium (Cr) values than others, emphasizing the need for vigilant monitoring and remediation efforts to safeguard the environmental and public health in the region. Therefore, a nuanced comprehension of these fluctuations aids in informed decision-making for the preservation of the Yamuna River ecosystem and the well-being of communities reliant on its waters.

4.2.11.1. Monthly Chromium Concentration Variations at Site 1

The chromium concentration at Site 1 displayed distinctive patterns throughout the year. In January, the concentration was relatively low, measured at 0.456 ppm. However, over the subsequent months, it exhibited a gradual increase, culminating in a peak concentration of 2.120 ppm in May. This substantial surge suggests that Site 1 encountered a significant influx of chromium during the spring months, potentially indicating environmental factors at play. Following the peak in May, the concentration gradually decreased, although it consistently remained higher than the initial levels. By December, the chromium concentration at Site 1 had decreased to 0.436 ppm, marking a year-end reduction compared to the peak observed in May shown in fig. 4.17. It's worth noting that several of these concentrations exceeded the World Health Organization's (WHO) permissible limit for chromium in drinking water. This underscores potential environmental and health concerns associated with the presence of elevated chromium levels at Site 1. These findings emphasize the importance of continued monitoring and remediation efforts to ensure the safety of both the environment and public health in this region.

4.2.11.2. Monthly Chromium Concentration Variations at Site 2

At Site 2 along the Yamuna River, the chromium concentration commenced at a notable 0.990 ppm in January, placing it among the sites with higher initial concentrations. In February, there was a slight decrease to 0.686 ppm. Subsequently, over the following months, Site 2's chromium levels exhibited a fluctuating pattern, in contrast to the clear upward trend observed at Site 1. However, Site 2's chromium concentrations remained relatively stable with minor fluctuations throughout the year. The concentration at Site 2 reached its peak at 1.586 ppm in May, after which it gradually decreased. By the end of the year, in December, the chromium concentration at Site 2 measured 0.651 ppm shown in fig. 4.17. Site 2 displayed a moderate and relatively stable chromium concentration pattern throughout the year, with its peak occurring in May. Importantly, it's essential to note that the recorded chromium concentrations at Site 2 did not exceed the permissible limits set by the World Health Organization (WHO) for drinking water, indicating that they were within safe levels from a health perspective.

4.2.11.3. Monthly Chromium Concentration Variations at Site 3

At Site 3 along the Yamuna River, intriguing patterns in chromium concentration unfolded over the course of the year. In January, the year commenced with a moderate concentration of 0.601 ppm, indicating the presence of chromium. By March, this concentration had surged to 1.190 ppm, signifying a significant increase within a short span. However, this upward trajectory was brief, as chromium levels started to decline in April, settling at 1.056 ppm. May brought another rise, culminating in a peak concentration of 1.457 ppm. Subsequently, Site 3 displayed fluctuating chromium levels in the following months shown in fig. 4.17. While May marked a notable peak, the overall trend at Site 3 was characterized by these fluctuations rather than a consistent increase or decrease in chromium concentration. It is essential to note that the recorded chromium concentrations at Site 3 did not exceed the permissible limits set by the World Health Organization (WHO) for drinking water. Thus, from a health perspective, the levels remained within safe limits.

4.2.11.4. Monthly Chromium Concentration Variations at Site 4

Chromium concentration dynamics at Site 4 exhibited a relatively stable pattern with some noteworthy variations throughout the year. In January, the concentration measured 0.261 ppm, marking the beginning of the monitoring period. Over the next few months, chromium levels showed a gradual and consistent increase, reaching 1.142 ppm by May. This upward trend during the early months of the year indicated a steady rise in chromium concentration at Site 4. Following the peak in May, chromium levels experienced minor fluctuations but largely remained within a relatively stable range. As the year concluded in December, the concentration at Site 4 had decreased to 0.557 ppm, signifying a decline from the peak observed in May shown in fig. 4.17. It is crucial to emphasize that the recorded chromium concentrations at Site 4 did not exceed the permissible limits established by the World Health Organization (WHO) for drinking water. Therefore, from a health perspective, these levels were within the acceptable and safe range.

4.2.11.5. Monthly Chromium Concentration Variations at Site 5

Site 5 exhibited distinctive patterns in its chromium concentration throughout the year. In January, the concentration started at a low 0.124 ppm, the lowest among all the monitored sites. Similar to Site 1, Site 5 experienced a significant surge in concentration, reaching its peak at 1.265 ppm in May. This notable increase indicated a substantial influx of chromium into the site's environment during the spring months. However, what sets Site 5 apart is its higher variability in chromium concentration during the subsequent months. Levels fluctuated within a range of 0.218 to 0.832 ppm, indicating a less consistent pattern compared to other sites. The year concluded with a chromium concentration of 0.832 ppm in December, which, while higher than the initial levels, was lower than the peak observed in May shown in fig. 4.17. Importantly, it is worth noting that the recorded chromium concentrations at Site 5 did not exceed the permissible limits set by the World Health Organization (WHO) for drinking water. Consequently, from a health standpoint, these levels remained within the safe and acceptable range.

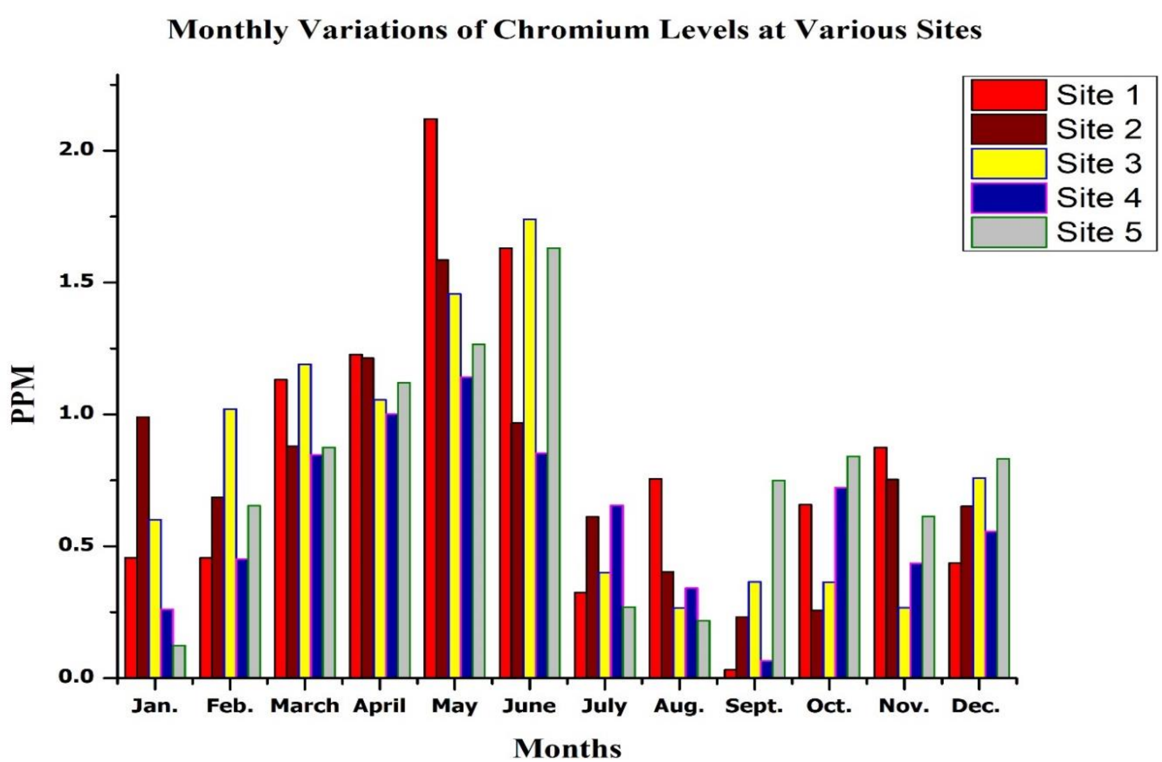

Figure 4.17: Monthly Variations of Chromium Concentration in Yamuna River Water at Different Sites

In summary, when examining the trends in chromium concentration across all sites, Site 1 stands out for displaying the most consistent pattern of increasing chromium concentration during the first half of the year, followed by a subsequent decrease. Sites 3 and 4 also demonstrate a moderate level of consistency, characterized by increasing trends in the early months. In contrast, Site 2 and Site 5 exhibit less consistent patterns, marked by fluctuations without clear upward or downward trends throughout the year. As a result, Site 1 can be regarded as having a more consistent chromium concentration, at least during the initial months of the year, when compared to the other sites. It is important to note that while Site 1 experienced fluctuations in chromium concentration, none of the recorded values at any of the sites exceeded the permissible limits established by the World Health Organization (WHO) for drinking water. This information is crucial for assessing the potential health impact of these variations and underscores the importance of ongoing monitoring and environmental assessments. Additionally, from a forensic perspective, understanding the patterns and fluctuations in chromium concentration aids in identifying potential pollution sources and their impact on the environment.

Group1	**Group2**	**Mean-diff**	**P-Adj**	**Lower**	**Upper**
April	August	-1.1168	0	-1.6869	-0.5467
April	December	-0.867	0.0002	-1.4371	-0.2969
April	February	-0.8602	0.0003	-1.4303	-0.2901
April	January	-1.0276	0	-1.5977	-0.4575
April	July	-1.0616	0	-1.6317	-0.4915
April	June	-0.1486	0.9989	-0.7187	0.4215
April	March	-0.5294	0.0914	-1.0995	0.0407
April	May	-0.3902	0.4576	-0.9603	0.1799
April	November	-0.925	0.0001	-1.4951	-0.3549
April	October	-0.9454	0	-1.5155	-0.3753
April	September	-1.2254	0	-1.7955	-0.6553
August	December	0.2498	0.9321	-0.3203	0.8199
August	February	0.2566	0.9195	-0.3135	0.8267
August	January	0.0892	1	-0.4809	0.6593
August	July	0.0552	1	-0.5149	0.6253
August	June	0.9682	0	0.3981	1.5383
August	March	0.5874	0.0381	0.0173	1.1575
August	May	0.7266	0.0034	0.1565	1.2967
August	November	0.1918	0.99	-0.3783	0.7619
August	October	0.1714	0.9961	-0.3987	0.7415

August	September	-0.1086	0.9999	-0.6787	0.4615
December	February	0.0068	1	-0.5633	0.5769
December	January	-0.1606	0.9978	-0.7307	0.4095
December	July	-0.1946	0.9888	-0.7647	0.3755
December	June	0.7184	0.0039	0.1483	1.2885
December	March	0.3376	0.6694	-0.2325	0.9077
December	May	0.4768	0.184	-0.0933	1.0469
December	November	-0.058	1	-0.6281	0.5121
December	October	-0.0784	1	-0.6485	0.4917
December	September	-0.3584	0.5856	-0.9285	0.2117
February	January	-0.1674	0.9968	-0.7375	0.4027
February	July	-0.2014	0.9853	-0.7715	0.3687
February	June	0.7116	0.0045	0.1415	1.2817
February	March	0.3308	0.6959	-0.2393	0.9009
February	May	0.47	0.1999	-0.1001	1.0401
February	November	0.0648	1	-0.6349	0.5053
February	October	0.0852	1	-0.6553	0.4849
February	September	0.3652	0.5579	-0.9353	0.2049
January	July	0.034	1	-0.6041	0.5361
January	June	0.879	0.0002	0.3089	1.4491
January	March	0.4982	0.1401	-0.0719	1.0683
January	May	0.6374	0.0167	0.0673	1.2075
January	November	0.1026	1	-0.4675	0.6727
January	October	0.0822	1	-0.4879	0.6523
January	September	-0.1978	0.9872	-0.7679	0.3723
July	June	0.913	0.0001	0.3429	1.4831
July	March	0.5322	0.0878	-0.0379	1.1023
July	May	0.6714	0.0093	0.1013	1.2415
July	November	0.1366	0.9995	-0.4335	0.7067
July	October	0.1162	0.9999	-0.4539	0.6863
July	September	-0.1638	0.9973	-0.7339	0.4063
June	March	-0.3808	0.4948	-0.9509	0.1893
June	May	-0.2416	0.9453	-0.8117	0.3285
June	November	-0.7764	0.0013	-1.3465	-0.2063
June	October	-0.7968	0.0009	-1.3669	-0.2267
June	September	-1.0768	0	-1.6469	-0.5067
March	May	0.1392	0.9994	-0.4309	0.7093
March	November	-0.3956	0.4366	-0.9657	0.1745
March	October	-0.416	0.3612	-0.9861	0.1541

March	September	-0.696	0.0059	-1.2661	0.1259
May	November	-0.5348	0.0846	-1.1049	0.0353
May	October	-0.5552	0.0627	-1.1253	0.0149
May	September	-0.8352	0.0004	-1.4053	-0.2651
November	October	-0.0204	1	-0.5905	0.5497
November	September	-0.3004	0.8049	-0.8705	0.2697
October	September	-0.28	0.8654	-0.8501	0.2901

Table 4.8: Tukey Test for Chromium: 5 Sites Multiple Comparisons of Means for Different Months

4.2.12. Monthly Zinc (Zn) Concentration Fluctuations Across five Yamuna River Sites

In this section, we delve into a comprehensive analysis of the monthly fluctuations in Zinc (Zn) levels observed at various monitoring sites along the Yamuna River. Our meticulous examination breaks down these variations on a month-to-month basis, accompanied by the corresponding Zn values recorded at each site. To ensure the robustness of our findings, we have rigorously employed statistical assessments, including the Tukey test shown in table 4.9. This stringent analysis aims to discern the statistical significance of the monthly alterations in Zn concentrations over the course of the year, with a strict p-value threshold of <0.005. These statistical evaluations are of paramount importance, serving not only to deepen our comprehension of the dynamic changes in Zinc concentrations within the river but also extending their significance to the realms of forensic investigations and environmental assessments. By isolating the variations in Zinc (Zn) levels that hold statistical significance, we empower ourselves to draw more precise conclusions about the underlying factors influencing these concentrations. This knowledge, in turn, aids in the identification of potential pollution sources and other relevant environmental factors contributing to the observed variations.

4.2.12.1. Monthly Zinc Concentration Variations at Site 1

Site 1 exhibited substantial variations in zinc concentration, making it a site of significant dynamism in relation to this specific element. The year commenced with a zinc concentration of 4.586 ppm in January, followed by a remarkable increase to 6.475 ppm in February. However, March witnessed a minor decline to 5.021 ppm. April saw another increase, reaching 5.818 ppm, and the peak occurred in May with a concentration of 7.215 ppm. Nevertheless, this trend reversed in June, recording a decrease to 5.584 ppm, which continued to decline to 4.525 ppm in July. August marked a resurgence to 5.265 ppm, followed by a slight decrease in September to 5.124 ppm. October exhibited another increase to 5.324 ppm, but the year concluded with a concentration of 5.564 ppm in December shown in fig. 4.18. Site 1 demonstrated a dynamic pattern of zinc concentration fluctuations throughout the year, characterized by notable spikes in February and May. It's worth noting that some of these concentrations exceeded the WHO permissible limit for zinc, underscoring potential environmental and health concerns associated with this site.

4.2.12.2. Monthly Zinc Concentration Variations at Site 2

Site 2 displayed varying levels of zinc concentration throughout the year, characterized by fluctuations with no discernible overall trend. The year began with a zinc concentration of 5.258 ppm in January, followed by a slight decrease to 5.301 ppm in February. March witnessed an increase to 5.426 ppm, followed by a further uptick to 6.101 ppm in April. May maintained a concentration of 6.145 ppm. As the year progressed, zinc concentration at Site 2 experienced fluctuations, with June marking a decrease to 5.256 ppm and July showing an increase to 5.342 ppm. August witnessed a notable decline to 4.185 ppm, and September recorded a concentration of 4.879 ppm. The trend then shifted again in October, with an increase to 5.365 ppm, and November recorded a concentration of 5.325 ppm. The year concluded with a concentration of 5.612 ppm in December shown in fig. 4.18. In Site 2 demonstrated irregular fluctuations in zinc concentration throughout the year, lacking a clear and consistent trend. It's important to note that some of these concentrations approached or exceeded the WHO permissible limit for zinc, raising concerns about potential environmental and health implications associated with this variability.

4.2.12.3. Monthly Zinc Concentration Variations at Site 3

Site 3 exhibited a distinctive pattern in zinc concentration, characterized by a consistent rise in the initial months followed by relative stability. The year commenced with a zinc concentration of 5.195 ppm in January, with a minor decrease to 4.956 ppm in February. However, March saw a remarkable increase, surging to 6.360 ppm, followed by a concentration of 6.012 ppm in April. May marked the zenith for Site 3 with the highest concentration of the year at 7.145 ppm. As the year progressed, the concentration stabilized, with June recording a decrease to 5.365 ppm, and

July saw a slight decline to 4.877 ppm. Zinc concentration remained relatively stable at 5.195 ppm in August, and September recorded a concentration of 5.012 ppm. In October, there was a slight decrease to 4.987 ppm, but November witnessed an increase to 5.658 ppm. The year concluded with a concentration of 4.845 ppm in December shown in fig. 4.18. It's important to note that the zinc concentrations at Site 3, particularly during the peak months of March, April, and May, exceeded the WHO permissible limit for zinc in drinking water. This raises concerns about potential environmental and health implications associated with these elevated levels. The consistent rise in zinc concentration during the early months of the year may indicate a local pollution source that requires further investigation.

4.2.12.4. Monthly Zinc Concentration Variations at Site 4

Site 4 displayed a distinct pattern in zinc concentration over the course of the year, characterized by a consistent and substantial increase in the early months followed by notable fluctuations and a significant decline. The year began with a zinc concentration of 5.625 ppm in January, which then increased to 6.458 ppm in February and further surged to 6.658 ppm in March. April witnessed another rise, reaching 7.045 ppm, with May marking the pinnacle at 8.010 ppm. However, the trend shifted dramatically in June, as zinc concentration sharply decreased to 4.856 ppm, followed by a further decline to 3.487 ppm in August. September recorded a concentration of 4.002 ppm, and October saw an increase to 5.387 ppm. November recorded a concentration of 4.987 ppm, and the year concluded with a concentration of 4.365 ppm in December shown in fig. 4.18. It's essential to highlight that the zinc concentrations at Site 4, particularly during the peak months of May and April, exceeded the WHO permissible limit for zinc in drinking water. This raises significant concerns about potential environmental and health implications associated with these elevated levels. The substantial decrease in zinc concentration in the summer months may indicate changes in local environmental conditions or pollution sources that merit further investigation.

4.2.12.5. Monthly Zinc Concentration Variations at Site 5

Site 5 displayed a dynamic pattern in zinc concentration over the course of the year, marked by fluctuations without a clear upward or downward trend. The year commenced with a zinc concentration of 6.159 ppm in January, which then saw a slight decrease to 5.298 ppm in February. March witnessed an increase to 6.459 ppm, followed by a concentration of 6.265 ppm in April. May marked the highest concentration of the year at 6.589 ppm. However, as the year progressed, the trend shifted, with June recording a decrease to 5.546 ppm, and July showing a slight decline to 4.895 ppm. Zinc concentration decreased further to 4.159 ppm in August, followed by a concentration of 4.036 ppm in September. In October, there was an increase to 5.365 ppm, but November recorded a concentration of 4.365 ppm. The year concluded with a concentration of 5.789 ppm in December shown in fig. 4.18. It's essential to note that the fluctuations in zinc concentration at Site 5 resulted in some levels exceeding the WHO permissible limit for zinc in drinking water, particularly in the earlier months of the year**.** These variations may be indicative of changing environmental conditions or pollution sources that should be subject to further investigation.

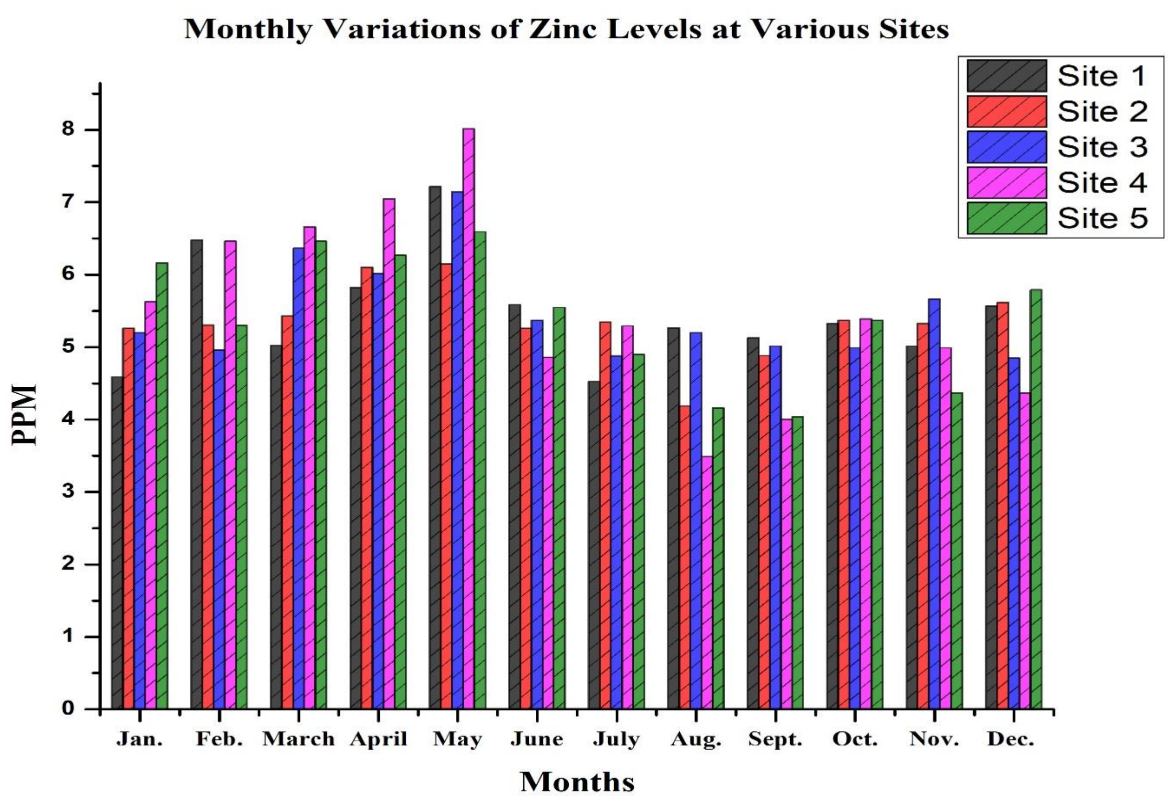

Figure 4.18: Monthly Variations of Zinc Concentration in Yamuna River Water at Different Sites

Group1	Group2	Mean-diff	P-Adj	Lower	Upper
April	August	-1.79	0.0004	-3.0091	-0.5709
April	December	-1.0132	0.1909	-2.2323	0.2059
April	February	-0.5506	0.9178	-1.7697	0.6685
April	January	-0.8836	0.3712	-2.1027	0.3355
April	July	-1.2626	0.0363	-2.4817	-0.0435
April	June	-0.9268	0.3027	-2.1459	0.2923
April	March	-0.2634	0.9998	-1.4825	0.9557
April	May	0.7726	0.5738	-0.4465	1.9917
April	November	-1.1788	0.0665	-2.3979	0.0403
April	October	-0.9626	0.2522	-2.1817	0.2565
April	September	-1.6376	0.0016	-2.8567	-0.4185
August	December	0.7768	0.5658	-0.4423	1.9959
August	February	1.2394	0.0432	0.0203	2.4585
August	January	0.9064	0.3341	-0.3127	2.1255
August	July	0.5274	0.9375	-0.6917	1.7465
August	June	0.8632	0.4061	-0.3559	2.0823
August	March	1.5266	0.0043	0.3075	2.7457
August	May	2.5626	0	1.3435	3.7817
August	November	0.6112	0.8494	-0.6079	1.8303
August	October	0.8274	0.4705	-0.3917	2.0465
August	September	0.1524	1	-1.0667	1.3715
December	February	0.4626	0.9748	-0.7565	1.6817
December	January	0.1296	1	-1.0895	1.3487
December	July	-0.2494	0.9999	-1.4685	0.9697
December	June	0.0864	1	-1.1327	1.3055
December	March	0.7498	0.6172	-0.4693	1.9689
December	May	1.7858	0.0004	0.5667	3.0049
December	November	-0.1656	1	-1.3847	1.0535
December	October	0.0506	1	-1.1685	1.2697
December	September	-0.6244	0.8313	-1.8435	0.5947
February	January	-0.333	0.9983	-1.5521	0.8861
February	July	-0.712	0.6876	-1.9311	0.5071
February	June	-0.3762	0.9951	-1.5953	0.8429
February	March	0.2872	0.9996	-0.9319	1.5063
February	May	1.3232	0.0229	0.1041	2.5423
February	November	-0.6282	0.8259	-1.8473	0.5909
February	October	-0.412	0.9896	-1.6311	0.8071

February	September	-1.087	0.1224	-2.3061	0.1321
January	July	-0.379	0.9948	-1.5981	0.8401
January	June	-0.0432	1	-1.2623	1.1759
January	March	0.6202	0.8372	-0.5989	1.8393
January	May	1.6562	0.0014	0.4371	2.8753
January	November	-0.2952	0.9994	-1.5143	0.9239
January	October	-0.079	1	-1.2981	1.1401
January	September	-0.754	0.6092	-1.9731	0.4651
July	June	0.3358	0.9982	-0.8833	1.5549
July	March	0.9992	0.2067	-0.2199	2.2183
July	May	2.0352	0	0.8161	3.2543
July	November	0.0838	1	-1.1353	1.3029
July	October	0.3	0.9993	-0.9993	0.9993
July	September	-0.375	0.9952	-1.5941	0.8441
June	March	0.6634	0.7718	-0.5557	1.8825
June	May	1.6994	0.0009	0.4803	2.9185
June	November	-0.252	0.9999	-1.4711	0.9671
June	October	-0.0358	1	-1.2549	1.1833
June	September	-0.7108	0.6898	-1.9299	0.5083
March	May	1.036	0.1672	-0.1831	2.2551
March	November	-0.9154	0.32	-2.1345	0.3037
March	October	-0.6992	0.7107	-1.9183	0.5199
March	September	-1.3742	0.0153	-2.5933	-0.1551
May	November	-1.9514	0.0001	-3.1705	-0.7323
May	October	-1.7352	0.0007	-2.9543	-0.5161
May	September	-2.4102	0	-3.6293	-1.1911
November	October	0.2162	1	-1.0029	1.4353
November	September	-0.4588	0.9763	-1.6779	0.7603
October	September	-0.675	0.7526	-1.8941	0.5441

Table 4.9: Tukey Test for Zinc: 5 Sites Multiple Comparisons of Means for Different Months

CHAPTER -5

CONCLUSSION

Conclusion

The research findings from this comprehensive study of water quality along the Yamuna River provide valuable insights into the state of this vital water source. These findings hold significant forensic significance as they shed light on the dynamic fluctuations of heavy metal concentrations across different sites and months. Such insights can aid environmental investigations by helping to identify potential pollution sources and their impact on the river's water quality. One of the key takeaways from this study is the presence of heavy metals such as lead, nickel, chromium, and zinc at concentrations that, in some cases, exceed the permissible limits set by the World Health Organization (WHO). This is a matter of grave concern, as it indicates the potential toxicity of the water in the Yamuna River, posing a severe threat to both aquatic ecosystems and human health. In particular, the presence of lead at levels exceeding WHO limits is alarming. Lead is a highly toxic heavy metal that, when ingested, can have severe health effects, especially in children. Long-term exposure to lead-contaminated water can lead to cognitive impairments, developmental issues, and a range of other health problems. Therefore, the elevated lead levels found in this study warrant urgent attention and remediation measures. Furthermore, the presence of other heavy metals like nickel, chromium, and zinc, also at levels exceeding WHO limits, adds to the complexity of the problem. These metals can have various adverse effects on both aquatic life and human health. For instance, chromium can lead to respiratory issues and skin irritation, while nickel exposure can result in allergies and lung damage. This research underscores the urgent need for comprehensive water quality management and remediation efforts along the Yamuna River. The forensic significance lies in its potential to guide investigations into pollution sources and their impact. However, the most critical aspect is the potential toxic effect of highly polluted water on human health. Immediate action is required to address this pressing environmental and public health issue, including improved water treatment processes, stricter pollution control measures, and heightened public awareness about the dangers of using contaminated water from the Yamuna River. Failure to take action could have dire consequences for both the environment and the well-being of the communities that rely on this water source.

The extensive research conducted on heavy metal pollution in the Yamuna River has yielded critical insights into the state of this vital waterway. The findings reveal a complex and concerning scenario that has far-reaching implications for both the environment and human health. Throughout the year, the river displayed dynamic fluctuations in the concentrations of heavy metals, notably lead, nickel, chromium, and zinc. These variations were not uniform across the monitoring sites, reflecting the heterogeneous nature of pollution sources along the river's course. Sites upstream tended to exhibit lower pollution levels, while downstream sites, closer to urban and industrial centers, showed significantly elevated heavy metal concentrations. A particularly alarming aspect of this research is the observation that, at various points during the year, heavy metal concentrations exceeded the permissible limits set by the World Health Organization (WHO). This signifies a clear and present threat to the health of communities relying on the Yamuna River for drinking water, agriculture, and other vital needs. From a forensic standpoint, this research can be instrumental in identifying potential sources of pollution and holding responsible parties accountable. Understanding the seasonal patterns of heavy metal contamination can aid investigative efforts, while the spatial distribution of pollution hotspots can guide enforcement actions and policy decisions. The environmental impact of heavy metal pollution on the Yamuna River is profound. Aquatic ecosystems suffer as aquatic life struggles to survive in toxic waters. Biodiversity is at risk, with potential long-term consequences for the health and resilience of the river's ecosystems. Additionally, the river's contamination raises significant public health concerns. Communities residing along its banks, often economically disadvantaged, face heightened risks of heavy metal exposure. This exposure has been linked to a range of health issues, from cardiovascular problems to neurological disorders, posing a grave threat to the well-being of vulnerable populations. In light of these findings, it is imperative that comprehensive and sustained actions be taken. Pollution mitigation measures must be implemented, targeting the sources of contamination and enforcing strict regulatory standards. Long-term monitoring and research should continue to track changes in pollution levels, assess the effectiveness of interventions, and inform adaptive management strategies. Furthermore, engaging local communities in pollution monitoring, awareness campaigns, and conservation efforts is essential. Empowering these communities to become stewards of the Yamuna River can foster a sense of ownership and collective responsibility for its restoration. This research underscores the urgency of addressing heavy metal pollution in the Yamuna River. It is not only an environmental concern but also a matter of social justice and public health. The Yamuna River has long been a lifeline for millions, and its restoration is a collective responsibility that demands immediate attention, informed action, and a commitment to safeguarding this invaluable resource for future generations.

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Appendix - I -

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Impact of Variation in Climatic Changes in Concentration of Lead & Nickel in Yamuna River Water, Delhi, India

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ABSTRACT

The Yamuna River A tributary of the Ganga river is one of India's most well-known and important rivers. Regrettably, numerous sections of the Yamuna River are heavily polluted, including many metropolitan areas like Prayagraj, Agra, Delhi etc. Water pollution with lead is a long-term problem. Rural and urban expansion, as well as rapid industrial development, are key sources of lead poisoning in lakes, rivers, groundwater, and other water sources as a result of increased population growth. Water samples were taken from each of the five sampling locations. Samples were taken throughout the course of a whole 2019 year, from January to December, with a 20–25-day break between them, with climate variation as a primary factor. Water sample were analysed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Atomic Absorption Spectroscopy (AAS) were used to quantify the content of lead (Pb) in water from the Yamuna in Delhi. When results were compared to the WHO permissible limits of Lead (Pb) and Nickel (Ni) in water, they were found to be greater. It can be observed that the concentration increases as the temperature rises and the humidity falls. Lead and nickel are both very poisonous in nature, and human and animal exposure to these heavy metals through water can cause chronic intoxication, which can be fatal.

Selection and peer-review under responsibility of the scientific committee of the National Conference on Environmental Toxicology: Impact on Human Health.

1. Introduction

Water is essential for human survival. Without water, there is no life. To exist, man must travel to great lengths to find water. Water can be derived from the seas, rain, streams, lakes, glaciers, or from subsurface sources [1]. Water is essential for life, and life as we know it would not be possible without it. Even if it is valuable, it causes sickness and disability in the population. Water already includes minerals and organisms that, due to their concentration and contents, may be harmful to people and animals [2]. River Yamuna is one of the most contaminated rivers in India. It arises from Yamunotri icecaps in the inferior Himalayas at a height of almost 6387 m. The barricades formed on the current are striking a major role in heightening the river contamination. The stream can split into five divisions on the basis of hydrological and environmental conditions. The water quality of only one segment (Himalayan segment) joins the river water quality criteria. Frequently no stream is permitted to flow downstream of the Himalayan section (Tejewala barrage), particularly in the summer and wintertime periods to accomplish the need for water of the neighboring area. Whatever flows downstream of the Tajewala barrage is untreated or partially treated residential and manufacturing effluent that has been provided by various drains. The removal of untreated residential and mechanical effluents has seriously influenced the condition of Yamuna River and presently it comes below category E, as a result, it is only suitable for recreational and industrial cooling purposes, thus cutting out the possibility of underwater life and residential supply. Nearly each year volume death of fish is proclaimed. Decay levels in the Yamuna River have increased [3,4]. The Yamuna River, Delhi's principal supply of drinking water, is one of the nation's most polluted rivers. Household and manufacturing sources account for approximately 85% of the pollution [5–7]. The river Yamuna is majorly involved as the main irrigation resource for the agricultural practices in Delhi–NCR for irrigation, and thus the field soil and crops are directly

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exposed to the heavy metals contaminated river water. Since life depending on the Yamuna river is consuming heavy metals via drinking polluted water and other food chains, this contaminated water is directly linked with human health [8–10]. The emission of untreated internal and automated effluents has a significant negative impact on the flow. The water is unfit for bathing, aquatic life, or home consumption. Pollutants of all types are regularly introduced into the water supply, and their toxicity is becoming a major concern for biological, evolutionary, and environmental reasons [11–14]. The Yamuna River is one of India's most polluted rivers. The nation's capital, Delhi, is the leading polluter of the Yamuna River, followed by Agra and Mathura [3]. Even when metal concentrations in water are exceedingly low and undetectable with current techniques of detection, metal enrichment in river sediments represents upstream contamination sources and pollution over time. Aquatic plants have the capacity to collect biogenic components and hazardous chemicals, including heavy metals, in addition to having a high absorption capability [15,16]. Metals pass through the aquatic life system, as well as the plants and animals that surround the river. Because heavy metals are non-degradable, they may readily collect in the environment and the tissues of aquatic biota, and this build-up in tissues can be harmful to both animals and humans [17]. Unwieldy contamination from urban and semi-urban constructions, large-scale disposal of undiagnosed or partially treated domestic wastewater and waste products, improper drain and sewage systems, unauthorised mining activities, and sedimentation in urban rivers all cause organic matter and heavy metals to accumulate continuously in surface water and groundwater [18–20]. The whole circulation of exposure to heavy metals is shown in the below Fig. 1.

The presence of Pb & Ni in the Yamuna River's water is a cause for worry, since Delhi's population is dependent on the river's water Industrial wastes such as paints, glass preparations, batteries, and sewage, as well as natural and human sources, as well as agricultural activities such as pesticide usage, have contaminated the Yamuna River water, contaminating drinking water in adjacent villages [21,22]. Sources of Ni toxicity are industrial waste such as Stainless -Steel Manufacturing Units, Electroplating Factory Discharge. The environmental impurities by the poisonous elements are increasing which is causing a significant threat to the regional users. A wide range of contaminants are incessantly introduced into the aquatic atmosphere, owing mostly to increased industry, technical advancement, and rising social population, as well as the abuse of agricultural, natural, and residential wash run-off [23]. Heavy metals are one of the most dangerous contaminants because of their consistent toxicity, quality, and proclivity to persist in organisms and transmit food supply chain amplification, and they are also non-degradable [24–28]. Intake of lead and nickel polluted water, fish, fruits, vegetables, and plants cause a threat to human health. Nickel has neurotoxic, genotoxic, and carcinogenic effects and nickel dermatitis disease in humans. While lead toxicity leads to Cognitive Impairment in Children, Peripheral Neuropathy in Adults, Developmental Delay. These are the chief sources of nourishment for people [29,30]. Human health is jeopardized by the presence of these heavy metals in water. Heavy metals dispersion revealed many areas of hazardous contamination and a steady upward trend downstream, indicating the significant influence of local sources such as agricultural and natural urban–industrial wastewater [31]. Pb & Ni in the water of the River Yamuna is a hot problem since the population of Delhi relies on the river's water. The threat of accumulation of heavy metals, specifically

Fig. 1. Major Sources of Contamination of Yamuna River from Pb & Ni and exposure to humans.

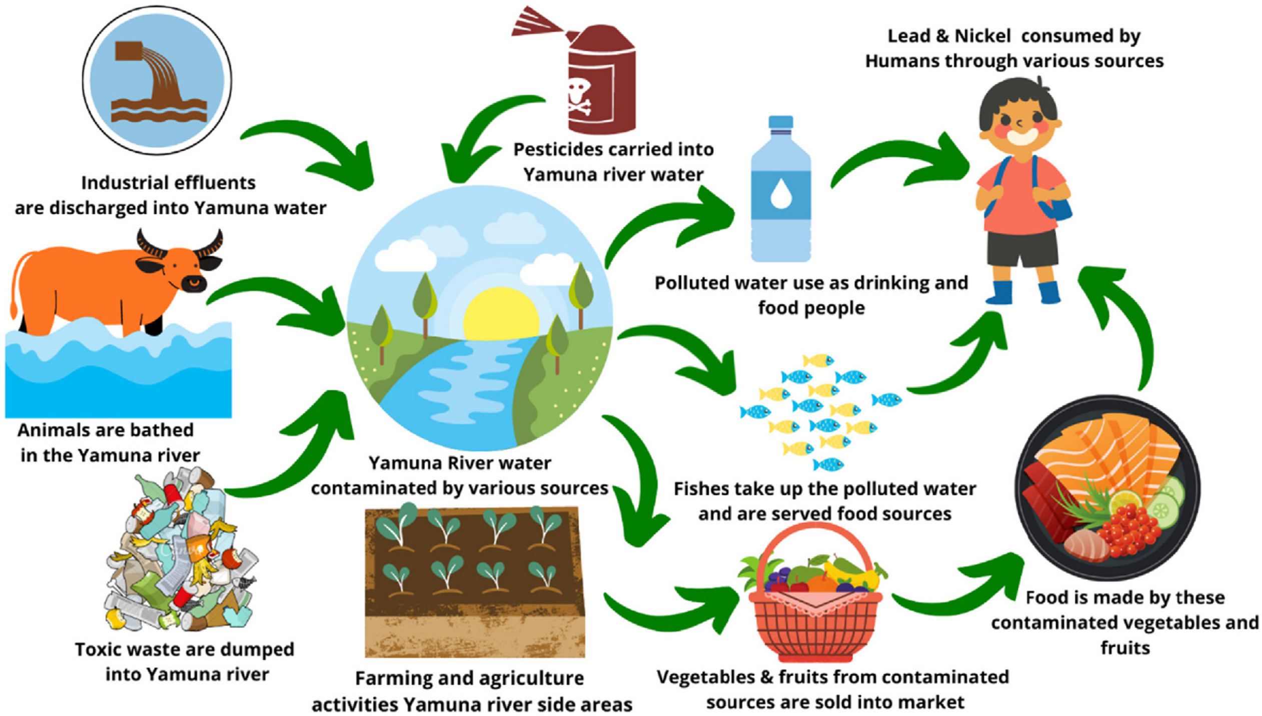

Fig. 2. Bioaccumulation of Pb & Ni and toxicity in humans and animals through Yamuna river.

bioaccumulation, endangers living being's wellbeing shown in Fig. 2. [32,33] This research study shows that dissolution of lead and nickel concentration has risen consequently due to environmental humidity and temperature. The toxicity of these heavy metals is a major threat leading to several health issues for humans and animals. Even though lead and nickel both have no organic role, they persist in the environment currently or the other forms having adverse effects on people's body and their work. This study conclusively aims at measuring the concentration of lead and nickel in Yamuna River, and climatic changes around its appreciation of the change in dissolved lead and nickel concentrations. This study also discusses various limitations and future prospects of this study. Possibilities of treatment of heavy metals from Yamuna river which could be helpful in making the quality of water usable in coming years.

2. Materials and methods

2.1. Samples collection

Collection of Water samples along the Yamuna River in Delhi, India was done from five different locations (Fig. 3).

2.2. Sample preparations

All of the sample locations were utilized for agriculture and drinking. From each site, water samples were taken for testing. All samples were obtained in 1.5 l sterilized plastic containers pre-washed with 10 g/100 g nitric acid (HNO_3) and de-ionized water. Sampling was carried out with all precautions taken, such as washing containers and washing at minimum 3 times from the study location. For the collection of samples, the bottle was immersed in water below 20 cm from the surface the prevention of contamination from trace elements in the air around the site. All water samples were immediately taken to the lab and filtered with Whatman No. 41 (0.45 m pore size) filter paper. The samples were acidified with 2 mL concentrated Nitric acid, then stored at 4 °C until the analysis to prevent lead and nickel precipitation, restrict adsorption of the analyses onto the walls of containers, and avoid microbial activity [34,35] as shown in Fig. 4. The content of lead (Pb) and Nickel (Ni) in water collected every 20–25 days for a year from January to December 2019 from the Yamuna river in Delhi was tested and compared to the World Health Organization's allowed levels (WHO). Sample collection, preparation and analysis methodology is shown in Fig. 4.

2.3. Instrumentation

Lead and Nickel levels in all samples were determined using inductively coupled plasma mass spectrometry and atomic absorption spectroscopy. It's a typical metal detector seen in laboratories.

3. Result

Lead and Nickel concentrations in the Yamuna River's water during different times of the year, with reference to average temperature and humidity.

Lead: The concentration of lead (Pb) in water samples in January was 0.76 ppm, followed by a modest rise in February concentration of 0.89 ppm, however there was an increase in March of 1.33 ppm and an increase in April of 1.65 ppm. In the month of May, the concentration of lead in water was 1.90 ppm, while in the month of June, the value was 0.85 ppm. A decrease in lead concentration was detected in July (0.33 ppm) or August (0.28 ppm) or September (0.24), with a minor increase in October (0.24), November (0.27), and December (0.29). Variation of concentration with respect to Humidity and Temperature in each month is shown in Fig. 5.

Nickel: In the month of January, the concentration of nickel in water samples was 0.64 ppm, followed by a slight increase in

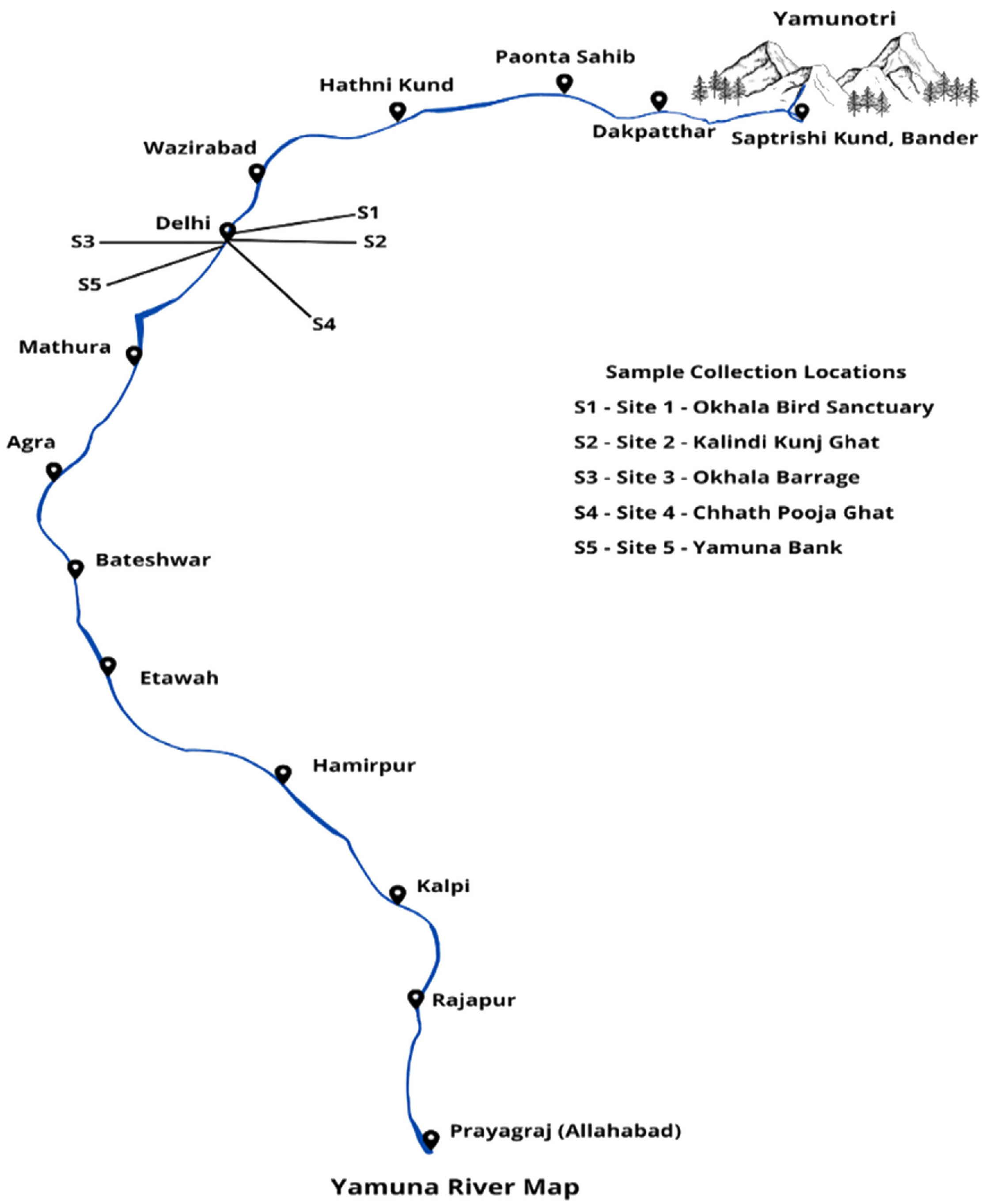

Fig. 3. Yamuna river mapping along with sample collection sites.

February concentration was 0.90 ppm, whereas there was an increase in the month of March 0.85 and increases in the month of April 1.45 ppm and further it intensifies in the month of May, the concentration of nickel in water was 1.83 ppm, month of June 0.22 ppm and increase in the month of July 0.28 ppm and then continuous decrease from month of August 0.23 ppm, month of September 0.15 and slight Increase month of October 0.14 month of November 0.12 month of December 0.13. Variation of concentration with respect to Humidity and Temperature in each month is shown in Fig. 6.

4. Discussion

The highest allowable amount of lead and nickel, according to WHO recommendations, is 0.001 ppm and 0.002 ppm. We discovered that the concentration of lead and nickel is much higher than the WHO permitted level and that the limit in the month of May concentration is much higher than the WHO allowable limit. There were considerable disparities between the WHO limit concentration and the Pb&Ni values recorded during these months. When we compared the concentrations of these metals across the differ-

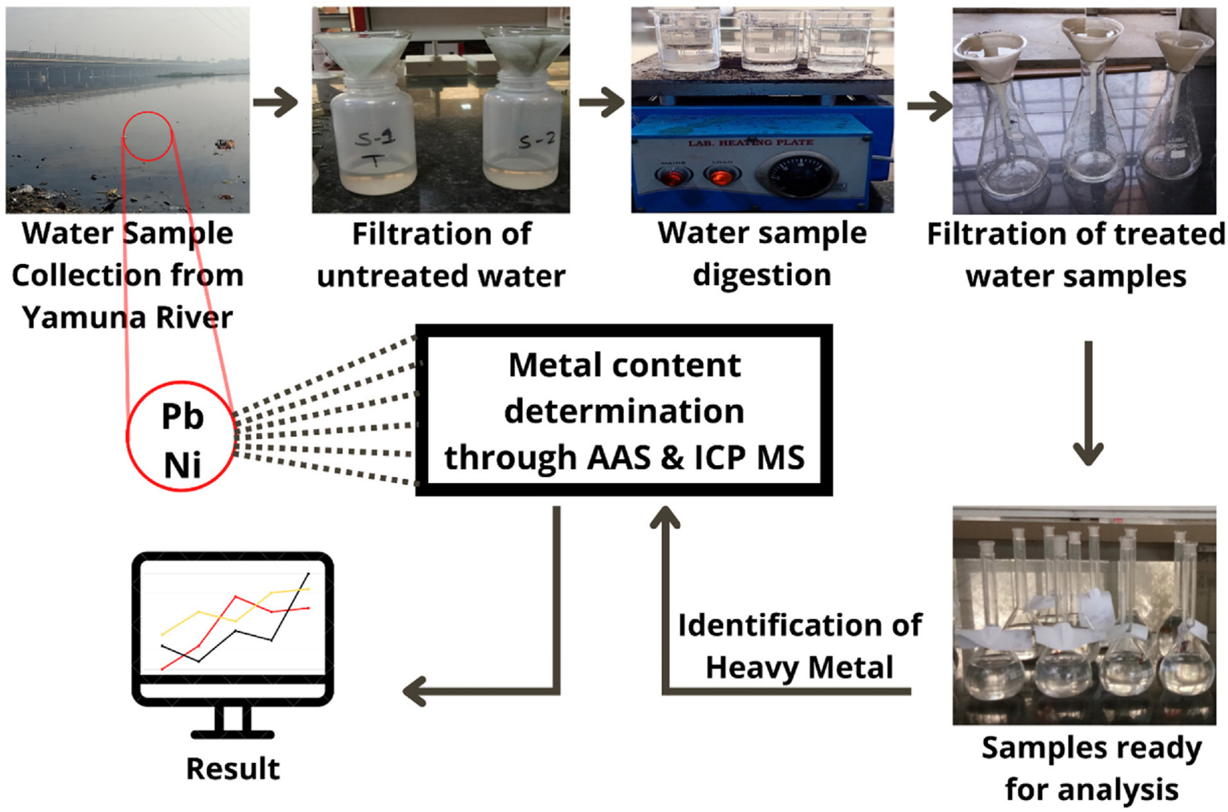

Fig. 4. This Figure shows the collection, preparation and analysis of lead and nickel in Yamuna river water.

ent months, we discovered substantial changes in concentrations with temperature and humidity is there. The results reveal that in the month of April, and May, the concentration increases with rising temperature and decreasing humidity. The changes in lead and nickel concentrations in river waters surpassed or were on the verge of exceeding the World Health Organization's permitted limits. Our study findings, which are backed by statistical analysis, show that the lead and nickel contents in river water have surpassed the allowable limits. However, in July, the water quality was determined to be unsafe for consumption, and the same was observed in the winter and early spring seasons. The quality of the water improved during the rainy season owing to the dilution impact. Ingestion of contaminated water has an obvious and harmful influence on human health, whether directly or indirectly through remnants in crops, fisheries, plants, fruits, and other food chains [36]. But ingestion of polluted water has a clear and negative impact on human health, whether directly or as residues in vegetables, seafood, plants, fruits, and other food chains. Heavy metals are widely found in bodies of water, and they are harmful both to human and aquatic life[37]. Various research on heavy metal toxicity have been published in the past, with levels of HMs in water sources. According to the research, given the existing state of metals contamination, the groundwater is really not suitable for drinking due to high concentrations of a few potentially harmful metals [38]. The WHO set a tight allowable limit, yet most water bodies are polluted by waste fluids generated by businesses and companies nearby. The drinking water tests had heavy metal concentrations that were higher than the WHO-recommended permissible levels. Heavy metal concentrations have been found in a variety of water bodies in India, according to toxicology research. The growth in elemental pollution renders water and fish unfit for food, posing serious health risks to humans. The pollution of the river and adjacent agricultural soils suggests that these metals may have entered the food chain. Due to their non-biodegradability in the environment, heavy metals must be removed [39].

5. Limitation of the study

From time to time, there may be occasional changes in the concentration of heavy metals beyond the levels demonstrated in this study. From this we can say imply that, with increase in the industrials effluents and sewage discharge the concentration might increase. The concentration could also vary based on the discharge of industrial effluents and if they are less or more toxic for the water. As it is a running water, the concentration may vary continuously at different places as well. At the time sample collection, the concentration might be more or less depending solely on the water and the sources so, continuous measurement of concentration is a must to maintain the good quality of water at all times.

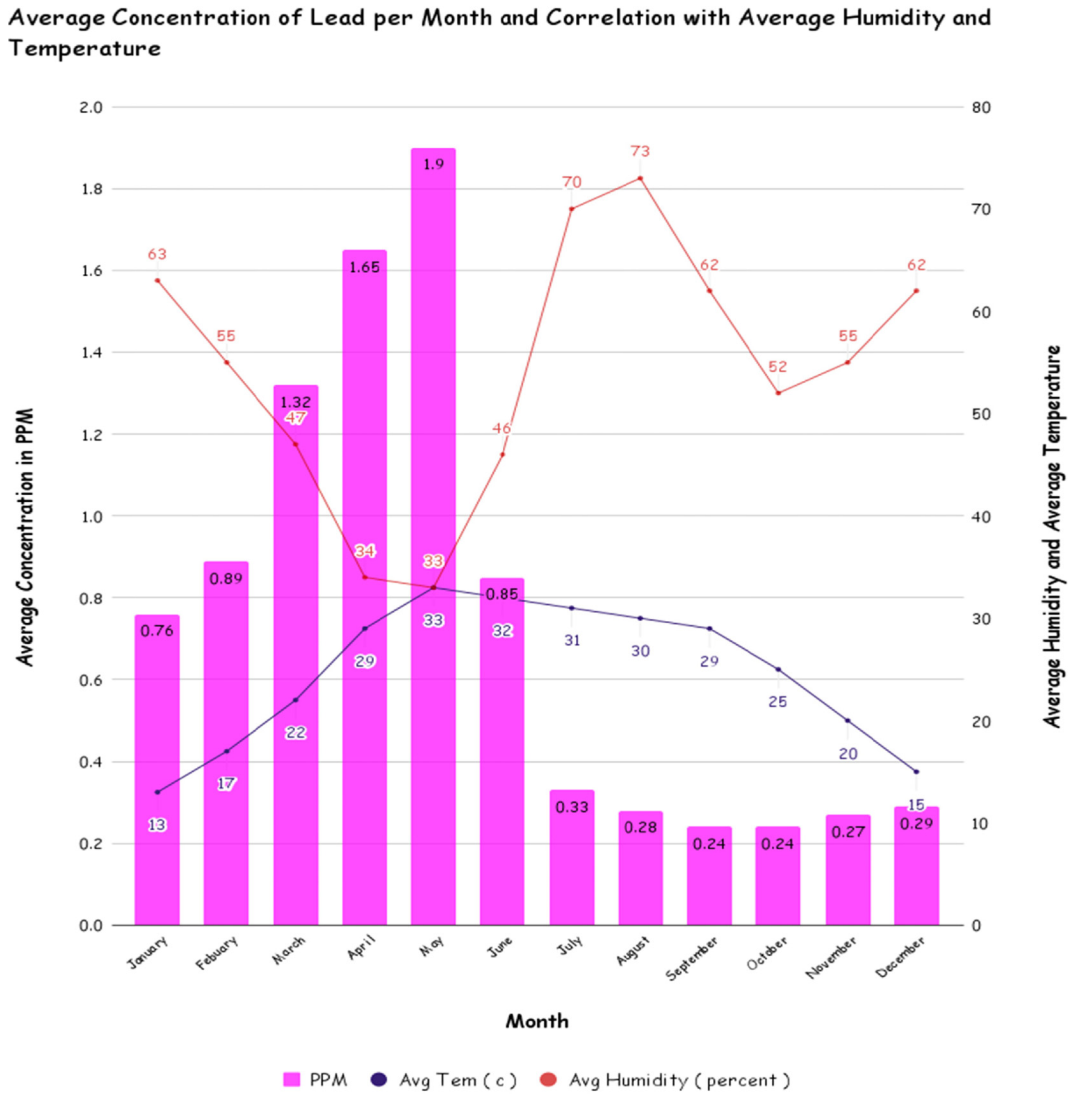

Fig. 5. Variation of Lead Concentration in the water of Yamuna River (Delhi) in different months in correlation with Temperature and Humidity.

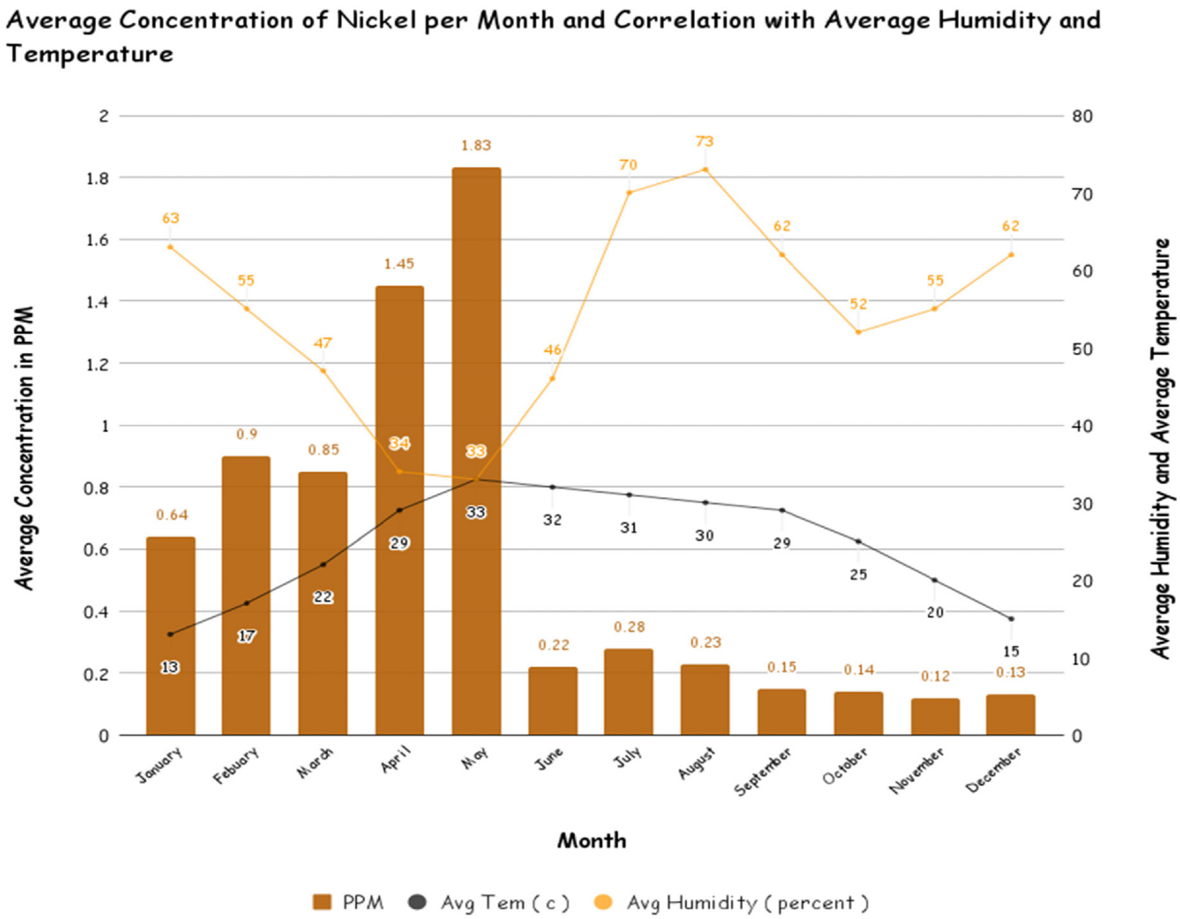

Fig. 6. Variation of Nickel Concentration in the water of Yamuna River (Delhi) in different months in correlation with Temperature and Humidity.

6. Conclusion

This research concludes that Pb levels in the River Yamuna are high which consequently is affecting humans as well as animals adversely. Toxicity changes in humans are due to lead. Workers who are directly in contact with industries are majorly affected. Exposure to lead has led to carcinogenicity and neurotoxicity in humans. The Pb content in Yamuna river water, sediments, plants, herbs, and soil has been consistently seen to be directly impacted by Yamuna river water and neighbouring Yamuna groundwater. The general population should be aware of the dangers of consuming tainted Yamuna river water. Farmers should dispose of agricultural waste in the Yamuna river with care and caution since we know that many insecticides and herbicides include Pb. Lead concentrations that exceed the acceptable and optimum values (WHO). The majority of the water samples were extremely polluted and could not be used for drinking. Here we conclude that Yamuna river is not fit for drinking as it was found much polluted and has also the concentration of Pb&Ni and despite been a holy river and various Hindu myths related to it also causes a big reason for its pollution like for example discarding household wastes and water wastes, flowers, incense stick ashes, Devotees about to immerse a large idol of the goddess, etc. The level of Pb & Ni in the Yamuna River's water is of particular significance since the inhabitants of Delhi rely on it. Agricultural fields are practiced in the Yamuna river and catchment areas that are disposed to pollution as we know that heavy metal contamination is dangerous to human health. In emerging nations where agriculture, urbanisation, E-waste, and industrialisation are leaving a legacy of Pb and Ni environmental deterioration, technologies for field farming and commercialization are recommended. It is advised that the general people be made aware of the hazards of eating polluted groundwater, such as the Yamuna river, which has a high concentration of Pb and Ni. Apart from the awareness, different techniques must be put to use for treatment of toxic river waters.

7. Recommendation for future studies

Considering the implication of the river water with the health of humans who rely on it, we recommend that future research be planned on the environmental toxicology of Yamuna river, using modern methods to assess its heavy metal contaminations. With the development of technology bio-markers should be installed for measurement and control of heavy metals concentration. Various bioremediation techniques could be employed for the necessary treatment of heavy metals in the Yamuna river.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author's contribution

Conceptualization and Methodology: Rajeev Kumar and Lalit Prasad; Data collection: Mahipal Singh Sankhla; Data analysis: Rajeev Kumar; All authors read and approved the final manuscript.

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Original Research Paper

Seasonal Variation of Nickel and Zinc Concentration in Water of River Yamuna, Delhi, India

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ABSTRACT :

Introduction: Yamuna river is the longest and second-largest tributary of the Ganga river. The tenacious river pollution concentrations of Nickel and Zinc were determined in water from river Yamuna, at Delhi. The polluted river water is mostly used for drinking, agricultural or aquacultural purposes and also stored as holy water. Due to growing community extension, farm and residential advancement and rapid technological progress are significant origins of the decay of lead in Yamuna river and various water sources.

Material & Method: The objective of this study was to determine the seasonal variation of Nickel and Zinc concentration in Yamuna river water from summer, monsoon and winter and water samples were collected from five different sites of the river. The seasonal variation of metal concentration is determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) & Atomic Absorption Spectroscopy (AAS).

Result: The Ni and Zn concentrations in Yamuna river water are higher than the limits of WHO set for heavy metals. The highest concentration of Ni and Zn metals in river water are found in the summer season. It is universally-known that the Ni and Zn are majorly toxic in nature. The exposure of the Ni and Zn through water is chronic toxicity, which could be quite harmful to humans as well as underwater life.

Conclusion: This research study shows that the water quality of the Yamuna river is not fit for drinking, bathing, agricultural purpose and aquatic life. The existing condition of the Yamuna river is of serious concern, and remediation of the river to prevent current and further pollution is the critical need for environmental conservation.

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Key words: Nickel, Zinc, Yamuna river, Water, Toxicity, Human, etc.

INTRODUCTION :

Water is the most plentiful compound on the earth as well as essential for every known form of life on earth. As the adequate quantitative supply of water is necessary to each and every region, where human and animal life exists, it is also essential to maintain the quality of water. The quality of water is directly connected to the health of respective living organisms, who are dependent on water. India is the country where rivers are considered as goddesses and lifeline of India's rich cultural heritage as well as environmental wealth. But the increasing population density, urbanization, unplanned development, industrialization, agricultural activities and some Hindu rituals are causing harm to the river water and this increasing pollution is being an issue of vital concern[1]. The humans are releasing municipal, industrial and agricultural waste into the environment i.e. air, water, soil etc. These undesirable changes in surroundings led the environment to face a curse of contamination for a long time and imparted its harmful effects on plants, animals and human beings. Water is one of the most prevalent resources for contamination. Various types of municipal, agricultural, industrial, hospital and domestic waste are intentionally released or accidentally entered into water systems, which may include biological and chemical contaminants including heavy metals. The water resources, especially fresh surface waters i.e. rivers are meeting water needs of humans, plants, animals, industries and agriculture. Thus, it is very important to conserve river water sources and prevent them from pollution. As municipal, industrial, and agricultural waste enter the water, biological and chemical contaminants including heavy metals also enter water resources[2].Yamuna river is the second-largest and longest tributary of India's most sacred river Ganga. This river is a prominent, sacred and also considered as the holy river in Hindu culture. The banks and basins of this river have well established various industries as well as highly fertile and high food grain yielding soil for agricultural purposes. The bank of river Yamuna has many of the famous pilgrimage places in India such as Yamunotri in Uttaranchal, Paonta Sahib in Himachal Pradesh, and Mathura, Vrindavan, Bateshwar and Allahabad in Uttar Pradesh. Various urbanized towns such as Gautam Budh Nagar, Faridabad, Yamuna Nagar, Sonepat, Mathura, Agra, Etawah as well as Delhi, the massive metropolitan area of India are also located on its banks. Although the Yamuna river is a lifeline of people and also has a positive influence over the economy of India, it is facing critical contamination issues of concern due to this continuously increasing industrialization, urbanization and rapid agricultural developments[3]. The Yamuna river flows from Hathni Kund barrage to Palla in Delhi and is trapped again for drinking water supply to Delhi at Wazirabad via barrage. From Wazirabad barrage no water is allowed to flow down particularly during summer, as the available water in the river is not adequate to fulfil the water supply-demand of Delhi. To fulfil the water demand of Delhi, water is not allowed to flow down during summer otherwise, it flows down and diverted into the Agra canal using Okhla barrage for irrigation. At downstream of Warizabad as well as Okhla barrage all the treated, partially treated or untreated industrial, urban and domestic wastewater drains join the river and eventually affect its quality by adding various contaminants. From Okhla barrage, the river flows down and reaches Gokul barrage at Mathura, where it is again diverted for drinking purposes. After travelling via Okhla barrage, the river again joined with city drains and industrial wastewater. Finally, the river Yamuna receives water through its other tributaries and joins river Ganga at Allahabad after traversing about 790 km via cities of Agra, Bateshwar, Etawah, Hamirpur and Pratapgarh[4]. Polluted water of river Yamuna is an issue of serious concern as the population of Delhi is dependent on the water of Yamuna. The hazard of biomagnification and bioaccumulation of the Ni and Zn causes extreme harm to human health and welfare. Industrial effluent is one of the prime sources of metal contamination in river waters is no exception[5-13]. Although Zinc is an essential element for a healthy body, excessive zinc can be extremely toxic to human health. Zinc is also necessary for a healthy immune system, cell division and synthesis of protein and collagen which is great for wound healing and healthy skin. But its consumption above a particular limit may lead to stomach cramps, nausea and vomiting. Its exposure for a longer period can cause severe health effects such as anaemia, pancreas damage and lower levels of high-density lipoprotein cholesterol[14]. Nickel is also an essential trace element for the human body as it aids the process of red blood cells production. But the higher dosage may lead to damage to the lung, liver and kidney. While, excessive consumption can cause severe diseases such as cancer, respiratory failure, birth defects, allergies, dermatitis, eczema, nervous system and heart failure[15,16].

The present research study noted that Nickel and Zinc concentration in water was different in seasonal variation of environmental conditions. Heavy metals toxicity has been established to be a threat and there are produced toxicity threats related to humans and animals. Consequently, this study aimed to measure the seasonal variation of concentration in Ni and Zn from the Yamuna river water.

MATERIALS AND METHODS :

Samples Collection

Five different sites of the Yamuna river in Delhi, India were selected for collection of water samples in different seasons summer, monsoon & winter.

Site 1: Okhla Bird Sanctuary **Site 2:** Kalindi Kunj Ghat

Site 3: Okhla Barrage **Site 4:** Yamuna Bridge

Site 5: Yamuna Bank

The five sites of sample collection were used for drinking and agricultural purposes. The sterile polyethylene bottles of 1.5 litres were pre-washed with 10% nitric acid and deionized water and then rinsed with water from the sampling site for three times. After neat rinsing, bottles were employed for collection of water samples from all selected sampling sites. To prevent the trace element contamination from the air, the polyethylene bottles were immersed to about 20 cm below the water surface.

All sampling bottles were brought to the laboratory by preventing external contamination. All water samples were filtered through grade 41 Whatman filter (0.45 µm pore size). After filtration, the samples were acidified with 2ml concentrated Nitric acid to prevent precipitation of Zinc, reduce adsorption of the analytes onto the walls of containers and to avoid microbial activity, then water samples were stored at 4°C until the analysis[17-18].

The concentrations of Nickel (Ni) and Zinc (Zn) in the water of Yamuna river in different seasons such as summer, monsoon and winter were determined. The determined concentrations were compared with the standard values recommended by the World Health Organization (WHO). In order to determine the water pollution status, a water sample was also collected from the above-mentioned sampling points.

Instrumentation : The concentrations of Zinc were determined in all samples by standard laboratory analytical tools for metal analysis that are Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Atomic Absorption Spectroscopy (AAS).

Statistical analysis : Level of significance due to seasonal variations and wastewater contamination in all the above-studied parameters were assessed using two-way analysis of variance (ANOVA) followed by the F-test & Tukey's test ($p<0.005$, R Programming) except heavy metal concentration. The statistically significant difference in the heavy metal concentrations was analyzed by two-way ANOVA followed by the F- test & Tukey's test ($p<0.005$, R Programming).

RESULT & DISCUSSION :

The river Yamuna is majorly involved as the main irrigation resource for the agricultural practices in Delhi–NCR for irrigation, and thus the field soil and crops are directly exposed to the heavy metals contaminated river water. Since life depending on the Yamuna river is consuming heavy metals via drinking polluted water and other food chains, this contaminated water is directly linked with human health.

Seasonal Variation of Nickel in Yamuna River Water : The seasonal variation in concentrations of nickel from Yamuna river water was shown in **(Figure 1)**. The result was compared with the permissible limits set by WHO. The results showed the temperature, rainfall, etc. affect the concentration of nickel i.e. in different seasons, there is seasonal variation in nickel concentration of Yamuna river. The higher concentration ($p<0.005$) of nickel was found in summer. The mean square value of nickel content was higher in the summer followed by winter and monsoon. The multiple comparisons of means of nickel content in different seasons using Tukey test were described in **(Table 1)**. The major sources of nickel contamination in river water are sewage water and wastewater. As the water level decrease during the summer season, the concentration of heavy metals in the water eventually increases.

Seasonal Variation of Zinc in Yamuna River Water

The seasonal variation in concentrations of zinc from Yamuna river water was shown in **(Figure 2)**. The result was compared with the permissible limits set by WHO. The results showed the temperature, rainfall, etc. affect the concentration of zinc i.e. in different seasons, there is seasonal variation in zinc concentration of Yamuna river. The higher concentration ($p<0.005$) of zinc was found in summer. The mean square value of nickel content was higher in the summer followed by winter and monsoon. The multiple comparisons of means of nickel content in different seasons using Tukey test were described in **(Table 2)**. The major sources of zinc contamination in river water are sewage water, wastewater and anthropogenic activities. As the water level decrease during the summer season, the concentration of heavy metals in the water eventually increases.

CONCLUSION :

The concentrations of nickel and zinc in river Yamuna have crossed the permissible limit recommended by the World Health Organization (WHO) for river water quality. Since

Table 1: Tukey Test of nickel Multiple Comparisons of Means different Seasons

Season	Difference	Lower	Upper	P-Value
Summer-Monsoon	0.8689333	0.4496586	1.2882080	0.0000198
Winter-Monsoon	0.1681733	-0.2327300	0.5690766	0.5729503
Winter-Summer	-0.7007600	-1.0690132	-0.3325068	0.0000813

Figure 1: Seasonal Variation of Nickel in Yamuna River Water

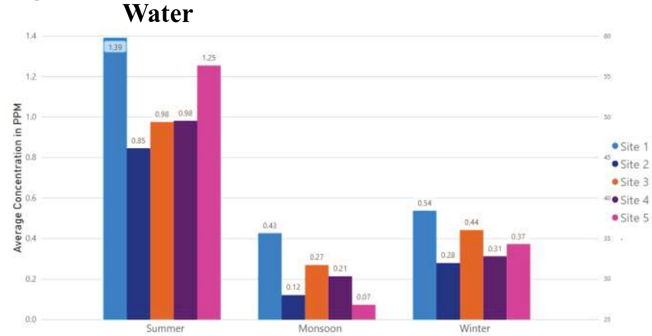
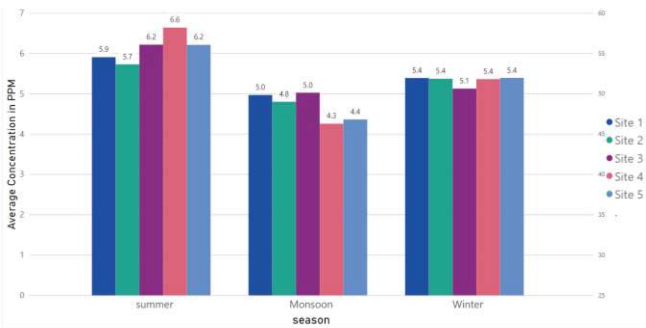


Table 2: Tukey Test of Zinc Multiple Comparisons of Means different Seasons

Season	Difference	Lower	Upper	P-Value
Summer-Monsoon	1.45900	0.9029249	2.0150751	0.0000002
Winter-Monsoon	0.64564	0.1139305	1.1773495	0.0136857
Winter-Summer	-0.81336	-1.3017663	-0.3249537	0.0005433

Figure 2: Seasonal Variation of Zinc in Yamuna River Water



human health is directly linked with the quality of water, consumption via drinking metal-contaminated water or metal-contaminated fishes, fruits, vegetables, plants, etc. The toxic heavy metal contaminants released through agricultural chemicals, industrial wastes, sewage, anthropogenic waste have contaminated the Yamuna river water, which eventually caused pollution of drinking water in surrounding regions. Consumption of heavy metal contaminated water poses various health risks like kidney failure, slow growth, neurotoxicity, respiratory problems, stomatitis, paralysis, vomiting, carcinogenicity, depression in such regions. Thus, every individual should have an idea about the occurrence, sources and ecotoxicity of heavy metal contaminated water and other contaminated food. On account of the research of the drinking water samples, they contain heavy metal concentration more than the admissible and desirable levels declared by WHO for river water quality. Most of the water samples were highly contaminated, which are not even worth to use for drinking purposes.

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Research Paper:

Seasonal Variations of Lead and Chromium Concentrations in the Water Samples From Yamuna River in Delhi, India

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ABSTRACT

Background: According to Hindu mythology, Yamuna River plays an impotent role as a holy water resource in Delhi, India. The lead and chromium concentrations were determined from the water samples collected from five different locations around this river in Delhi area. The contaminated water from this river is mostly used for drinking, agriculture, aquaculture, and storage as a holy water.

Methods: The seasonal variations of heavy metal concentrations in the water samples collected from Yamuna river were determined for the summer, monsoon and winter supplies, using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Atomic Absorption Spectroscopy (AAS).

Results: In the summer water samples, we found greater concentrations of both heavy metals than those for the monsoon season. The concentrations of lead and chromium in the water samples were higher than the permissible limits recommended by the World Health Organization (WHO). The water quality was not safe for drinking, cleaning and agriculture, nor for the aquatic animals, such as fish, amphibians and others.

Conclusion: The condition of the water in Yamuna river is of great health concerns. Therefore, it is vital to take necessary actions to decontaminate the water from this river, and to draw effective strategies to minimize or prevent the current and future contaminations added to this important water resource in India.

Keywords: Lead, Chromium, Yamuna River, Water resources, Toxicity, Human and aquatic health

Introduction

Rivers are vital human resources for consumption by people and communities. Water is vital for numerous human needs, such as agriculture, and essential for hydropower plants, and to refine the climate, among others [1]. Yamuna river portrays a significant character in the daily life of many people in India who reside on its shores and the vicinity. This river has a broad catchment zone covering numerous Provinces near Delhi and is being used for many agricultural, manufacturing and residential purposes. With the rapid growth of the population and technology during the last decades, this river has become one of the most contaminated streams in India. Waste waters from the manufacturing plants and marshlands represent the primary sources of pollutants added to this river, causing its current grave situation. In Delhi area itself, there are 22 submerged sewers and drains that pour their contaminated waters into the Yamuna river [2]. Insecticides leakage from farm lands and heavy metals from

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manufacturing plants and wastelands are often poured at large scales into this river. Also, this river has become a dumpster for cattle manure, and other contaminated overflow from the surrounding lands.

Some heavy metals are capable of activating various enzymes, which can be lethal to humans even at very low concentrations [3]. Since many farms around Delhi use the water from this river for agricultural purposes, the heavy metals, such as lead and chromium, from the water eventually find their way into the food chains, causing great health concerns and leading to numerous diseases in humans and animals [4]. Further, heavy metals are found in the earth's crust and may enter water resources through natural processes, i.e., heavy rain falls that leach them out of the soil and add them to local streams and eventually poured into Yamuna river [5-10]. In this context, Yamuna river is facing its darkest point in history, not only because of the large amounts of contaminants being continually added to it, but also because the alternative water resources in the area are being exhausted due to environmental mismanagement.

Considering the absence of appropriate environmental regulations and lack of modern water treatment plants to refurbish the water in Yamuna river, it has become an unfit resource to provide for otherwise desired role in Delhi area [11]. This river is currently one of the dirtiest water resources in India because of its toxic heavy metal contents [12-15]. The contaminated water from this river is of great concerns as numerous populations in Delhi areas depend on it for their water needs. The accumulation of lead and chromium poses extreme harms to the health of humans and animals alike [16-21]. Currently, waste waters from manufacturing plants are the major sources of heavy metals entering the waters of Yamuna river [22, 23]. Since heavy metal toxicity is a threat to human and animal health, this study aimed to investigate the seasonal variations of lead and chromium in Yamuna river under a variety of environmental conditions.

Materials and Methods

Samples collection: The water samples were collected from five different sites around Yamuna river in Delhi area as follows: 1. Okhala Bird Sanctuary; 2. Kalindi Kunj Ghat; 3. Okhala Barrage; 4. Yamuna Bridge, and 5. Yamuna Banks. All of these locations were the consumers of the water from Yamuna river for agricultural and human consumption purposes. Several water samples (1.5 liters) were collected for laboratory examination from each location in sterile polyethylene bottles that had been washed with de-ionized water and 10% nitric acid. Prior to sampling, the containers were washed at least 3 times with water from the specimen locations. The containers were deep to about 20cm under the water surface to stop pollution of trace elements from the air also gathered for examination from every location.

Sample preparation: All water specimens were brought to the lab where they were filtered through Whatman's #41 (0.45 µm pore size) filter paper. The specimens were acidified with 2ml concentrated nitric acid to prevent precipitation of Chromium, decrease adsorption of the analytes onto the walls of containers, and to avoid microbial growth. These water samples were then stored at 4°C until further analysis [24]. The lead and chromium concentrations were determined in the water samples from Yamuna river for summer, monsoon and winter seasons. The determined concentrations were compared to the admissible limits recommended by the World Health Organization (WHO). Water samples were also collected from the specimens dated back to the point before a directive was issued to regulate the water contamination in the Yamuna river.

Instrumentation: The concentrations of lead and chromium were determined in all samples by inductively coupled plasma mass spectrometry and atomic absorption spectroscopy. It is a standard laboratory diagnostic device for metal detection.

Statistical analyses: The levels of lead and chromium contaminations were measured in all water samples collected in different seasons. The data were analyzed, using two-way Analysis of Variance (ANOVA) followed by Fand Tukey's tests ($P<0.005$).

Results

Seasonal Variations in Lead: The seasonal variations in the concentrations of lead in the water samples from Yamuna river are shown in Figure 1. The contamination findings were not consistent with those permissible by the World Health Organization. The lead contamination also differed depending on the climate condition, such as rainfall and temperature changes. For instance, the water samples collected in the summertime displayed significantly greater concentrations of lead ($P<0.005$) followed by those from the winter and rainy seasons. The mean square values of the lead contents were greater in the summer followed by winter and monsoon. Table 1 shows the comparison of the means for different seasons based on Tukey's test. The results confirmed that the wastewater and effluent samples were the key cause of lead contamination in the river water. Reduction in the volume of

Table 1. Tukey's test of multiple comparisons of the means for lead concentrations in different seasons.

Season	Difference	Lower	Upper	P
Summer-Monsoon	1.15060	0.83442891	1.4667711	0.0000000
Winter-Monsoon	0.21004	0.09227739	0.5123574	0.2241085
Winter-Summer	-0.94056	1.21825625	0.6628637	0.0000000

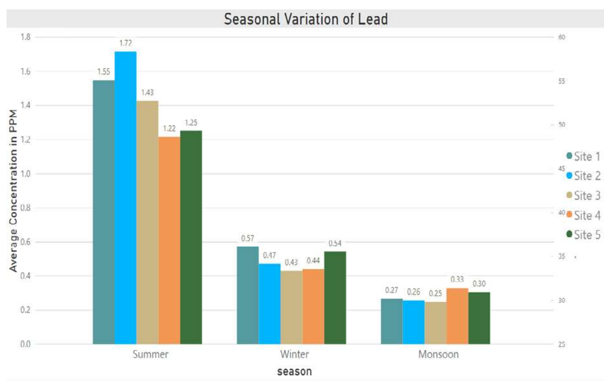

Figure 1. Sessional variation of lead in Yamuna river water samples

the river water during the summer season caused a major surge in the lead concentration. Table 1 shows comparisons of multiple seasons. Pairs of seasons indicate that the research was conducted during those periods.

Seasonal variations of chromium: The seasonal variations in the concentrations of chromium in the water samples from Yamuna river are shown in Figure 2. The results were not consistent with the permissible level recommended by the World Health Organization. The chromium concentration varied under different conditions, i.e., summer, monsoon, winter. The chromium concentration in the summer period was greater than those for the winter and rainy seasons. The order of the mean square values of lead contents was greater in the summer followed by the winter, monsoon and rainy seasons. The multiple comparisons of the means based on Tukey's test are shown in Table 2. The data indicated that sewage waters, anthropogenic activities and effluents were the major source of chromium contamination in the river water. The reduction in water volume due to evaporation during hot seasons led to an upsurge in the contents of chromium and other heavy metals in the river. Table 2 shows comparisons of multiple seasons. Pairs of seasons indicate that the research was conducted during those periods.

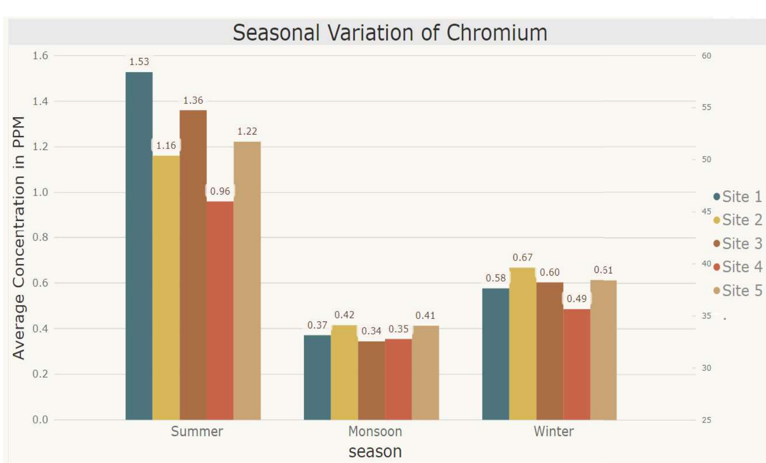

Figure 2. Sessional variation of chromium in Yamuna river water samples

Table 2. Tukey's test for chromium by multiple comparisons of the means in different seasons

Season	Difference	Lower	Upper	P
Summer-Monsoon	0.86755	0.642479182	1.0926208	0.0000000
Winter-Monsoon	0.20956	0.005648865	0.4247689	0.0578548
Winter-Summer	-0.65799	-0.855671965	-0.4603080	0.0000000

Discussion

The Seasonal variations in the concentrations of lead and chromium exceeded or were barely at the margin of the acceptable limits permissible by the World Health Organization in the river waters. Our study findings supported by the statistical analyses indicate that the lead and chromium concentrations the river water have exceeded the permissible limits. Human health is definitely and adversely affected by the ingestion of such contaminated water either directly or as residues in vegetables, fish, plants, fruits, and other food chains.

Heavy metals are commonly found in the water bodies & these are dangerous for both aquatic and human life. There are various studies related to heavy metal toxicity in previous literature reporting the levels of heavy metals in water bodies. The WHO had strictly suggested the permissible limit but most of water bodies are contaminated with waste waters released from the industries and nearby factories. Of note, the drinking water samples contained heavy metal concentrations, which were more than the admissible levels recommended by WHO. Toxicology studies have frequently detected heavy metal concentrations in various water bodies in India. The rise in the elemental pollution makes water and fish not suitable for consumption and may cause severe human health problems.

Conclusions

Based on the current study findings, most of the agricultural activities in Delhi areas occur near Yamuna river where the industrial wastes, sewage, natural sources and anthropogenic waste materials contaminate Yamuna river water with hazardous pollutants. Consequently, major diseases, such as kidney failure, slow growth, cancer and neurotoxicity are associated with the contaminated Yamuna river water in the surrounding areas. The Individuals residing near the river should be fully informed of the adverse effects of drinking the water and edibles irrigated with the river water. Our analyses clearly indicate that the drinking water samples in the Yamuna area contain heavy metals, such as lead and chromium with the levels being beyond the WHO permissible limits. Most of the examined water samples were too contaminated to be used for drinking, cooking or washing purposes.

Limitation of the study: At times, there may be occasional rises in the concentrations of heavy metals beyond the levels demonstrated by this study. This implies that the industrial discharges and effluents may increase suddenly, which adversely impacts the quality of the river water.

Recommendation for future studies: Considering the implication of the river water with the health of humans who rely on it, we recommend that future research be planned on the environmental toxicology of Yamuna river, using modern methods to assess its heavy metal contaminations.

Ethical Considerations

Compliance with ethical guidelines

There were no ethical considerations to be considered in this research.

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Author's contributions

Conceptualization and Methodology: Rajeev Kumar and Lalit Prasad; Data collection: Mahipal Singh Sankhla; Data analysis: Rajeev Kumar; All authors read and approved the final manuscript.

Conflict of interest

This research did not receive any grant from funding agencies in the public, commercial, or non-profit sectors.

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Scientific Correspondence

Estimation of Zinc Concentration in Yamuna River (Delhi) Water Due to Climatic Changes

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ABSTRACT :

Introduction: Water is increasingly becoming an unusual resource, both in the relation to quantity and quality. Yamuna river water may become contaminated by the accumulation of Zinc through emissions from the rapidly expanding industrial areas, disposal of high element wastes, fertilizers, animal manures, sewage sludge, pesticides, and wastewater irrigation.

Material and Methods: Samples of water were collected from the five different sampling sites. Samples collected in the duration of 8 months from January to August with the gap of 20-25 days keeping the climatic change as a major parameter. The concentration of Zinc (Zn) in water from River Yamuna, Delhi was determined by Inductively Coupled Plasma Mass Spectrometry (ICP-MS).

Result and Discussion: It was found that the concentration of zinc (Zn) is higher than the permissible limits of WHO and lower than permissible limits only in the month of August. This can be established that the concentration increases with rising temperature and reducing humidity.

Conclusions: It is universally-known that zinc is majorly toxic in nature and humans & animals. Exposure of zinc through water may produce chronic toxicity that could be quite harmful to human life.

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Key words: Key-Words: - Zinc, Yamuna River, Water, Toxicity, Human, etc.

INTRODUCTION :

Water is vital for human existence. There's no life without water. To survive man has to go to several extents to search for water. Water can be obtained from oceans, rain, streams, lakes, glacier, or underground[1]. Water is essential for life and life without it, as we know it would have not been possible. Though its precious it brings disease and disabilities to the public. Water already contains minerals and organisms that may cause harm to humans as well as animals because of their concentration and contents[2]. Rivers are a vital source for human civilizations as they meet water demand for rivers are important resources for human various uses apart from supporting flora and fauna, improving aesthetic and landscape quality, moderating climate and providing resources for hydropower [3].

The river Yamuna passes through a distance of about 1370 km in the basic from Saharanpur district of Uttar Pradesh to the flowing together with river Ganga at Prayagraj. The major streams of the river are Tons, Betwa, Chambal, Ken, and Sindh, and these altogether contribute 70.9% of the catchment area and sense of balance 29.1% is the direct drainage of main River and smaller streams. Based on the area, the catchment basin of Yamuna volumes to 40.2% of the Ganga Basin and 10.7% of the nation[4]. The Yamuna river is one of the most polluted rivers in India. The capital of the nation, Delhi is the major contributor to pollution in the Yamuna River, followed by Agra and Mathura [5].

Zinc is found in the physical background on earth's crust and can consequently enter water sources through natural procedures and the example of sometimes heavy rains and water can leach zinc out of natural sources [6]. Zinc insufficiently has been recognized by several experts as an important public health issue, especially in developing countries. The prevalence and clinical consequences of zinc deficiency on growth delay, diarrhea, pneumonia, disturbed neuropsychological performance, and abnormalities of fetal development[7].

Zinc has naturally originated either from geological and chemical variance or tailings site. Zinc indicates an anthropogenic source due to the sulfide minerals oxidation in mine waste disposal sites. Over the past year's environmental principles have developed more stringent, necessitating an enhanced better quality of removing toxic waste for treatment and zinc material to the defense of the environment, human health, and aquatic life[8]. The zinc (Zn) enters the environment through aquatic life systems and plants and animals surrounding the river[9]. Zinc is a very communal pollutant in the environment; its occurrence may be impeding the water's ecological environment. Consequently, much study effort has been directed toward the spreading of Zn in the water environment. Anthropogenic actions counting municipal wastewater releases, coal-burning power plants; industrial methods involving metals; and the atmospheric outcome are the main source of Zn contamination[10]. Extreme discharge of zinc contaminates the surface water and subsurface environment and contribute to groundwater pollution. Groundwater is often extremely polluted near mines of sulfide minerals[11].

In natural waters, zinc can be found in some chemical methods, such as hydrated ions, metal-inorganic complexes, or metal-organic complexes. Hydrated zinc cations may be hydrolyzed to form zinc hydroxide or zinc oxide. In anaerobic environments, Zinc sulfide may be formed [12].

The environmental contaminations by the toxic substances are increasing which is causing a major threat to the local users. A wide range of pollutants are endlessly introduced into the aquatic environment mainly due to enlarged industrialization, technological growth, increasing human populace and misuse of agricultural, natural resources, and domestic wastes run-off. Among these pollutants, heavy metals constitute one of the most unsafe groups because of their persistent toxicity, nature, and tendency to gather in organisms and undergo food chain amplification, and more still, they are non-degradable [13].

Polluted water of Yamuna River is a matter of concern as the population of Delhi is dependent on the water of Yamuna. The hazard of biomagnification and bioaccumulation of the Zn causes extreme harm to human health and welfare[14]. Citizens might experience during disease on drinking water with a high concentration of heavy metals. They might contain physiological effect as on kidney, digestive system, circulatory system, nervous system, etc. different additional organs and diverse systems of the body [15].

This research study noted that dissolved zinc concentration was more in the rise in environmental temperature and humidity. Zinc toxicity has established to be a major risk and there are several health threats related to humans and animals. The toxic effects of zinc, even though they do not have any organic role, persist current in approximately or the other form damaging for the people's body and its suitable working. Consequently, the present study aimed to measure the concentration of zinc from the Yamuna River climate changes to appreciate the change in dissolved zinc concentrations.

MATERIALS AND METHODS :

Samples Collection : The water samples were collected from the five different Sites of Yamuna River in Delhi, India.

Site 1: Okhala Bird Sanctuary

Site 2: Kalindi Kunj Ghat

Site 3: Okhala Barrage

Site 4: Yamuna Bridge

Site 5: Yamuna Bank

All sampling sites were used for farming and drinking purpose. Water samples were collected for analysis from each Site. All samples were collected in 1.5 liters of sterile polyethylene bottles, which were pre-washed with 10% nitric acid and de-ionized water. Before sampling, the bottles were rinsed at least three times with water from the sampling site. The bottles were immersed to about 20 cm below the water surface to prevent contamination of trace elements from the air also collected for analysis from each site.

All water samples were immediately brought to the laboratory where they filtered through Whatman No.41 (0.45 µm pore size) filter paper. The samples were acidified with 2 ml concentrated Nitric acid to prevent precipitation of Zinc, reduce adsorption of the analyses onto the walls of containers and to avoid microbial activity, then water samples were stored at 4°C until the analysis[16].

The concentration of Zinc (Zn) in water collected in every 20-25 days during four months from January to August 2019 from Yamuna river, Delhi were Zinc (Zn) measured and compared with the permissible limits as set by the World Health Organization (WHO).

Instrumentation

The concentrations of heavy metals were determined in all samples by Inductively Coupled Plasma Mass Spectrometry

(ICP-MS). It is a standard laboratory analytical tool for metal analysis.

RESULTS & DISCUSSION :

The concentration of Zinc in Water samples :

In the month of January, the concentration of zinc (Zn) in water samples was 5.4 ppm followed by a slight decrease in February concentration was 5.7 ppm whereas there was an increase in the March 6.0 and increases in the month of April 6.2 ppm and further it increases in the month of May, the concentration of zinc in water was 7.0 ppm and decrease in the month of June 5.3 ppm and July 5.0 ppm or month of august 4.5 ppm According to the WHO guidelines, the maximum permissible limit of zinc is 5.00ppm. We found that the concentration of zinc is very high as compared to the permissible limit, and almost 1.4 times higher than the WHO limit in the month of May and month of August concertation is lower than WHO Permissible Limit. There were significant differences between the concentration of WHO limit and Zn levels measured during these months. On comparison of the concentration of Zn among the different months, we found significant differences in concentration of Zn with temperature and humidity result shows that in the month of April or May can be established that the concentration increases with rising temperature and reducing humidity **(Figure 1)**

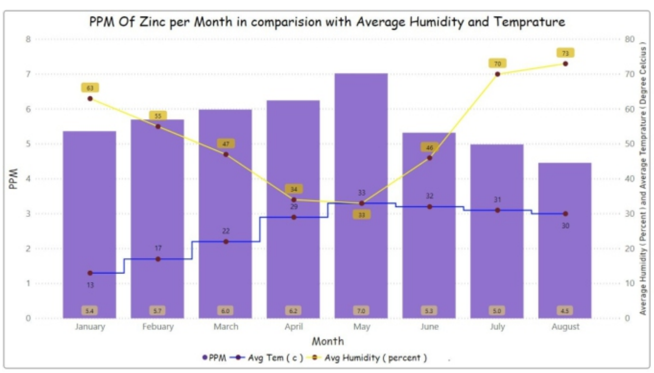

Figure 1: Climatic changes and Concertation of Zinc in water.

CONCLUSION :

The concentrations of zinc (Zn) have already crossed or are at the borderline of the permissible limit as declared by the World Health Organization in most river bodies. Although some previous data suggests that somewhere the elemental concentrations are still below the permissible limit. Human health is directly affected by the consumption of polluted water, sediment, fishes, fruits, vegetables, plants, etc. Studies show that Industrial wastes, Sewage, Natural source, anthropogenic source, and Agricultural actions that have contaminated dangerous and toxic constituents in the Yamuna River water thereby, led to pollution of drinking water in near areas. Diseases like Neurotoxicity, Carcinogenicity related to contamination of Zinc in water in such areas. The practice of trace element detection should be continued to lower the possible consumption of contaminated eatables. People should be aware of the hazardous effects of the consumption of polluted water and eatables. On account of the research of the drinking water samples, contain Heavy metal concentration more than the admissible and desirable levels (WHO). Most of the water samples were highly contaminated, which are not possible to use for drinking purposes.

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Original Article

Zinc Impurity in Drinking Water and Its Toxic Effect on Human Health

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ABSTRACT

The levels of zinc (Zn) pollution in several water sources as ground, river, tap, lake water etc. Zinc are possibly toxic and are moved to the nearby environment through different pathways. Among mining activity, waste dump contaminants one of the most hazardous groups for of their determined nature, tendency, toxicity, to collect in creatures and undertake food chain increase and more still, they are non-degradable. Zinc concentration are found in water are higher than the permissible limits of WHO, USEPA that gives an indication of hazardous risk to human health. This review study also reveals that zinc contamination through water and major health effects on human health.

Keywords: Heavy metals, Zinc, Environment, Water, Toxicity

INTRODUCTION

Water is a valuable and most frequently used resource. Zinc is one of the most abundant compounds on earth, and covers two thirds of the earth's surface [1]. Humans lack access to clean and pure safe water [2-3]. Zinc is a very communal pollutant in environment; its occurrence may be impends the water ecological environment. Consequently, much study effort has been directed toward the spreading of Zn in water environment. Anthropogenic actions counting municipal wastewater releases, coal-burning power plants; industrial methods involving metals; and atmospheric outcome are the main source of Zn contamination [4]. Extreme discharge of zinc contaminate the surface water and subsurface environment and contribute to groundwater pollution. Groundwater is often extremely polluted near mines of sulfide minerals [5]. Development is the growth of rational and financial trade that changes a people assembly from a rural culture into a current one. India began its manufacturing development after independence. The manufacturing strategy resolve of 1948 obvious the opening of the progress of manufacturing policy [6]. Mining Auctions, water bodies are most insistently polluted. The metals are taken as either dissolved species in water or as an essential part of on hold sediments. They may then be kept in bed residues or seep into the groundwater, mainly wells and springs; and the amount of pollution will be gritty by on the nearness of the well and spring to the mining site. As an outcome of these issues, metal absorption in the natural environment changes in space and time. In fact, during the last few decades, industrial and urban actions have contributed to the growth of metals pollution into semi-arid environment and have directly partial urban ecosystems producing toxic, mutagenic or carcinogenic effects to the human health dependent on the elements properties. The probable effect of these elements may be showed by risk assessment [7]. The main sources of anthropogenic action zinc are found in the environment from metal smelters and mining actions [8]. In natural waters, zinc can be found in some chemical methods, such as hydrated ions, metal-inorganic complexes, or metal-organic complexes. Hydrated zinc cations may be hydrolyzed to form zinc hydroxide or zinc oxide. In anaerobic environments, Zinc sulfide may be formed [9].

Major sources of Water Contamination

Sewage and wastewater

Regular local households and outdated rural practices produce wastewater proficient of contaminating rivers tributaries and lakes. In the lack of fresh water and hygienic situations, efficient elimination of sewage is non-existing, and encourages water-borne ailments [10].

INDUSTRIAL WASTE

Industrial wastes are the main sources which pollute water. Presenting extremely toxic contaminants affecting humans and the environment [11]. The industrial use of freshwater in manufacturing and treating and through the contaminated water into lakes, rivers and groundwater [12].

MINING ACTIVITIES

Zinc is found in physical background on earth's crust and can consequently enter water sources through natural procedures and the example of sometimes heavy rains and water can leach zinc out of natural sources [13]. The methods are improved when this physical condition of earth is troubled by financial actions such as mining. These procedures of description the mined-out range to water and air, and can lead to significances such as acid mine drainage. Low pH situations related with acid mine drainage mobilize heavy metals, containing radio nuclides where these are present in the mines [14].

Zinc Toxic Effect on Human Health

Gastrointestinal Effects

Various research have recommended that zinc inhalation and drinking polluted water may origin signs of gastrointestinal diseases or modifications in gastrointestinal soft tissue. One example of A person who consumed around 3 grains of a zinc chloride defined critical signs that happened nearly instantly after interaction with the complex, containing scorching, mouth and esophagus was vomiting and paining [15].

Immunological and Lymph reticular Effects

Zinc play a major part the regular growth and preservation of the immune structure, such as in the lymphocyte reaction to mitogens and as a cofactor for the thymic hormone thymulin [16-17]. Metal smoke infection is assumed to be a resistant reaction to zinc oxide. A connection among the amount of floating zinc and quantity of all forms of T cells in the Broncho alveolar lavage liquid of people, probably associated to the start of metallic smoke infection, was seen in a critical period breathing study [18]. Decreased resistant reaction in people has been informed in a middle period oral study[19].

Cardiovascular Effects

Reported signs in humans showing excessive concentration of zinc containing premature atrial strokes, hypertension subordinate to intravascular volume, hypovolemic shock wave (pulse over 120 beats per minute) and hypertension [20].

Carcinogenic Effect

The molecular mechanisms damages of zinc. DNA damage considered to defend against effects genetic constancy and purpose, improves the vulnerability to DNA-damaging agents and furthermore moves cellular differentiation, proliferation and apoptosis. This has led people to hazard that zinc deficiency is a probable risk factor for cancer [20].

Neurotoxicity

High level of Consumption zinc have caused in tiredness, dizziness, shocking, trouble in writing properly, anxiety, sadness, somnolence and dragging [20]. Confounding gait and illusions were informed in a specific who purposely breathe in metallic paint vaporizers [21]. The instantaneous contact to copper and hydrocarbons. Common Signs of neurological toxicity (dizziness, pain, headache and tiredness) have been described by human's subsequent critical oral intake to zinc [22, 23]. Actual Restricted Information Recommend that overdoses oral intake of zinc can result in light neuron collapse and change of emission of the hypothalamus in rats [24, 25]. Further researches by all tracks of contact would be beneficial to decide if zinc contact to complexes would result in neurological toxicity [26].

Toxicokinetics

There is partial data on the toxic kinetic of zinc subsequent breathing or skin exposure. Level of zinc increases in urine or blood of people and the soft muscle of animals later drink contaminated water, breathing and skin contact to zinc, individually, show that zinc is engrossed by these paths. The zinc consume been broadly ingested toxicokinetic properties. The involvement of zinc after the abdominal area is homeo statically controlled; below regular physical situations, 20–30% of consumed zinc is absorbed. After the Zinc taken abdominal includes submissive dispersion and a carrier facilitated procedure. A amount of features impact the involvement of zinc contain soluble in the zinc complex as Interception such as phosphorus, calcium and nutritional phytates or fiber and accompaniments, such as picolinic acid, amino acids and prostaglandin E2. Absorption of the zinc is broadly dispersed all over the body. Zinc contented is leading in muscular, bones, abdominal tract, lung, brain, pancreas, kidney, and skin and cardiovascular. In plasma, two-thirds of the zinc is certain to albumin which signifies the metabolic activity group of zinc. This group of plasma zinc is generally declared to as lightly certain zinc since albumin has the capability to provide to certain zinc to muscles [26].

DISCUSSION

The water is the main route and source to intake the zinc directly. If they found zinc in excessive amount of the permissible levels according to procedures of drinking water given by WHO, USEPA. Several deaths due to high concentration of zinc toxicity to human. There is a need of solid waste management in major human settlements so that dangerous chemicals are not pollute the water bodies. The type of contamination is dependent on different type of usage of water and other activities like Industrial, Agricultural and sewage. Several types of biological, organic, and inorganic contamination have major effects on water quality. Many cost-effectiveness are the important factors that play major roles in the assortment of the most appropriate treatment system for wastewater.

CONCLUSION

Zinc has naturally originated either from geological and chemical variance or tailings site. Zinc indicate an anthropogenic source due to the sulfide minerals oxidation in mine waste disposal site. Over the past year's environmental principles have developed more stringent, necessitating an enhanced better quality of removing toxic waste for treatment and zinc material to defense of the environment, human health and aquatic life. Optional that, mining wastes must be treated before discarding them to the land and natural water resources. This will protect human health along with the environment.

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Objectives

To look for a challenging and interesting career at an association that encourages learning and provides exposure to new advanced techniques to achieve professional and personal growth along with the organization.

Research Outline

- Patent Grant: 3
- Indian Copyright: **2**
- h-Index: **19**
- i10 Index: **36**
- Total No. of Citations: **1510**
- Book Edited: **6**
- Book Accepted:**5**
- Number of Published Papers: **134**
- No of Published Chapters: **24**
- Submitted Chapters & Papers: **20**
- Accepted Papers: **16**

Education

- **Ph.D. Forensic Science |** Galgotias University | 2017 to till date | 1st Division, 8.67 CGPA
- **M.Sc. Forensic Science |** Galgotias University | 2015 – 2017 | 1ST Division, 7.33 CGPA
- **B.Sc. (Hons.) Forensic Science |** Galgotias University | 2012 – 2015 | 1st Division, 7.04 CGPA
- **Diploma in Photography** |MDVTI, New Delhi| 2021-2022 | 1st Division, 86.66%

Key Skills & Capabilities

- Ambitious
- Leadership qualities
- Enthusiastic
- Hard working

IT Course

"Rajasthan State Certificate Course in Information Technology" (RS-CIT), VMOU, Kota.

Research Projects

- Dissertation Thesis Entitled "**Accumulation of Heavy Metals in Ayad River at Udaipur, Rajasthan and their Toxic Effects on Human Health**".
- A Minor Project (Term Paper) on "**Touch DNA: A New Tool for Investigation in Forensic Science**"

Work Experience

- **04/07/2023 to till date** Working as a **Mentor** in Atal Innovation Mission, **Niti Ayog**, **Government of India**.
- **13/03/2023 to till Date** Working as an **Assistant Professor** in Department of Forensic Science & University Center for Research and Development, **Chandigarh University,** Mohali, Punjab.
- **16/06/2021 To 10/03/2023** Working as an **Assistant Professor** in Department of Forensic Science, Faculty of Basic and Applied Sciences, **Vivekananda Global University**, Jaipur, Rajasthan.

- **15/01/2021 TO 12/06/2021** Working as an **Assistant Professor** in Department of Forensic Science, Institute of Sciences, **SAGE University**, Indore, M.P.

Member of Board of Study

- **BOS Member** of B.Sc. Department of Forensic Science, **Centurion University**, Visakhapatnam, Andhra Pradesh 2022 to till date.
- **BOS Member** in Diploma of Photography, **Vivekananda Global University**, Jaipur, Rajasthan 2021 to 2022.

External Examiner

- Independent External Examiner in The **University of the West Indies**, Mona, Jamaica, West Indies.
- External Examiner in the Department of Forensic Science, **Parul Universit**y, Vadodara, Gujrat.
- External Examiner in the Department of Forensic Science, **Medi-Caps University**, Indore, M.P.
- External Examiner in the Department of Forensic Science, **Satrex Universit**y, Gurugram, Haryana.
- Question Paper Setter in the Department of Forensic Science, **Medi-Caps University**, Indore, M.P.

Training/Internship

- 7 Days Short Term Training Program (STTP) in "**Impact & Panacea of Environmental Pollution: The Past, Present and Future**", Raj Rishi Govt., Autonomous College, Alwar, 2022.
- **7** Days Short Term Training Program (STTP) in **"Design of Soft Computing Based Machine Learning Models",** Sponsored by AICTC in the Panipat Institute of Engineering and Technology, Samalkha, Panipat, 2021.
- 2 Month Training in **"Central Forensic Science Laboratory, Central Bureau of Investigation (CFSL, CBI)"** In the Division of **Ballistics & Explosive**, 2018.
- 4 Month Training in "**Rajasthan State Mines & Minerals Limited.**" in the "**Analytical Laboratory & Instrumentation**", 2017.
- 2 Month Internship in "**Legal Desire Media and Publications"** as "**Research Intern for Dept. Of Forensic Sciences"**, 2017.
- 1 Month Training in "**Sate Forensic Science Laboratory U.P. Lucknow**" In the Division of D.N.A.**, Toxicology, Forensic Chemistry, Question Document, Ballistics, & Medico Legal,** 2016.

- 15 Days Training in "**Rajasthan State Mines & Minerals Limited.**" in the "**Analytical Laboratory & Instrumentation**", 2016.
- 21 Days Training in **Criminal and Civil Documents Verification & Evidence Related to Forensic Prospective,** District Court Agra, 2016.
- 2 Month Training in "**Codon Institute of Biotechnology**" in the **Forensic Science & Instrumentation,** 2014.
- Attended **Post-Mortem (Autopsy)** Training Session at **AIIMS, Delhi**, 18th November 2016.
- Attended **Post-Mortem (Autopsy)** Training Session at **KGMU Hospital, Lucknow,** 28th June 2016.
- Attended **Post-Mortem (Autopsy)** Training Session at **AIIMS, Delhi**, 24th April 2015.

Laboratory Experience

- Development of Fingerprints by Nanoparticle.
- Extraction and isolation of Heavy Metals, Insecticides, Pesticides, Volatile, Drugs and Vegetable Poison from Biological Matter.
- Green Synthesis Nanoparticle for Wastewater Treatment.

Patent

- **"Banana Peel Biochar for The Development and Visualization of Latent Frictions Ridges"**, Application No: 202022104027, German Patent, Grant on 28 September, 2022.
- **"Pharmaceutical Waste Treatment Device"** Application No: 388131-001 Indian Patents, Design and Trademark.
- **"Smart Plastic Waste Management Device"** Application No: 388132-001, Indian Patents, Design and Trademark.

Copyright Publication

- Indian Copyright entitle **"Sugarcane Bagasse Nano-Biochar for The Development of Latent Fingerprint",** ROC Number: L-115542/2022, 17 May 2022.
- Indian Copyright entitle **"Green Nanotechnology Advancement in Phytoformulation Research"** ROC Number: L-123815/2023, 6 June 2023.

Edited Books/Special Issues

1. Edited Book: **"Guide to Forensic & Indian Law Investigating Crime in 21st Century"** Published by Legal Desire Publications, *2021*, *1st Edition (ISBN:978-0-578-89799-8).*
2. Edited Book: **"Environmental Toxicology: Pollutants and Health Impacts",** Published by Shiv Shakti Book Traders, India, 2022, *1st Edition (ISBN:978-9-383-80516-7).*
3. Edited Book: **"Arsenic Toxicity: Effect on Human",** Published by Shiv Shakti Book Traders, India, 2022, *1st Edition (ISBN: 978-9-383-80517-4).*
4. Edited Book: **"Emerging Trends in Forensic Science",** Published by Shiv Shakti Book Traders, India, 2022, *1st Edition (ISBN: 978-9-383-80520-4).*
5. Edited Book: **"Arsenic in Rice: A Global Menace"** Published by Apple Academic Press, CRC Press, Tylor and Francis Group, 2023, *1st Edition* (*ISBN:* 978-1-774-91466-3).
6. Edited Book: **"Friction Ridge Analysis: A Guide to Application of Nanoparticles for Development of Latent Fingerprints"** under series of Materials Horizons: From Nature to Nanomaterials Published by Springer Nature 2023, *1st Edition* (*ISBN:* 978-981-99-4030-1)
7. Edited Book: **"Artificial Intelligence in Forensics- An Emerging Tech to Criminal Investigation System"**, Published by CRC Press, Tylor and Francis Group. (*ISBN:* 978-103-22-6337-3).
8. Edited Book: **"Nanoparticles in Fingerprinting: Advanced Method for Development of Latent Fingerprints"** Published by Apple Academic Press, Tylor and Francis Group.
9. Edited Book: **"Bioremediation of Environmental Toxicants: Toxicants, Sources, Mechanism, Impact on Human health & Bioremediation approaches"** Published by CRC Press.
10. Edited Book: **"Forensic Science in Ancient India"**, Published by Apple Academic Press, CRC Press, Tylor and Francis Group.
11. Edited Book: **"Forensic Entomology: Unveiling the Secrets of the Silent Witnesses"**, Published by Apple Academic Press, CRC Press, Tylor and Francis Group.
12. **Guest Editor** of Special Issue in **Materials Today proceedings** for National Conference on Environmental Toxicology: Impact on Human Health, EnvTox-2021 **(Elsevier), 2022.**
13. **Guest Editor** of Special issue in International journal of **Environmental and Pollution Research** for National Conference on Environmental Toxicology: Impact on Human Health **(Springer), 2022.**
14. **Guest Editor** of Conference Proceedings of the Environmental Toxicology: Impact on Human Health (Environ Tox 2021) in **Proceedings International, 2022.**
15. **Guest Editor** of Special issue in International journal of **Environmental and Pollution Research** for National Conference on Environmental Toxicology: Impact on Human Health **(Springer), 2023.**

16. **Guest Editor** of Special Issue in **Materials Today proceedings** for National Conference on Environmental Toxicology: Impact on Human Health, **(Elsevier), 2023.**
17. **Guest Editor** of Special Issue in **Forensic Science International: Animal and Environment** for National Conference on Environmental Toxicology: Impact on Human Health, **(Elsevier), 2023.**

Book Chapters

1. Book Chapter: **"Child Pornography: The Filth of Society"**, *In* Book "Advancements in Cybercrime Investigation and Digital Forensics", Published by Apple Academic Press, Inc. Co-published with CRC Press (Taylor & Francis), April 2023. (ISBN: 978-1-774-91303-1).
2. Book Chapter: **"Carbon Nanostructures for Fighting Antimicrobial Resistant Bacteria"**, *In* Book "Nano-Strategies for Addressing Antimicrobial Resistance", Published by Springer Nature, December 2022, (ISBN: 978-3-031-10220-2). https://doi.org/10.1007/978-3-031-10220-2_11
3. Book Chapter: **"Nanobiosensors and Industrial Wastewater Treatments"**, *In* Book Nanobiosensors for Environmental Monitoring, Published by Springer Nature, November 2022, (ISBN: 978-3-031-16106-3). https://doi.org/10.1007/978-3-031-16106-3_17
4. Book Chapter: **"Collection of Botanical Evidence"**, *In* Book Manual of Crime Scene Investigation, Published by *CRC Press*, August 2022. (ISBN: 9781003129554). https://doi.org/10.4324/9781003129554-7
5. Book Chapter: **"Advancement of Deep Learning and Blockchain Technology in Health Informatics"** *In* Book "Digitization of Healthcare Data Using Blockchain", Published by *Scrivener Publishing Llc, Willey* July 2022. (ISBN: 978-1-119-79185-0). https://doi.org/10.1002/9781119792734.ch11
6. Book Chapter: **"Convergence of IoT and Blockchain in Healthcare"** *In* Book "Digitization of Healthcare Data Using Blockchain", Published by *Scrivener Publishing Llc.*, *Willey*, July 2022. (ISBN: 978-1-119-79185-0). https://doi.org/10.1002/9781119792734.ch8
7. Book Chapter: **"Heavy Metal Contamination of Water and Their Toxic Effect on Living Organisms"**, *in* book "The Toxicity of Environmental Pollutants", Published by *IntechOpen*, June 2022. (ISBN: 978-1-80355-580-5). DOI: 10.5772/intechopen.105075
8. Book Chapter: "**Carbon Based Nanomaterials Nanobiosensors Detecting Environmental Pollution**" *in* book " Nanotechnology for Environmental Pollution Decontamination: Tools, Methods, and Approaches for Detection and Remediation", published by Apple Academic Press (AAP), CRC-Press Taylor & Francis. June 2022. (ISBN: 978-1-00327-956-3).
9. Book Chapter: **"Microbes as biocontrol agent: From Crop Protection till Food Security"** *in* book Relationship Between Microbes and the Environment for Sustainable Ecosystem Services, Volume 1, published by *Elsevier*, May, 2022. https://doi.org/10.1016/B978-0-323-89938-3.00011-6

10. Book Chapter: **“Global status of bacterial fish diseases in relation to aquatic pollution”** *in* book “Bacterial Fish Diseases”, published by *Elsevier*, April, 2022. https://doi.org/10.1016/B978-0-323-85624-9.00017-8

11. Book Chapter: **“Artificial intelligence on edge devices”** *in* book “Advances in Computers”, Published by *Elsevier*, April, 2022. https://doi.org/10.1016/bs.adcom.2022.02.013

12. Book Chapter: “**The Future of Edge Computing”,** *in* book “Advances in Computers”, Published by *Elsevier* March 2022. https://doi.org/10.1016/bs.adcom.2022.02.009

13. Book Chapter: **“Heavy Metal Contamination in Vegetables and Their Toxic Effects on Human Health”**, *in* book Heavy Metals, Published by *IntechOpen*, March 2022. (ISBN: 978-1-80355-697-0). DOI:10.5772/intechopen.102651

14. Book Chapter: **“Chemistry and Material Studies in Fermented Dairy Products”** *in* book “Advances in Dairy Microbial Products” Published by *Elsevier*, January 2022. DOI: 10.1016/B978-0-323-85793-2.00017-5

15. Book Chapter**:** “**Climate change and soil dynamics: Effects on Soil Microbes and Fertility of Soil”** *in* book "Microbiome Under Changing Climate: Implications and Solutions" Published by *Elsevier*, January 2022. (ISBN: 978-032-39-0932-7) DOI: 10.1016/B978-0-323-90571-8.00020-1

16. Book Chapter: ***“*Heavy Metal Contamination of Food Crops: Transportation via Food Chain, Human Consumption, Toxicity and Management Strategies*”*** *in* book Heavy Metals - New Insights Published by *IntechOpen*, January 2022. (ISBN: 978-1-80355-526-3) DOI: 10.5772/intechopen.101938

17. Book Chapter: **“Artificial Intelligence in Life Sciences”** *in* book New Horizons in Life Science published by *Vital Biotech Publication*, January 2022, India, *(ISBN No: 978-93-92953-00-2).*

18. Book Chapter: **“Cyber Bullying”** For Book entitles **Combating the Exploitation of Children in Cyberspace**, Published by *IGI Global Publisher*, 2021, (ISBN: 9781799823605) DOI: 10.4018/978-1-7998-2360-5.CH001.

19. Book Chapter: **“Blockchain IoT Concepts For Smart Grids, Smart Homes, and Smart Cities”** *For Book* Entitles Blockchain And IoT Integration: Approaches And Applications Published By CRC-Press Taylor & Francis, 2021 *(ISBN: 9781003094210)* Doi:10.1201/9781003094210-7

20. Book Chapter: **“Blockchain for IoT Edge Devices and Data Security”** *In* Book “Handbook Of Green Computing And Blockchain Technologies”, Published By CRC-Press Taylor & Francis, 2021 *(ISBN: 9781003107507)* DOI: 10.1201/9781003107507-11

21. Book Chapter: "**New And Advanced Technologies In Aquaculture To Support Environmentally Sustainable Development**" *In* Book "Microbial Biotechnology Basic Research And Applications" Published By Springer Nature, 2020, (ISBN: 978-981-15-2817-0), https://Doi.Org/10.1007/978-981-15-2817-0_11

22. Book Chapter: **Scenario XXI Adult Fracture** for book entitles **"Practical Workbook on Trauma & Toxicology"** Published by Red Flowers Publications, New Delhi. *1st Edition, July 2019. (ISBN: 978-81-930735-6-8).*

23. Book Chapter: **Drug Schedules in Drug & Cosmetics Act** for book entitles **"Critical Care Nursing in Emergency Toxicology"** Published by Red Flowers Publications, New Delhi. *1st Edition, July 2019. (ISBN: 978-81-942550-2-4).*

24. Accepted Book Chapter: **"Phytometalloproteins and Restoration of Freshwater Ecosystems"** *in* book Biomarker Phyto-metalloproteins: A Dynamic Approach for Remediation of Contamination, published by Springer Nature.

25. Accepted Book Chapter: "**Phytochelatins and Metallothioneins: Role in Heavy Metal Detoxification"** *in* book "Biomarker Phyto-metalloproteins: A Dynamic Approach for Remediation of Contamination", published by Springer Nature.

26. Accepted Book Chapter**: "Water Nano-phytoremediation"** *in* book "Nano-phytoremediation and Environmental Pollution: Strategies and Mechanisms", Published by CRC-Press Taylor & Francis.

27. Accepted Book Chapter**: "Green- synthesis of nanomaterials for environmental remediation"** *in* book "Nano-phytoremediation and Environmental Pollution: Strategies and Mechanisms", Published by CRC-Press Taylor & Francis.

28. Accepted Book Chapter**: "Forensic Entomology: Progress and implications"** in book "Insect Diversity and Ecosystem Services" Published by **Apple Academic Press (AAP)**, CRC-Press Taylor & Francis.

Editorial

- **Editorial** – "**Environmental Toxicology: Impact On Human Health"** (Environ Tox 2021) 25th-26th November 2021, Jaipur, Rajasthan, India. Volume 6, 2021, pp 1-2. https://doi.org/10.33263/proceedings36.001
- **Editorial – "The Toxicity of Everyday Life: Understanding The Environmental Risks to Human Health"**, Environmental Science and Pollution Research (ESPR), Springer Nature, 5 May 2023, pp 1-3. https://doi.org/10.1007/s11356-023-27378-3

Research Publications

1. **<u>Mahipal Singh Sankhla</u>**, Anubhav Singh, Varad Nagar, Vinay Aseri, Ashrut Singhal, Rushikesh L Chopade, Apoorva Singh, Priyanka Kacker. **"Depression Analysis of Youth Its Relation with Future Suicidal Ideation for Forensic Consideration of Delhi NCR Region Population",** International Journal of Medical Toxicology and Legal Medicine 25(1-2):191-195, 2022.
2. **<u>Mahipal Singh Sankhla</u>**, Rajeev Kumar, Lalit Prasad, **"Impact of Variation in Climatic Changes in Concentration of Lead & Nickel in Yamuna River Water, Delhi, India"**, Materials Today: Proceedings, Elsevier, 2022.
3. **<u>Mahipal Singh Sankhla</u>**, Rajeev Kumar, Lalit Prasad, **"Seasonal Variation of Nickel and Zinc Concentration in Water of Yamuna River, Delhi, India"**, Punjab journal of Forensic Medicine and Toxicology. Volume 21, Issue 2, PP 254-257. 2022.
4. **<u>Mahipal Singh Sankhla,</u>** Kapil Parihar, Rajeev Kumar, Devidas S. Bhagat, Swaroop S Sonone, Gaurav Kumar Singh, Varad Nagar, Garima Awasthi, Chandra Shekhar Yadav **"Ecofriendly Approach for Steroids, Terpenes, and Alkaloids-based Biosurfactant"** Biointerface Research in Applied Chemistry Journal, Volume 13, Issue 2, 2022, pp 1-23.
5. **<u>Mahipal Singh Sankhla</u>**, Rajeev Kumar, Lalit Prasad, "**Estimation of Zinc Concentration in Yamuna River (Delhi) Water Due to Climatic Changes**", Punjab journal of Forensic Medicine and Toxicology. Volume 21, Issue 1, PP 254-257. 2021.
6. **<u>Mahipal Singh Sankhla</u>**, Rajeev Kumar, Lalit Prasad, "**Seasonal Variations of Lead and Chromium Concentrations in the Water Samples from Yamuna River in Delhi, India",** Iranian Journal of Toxicology, Volume 15, Issue 2, PP109-114.
7. **<u>Mahipal Singh Sankhla</u>**, Rajeev Kumar, Lalit Prasad, "**Variation of Chromium Concentration in Yamuna River (Delhi) Water due to Change in Temperature and Humidity"**, Journal of Seybold Report, Volume 15, Issue 9, 2020, PP 293-299.
8. **<u>Mahipal Singh Sankhla</u>**, Rajeev Kumar, Amitabh Biswas, **"Dynamic Nature of Heavy Metal Toxicity in Water and Sediments of Ayad River with Climatic Change",** International Journal of Hydrology, Volume 3 Issue 5 , 2019.
9. **<u>Mahipal Singh Sankhla</u>**, Rajeev Kumar, **"Crime Investigating Technique to Development of Invisible Fingerprints on Surfaces using Rock Phosphate Powder",** International Journal of Forensic Sciences, Volume 2, Issue 3, May 2018.

10. **Mahipal Singh Sankhla**, Ramesh Kumar Pandey, Kapil Parihar, Rajeev Kumar, **"Marble Slurry Powder are Using Visualization on Latent Fingerprints on Different Surfaces",** Journal of Forensic Sciences & Criminal Investigation (JFSCI), Volume 9, Issue 3, June 2018.
11. **Mahipal Singh Sankhla**, Kapil Parihar, Jyoti Daksh, Rajeev Kumar, Prashant Agrawal, Lokesh Vaishnav, "**Indian Juvenile Depression and Future Criminal Behavioral Forensic Analysis of Udaipur District Population",** IOSR Journal of Humanities and Social Science (IOSR-JHSS) Volume 23, Issue 5, Ver. 5 (May. 2018) PP 82-89.
12. **Mahipal Singh Sankhla**, Mayuri Kumari, Manisha Nandan, Shriyash Mohril, Gaurav Pratap Singh, Bhaskar Chaturvedi, Dr. Rajeev Kumar, **"Effect of Electronic waste on Environmental & Human health- A Review"**, IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT), Volume 10, Issue 9 Ver. I (Sep. 2016), PP 98-104.
13. **Mahipal Singh Sankhla,** Mayuri Kumari, Manisha Nandan, Rajeev Kumar, Prashant Agrawal, "**Heavy Metal Contamination in Soil and their Toxic Effect on Human Health: A Review Study"**, International Journal of All Research Education and Scientific Methods (IJARESM) ISSN: 2455-6211, Volume 4, Issue 10, October- 2016.
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119. Supriya Kumari, Surbhi Kumari, Apoorva Singh, Pritam P. Pandit, **Mahipal Singh Sankhla,** Tanvi Singh, Gajendra Pal Singh, Payal Lodha, Garima Awasthi, Kumuad Kant Awasthi. **"Employing Algal Biomass for Fabrication of Biofuels Subsequent to Phytoremediation"**, International Journal of Phytoremediation 24(12):1-15, 2022.

120. Sanskruti C. Raje, Devidas S. Bhagat, Ranjitsingh K. Nimbalkar, Sampada K. Shejul, Gurvinder Singh Bumbrah, **Mahipal Singh Sankhla** **"Contributions and Current Trends of Forensic Botany in Crime Scene Investigation",** Forensic Science Journal, 21(1):1-12.

121. Vanishree C. Raveendran, Vanisha Godara, Dion Mistry, Mahipal Singh Sankhla, Kumud K. Awasthi, Gajendra P. Singh, Payal Lodha, Garima Awasthi, **"Nano-Pesticides: Composition, Bioavailability and Release Mechanism in The Environment"**, International Journal of Plant and Environment 8(2):116-121.

122. Rushikesh L. Chopade, Pritam P. Pandit, Varad Nagar, Vinay Aseri, Badal Mavry, Anuj Sharma, Apoorva Singh, Rohit Kumar Verma, Garima Awasthi, Kumud Kant Awasthi, **Mahipal Singh Sankhla** **"Carbon Nanotube-Based Nano-Biosensors for Detecting Heavy Metals in The Aquatic Environment",** Environmental Science and Pollution Research, Springer Nature, 2022.

123. Apoorva Singh, Varad Nagar, Badal Mavry, Abhishek Rai,Vikas Kanoujia, Priyanshu Prajapat, Kumud Kant Awasthi, **Mahipal Singh Sankhla**, "**Identification of Adulteration in Hand Sanitizers of Jaipur City Using Raman Spectroscopy"**, International Journal of Medical Toxicology and Legal Medicine 25(3-4):206-209.

124. Supriya Kumari, Surbhi Kumari, Pritam P Pandit, Leena Bhardwaj, **Mahipal Singh Sankhla**, Anil Sharma, Ravindra Chauhan, **"Optical Modality of Ink Examination Using Different Ink Through VSC 8000"**, International Journal of Medical Toxicology and Legal Medicine 25(3-4):253-258.

125. Leena Bhardwaj, Supriya Kumari, Vijay Kumar, **Mahipal Singh Sankhla**, Shribhagwan, Ravindra Chauhan, Anil Kumar, **"Utility of Human Hair as Biological Evidence in Drug Abusers for Solving Legal Issues"**, International Journal of Medical Toxicology and Legal Medicine 25(3-4):239-243.

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127. Vanisha Godara, Sneha Lohar, Poonam Kumari, Ashrut Singhal, Priyanshu Prajapati, Vinay Aseri, Badal Mavry, Varad Nagar, Monika Kumari Prajapati, **Mahipal Singh Sankhla**, **"Depression Analysis due to Impact of Working from Home during COVID-19 Pandemic"**, International Journal of Medical Toxicology and Legal Medicine 25(3-4):248-252.

128. Vanisha Godara, Vinay Aseri, Sneha Lohar, Poonam Kumari, Badal Mavry, Varadnagar, Ashrut Singhal, Apoorva Singh, Kumud Kant Awasthi, **Mahipal Singh Sankhla,** **"Comparative Study of Rose and Hibiscus Petals Powders in Latent Friction Ridge Analysis",** Problems Of Forensic Sciences 2022, Vol. 130, 131, 145–155.

129. Rohit Kumar Verma, Varad Nagar, Anuj Sharma, Badal Mavry, Poonam Kumari, Sneha Lohar, Ashrut Singhal, Monika Kumari Prajapati, Apoorva Singh, Kumud KantAwasthi, **Mahipal Singh Sankhla** **"Green**

Synthesized Nanoparticles Targeting Antimicrobial Activities", Biointerface Research in Applied Chemistry, 13, (5),469. 2023.

130. Apoorva Singh**,** Varad Nagar, Badal Mavr, S.S. Daga, Chandra Shekhar Yadav, Kumud Kant Awasthi, **Mahipal Singh Sankhla, "Reviving destroyed latent fingerprints: Assessing the efficacy of neem nano-biochar against common household liquid agents",** Materials Today Proceedings, Elsevier, 2023, (In Press).

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132. Divyansh Jain, Rohit Kumar Verma, Vaibhav Sharma, Anureet Kaur, Abhishek R. Rai, Poonam Kumari, Varad Nagar, **Mahipal Singh Sankhla**, Kapil Parihar **"Associations between high levels pesticide and adverse reproductive outcomes in females: A comprehensive review",** Materials Today Proceedings, Elsevier, 2023, (In Press).

133. Abhishek R. Rai, Vaibhav Sharma, Divyansh Jain, Anureet Kaur, Varad Nagar, Pritam P. Pandit, Snehalata U. Shenoy, Rohit Kumar Verma, Kumud Kant Awasthi, **Mahipal Singh Sankhla "Qualitative and Quantitative Analysis of Fresh Water Protozoa from Godavari River",** Materials Today Proceedings, Elsevier, 2023, (In Press).

134. Vaibhav Sharma, Divyansh Jain, Abhishek R. Rai, Poonam Kumari, Varad Nagar, Anureet Kaur, Anubhav Singh, Rohit Kumar Verma, Harsh Pandey, **Mahipal Singh Sankhla "Toxicological assessment and concentration analysis of Bisphenol A in food grade plastics: A systematic review",** Materials Today Proceedings, Elsevier, 2023, (In Press).

Research/Review Papers Accepted

- Accepted Research Paper **"Development Latent Fingerprint on Porous and Non-Porous Surfaces Using Water-Chestnut; (Singhara) Flour"**, NCRB Journal.
- Accepted Review Paper **"Psychological Influences of Cyber Crimes on Human Mind and Behaviour",** Indian Police Journal, BPR&D.

Invited Speaker/ Session Chair

- **Guest Lecture** on "**Research and Innovation in Forensic Science Current Development and Future Directions"** held on 06 April 2023, Organized by Department of Forensic Science, Kalasalingam Academy of Research & Education, Tamil Nadu.
- **Speaker** in **"2nd International Forensic Forum 2022"**, held on 21-23 November 2022, Organized by School of Allied Health Sciences, Sharda University, Greater Noida.
- **Session Chair** in **"2nd international multidisciplinary conference on "law and forensic science: a global challenge"**, held on 17-19 May, 2022, Organized by Bio Forensics Research Center, Rome Italy in Collaboration with School of Law, Manipal University Jaipur.
- **Guest Lecture** on "**Juvenile Delinquency**", held on 09th November 2021, Organized by Amity University, Noida.
- **Speaker** in short term course on **"3 Days Short Term Awareness Course on Cyber Crimes"**, held on 19th September 2021, Organized by World Cyber Security Forum, India.
- **Speaker** in Webinar on **"Toxic Effect of Adulterated Alcohol on Human Health"**, held on 18th June 2021, Organized by Department of Forensic Science, Tirthankara Mahaveer University, Moradabad.
- **Speaker** in Expert Talk on **Advance Method of Development of latent Fingerprint",** held on 4th June 2021, Organized by Forensic Intelligence Bureau (FIB), India.
- **Speaker** in Online Training-Cum Certificate Programme on entitle **"DNA Fingerprinting Analysis",** held on 30th May 2021, Organized by Narayana Institute of Advance Sciences (NIAS) under the aegis of International Society of Life Sciences (ISLS), India.
- **Speaker** in Webinar on **"Editing and Write ups: Trending Filed in Forensic Science"**, held on 15th May 2021, Organized by Center for Forensic & Clinical Psychology, India.
- **Speaker** in **"International Webinar on Forensic Toxicology"**, held on 12th June 2020, Organized by European Society of Forensic Sciences, Europe.
- **Speaker** in **"National Webinar on Emerging Trends in Forensic Science Sector"**, held on 12th June,2020 Organized by Nexus-The Ultimate Forensics.
- **Speaker** in **"Latest Trends in Forensic Science"** held on 11th – 14th May 2020, Organized by Sage Summer Training, Institute of Science, Sage University, Indore, M.P.
- **Speaker** in **"International Webinar on Role of Forensic Science in 21st Century"**, held on 10th April 2020, Organized by Department of Forensic Science & Criminal Investigation, Legal Desire Media Insights.
- **Speaker** in **"National One Day Workshop on Crime Scene Investigation"**, held on 16th September 2018, Organized by Legal Desire Media & Publication.

- **Session Chair** in "**National Debate on Abolition of Caste System in India is Required for National Integrity"**, Organized by Faculty of Law Swami Vivekanad Subharti University & Unmukt Bharat in Association with Legal Desire held on 26 Nov., 2016.

Oral Paper Presentation

- Oral Paper Presentation entitled "**Accumulation of Chromium Toxicity and Its Seasonal Variation in Yamuna River Water Delhi"** in International Conference on Research and Development in Forensic Science & Cyber Forensics, held on 21st-22nd May 2021, Organized by Institute of Sciences, SAGE University, Indore.
- Oral Paper Presentation in titled **"Assessment of Lead Toxicity and its Sessional Variation of Concentration in Yamuna River Water Delhi"** in 4th International Conference on Forensic Science & Criminalistics, Forensis Agora 2021 held on 15th- 16th May 2021, Organized by Department of Forensic Science, SBAS, Galgotias University.
- Oral Paper Presentation in **"Contaminant of Heavy Metals in Water & its Toxic Effects on Wildlife Animals,** in International Conference on Wildlife Forensic, Its Laws & Conservation, held on May 28-29 July 2020, Organized by Department of Forensic Science and Criminal Investigation, Legal Desire Media and Insights
- Oral Paper Presentation in **"Accumulation of Heavy Metal Toxicity in Yamuna River Water Delhi"** in International Forensic Science & Criminal Investigation Summit & Awards IFCI 2020 held on May 28-29 May 2020, Organized by Department of Forensic Science and Criminal Investigation, Legal Desire Media and Insights
- Oral Paper Presentation in **"Seasonal Variation of Nickel Concentration in Yamuna River Water Delhi"** In 2nd International Virtual Conference on Forensic Investigations - Stepping Stone for The Future Technologies & Advancements held on May 15, 2020, Organized by Department of Forensic Science and Criminal Investigation, Legal Desire Media and Insights.
- Oral Paper Presentation in titled "**Assessment of Zinc Toxicity and Its Seasonal Variation of Concentration in Yamuna River Water Delhi",** in National Seminar on Recent Advance in Life Science (RALS-2020) held on 22 February 2020, Organized by Department of Life Science, DPG Degree College, Gurugram.
- Oral Paper Presentation in titled **Lead Toxicity in Yamuna River Water Due to Climatic Change** in 4th National Conference on Forensic Science & Cyber Threats: Countermeasure, Forensis Agora 2019 held on 30th Nov. - 1st Dec. 2019, Organized by Division of Forensic Science, SBAS, Galgotias University.

- Oral Paper Presentation in titled **"Concentration of Nickle Toxicity in Water of Yamuna River, Delhi",** in National Conference on A Step Towards Sustainable Environment held on 5th November 2019, Organized by Department of PG Studies & Department of Chemistry Pacific University.
- Oral Paper Presentation in titled **"Status of Chromium Toxicity in Water of Yamuna River, Delhi",** in 2nd International Conference on Medico-Legal Issues & Use Forensic in Criminal Investigation, held on 21st July 2019, Organized by Legal Desire Media & Insights.
- Oral Paper Presentation in titled "**Distribution of Lead in Water & Sediments of Waste Dump Sites in Ayad River at Udaipur, Rajasthan",** in International Conference on Chemical Science in New ERA, held on 5th-06th October 2018, Organized by Department of PG Studies & Department of Chemistry in Association with Indian Chemical Society, Kolkata.
- Oral Paper Presentation in titled "**The Devil's Breath: Scopolamine Drug and its Effect Human Health",** in International Conference on Medico-Legal Issues & Use Forensic in Criminal Justices System: Challenges & Way Forward, held on 17th June 2018, Organized by Legal Desire Media & Publication.
- Oral Paper Presentation in titled **"Treatment of Nitrate Contaminated Waste Water using Green Filter"** in 3rd National Conference on Forensic Science and Criminalistics, Forensis Agora, held on 21st -22nd April 2018, Organized by Division of Forensic Science, SBAS, Galgotias University.
- Oral Paper Presentation in titled **"Accumulation of Heavy Metals in Ayad River at Udaipur, Rajasthan and their Toxic Effects on Human Health"** in 2nd National Conference on Forensic Science and Criminalistics, Forensis Agora, held on 21st -22nd April 2017, Organized by Division of Forensic Science, SBAS, Galgotias University.
- Oral Paper Presentation in titled "**Toxic Effect of Agrichemicals on Human Health**" in 2nd National Conference on Emerging Trends in Applied Sciences, held on 17th – 18th August 2017, Organized by SBAS, Galgotias University.
- Oral Paper Presentation in titled **"A New Technique for Visualization of Latent Fingerprints on Various Surfaces Using Rock Phosphate Powder"** in 2nd National Conference on Forensic Science and Criminalistics, Forensis Agora, held on 21st -22nd April 2017 Organized by Division of Forensic Science, SBAS, Galgotias University.
- Oral Paper Presentation in titled "**Heavy Metal Contamination in Soil & Water & Their Toxic Effect on Human Health**" in National Conference on Emerging Trends in Applied Sciences, held on 23rd – 24th September 2016, Organized by SBAS, Galgotias University.
- Oral Paper Presentation in titled **"Current Scenario of water pollution in water bodies of India"** in International Social impact summit 2015 organized by Legal Desire & Unmukt Bharat in association with Swami Vivekanad Subharti University.

Poster Presentation

- Presented Poster Titled "**Touch DNA**: **A New Tool for Investigation in Forensic Science**" in National Seminar on Issue and Challenges in Forensic Medicines and Forensic Science, held in 9th-10th March 2016 Organized by Department of Forenisc Science, Shiats, Allahabad.
- Presented Poster Titled **"Bite Marks Identification in Sexual Assault Cases", "Paperless AFIS: Live Scan"** In National Conference on Forensic Science and Criminalistics, Forensis Agora, 2016 held on 21st - 22nd Organized by Division of Forensic Science, SBAS, Galgotias University.
- Presented Poster On "**Immunophilia**" Organized by Division of Biochemistry, School of Basic and Applied Sciences, Galgotias University in Association with Indian Immunology Society on April, 29th, 2016, Organized By Division Of Biochemistry, SBAS, Galgotias University.
- Presented Poster Titled "**Forensic Application of Rugoscopy In Personal Identification**" & "**Computer Forensic Data Recovery from Hard Drive**" In National Conference on Emerging Trends in Applied Sciences, Held On 23rd – 24th September 2016, Organized by SBAS, Galgotias University.
- Presented Poster Titled **"Cigarette Butts DNA: An Investigating Tool for Forensic Science"**, In National Conference on Impact of Pharmaceutical Biotechnology on Future of Medicine, held on 24th-25th March 2017, Organized by Geetanjali Institute of Pharmacy, Geetanjali University, Udaipur.
- Presented Poster Titled "**A New Source of Nicotine Poisoning: E-Cigarettes And E-Liquid Nicotine**", In National Conference and Workshop on Trends and Scope of Forensic Science, held on 11th – 12th, April 2017, Organized by Department of Biomedical Science, ANDC, Delhi University.
- Presented Poster Titled **"Toxic Effect of Industries Waste on Public Health & Environment"**, in National Workshop on Celebrating Earth Day: A Step Towards Nurturing Nature, Held On 28 April 2017, Organized by School of Engineering Gd Goenka University, Gurgaon & National Environmental Science Academy (NESA), Delhi.
- Presented Poster Titled **"Use of Nanotechnology in Forensic Science"** In National Workshop on Frontiers in Nano-Technology, Held On 19th September 2015, Organized by School of Basic and Applied Sciences, Galgotias University.

Faculty Development Programme (FDP)

- Attended 5 Days Faculty Development Programme (FDP) on "**Interdisciplinary Aspects of Life Sciences for Transnational Research"** held on 24th –28th January 2023, Organized by Division of Life Sciences, Department of Bio Sciences, SBAS, Galgotias University.
- Attended 3 Day Faculty Development Programme on **"Emerging Paradigms in Forensic Science: A Multidisciplinary Approach"** held on 2 June – 4 June 2022, organized by Department of Forensic Science Govt. Holkar (Model, Autonomous) Science College, Indore, M. P.
- Attended 5 Day Faculty Development Programme on **"Emerging Technologies and Teaching Pedagogies in Forensic Science"** held on 21st February - 25th February 2022, organized by 360^{o} Academic Association, Dept. of Forensic Science, Faculty of Science, SGT University, Gurugram.
- Two-week Faculty Development Programme on **"Teaching, Learning and Research"** held on January 12-25, 2022 organized by FDC, M.D. University, Rohtak, Haryana.
- Attended 5 Day Faculty Development Programme on **"Learning and Pedagogy and Effective use of Case Methodology"**, held on 17th May to 21st May 2020 Organized by ASM Group of Institution and ASMA.
- Attended 5 Day Faculty Development Programme on "**Python 3.4.3."** held on 18th May to 22th May 2020 organized by Galgotias University and Spoken Tutorial Project IIT Bombay.
- Attended 5 Days Faculty Development Programme (FDP) on **"Entrepreneurship and Innovation"** held on 9th June to 13th June 2020 organized by Parul University.
- Attended 5 Days Faculty Development Programme (FDP) on **"Teaching Beyond Boundaries: Emerging Trends in Forensic Education"** held on 16th June to 20th June 2020 Jointly organized by Department of Forensic Science & Criminal Investigation, Legal Desire Media and Insights & Department of Forensic Science, Parul University.
- Attended 5 Days Faculty Development Programme (FDP) on "**Interdisciplinary Research in Forensic Science"** held on 15th – 19th February 2021, Organized by Department of Forensic Science, SBAS, Galgotias University.
- Attended One-Week Faculty Development Programme (FDP) on **"Cyber Security and Digital Forensic"** held on 15th – 20th February 2021, organized by Department of Information Technology of Nagpur Institute of Technology, Nagpur, Maharashtra.
- Attended 5 Day Faculty Development Programme on **"Pedagogy, Learning and Effective use of Forensic Science in Criminal Investigation"** held on 22nd March 2021 to 26th March 2021 Organized by Institute of Sciences, SAGE University, Indore.
- Attended **"4 Day Faculty Development Programme"** held on 26th April 2021 to 29th April 2021 Organized by Institute of Journalism and Mass Communication, SAGE University, Indore.

- Attended 5 Day Faculty Development Programme on **"5 Ways to Unlock the Research Grant"** held on 17th May to 21st May 2021, Organized by Department of Computer Science Engineering, Chitkara University association with CURIN.
- Attended 2 Week Faculty Development Programme on "**Developing Online Course for SWAYAM"** held on 21st June to 5th July 2021, Organized by school of computer science & IT and online programme cell Uttarakhand Open University, Haldwani.
- Attended 1Week Faculty Development Programme on **"Emerging Trends of Blockchain Technology in Engineering",** held on 02-06 August 2021, Jointly organized by the Department of Electrical and Electronics Engineering and Department of Information Technology.

Instrument Hands on Experience

- Gas Chromatography (GC).
- High Performance Liquid Chromatography (HPLC).
- Fourier Transform Infrared Spectroscopy (FTIR).
- Atomic Absorption Spectroscopy (AAS).
- UV Visible Spectrophotometer.
- Flame Photometer.
- Video Spectral Comparator (VSC).
- Spectrophotometer.
- RT-PCR
- Scanning Electron Microscopy (SEM)
- Compression Microscope

Techniques Known

- DNA Profiling.
- Polymer Chain Reaction (PCR).
- Thin Layer Chromatography (TLC).
- Paper Chromatography.
- RBC Counting.
- Microbial Forensic.

Editorial Board Member & Reviewer

- **Guest Editor** of Special Issue of International journal of **Materials Today proceedings** for National Conference on Environmental Toxicology: Impact on Human Health **(Elsevier),** 2022.
- **Guest Editor** of Special issue of International journal of **Environmental and Pollution Research** for National Conference on Environmental Toxicology: Impact on Human Health **(Springer)**, 2022.
- **Guest Editor** of Special Issue of International journal of **Materials Today proceedings** for National Conference on Environmental Toxicology: Impact on Human Health **(Elsevier),** 2021.
- **Guest Editor** of Special issue of International journal of **Environmental and Pollution Research** for National Conference on Environmental Toxicology: Impact on Human Health **(Springer)**, 2021.
- **"Editorial Board Member"** at Method X Journal, Elsevier.
- **"Reviewer"** at Scientific Report, Nature

Fellowship Member

- **Fellow Member** of **India School of Internet Governance (Insig2022)** at Hyderabad Chapter.

Awards & Honor's

- **"Forensic Research Excellence Award",** in NFCI Summit and Award 2023, Dept. of Forensic Science & CI, Legal Desire & Insights & Dept. of Forensic Science, Vivekananda Global University on 21 January 2023.
- **"Best Young Researcher Award"** in IFCA Award & Summit 2021, Department of Forensic Science & CI, Legal Desire & Media Insights on 7 august 2021.
- **"Young Scientists Award"** for Best Paper Presentation in **2nd National Conference on Forensic Science and Criminalistics,** Forensis Agora 2017.
- Awarded **"Junior Research Fellowship-JRF", DST-Funded Project** in Department of Chemical Engineering at **"Malaviya National Institute of Technology- MNIT"**, Jaipur.
- Awarded **Second Prize** for Oral Research Paper Presentation in "**4th National Conference on Forensic Science & Cyber Threats: Countermeasure"** held on 30th Nov. - 1st Dec. 2019.
- Awarded **"Scholarship 300$ Online Certificate Course"** by True Forensic Science, USA.
- Awarded **"Excellence in Reviewing"** in International Journal for Innovative Research in Science & Technology (IJIRST).

- Awarded **“Excellence in Reviewing”** in Asian Journal of Advance Research & Reports.
- Awarded “**Certification of Appreciation**” for Hard Working in Legal Desire Media & Publication.

Research Supervision

- Masters Student submitted thesis**: 4**

Organized Conference/ Seminar/ Workshop/Webinar/FDP

- Coordinator of Online Workshop on “**Intellectual Property Awareness”** program under the mission of National Intellectual Property Awareness Mission (NIPAM), Intellectual Property Office, Govt. of India. held on 02 May 2023.
- Organizing Secretary of “**National Forensic Science Summit and Award 2023**”, held on 21 January 2023.
- Organizing Secretary of **“2nd International Conference on Recent and development in Forensic Science, Forensic Gyan 2021”** held on 10-11 October 2022.
- Joint Organizing Secretary of **“National Conference on Environmental Toxicology Impact on Human Health”** held on 25-26 November 2021.
- Organizing Secretary of **“International Conference on Recent and development in Forensic Science, Forensic Gyan 2021”** held on 21-22 October 2021.
- Co-convener of “**International Conference on Research and development in Forensic Science and Cyber Forensics”** held on 21-22 May 2021.
- Co-convener of “**5 Days Faculty Development Programme on Pedagogy, Learning and Effective Use of Forensic Science in Criminal Investigation”** held on 22-26 March 2021.
- Convener of “**International Conference on Wildlife Forensic, Its Laws & Conservation**”, held On May 28-29 July 2020,
- Active Member of Organizing Committee **“**5 Days Faculty Development Programme (FDP) on **“Teaching Beyond Boundaries: Emerging Trends in Forensic Education”** held on 16th June to 20th June 2020.
- Active Member of Organizing Committee “**International Forensic Science & Criminal Investigation Summit & Awards (IFCI2020)”** held on 28-29 May 2020.
- Active Member of Organizing Committee **How to Live with Covid-19** held on 24th May 2020
- Active Member of Organizing Committee **Forensic Accounting: Emerging Trends in Forensic Science** held on 5th June 2020

- Active Member of Organizing Committee **"Webinar on Basic Structure of Indian Constitution: Interesting & Rare Facts About Kesavananda Bharti V. State of Kerala"** held on 17th May 2020.
- Active Member of Organizing Committee **"2nd International Virtual Conference on Forensic Investigations: Stepping Stone for The Future Technologies & Advancements"** held on May 15th 2020.
- Active Member of Organizing Committee "**Digital & Mobile Forensic"** held on 12th May 2020**.**
- Active Member of Organizing Committee in Webinar On **"Questioned Document Examination"** held on 13th 2020.
- Active Member of Organizing Committee in **"Legal Desire Virtual Summit 2020"** held on 2nd -3rd May 2020.
- Active Member of Organizing Committee in Webinar on **"Stress & Time Management for Lawyers & Law Students"** held on 26 April 2020**.**
- Active Member of Organizing Committee in National Webinar on **"Cybersecurity Laws and Regulation Discussing Road Map for India"** held on 26 April 2020**.**
- Active Member of Organizing Committee in **"International Virtual Conference on Role of Forensics in Criminal Investigation"** held on April 20, 2020
- Active Member of Organizing Committee in **"International Webinar on Role of Forensic Science in 21st Century"** held on 10th April 2020.
- Active Member of Organizing Committee in **"Toxic Detective -Masterclass on Toxicology, Hand's-On Training and Simulation Workshop,** held on 4th February 2020.
- Active Member of Organizing Committee in **4th National Conference on Forensic Science & Cyber Threats: Countermeasure**, **Forensis Agora,** 2019.
- Active Member of Organizing Committee in **2nd International Conference on Medico-Legal Issues & Use Forensic in Criminal Investigation**, 2019.
- Active Member of Organizing Committee in **"National One Day Workshop on Crime Scene Investigation"**, 2018.
- Active Member of Organizing Committee in **"International Conference on Medico-Legal Issues & Use Forensic in Criminal Justices System: Challenges & Way Forward"**, 2018.
- Active Member of Organizing Committee in **3rd National Conference on Forensic Science and Criminalistics, Forensis Agora,** 2018.
- Active Member of Organizing Committee in **2nd National Conference on Emerging Trends in Applied Sciences.**
- Active Member of Organizing Committee in **National Legal Desire Summit & Award,** 2018.
- Active Member of Organizing Committee in **Global Enviro Care Summit**, By Unmukt Bharat 2016.

Member of Scientific Society

- Honorary Member of **UniBioFor - Italian Society of Forensic Biologists, Italy.**
- Annual Member of **European Society of Forensic Science, Europe.**
- Life time Member of **Indian Academy of Forensic Proficient Society, India.**
- Life Time Member of **Nexus Forensic Science Development Society, India.**

Extra-Curricular Activities

- Volunteered in **National Conference on Forensic Science and Criminalistics, Forensis Agora,** 2016.
- Volunteered in **National Conference on Emerging Trends in Applied Sciences.**

References

1. **Prof. (Dr.) Rajeev Kumar**

Professor & Head
Department of Forensic Science,
Galgotias University, Greater Noida, U.P.
Email: rajeev4n6@gmail.com

Declaration

It is certified that all information given by me above is true to the best of my knowledge. If any information was found false, I am aware that my candidature is liable for cancellation.

Date: 28.09.2023 **(MAHIPAL SINGH SANKHLA)**