Water Quality Monitoring of Rawal Dam and its Tributaries

By Ahmed Waleed

00000318693

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Institute of Environmental Sciences and Engineering (IESE)
School of Civil and Environmental Engineering (SCEE)
National University of Sciences and Technology Islamabad
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Approval Certificate

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"Water Quality Monitoring of Rawal Dam and its Tributaries"

Submitted by

Ahmed Waleed

Has been found satisfactory for partial fulfillment of the
requirements of the degree of Master ofScience in
Environmental Sciences.

Supervisor: ....
31/08/2023.

Dr. Imran Hashmi

Professor

SCEE (IESE) NUST

GEC Member: ....

Dr. Sher Jamal Khan

Professor

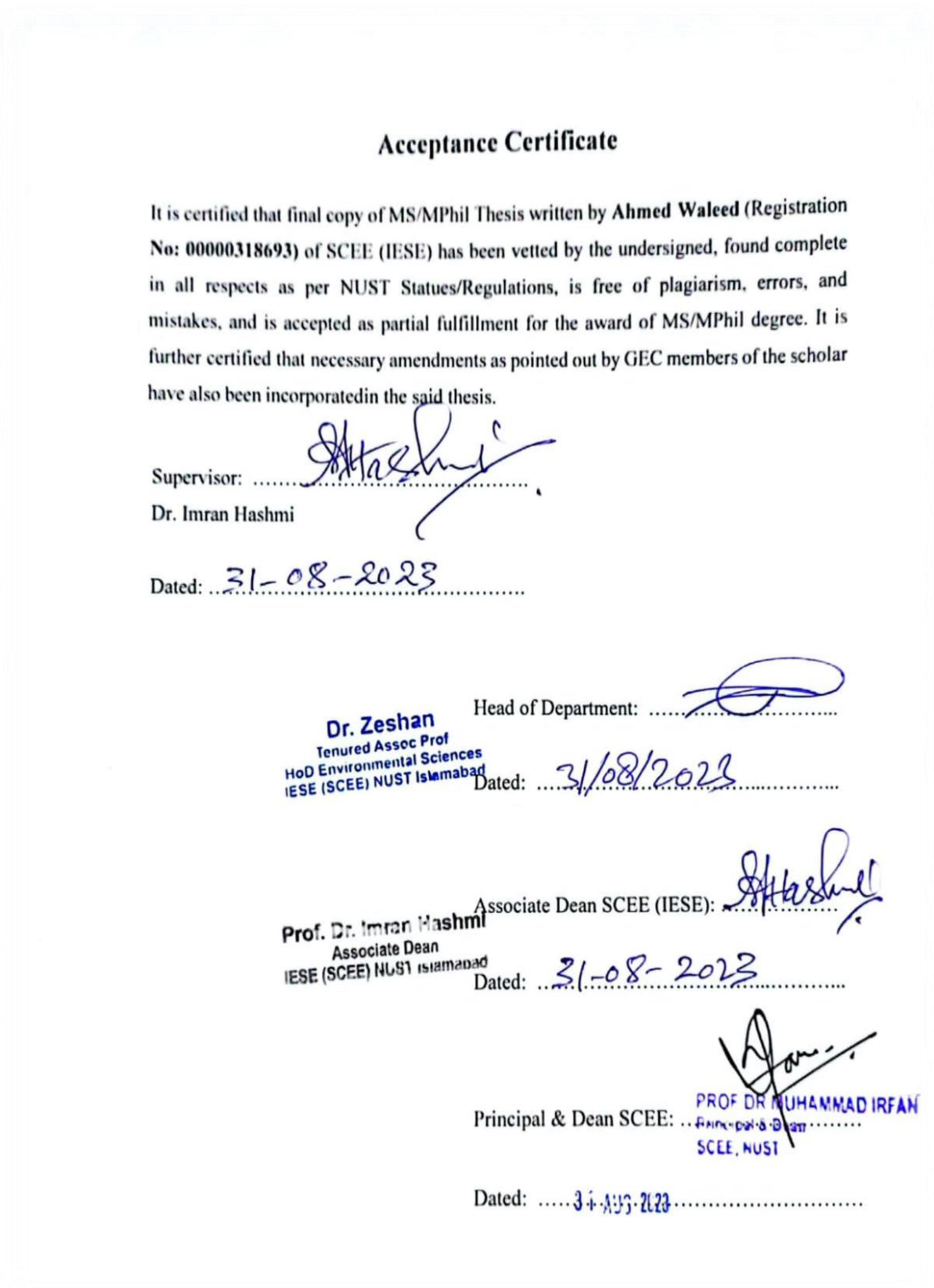
SCEE (IESE) NUST

GEC Member: ....

Dr. Aneela Javed

Associate Professor

ASAB, NUST



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Supervisor: ……………………………………

Dr. Imran Hashmi

Dated: 31-08-2023

Dr. Zeshan
Tenured Assoc Prof
HoD Environmental Sciences
IESE (SCEE) NUST Islamabad

Head of Department: ……………………………

Dated: 31/08/2023

Prof. Dr. Imran Hashmi
Associate Dean
IESE (SCEE) NUST Islamabad

Associate Dean SCEE (IESE): ……………

Dated: 31-08-2023

Principal & Dean SCEE: ……………………

PROF DR MUHAMMAD IRFAN
Principal & Dean
SCEE, NUST

Dated: 31 AUG 2023

Declaration Certificate

I declare that that this research work titled "**Water Quality Monitoring of Rawal Dam and its Tributaries**" is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources as been properly acknowledged/referred.

Student Signature: WALEED.

Student Name: Ahmed Waleed

Date: 31/08/23

Dedication

This research is a heartfelt tribute to my cherished parents, whose unwavering love and support transformed my dream of attaining this degree into a beautiful reality. No words can truly convey the profound gratitude I hold in my heart for them

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

EC	Electrical Conductivity
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
TS	Total Solids
Cd	Cadmium
Cr	Chromium
Pb	Lead
AAS	Atomic Absorption Spectrophotometer
TKN	Total Kjeldahl’s Nitrogen
NEQS	National Environmental Quality Standards
NSDWG	National Standards for Drinking Water Quality
WHO	World Health Organization
DO	Dissolved Oxygen
UNEP	United Nation’s Environmental Programme
USDGs	United Nation’s Sustainable Development Goals
USD	United States Dollar
BCM	Billion Cubic Meters
PWA	Pakistan Water Act
PCRWR	Pakistan Council of Research in Water Resources
IDS	Indus Drainage System

ABSTRACT

Rapid urbanization, industrial development and population growth have resulted in water contamination and water quality deterioration at an alarming rate. To sustain quality of life, it is imperative to detect water pollutants causing contamination. The aim of the current study was to assess the water quality consumed by the public residing around Rawal Dam and its tributaries using physicochemical and microbiological analysis. The results of water samples and sediment samples from Rawal Dam and its tributaries showed microbial contamination with microbial count for gram negative bacteria ranging from 3.30E+03 to 2.80E+05 CFU/mL in water samples while 1.01E+04 to 2.56E+05 CFU/mL in sediment samples which indicates the intrusion of sewage sludge including fecal contamination rendering it unfit for human consumption. Physicochemical analysis showed that total hardness (127-208 mg/L), phosphate (0.51-4.14 mg/L) and COD values (74-394 mg/L) at all the tributaries and Rawal Dam were exceeding the WHO limits which indicates wastewater intrusion and presence of organic matter. Chromium (4.8-14.2 mg/kg) was also detected at elevated levels from the sediments of all the selected sites of Korang, Shahdara, Rawal Dam and Nurpur stream. The experimental results obtained from this study emphasize the need for regular water monitoring of Rawal Dam and its tributaries to identify the water contamination sources. The study may also be practically used for environmental monitoring by providing stakeholders with relevant and timely information for sound decision making.

Chapter-1

INTRODUCTION

Globally, the demand for water is rising in the coming decades. According to reports, the problem will get worse by 2025 because of a lack of water for the world's population. Water problems have been reported in several places, mainly in Asian countries like China, Pakistan, Vietnam, Bangladesh, and India. Various chemicals and toxins are currently contaminating water sources. There are many different types of water pollution, including organic pollution, which is when organic matter is released into water bodies, processing of food and beverages, untreated household manure, domestic animal wastes, textiles, tanneries, etc. Most of the solid trash is immediately deposited into creeks, rivers, drains, and other waterways. Water deteriorates significantly, smells bad, and becomes contaminated (Sanjrani *et al*., 2017).

Water is being rendered amongst the most pivotal existing natural resources for the sustenance of life and it is present in abundance in the Earth's crust. It covers over 75% of the entire of the globe (Noreen *et al.,* 2019). Every living thing on earth depends on water, which is a finite and unreplaceable resource. The sources of surface and groundwater are interdependent. A significant amount of the flow in many surface streams comes from groundwater. On the other hand, groundwater is mostly recharged by water from surface watercourses. As a result, the two sources of supply are intertwined, and using one of them may reduce the amount of water available from the other. Groundwater is increasingly being used nationwide for irrigation as well as for drinking (Rahman and Mohan, 2007). Human body is made up of over 70% of the water content, and loss of it even by a fraction may cause severe dehydration and if lost in large quantities may cause death. Human body may survive up to 30 days without food however without water functionality of the organs seizes and death may occur within 3 days, this tells the essentiality of water. Dependence of life highly on water depicts the origin of life on earth was about 3.7 billion years ago along with evolution of microorganisms in water. The Uniqueness of this natural resource has made the existence of life possible on the planet therefore, it is also referred to as “the molecule that has made us”. Water is not only essential for human beings but all the biotic ecosystems which exist in this world. Industrial, agricultural recreational and domestic activities all cease to exist without the constant supply of water.

Access to fresh and clean drinking water is crucial for achieving sustainable development goals (Sharma *et al.,* 2021). Despite the abundance of water, many developing nations still lack access to this vital natural resource. Ensuring an adequate and secure supply of water requires utmost attention (Mishra *et al*., 2019). The improper disposal of waste and leachates from landfills significantly pollute a substantial portion of freshwater bodies, rendering them unsuitable for human consumption (Boadi & Kuitunen, 2002). Therefore, drinking water has become scarce for the masses (Edokpayi *et al.,* 2017). The rapid population growth in urban areas has led to increased urban water pollution, creating fierce competition among people to access the limited available fresh water (Saghir & Santoro, 2018). The demand for clean freshwater has risen globally across various sectors such as energy, domestic consumption, agriculture, and industries, mainly due to the escalating annual population growth rate. However, the occurrence of naturally derived hydro-climatic extremes like droughts and floods exacerbates the severity of this issue. Additionally, increased water demand and reduced availability contribute to the decline in water quality, especially in developing nations.

The pursuit of sustainable development goals for 2030, which strive to secure access to clean drinking water for everyone by that year, faces considerable challenges due to human-induced changes (Olsson, 2018). To gain a comprehensive understanding of the factors contributing to water scarcity, researchers have been conducting extensive examinations of water quality-related parameters over the course of several years. It is crucial to carry out these tests because they aid in determining the severity of water scarcity and direct decision-making. Water shortages are frequently caused by a lack of fresh water, but contamination and drought are also the main problems (Haldar *et al.*, 2020). Due to an expanding global population and increasing needs, there is a huge decrease in freshwater available. The need to find more fresh water will increase in importance as the world's population is predicted to reach 9.7 billion people by 2050.

More than 1.5 billion people lack access to clean drinking water, and more than 2.5

billion lack sufficient sanitation facilities, according to the World Health Organization. The ratio of freshwater use to available water sources must be considered while making plans. This index has served as a key parameter in various scientific studies and has been presented as an indicator for the United Nations Sustainable Development Goals (USDGs).

For years, the scarcity of freshwater resources has been acknowledged, and recent attention has shifted towards groundwater. Although groundwater is often perceived as a safe water source, this is not always the reality. Vanham and his co-workers conducted a study in 2018 highlighting the deficiencies of existing water resources, which encompassed issues like poor water quality, inadequate use of non-traditional water sources, and the mismanagement of polluted water.

Raising awareness among the population about the reasons for water scarcity is vital. People need to be aware of the substantial effects that water quality and quantity may have on the environment and human health (Vliet *et al*., 2017).

Freshwater supplies are under extreme stress because of both natural and human-made processes. Toxic metals, sediments, organic and inorganic compounds, and pesticides are released into bodies of water because of anthropogenic activities such as mining, agrichemical use, industrial waste, and domestic sewage. As a result, freshwater quality has drastically declined (Chen *et al*., 2019). When contaminants from home, agricultural, and industrial sources are dumped into water bodies without being properly treated, water pollution results. Water pollution has far-reaching effects, including poor water quality and tainted groundwater, surface water, and drinking water. It also disturbs aquatic habitats, which leads to the loss of many species (Colic *et al*., 2010; Niroumand-Jadidi *et al.*, 2019).

Water quality is still a major problem in many parts of the world since water sources continue to contain dangerous toxins and microorganisms. Water quality is still a major problem in many parts of the world since water sources continue to contain dangerous toxins and microorganisms. While dams are sometimes constructed as a response to water pollution, they too may be affected by issues such as excessive nutrient input, heavy metal contamination, eutrophication, and improper fishing practices. The impacts of water pollution have been extensively documented, affecting both human populations and aquatic species. The consequences of these inputs extend beyond just the country's socioeconomic activities; they also have significant implications for the native aquatic species. Anthropogenic sources play a crucial role in introducing pollutants into water bodies. Underdeveloped nations, like Pakistan, experience a considerable burden of water pollution, mainly attributed to limited resources and awareness, alongside rapid industrialization and population growth (Akbar *et al*., 2022).

1.1 National Scenario

Pakistan, being an arid country, relies heavily on river flows for its water supplies. In contrast, other South Asian countries like India, which benefit from a tropical monsoon climate with rainfall exceeding 1000 mm annually. Pakistan, on the contrary, receives an average annual rainfall of only 508 mm, making it susceptible to water shortages. Consequently, the country heavily depends on the Indus River basin for its freshwater supply, which is often overexploited. This reliance on a single basin leaves Pakistan vulnerable, particularly considering the pollution induced by human activities that pose a threat to water security. Industries and households contribute to river, stream, and nearby drain pollution through the unregulated discharge of wastewater. Aquifers and drains are also contaminated by continuous discharge of industrial effluents, pesticides, and agricultural chemicals, affecting both freshwater bodies and groundwater reservoirs, leading to the deterioration of the freshwater ecosystem.

In 2020, the World Resource Institute predicted that Pakistan would face severe water stress, with the situation worsening by 2030, ranking the country among the most water-scarce in the world. Poor water management practices and limited storage capacity are major contributing factors to this problem, with a significant amount of water being lost to the Arabian Sea each year. Transboundary disputes further exacerbate the issue. Moreover, outdated Water Distribution Networks struggle to meet the ever-increasing demand resulting from the booming population. Excessive pumping is causing rapid declines in groundwater levels. Additionally, incentives for water conservation are distorted due to extremely low tariffs, and underfunded water projects lead to low recovery and high losses. Addressing such issues requires effective water management practices.

1.2 Water Availability and Quality

Presently, Pakistan confronts not only limited water supply, but it also faces increased vulnerabilities to extreme weather events due to the exacerbation of global climate change. Concurrently, water demand is steadily rising due to extensive urbanization and a population boom, resulting in an imbalance that has pushed the country into a severe water shortage.

The alteration of water quality is influenced by three main factors: the location of the water source, the extent of anthropogenic activities in that area, and water resource management practices. Assessing specific physicochemical and microbiological parameters like temperature, dissolved oxygen, and the presence of minerals helps determine water quality. In Pakistan, water quality is rapidly deteriorating as most water sources, including rivers, canals, and underground aquifers, are highly contaminated due to industrial, municipal, and domestic discharges. Additionally, agricultural practices contribute to the problem, with the intensive use of harmful chemicals like pesticides, insecticides, and fertilizers (Shah *et al*., 2022).

1.3 Socio-Economic Status

A recently published report titled "Water Crisis in Pakistan" shed light on the socio-economic implications of the water crisis. The report presented eye-opening statistics, emphasizing the significant risks associated with Pakistan's over-reliance on a single river basin, rendering the country highly vulnerable.

Pakistan's water withdrawal rate ranks as the 8th lowest globally, generating per cubic water, in stark contrast to countries like the Republic of Korea (37th), Malaysia (35th), China (71st), and Turkey (87th). In contrast to world, Pakistan lags significantly, with merely 1% of wastewater being treated, making it one of the worst countries in terms of treatment rate. This situation stems from poor water management practices and negligible recycling efforts.

1.4 Challenges and Major Sources of Water Contamination

The water crisis in Pakistan is primarily attributed to several factors, including a rapidly growing population, the occurrence of extreme climatic events such as droughts and flash flooding, inadequate water management practices, challenges in the agricultural sector, insufficient infrastructure, and water pollution. The convergence of these issues has not only intensified the water crisis but has also led to heightened tensions among different provinces within the country.

1.5.1 Unplanned Urbanization

The deteriorated water quality in Pakistan is primarily threatened by rapid population growth and unplanned urbanization. Over the past five decades (1970-2020), Pakistan has witnessed a population boom, increasing 2.6 times, propelling the country from the 9th rank to the 5th in terms of population size. In comparison, Bangladesh experienced a population growth rate of 1.5 times during the same period.

This surge in population has led to a corresponding increase in water usage rate by 0.7%. The demand for water is surging while the replenishment rate is diminishing. According to projections, the population growth rate is expected to increase by 53% prior to 2050. This scenario raises concerns over water management inefficiency.

1.5.2 Climate Change

Disturbed monsoon patterns, rising average temperatures, glacier melting, flooding, and droughts have been observed with intensified frequency. These calamities have caused severe loss of life and inflicted damages worth over 10 billion USD to infrastructures, as seen in the 2010 floods.

Droughts have also increased in Baluchistan, with Quetta experiencing an 8-year drought from 1997 to 2005. Projections indicate that climate change may alter aggregate water flows, with a decline in water flow and an increase in extreme events. Indus River basin is Pakistan's major water resource, relies on rainfall and glacial melt, making it highly susceptible to climate change. Already, the river's flow reduces to just a canal by the time it reaches Sindh province, forcing many farmers to migrate to urban areas due to the lack of water availability for sustaining agricultural activities. The Indus River accounts for

50-80% of its total load from ice and glacier melting, making it crucial for Pakistan's water supply.

1.5.3 Poor Water Management

The agricultural sector in Pakistan accounts for over 80% of total water usage, focusing on four major crops - wheat, cotton, rice, and sugarcane. However, despite contributing only 5% of the country's GDP in terms of revenue, the productivity of the agriculture sector remains notably low compared to other developed agrarian economies.

One of the factors contributing to this inefficiency is the minimal pricing of water canals, leading to the misuse of this valuable resource. Additionally, while the farm sector accounts for half of the country's employment, it comprises only 1/5th of the GDP, generating less than 0.1% of the total tax revenues. As a result, limited finances are available for maintaining irrigation systems, which further exacerbates water wastage due to substandard water management practices.

Regrettably, Pakistan's irrigation systems are among the most inefficient globally, with an efficiency rate of just 39%. Out of the total available water of 143 BCM (billion cubic meters), only 55 BCM is utilized. This inefficiency stands in stark contrast to other countries, where the world's average efficiency is 40%, while Pakistan's efficiency is merely 9%.

1.5.4 Water Pollution

In Pakistan, drinking contaminated water has become a major issue, putting 60% of the population at risk of contracting diseases that could be fatal. Patients with waterborne diseases occupy roughly one-third of hospital beds and are responsible for 40% of all premature deaths in the nation. Disturbingly, statistics from 2017 indicate that due to inefficient sanitation and inadequate water supply, around 60,000 people died prematurely, and half of them were children aged between 2 and 5 years old.

Currently, Pakistan is facing a resurgence of diseases like diarrhea, polio, hepatitis A and E, and dengue fever. Diarrhea alone is responsible for 54,000 deaths, which means that every hour a child dies in Pakistan due to diarrhea. The economic cost of floods, poor water sanitation, and droughts is estimated to be around 12 billion USD, accounting for

4% of the total country's GDP. These figures highlight the urgent need for effective measures to address the water pollution and sanitation challenges in Pakistan.

1.5.5 Water Policies

Pakistan’s first national water policy was formulated in year 2018, for the first time it was acknowledged that water is a finite resource, and it must be protected. It emphasized on the recovery of the water management and irrigation systems in the country. However, these initiatives still lack many aspects and completely ignore the scientific proportion, water quality, clear referencing, sustainable development goals, gender inclusion and targets etc. these gaps must be addressed to formulate a comprehensive water policy which may be realistically implemented. Also, the need is for political will, timeliness, financial capital and capacity.

1.5.6 Water Distribution Issue within Provinces

Due to increased water scarcity problem in Pakistan, conflict have arose among the different provinces regarding the distribution of water. Under Pakistan water accord 1991 canal water is being distributed among the provinces. A total volume of 145 BCF water is distributed in between 4 provinces; out of which 48% is allocated to Punjab, 42% to Sindh, 7% to Khyber Pakhtunkhwa and around 3% to Baluchistan. This accord was defined as per ample supply of water however it overlooks the apportionments for water shortage. Over the course of a year in months of lesser rainfall and excessive heat supply is reduced thus causing the conflict in between upstream province Punjab and downstream provinces Sindh and Baluchistan. Punjab is alleged for water theft by Sindh and Baluchistan blames Sindh for not providing its share from Sukkur and Guddu barrages.

1.5.7 Estimation of Pollution in Rivers and Dams of Pakistan

Rivers and Dams serve as crucial channels for transporting fresh water and minerals throughout the entire country. They play a significant role in influencing the hydrological cycle by providing outlet channels for surface runoff. Despite being blessed with one of the world's largest glaciers, Pakistan still ranks 36th among water-stressed countries.

Most freshwater lakes in the region are facing vigorous pollution, while those that remain unpolluted are under severe threat to their ecological status. The water quality in many reservoirs has deteriorated, falling below the standards set by the World Health Organization (WHO). Moreover, increasing temperatures are causing glaciers to lose their flora and fauna at an alarming pace (PCRWR, 2020). These challenges highlight the urgent need for sustainable water management and conservation efforts in Pakistan.

1.6 Present Study

This research aimed to evaluate the water quality of Rawal Dam Lake and its tributaries. Rawal Dam covers an area of approximately 8.75 km^2 with a depth of 31 m. The dam's catchment area encompasses 268 km2, divided into four primary tributaries: Nupur Stream, Shahdara Stream, Jinnah Stream, and Korang River. These tributaries receive runoff from several other small channels, which unfortunately carry a significant number of contaminants due to the presence of poultry farms, sewage drains, and solid waste dumping sites near the streams.

Various initiatives have been undertaken to improve the water quality of the dam, focusing on controlling wastewater intrusion and implementing regular water quality monitoring projects. Previous studies in different countries have indicated that untreated sewage and industrial effluents are major sources of pollution (Singh *et al*., 2005). Globally, algal blooms, biodiversity loss, and oxygen depletion resulting from high concentrations of chemical and biological contaminants have been observed.

The contamination of Rawal Dam is primarily attributed to the discharge of untreated waste from adjacent areas (Aftab, 2010). Additionally, excessive irrigation in agriculture leads to the washing away of toxic chemicals like pesticides and herbicides, which find their way into the dam (Iram *et al.*, 2009). Although several studies have been conducted to monitor the water quality of Rawal Dam, little research has been focused on the streams and the main sources of pollution (Azizullah *et al*., 2011; Waseem *et al*., 2014). More comprehensive efforts are needed to address these issues and safeguard the water quality of the dam and its surrounding tributaries.

1.7 Study Objectives

1. Walkthrough surveys for Identification of sampling points
2. Monitoring of microbial and physicochemical characteristics of the Rawal Dam and its tributaries.
3. Heavy metals determination of the sediments using Flame Atomic Absorption Spectrophotometry (FAAS)

Chapter-2

LITERATURE REVIEW

The Indus River including Ravi, Chenab, Sutlej and Jhelum and Sutlej and western tributaries like the Kabul and Swat, forms Indus Drainage System (IDS) which is the Pakistan's largest inland River System. The total drainage area of River Indus is 1,165,000 km^2. The annual flow of the river is around 6600.01 m^3/s. The Indus Drainage System is playing a major role in driving economy of Pakistan by meeting industrial, domestic, and agricultural water demands. It also supports plains, arid farmland, and temperate forest ecosystems across the country. The Indus River Basin has an annual available water resource of about 229 billion cubic meters (BCM).

The water consumption breakdown in the basin is as follows: the industrial sector consumes about 80%, domestic consumption accounts for approximately 23%, and the agriculture sector, being the largest water consumer, utilizes 69%. Recent developments in industrialization, modern agricultural activities, and urbanization along the IDS basin have put immense pressure on the sewage system. This has led to the direct discharge of industrial and domestic effluents into the river system, causing serious pollution in the river water and surrounding atmosphere.

Among the main eastern tributaries, the Soan River in northern Punjab is a significant watershed, originates from Bun village situated in Murree Chemical drainage from the Industrial area of Sihala poses a direct threat to the freshwater ecosystem in the Soan River by deteriorating water quality through the contamination of untreated effluents.

River Ravi, running approximately 725 km and forming a transboundary river between India and Pakistan, serves as the third main eastern tributary of River Indus. With a total basin area of 14,442 km^2 and a mean annual flow of 267.50 m^3/s, it plays a crucial role in providing water for irrigation and domestic use in Punjab, Pakistan. However, the overall pollution level in the Indus River is alarmingly high, primarily due to the careless disposal of large amounts of urban and agricultural runoff, drainage sewage, and industrial effluents from both countries. The drainage basin of the associated IDS tributaries has an average available water of about 229 BCM, which significantly contributes to driving Pakistan's economy, sustaining the country's ecosystems of temperate forests, plains, and arid farmlands, and supporting overall economic growth. Nevertheless, increasing anthropogenic activities along the Indus basin are posing serious threats to riverine water and the surrounding atmosphere. Developing countries face additional challenges related to water quality problems, mainly due to insufficient resources and management facilities (Farid *et al*., 2014).

Pakistan has already utilized a significant portion of its available water resources and may soon transition from being categorized as water-stressed to water-scarce. Water quality is a critical factor that impacts human and animal health. It is influenced by both anthropogenic inputs and natural processes, which include weathering of sediments, rocks, and natural disasters. Natural catastrophes may result in the breakdown of sewage and sanitary systems, which will lower the quality of the water (Hashmi *et al*., 2009).

Constant pollution discharge from anthropogenic activities is exacerbated by climate change, which also has an impact on natural processes like runoff within a basin (Singh *et al*., 2004). Addressing water quality concerns in Pakistan and other developing countries requires a comprehensive approach, considering both natural and human-induced factors.

River Ravi, spanning around approximately 725 km and forming a boundary between India and Pakistan, boasts a mean annual flow of 267.50 m^3/s and encompasses a total basin area of 14,442 km^2. Within Punjab, Pakistan, the river serves as a crucial water source for irrigation and domestic purposes. Unfortunately, its overall pollution level has been reported as very high, primarily due to the negligent disposal of significant quantities of industrial effluents, urban and agricultural runoff, and drainage sewage from both countries.

In the broader context, the drainage basin of associated IDS tributaries contributes to an annual water availability of about 229 BCM, playing a pivotal role in Pakistan's economy by meeting the demands for agricultural, domestic, and industrial water use, while also supporting the ecosystems of temperate forests, plains, and arid farmlands. However, the intensifying anthropogenic activities along the Indus basin are posing serious threats to the riverine water and the surrounding atmosphere.

Water quality-related issues in developing countries are exacerbated due to a lack of resources and inadequate management facilities (Farid *et al.*, 2014). Pakistan has already utilized a significant portion of its available water resources and may soon change from being a water-stressed country to becoming water scarce. The quality of water plays a crucial role in influencing the health of both humans and animals. Water quality is influenced by both anthropogenic inputs and natural processes, which include the weathering of sediments, rocks, and occurrences of natural disasters. Natural disasters may lead to the destruction of sewage and sanitary systems, further deteriorating water quality (Hashmi *et al.*, 2009).

The rapid pace of urbanization and continuous industrialization has resulted in the limited availability of natural resources, particularly freshwater resources. The global increase in population has further accelerated the decline in the availability of fresh water. The scarcity or limited access to water has driven the need for alternative resources to meet the growing water demand (Woltersdorf *et al.*, 2018). Previous studies have indicated that a massive 2 million tons of effluents from various sources are discharged into the world's water resources daily (Kahlown *et al*., 2003). Industrial effluents are a major source of contamination, releasing tons of toxic chemicals such as As, Fe, Cd, Ni, Zn, Mn, Co, Ag+, and Hg (Farooqi *et al.,* 2007), along with different microbial contaminants, including coliform, fecal coliform, and *E. coli* (Nickson *et al*., 2005; Sial *et al*., 2006; Farooqi *et al.,* 2007; Ullah *et al*., 2009).

According to a UN report in 2015, 780 million people still lack access to safe drinking water, and by 2025, the world population is expected to face severe water shortages (Azizullah *et al.,* 2011). In Pakistan, due to poor management facilities, approximately 60% of fresh water is wasted, while the remaining water is available for domestic and industrial use (Bhutta *et al*., 2005).

Awais *et al.* (2016) conducted a study to determine how urbanization affected Rawal Lake's water flow and quality. The results showed that the catchment region's population increased over an 11-year period (1998–2009), and there were changes in the land use patterns, including a decline in forest area (from 54% to 48%) and an increase in built-up land (from 14.7% to 23.12%). Water input into the lake reduced despite no appreciable change in the local precipitation, demonstrating the impact of urbanization on inflows. The investigation also discovered that the water quality in two significant tributaries, Korang River and Nurpur Stream, had declined to the point that it was unsafe for human consumption.

In a study, using statistical research, it was looked at the soil quality metrics of Rawal Lake and its nearby tributaries, such as Bari Imam, Chattar Stream, Jinnah Stream, Shahadra Stream, and Nurpur Stream (Firdous *at al.*, 2016). The study demonstrated significant difference ($p < 0.05$) in the parameters at various sampling sites, indicating that land use patterns and seasonal variations strongly influenced soil and water quality.

In another study, the impact of anthropogenic activities on water quality and bacterial diversity in Rawal Lake, Islamabad, was assessed. The researcher collected grab samples from ten different locations in the lake and tributaries over an eight-month period. Various physicochemical parameters were evaluated to determine water quality characteristics. The results indicated higher values of these parameters in the tributaries compared to the lake, primarily due to the direct discharge of poultry and household waste into the tributaries (Saeed & Hashmi, 2014).

In another study, the risk assessment of sediments and the enrichment of heavy metals has been examined across Korang river. Over the course of two years, sediment samples were taken seasonally from 21 distinct sites. The investigation showed that anthropogenic activities were mostly to blame for the high levels of manganese (Mn) pollution and moderate levels of iron (Fe) contamination. Additionally, levels of nickel (Ni) and zinc (Zn) were higher than allowed, suggesting a possible danger to aquatic life (Zahra *et al.*, 2014).

The risk assessment and statistical distribution of a few heavy metals in sediments from Rawal Lake were studied by Iqbal *et al.* (2013). The purpose of the investigation was to pinpoint the origin of heavy metals in recently deposited sediments. Cluster analysis and principal component analysis. The study found that several physicochemical parameters did not correlate positively, likely due to human activity. Furthermore, most of the parameters exceeded the permissible limits set by the World Health Organization (WHO).

2.1 Water Quality Parameters

2.1.1 pH

The measurement of pH reflects the acidity or alkalinity of water sources and may result in sour or alkaline tastes. pH is determined by the concentration of hydrogen and hydroxyl ions in a solution, using a logarithmic scale. This measurement indicates whether the solution is alkaline i.e. $pH > 7$ or acidic with $pH < 7$. Typically, the pH of freshwater ranges between pH 6 and pH 8. The pH level significantly influences the availability and solubility of nutrients that aquatic organisms require for their utilization. A rise in pH in a stream or water body may be attributed to soils rich in carbonates, such as limestone, as well as the presence of nitrate-based fertilizers. On the other hand, phosphoric acid, which is present in phosphorous fertilizers, frequently results in a drop in pH. Additionally, the decomposition of household garbage may result in the production of carbonic acid, which lowers the pH of rivers.

2.1.2 Temperature

Latitude, altitude, season, time of day, air circulation, cloud cover, and the flow and depth of the water body are some of the variables that affect surface water temperature. As a result, temperature is a key factor affecting a variety of physical, chemical, and biological processes in water. The pace of chemical reactions and the evaporation and volatilization of compounds from water both tend to accelerate as water temperature rises. Additionally, higher temperatures reduce the solubility of gases in water, such as oxygen, carbon dioxide, nitrogen, methane, and others. The functioning of aquatic organisms heavily relies on temperature, affecting their metabolic rate and respiration rates. For instance, in warm water, respiration rates are high, leading to increased oxygen consumption and promoting the decomposition of organic matter. In addition, higher temperatures promote the growth of organisms, particularly bacteria and phytoplankton, whose populations can multiply quickly in an environment with adequate nutrients. Algal blooms may then develop, and water turbidity may rise as a result of this.

2.1.3 Turbidity

Turbidity is a term used to describe the amount of fine suspended matter in water, including clay, silt, organic matter, and inorganic particles. Turbidity is used to quantify the clarity of water. Furthermore, the presence of plankton and other tiny organisms may be a factor in the increased turbidity levels. Furthermore, siltation, a substantial contributor to turbidity, may be caused by human activities, notably agriculture close to riverbanks. The disruption of the riverbed caused by sand mining is another human-related element that may cause turbidity levels to increase (Ullberg, 2015).

Reduced availability of macroinvertebrates might result from high levels of turbidity in water. Aquatic organisms' prey-predator relationships could be harmed by the increased turbidity because some species rely on others for food. As a result, the increased turbidity may make it more difficult for these organisms to find and catch their food.

2.1.4 Electrical Conductivity

The vital indicator of water quality is electrical conductivity. The quantity of soluble salts in the water supply is shown by the EC value, which is valuable information because it may have a big impact on the flavor of drinking water. We can determine the concentration of different solutions, look for probable pollutants, and analyze the overall purity of the water using conductivity data. The ability of water to conduct an electrical current is referred to as its electrical conductivity (EC), and the quantity of ions in the solution affects this attribute. The conductivity increases along with the ion concentration. As a result, EC becomes a crucial factor in deciding whether water is suitable for uses like irrigation and firefighting.

2.1.5 Nitrate

Natural nitrate concentrations in surface waters are frequently less than 1 mg/L, and in some cases considerably lower. Nitrate is typically safe at these concentrations, but when it rises too high, aquatic organisms may have negative health impacts. Harmful algal blooms (HABs) may develop when excessive nutrients, such as nitrate and phosphorus, are washed into water bodies. These blooms have the potential to kill fish by producing toxic byproducts and reducing the amount of dissolved oxygen in the water. The problem becomes especially worrying when such algal blooms take place in water bodies that are sources of drinking water.

Drinking water with high nitrate concentrations may potentially have negative health effects, especially in young children. Having a high nitrate concentration in your water may lead to (Aydin, 2007). Nitrate levels in water sources must be closely monitored and kept under control to protect aquatic life and public health.

2.1.6 Dissolved Oxygen

Most aquatic species require dissolved oxygen (DO), as crucial component for life. It is one of the fundamental indicators of water quality and is measured for a variety of reasons depending on the surroundings. Since aquatic life depends on DO for survival, it provides a clear indication of a water body's capacity to support creatures. However, there may be a DO imbalance, especially in the presence of harmful algal blooms (HABs).

Microbes are essential to the treatment process at wastewater treatment facilities because they consume garbage and turn it into safe byproducts. Because these microorganisms rely on DO to break down pollutants like organics or ammonia found in wastewater, DO is crucial to this process.

Chapter-3

MATERIALS AND METHODS

The flowchart shown below shows how this investigation was carried out in four distinct phases. The main goal of this study was to monitor the soil, sediment, and water quality to determine whether the water in the chosen study region was fit for drinking and other intended uses. The study also sought to determine the degree of anthropogenic activity in the vicinity of the Rawal Dam region. The focus of the study was on analyzing microbial, physicochemical, and heavy metal concentrations in the water and soil/sediment samples to draw essential conclusions and provide necessary recommendations based on the findings.

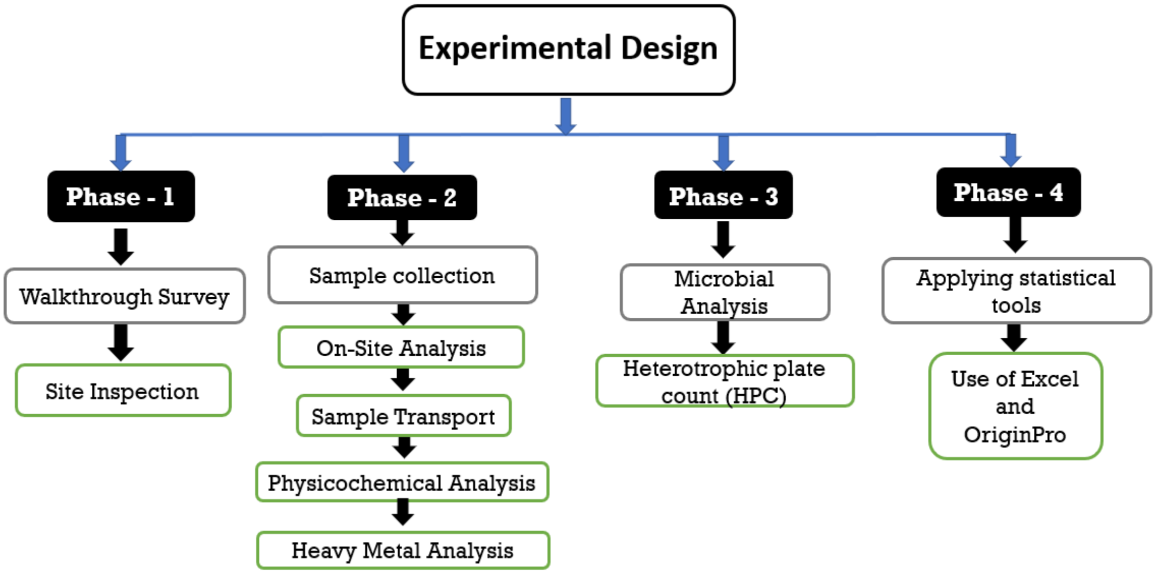

Figure 3.1: Experimental Design

3.1 Data Acquisition and General Overview

To gather data, walkthrough surveys were conducted to gain a comprehensive understanding of the study area and identify suitable sampling locations. A thorough site inspection was then carried out, and samples of water, soil, and sediment were collected in triplicates from the designated sites specified in table 3.1. On-site parameters such as pH, temperature, dissolved oxygen, and electrical conductivity were measured at each sampling site. Subsequently, the collected samples were transported to the laboratory for further analysis, which encompassed microbiological parameters, physicochemical properties, and heavy metal analysis following the standards set by APHA (American Public Health Association).

3.2 Study Area Map and Sampling Points

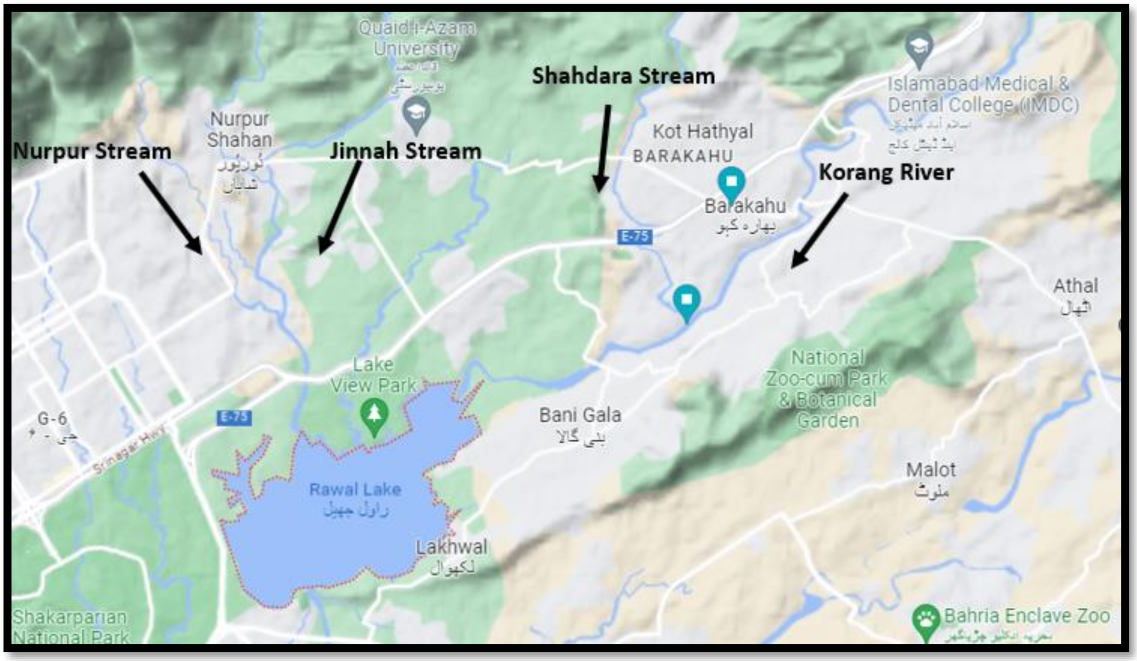

Figure 3.2: Google map of Study Area

3.3 Microbiological Analysis

To conduct microbial analysis, sterile Pyrex glass bottles with a volume of 500mL were prepared. The sterilization process involved rinsing the bottles, followed by autoclaving at 121°C for 15 minutes, and then oven drying for two hours at a temperature of 115°C. The same procedure was applied to the sampling bottles used for collecting physicochemical and soil/sediment samples. After the bottles were completely dried, they were tightly sealed and transported to the sampling stations in an icebox to maintain the integrity of the samples.

3.4 Methodology Adopted for Sample Collection

Water samples were collected using a simple grab sampling approach, and the collection was carried out in biological triplicates from their respective sampling sites. Similar approach was done for the collection of sediment samples, which were later subjected to heavy metal analysis following microbial analysis. Grab samples were obtained within a single time frame, usually not exceeding 15 minutes, and were collected manually. In some cases, automated samplers were used for frequent sampling requirements. During sample collection, GPS coordinates were recorded using GARMIN GPSMAP 64x, and on-site parameters like Temperature, Dissolved Oxygen (DO), Electrical Conductivity, and pH were analyzed using Lutron multimeter WA-2015. Once sampling was completed, the obtained samples were promptly preserved and transported to the laboratory.

To ensure sample integrity, they were stored in an icebox during transportation. Sample collection procedures followed the Standard Operating Procedures (SOPs) devised by the Environmental Protection Agency (EPA). Before filling the sample bottles, they were rinsed with sampling water to ensure complete homogenization with the sample water, leaving approximately 2 cm of headspace in the bottles before tightening the caps.

Table 3.1: List of Sampling sites along with GPS Coordinates

Sampling Sites	Latitude	Longitude
Korang River Upstream	33°43’23” N	73°10’0” E
Korang River Midstream	33°43’11” N	73°9’42” E
Korang River Downstream	33°43’13” N	73°9’33” E
Shahdara Upstream	33°46’44” N	73°10’8” E
Shahdara Midstream	33°46’33” N	73°9’55” E
Shahdara Downstream	33°46’41” N	73°10’10” E
Nurpur Upstream	33°44’0” N	73°7’4” E
Nurpur Midstream	33°44’43” N	73°6’21” E
Nurpur Downstream	33°44’39” N	73°6’57” E
Jinnah Upstream	33°46’1” N	73°8’6” E
Jinnah Midstream	33°44’2” N	73°8’38” E
Jinnah Downstream	33°44’1” N	73°8’39” E
Rawal Dam Upstream	33°41’30” N	73°6’21” E
Rawal Dam Midstream	33°42’21” N	73°7’26” E
Rawal Dam Downstream	33°41’44” N	73°6’48” E

Sampling was conducted over a period of 5 months, specifically from August 2021 to December 2021. To ensure comprehensive data, three distinct locations were identified at each sampling station: upstream, midstream, and downstream, based on their accessibility. Upon reaching the laboratory, the collected samples were subjected to microbiological analysis applying the Heterotrophic Plate Count (HPC) technique. Subsequently, physicochemical analysis was carried out, which included parameters such as Nitrite-Nitrogen, Nitrate-Nitrogen, Total Kjeldahl Nitrogen, Phosphate-phosphorus, Total Alkalinity, Total Hardness, Chemical Oxygen Demand, Total Suspended Solids, Total Dissolved Solids, and Total Solids.

3.5 Heterotrophic Plate Count Technique

HPC (Heterotrophic Plate Count) is a laboratory technique used to quantify the living bacterial species present in the specimen being analyzed. This method involves the use of various selective and non-selective agar media to promote or inhibit the growth of specific bacterial types. In this particular study, MacConkey agar, a selective medium, was employed to inhibit the growth of gram-negative enteric bacteria like *Escherichia coli*, *Salmonella typhimorium*, and *Enterobacter aerogenes* etc. To prepare the MacConkey agar, it was weighed and mixed thoroughly with distilled water using a magnetic stirrer. The mixture was then autoclaved at 121°C and 15 psi for 15 minutes. After cooling to 50°C, the agar solution was poured into petri dishes and left in a level two biological safety cabinet to solidify. Sterility tests were performed by incubating the plates at 37°C for 24 hours, and if no growth was observed, the plates were deemed sterile and ready for sample spreading (APHA, 2021).

Water, soil, and sediment samples collected from designated sampling locations were then subjected to serial dilutions to bring the bacterial colony growth within a countable range (30-300 colonies). Three-fold 10^{-3} dilutions were prepared using Phosphate Buffer Saline (PBS), where 1 mL of the sample was mixed with 9 mL of autoclaved PBS in a sterile test tube using a vortex mixer. From each dilution, 100µl was spread onto the prepared media plates and then incubated at 37°C for 24-48 hours to allow bacterial growth. After incubation, bacterial colonies were counted using a 560 Suntax Colony Counter.

Chapter-4

RESULTS AND DISCUSSIONS

The objective of this study was to delve into the escalating issue of water pollution in the suburban areas surrounding Rawal Dam, prompted by the swift urbanization. A particular focus was directed towards the microbiological aspect of the examined water bodies, in addition to conducting physicochemical and heavy metal analysis of soil and sediment samples. All the parameters underwent testing in alignment with the APHA 2021 standards, and a comparison was drawn against WHO, NSDWQ and NEQS standards for drinking water quality to evaluate the current situation.

Table 4.1 List of Physicochemical Parameters and Standards

Parameters	Units	WHO	NSDWQ	NEQS
pH	-	6.5-8.5	6.5-8.5	6-9
Dissolved Oxygen	mg/L	6.5-9	-	-
Turbidity	NTU	5	5	-
COD	mg/L	-	-	150
Phosphates	mg/L	0.3	-	-
Total Hardness	mg/L	100	500	-
Total Alkalinity	mg/L	200	200	-
Nitrite-Nitrogen	mg/L	3	3	-
Nitrate-Nitrogen	mg/L	45	≤50	-
TKN	mg/L	-	-	35
TDS	mg/L	<1000	-	3500

Table 4.2 Standards Heavy Metals in Soil/Sediment

Heavy Metal	WHO	USEPA	WSRA
Cadmium (Cd)	3	<6	0.3
Chromium (Cr)	100	<25	71
Lead (Pb)	100	<40	16
Arsenic (As)	20	ND	10

4.1 Walkthrough Survey and Site Inspection

Conducting site inspections and walkthrough surveys played a pivotal role in identification of the study area and pinpointing the suitable sampling locations. Vital observations were meticulously recorded to establish connections with the outcomes of the tested parameters mentioned earlier.

Site 1: Korang River

At Korang river upstream slight algal growth, excessive vegetation and construction in progress were observed. Besides this plastic waste such as shopping bags and wrappers were also noticed.Midstream and downstream were found more deteriorated as compared to upstream with excessive intrusion of sewerage and wastewater from the nearby households.

Figure: 4.1 Korang River observations

Site 2: Shahdara Stream

The upstream section of Shahdara Stream exhibited greater contamination and turbidity, characterized by rocky terrain and abundant vegetation. However, as we progressed from midstream to downstream, the water's turbidity diminished. Moreover, a notable increase in anthropogenic activities, along with the presence of animal waste and wastewater intrusion, was observed in the upstream region.

Figure 4.2 Shahdara Stream observations

Site 3: Jinnah Stream

Turbidity was noticeable in the water of Jinnah Stream, and downstream areas exhibited clear signs of algal growth, likely influenced by the presence of animal waste, as observable animal manure was also identified.

Figure 4.3 Jinnah Stream observations

Site 4: Nupur Stream

The water quality in Nurpur Stream appeared significantly degraded, with a notable presence of extensive algal growth in the upstream section. Additionally, observations revealed instances of littering, car washing, human interference, and open drains in the mid-stream and downstream areas.

Figure 4.4 Nurpur Stream Observations

Site 5: Rawal Dam

In the upper reaches of Rawal Dam, there was a noticeable increase in boating activity, leading to the water becoming muddy and displaying high turbidity levels. The presence of a large number of tourists was evident, and unfortunately, littering was also observed in the area. However, as we moved to the middle and lower parts of the stream, the water began to appear relatively clearer.

Figure 4.5 Rawal Dam observations

4.2 On-site Analysis

In the process of collecting samples, various on-site parameters including pH, dissolved oxygen (DO), electrical conductivity (EC), and temperature were evaluated. This analysis was carried out using the Luton multimeter model W.A. 2015

4.2.1 pH

pH is a fundamental but highly significant parameter in water quality assessment, serving as an indicator of whether water is acidic or alkaline in character (Sailaja *et al.*, 2015). The neutrality of water falls within the pH range of 6.5 to 8.5, ensuring its suitability for various uses without adverse effects. pH was assessed across all 15 designated sampling sites, and the outcomes demonstrated conformity with the permissible guidelines set by the World Health Organization (WHO) as shown in Figure 4.6. In a similar study, the pH of water in Rawal Dam and its tributaries were found between 6-8 (Akbar et al., 2022).

4.2.2 Dissolved Oxygen

Dissolved Oxygen refers (DO) to the quantity of oxygen present in water in a dissolved state, constituting a vital parameter for gauging both physical and biological processes occurring within aquatic environments. Dissolved oxygen levels within water may be influenced by various factors including contact with the atmosphere, photosynthesis, and aeration. Water movement plays a significant role in DO concentration, with higher movement correlating to increased DO content. Comparatively, cooler and fresher water tends to contain higher level of dissolved oxygen than warmer and saline water due to oxygen escaping more readily in warmer water with vigorous movement. The analysis of DO values within the vicinity of Rawal Dam is presented in Figure 4.7. The findings of the current study indicate that DO levels at all sampling stations exceeded the permissible limits for drinking water (6.5-8.5), with exceptions observed at Korang River Midstream, Korang River Downstream, and Nurpur Upstream.

4.2.3 Electrical Conductivity

Electrical Conductivity (EC) defines the capability of water to conduct electric current, serving as a gauge of the concentration of dissolved ionic substances within the water. The presence of total dissolved solids in water significantly influences its EC measurement. Throughout this investigation, most sites exhibited EC readings that exceeded the acceptable limits. However, the sampling sites for Korang River and Nurpur Stream demonstrated EC measurements within the permissible range of 600μs/cm, adhering to the guidelines set by the WHO. The reason behind this observation could be attributed to the elevated concentration of dissolved ions stemming from ongoing recreational activities and the presence of construction waste, as illustrated in Figure 4.8. The EC of the Rawal Dam lake was found between 800-1000 Us/cm (Chandio H., et al., 2019).

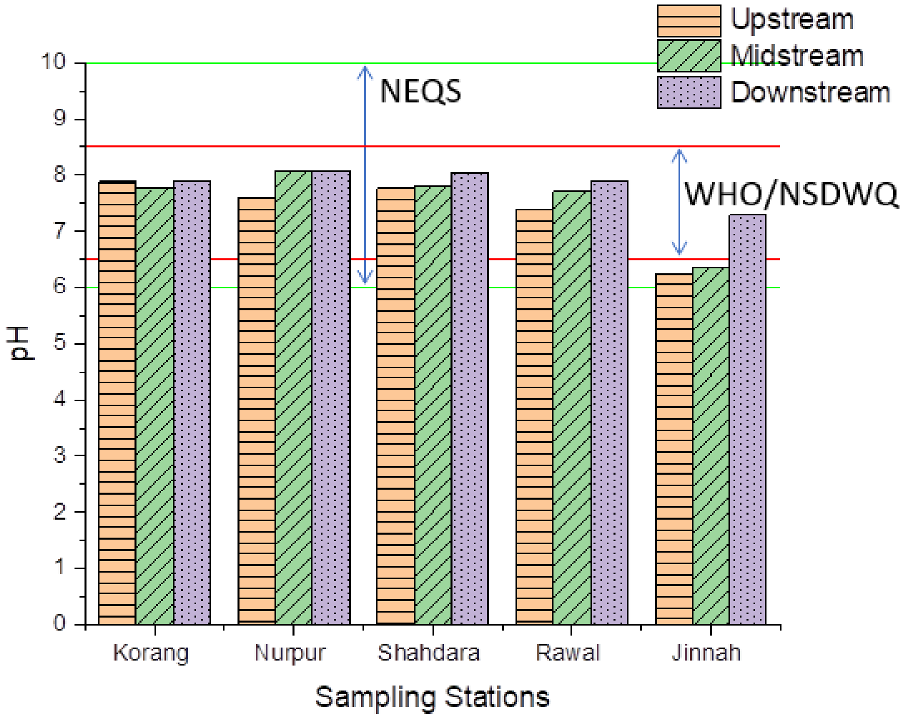

Figure 4.6 pH Variation in Water at Sampling Stations

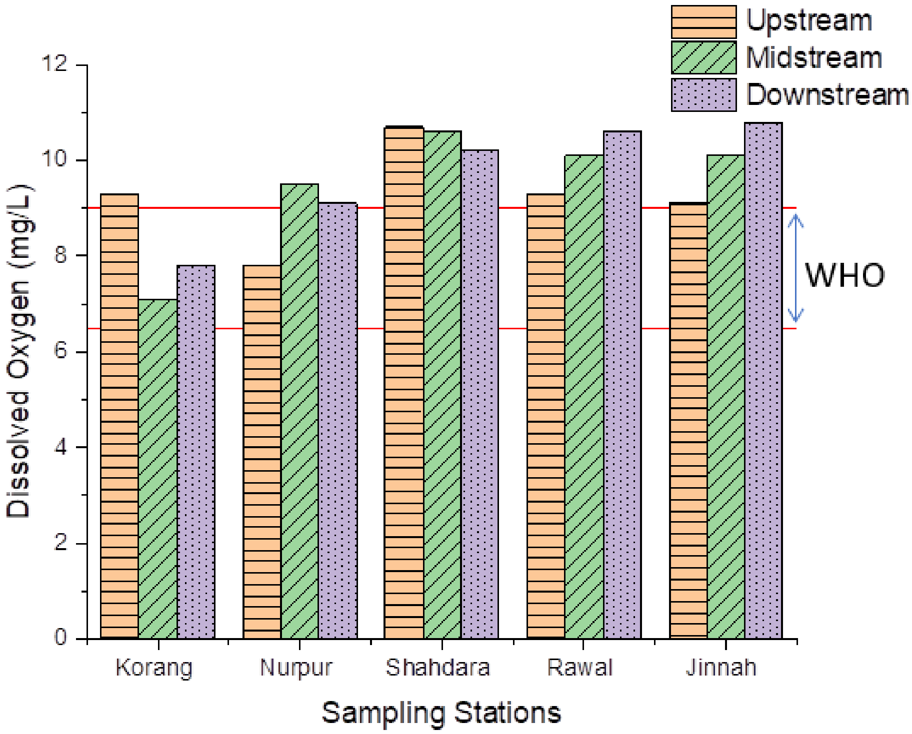

Figure 4.7 DO Variation in Water at Sampling Stations

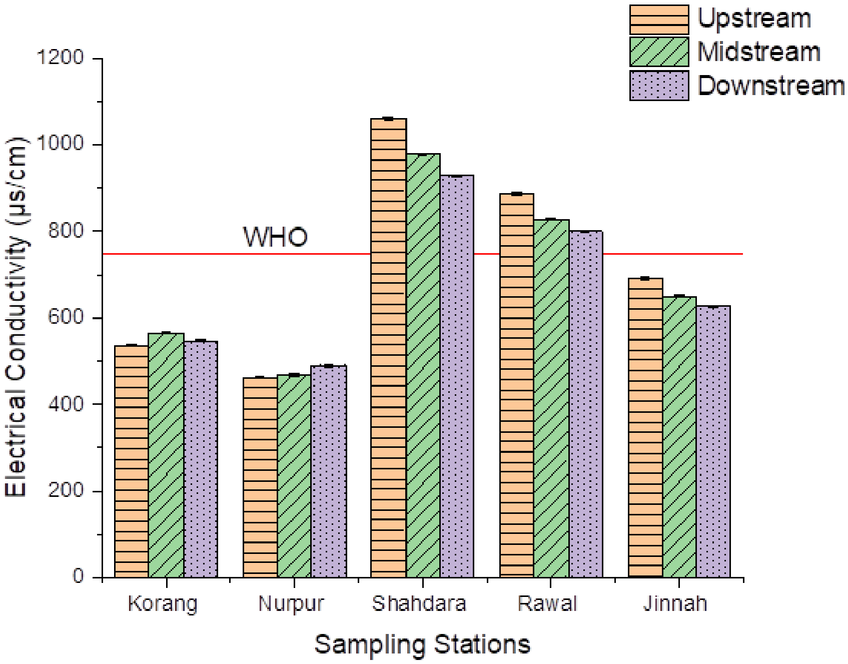

Figure 4.8 EC Variation in Water at Sampling Stations

4.3 Microbiological Analysis

Following the transportation of both water and soil/sediment samples, a comprehensive microbial analysis was conducted to examine the microbial profiles. Growth was observed and colonies were enumerated across all sampling sites, subsequently computing the mean values of colony forming units per milliliter (CFU/mL) of the samples. The computed values were then presented in graphical format.

Upon scrutinizing the graphs detailing the microbial profiles, a clear pattern of heightened microbial contamination emerges across all sites, with the exception of Jinnah Stream, particularly in its water samples. This notable divergence may be attributed to the lower population density in the Jinnah Stream area, resulting in less pronounced microbial contamination. This observation serves as a significant indicator of the presence of fecal and sewage intrusion in the water bodies that feed into Rawal Dam, including the dam itself, as indicated in Figure 4.9.

Similarly, when examining sediment samples, the prepared dilutions revealed a noteworthy discrepancy in bacterial growth when compared to water samples, signifying a higher prevalence of bacterial presence in the sediment samples. This disparity is visually illustrated in Figure 4.10.

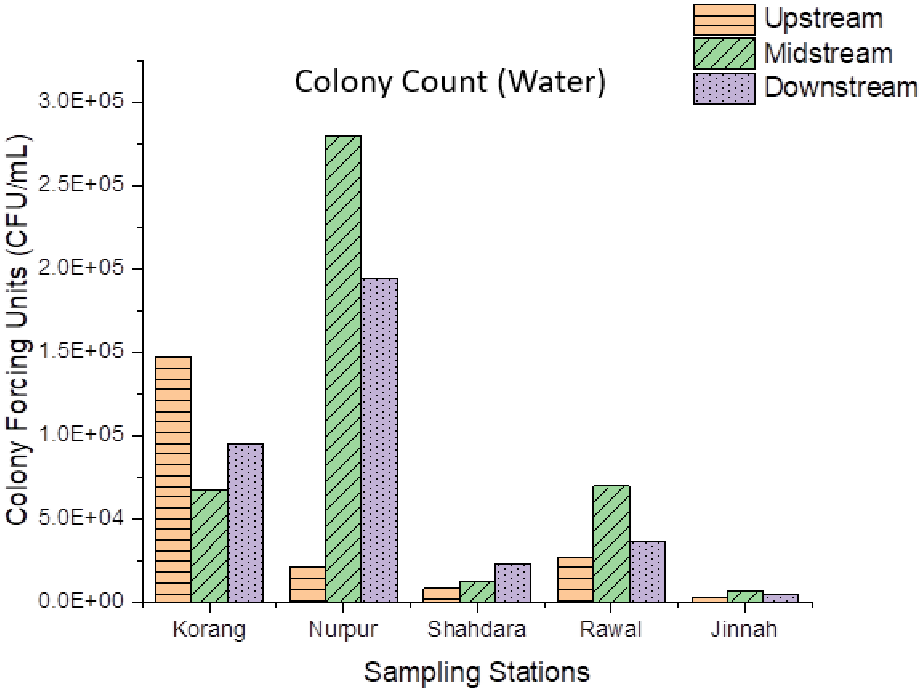

Figure 4.9 Colony Count of Water Samples

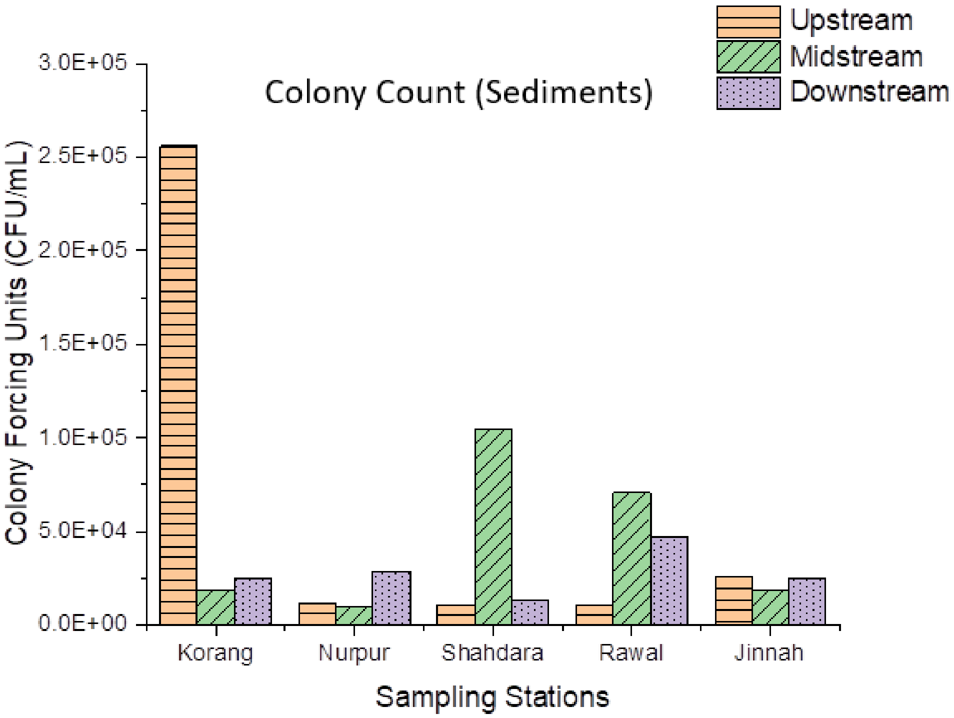

Figure 4.10 Colony Count of Sediment Samples

4.4 Physicochemical Analysis

Likewise, a comprehensive analysis of 12 physicochemical parameters was conducted across all five sites. Samples were collected in triplicate from each location, and subsequent calculations were carried out to determine the mean values of these parameters.

4.5 Physicochemical Profile of Sampling Stations

4.5.1 Nitrite-Nitrogen

Nitrite serves as an intermediary in the conversion of ammonia to nitrate through oxidation. Elevated levels of nitrite are commonly associated with sewage contamination due to its elevated ammonia content. The assessment of nitrite levels is crucial within the initial 24-hour window of sampling due to its inherent instability. Notably, all the collected samples demonstrated compliance with the permissible limits set by WHO, as illustrated in Figure 4.11.

4.5.2 Nitrate-Nitrogen

Positive nitrate values were detected across all the sampling sites, yet they remained significantly below the permissible limits established by WHO. It is noteworthy that all the collected samples exhibited compliance with the WHO's permissible limits. The nitrate concentrations for each of the sampling sites have been visualized in Figure 4.12

4.5.3 Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) represents the cumulative measurement of ammonia and total organic nitrogen. Notably, water samples obtained from the Midstream and Downstream of Korang River, as well as Shahdara Stream along with the upstream of Rawal Dam, exhibited values surpassing the permissible limits set by the WHO. The TKN results have been visually presented in Figure 4.13.

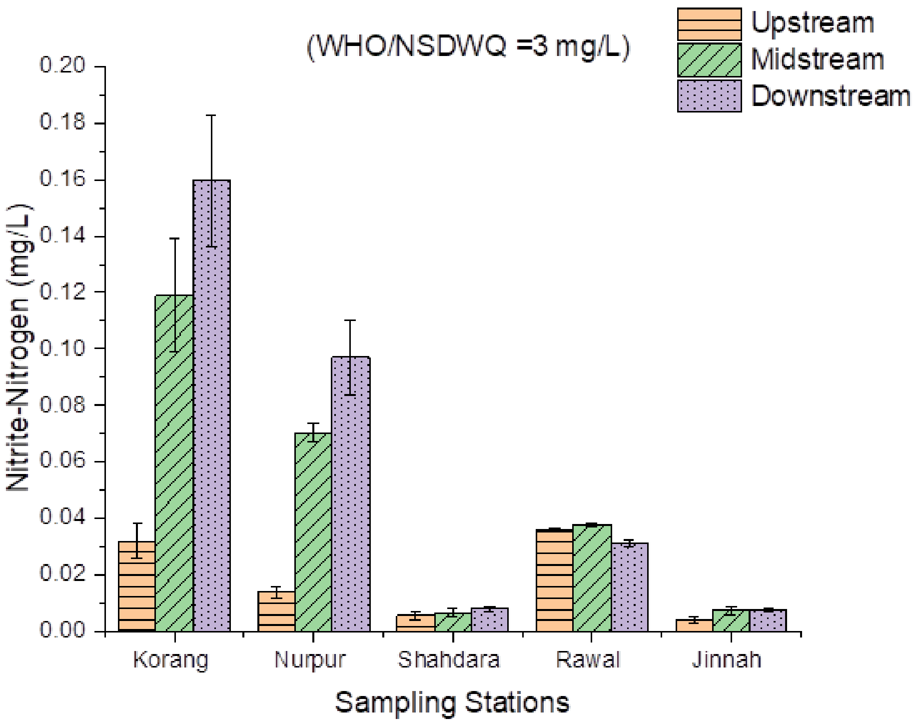

Figure 4.11 Nitrite-N Variation in Water at Sampling Stations

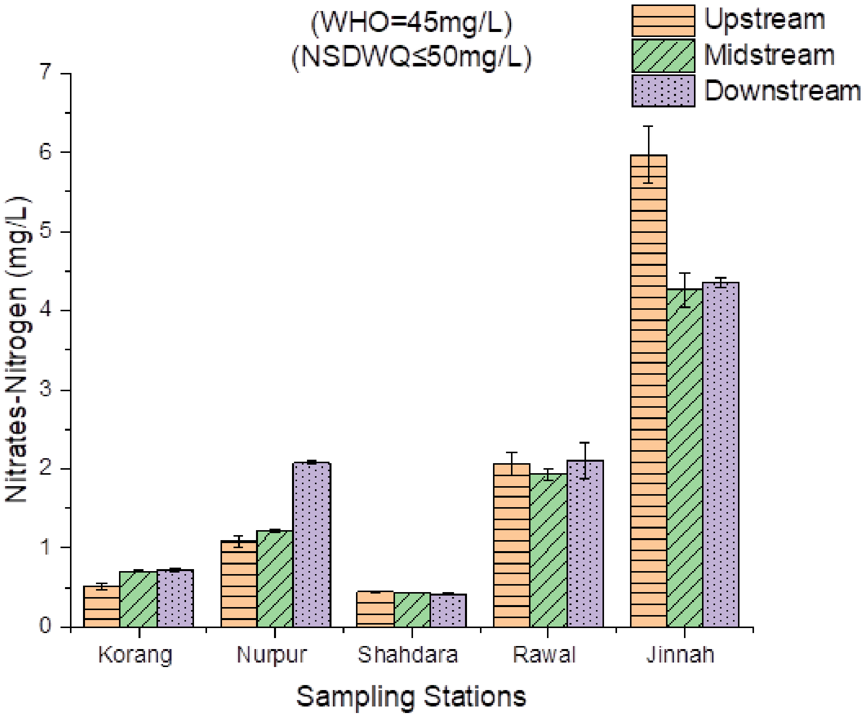

Figure 4.12 Nitrate-N Variation in Water at Sampling Stations

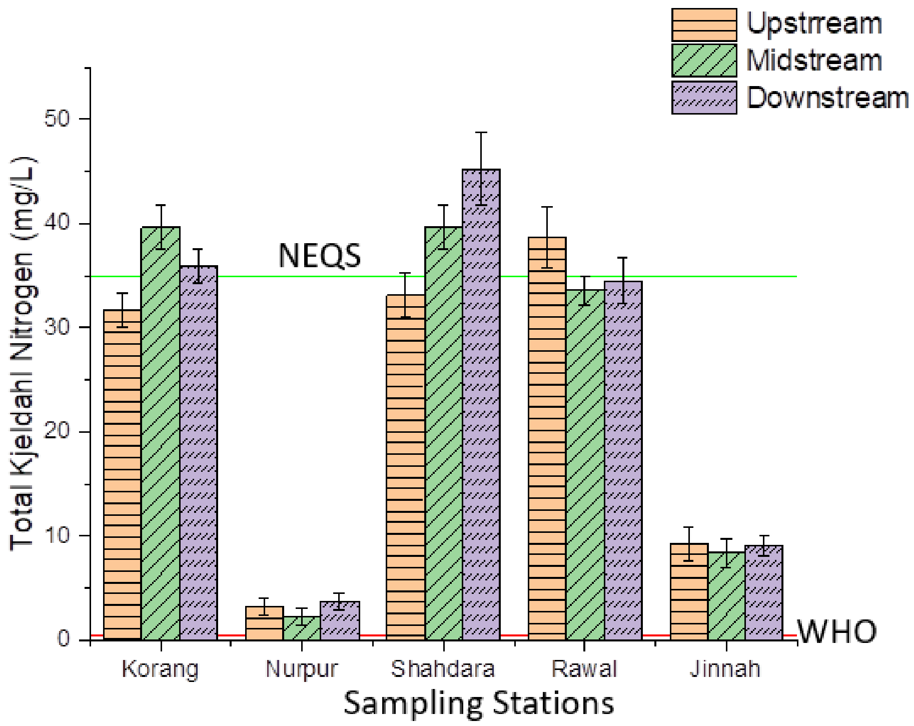

Figure 4.13 TKN Variation in Water at Sampling Stations

4.5.4 Total Dissolved Solids (TDS)

The relationship between Total Dissolved Solids (TDS) and Electrical Conductivity (EC) is linear. It's worth noting that all collected samples exhibited values that fell within the acceptable range, as illustrated in Figure 4.14.

4.5.5 Total Alkalinity

Elevated levels of Total Alkalinity were identified at Midstream and Downstream of Nurpur Stream, as well as Upstream and Midstream of Shahdara Stream, likely due to the influence of human activities like detergent washing and car washing in the water. However, it's noteworthy that the Total Alkalinity values were still within the acceptable range set by the WHO for all the sampled sites, as depicted in Figure 4.15.

4.5.6 Total Hardness

The levels of Total Hardness surpassed the allowable limits established by WHO for all the streams connected to Rawal Dam, including the dam itself. This could potentially be attributed to the presence of domestic wastewater that likely carries calcium, magnesium, and other cations derived from cleaning products, food remnants, and human waste, as visually represented in Figure 4.16. Notably, a study by (Memon *et al.*, 2016) reported analogous findings concerning total hardness in water samples collected from the Indus River, citing the impact of high sediment load due to rocky surfaces and limited vegetation cover.

4.5.7 Chemical Oxygen Demand

The levels of COD were found to be within permissible boundaries across all the sites, with the exception of Shahdara stream, as illustrated in Figure 4.17. It's worth noting that COD exhibits an inverse relationship with DO, which points to the presence of organic loading within the water bodies.

4.5.8 Phosphate-Phosphorus

Phosphate phosphorus levels were notably detected at elevated concentrations, primarily attributed to the existence of organic materials within the water bodies. The presence of chicken and dairy farms adjacent to Korang River and Nurpur Stream has been identified as a significant contributing factor to the heightened levels of phosphate phosphorus, as demonstrated in Figure 4.18.

Rafiq and Sabir, (2022) evaluated and found the similar results for Phosphates in Rawal Dam and its tributaries.

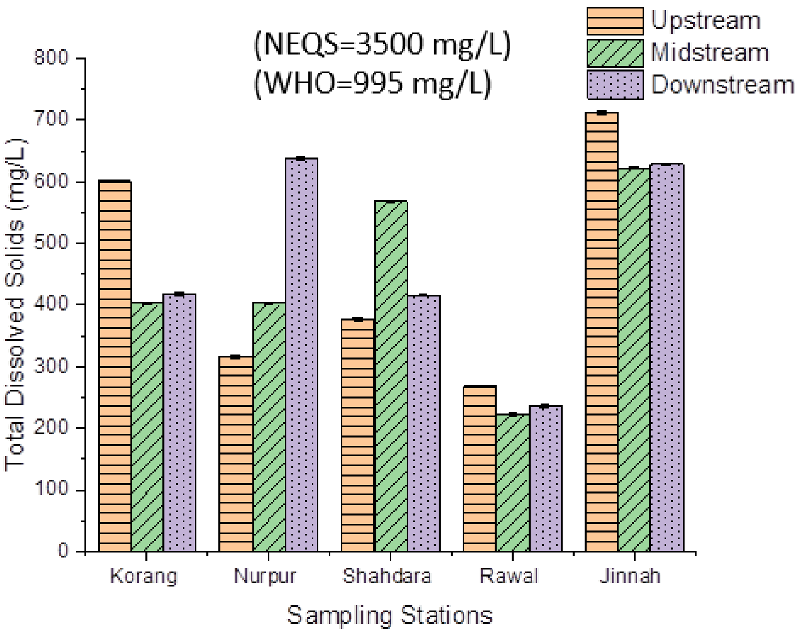

Figure 4.14 TDS Variation in Water at Sampling Stations

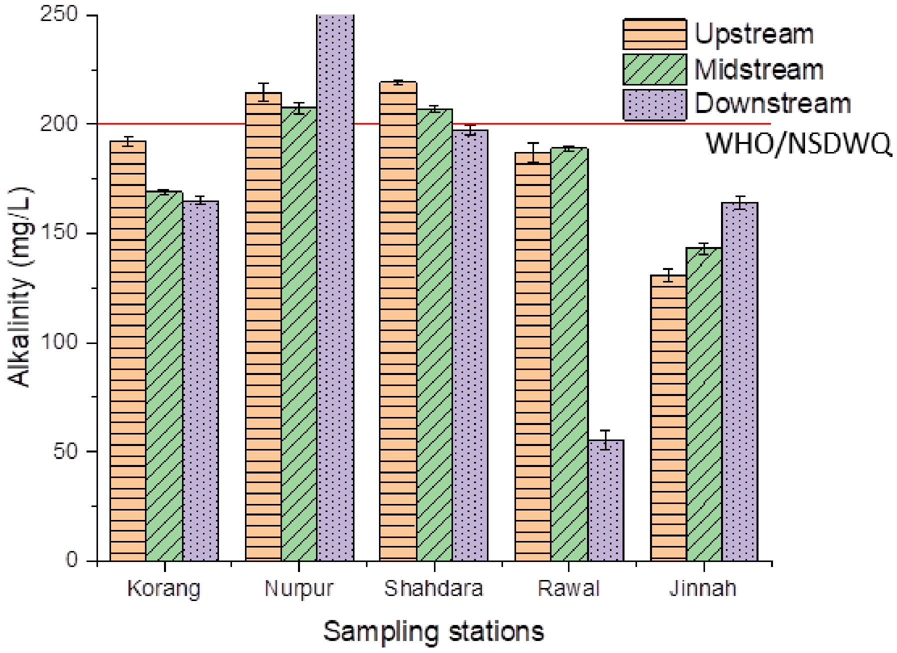

Figure 4.15 Total Alkalinity Variation in Water at Sampling Stations

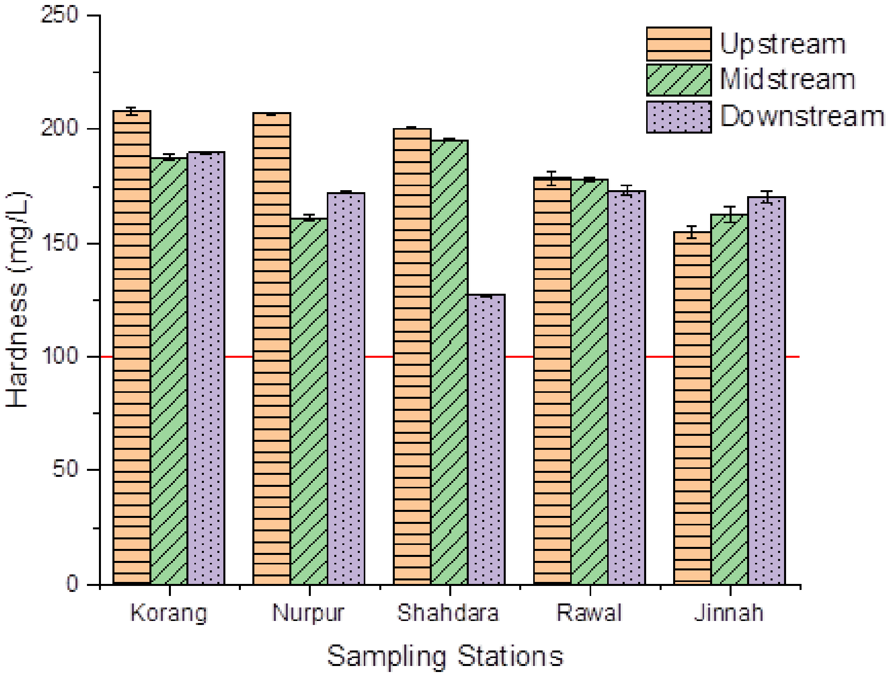

Figure 4.16 Total Hardness Variation in Water at Sampling Stations

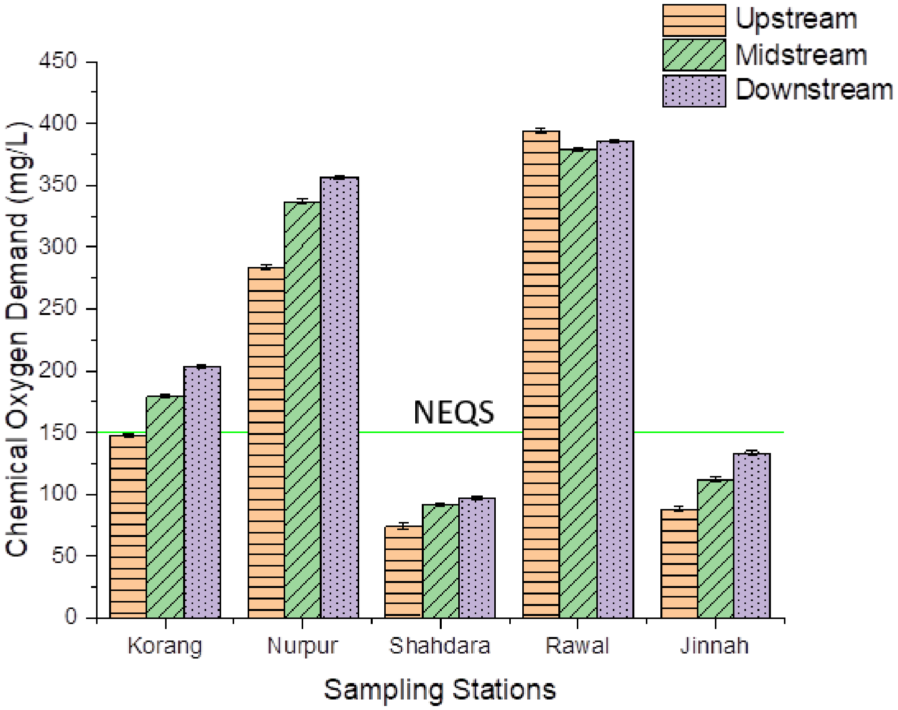

Figure 4.17 COD Variation in Water at Sampling Stations

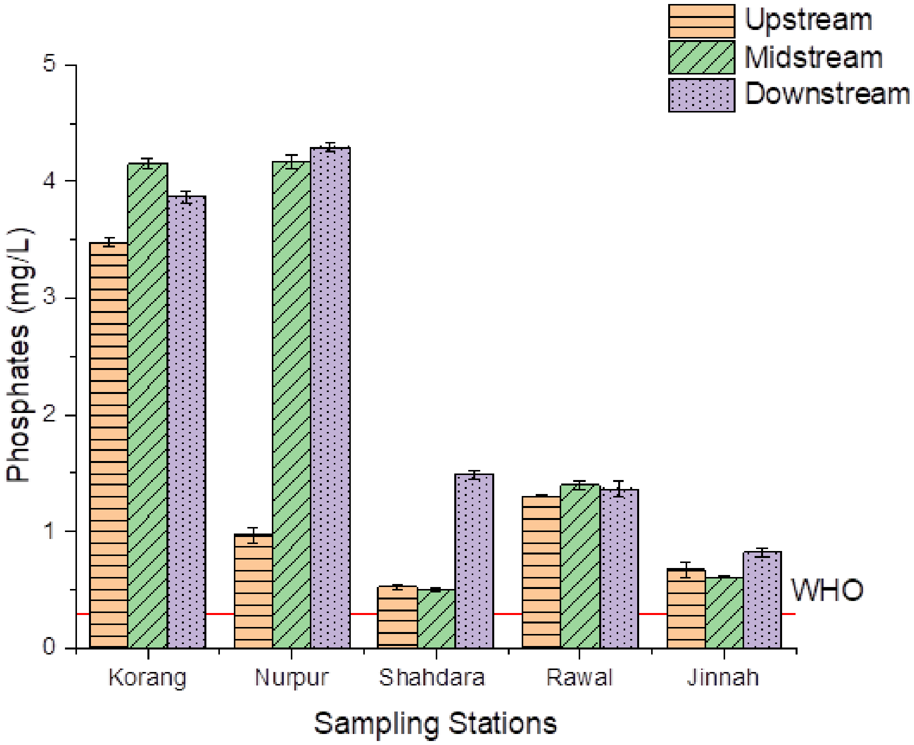

Figure 4.18 Phosphate-phosphorus Variation in Water at Sampling Stations

4.6 Heavy Metal Analysis

4.6.1 Cadmium

The findings revealed that Cadmium levels were within permissible limits in Jinnah Stream and Korang River. However, significantly elevated concentrations of Cadmium were detected in Rawal Dam Shahdara Stream and Nurpur Stream. Notably, substantial industrial emissions of cadmium stem from waste streams and leaching of landfills, along with various operational sources. Car wash facilities situated near the water bodies may also contribute to cadmium accumulation. This trend is visually represented in Figure 4.20.

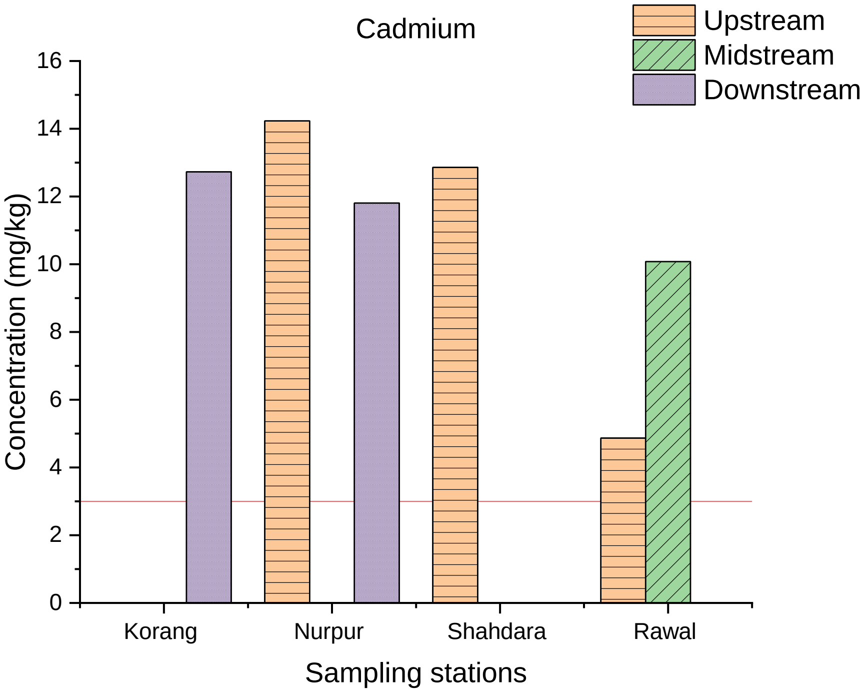

Figure 4.19 Cadmium Concentration Variability at Sampling Stations

4.6.2 Lead

Lead was found to be within permissible limits, but it was present in higher quantities in some parts of Jinnah Stream, most probably due to vehicular emissions as depicted in Figure 4.22.

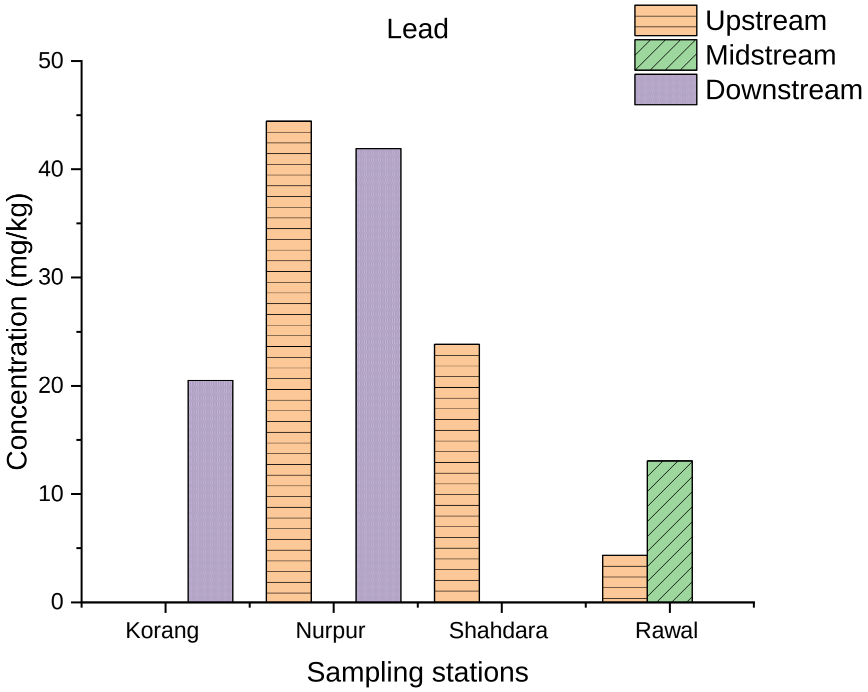

Figure 4.20 Lead Concentration Variability at Sampling Stations

4.6.3 Chromium

Chromium concentrations were determined to be within permissible limits, yet elevated levels were detected at all the sites, with the highest concentration observed at Jinnah Stream and Korang River, as illustrated in Figure 4.23. Notably, industries such as electroplating, leather tanning, and textiles are recognized sources of notable chromium releases.

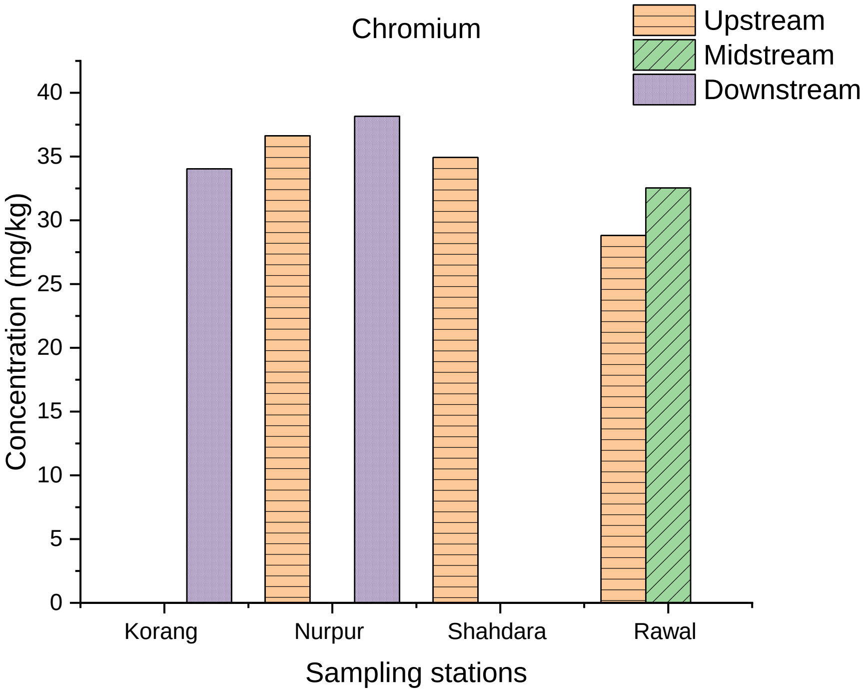

Figure 4.21 Chromium Concentration Variability at Sampling Stations

Chapter-5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

High Total Hardness (127-208 mg/L), Phosphate Phosphorus (0.51-4.14 mg/L), COD values (74-394 mg/L) at all the tributaries and Rawal Dam indicate wastewater intrusion and presence of organic matter. Microbial contamination (Gram Negative bacteria) has been observed in all the samples of sampling points indicates the intrusion of sewage sludge including fecal contamination rendering it unfit for human consumption. Higher microbiological count in Korang River, Nurpur and Jinnah Stream with highest value 2.80E+05 CFU/mL in water samples of Nurpur Midstream and 2.56E+05 CFU/mL in sediment samples of Korang River Upstream indicate that water is unfit for the human consumption. Chromium has shown elevated levels from the sediments of all the selected sites of Korang, Shahdara, Rawal Dam and Nurpur stream, which is a serious concern for health issues.

5.2 Recommendations

i. Regular water monitoring of Rawal Dam and its tributaries should be carried out to identify the water contamination sources.

ii. Car wash stations and poultry farms must be regulated vigorously and must comply with proper sewerage systems.

iii. Tourism department must impose strict actions against illegal waste dumping and effluent discharges in the water bodies.

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