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COMPREHENSIVE SURVEY AND WATER QUALITY ASSESSMENT OF NORTH - CENTRAL DELHI AQUATIC BASIN

7

A Dissertation Submitted
In Partial Fulfillment of the Requirements
for the Degree of

Master of Science (M.Sc.)

in

CHEMISTRY

By

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DECLARATION

We, **ABHISHEK & DEEPENDRA**, hereby declare that the work which is being submitted in this dissertation entitled "**Comprehensive survey and water quality Assessment of North-Central Delhi aquatic basin**" in the partial fulfilment for the award of the degree of **Master of Science** in the **Department of Applied Chemistry**, Delhi Technological University is an authentic record of our own work carried out during the period from **October, 2025 to April, 2026** under the supervision of **Dr. Poonam Singh (Assistant Professor , Department of Applied Chemistry, Delhi Technological University)**.

We further declare that the dissertation has not been submitted by us for the award of any other degree of this or any other Institute.

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CERTIFICATE

This is to certify that the Project Report entitled **" Comprehensive survey and water quality Assessment of North-Central Delhi aquatic basin "** which is submitted by Abhishek Kumar Vishwakarma (24/MSCCHE/26) and Deependra Kumar (24/MSCCHE/08), Department of Applied Chemistry, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Science, is a record of the project work carried out by the students under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

In this work, water samples were collected from five distinct locations in the North-Central Delhi aquatic basin (Western Yamuna Canal, Haiderpur–Badli Canal, Bhalswa Lake, Yamuna River at Vasudev Ghat, and Naini Lake) on the same day. The set of samples was collected during the winter season to evaluate water quality under low-flow and high-concentration conditions. Over the due course of time, various parameters regarding the water quality were analyzed, and the Indian Standard: 10500 (Drinking Water Specifications) was used to verify the acceptability of the water. The analyzed parameters included Total Dissolved Solids (TDS), Total Suspended Solids (TSS), determination of pH, determination of chloride content, Total Hardness (including permanent and temporary components), and Free Residual Chlorine.

Experimental results revealed pH levels (6.88–7.67) remained within the permissible range of 6.5–8.5, most other parameters indicated severe degradation. Total Hardness was found to be at an absolute maximum value of 1,000 mg/l in Badli Village, whereas TDS content in Yamuna River (976 mg/l) was extremely above its desirable level of 500 mg/l. Moreover, an extremely hazardous concentration of Free Residual Chlorine was measured in Yamuna River (35.5 mg/l), which is almost 177 times its permissible level and poses serious hazards of carcinogen byproduct formation. The concentration of Total Suspended Solids was also very alarming in flowing canals, being more than 1,467 mg/l. The majority of the parameters studied were found to be not in their desirable level for drinking water, which clearly indicates the dominating anthropogenic effects on the basin. Hence, appropriate measures, such as decentralized wastewater treatment and stricter industrial discharge mandates, were suggested to improve the quality of water and protect the health of the surrounding urban community.

Keywords: Water quality, Delhi-NCR, Yamuna River, TSS, TDS, pH, Chloride, Total Hardness, Residual Chlorine, Chloride, IS: 10500.

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LIST OF ABBREBIATIONS

APHA	American Public Health Association
BIS	Bureau of Indian Standards
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
DO	Dissolved Oxygen
DPCC	Delhi Pollution Control Committee
IS	Indian Standard
MLD	Million Litres per Day
PFAS	Perfluoroalkyl Substances
PhACs	Pharmaceutical Active Compounds
WQI	Water Quality Index
WYC	Western Yamuna Canal
YAP	Yamuna Action Plan

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CHAPTER 1
INTRODUCTION

1.1 Importance of water

All life on Earth depends on water. It supports human survival, agriculture, industrial activities, etc. In addition, it is also necessary for food production, energy generation and economic development. Therefore, access to adequate and clean water is critical to the overall well-being and progress of society [10,15].

Earth's surface is covered by seventy percent of water. However, most of it is salty and present in oceans [14]. A mere 2.5 percent of the total water supply is freshwater. Of this only less than one percent is available for human use [15]. This is present in rivers, lakes and near surface groundwater. Much of the fresh water is present in glaciers and polar ice caps. This renders it inaccessible for direct use. This scarcity emphasizes the need to conserve and manage freshwater resources effectively [1].

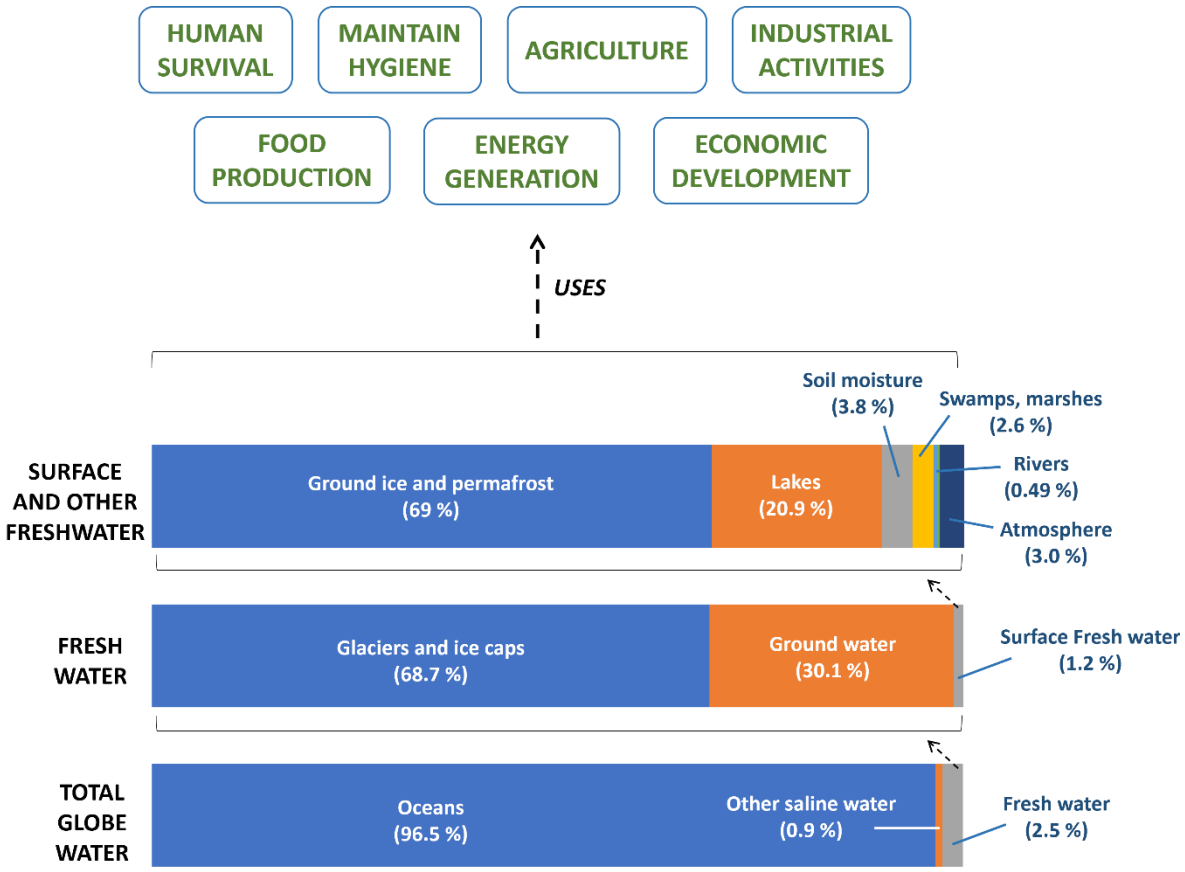


Figure 1: Distribution of water across Earth and its various uses

Freshwater sources are becoming increasingly stressed due to several contributing factors. Some major factors are increasing population, rapid urbanisation and industrialisation. This has led to high consumption and pollution of water [9]. In addition, reliability on water source reduces to changing climate condition. Altering patterns in rainfall may result in droughts. These factors together increase the strain on already scarce freshwater resources [3,4].



Figure 2: Increasing stress on sources of freshwater due to various factors

Water is essential, yet its quality holds the same level of importance. Safe drinking water is necessary to prevent waterborne diseases. Common diseases include cholera, diarrhea and typhoid [5]. Contaminated water poses serious health risks. Such risks increase when populations are dense and where development takes place. Access to safe drinking water is a very important public health concern. Safe drinking water is one of the basic human rights. Even though water is important, the quality of water is equally important. The lack of clean drinking water affects health and productivity.

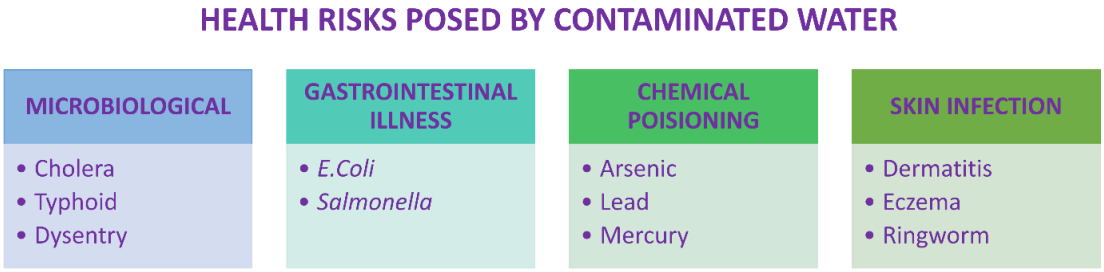


Figure 3: Health issues due to utilisation of contaminated water

The problem of water shortage relates to the availability as well as the quality of water. Water may exist in sufficient quantity but still not be safe for consumption. This may be due to contamination from natural and human made sources. Chemicals, heavy metals and pathogens are among the pollutants that can lower water quality. This makes it unsuitable for consumption. Therefore, providing safe and clean water requires tackling both quantity and quality together.

1.2 Water pollution

Water pollution is the degradation of water quality in natural sources such as rivers, lakes, groundwater, and seas. It becomes unsafe for human consumption, aquatic life and other uses. This contamination occurs when pollutants are directly or indirectly introduced into water systems. This results in altering their physical, chemical and biological characteristics. As a result, this can pose serious risks to human health and the environment.

Water pollutants can be broadly classified as biological, chemical and physical. Biological pollutants are living organisms or pathogens that contaminate water and cause waterborne diseases. These may be bacteria, viruses or parasites. These

microorganisms usually enter water through untreated sewage and improper sanitation systems.

Chemical pollutants are harmful substances that dissolve or remain suspended in water. They can have toxic effects on living organisms. These may be heavy metals such as lead, arsenic, and mercury, nitrates from fertilizers, pesticides used in agriculture, etc. They have a tendency to accumulate in humans with time, leading to some major health complications.

Physical pollutants are those that affect the aesthetics of water. They are not necessarily dissolved in water. But they contribute significantly to the poor quality of water. Examples include sediments and suspended solids. Such as dust, sand, and silt. They increase the turbidity of the water.

Emerging pollutants refer to those pollutants that have been newly discovered by researchers, and they are now posing a threat to water bodies. Microplastics, pharmaceutical residues including antibiotics, and hormones, among others, come under this category. The removal of emerging pollutants from water sources is quite challenging through conventional water treatment processes.

The assessment of water quality involves an array of biological and physical characteristics that act as a crucial indicator of water quality, both in terms of the needs of the organisms and people.

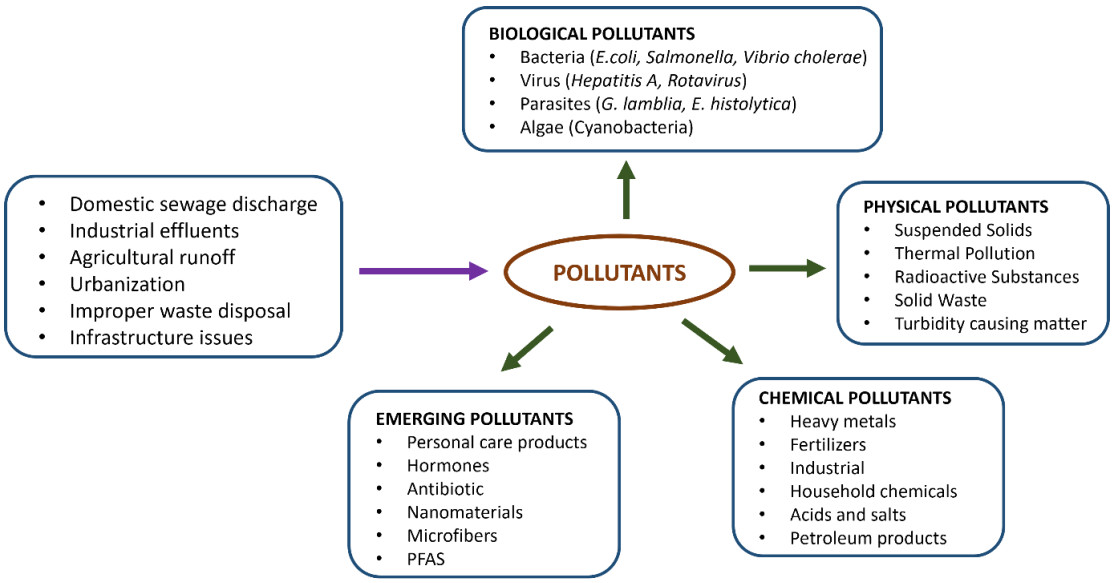


Figure 4: Major pollutants

1.3 Water Quality

The following are the two major classifications of pollutants depending upon their source:

i. Point Sources: These are defined sources of pollution, for example, outfalls of industries and municipalities or discharges of sewage plants [11,19].

ii. Non-Point Sources (Diffuse Sources): These are sources that are distributed in larger areas and are difficult to trace to one source only. This category includes agricultural runoff, storm water runoff from paved areas, urban offerings of idols etc. [14,19].

14

Water quality is measure of the physical, chemical and biological characteristics of water relative to the requirements of biotic species or human needs. It serves as a gauge to determine the fitness of water for specific uses, such as drinking, irrigation, industrial processes, or the maintenance of healthy aquatic ecosystems [19]. Analyzing dozens of individual variables is complex, researchers often use a **Water Quality Index (WQI)** [29]. WQI is a mathematical tool that transform complex data into a single numerical value (typically between 0 and 100) representing the overall status of the water [21,29].

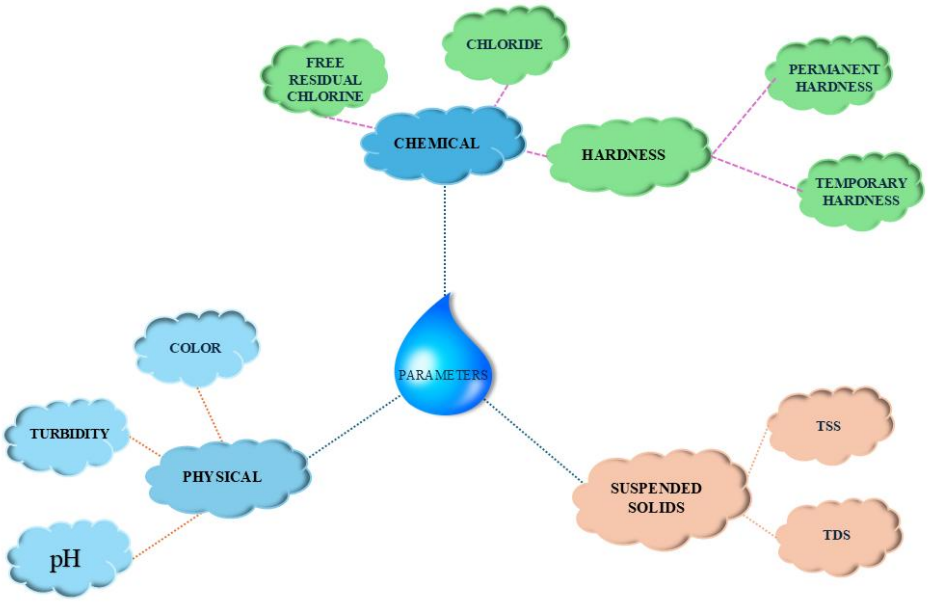


Figure 5: Water Quality Parameters

Water quality parameters are broadly categorized into four groups based on their nature and the methods used to measure them:

a) Physical (Organoleptic) parameters

These parameters define the physical appearance and "feel" of the water and are often the first indicators of pollution [47].

i. Temperature

ii. Color and Odor

iii. Turbidity

iv. Total Suspended Solids (TSS)

v. Electrical Conductivity (EC)

b) Chemical parameters

This is the largest category and is further subdivided into **inorganic** and **organic** constituents [14].

i. Inorganic Constituents: include pH (acidity/alkalinity), Total Dissolved Solids (TDS), Alkalinity, and Total Hardness (caused by Calcium and Magnesium). It also includes major ions. Like Chlorides, Sulphates, and Fluorides [22].

ii. Nutrients: Primarily Nitrogen (Nitrates/Ammonia) and Phosphorus (Phosphates) [22].

26 iii. Organic Demand Parameters: Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO) [20].

c) Biological (Microbiological) Parameters

They measure the presence of pathogens. Also, disease-causing microorganisms.

i. Indicators Organisms: The total coliform and fecal coliform indicate levels of contaminants in water bodies that cause illnesses such as cholera and typhoid [17].

ii. Bacteria, Parasites, and Viruses: Human and animal wastes harbor these microorganisms [17].

d) Toxic and Other Pollutants

They consist of substances that are highly dangerous even at minimal amounts.

i. Persistent organic pollutants: Such compounds include pesticides. Also detergents, and petrochemicals [1].

ii. Heavy metals: They refer to non-biodegradable minerals like lead (Pb), mercury (Hg), arsenic (As), and cadmium (Cd). These accumulate inside the body [3,47].

1.3.1 Physical characteristic of water

The discharge of water is measured in cumecs by use of a current meter. By determining the rate of flow of water alongside pollutant concentrations, it becomes easier to identify sources of major pollution and factors that contribute to peak pollution [3,21,27].

Color in water results from metallic compounds found in rocks and soil, as well as organic materials from decomposing organisms. It might be a result of certain by-products like dyes within industrial processes. Water is identified using Hazen units [10,20].

Smell and Taste analyzed using qualitative human receptor method. Are very significant indicators in terms of presence of contaminants such as sewage or hydrogen sulfide, in particular very important for the food and beverages industries [14,17].

Temperature measured in situ in degree Celsius, an important variable that determines the usage of the water body and what kind of treatment would be required in case of contamination. Temperature affects the reaction rate between different compounds and organisms in the aquatic environment [14].

pH value refers to if water acidic or basic. Acidic water with pH value less than 7. While water with pH value greater than 7 is basic. Determination of pH is done using a pH meter which measures the voltage produced by hydrogen (H^+) ions [14,30].

Turbidity means clay, silt, soil particles and other colloids that interfere with light passing through. Determined in Nephelometric Turbidity Units (NTU) based on concentration and particle size of the suspended matter. Surface water that exhibit a sudden increase in turbidity due to rain are referred to as "flashing waters" and are more challenging to treat than non-flashing waters [14,17].

1.3.1 Chemical Characteristic of water

Hardness is the sum of calcium and magnesium concentrations, expressed as $CaCO_3$ equivalent. Originating from minerals like limestone, classified from soft to very hard (>180 mg/l). Standard drinking limits under IS: 10500 is 200–600 mg/l yet urban sources often exceed this, reaching 1,000 mg/l [14,20].

Permanent Hardness is the non-carbonate portion of total hardness caused by sulfates, chlorides, and nitrates of calcium and magnesium. Unlike temporary hardness, it cannot be removed by boiling. It is calculated as the difference between total hardness and total alkalinity [33,34,36].

Temporary Hardness caused by calcium and magnesium bicarbonates, uniquely precipitating as insoluble ppt when boiled. This "carbonate hardness" is numerically equivalent to total alkalinity when total hardness exceeds [33,34].

Free Residual Chlorine is defined as an equilibrium mixture of dissolved gas (Cl_2), hypochlorous acid (HOCl), and hypochlorite ion (ClO^-). IS:10500 desirable limit for drinking water is a minimum of 0.2 mg/l, as a residual 0.1 mg/l effectively ensures the deactivation of pathogenic bacteria [22,30].

Chloride (Cl^-) is an inorganic anion present in natural waters, originating from rock weathering, salt deposits, sewage discharge, industrial effluents, and seawater intrusion. It is typically measured using the argentometric (Mohr's) titration method and expressed in mg/l. IS: 10500-2012, desirable limit is 250 mg/l, extendable to 1000 mg/l [14,29]. Elevated chloride levels impart a salty taste cause irritation and gastrointestinal discomfort. In aquatic systems high chloride disrupts osmotic balance, adversely affecting sensitive organisms [27].

1.3.2 Suspended solids

Total Dissolved solid **(TDS)** concentration (mg/l) is used in tandem with chemical investigations to evaluate the viability of water for agricultural or industrial purposes [15]. Theoretically, its value should fall within the range of 0.55 to 0.70 of the conductivity coefficients. It can be measured using a potentiometer or through gravimetric analysis.

Total Suspended Solids (**TSS**) refer to insoluble particles such as silt, clay, organic matter, algae, and industrial waste that cannot pass through a 2-micron filter. Measured in mg/l using gravimetric methods. TSS increases water turbidity, reducing light penetration and inhibiting photosynthesis [14].

CHAPTER 2

LITERATURE REVIEW

The literature review provides a insight of existing research on physiochemical and biological status of Indian water bodies, focus on the Yamuna River, urban lake in Delhi. Current literature underscores nearly 70% of India's available water is polluted due to discharge of untreated domestic sewage and industrial effluents [15,26].

2.1 Water quality assessment in India

Research across Indian reveal systematic decline in water quality. A literature survey of important Indian water bodies indicate that river Ganga, Yamuna, Godavari, and Cauvery are severely polluted along urbanized stretches [12].

Studies, on the Ganga River in Allahabad revealed significant contamination due to the disposal of large amounts of sewage and effluents from tanneries and plating industries. The use of Water Quality Index (WQI) is vital tool for summarizing complex datasets into single numerical value [15,22]. In Uttarakhand, WQI assessments have been used to depict overall water quality status for the selection of appropriate treatment techniques. Seasonal changes have been a common factor in the literary works of India, but studies done on the lakes in Nagpur show that water quality decreases from the winter season to the summer season due to the increased activity of microorganisms and pollutants. [22,29].

2.2 Water Quality in Delhi

These issues have been experienced in various urban areas including Delhi due to the effects of urbanization and increase in population, leading to a great effect on water quality [2,21]. The rivers provide the main source of water for the nation capital territory, covering an area of approximately 1,483 square kilometres. The Yamuna River

originates from the Yamunotri glacier in the lower Himalayas (elevation ~ 6,387 m) and flows 48 km through Delhi, entering at Palla and leaving at Jaitpur. The Western Yamuna Canal serves as the crucial conduit supplying about 70% of the water requirements in Delhi [3,4]. From the past trend (16.7M-20.2 M mid-2020s), population pressure has been very harsh on this river basin leading to the creation of more wastes. Recent estimates indicate that Delhi produces 3,800-4,426M of sewage wastes daily. Household waste makes up 80-85% of the total population burden in the river. Delhi has 26 industrial regions and only 13 common effluent treatment facilities with a capacity of 221 MLD [6,8,26].

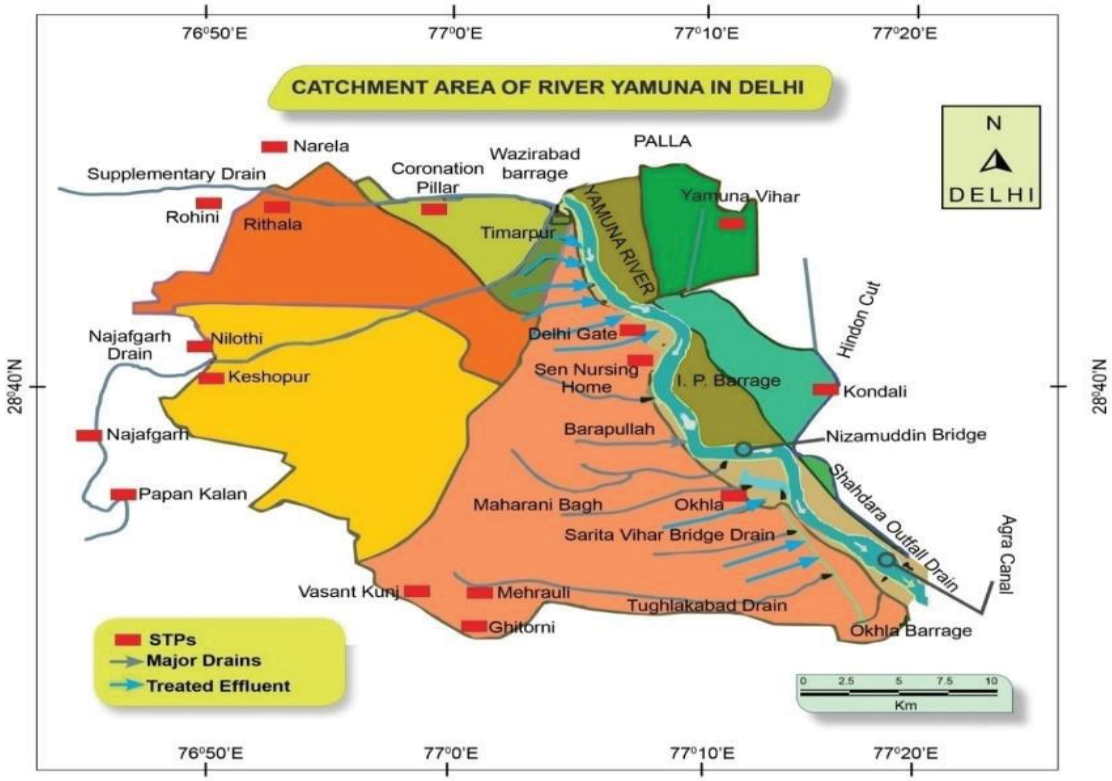


Figure 6: Major Pollution Sources of River Yamuna [15].

The underground water table in Delhi is suffering from the stress of over-exploitation as well as contamination through leaching. Through research conducted at 32 locations, it is revealed that there is an alarming situation regarding the provision of clean drinking water, which is further aggravated by the density of the urban population [43]. An instance of a particular concern is that of the Bhalswa Landfill Site, where leaching of contaminants from solid waste to groundwater occurs.

In the industrialized areas of Badli and Wazirpur, trace metal contaminants as well as dissolved solids are found in excessive amounts.

2.2.1 Yamuna River

The most documented instance of degradation of the river in India is Yamuna river stretch covering 22km in Delhi. The aforementioned part constitutes over 2% of the entire length of the river and carries 76%-80% of the river's total population burden [14,42].

Pre-Delhi diversion of the river sees extraction of about 9.5 billion cubic meters for purposes of irrigation and consumption, leaving very little fresh water for dilution in the city [3].

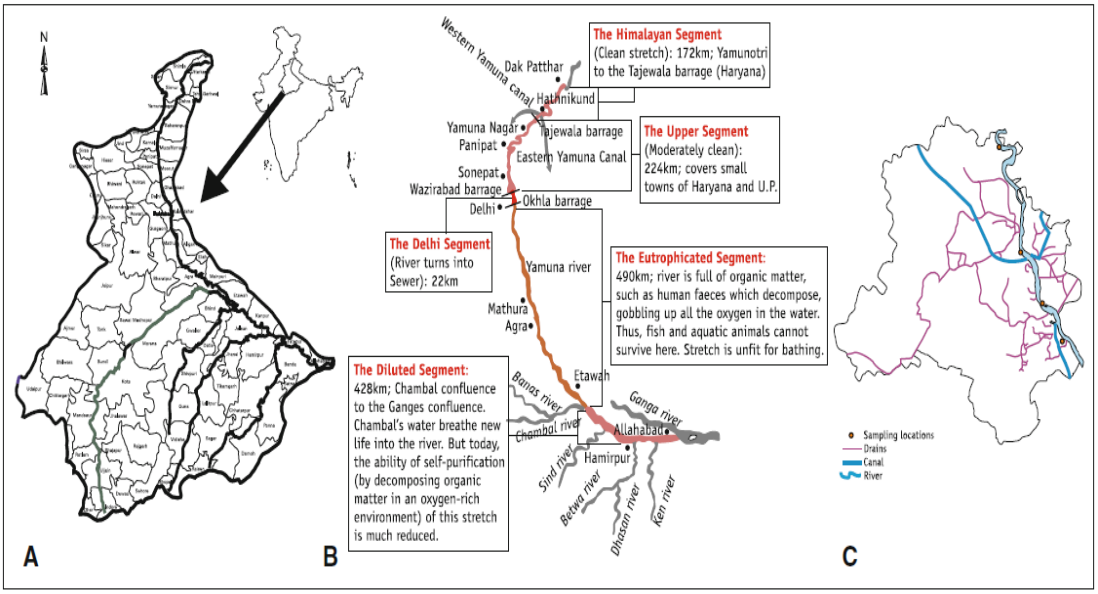


Figure 7: Different segments of river Yamuna. A- Basin map of River Yamuna, B- River classification according to pollution, C. Location of monitoring stations (CPCB) in NCT (Delhi) [2].

Preliminary analysis (2009-2019) carried out at Palla station showed TDS to be satisfactory, but BOD and COD were consistently over permissible limits, while coliform bacteria grew exponentially to 100-1000 times the IS: 2296 standard. Even worse is found in downstream monitoring, showing total ammonia concentration of 12.55-13.30 mg/l, toxic for aquatic species [3].

The river's state is mostly affected by 21 major drainage channels. About 60%-67% of total pollution coming from drains ends up in the Delhi stretch of the river. Non-monsoon season sees almost all river flow consisting of drain water [5,8].

CCME WQI assessment proved that while Palla had "good" or even "marginal" quality water, "poor" was observed at ODRB, Nizamuddin and Okhla sites. pH was often the only parameter. Meeting standards throughout the stretch.

2.2.2 Bhalswa and Naini lake

Delhi lakes act as sink for pollutants both regionally and locally.

For instance, Bhalswa lake which is an ox-bow lake of the river Yamuna has been documented to be a highly polluted lentic ecosystem. Research studies have shown that it is organically polluted and nutrient enriched, with TDS levels up to 3,310 mg/l. It receives effluents from nearby dairies and settlements, thus causing increased algal growths with pH levels of 8.7 - 8.95 [22].

In contrast to the flow systems, Naini lake acts as a stagnant water body where total suspended solids (TSS) depend mainly on the generation of the biomass and surface effects. Comparison has been made showing that stagnant water bodies such as Naini accumulate more minerals than flowing systems [27].

Aquatic pollution through heavy metals is the most lethal pollutant considering the fact that they are biodegradable and non-degradable.

Studies conducted in the Delhi stretch of Yamuna have shown that there were heavy metals with the concentration in order Fe > Cr > Mn > Zn > Pb > Cu > Ni > Hg > As > Cd in the water.

These toxic metals enter the body either through food and water sources. For instance, Lead (Pb) in excess amounts can affect children's cognition while Cadmium (Cd) tends to accumulate in kidneys and liver leading to damage. Toxic metals have also been found in the fish species in river banks and even vegetables grown there.

Recent studies broadened the scope to include PFAS (perfluoroalkyl substances) and pharmaceutical active compounds (PhACs). PFAS have been detected in both river and groundwater in the Ganges basin, with significant implications for long-term human exposure.

2.3 Study Area

The North-Central Delhi Region has a complex network of river basins, which is connected to various natural water bodies such as such as Bhalswa Lake and Yamuna River. The connectivity between these water bodies is primarily hydraulic and drainage-based. Within this connectivity mentioned water bodies are linked shown in Figure 6. We classify the river based on pollution levels. **Western Yamuna Canal** connected to the Himalayan Segment stretch between Yamunotri to the Tajewala Barrage. This canal is part of Northern Delhi Segment which receives effluents from industries and household. Around this canal dispose of religious offering and last rites perform which increase the organic load in the water. Further downstream, the canal joins with **Haider Pur Badli Canal** near Badli Village. The Haiderpur and Badli areas are part of this drainage. The Najafgarh Drain receives secondary discharge from these areas, is the largest polluter of the Yamuna, contributing approximately 67% of the river's total pollution load. Pollution in these streams is a combination of localised and regional sources. Industries located in Badli and Wazirpur are major contributors of heavy metals to the basin. The Yamuna has minimal fresh water flow during non-monsoon months without dilution, these industries' toxins persist, leading to a critical water quality status unsuitable for industrial cooling. During the monsoon season, this supplementary drain overflows, causing wastewater to mix directly with Bhalswa Lake. **Bhalswa Lake** is an oxbow lake formed by a past course of the Yamuna River in North-Central Delhi. The lake is connected to the larger Yamuna basin via the Supplementary Drain (a branch of the Najafgarh Drain) shown in Figure 4. The primary pollutants are effluent from the Bhalswa Dairy, domestic sewage from surrounding residential colonies and leachate from the nearby Bhalswa Landfill percolates into the groundwater and eventually into the lake. In addition, stagnant water bodies (**Naini Lake**) receive pollutant from residential colonies or leach from surrounding soil during monsoon season. Algal bloom is also observed in the lake which deteriorate the water quality, tourist attraction further intensifies the pollution load.

2.4 Objective of the study

In the Delhi segment, the river effectively functions as a drain during non-monsoon periods due to the lack of fresh water. The river receives untreated or partially treated waste from 21 major drains.

Based on the literature study, we carried out survey in our nearby premises so as to evaluate the effect of industrial effluents. The present work survey analysis was carried out in 5 regions mainly in North Delhi which are mentioned below:

I. BHALSWA (SAMPLE 1)
II. VASUDEV GHAT, YAMUNA RIVER (SAMPLE 2)
III. WYC (SAMPLE 3)
IV. BADLI VILLAGE (SAMPLE 4)
V. NAINI LAKE (SAMPLE 5)

2 This study determines water quality in the non-monsoon season, as the flow of the Yamuna River varies during the monsoon (July - September) and non-monsoon (October - June) seasons. Based on seasonal variation the result may vary.

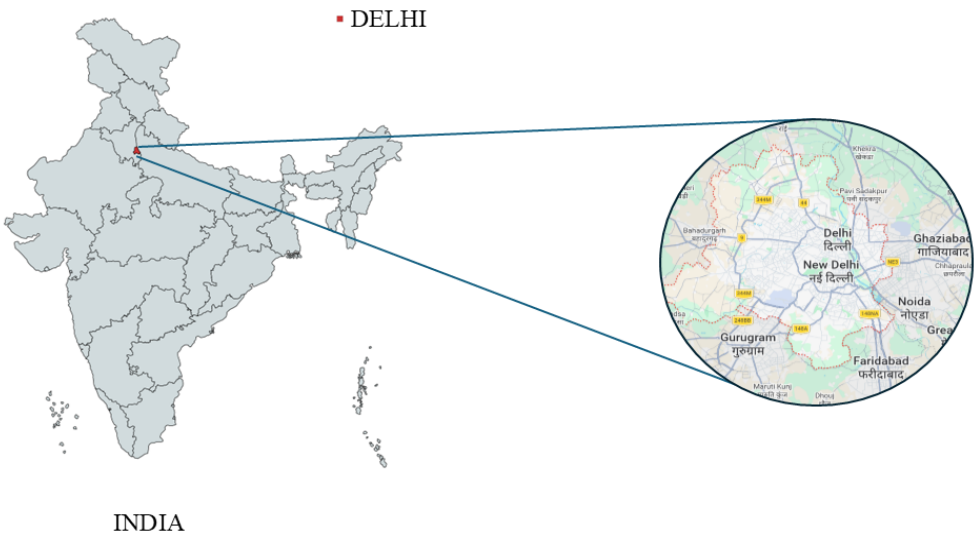


Figure 8: - Geographical Map of India showing Delhi region

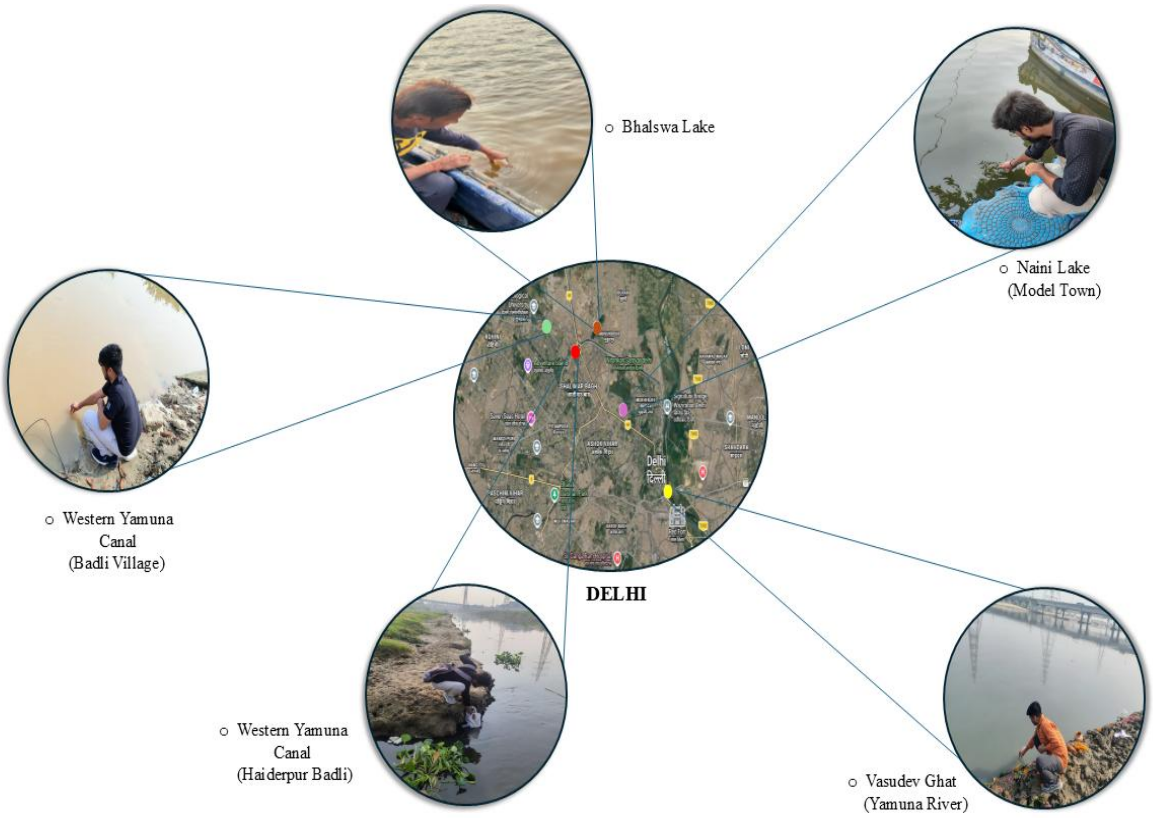


Figure 9: Different sampling site in Delhi region

CHAPTER 3

METHODOLOGY

3.1 Sample Collection

All samples were collected as grab samples, providing a "snapshot" of the physicochemical and biological composition at a specific point in time and space [20].

Samples were taken from the shore side of the water bodies, which is a critical zone where human contact and animal consumption are most frequent. To avoid surface scum or raised bed sediments, pre-washed 1L water bottles were dipped approximately 5 cm below the surface [20].

Bottles were rinsed with sample water prior to final collection. To maintain the integrity of constituents. Along with retard biological or chemical changes. Lids were tightly sealed. While submerged to exclude atmospheric oxygen [20].

Samples were immediately labelled. This was with numbers, dates, and locations. Then transported to the laboratory.

Table 1: Collected Samples

S. No	Sample location	Population (Million)	Number of samples
1.	Bhalswa	3.5-4.5	1
2.	Vasudev Ghat, Yamuna River	3.5-4.5	1
3	WYC	1.5-2.5	1
4	Badli Village	1.5-2	1
5	Naini lake	3-3.5	1

Table 2: Drinking water quality parameters according to Indian Standard (IS: 10500) & WHO

S. No	Parameters	Technique used	WHO Standard	Indian Standard (IS:10500/2296)
1.	Color	Visual	-	5 Hazen units
2.	Turbidity	Nephelometer	-	-
3.	pH	pH Meter	6.5-9.5	6.5-8.5
4.	Total Dissolved Solids (TDS)	TDS Meter	500 mg/l	500 mg/l(Desirable) 2,000 mg/l (Permissible)
5.	Total Suspended Solids (TSS)	Gravimetric	50 mg/l	100 mg/l
6.	Total Hardness • Calcium • Magnesium	Complexometric titration Complexometric titration Complexometric titration	200 mg/l - -	200 mg/l 75 mg/l 30 mg/l
7.	Permanent Hardness	Complexometric titration	_	_
8.	Temporary Hardness	Complexometric titration	_	_
9.	Free Residual Chlorine	Iodometric method	0.5 mg/l	0.2 mg/l
10.	Chloride	Argentometric/Mohr's Method	250 mg/l	250 mg/l

3.2 Analytical procedure

The determination of the water quality in this report will be done by adopting a double approach to its physicochemical properties that also act as indices for ecological as well as human health. This follows the standards stipulated by APHA (2017) and BIS (IS: 3025) which state that "all" these parameters are evaluated based on certain principles for contamination levels.

a) In-situ Measurements: Parameters like pH, Temperature, and Electrical Conductivity (EC). Are measured at the site. Using a digital pH meter, thermometer and conductivity meter.
b) Gravimetric Analysis: TSS, TDS
c) Titrimetric Methods: Total Hardness. Chlorides (Mohr's Method/Argentometric titration). Residual Chlorine (Iodometric titration).

3.2.1 pH

Hydrogen ion concentration, referred to as pH, is among the key parameters that indicate the degree of acidity or basicity in the aqueous solution. pH can be described mathematically as follows:

$$\text{pH} = -log\,[H^+]$$

The range of pH levels is 0-14, whereby the level of 7.0 at 24° C indicates neutral conditions, whereas lower and higher levels indicate acidity and basicity, respectively.

As far as the pH determination technique is concerned, the most accurate technique is the electrometric method based on a cell that consists of a glass electrode that reacts to H^+ ions and a standard reference electrode, such as Ag-AgCl electrode or calomel electrode. In this context, the electrical potential (electromotive force) generated by ions is measured. Although the colorimetric test gives only an approximate value, the electrometric technique is the most effective for water treatment purposes because it is not affected by color or turbidity. The measurement of pH is essential in various spheres, including pharmacology, agriculture, civil engineering, as nearly every step is associated with pH levels.

In this study, pH was recorded across five sampling sites, revealing neutral to slightly alkaline conditions.

3.2.2 Gravimetric Analysis

It is a chemical analysis technique. It calculates the amount of a chemical compound based on its mass. Gravimetric analysis is considered the standard method. For testing water for Total Suspended Solids (TSS) and Total Dissolved Solids (TDS).

Although these two methods use similar principles. Involving weighing and drying, the key difference between the two lies in the filtration process.

a) Total Suspended Solids **(TSS)**: Here, water from a measured volume is filtered. Using a pre-weighted 0.45 or 2.0 microns filter paper. The filtrate on the filter paper is then dried in an oven at 103 -105 degrees Celsius until a constant weight is achieved. An increase in the filter's weight will give us the total suspended solids.

b) Total Dissolved Solids **(TDS)**: Water filtrate from the previous stage. Which is the filtrate, is evaporated in a pre-weighted dish. Then dried in an oven at 180 degrees Celsius (+/- 2). Residue left in the dish is the total dissolved solids.

Gravimetric analysis may be the "gold standard" technique for measuring the two water contaminants, but a digital TDS meter is preferred due to the following reasons:

i. Fast and Quick Analysis: Gravimetry is a time-consuming process. Taking several hours of drying and weighing procedures. The meter gives an instant result.
ii. Relation to Conductivity: Total dissolved solids (TDS) have a direct relationship with Electrical Conductivity (EC). It is due to the fact that most TDS consist of inorganic salts having an electric charge. Meter calculates the AC resistance of the sample and multiplies it by a constant factor ranging from 0.55 to 0.90 to find out the concentration of TDS in the sample.
iii. Accurate Measurements at Trace Concentrations: In case of very pure water like demineralized water. The weight of the residue remaining after drying cannot be accurately measured. Via using an ordinary analytical balance. In such conditions, only conductivity measurement can provide an estimate. Of TDS concentration.

iv. Economical: Hand-held meters are cheap. Handy to perform tests rapidly and extensively.

3.2.3 Titrimetric Method

Titration is one of the basic forms of quantitative analysis which includes finding out the volume of a solution whose concentration is known (standard solution) needed to react with a certain amount of the sample to be analyzed. The end point of such reactions is normally marked with a color change in the solution which is triggered by the addition of an additional solution referred to as an indicator.

Titration Methods Used in Water Quality Analysis

From the sources provided, some of the titration methods used to find out different water quality parameters include:

a) **Complexometric Titration** (EDTA Titration): This is the most reliable technique. Used for determining total hardness. Also, levels of calcium and magnesium. At pH 10.0, calcium and magnesium ions react with indicators. Such as Eriochrome Black T to form a red complex. On adding EDTA solution, the complex breaks down. Changing color from red to blue.

b) **Argentometric Titration** (Mohr's Method): Used primarily to determine Chloride content. The sample is titrated with standard silver nitrate () using potassium chromate as an indicator. The end point is reached when silver chloride precipitates completely and a persistent brick-red precipitate of silver chromate begins to form.

c) **Iodometric Titration**: The iodometric method is an indirect redox titration used in wastewater analysis to quantify specific chemical species based on their oxidizing properties. It relies on reacting an analyte with excess potassium iodide (KI) to liberate molecular iodine (I_2). The liberated iodine is subsequently titrated with a standard sodium thiosulfate ($Na_2S_2O_3$) solution using a starch indicator. Chlorine oxidizes iodide to iodine in an acidic medium. The resulting iodine is titrated to determine the total oxidizing chlorine present

d) **Acid-Base Titration**: Used to calculate Alkalinity (Carbonates and Bicarbonates). The water sample is titrated with a standardized acid (such as H_2SO_4or HCl) to specific pH end points (8.3 for phenolphthalein alkalinity and 4.5 for total alkalinity).

CHAPTER 4

EXPERIMENTAL DETAILS

EXPERIMANTAL PROCEDURES

4.1 pH

Chemical Required

- Buffer Solution (4.0, 7.2, 9.0).

Apparatus Required

- Beaker (30ml, 100mL).
- pH meter.

Procedure

1. 100ml beaker filled with water sample.
2. Electrode cover clean with a whatmann filter paper.
3. Before recording pH of the sample, device calibrated using buffer solution of pH value 4.0, 7.2, 9.0.
4. Electrode was rinsed with distilled water and gently blotted before use.
5. Electrode used to measure the pH of the sample.
6. Measurements taken under constant stirring to maintain uniformity.

4.2 TDS

Apparatus Required

- Digital TDS meter (The misto TDS-30).
- Beaker (30ml).

Procedure

1. Tip of TDS meter clean using filter paper.

2. For measurement TDS meter dipped in the sample and value recorded.

4.3 TSS

Apparatus Required

- Beaker (100ml)
- Hot air Oven
- Filtering funnel
- 42 Whatmann Filter paper
- Desiccator

Procedure

1. Weigh filter paper on digital balance.
2. Pre-weight filter paper used to filter water sample (10ml) placed in filtering funnel.
3. To dry filter paper, heat it in hot air oven for an hour at 100 degree Celsius.
4. Let it cool in desiccator to balance temperature and weight on digital balance
5. Repeat the process until reach a continuous weight increase of 0.5 mg or a constant weight loss of more than that come.

Calculation,

$$\text{TSS, mg/l} = \frac{(A-B)\times 1000}{V} \quad \text{- Eq 1}$$

Here,

- A: Final weight (mg)
- B: Initial weight (mg)
- 1000 = Conversion factor to express concentration in mg/l
- V: Volume of sample (mL)

4.4 Hardness

Reagents required

- EDTA solution (0.01N)
- Eriochrome Black T (EBT) Indicator
- Ammonia Buffer Solution (pH 10)

Apparatus Required

- Burette (30ml)
- Pipette (10ml)
- Erlenmeyer flask/conical flask (100ml/150ml)
- Measuring cylinder (10ml)
- Beaker (20ml,100ml)
- Volumetric flask (100ml)

Procedure

First, make standard EDTA solution (0.01N)

- Weigh 0.372 g of EDTA salt on weighing balance.
- Transfer EDTA salt in 100 ml volumetric flask with the help of a funnel. Dissolve the EDTA salt and make up the volume of the volumetric flask.

Next, make EBT indicator

- Weigh 0.25 g of EBT
- Transfer EBT in 100 ml volumetric flask with the help of a funnel. Dissolve the EBT and make up the volume of the volumetric flask.

1. Now fill the burette with standard EDTA solution of 0.01N.
2. 10ml volume of sample taken in a conical flask (100ml).

3. 5ml volume of ammonical buffer added in conical flask with help of measuring cylinder and 1-2 drops of EBT indicator added, mixed thoroughly. Color of solution will be Wine red.
4. Titrated this mixture against standard EDTA solution in the burette until wine red color turns to Blue.
5. Repeat the titration as long as the concordant readings are observed.

Calculation,

$$\text{Total hardness (as } CaCO_3\text{), mg/l} = \frac{M \times V \times 100 \times 1000}{Volume\ of\ sample\ (ml)} \quad \text{- Eq 2}$$

Here:

- M = Molar Strength of EDTA solution.
- V = Volume of supplied EDTA solution.
- 100 = Molecular weight of $CaCO_3$
- 1000 = Conversion factor to express concentration in mg/l.

Magnesium hardness = Total hardness − Calcium hardness

4.4.1 Permanent Hardness

Measurement of hardness after boiling the sample is the permanent hardness.

Required Reagents

- EDTA solution (0.01N)
- Eriochrome Black T (EBT) Indicator
- Ammonia Buffer Solution (pH 10)

Apparatus Required

- Burette (30ml)
- Pipette (10ml)
- Erlenmeyer flask/conical flask (100ml/150ml)
- Measuring cylinder (10ml)
- Beaker (20ml,100ml)

- Volumetric flask (100ml)

Procedure

First, make standard EDTA solution (0.01N)

- Weigh 0.372 g of EDTA salt on weighing balance.
- Transfer EDTA salt in 100 ml volumetric flask with the help of a funnel. Dissolve the EDTA salt and make up the volume of the volumetric flask.

Next, make EBT indicator

- Weigh 0.25 g of EBT
- Transfer EBT in 100 ml volumetric flask with the help of a funnel. Dissolve the EBT and make up the volume of the volumetric flask.

1. Now, 100ml sample taken in a beaker (250ml).
2. Put the beaker on heating plate set to 100 degrees Celsius for 1hour.
3. After 1hour cool the sample at room temperature and use it for titration.
4. fill the burette with standard EDTA solution (0.01N).
5. 10ml volume of sample taken in a conical flask (100ml).
6. 5ml volume of ammonical buffer added in conical flask with help of measuring cylinder and 1-2 drops of EBT indicator added, mixed thoroughly. Color of solution will be Wine red.
7. Titrate this mixture against standard EDTA solution in the burette until wine red color turns to Blue.
8. Repeat the titration as long as the concordant readings are observed.

Calculation,

$$\text{Hardness, mg/l} = \frac{M \times V \times 1000}{Volume\ of\ sample\ (ml)} \quad \text{- Eq 3}$$

Here:

- M = Molar Strength of EDTA solution.
- V = Volume of supplied EDTA solution.
- 1000 = Conversion factor to express concentration in mg/l.

4.4.2 Temporary Hardness

Measurement of hardness without boiling of the sample is the permanent hardness.

Calculation,

Temporary hardness = Total hardness – Permanent hardness - Eq 4

4.5 Residual Chlorine

Reagents required

- Acetic acid, glacial
- Potassium iodide – crystal
- Standard sodium thiosulphate (0.025N)
- Starch indicator solution

Apparatus Required

- Burette (30ml)
- Pipette (10ml)
- Volumetric flask (100ml)
- Erlenmeyer flask/conical flask
- Measuring cylinder (10ml)
- Beaker (20ml,100ml)
- Heating plate

Procedure

First, make standard Sodium thiosulphate solution (0.025N)

- Weigh 0.62 g Sodium thiosulphate on weighing balance.
- Transfer Sodium thiosulphate in 100 ml volumetric flask with the help of a funnel. Dissolve the Sodium thiosulphate and make up the volume of the volumetric flask.

Next, make Starch indicator (1%)

- Weigh 0.2 g of starch on weighing balance.
- Transfer starch in 100ml beaker. Boil solution by constant stirring with glass rod until clear solution appear.
- Cool the solution at room temperature and stored in reagent bottle.

Potassium iodide solution (10%)

- Weigh 10 g potassium iodide on weighing balance.
- Transfer potassium iodide in 100 ml volumetric flask with the help of funnel. Dissolve the potassium iodide and make up the volume of the volumetric flask.

1. Now, Fill the burette with standard Sodium thiosulphate solution (0.025N)
2. Measured volume of 10ml sample taken in conical flask, acidified with 1ml acetic acid solution to maintain pH (3-4).
3. 2ml potassium iodide (10%) solution added, color of solution will be yellow.
4. Titrate this mixture against standard sodium thiosulphate solution (0.025N) till the color of the mixture disappear.
5. Immediately add Starch indicator in the above mixture, solution will appear blue.
6. Continue titration till the blue color of the solution disappears.
7. Repeat the titration as long as the concordant readings are observed.

Calculation,

$$\text{Free Residual Chlorine, mg/l} = \frac{V \times 1000 \times 0.025 \times 35.5}{Volume\ of\ sample\ (mL)} \quad \text{- Eq 5}$$

Here:

- V= Volume of standard sodium thiosulfate solution (mL)
- 1000 = Conversion factor to express concentration in mg/l
- 0.025= Normality of standard sodium thiosulfate solution
- 35.5 = Equivalent weight of chloride (Cl^-)

4.6 Chloride (Argentometric Method)

In a neutral or slightly alkaline solution, potassium chromate can indicate the end point of the silver nitrate titration of chloride. Silver chloride is precipitated before red silver chromate is formed.

Reagents required

- Potassium Chromate indicator
- Silver Nitrate (0.01N)

Apparatus Required

- Burette (30ml)
- Pipette (10ml)
- Erlenmeyer flask/conical flask
- Measuring cylinder (10ml)
- Beaker (20ml,100ml)

Procedure

Firstly, make potassium chromate solution

- Dissolve 5 g of potassium chromate in a little distilled water. Add silver nitrate solution a definite red precipitate is formed. Filter it and dilute to 100ml with distilled water.

Secondly, standard silver nitrate titrant (0.01N)

- Dissolve 0.24 g of silver nitrate in distilled water and dilute it to 100ml.

1. Fill Burette with Silver nitrate solution.
2. Take a conical flask, add 10ml sample with measuring cylinder.
3. Add few drops of potassium chromate indicator, solution appear yellow.

4. Titrate the mixture with silver nitrate solution in the burette till brick-red precipitate appear.
5. Repeat the titration as long as the concordant readings are observed.

Calculation,

$$\text{Chloride, mg/l} = \frac{\text{V} \times \text{N} \times 35.5 \times 1000}{Volume\ of\ sample\ (mL)} \quad \text{- Eq 6}$$

Here:

- V = Volume of titrant (ml)
- N = Normality of the silver nitrate solution
- 35.5 = Equivalent weight of chloride (Cl^-)
- 1000 = Conversion factor to express concentration in mg/l

CHAPTER 5

RESULT & DISCUSSION

5.1 Result

5.1.1 pH

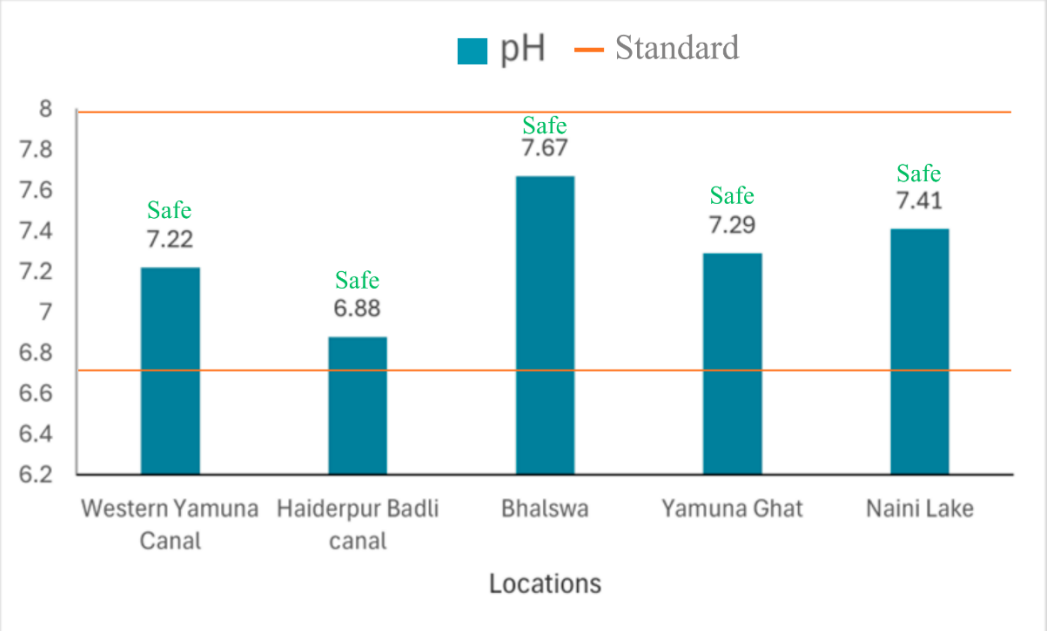


Figure 10: pH of Water Sample recorded at different studied sites

pH value is a critical variable that determines solubility and bioavailability of chemical constituents, including essential nutrients like phosphorus and nitrogen, as well as toxic heavy metals such as Lead (Pb), Copper (Cu), and Cadmium (Cd). The pH acts as a controlling mechanism. In the chemical speciation of various elements. For example, metals usually dissolve better. And become dangerous at lower or acidic pH. The pH readings for this study are given follows:

For the stagnant water in **Bhalswa Lake and Naini Lake**. The high pH (7.67 and 7.41) may be responsible for the high availability of phosphorus. Causing **algae growth**. All pH values, despite currently being in the neutral region, will eventually lead to

increasing alkalinity in these stagnant bodies of water, reducing the **effectiveness of chlorine disinfection**. This requires high doses of chlorine and higher contact times to ensure the microbial safety of the water, which becomes worrisome considering the high level of residual chlorine in the basin. High pH results in an unpalatable **bitterness** in water and **mineral scaling** in pipelines and industrial equipment. On the other hand, the low pH reading. From the flowing **Badli Village Canal (6.88)**. Indicates a higher possibility of metal **corrosion**.

5.1.2 TDS

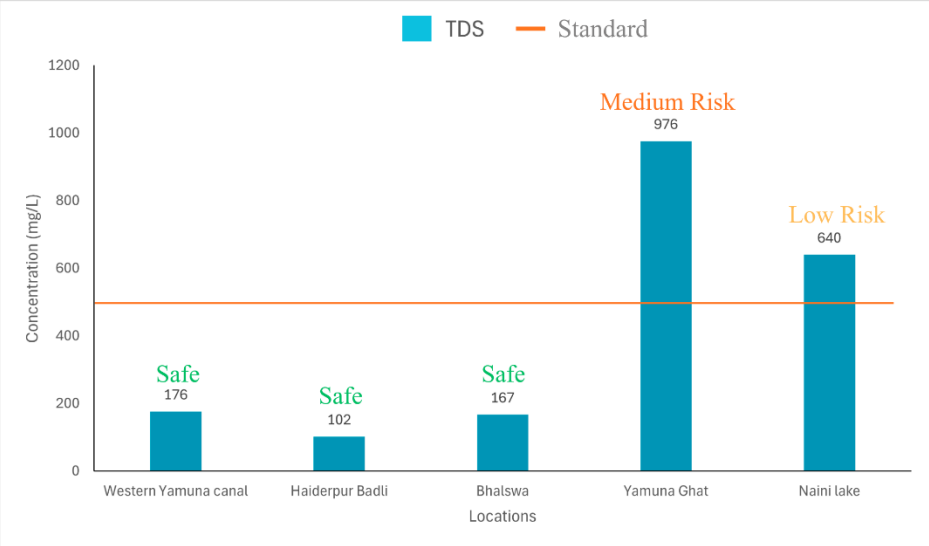


Figure 11: TDS of Water Sample recorded at different studied sites

The rivers and lakes that had the maximum amount of TDS were Yamuna River. This was at Vasudev Ghat (976 mg/l) Also Naini Lake (640 mg/l). These high readings are due to the pollution. Caused by the constant discharge of wastewater. From industries and household wastes collected from urban drainage into the river. Thus contributing large amounts of calcium, magnesium and chloride ions. The lowest amounts of TDS were recorded in Badli Village Canal (102 mg/l). This was followed by Bhalswa Lake (167 mg/l), and Western Yamuna Canal (176 mg/l) in this study. Even though Bhalswa Lake is known as a chemical sink and the TDS can go up to 3,298 mg/l because of leachate, this particular study did not show such results.

5.1.3 TSS

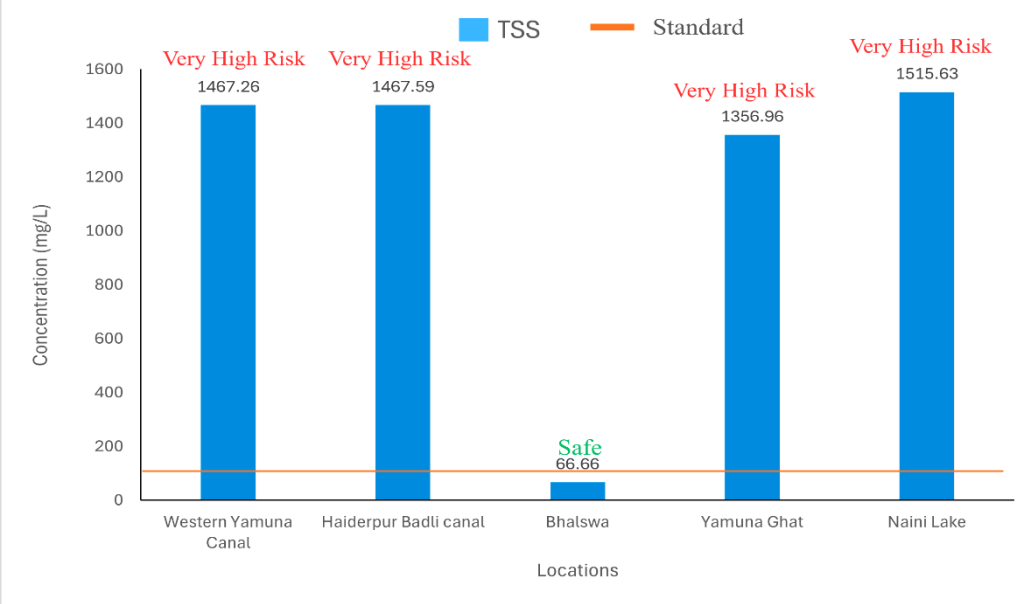


Figure 12: TSS of Water Sample recorded at different studied sites

Suspension levels were extremely high in Badli Village Canal (1467.59 mg/l). This followed by Western Yamuna Canal (1467.26 mg/l), and Yamuna River (1356.96 mg/l). Here, the high TSS concentration was mainly because of sediment movement. Also, domestic waste without treatment, and industrial waste from Badli and Wazirpur. The highest TSS level was seen in Naini Lake (1515.63 mg/l). Which can be explained by the biological process taking place inside (algae). Also, water turbulence in this lake which does not flush very much. On the other hand, the lowest TSS concentration was detected in Bhalswa Lake (66.66 mg/l). Where particles settle due to stillness.

5.1.4 Total Hardness (TH)

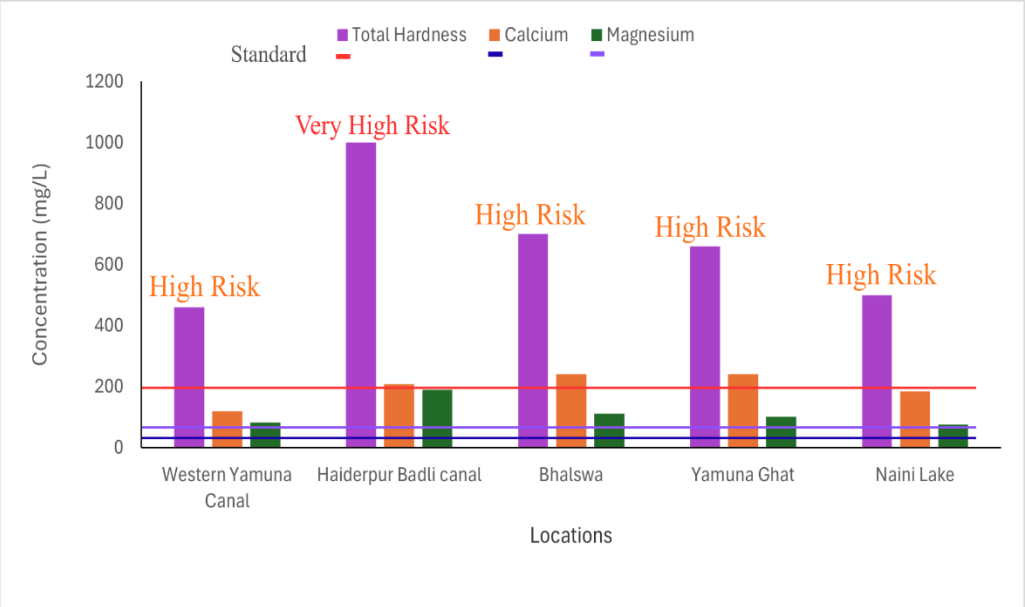


Figure 13: Hardness (Ca^{+2} and Mg^{+2}) of Water Sample recorded at different studied site

The measure of hardness of water is used in determining how the water reacts and forms soap scum. Hardness of water is not a single component; it is a combination of polyvalent metal ions such as those of Calcium and Magnesium. The scientific definition of Total Hardness (TH) is a summation of all polyvalent metallic cations' concentration, expressed in terms of Calcium Carbonate equivalents in mg/l.

The types of hardness are classified in relation to the specific nature. Of the anion bound with divalent cations and heat energy:

a) **Temporary (Carbonate) Hardness**- Caused by Calcium and Magnesium **bicarbonates/carbonates.** It is called temporary because the hardness can easily be dissolved. Or precipitated using heat. Particularly by boiling to 100°C, thereby converting the bicarbonates to carbonates.

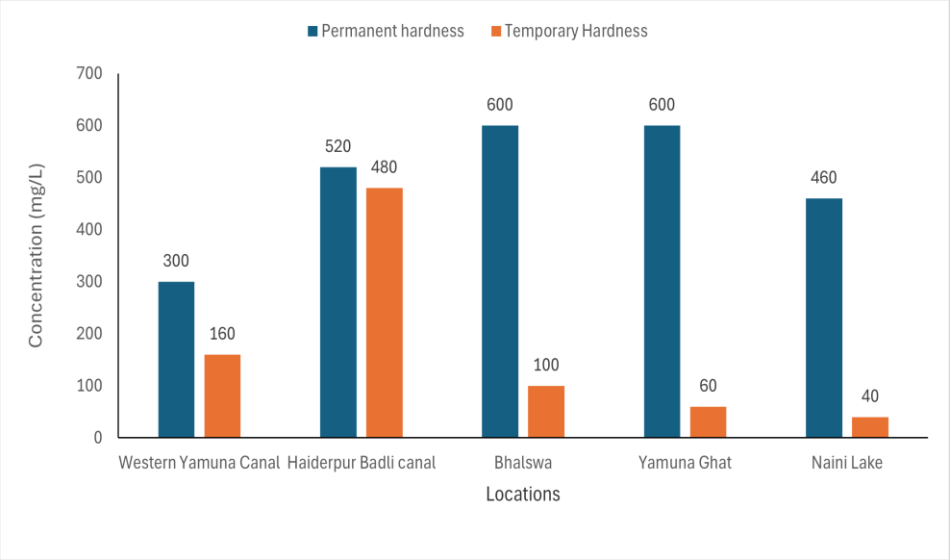


Figure 14: Permanent and Temporary Hardness of Water Sample recorded at different studied sites

11

b) **Permanent (Non-carbonate) Hardness**- Caused by **sulphates, chlorides and nitrates** of calcium and magnesium. It **cannot be removed by boiling**. Needs to undergo more complex treatments such as ion exchange and reverse osmosis. The canal in Badli village demonstrated the maximum total hardness (1,000 mg/l) due to the high temporary hardness (480 mg/l). Such a figure is explained by the large input of effluent and sewage water originating from the Badli-Wazirpur industrial zone. The drop in total hardness is seen when transitioning from flowing to stagnant lakes. For instance, the lower temporary hardness of 40 mg/l in Naini lake could be related to processes occurring within the lake itself, such as precipitation of calcium carbonate during photosynthesis performed by algae. 85% - 90% of the total hardness (permanent hardness of 600 mg/l) was found in the Yamuna River and Bhalswa lake. Such results indicate that non-carbonate salts (sulphates and chlorides) make up the dominant part of the water due to pollution.

5.1.5 Residual Chlorine

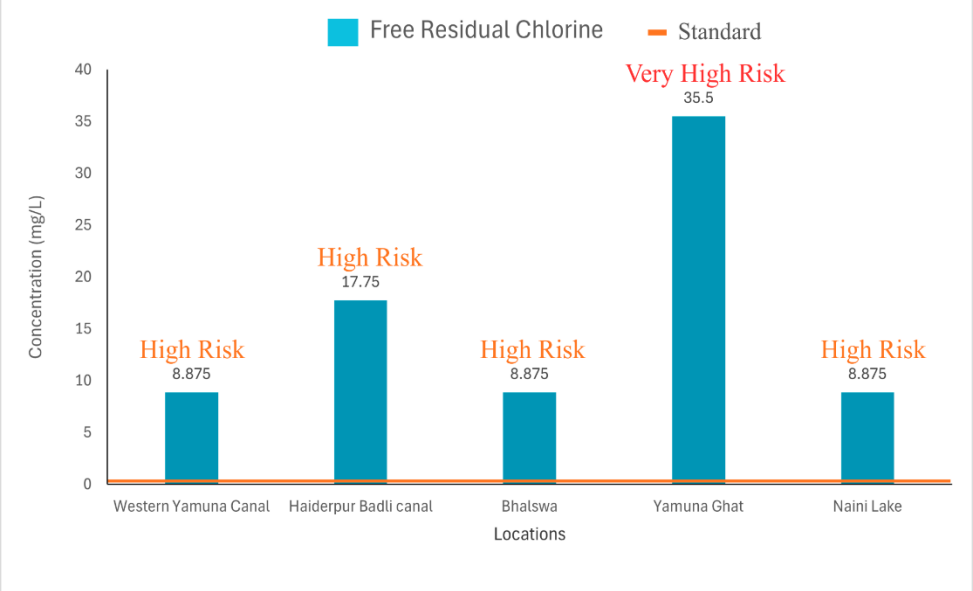


Figure 15: Free Residual Chlorine of Water Sample recorded at different studied sites

The level of the residual chemicals in the Yamuna River at Vasudev Ghat is at 35.5 mg/l, which is almost 177 times greater than the regulatory limit. This indicates that there is a very high level of chemical presence, which may be caused by the bleaching process from the industries upstream or because of the high level of dosing in the area due to high amounts of organic waste present in the water. The same high residuals have been observed in places such as Badli and Naini Lake.

5.1.6 Chloride

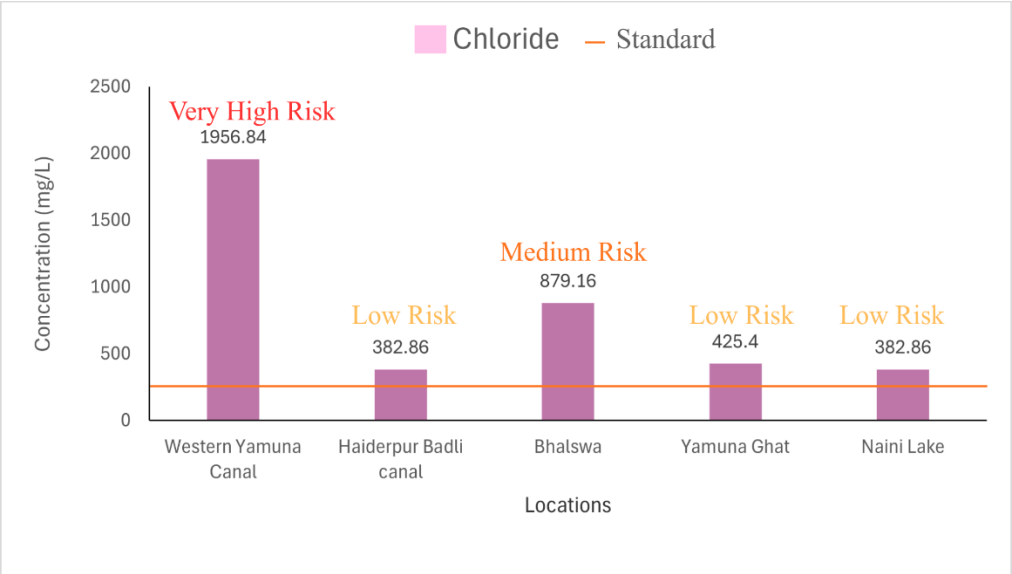


Figure 16: Chloride Concentration of Water Sample recorded at different studied sites

The Bhalswa Lake was found to have the highest value for chloride content, which was 1,749 mg/l. Such a high value for chloride is due to the use of this lake as a receptacle for chemicals, especially the leakage from the landfill of the Bhalswa area and also the overflowing of the Najafgarh-Supplementary Drainage System. The maximum amount of pollution was found in the case of the Yamuna River (Vasudev Ghat), where the values rose from about 138 mg/l at the entry points to 610-810 mg/l at the downstream barrages. This indicates massive pollution from the urban sewage drains that pour out high salinity liquid waste.

Table 3: Comparative Study of Water Quality Parameters at Different Sampling Sites

S.No.	Parameter	Units	Locations				
			Bhalswa	Vasudev Ghat (Yamuna River)	WYC*	Badli Village	Naini lake
1.	Color	Hazen	-	-	-	-	-
2.	pH	-	7.67	7.29	7.22	6.88	7.41
3.	TDS*	mg/l	167	975	176	102	640
4.	TSS*	mg/l	66.66	1356.96	1467.26	1467.59	1515.63
5.	TH* Calcium Magnesium	mg/l mg/l mg/l	700 240 110.4	660 240 100.8	460 120 81.6	1000 208 190.08	500 184 75.84

6.	PH*	mg/l	600	600	300	520	460
7.	TH**	mg/l	100	60	160	480	40
8.	Free Residual Chlorine	mg/l	8.875	35.5	8.875	17.75	8.875
9.	Chloride	mg/l	879.16	425.4	1956.84	382.86	382.86

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[TDS: Total Dissolved Solids • TSS*: Total Suspended Solids • TH*: Total Hardness • PH*: Permanent Hardness • TH**: Temporary Hardnes • WYC*: Western Yamuna Canal]*

5.2 Discussion

According to experimental data, a unique trend for hydrodynamics is observed. Whereby the pH tends to rise when moving from flowing to stagnant systems. Flowing Systems (WYC and Yamuna River): Low pH (6.88 – 7.29) is due to microbial respiration, along with decomposition of organic matter in the form of untreated sewage effluents, which results in carbonic acid production and low pH. Rising trend (7.41 – 7.67) is due to higher photosynthetic activity. Lentic ecosystems in such environments have floating algae that absorb dissolved in water for photosynthesis, hence reducing the amount of carbonic acid. It is facilitated by the presence of calcium carbonate and magnesium bicarbonate in the system.

For **humans**, high/low pH can irritate or even affect the eyes, skin, and mucous membranes. Extremely alkaline (pH 10 – 12.5) water is associated with swelling in hair follicles, exacerbating any skin condition. For sensitive persons, neutral pH water is necessary to reduce gastrointestinal irritation.

Higher values of TDS tend to make water less palatable. Causing an unpleasant salty. Also, metallic taste in water.

Technical Hazards- Water containing higher levels of dissolved solids. Causes encrustation and scaling. In household pipes, boilers, and industrial cooling towers. Due to lower heat transfer and the risk of bursting pipes.

Environmental Impact: High levels of TDS in water increase the water density. Also, osmoregulation (balance of fluid) of organisms. Organisms that are adapted to a low salinity environment would face difficulties due to changes in ions.

While TDS is a secondary (aesthetic) parameter, very high levels could lead to irritation in the gastro-intestinal system and act as a cathartic effect. The consumption of highly mineralized water was suggested as the cause of kidney stones. The use of water that

contains more than 500 mg/l of TDS continually could harm livestock because of weakened bones, scouring, and reduction in output. From the results shown above, it can be seen that water from both Yamuna River and Naini Lake is not suitable for consumption since it exceeds the desirable value of 500 mg/l of TDS.

According to general environmental standards, the desirable limit for TSS is typically <100 mg/l. Except for Bhalswa Lake (66.66 mg/l), all sites exceed the 100 mg/l standard, with Naini Lake and the canals exceeding the limit by over 14 to 15 times.

Every site in North-Central Delhi exceeds the 200 mg/l desirable limit. Furthermore, Badli, Bhalswa, and the Yamuna River exceed even the 600 mg/l maximum permissible limit. Continuous consumption of such hard water has been linked to the formation of kidney stones and gastrointestinal issues. Socially, it causes poor lathering with soap, deterioration of clothing quality, and high maintenance costs due to encrustation and scaling in domestic plumbing and appliances.

Chloride concentration in Bhalswa lake (1,749 mg/l) exceeds the maximum permissible limit. The Yamuna River (up to 810 mg/l) and other urban sites frequently exceed the 250 mg/l desirable limit, rendering the water poor for direct consumption.

CHAPTER 6

FUTURE PROSPECTS, CONCLUSION & SOCIAL IMPACT

6.1 Future Prospects

The assessment of urban aquatic ecosystems remains a critical priority for sustainable development, and the data reported here demonstrate that water quality in North-Central Delhi can be effectively diagnosed through integrated physico-chemical analysis and the Water Quality Index (WQI). Whereas much headway has already been made in terms of pollution monitoring, the area itself presents a great deal of potential, with many improvements being possible through advancements in predictive techniques and the use of novel sensors.

Water quality monitoring in urban environments is still relatively new when compared to the decades of development in relation to grab sampling. However, it also presents many benefits, including the ability to measure and manage risk factors through real-time measurements, which can help prevent disasters like the one resulting from the Free Residual Chlorine levels (35.5 mg/l) in the Yamuna River. Secondly, by being automated, they are able to provide high-resolution measurements of even the most abrupt shifts in water quality that would not be noticed with manual sampling.

Thirdly, such techniques can run constantly, and thus provide much greater efficiency than manual techniques in relation to management and analysis of results, since there is no need to transport samples and analyze them retrospectively. Therefore, using IoT sensor networks looks like an excellent way forward in the Delhi-NCR region.

The use of low-cost adsorbents and nanomaterials can provide feasible alternatives for eco-friendly water purification processes. The utilization of natural materials such as Amorphophallus campanulatus (Yam), Coconut shell, and chemically modified sugarcane bagasse can enhance removal efficiency in cases of heavy metals and high-hardness levels (of up to 1,000 mg/l, seen at Badli). While problems of regeneration efficiency and environmental impact of chemical regenerators must be considered, these factors will be required for localized/decentralized treatment processes. The decentralized approach can also be facilitated through the use of Nature-Based

Solutions (NbS) as well as cutting-edge multistage biological engines, such as Soil Biotechnology (SBT) technology that involves low power consumption and the creation of green habitats.

Technological integration can also be achieved through the application of Remote Sensing and GIS framework mapping. This approach allows creating spatially unique environments that predict unknown pollutant concentrations and combined with machine learning can reveal new trends in point-source pollution. River rejuvenation projects, such as Yamuna Action Plan (YAP), require the assessment of Water Quality Index metrics along with other spatial evaluations. In the end, creating effective, scalable, and genuinely sustainable management processes will require interdisciplinary cooperation between hydrologists, environmental chemists, urban planners, and data scientists.

- **Future directions include:**

(i) Conducting research on developing long-lasting green absorbent material from locally available biomass (yam/wheat husk) considering the high mineral concentration and 'Very Hard' nature of the urban lakes.

(ii) Implementing automated real-time monitoring sensors along with SCADA connectivity network so that real-time water quality monitoring becomes a reality from source to tap.

(iii) Leveraging synergies between academic institutions, regulatory authorities (CPCB/DPCC) and industries ensuring compliance with the environmental standards mentioned in IS: 10500-2012.

6.2 Conclusion

Study show massive concentrations of Total Suspended Solids (TSS) in flowing systems, with the Badli Village Canal (1467.59 mg/l) and Western Yamuna Canal (1467.26 mg/l) showing high loading due to sediment transport and untreated sewage. In contrast, Bhalswa Lake (66.66 mg/l) showed significantly lower TSS, likely due to the settling of particles in a quiescent environment.

The pH shows a gradual increase from flowing water to stagnant lakes, with Bhalswa Lake (7.67) being more alkaline than the Badli Canal (6.88) due to enhanced photosynthetic activity by algae. Total Dissolved Solids (TDS) showed a steady rise as

the water moved downstream, peaking at 976 mg/l in the Yamuna River, driven by evaporation and intense anthropogenic mineral loading.

According to CPCB guidelines, the Yamuna River Delhi stretch is classified as Category E, rendering it fit only for industrial cooling, irrigation, and controlled waste disposal.

Badli Village Canal recorded a total hardness of 1,000 mg/l, which is categorized as "Very Hard". Such extreme levels can cause encrustation in pipes and have been linked to kidney stones in humans.

Chlorides form an important criterion for determining the pollution levels, and highest values were recorded in the Western Yamuna Canal (1956.84 mg/l). This indicates an extremely high quantity of domestic and industrial pollutants, which might affect the kidneys' functionality and impart a bitter taste.

A dangerously high level of Free Residual Chlorine was observed, with its concentration being 35.5 mg/l in the Yamuna River. Free Residual Chlorine can cause the development of toxic substances. Especially when reacted with organic matters. And can adversely affect fish by damaging their gills and mucus.

6.3 Social Impact

Social ramifications of shifting away from traditional, highly chemical-based water treatment and remediation techniques are equally significant. Traditional waste disposal in urban areas of Delhi utilizes the practice of releasing untreated effluents and employing large amounts of harsh chemical disinfectants, as seen through extremely elevated Free Residual Chlorine concentration (35.5 mg/l) in the Yamuna [516, previous turns]. Not only is this method damaging to the environment; it is also creating an ethical dilemma due to the inability to ensure that people's main source of water is safe.

although the high degree of mineralization, which reached 1,000 mg/l of total hardness, directly affects the health of the local population with increased risks of kidney stones and gastrointestinal complications. As a solution to these negative environmental and social aspects, it is important to introduce biological adsorbents, for instance, Amorphophallus campanulatus or Elephant Foot Yam.

Apart from protecting residents, the aforementioned methods are beneficial for sanitation workers and riverine farmers in preventing chemical intoxication and damage to the tissues as well. Thus, using non-toxic substitutes to reagents reduces the likelihood of poisoning and the destruction of tissues in individuals working with river water on a daily basis. Moreover, such methods also help reduce the negative impact of industry and landfills. For example, the contamination with a significant amount of chloride ions (1,749 mg/l), coming from landfills like the Bhalswa Landfill, can be alleviated through the usage of local biomass instead of chlorinated reagents.

Making sure that sustainable water production is achieved helps meet public health goals by ensuring that the process of managing water in Delhi is conducted safely and ethically, especially considering that 70 percent of water comes from Western Yamuna Canal. Using green chemistry and natural methods in industries and municipalities not only stimulates cooperation between different professionals, including urban designers, hydrologists, and environmental chemists, but also promotes innovation according to Global Sustainability Targets (SDG 6). Such actions provide scientists with necessary data and help develop new policies concerning such issues as the development of circular water economies and zero-liquid discharge policy.

The conclusions reached through this study go a long way in supporting the aim of having a better world in the future and also making sure that the scientific community is acting responsibly. Shifting focus from the current chemical intensive remediation practices to eco-friendly methods will help revive the Yamuna River into a valuable "green-blue resource.

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