EVALUATION OF THE PERFORMANCE EFFICIENCY OF SELECTED WASTEWATER TREATMENT PLANTS OF ISLAMABAD AND GROUNDWATER QUALITY OF THE ADJACENT AREAS

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2024

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A thesis submitted to Bahria University, Islamabad in partial fulfillment of the requirement for the degree of M.S in Environmental Sciences

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ABSTRACT

The escalating urbanization and industrialization in cities have led to a considerable increase in wastewater generation, posing significant challenges to water resource management. This study investigated the water quality of wastewater and groundwater in Islamabad, Pakistan, focusing on five sewage treatment plants (STPs) and their surrounding areas. The study analyzed heavy metals and biological, chemical, and physical factors. Excessive levels of pollutants (physicochemical, biological, and metals) were detected in the sewage wastewater, and groundwater beyond the limit allowed by the Pakistan EPA. The groundwater samples from different sectors showed varying levels of bacterial contamination. In some sectors, the total bacteria count exceeded permissible limits; coliform presence indicated poor water quality in others. Regular monitoring and remedial actions are necessary to ensure groundwater quality meets safety standards across different sectors. Groundwater pH values exceeded the lower limit, while EC and temperature were within limits. Some samples exceeded the permissible TDS and salt limits, and turbidity levels were high in one sample. Wastewater pH, salts, turbidity, and temperature surpassed limits but slightly decreased after treatment. All chemical parameters for groundwater were within the recommended limit of Pak EPA. Some values exceeded the acceptable limit for wastewater, including alkalinity and BOD. Groundwater heavy metals varied, with some samples exceeding acceptable limits for Mn and Fe. Some wastewater samples exceeded limits for Cr, Cd, and Mn before treatment but showed a decreasing trend after. Pb and Fe were within limits. Different sewage treatment plants showed varying effectiveness in removing pollutants from wastewater. Tele Gardens STP had high removal efficiencies, while Multi Gardens STP had lower removal efficiencies. Zaraj Housing Scheme STP was effective for removing heavy metals, but River Gardens STP showed lower removal efficiencies. CDA STP was effective in removing turbidity from wastewater. These findings highlight the need for ongoing monitoring and improvement of sewage treatment processes to maintain consistent water quality standards. The findings underscore the importance of proactive measures to mitigate the adverse effects of wastewater discharge on groundwater quality and safeguard public health and environmental integrity in Islamabad.

ACKNOWLEDGEMENTS

First, I am grateful to Allah, the Most Gracious and The Most Merciful, for his blessings during my study time and for completing my thesis. Secondly, I would like to thank my parents as this endeavor would not have been possible without the constant support of my parents and family. I would like to express my deepest gratitude to my parents who stood by my side and supported me wholeheartedly throughout my degree program. I would like to extend my sincere thanks to my supervisor Dr. Said Akbar, for his invaluable advice, knowledge, and constant support in my research work. I would also like to thank my lab supervisor Sir Imtiaz Khan and Sir Imtiaz from Pak EPA who guided me and helped me in whatever way possible to finalize my work on time. I would like to thank once again my Head of Department Dr. Said Akbar Khan, for his valuable advice, support, and sincere help throughout my research time. Lastly, I appreciate all the help received from my friends throughout thesis work and studies. I am profoundly grateful to everyone for all the help and sincere support.

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ABBREVIATIONS

ASS	Atomic Absorption Spectroscopy
BOD	Biological Oxygen Demand
CDA	Capital Development Authority
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EBT	Eriochrome black T
EC	Electrical Conductivity
GW	Ground Water
NTU	Nephelometric Turbidity Unit
IWM	Integrated Water Management
MAC	MacConkey
CFU	Colony Forming Units
NA	Nutrient Agar
NEQs	National Environmental Quality Standards
NCS	National Conservation Strategy
PAK EPA	Pakistan Environmental Protection Agency
PCRWR	Pakistan Council of Research in Water Resource
PSQCA	Pakistan Standards and Quality Control Authority
PPM	Parts per million
STPs	Sewage Treatment Plants
Mg/L	Milligram Per Litre
TDS	Total Dissolved Solids
WHO	World Health Organization
WWTPs	Wastewater Treatment Plants
AT	After Treatment
BT	Before Treatment

CHAPTER 1

INTRODUCTION

Almost 71% of the Earth's surface is covered by water, and all living things rely on it. It occurs on Earth in big water bodies like oceans and underground aquifers. Only a small amount, 1.6%, is underground, and even less, 0.001%, is in the air as vapor, clouds, and rain. 97% of the water on Earth's surface is in the oceans. Only a small amount, 2.4%, is locked in glaciers and polar ice caps. Another small portion, 0.6%, is found in other surface waters like lakes, rivers, and wetlands (Gorde & Jadhav, 2013). Water is essential to life and a key component of the world's ecosystem (UNICEF, 2010). One of the most important, rare, and replenishable natural resources available is water (WWAP, 2009). The primary supply of water for drinking, industry, and residential use in urban areas is groundwater, which is frequently over-utilized. Groundwater is frequently degraded in metropolitan areas due to increasing industrialization and poor solid and toxic waste management techniques, which makes the water drinkable for future use. In addition to lowering water quality, groundwater pollution also poses a risk to social progress, economic growth, and public health (Kavitha, 2010).

In addition to humans, all other living forms on Earth depend on freshwater resources. The use of water resources is made up of subsurface water (95–96%) and surface water (e.g., lakes, rivers, etc.) (3.5%). Groundwater extraction is the simplest solution to meet the rising water demands as water scarcity issues arise in many places worldwide (Lockhart, 2013). An estimate of the average daily water use for residential purposes, personal cleanliness, planting, drinking water, and cooking in developed nations is 315 liters. The most crucial amount for survival is 8 liters per day, which comes from preparing food and using drinkable water (Díaz-Cruz, 2008). Over the past few decades, a shortage of availability to clean, drinkable water has caused millions of deaths. According to calculations that include the manufacturing process, urban and rural consumption of water, and other factors, it is estimated that each individual has access to exceptionally low quantities of water per day (Giordano, 2009).

Due to the whims of the monsoon and a lack of surface water, the majority of the world's semi-arid and dry areas are becoming increasingly dependent on groundwater. This is especially true for Pakistan, one of the driest countries on earth, which has been labeled as water-challenged and is projected to experience water scarcity in the coming years (Hamazah, et al., 1997). The amount of water in rivers, lakes, and groundwater is also decreasing as a result of a mix of lower rainfall and increasing evaporation. Long-lasting droughts and the failure to develop new water supplies worsen the condition of water scarcity (Fordyce, et al., 2007). Thousands of people are now forced to drink brackish water due to the severe drought that has destroyed livelihoods in the nation's semi-arid regions, especially in Sindh Province. Additionally, it is said that the subsurface aquifers in Baluchistan Province are disappearing at a rate of 3.5 meters per year and will dry up in the next fifteen years (Sial JK, 1999).

Additionally, in the past ten years, growing population, urbanization, and industrialization have led to increased pollution, one of the biggest threats to water resources, and overuse of the country's water resources, particularly groundwater (Khahlown, et al., 2002). The state of groundwater, and degradation in general and in particular is a major problem (Qadir, et al., 2008). According to reports, the unregulated release of untreated wastewater from municipalities and industries and overuse of fertilizers and insecticides are to blame for the poor quality of water in major cities like Sialkot, Gujarat, Faisal Abad, Karachi, Kasur, Peshawar, Lahore, Islamabad, Rawalpindi, and Sheikhupura (Bhutta, et al., 2002).

In addition to lowering groundwater levels, excessive withdrawal from a subsurface aquifer for agricultural and industrial purposes has also damaged drinking water quality (Ahmed, et al., 2019). The most essential element of our system for maintaining life is groundwater, which also makes a considerable contribution to economic growth (Umar, et al., 2022). Despite its significance, rising consumption by humans and industrial activity has drastically degraded groundwater (Rammohan, 2015). At the time of its independence, Pakistan had a population of just 32.5 million, which increased dramatically to 231.4 million in 2021. This information is from the Pakistan Bureau of Statistics (2019).

Our country's finite natural resources are severely threatened by this expanding population trend (Saatsaz, et al., 2011).

Pakistan's once-abundant water supply has run dry, and the country is currently experiencing severe water scarcity. The supply of water per person has dropped from 5300 m^3 in 1951 to 1105 m^3 in the present, exceeding the 1000 m^3 threshold of water scarcity (Qureshi A. , 2015). The main factors contributing to a decrease in the availability of water are an increasing population, declining water storage capacity, and environmental harm caused by the discharge of unregulated agricultural and sewage wastes into streams and rivers (Li, et al., 2019). The treatment of home and industrial wastewater is a significant issue because it jeopardizes freshwater supplies, public health, and agricultural growth. The quality of groundwater deteriorates as a result of water infiltration from drains and settling basins (Qureshi, et al., 2010).

1.1 Groundwater pollution

Since fresh water is a scarce commodity and a vital component of life, excessive use of it lowers the quantities that will be accessible to future generations. All living things that rely on the hydrologic cycle are directly impacted by water resource pollution (Sajjad, et al., 2022). Due to excessive abstraction, excessive use, and a lack of conservation efforts, most developed nations, including Pakistan, lack freshwater resources. Urban, agricultural, and industrial developments, require significant amounts of water and are characteristics of big urban areas in the developed world. The regional water supplies are degraded qualitatively as a result of excessive usage. In developed places, the quality of subsurface water varies from good grade fresh water (potable), through medium quality (domestic, industrial), to unsuitable quality for any application. A variety of synthetic and natural pollution sources contribute to the deterioration of water quality (Nickson, et al., 2005).

Over pumping, wastewater treatment facilities, and their waste products discharge, excessive use of fertilizers, mining operations, garbage dumps, and burial grounds are just a few examples of direct anthropogenic activities. Indirect impacts of humans include raised urban development, expansion of infrastructure, climate change water reservoirs, and disruption of river networks (Abbas, et al., 2014). Naturally, deterioration of water takes place as a result of saltwater intrusion and infiltration, which has adverse effects similar to those of over-abstraction, geothermal saltwater penetration, which takes place in geothermal areas, interactions among rock and water, and radioactive decomposition of uranium and thorium series, which leads to radon gas pollution and can raise levels of elements that harm underground water quality. All these factors contribute to the degradation of groundwater and may lead to health impacts among consumers used for various purposes (Khalid, et al., 2018).

1.2 Sources of Groundwater Pollution

Pollution of groundwater and declining water quality are two usual sources of pollution. Household and municipal trash, waste from industries (organic, inorganic, trace elements, etc.), and mining activities (chemical, minor elements, intrusion, etc.) are a few examples of the sources of contamination. Installation, usage, and recycling of water supply sources can lead to deterioration due to infiltration, over-pumping, saltwater mixing, pollution of surface water, and rock-water interactions. Numerous human activities that alter the physicochemical properties of water lead to the decline of groundwater quality and the subsequent contamination of water resources. The majority of pollution sources are water usage discharge of harmful substances. It is simpler to find pollution in sources of surface water. In contrast, it is challenging to locate the sources of underground water contamination, which persists for years (Karunanidhi, et al., 2021).

1.2.1 Anthropogenic and natural sources of groundwater pollution

The majority of pollution comes from sources that are generated by humans. This category often consists of the removal and release of effluent and solid waste; the removal and burial of industrial waste; the application of chemicals such as pesticides and insecticides; the removal and burial of waste from mining operations; and the removal and burial of nuclear energy waste. Human-caused sources can result from a variety of activities, including excessive withdrawal of groundwater, unrestricted application of fertilizers, mining operations, garbage disposal, extended urban development, improper use of chemicals, the burial of inorganic and organic substances, and sewage storage (infiltration), disruption of river networks, the extraction and processing of toxic minerals, and waste from graveyards, which may also seep into the deep undisturbed soil (Rail, 2000).

Elements that are trace and other chemicals, such as those produced by extraction of minerals, wastewater from cities and farms, nutrients, energy sources, and other anthropogenic activities, can be found in the waste matter and water and can be hazardous and fatal to people. For example, many elements have been found in underground water sources. Additionally, the usage of fertilizers, farm animals, farming activities, and wastewater leaks have all been related to contamination by greater amounts of essential nutrients, this may include ions or organic substances of nitrogen and phosphorus. Petroleum hydrocarbons and biological waste (bacteria, viruses, and parasites) are other pollutants that have been found in groundwater and are linked to human activity. The contamination of various inorganic substances, which can be harmful and are linked to the salt content of water resources due to elevated levels of Ca, Mg, Na, Cl, and F, is caused by the penetration of disposals, extraction operations, and wastewater leaks (Kuroda & Fukushi, 2008).

Additionally, due to weathering, erosion processes, or other natural occurrences, groundwater can become contaminated. This group involves the following kinds of sources: easily dissolved rocks (such as gypsum and mineral salt), disintegration of rocks can also contaminate the water aquifers underground, strong evaporation, particularly in shallow waterways that elevates groundwater and leads to salt accumulation in water channels, deterioration of water sources in locations near hot geothermal and volcanic fields which may also alter the chemical properties of water, rock oxidation, contamination by seawater, decay of radioactive substances from uranium-rich rock foundations, and the chemical breakdown involving substances in the air or the water. This process can occur both naturally and due to the impact of human activities (Machiwal & Jha, 2015).

1.2.2 Point and non-point sources of pollution

There are many potential causes of water pollution, and they can be divided into point sources and diffused contamination sources (see the figure below). The point sources are mostly from one identifiable source which is easy to locate whereas non-point or diffused sources of pollution are exceedingly difficult to identify as they come from multiple sources. According to the figure below, surface water pollution is closely related to subsurface water pollution, thus when surface water pollution occurs, the corresponding groundwater pollution also occurs. Public and commercial treatment facilities for waste products, which can be found in urban, industrial, or agricultural environments, are significant point sources. The wastewater from treatment plants and other sources may occasionally combine to harm groundwater and surface water bodies. Such waste and chemicals in the water have a significant impact on changing the quality of the water. Manufacturing operations like food production, mining operations, producing goods, animal farms, and dumps are additional point causes of groundwater pollution. Additionally, dumping pollutants into percolating water bodies, water seepage holes, excavations, dry streambeds, dumping boreholes, and wells for injection are other human activities that may lead to groundwater pollution (Saracino & Phipps, 2008).

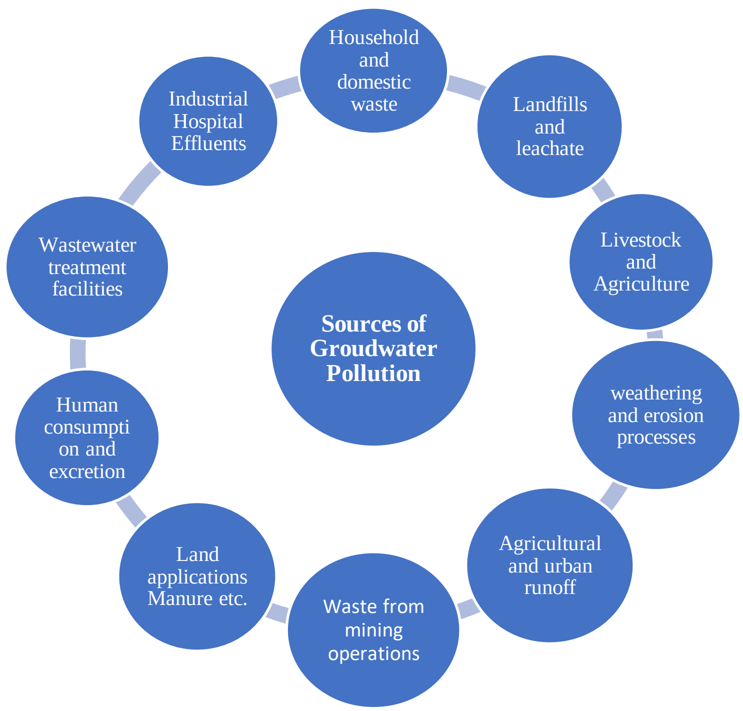

Figure 1.1: Potential point and non-point sources of groundwater pollution

1.3 Effects of Groundwater Pollution

In Pakistan, poor water quality is the main issue affecting both the environment and public health. Both groundwater and surface water in the country have been polluted with many toxic substances and microbes that make them unfit for drinking. Drinkable water has become contaminated due to poor living circumstances and some lack of attention (Azizullah, et al., 2011). Only a few urban places have water purification facilities installed; however, some of them are ineffective and fail to detect microbial contamination. According to a government survey on clean and safe drinking water, just 56% of all residents in the country have access to it, while 44% of residents living in rural regions lack access to clean water (Rasheed, et al., 2009). According to multiple studies, 70% of people lack the availability of safe drinking water. The polluted conditions in Pakistan have led to a high number of people being affected by diseases like typhoid, hepatitis, dysentery, cholera, and diarrhea. Around 20-40% of hospital beds are occupied by patients with these water-related diseases. Furthermore, waterborne diseases are responsible for a massive portion of fatalities in the nation, accounting for 33% of all deaths (Amin, et al., 2012).

One of the primary causes of health-related issues is the contamination of surface and groundwater. According to the 2003 UN World Water Development Report, 2.3 billion people worldwide suffer from diseases caused by contaminated water (Rakib, et al., 2020). The World Health Organization estimates that each year more than 2.2 million people in underdeveloped nations pass away from illnesses brought on by a lack of accessibility to clean water and sufficient sanitation. Infectious and parasitic disorders, the majority of which are water-related, are responsible for almost 60% of premature deaths globally. In the past 20 years, there has been a 200% increase in the number of people with water-borne illnesses who are being treated in Pakistani hospitals (Ahmed K, 2000). According to the National Conservation Strategy (NCS) study, water-borne infections are thought to be responsible for 40% of fatalities. 60 percent of baby deaths are related to the same diseases, which account for around 25 to 30 percent of every admission to the hospital. The most common ways for diseases with symptoms including stomachache, weakness in the body, lack of appetite, eye infections, discomfort of the skin, and fever to spread are through drinking and bathing in contaminated water. According to reports, more people are being diagnosed with such diseases, especially in Sindh Province (Ishaque M, 2001).

In water bodies, where the concentration of sodium is higher, people usually suffer from hypertension and kidney issues. The surplus amount of heavy metals in water bodies is carcinogenic for humans. In Pakistan, it is estimated that due to waterborne diseases about 230,000 infants (less than five years old) die each year (Ezeribe, et al., 2012). Reproductive and endocrinal damage is caused by the excess amount of chlorides in the water. The spread of these diseases can be prevented by proper monitoring and filtration techniques. Although, for the emerging contaminants the conventional filtration methods for water purification are not efficient as these contaminants are often not even evaluated (Jehan, et al., 2009).

Due to the contamination of surface or ground water various diseases spread. Human health is affected by contaminated water and can be fatal sometimes. When the physical, chemical, and biological parameters exceed the permissible limit, they hurt human health. Pathogenic organisms, which are responsible for water pollution may cause intestinal infections like cholera, dysentery, fevers, skin diseases, and food poisoning. Due to the poor water quality in Asia, diarrhea is one of the leading causes of death among infants and causes illness to every fifth person (Noori, et al., 2013).

The region of Punjab has a problem with the quality of its drinking water due to inadequate treatment, surveillance, and drainage systems. The presence of hazardous metals, artificial chemicals, and microbes in water hurts people's health. People have been suffering from waterborne infections, and feces are a major factor. Waterborne illnesses such as diarrhea, typhoid, hepatitis, and cholera are effectively detected in both rural and urban regions of the region. In any event, it is extremely difficult to gauge the likelihood of diseases. Smith (1999) highlighted the ailments and inadequate record-keeping in hospitals, clinics, and hospital emergency rooms that were known to have infections brought on by contaminated water (Smith, 1999).

More than 60% of people in Pakistan drink water from underground sources. The majority of rural inhabitants in Pakistan lack access to clean water for drinking. About 68% of them have poor-quality water. According to a report from GWSSAR in 2000, over 3 million people in Pakistan are sick because of the polluted water, and 0.1 million of them die every year. In Pakistan, hospitals see one hundred million cases of diarrhea every year, and 0.25 million children lose their lives as a result of drinking impure water. Poor sanitation, unclean water, and lack of hand hygiene can result in diarrhea. Annually, this leads to the death of 0.25 million children under five (Bhatti, et al., 2018).

1.4 Status of Groundwater Quality in Pakistan

The majority of agricultural land in Pakistan experiences dry to slightly dry weather, making it necessary to adequately water crops to yield good harvests. There is not enough clean water on the surface to water the crops. To address the shortage of quality water, we need to consider using groundwater instead. In Pakistan, there is a large area called the Indus Plain Aquifer that is over 210,000 square kilometers in size. It is made up of loose soil and rocks that are good for holding water, so it is easy to pump groundwater from there. To address the issue of soil salinity and waterlogging, WAPDA has set up over 16,000 large tube wells to facilitate agricultural activities. However, even low-quality water from these tube wells was used to increase the limited supply of good-quality water. Furthermore, the farming community has installed over 515,000 private tube wells to add to the water for irrigating crops. The amount of salt in various parts of the country can vary a lot, both up and down and side to side. The level of saltiness can vary from acceptable to extremely high. Groundwater tends to be pure around rivers but becomes polluted in the vicinity of doab regions. (Zhonghua, 2013)

Several surveys across the country have found that 49.4% of the groundwater in most areas has less than 1500 ppm of salt, 11.8% has between 1500-3000 ppm, and 38.8% has more than 3000 ppm. Therefore, not all the groundwater can be used for watering crops. If we use it, the land will become less fertile and turn into a desert. There are big problems with groundwater. Excessive salt or minerals, overuse of water, poor planning in groundwater usage, and contamination from chemicals and waste are all contributing factors. Rural and urban areas, particularly in farming regions, suffer from these issues, leading to health concerns (Bhutta, et al., 2005).

Islamabad's population has grown from 0.117 million in 1961 to 2.4 million in 2023. The projected number is 4.443 million by the year 2050. The built-up area of Islamabad has grown substantially from 2,693 hectares in 1990 to 18,469 hectares in 2020, marking a 585% growth. Islamabad's green area declined from 28,060 hectares in 1990 to 25,243 hectares in 2020. Islamabad's average temperature rose by 3°C from 1961 to 1990. Temperatures are projected to rise by 2.2°C by 2069. Urbanization is causing a rise in urban flooding issues. In the past 30 years, the groundwater level in the Potohar region has dropped by 116 meters, while per capita water availability has plummeted from 5,300 cubic meters in 1951 to 850 cubic meters in 2013. The total water supply from these sources is capped at 84 million gallons per day (MGD), although Islamabad's average water consumption is 176 MGD.

Excessive usage of groundwater in Pakistan has led to major difficulties in its management. This is necessary to ensure sufficient food for the increasing population. These problems with managing water need us to look at how we monitor both surface water (like rivers and lakes) and groundwater. A study by (Raza, et al., 2017) assessed the quality of groundwater consumed by people in Pakistan following the implementation of specific targets. The study investigated the origins of harmful substances in water and their impact on its quality. It also looked at how this affects people's health. The water quality tests indicated that the majority of the water did not exceed the standards established by the World Health Organization and National Environmental Quality Standards. The contamination of natural groundwater sources is a result of human activities such as mining and the disposal of industrial and household waste. Approximately 780 million individuals worldwide lack access to clean water.100 million people in Pakistan do not have access to clean water. This review illustrates the necessary steps to ensure universal access to clean drinking water by 2030. This review proposes establishing an effective monitoring system, constructing wastewater treatment facilities, and implementing environmental protection laws (Raza, et al., 2017).

The main source of clean water in Pakistan is the Indus River and its smaller rivers. As the population grows, we need more water for growing food, cities, and industries. This means we rely more on water from the ground. There has been a significant increase in the installation of private tube wells in Pakistan since the 1960s. In 1960, there were about 20,000 private tube wells in the country. Now, there are over one million tube wells, mostly used for watering crops. Most of the private tube wells in Pakistan are found in the Punjab Province, which has 93% of them. The amount of water going into the ground is less than the amount coming out, so the water levels are dropping quickly in many areas of the country. It is crucial to monitor and preserve the depleting groundwater in Pakistan without delay (Bhatti, et al., 2017)

1.5 Importance of Sewage Treatment Plants (STPs)

The two primary water sources that supply Pakistan's Federal Area (Islamabad) with water are i.e., the Simly Water Treatment Plant (SM-WTP) and the Sangjani Water Treatment Plant (SG-WTP). The Khanpur Dam, built on the Horo River, provides water for treatment at the SG-WTP. 51 MGD (million gallons per day) is its intended capacity. Rapid gravity filtration, flocculation, sedimentation, coagulation with an alum dosage, and chlorination make up the SG-WTP treatment module. Water from the Simly Dam, built on the Soan River, is intended to be treated by the SM-WTP. The 42 MGD capacity is its intended capacity. Chlorination, rapid gravity filtration, sedimentation, and coagulation and flocculation systems are also included (Ali, et al., 2012).

Wastewater treatment plants help protect the environment. To make water fit for drinking or other purposes, it requires a lot of effort to obtain high-quality water. Now, there are advanced technologies available that use biology and advanced methods to clean out things like organic matter and pollutants from the water. These technologies work well, but they use a lot of energy. The activated sludge system is a current way to clean water in sewage plants. It uses over 40% of the electricity needed to run the whole sewage plant. The energy consumption in WWTPs varies depending on the size, construction, operation, and type of wastewater being treated. Overall, it is usually thought to be around 108,000–216,000 kJ per person each year (Silvestre, et al., 2015).

Today, the efficiency of wastewater treatment plants in purifying water has increased but the focus on the amount of energy they consume has also shifted recently. In the water industry, the challenge remains using less energy to clean up water better. Pollution has made wastewater treatment plants remove more nitrogen and phosphorus. Also, taking action to fix sewer overflows has led to more wastewater getting to treatment plants. This has caused even more energy to be used which is a challenge for developing countries like Pakistan struggling financially in the wake of political instability (Adamus-Białek, et al., 2015). The process of sewage treatment involves purifying wastewater from households so that it can be reintroduced into the environment without causing harm. It uses different processes to clean the water and make it safe for the environment by removing harmful substances. The treatment has three parts, before, main, and after. Before the water is treated, big pieces of garbage and sand are taken out by using a screen. The initial stage of purifying the water involves allowing it to rest, enabling the dirt to settle to the bottom and the oil and grease to rise to the surface. The sludge undergoes further treatment in the sludge digesters during the second stage of the process (Demirbas, et al., 2017).

Sewage treatment plants (STPs) offer agricultural advantages through the provision of irrigation and non-traditional fertilizers. Farmers in nearby communities utilize partially treated water from Sewage Treatment Plants (STPs) containing high levels of fertilizers for irrigation. STPs not only reduce pollutants from households and industrial effluents to fulfill pollution requirements but also offer irrigation and fertilizer benefits to farms. All of these wastewater treatment plants can clean 919.82 million liters of wastewater every day. Several types of contaminants can be removed from sewage through the process of breaking them down with bacteria or chemicals, adhering to sludge, or transforming into gas. Researchers have examined the detection and removal of pollutants from sewage and landfill wastewater in distinct locations. They have also compared the different methods used. There have been a limited number of studies on the impact of disposing of wastewater and sludge on the environment and water resources (Yamin, et al., 2015).

1.6 Effect of sewage treatment plants (STPs) on groundwater quality

Pakistan is an agricultural-dependent nation with limited water resources. The number of people living there will go up from 152 million in 2005 to 208 million in 2025. By then, around half of the population will be living in cities. More people and less water mean we need to find ways to use city wastewater in farming. However, even though wastewater is important and can be harmful to health, it has not been included in national policies for its safe and sustainable use. Approximately 64% of the polluted water in Pakistan is disposed of in rivers or the Arabian Sea (Lamma, 2021). Policies are regulations implemented to remove polluted water from urban areas. Engaging in these activities poses a risk to both individuals and the environment while also contributing to the depletion of Pakistan's water supply. Similarly, various research studies conducted by different organizations have shown that wastewater can contaminate both the soil and water. This can harm the soil and hinder its ability to be used for drinking and farming water. Using various water sources such as wastewater, canals/tube wells, and mixed sources can lead to illness in both animals and humans in certain areas. (Ensink, et al., 2004)

One major challenge faced by developing nations in the modern era is the management of industrial effluent. Wastewater from industrial discharges is released into neighboring fields, internal septic tanks, sewage systems, or natural drains in these countries. Some industrial wastewater effluents are either inadequately treated or not treated at all before being discharged (Martin & Griswold, 2009). Industrialization and urbanization in emerging nations have led to environmental deterioration, negatively impacting the quality of surface and groundwater resources. The decline in water bodies that receive nutrients is due to the poor quality of sewage from wastewater treatment plants. This is because poorly treated or untreated industrial wastewater effluents have the potential to produce eutrophication in the receiving water bodies and create an environment that is conducive to the growth of waterborne pathogens that produce toxins. Before discharge, wastewater must be properly treated to comply with regulations and laws. Industrial wastewater effluents must be properly treated to reduce the risk to the environment and public health (Ilyas, et al., 2019).

In Pakistan, waste from homes, comprising human waste and home sewage, is disposed of in internal septic tanks, neighboring fields, natural drains or water bodies, or sewage systems. Most municipal wastewater is untreated, with only Islamabad and Karachi having biological treatment facilities. However, the volume of wastewater treated in these cities before disposal remains limited. Municipal treatment plants are estimated to treat 8% of urban wastewater, assuming that all of the installed treatment plants are operating at full capacity (Ikram, 2012).

1.7 Review of literature

Groundwater is an important source of water in Pakistan, supplying all the water required for commercial procedures and activities, approximately sixty percent for agriculture and crop production, and ninety-three for use by humans. Everyone is entitled to drill as many boreholes as they like and draw water from anywhere because there is no governing body for groundwater in Pakistan, which has led to a disturbing rate of decline in resources. The problem is getting worse in several Pakistani cities, and it is even worse in Baluchistan where the water level has dropped by three meters (Farooq, et al., 2008).

A big problem that is worrying people locally, nationally, and internationally is when groundwater gets contaminated with heavy metals. This is a problem because it can harm the environment and affect people's health. (Goldhaber, 2003) Ullah and his team did a study in 2009 to check how polluted groundwater was with heavy metals and how it was affecting people's health. Water samples were taken from 25 places in Sialkot, a city in Pakistan, during October and November 2005. The experts assessed the characteristics of the subterranean water in this industrialized municipality. (Singh, et al., 1993). A researcher looked at 22 different measurements of water quality, such as pH, temperature, and the amounts of certain substances like sulfate and iron. The results were measured against the recommended criteria for water quality determined by both the Pakistan Standard Quality Control Authority (PSQCA) and the World Health Organization (WHO). The sites were grouped into four distinct categories using cluster analysis. This was done by looking at how similar or different the physical and chemical measurements were in each location. (Clarke, et al., 1995). Site 1 had a lot of dirtiness and pollution. The levels of EC, TDS, SO4, Cl, total hardiness, Zn, Pb, and iron were higher than the allowable limit. 19 places discovered the chemical chromium. According to statistical analysis and quantitative evaluation, important variables were found that have a direct effect on the condition of groundwater and can alter the chemistry of water. The study discovered that a sizable portion of the subterranean water in the region is highly turbid (57% of all locations) and contains excessive amounts of Zn, Fe, and Pb. These levels are higher than what is considered safe by the WHO and PSQCA. Therefore, it is incorrect to claim that the quality of this water is satisfactory. (Uma KO, 1985). The utilization of a Geographic Information System (GIS) enabled the generation of visual representations pinpointing the locations where various water quality measurements were taken. The maps showing how water is distributed were particularly important for understanding the environment of the underground water systems. They helped us find out which factors of water quality were too high according to WHO standards. We also used the maps to find places where water treatment facilities or innovative technology could be helpful in Sialkot. (Ullah, et al., 2009).

One of the biggest dangers to people's health, especially in poor countries, is when the water they drink is contaminated with harmful tiny organisms. Abbas M. T., (2012) conducted research and assessed the drinking water quality in Punjab Province. It focuses on the presence of harmful bacteria in the water, its chemical properties, and how it affects people's health. Investigating pollution levels in the drinking water across various regions in Punjab province was the primary objective of this study. The water was getting worse because more people were living there, the area was growing quickly, and people were not disposing of waste properly. (Abbas M. T., 2012). In a recent investigation conducted in the Punjab area, it was observed that the majority of spots suffer from the issue of polluted drinking water.

The water that people drink in the provinces has become unsafe due to the presence of harmful bacteria, hazardous metals, and chemicals. This includes water from rivers, lakes, and underground sources. In the area, the bad air is making people extremely sick and even causing death. The rules for clean drinking water made by the WHO are often not followed. The main reasons why water quality is getting worse are the wrong use of chemicals in farming, improper throwing away of city waste, and the release of polluted water from factories (Qasim, et al., 2014). Diarrhea, cholera, and typhoid are the three main diseases caused by contaminated drinking water in Punjab. Stomach problems, intestinal worms, and bacterial infections are also caused by drinking dirty water, leading to higher rates of infant deaths. We must take immediate action to prevent water deterioration and ensure people's protection against waterborne illnesses. It is crucial to expedite the enforcement of laws, regulations, and the WHO's suggestions to establish the safety of drinking water. (Riaz, et al., 2016).

In the south part of Lahore, research investigated the groundwater's state by gathering two distinct water samples before and following the rainy season. They did this to gather significant data on the physical and chemical properties as well as the presence of bacteria in the water. According to the research, the samples' water quality ranged from 50% to 62%.5% before the monsoon. Post-monsoon, there was a notable improvement, with the percentage rising to 75% (Farid, et al., 2012). Water pollution occurs because of leaks in the pipes that carry and supply water. It happened because these pipes are all connected. Water samples collected from the city areas of Faisalabad have been analyzed, discovering that it is unfit for consumption. Many of the samples had considerable amounts of TDS (total dissolved solids), alkalinity, sulfate, and chloride. Dirty water containing waste from toilets and drains made the quality of the groundwater in Faisalabad's cities worse (Hayder, et al., 2009).

Khattak and others made a discovery close to the drain channel of the Hudiara factories in Lahore. In 2012, experts checked how good the water in the ground was for drinking and farming. The results indicated that the water samples obtained from different areas were good in terms of quality and showed no evidence of contamination caused by human activities. Only 21% of the samples were somewhat suitable for farming if changes were made and special methods were used, while 79% of the samples had harmful substances and were not suitable for eating or farming (Batool, et al., 2018). An investigation was conducted in Bahawalpur City to examine the characteristics of underground water. The results of the study found that the water underground was not good enough, which led to many people getting sick from water-related diseases. The Islamic colony had a particularly high rate of serious illnesses, with approximately 36% of the community affected. The occurrence of waterborne diseases was less prevalent among the individuals residing in Satellite Town and Shahdrah, in comparison to those in the Islamic colony (Khattak, et al., 2012)

The assessment of the water in Bhalwal City revealed that it contains excessive amounts of TDS, EC, and potassium. The THQ statistics revealed the information relating to the patients. According to hospital records, there were differing amounts of kidney stone cases every month in 2017. (Farooqi, et al., 2007). Checking the quality of groundwater is crucial in determining its safety for consumption and its impact on personal well-being. Deeba et al. In a study conducted in 2019, researchers investigated the groundwater quality in Sahiwal and Sheikhupura. In Sheikhupura, the water was discovered to be high in fluoride, iron, nickel, cadmium, and microorganisms according to the study. Conversely, Sahiwal's water samples exhibited elevated alkalinity and electronic conductivity levels. (Deeba, et al., 2019).

There are 115 local water supply sources in Mianwali, where the analysis of groundwater samples and their origins focused on both microscopic and chemical qualities. To check if there are germs in water, biological parameters in water samples were evaluated. In addition, the study results indicated that a higher percentage of tap water samples (71%) were polluted compared to samples from WSS, which showed a contamination rate of 41%. Because WSS was accountable for 30% of the water pollution in Mianwali, there was a lack of consistent provision of safe drinking water. (Akhtar, et al., 2019).

Abbas and his team conducted research in the city of Jhang in 2018, a study examined how the water quality is affected by the waste produced by cities. The study found that the EC was high in 90% of the samples, TDS in 75% of the samples, hardness in 60% of the samples, chloride in 35% of the samples, calcium in 30% of the samples, and alkalinity in 25% of the samples. The study showed that the water near the landfill is not safe to drink. The objective was to assess its adequacy for practices such as agriculture and residential purposes. The aim was to determine if it was suitable for activities like farming and household activities. (Rehman, et al., 2019). The correlation between ten various substances submerged in the water was investigated. Calcium, sodium, potassium, magnesium, copper, iron, nitrates, sulfates, and chloride, are among the substances. The results indicate that groundwater cannot be consumed as it is not safe to drink. However, it can still be useful for farming purposes. (Abbas, et al., 2018).

In simpler terms, Munir and his team studied the features of substances and materials their chemistry, and the Earth's processes. In 2011, researchers checked how good the groundwater was in the area near Lei Nala in Islamabad. Researchers collected 10 water samples from the surface of Lei Nala and 12 water samples from deep underground at four different spots for investigation. Bicarbonate and Ca, Mg type fluids were detected in the groundwater samples, suggesting the breakdown of limestone (Asadi, et al., 2019). The tested area contains 53. 86% of water consists of calcium and magnesium. In most of the samples (96. 15%), the water had a higher concentration of the HCO3 type of anions. Most of the chemicals present in the water within the study area originate from natural sources, as there have been no noticeable variations in their types. This happens because water underground moves through rocks that are made of sand and mud, and as it moves, it mixes with rocks, which mainly contain substances called HCO3, Calcium, and magnesium. (Munir, et al., 2011).

Overwhelming metals can be present in groundwater sources through normal or human exercises, and the utilization of contaminated water can result in cancer or persistent health issues in people. A study in Islamabad, Pakistan, explored the presence of arsenic (As) and overwhelming metals (HM) in different drinking water sources. Tests from tube wells, taps, bottled water, filtration plants, and bore wells were gathered and evaluated for different parameters. The results revealed concentrations of arsenic, lead, nickel, press, and cadmium that surpassed the allowable limits set by WHO (Abeer, et al., 2020).

Due to the destitute framework, Faisalabad is regarded as a contaminated industrial city. To distinguish the social variables that impact the use of clean potable water, 225 tests of water were collected. The Logit Show (LM) was at that point utilized to assess the information. The results appeared a negative effect in which all tests were contaminated with microscopic organisms such add up to coliform, add-up to plate tally, and E. coli (0157), as elevated levels of add-up to hardness and turbidity had been predicted. Atomic Absorption Spectrometer (ASS) estimations were made on water tests collected for physiochemical think about from Sargodha city haphazardly (Riaz, et al., 2016). The comes about when compared to WHO appears that all factors, with the exemption of pH and Ca, are profoundly concentrated within the investigate range. As a result, it turns out that the tested area's groundwater quality is unfit for human utilization. In an additional examination, the effect of Sargodha's groundwater on populace well-being was inspected physio-chemically (Faruqui, 2004). The study's discoveries demonstrated that Area 1 had the most noteworthy rate of water-related ailments. Concurring to the study assessment, 43.49% of individuals had waterborne contaminations, whereas the predominance in other zones was way better, with 29.68%, 26.33%, and 25.83% of people affected in local areas 2, 3, and 4. (Gadgil, 1998).

To survey the state of the groundwater within the Kalalanwala region inside the Kasur locale, another examination was conducted. The study's discoveries appeared a noteworthy level of contamination from specific factors. The large profundity of the aquifer and a more profound groundwater test were compared. Whereas contamination from fluoride was missing from the subsurface aquifer, it was found to be exceedingly concentrated near the ground. The comes about of this examination illustrated the high SO4, F, and As concentrations in both rain and groundwater. (Farooqi et al., 2007). Contamination from the environment can hurt the well-being of people. Dry and semi-arid regions all around the world are affected by this problem. In a few parts of Pakistan, human exercises are impacting the overall quality of the groundwater. In case not appropriately kept, mechanical, and urban waste can leak into the soil, enter aquifers, and debase the quality of groundwater (Jain, et al., 2005).

Many developing communities keep using sewage water to water crops, even though it harms the environment. In addition to causing harm to the soil, plants, and seeds, sewage water used for irrigation can also have serious effects on the groundwater. These impacts pose a greater danger than we may recognize. A study by Sial, et al., (2005), aimed to examine how the utilization of different water sources for irrigation influences the underground water quality. They compared using canal water, half wastewater, and all wastewater for irrigation. It was found that using wastewater directly not only caused saltiness but also made the groundwater quality worse by making it more solid. The plants watered with 100% wastewater were in worse condition compared to the ones watered with 100% canal water. Out of all the heavy metals, iron had the highest amount at 56% of the total, while chromium had the least amount. The amount of metals like manganese, nickel, chromium, lead, iron, and zinc was okay. Using untreated wastewater is a very careless and illegal act, and people who do this need to be punished (Sial, et al., 2005).

Khan, et al., (2017) analyzed the physicochemical assessment of different parameters and the concentrations of heavy metals in wastewater, along with a check on the efficacy of the wastewater treatment plant, which was conducted at the I-9 treatment plant in Islamabad. So, from influent, effluent, and external streams, composite wastewater samples were gathered. They contrasted their findings with the Pakistan Environmental Protection Agency's Maximum Permissible Limits (MPL) (Pak EPA). The pH of the wastewater samples from the influent, effluent, and external stream ranged from 6.2 to 6.9, 6.4 to 6.9, and 6.8, respectively. The EC ranged from 700 to 1250 µS/cm. The concentrations of heavy metals such as iron, manganese, zinc, nickel, lead, cadmium, and chromium were analyzed using Atomic Absorption Spectroscopy (AAS). The concentration of these heavy metals varied within the ranges reported. Many parameters, including those for nickel, lead, chromium, and cadmium, showed results that were higher than the Pak-EPA's allowable limits. Therefore, treating wastewater in an industrial area is advised. In the Lai stream, only treated water should be permitted to flow (Khan, et al., 2017).

Pakistan, similar to other developing nations, confronts significant challenges of urbanization and uncontrolled expansion in its major cities such as Karachi, Lahore, and Islamabad. The country is witnessing a substantial societal shift as individuals migrate from rural regions to urban areas at an alarming rate. As a consequence of limited financial resources, the government was unable to halt this perilous pattern. Consequently, the current sewer systems and sewage plans in these urban areas were unable to withstand and support the increased biological waste due to population shifts. Ultimately, there is a widespread issue concerning the management and disposal of residential sewage and human waste. As the severity of this issue escalated, the notion of utilizing advanced smart technology to implement Sewage Treatment Plants (STPs) emerged. While this practice is not yet widespread in all major cities of Pakistan, a study focused specifically on the capital city of Islamabad, where STPs have already been implemented. The study's findings demonstrate that the procurement and installation of STPs in residential areas face obstacles due to socio-political issues and economic constraints. Furthermore, private societies and public service departments exhibit reluctance and lack confidence in adopting this smart technology. Additionally, the study highlights the advantages and benefits of utilizing Sewage Treatment Plants. Lastly, the study provides viable recommendations to overcome these challenges.

1.8 Problem statement

Pakistan is using more groundwater as surface water supplies are becoming scarcer. Groundwater systems are now being used more frequently, which has resulted in the depletion of the resource (Shakoor, et al., 2015). Excessive use and the ongoing drought in Pakistan are two potential reasons why there are not enough supplies of drinking water and groundwater aquifers are not being adequately replenished (Mohsin, et al., 2013).

Islamabad's population has increased from 0.117 million in 1961 to 2.4 million in 2023. The aquifers are not getting recharged at the rate, the rate at which the water is discharged or pumped out. There has been an increase in population and construction activity. Due to economic and infrastructure expansion, the city has become a center for immigrants over time (Memon, et al., 2011). The majority of the city's water supply needs are fulfilled by groundwater, except for Rawal and Simly Lakes. However, these groundwater resources now face significant contamination risks as a result of population growth and industrial development. The rise in population and industrialization is leading to an increase in wastewater in cities. Massive quantities of untreated wastewater from the cities are being discharged into rivers, which affects the quality of both surface and groundwater resources. Apart from Islamabad and Karachi, which treat a relatively small percentage, less than 8 percent of their wastewater before disposal, the majority of this wastewater is not treated and neither city has a biological treatment process (Murtaza & Zia, 2012). A performance assessment of a treatment plant is necessary to determine the current quality of treated sewage and to assess the efficiency of currently operating treatment facilities. The health of the public depends critically on the regular monitoring of the water quality that treatment plants treat, as well as the performance evaluation of their unit operations and processes.

Therefore, the goal of this study is to evaluate the effectiveness of sewage treatment plants in Islamabad and assess the quality of groundwater in the surrounding areas. The current state of events suggests that government improvements are necessary to safeguard the groundwater resource. Governments must implement rules and regulations in institutions and foster advances in technology to improve the policies.

1.8.1 Research objectives

The objectives of the study are:

1. To analyze the efficiency of selected wastewater treatment plants of Islamabad to treat domestic sewage by assessing the physicochemical parameters and heavy metals of both influent and effluent
2. To determine the quality of groundwater in the vicinity of sewage treatment plants in the study area by assessing physicochemical and biological parameters and also heavy metals to evaluate the effect of wastewater on groundwater quality.

The findings of this study can be used to know the quality of groundwater resources near the sewage treatment plants in the study area. The research is important for people who are experts in local government, the department that manages water resources, and other government officials. This will help them make better plans to deal with changes in specific areas, improve the quality of underground water, and efficiency of wastewater treatment plants (WWTPS), and save these resources for the future.

CHAPTER 2

METHODOLOGY

2.1 Study Area

Islamabad is a carefully planned metropolis and serves as the capital of Pakistan. The coordinates of its location are 72° 48′ 42.08″E and 33° 29′ 26.7″N to 33° 48′ 1.34″N and 73° 22′ 48.51”. It is situated near the northern boundary of the Pathovar Plateau, situated at the base of the Margalla Hills, with a height of 540 meters (1,770 feet). The climate of Islamabad exhibits seasonal variations and is generally characterized as a humid subtropical region with five distinguishable seasons. Typically, January is the coldest month. It has significant precipitation in July, which can lead to the occurrence of flooding and thunderstorms. The population of Islamabad is steadily increasing annually due to rural-urban migration driven by the desire for improved employment prospects, healthcare facilities, and educational possibilities. The inhabitants of Islamabad depend on both underground and surface water sources (Sohail, et al., 2022).

In the city of Islamabad, drinking water quality at the treatment plants usually meets the country’s hygienic standards. Five wastewater treatment plants in Islamabad have been selected for this study, with the help of Pak-EPA. The first treatment facility was chosen within a residential development that has received approval from the CDA (Capital Development Authority). It is located between phase two of DHA and zone five. The area is equipped with modern facilities such as wide roads and a well-functioning drainage system, as well as essential utilities like gas and electricity. The neighboring societies of the Zaraj Housing Scheme comprise Emmar, Agosh, DHA, and Bahria Town. This housing scheme has adhered to all the development requirements prescribed by the CDA authority.

The second treatment plant was chosen in the Tele Gardens housing society, which is situated in an optimal location and covers an expansive area of 2750 Kanal land. Tele-Gardens F-17 is an organized residential area that is subdivided into distinct sectors: F-17/1, F-17/2, F-17/3, F-17/4. Furthermore, Tele-Gardens F-17 is one of the older housing developments in Islamabad. The housing scheme's Layout Plan has also received approval from the Capital Development Authority.

Multi Gardens is located on the western outskirts of Islamabad and is separated into two separate phases, Phase 1 and Phase 2. This location has been designated as the third site for the sewage treatment plant. The initial phase is separated into three segments: A, B, and C. It is located on the GT road, approximately one kilometer before the Taxila bypass. The fourth location chosen for the sewage treatment facility is River Gardens, which is positioned at the junction of the Soan River and Islamabad Express Way, offering an attractive view. The town, spanning 810 Kanal, has been approved by the CDA and is not subject to any legal restrictions on its expansion. The last sewage treatment plant selected is located in sector I-9. I-9 is a sector located next to IJP Road and facing Rawalpindi. It runs parallel to I-8 and is separated from it by 9th Avenue. The main purpose of this plant is to make sure that the sewage produced in Islamabad is discharged after undergoing appropriate treatment and per the National Environmental Quality Standards. This facility is currently being run and maintained by CDA.

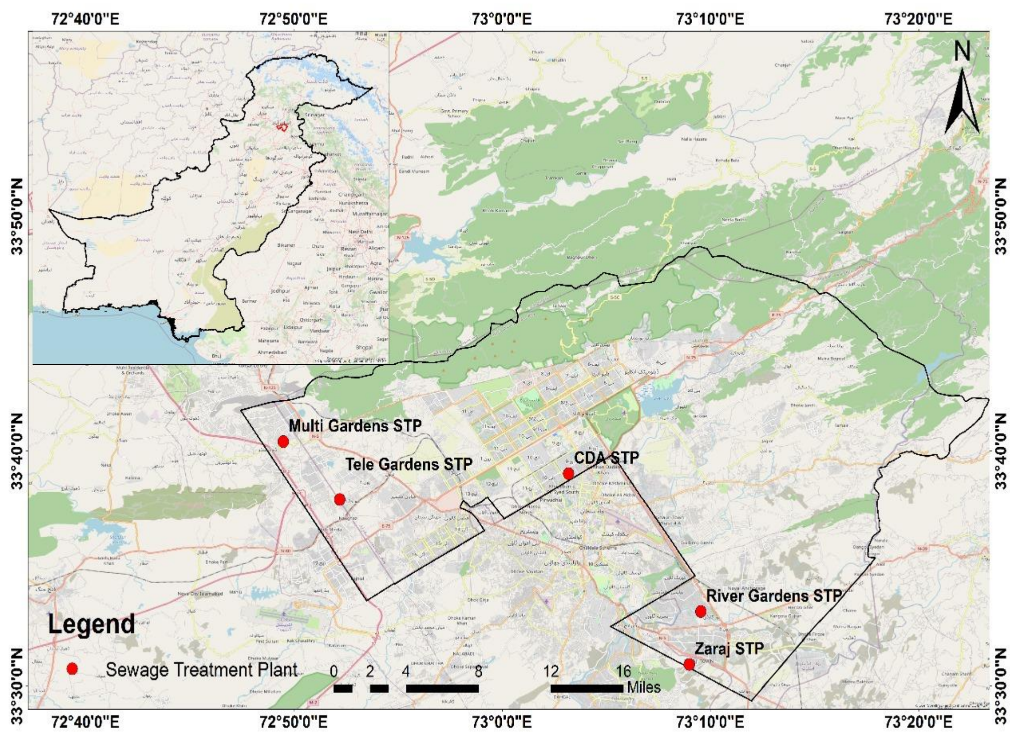

Figure 2.1(a): Study area map of five Sewage Treatment plants

Figure 2.1(b): Groundwater sampling points

The following are the names of sewage treatment plants selected for the study:

i. Zaraj Housing Scheme Sewage Treatment Plant, Zone 5 Islamabad
ii. Tele Gardens Sewage Treatment Plant, F-17 Islamabad
iii. Multi Gardens Sewage Treatment Plant, B-17 Islamabad
iv. River Gardens Sewage Treatment Plant, Express Highway Islamabad
v. CDA Sewage Treatment Plant, I-9 Islamabad

2.2 Sample Collection

The purpose of this study is to investigate the treatment effectiveness of selected wastewater treatment facilities (WWTPs) in Islamabad and assess the quality of groundwater in the surrounding area. An evaluation will be conducted to establish the level of contamination and the appropriateness of the groundwater for drinking purposes.

A total of 80 samples were obtained from five sewage treatment facilities in Islamabad and the surrounding regions. A total of thirty wastewater samples were obtained from sewage treatment facilities. A total of six samples were obtained from each sewage treatment plant, consisting of three samples taken before treatment and three samples taken after treatment. The samples were obtained at three distinct time intervals: morning, afternoon, and evening.

In addition to collecting wastewater samples, 50 groundwater samples were also obtained from the neighboring residential areas, comprising 10 samples of drinking water from each location. Both wastewater and groundwater samples were examined for physico-chemical parameters, such as pH, temperature, turbidity, electrical conductivity, total dissolved solids, total suspended solids, sulfates, nitrates, and chlorides. Additionally, heavy metals including Fe, Co, Cd, Zn, Ni, Pb, and As were analyzed, as well as biological parameters such as total bacteria and total coliform in groundwater. The wastewater will undergo analysis for Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) to assess the waste concentration in the water.

2.3 Sample Preparation

For the sampling procedure, groundwater and wastewater samples were collected following the predetermined protocols. The groundwater samples were collected in clean plastic bottles (for physical-chemical analysis) and sterilized bottles (for biological analysis). The samples of wastewater were collected in clean plastic containers by washing them in non-ionic detergent, rinsing them with tap water, and then soaking them in 10% HNO_3 for 24 hours. The pH was then adjusted to 3.5 before use by rinsing with deionized water. Because heavy metals easily combine with organic components, it is always necessary to digest them with powerful acids to destroy them. During digestion, the organic matter was destroyed, interfering ions were removed, and metallic compounds were brought to the solution. The samples were properly labeled and transported to the laboratory, where they were stored in a refrigerator at around 4ºC before analysis. The wastewater samples were prepared by combining a 50 ml wastewater sample with 10 ml of concentrated HNO_3. After continuing to heat the mixture, a small amount of HNO_3 was added until the solution appeared light in color and clear. The samples were then allowed to cool and diluted with distilled water until the desired concentration was reached and were filtered into a 50-ml standard flask, labeled, and ready and used for analysis.

2.4. Analytical Procedures

Following are the analytical methods that were used to assess water quality parameters.

Table 2.1. Wastewater quality parameters and analysis methods

<table>
<tr><th>S. No</th><th colspan="2">Parameters</th><th>Methods</th></tr>
<tr><td>1</td><td rowspan="2">Physical</td><td>pH, TDS, EC, Salts, Temperature</td><td>Multi-Parameter Tester</td></tr>
<tr><td>3</td><td>Turbidity</td><td>Turbidity Meter</td></tr>
<tr><td>4</td><td rowspan="4">Chemical</td><td>Biological Oxygen Demand (BOD)</td><td>BOD Meter</td></tr>
<tr><td>5</td><td>Chemical Oxygen Demand (COD)</td><td>COD Meter</td></tr>
<tr><td>6</td><td>Chlorides, Alkalinity, Hardness, Carbonates</td><td>Titration</td></tr>
<tr><td>7</td><td>Nitrates</td><td>UV Spectrophotometer</td></tr>
<tr><td>8</td><td rowspan="2">Heavy Metals</td><td>Fe, Cr, Cd, Mn, Pb</td><td>Atomic Absorption Spectroscopy</td></tr>
<tr><td></td><td>As</td><td>Arsenic Kit</td></tr>
</table>

Table 2.2. Groundwater quality parameters and analysis methods

S. No	**Parameters**		**Methods**
1	Physical	pH, TDS, EC, Salts, Temperature	Multi-Parameter Tester
3		Turbidity	Turbidity Meter
4	Chemical	Chlorides, Alkalinity, Hardness Carbonates	Titration
5		Nitrates	UV Spectrophotometer
6	Biological	Total Bacteria, Total Coliform	Plate Count Method
7	Heavy Metals	Fe, Cd, Cr, Mn, Pb,	Atomic Absorption Spectroscopy
		As	Arsenic Kit

Performance appraisal was carried out by comparing the concentrations of pollutants at the inlet and outlet of the treatment plant. Groundwater samples were collected from the vicinity of sewage treatment plants and samples of raw (untreated) and treated wastewater were taken at the inlet and outlet of the sewage treatment plants (STPs). The samples were then examined according to the established procedures for the analysis of water and wastewater. The effectiveness of each sewage treatment facility was assessed based on the findings, and the impact of wastewater on groundwater quality was also determined.

2.5 Analysis of Physical Parameters

2.5.1 pH, EC, TDS, Salts, Temperature

The factors assessed were pH, temperature, electrical conductivity, salts, and total dissolved solids for both wastewater and groundwater.

Procedure

The multi-parameter tester was calibrated using standards before analyzing our sample. A 50 ml water sample was measured in a graduated cylinder and transferred to a beaker. Subsequently, a multi-parameter tester was immersed in the water sample, providing the value of each physical parameter after one minute. The values were recorded.

2.5.2 Turbidity

Procedure

10 milliliters of the sample were placed in the provided vial from the kit. The bottle was inserted into the turbidity meter, and the Test/CAL button was pressed to enable light to pass through the sample. The particles in the water dispersed a concentrated laser beam aimed at the sample. The light that is dispersed is measured at different angles from the original route, and the measurements are recorded.

2.6 Analysis of Chemical Parameters

The quantity of salts and other chemicals in water samples was determined using tests including Hardness, Alkalinity, Chloride, and Carbonates tests.

2.6.1 Carbonates Test

Calculation

$m1v1 = m2v2$

m = Molarity

v = Volume of Solution

Procedure

For the carbonate test, burettes were filled with a 0.1 M solution of hydrochloric acid. 10 ml of water was measured in a graduated cylinder and transferred to an Erlenmeyer flask. Two drops of methyl orange indicator were added using a dropper. Upon titration, the sample changed color from orange to pink, indicating the endpoint. Three readings were collected for each sample to prevent human error. We determine the amounts of Na2CO3, NaHCO3, HCO3, and CO3 in our water samples using this procedure.

2.6.2 Chloride Test

Calculation

Chloride (mg/L) = $\frac{V \times N \times 35.54 \times 100}{Sample\ Volume}$

N= Normality of silver nitrate

V= Volume of reagent used

Procedure

For the carbonate test, burettes were filled with a 0.1 M solution of hydrochloric acid. 10 ml of water was measured in a graduated cylinder and transferred to an Erlenmeyer flask. Two drops of methyl orange indicator were added using a dropper. Upon titration, the sample changed color from orange to pink, indicating the endpoint. Three readings were collected for each sample to prevent human error. We determine the amounts of Na2CO3, NaHCO3, HCO3, and CO3 in our water samples using this procedure.

2.6.3 Alkalinity Test

Calculation

Alkalinity (mg/L) = $\frac{N \times V \times 1000}{Sample\ Volume}$

N= Normality of sulfuric acid

V= Volume of reagent used

Procedure

The burette was filled with sulfuric acid (H2SO4) with a concentration of 0.02 M. A volume of 50ml of the water sample was measured in a graduated cylinder and added to a beaker. The pH of the sample was checked, and if it was below 8.5, methyl orange indicator was used; if it was above 8.5, phenolphthalein indicator was used. The water sample was then transferred to an Erlenmeyer flask with the chosen indicator. After titration, the endpoint was reached when the colour changed from orange to yellow or peach. Three readings were obtained to prevent human error.

2.6.4 Hardness Test

Calculation

Total Hardness = $\frac{A \times B \times 100}{Sample\ Volume}$

A= EDTA used for a sample – EDTA used for a Bank sample (distilled water)

B = Normality of EDTA

Procedure

In this experiment, the burette was filled with Ethylene Diamine Triacetic Acid (EDTA) and a 50 ml distilled water sample was transferred from a graduated cylinder to an Erlenmeyer flask. Using a 1 ml syringe, 2 ml of Ammonium Chloride (NH4Cl) was added to the blank water sample. The pH of the solution was then measured using a pH metre to determine if it was equal to or greater than 100. We added two drops of Eriochrome Black T (EBT) indicator using a dropper. The sample went red first and then changed to blue at the end point of titration. The technique was repeated for the water samples, and the amount of EDTA used for the black sample was subtracted from the amount used for the water samples. We determine the overall hardness and the levels of calcium and magnesium in our water samples with this technique.

2.6.5 Nitrates

Nitrate is a crucial nutrient required by live bacteria. It is essential for the physiological functions of bacteria. If the concentration exceeds the allowed limit, it is classified as a pollutant. Nitrate levels were determined using a UV spectrophotometer. The spectrophotometer operates on the Beer-Lambert law, which establishes a direct correlation between the concentration and absorption of a sample. The volumetric flask, beaker, and measuring cylinder were cleaned and cleaned with distilled water.

Procedure

Initially, the blank is run with all components save the one being measured. The correction was made. Combine 10 ml of pure water with 0.2 ml of 1 N HCl in a beaker. Add 0.2ml of 1 N HCl to a 10ml water sample. Place the sample in the cuvette and record the measurement at 220 nm using the UV 4000 spectrophotometer.

Calculation

$$Conc.\ of\ sample = abs.\ of\ sample \times conc.\ of standard /\ abs.\ of\ standard$$

2.6.6 Chemical Oxygen Demand (COD)

Procedure

50mL of the sample was put into refluxing flasks. Subsequently, glass beads and 1g of $HgSO_4$ were introduced into the flasks. Next, 5mL of sulfuric acid reagent was added gradually to dissolve HgSO, and the mixture was cooled while stirring. 25 milliliters of standard dichromate solution were added and carefully mixed. The flask was connected to the condenser, and the cooling water was activated. Poured the remaining 70mL of sulfuric acid reagent into the condenser through the open end while twisting and combining. The recirculating fluid was properly mixed, and the open end of the reflux condenser was shielded with a tiny beaker. Subsequently, heat was applied, and the mixture was refluxed for two hours. After two hours of heating, the substance was allowed to cool, and the condenser was rinsed with distilled water. The reflux condenser was removed, and the mixture was diluted to double its original volume. The solution was cooled to room temperature, and the surplus $K_2Cr_2O_7$ was titrated with FAS using ferroin as an indicator. The endpoint was the initial distinct transition in color from blue-green to reddish-brown. The experimental procedures outlined above were performed using 50mL of distilled water as a control sample.

Calculation

The COD of the sample was calculated as given below:

COD as mg O_2 /L= (A-B) x M x 800

Volume of sample (mL)

Where.

A = Volume of FAS used to titrate the blank in ml B = Volume of FAS used to titrate sample in ml M = Molarity of FAS solution

2.6.7 Biological Oxygen Demand (BOD)

Procedure

Five disinfected BOD bottles with a size of 300ml each were used. Four BOD bottles were utilized to create various dilutions of a sample, along with one bottle for the blank. Four distinct volumes of the material were obtained using pipettes, staying within the volume restrictions. Every bottle included dilution water. The initial dissolved oxygen (DO) levels of each sample dilution and the blank were measured using an Oxygen Sensitive Membrane Electrode. No contamination occurred in the bottles during this stage. The stoppers were positioned on each bottle to ensure the absence of any air bubbles inside. All the bottles were placed in an incubator at a temperature of 20°C for a duration of five days. The final optical density (DO) and D2 values of each sample dilution and the blank were measured after the incubation period. The dilutions that displayed drops of dissolved oxygen within the specified limits were chosen.

Calculation

Calculated the BOD using the formula:

1. When Dilution water is not seeded

BODs, mg/L = D1 - D2/P

2. When Dilution Water is seeded

Where:

BOD’s mg/L (D1-D2) - (B1-B2)f/P

- D1 = DO of diluted sample immediately after preparation, mg/L.
- D2 = DO of diluted sample after 5 d incubation at 20°C mg/L.
- P = decimal volumetric fraction of sample used.
- B= DO of seed control before incubation, mg/L.
- B2 = DO of seed control after incubation, mg/L.
- f= ratio of seed in diluted sample to seed in seed control =
- (% seed in diluted sample)/(% seed in seed control)

- If seed material is added directly to the sample or seed control bottles: 1 = (Volume of seed in diluted sample)/(volume of seed in seed control)

2.7 Analysis of Biological Parameters

The plate count method was used for the assessment of biological parameters.

2.7.1 Plate Count Method

Two media culture plates were produced in the lab for the sample collection. Nutrient Agar is abbreviated as NA, whereas MacConkey agar is abbreviated as Mac. The agar was made in glass reagent vials of appropriate size and sealed with cotton plugs. The items were sterilized in the autoclave at 121°C for 30 minutes and then opened in the laminar flow. The petri plates were filled with individual culture media.

Biological parameter samples were gathered and placed in a laminar flow on the same day. Each sample was sequentially opened, obtained using a pipette from a bottle, poured onto the media, and evenly dispersed with a glass spreader. After each dish, the spreader was disinfected with spirit, dried with a spirit lamp, and cooled. After each sample, petri dishes were sealed, labeled, inverted, and placed in the incubator at a temperature of 30-36°C. After 24 hours, the petri dishes were examined, and the bacteria were quantified by marking them on the dishes using a marker.

2.8 Heavy metals

The wastewater samples and groundwater samples from five sewage treatment plants and surrounding regions were subjected to testing for heavy metals, specifically Iron (Fe), Arsenic (As), Cobalt (Co), Cadmium (Cd), Zinc (Zn), Nickel (Ni), Manganese (Mn), and Lead (Pb).

2.8.1 Arsenic testing

Arsenic testing was conducted using an arsenic testing kit, where the water samples were prepared by adding specific reagents provided in the kit.

Reagent 1: This reagent is designed to help stabilize the arsenic present in the water sample and prevent any unwanted reactions during the testing process.

Reagent 2: Reagent 2 is the primary agent responsible for the chemical reaction that occurs with arsenic in the water. It helps to form a color complex with arsenic ions, resulting in a visible color change on the test

Reagent 3: This reagent serves as a catalyst or enhancer to improve the sensitivity and accuracy of the color reaction when arsenic is present in the water sample.

The contents were mixed thoroughly by stirring. Next, test strips were immersed into the prepared water samples and allowed to react for approximately 10 minutes. The reaction resulted in a color change on the test strips, and the intensity of this color was then matched with a color chart supplied in the testing kit. By comparing the strip's color with the chart, the amount of arsenic present in the water sample was determined.

2.8.2 Determination of Fe, Cr, Cd, Mn, and Pb through Atomic Absorption Spectroscopy (AAS)

One of the most often employed methods for analytical purposes is atomic absorption spectrometry (AAS). It has been extensively employed in research labs, as well as in the fields of food, the environment, medicine, petroleum, and other industries (Sergio, et al., 2018). Measurement of element concentrations is done analytically using atomic absorption spectroscopy (AAS). It uses the light absorption caused by various substances to calculate the concentration of each. The absorption of ground-state atoms in the gaseous state can be measured by atomic absorption spectroscopy. The atoms move to higher electronic energy levels after absorbing ultraviolet or visible light (Ahmed, 2012). Once the instrument has been calibrated using standards of known concentration, concentration measurements are typically made using a working curve. A highly popular method for finding metals and metalloids in environmental materials is atomic absorption (Ahmed & Ishiga, 2006). Four main parts make up an atomic absorption spectrometer: a light source (often a hollow cathode lamp), an atom cell (atomizer), a monochromator, a unit for detection, and a read-out device. All prepared water samples were evaluated and analyzed using Atomic Absorption Spectroscopy AAS (Model AA-7000), for five selected heavy metals named Cobalt (Co), Iron (FE), Cadmium (Cd), Zinc (Zn), Nickel (Ni), Manganese (Mn), and Lead (Pb).

2.9 Treatment Methodologies of Sewage Treatment Plants

In Pakistan, residential waste, which includes household effluent and human waste, is often disposed of by being released directly into a sewage system, a natural drain or water body, a neighboring field, or an internal septic tank. Most cities do not handle municipal wastewater, except Islamabad and Karachi which have biological treatment processes in place. These cities only treat a small fraction of their wastewater before disposing of it. Approximately 8% of urban wastewater is processed at municipal treatment plants, assuming all plants are operating at full capacity. Urban centers are the primary source of water contamination in this country. The centralized treatment plants were not sustainable due to insufficient capacity and resources for management. A decentralized and localized approach to wastewater treatment is required. Implementing natural, cost-effective, and sustainable wastewater treatment solutions. The recycling and reuse of treated water are progressing towards achieving zero liquid discharge.

2.9.1 Treatment methodology of Zaraj Housing Scheme, Tele, Multi, and River Gardens STPs

All treatment plant's system distinctiveness stems from their compact design, which efficiently treats sewage and waste including heavy metals and organic compounds while maintaining an aesthetically pleasing appearance. The system primarily includes an Anaerobic Baffled Reactor (ABR) and a built wetland. The water passes through the created wetland, where plant roots and the substrate filter out the bigger particles in the wastewater. The pollutants and nutrients in the wastewater are naturally decomposed and absorbed by the bacteria and plants, eliminating them from the water. The system consists of four distinct steps, each with its own estimated hydraulic retention time.

Stage I has a Collection Tank, in which the total wastewater from various blocks is collected in a raw sewage collection tank. This wastewater is lifted to the next treatment facility by a level switch-controlled sludge pump. The wastewater treatment system in Stage II has an Anaerobic Baffled Reactor (ABR) consisting of 6 HDPE tanks, each with a capacity of 2000 liters. It promotes organic decomposition and reduction of inorganic matter through anaerobic digestion, which involves Hydrolysis, Fermentation, and Methanogenesis. This unique feature reduces the cost of wastewater treatment systems.

On the other hand, Stage III has a Constructed Wet Land (SSHF-CW), which is a shallow tank filled with special gravel media and is a Sub-Surface Horizontal Flow Constructed Wetland (SSHF-CW). Aquatic submerged plants like duckweed, water lettuce and typha, common reed are used for phytoremediation to fix heavy metals load. Stage IV has a Free Water Surface-Constructed Wetland (FWS-CW) which is a partially filled tank with gravel that presents surface water. The aerobic digestion mechanism is defined through the interaction with oxygen (air) in the environment. To give an aesthetic look to the wetland, Pennywort, a perennial broadleaf plant with creeping underground stems, is used, which can uptake and fix nitrogen and phosphorus. The quality of the treated water is good enough to be used for gardening, agriculture and other general purposes. All the wastewater is being treated using a low-cost, sustainable, nature-based solution. It is an eco-friendly approach that can convert harmful contaminants into less harmful substances. But it is a slow process, has limited applicability and require close monitoring.

2.9.2 Treatment Methodology of CDA STP

Sewer trunk lines receive raw sewage from different sectors of the Capital, CDA, and Islamabad. It contains 99% water with 1% suspended solids, including organic and inorganic pollutants. The first step of the treatment process is Coarse Screening, where large debris and particles of about 50mm in size are removed. Raw sewage flows into a 60 ft. deep structure and is screened using a 50mm vertical automatic bar screen to remove debris and coarse material. The screen is equipped with a time-controlled and manually operated skip-through bar raking mechanism. Raw sewage flows to the pumping station where 4 submersible pumps (75 KW) for Phase IV and 3 pumps for Phase III are installed. The pumping station serves both phases and the pumps operate automatically and manually depending on the sewage flow. The pumps lift sewage water to fine screening for further processing. Fine Screening is the process of removing small particles of 10-20mm from raw sewage water. Fine screens are used for this purpose, which are designed to remove suspended particles. The removed particles are then compacted and disposed of periodically. It is an automated mechanical system that can be operated manually by the Plant Operator. After screening, sewage goes to the Grit Removal Chamber where heavy grit particles settle to the bottom and are removed to a sand/grit storage tank. The grit is extracted by an airlift/blower pump and deposited in the sand pit. The wastewater leaves by gravity to the Primary Settling Tanks. The grit chamber includes one agitator with blades, two airlift blowers, two solenoid valves, and one high-pressure detector.

The primary settlement tank settles sewage, with overflow weirs for recovery and pumping of primary sludge mixed with biological sludge. Biological treatment is done through Aeration Tanks and Final Settlement. Aeration is done using surface cone aerators. In Phase III, there are four aerators, and in Phase IV, there are six. DO level control is used to operate the aerators, with a minimum of 1.5 mg/l and a high of 2.5 mg/l set in each tank. When the high level is reached, one aerator is switched off, and both operate when the level drops to 1.5 mg/l. The aerators supply oxygen to microbes that play a role in the bio-dig ratio of pollutants. Final Settlement takes place in cylindrical-conical tanks supplied with aerated sewage, where clarified wastewater is recovered by overflow weirs and biological sludge is pumped out. Gravity thickening involves feeding dilute sludge to a circular tank, allowing it to settle and compact, and withdrawing the thickened sludge from the bottom. Sludge is gently stirred to open up channels for water escape and promote densification. Sludge collected at the bottom of the tank is pumped to the aerobic digesters. A sludge blanket is maintained at the bottom of the thickener to concentrate the sludge. The sludge volume ratio is an operating variable that ranges between 0.5 and 20d. Sludge is pumped to drying beds for 2-4 weeks, then removed or stored. Liquor is collected in drains and returned to the head of the works. The Sludge Stabilization Tank receives thickened sludge and stabilizes it aerobically using surface-mounted turbines. This process kills pathogenic organisms and allows the sludge to be pumped to dry beds. Lastly, 70 to 80% of the treated water is discharged into the Nallahs and 20-30% is utilized in gardening and other agricultural activities.

The activated sludge process is efficient in removing organic matter from wastewater and produces high quality effluent but it requires high energy for aeration, can be sensitive to fluctuations in wastewater composition, requires skilled operation and maintenance and produces sludge that needs proper disposal.

CHAPTER 3

RESULTS AND DISCUSSION

The chapter discusses the results of water quality i.e. physical, chemical, biological, and heavy metal analysis of five sewage treatment plants and the groundwater quality of their surrounding areas in Islamabad. Additionally, the chapter also discusses the impact of wastewater on the groundwater quality of surrounding areas and the resulting impacts on the consumers. The removal efficiency of all five sewage treatment plants for all physical, chemical, and heavy metals is also discussed in the chapter.

3. Results of physical parameters of groundwater samples

The groundwater samples from the surrounding areas of five sewage treatment plants were assessed for physical parameters i.e., pH, temperature, electrical conductivity (EC), turbidity, salts, and total dissolved solids (TDS). The results of the physical parameters of all water samples are discussed below.

3.1 pH

The pH is a measure of the hydrogen ion concentration. Hydrogen ion concentration (pH) strength is of critical importance in the quality of water. Other contaminations, such as microbial activities and metal salt solubility and stability, etc., mainly depend on the water pH level (Batool, et al., 2019). According to Pak EPA water guidelines, the pH value must be in the range of 6.5-8.5.

3.1.1 Sector I-9

According to Pak EPA water guidelines, the pH value must be in the range of 6.5-8.5. According to the results of pH for groundwater samples collected from sector I-9, the pH values of the samples exceeded the lower range with a recommended limit of 6.5.

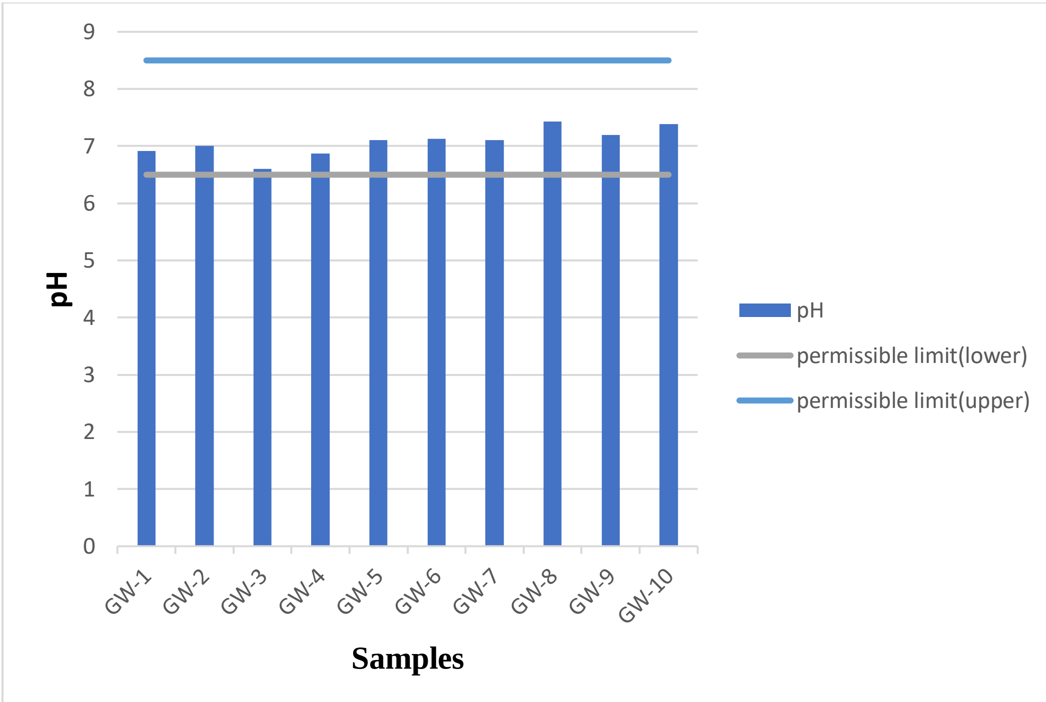

Figure 3.1(a): Levels of pH in collected groundwater samples from I-9

3.1.2 Tele Gardens

The pH of all the groundwater samples of Tele Gardens (GW-11 to GW-20) was within permissible limit of Pak-EPA (6.5-8.5).

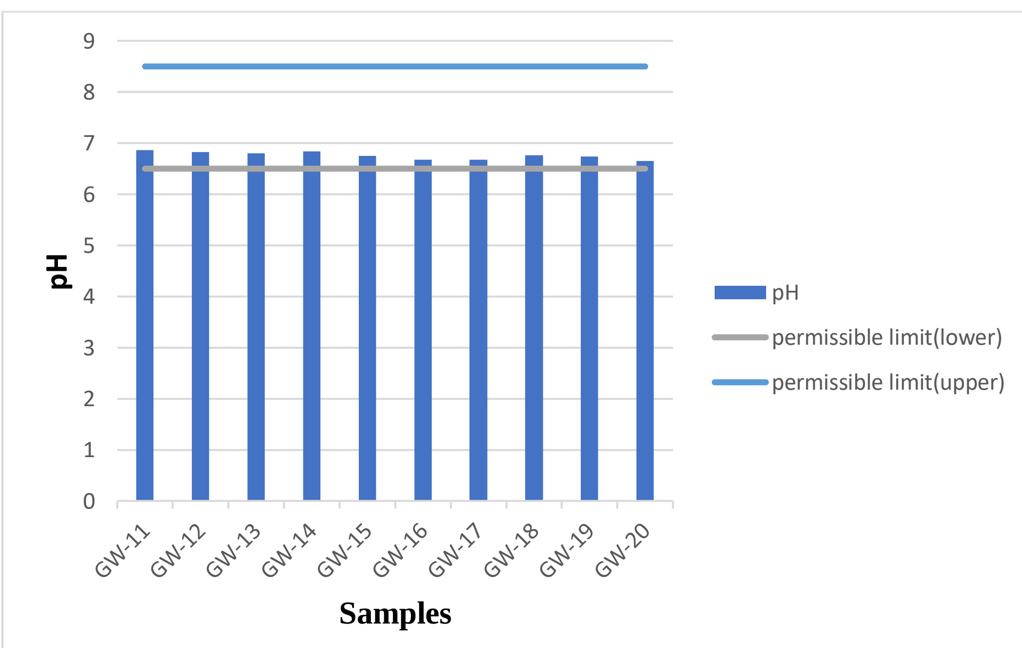

Figure 3.1(b): Levels of pH in collected groundwater samples from Tele Gardens

3.1.3 Multi Gardens

The pH of all the groundwater samples of Tele Gardens (GW-21 to GW-30) was within permissible limit of Pak-EPA (6.5-8.5).

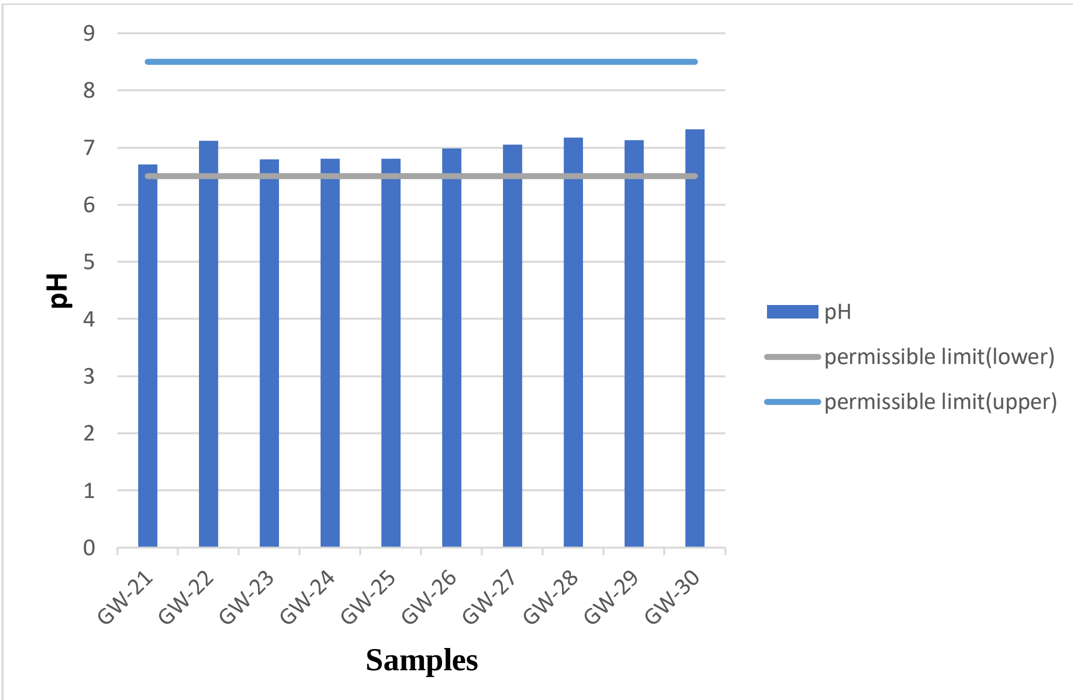

Figure 3.1(c): Levels of pH in collected groundwater samples from Multi Gardens

3.1.4 Zaraj Housing Scheme

The pH of all the groundwater samples of Tele Gardens (GW-31 to GW-40) was within permissible limit of Pak-EPA (6.5-8.5).

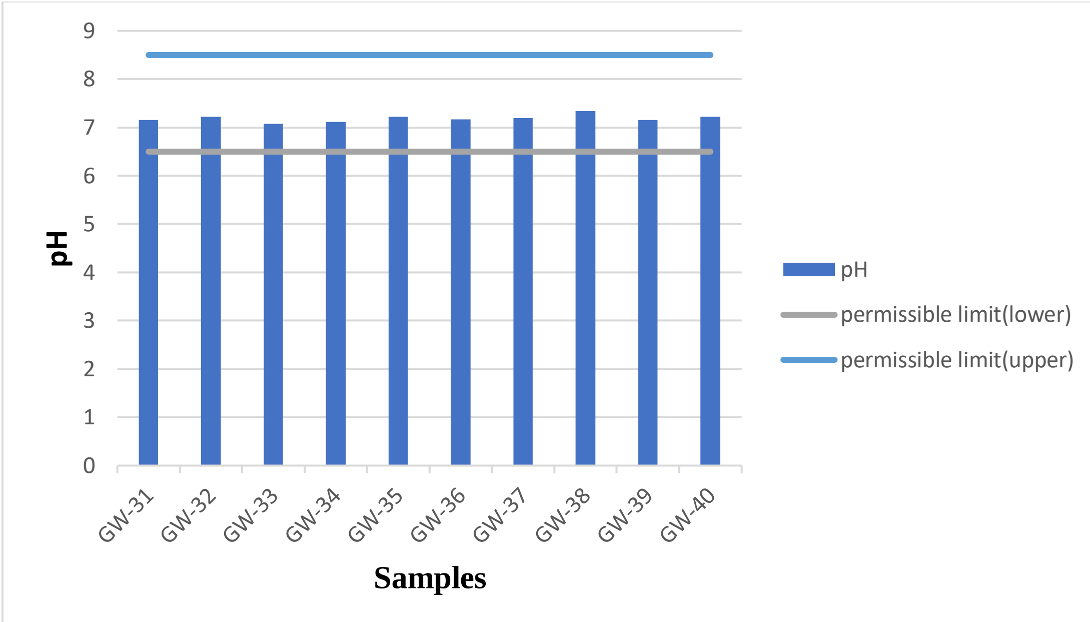

Figure 3.1(d): Levels of pH in collected groundwater samples from the Zaraj Housing Scheme

3.1.5 River Gardens

The pH of all the groundwater samples of Tele Gardens (GW-41 to GW-50) was within permissible limit of Pak-EPA (6.5-8.5).

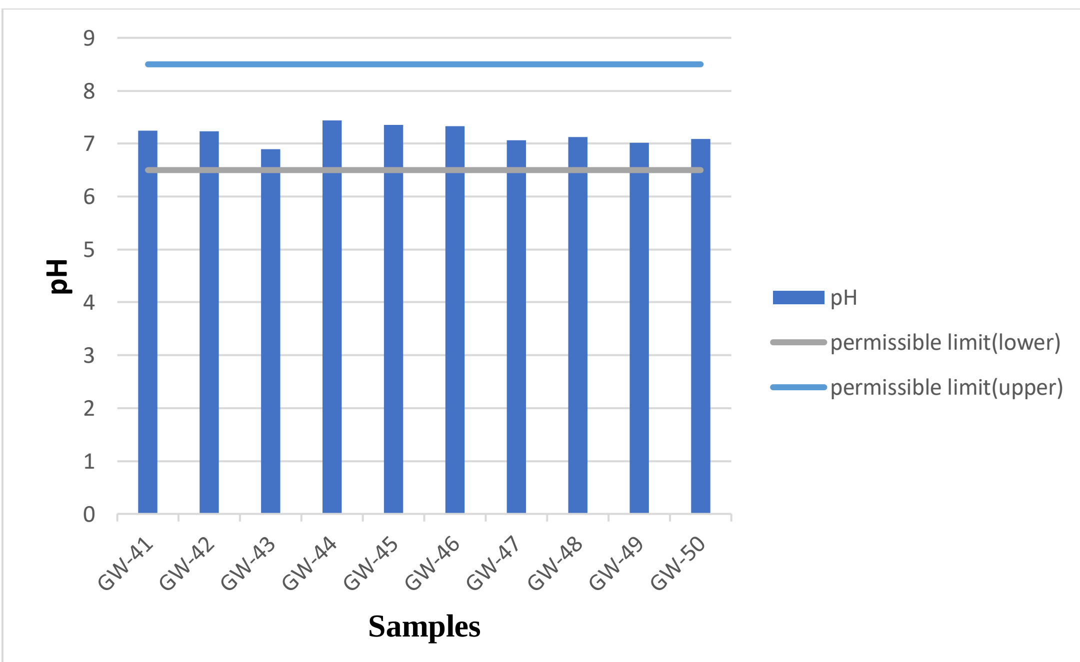

Figure 3.1(e): Levels of pH in collected groundwater samples from River Gardens

3.2 Electrical Conductivity

Electrical conductivity is a measure of its ability to conduct electricity. It is a measure of the concentration of ions in water. Its value is a clear indicator of the presence of mineral salts in the water. Conductivity is linked directly to the total dissolved solids (TDS) (Adegbola, et al., 2014). Pak EPA's guideline value for electrical conductivity for water is 1000 µS/cm^3. Conductivity is directly related to total dissolved solids (TDS).

3.2.1 Sector I-9

The results of all the groundwater samples of Sector I-9 for electrical conductivity were within the permissible range of Pak EPA (1000 µS/cm^3).

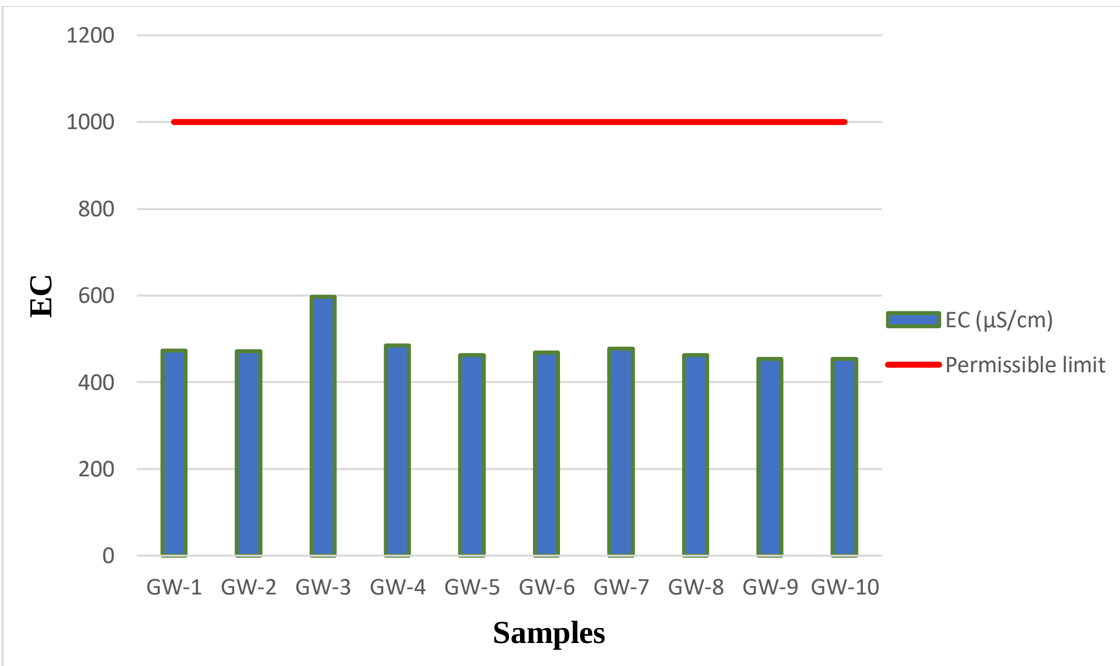

Figure 3.2(a): Levels of EC in collected groundwater samples from sector I-9

3.2.2 Tele Gardens

The results of samples GW11, GW12, GW13, GW16, and GW20 for electrical conductivity were within the permissible range. However, samples GW14, GW15, GW17, GW18, and GW19 exceeded the recommended limit Pak EPA which is 1000 µS/cm$^{3.}$

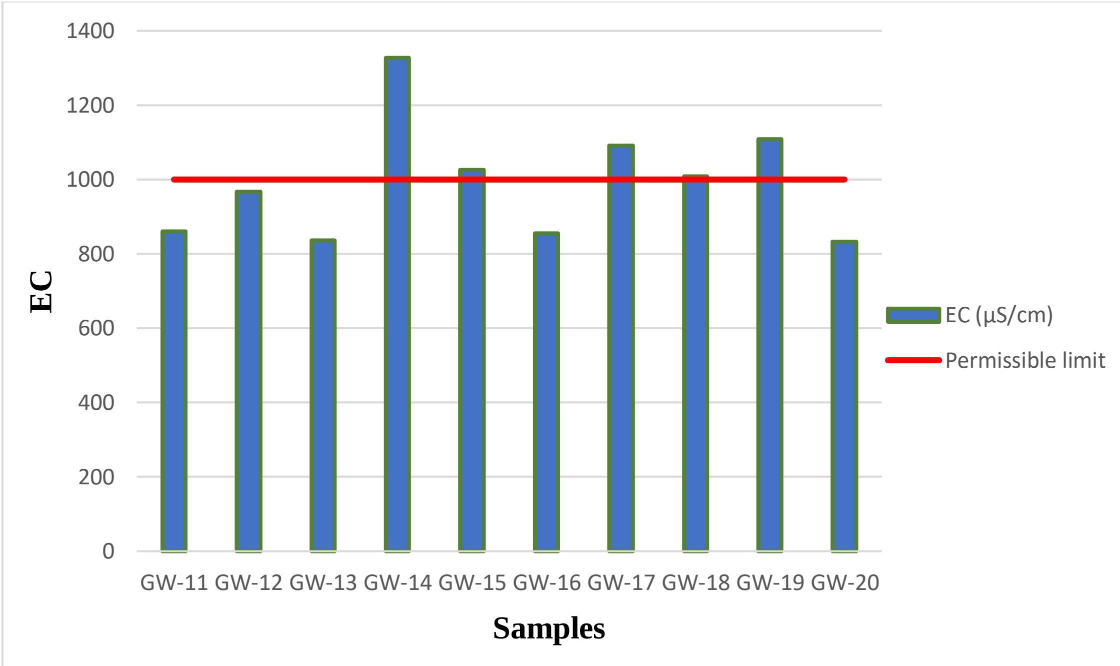

Figure 3.2(b): Levels of EC in collected groundwater samples from Tele Gardens

3.2.3 Multi Gardens

The results of all samples, GW21 to GW30 for electrical conductivity were within the permissible range of Pak EPA (1000 µS/cm^3).

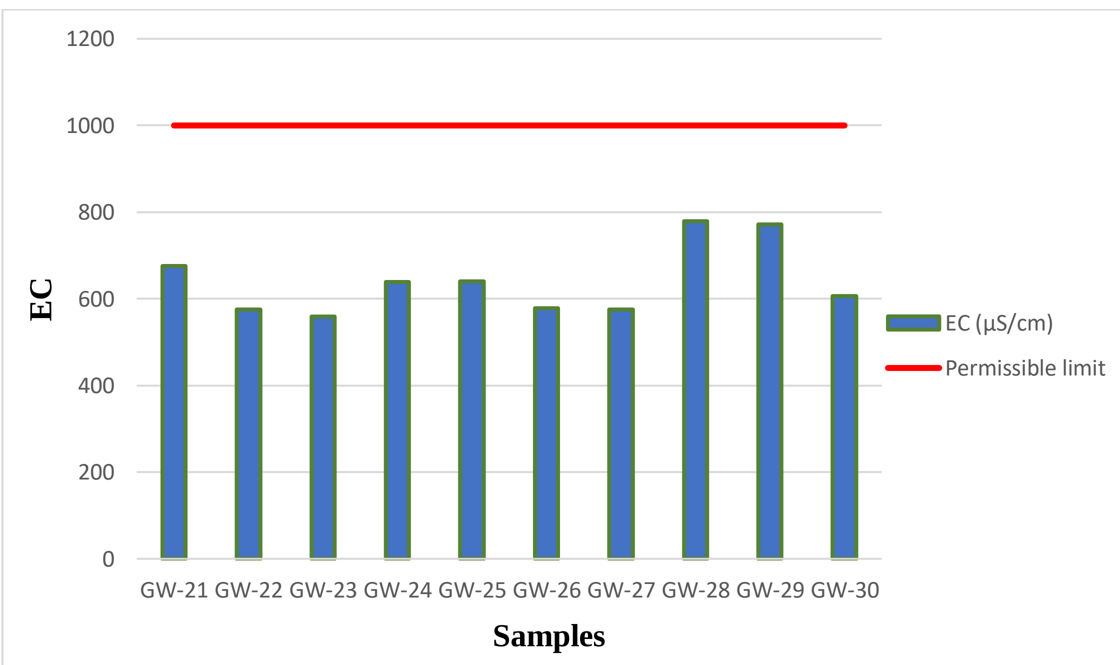

Figure 3.2(c): Levels of EC in collected groundwater samples from Multi Gardens

3.2.4 Zaraj Housing Scheme

The results of all samples, GW31 to GW40 for electrical conductivity were within the permissible range of Pak EPA (1000 µS/cm^3).

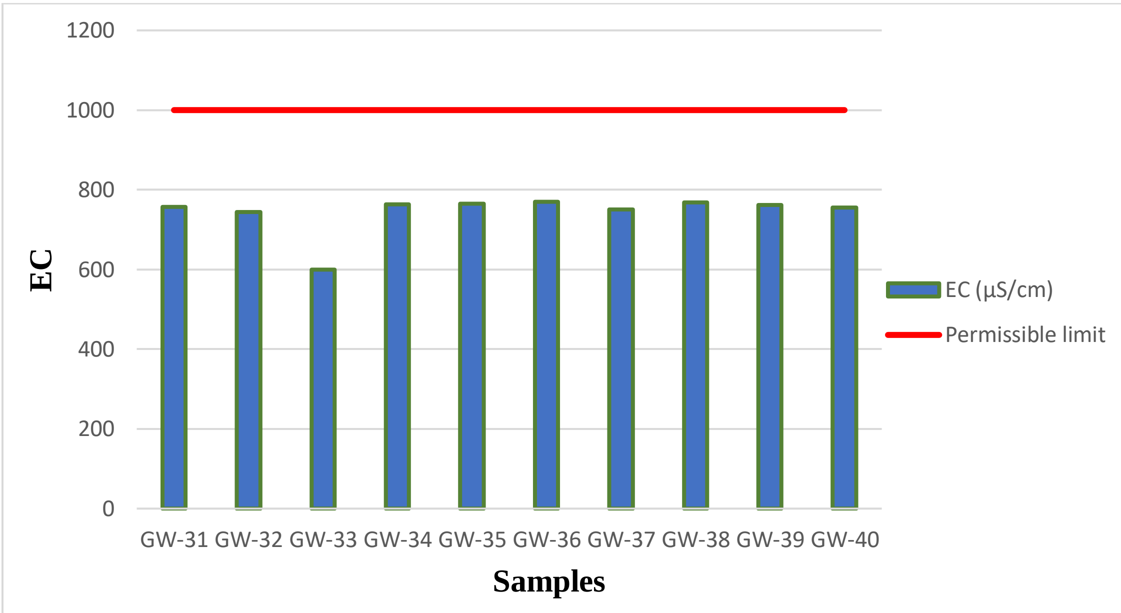

Figure 3.2(d): Levels of EC in collected groundwater samples from Zaraj Housing Scheme

3.2.5 River Gardens

The results of all samples, GW41 to GW50 for electrical conductivity were within the permissible range of Pak EPA (1000 µS/cm^3).

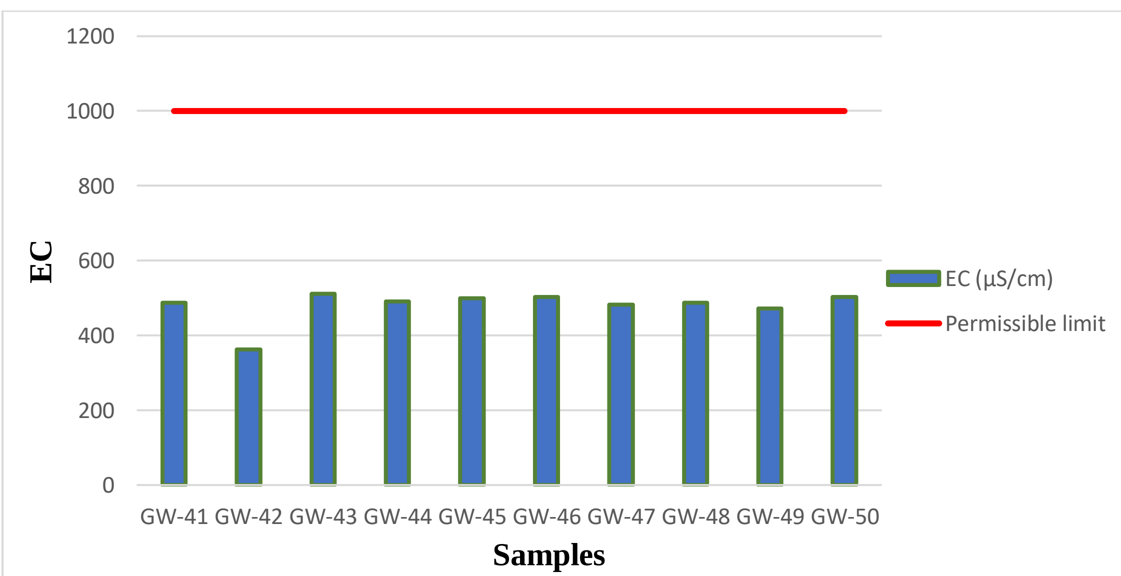

Figure 3.2(e): Levels of EC in collected groundwater samples from River Gardens

3.3 Total Dissolved Solids

Total dissolved solids provide an estimate of the organic and inorganic soluble salts in water. For drinking purposes, the EPA has suggested a permissible range of 500 mg /l. Water with a high TDS value shows water to be highly mineralized (Payment, et al., 2003).

3.3.1: Sector I-9

The results of TDS in all groundwater samples of Sector I-9 were within the permissible limit of Pak EPA (500 mg /l).

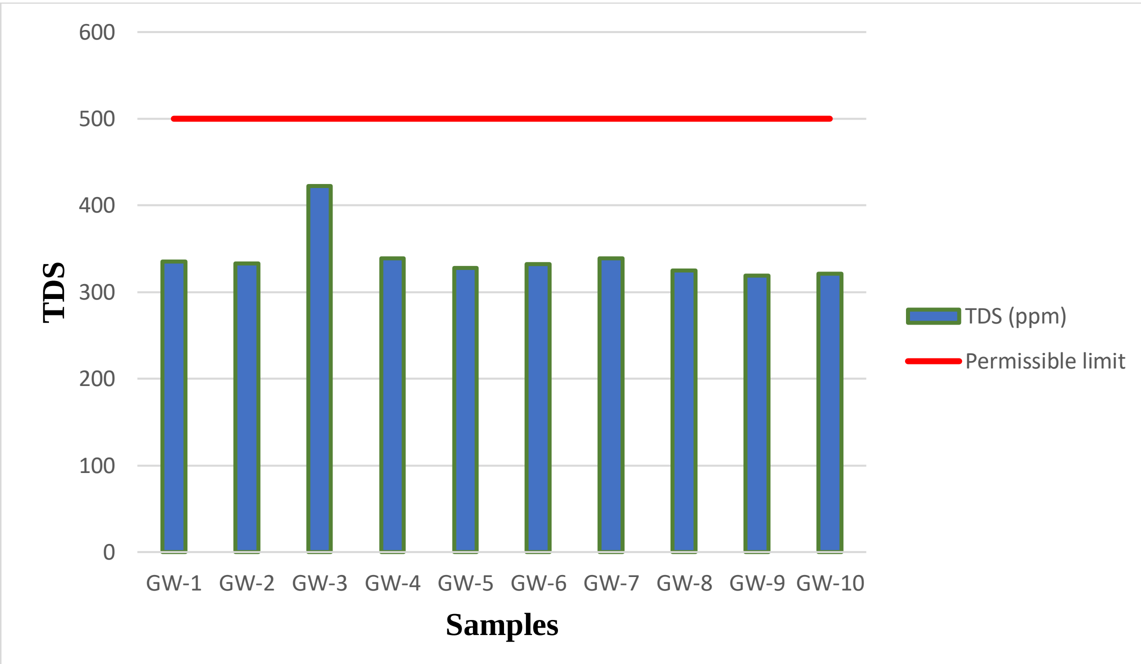

Figure 3.3(a): Levels of TDS in collected groundwater samples from sector I-9

3.3.2 Tele Gardens

The results of all samples GW11 -GW20 exceeded the recommended limit of Pak EPA (500 mg /l).

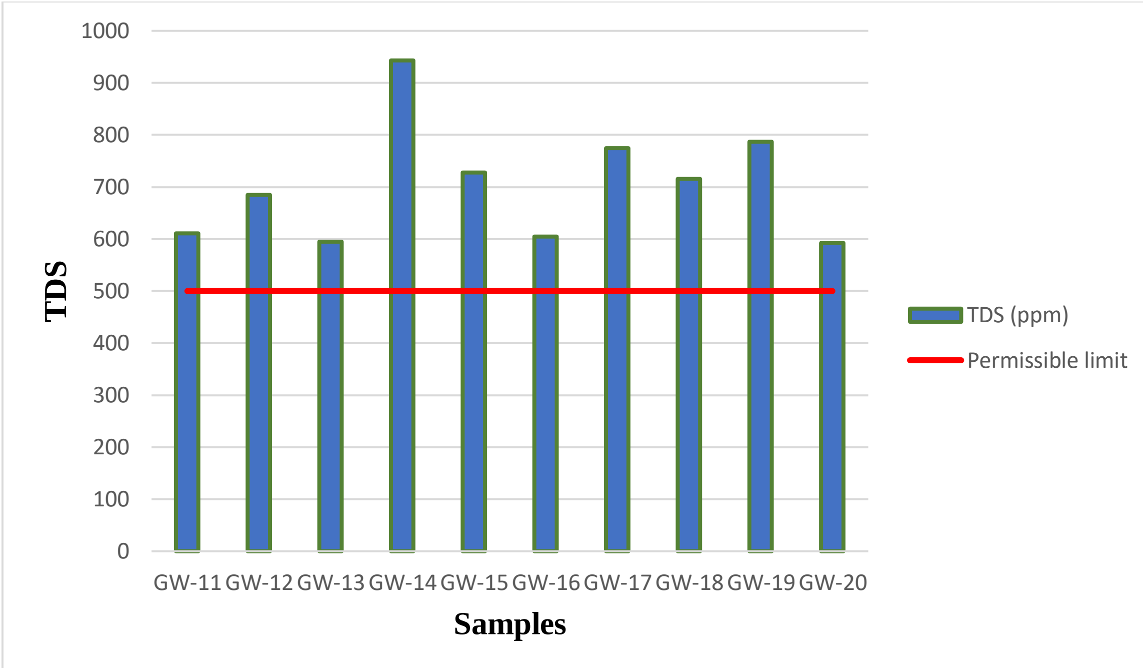

Figure 3.3(b): Levels of TDS in collected groundwater samples from Tele Gardens

3.3.3 Multi Gardens

The results of all samples were within the recommended limit except for two samples, GW28 and GW29, which exceeded the limit.

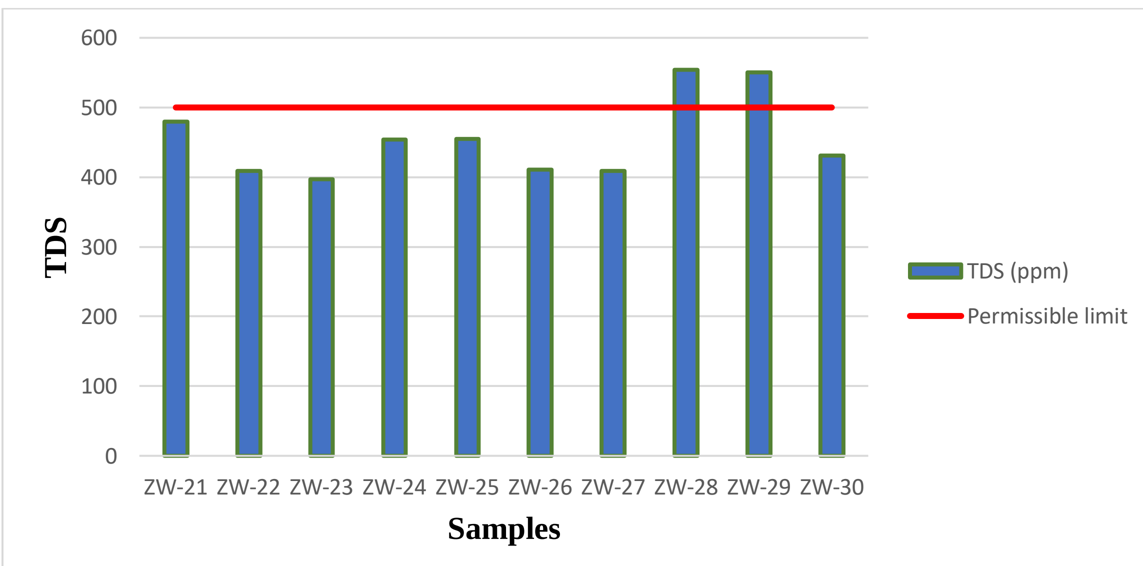

Figure 3.3(c): Levels of TDS in collected groundwater samples from Multi Gardens

3.3.4 Zaraj Housing Scheme

The results of all samples exceeded the recommended limit except for one sample, GW33, which exceeded the recommended limit of Pak EPA (500 mg /l).

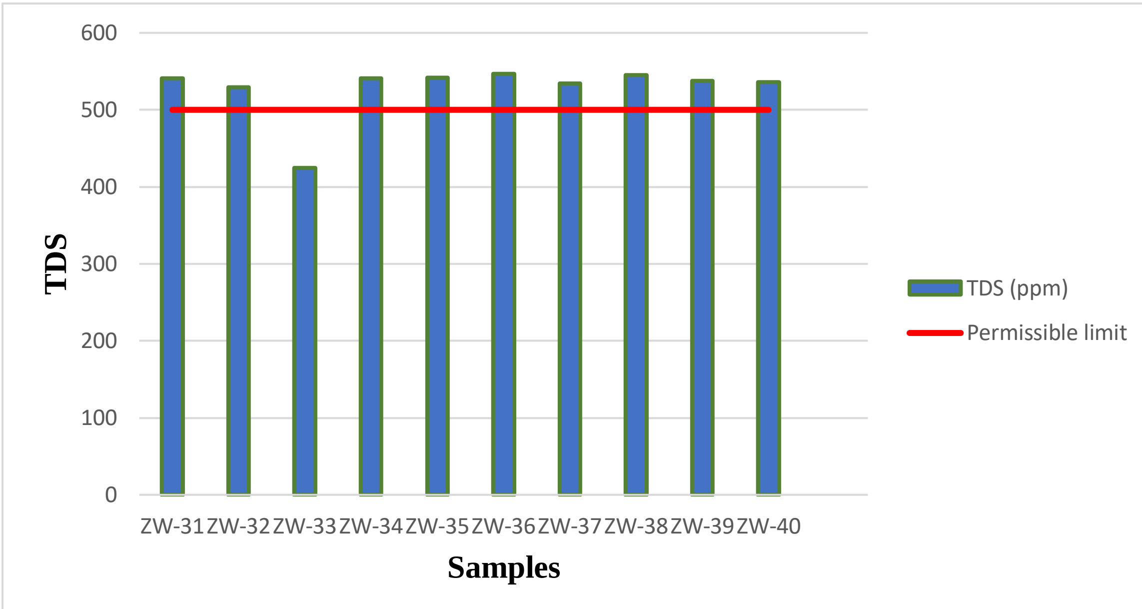

Figure 3.3(d): Levels of TDS in collected groundwater samples from Zaraj Housing Scheme

3.3.5 River Gardens

The results of all samples, GW41 to GW50 were within the recommended limit of Pak EPA (500 mg /l).

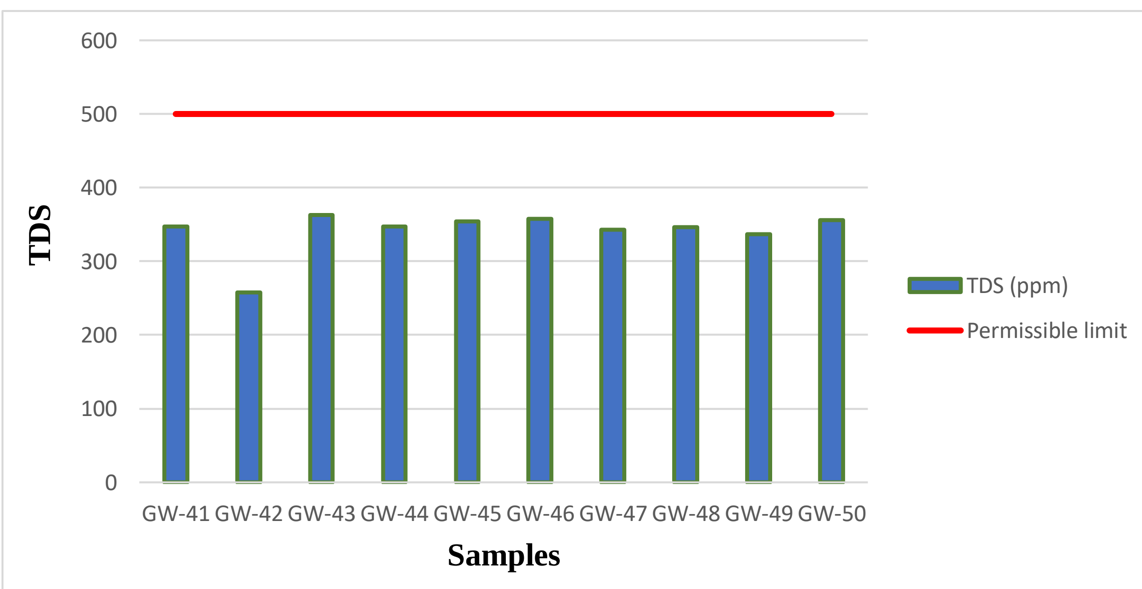

Figure 3.3(e): Levels of TDS in collected groundwater samples from River Gardens

3.4 Salts

Salts are mostly composed of carbonates, bicarbonates, chlorides, sulfates, phosphates, nitrates, calcium, magnesium, sodium, potassium, iron, manganese, etc. They may not contain gases, colloids, sediments, or any other minerals found on the surface of the earth. An unpleasant taste or appearance can be created by the dissolved minerals (Poonam, et al., 2013). Pak EPA's recommended permissible salt limit is 200 mg/l. The result of all groundwater samples for salts exceeded the permissible limit of 200 mg/l except for GW-42 sample of River Gardens.

3.4.1 Sector I-9

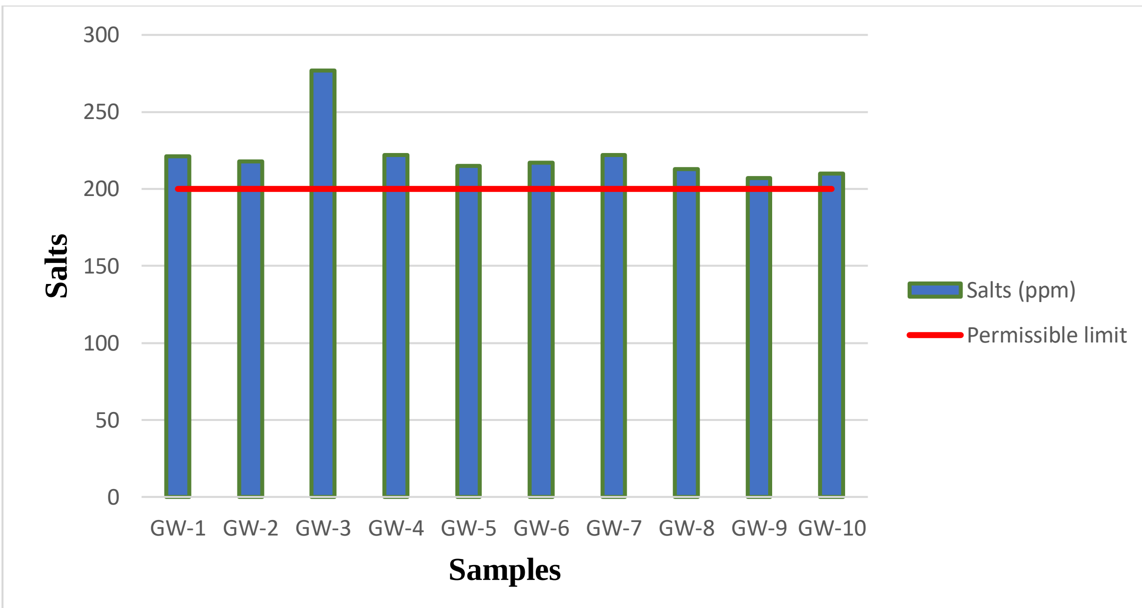

Figure 3.4(a): Levels of salts in collected groundwater samples from I-9

3.4.2 Tele Gardens

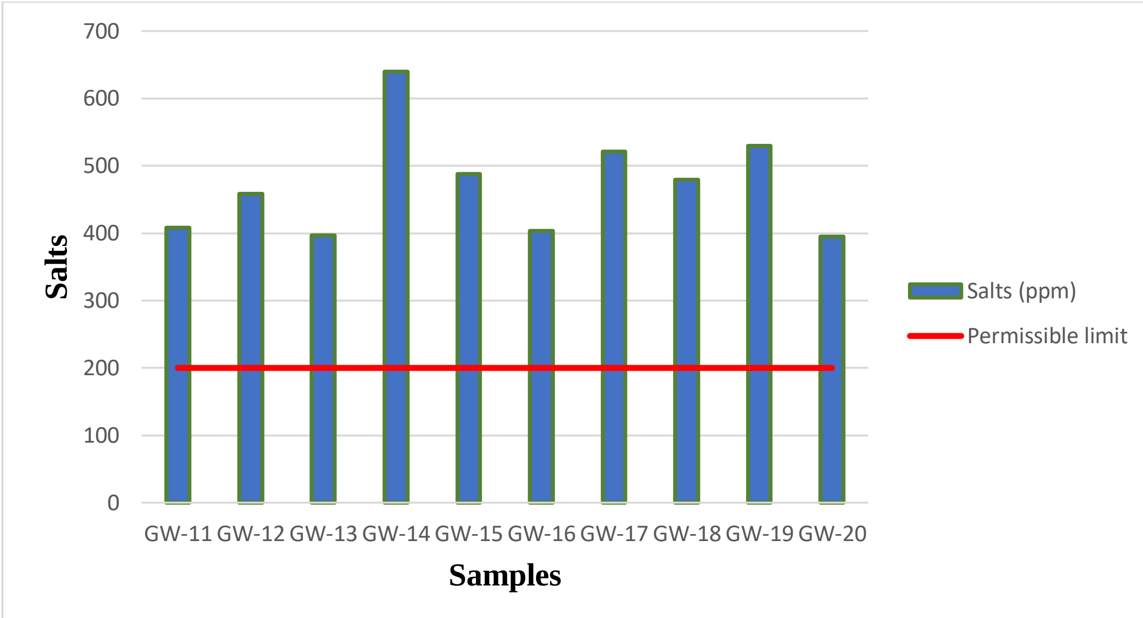

Figure 3.4(b): Levels of salts in collected groundwater samples from Tele Gardens

3.4.3 Multi Gardens

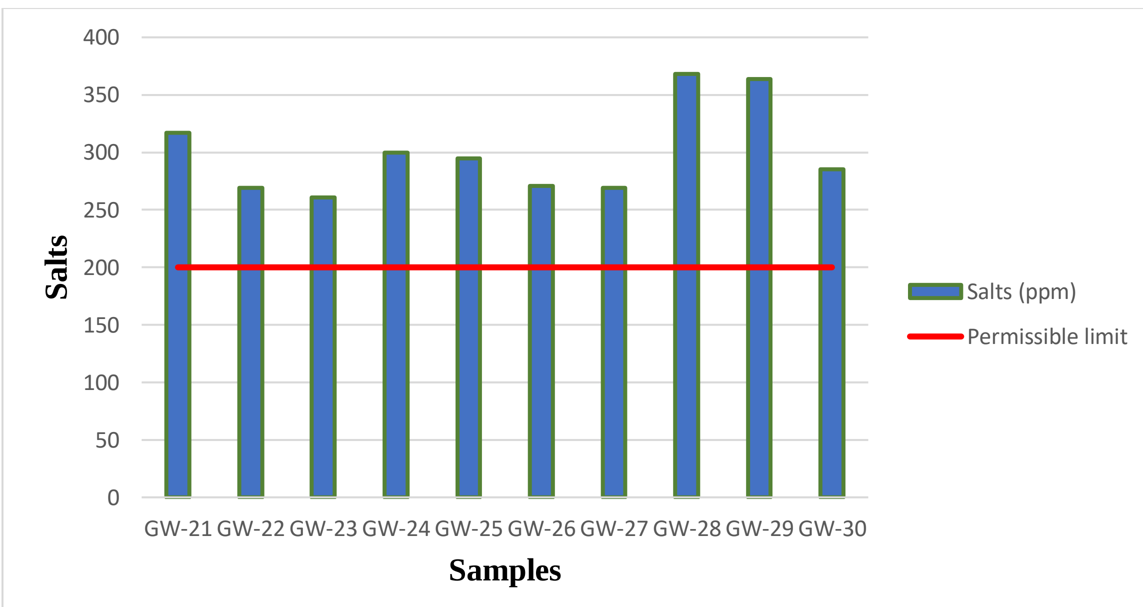

Figure 3.4(c): Levels of salts in collected groundwater samples from Multi Gardens

3.4.4 Zaraj Housing Scheme

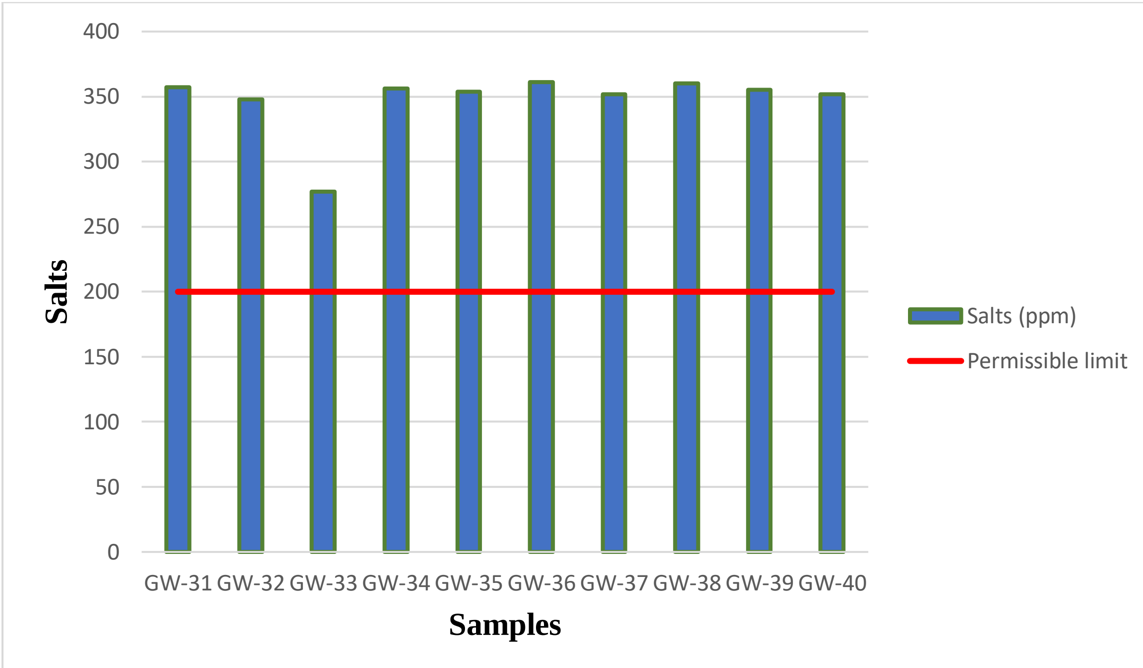

Figure 3.4(d): Levels of salts in collected groundwater samples from Zaraj housing Scheme

3.4.5 River Gardens

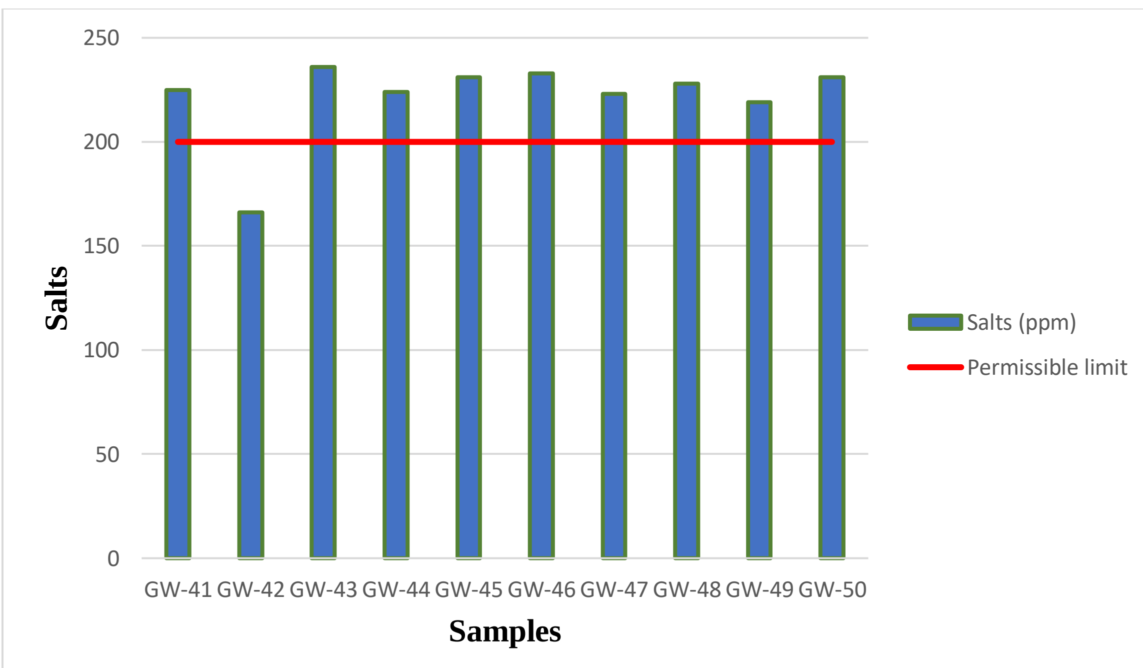

Figure 3.4(e): Levels of salts in collected groundwater samples from River Gardens

3.5 Temperature

Temperature is an indirect contamination indicator. High temperatures have an adequate microbial growth environment and promote the growth of various bacteria (Gorde & Jadhav, 2013). The temperature of all the collected groundwater samples was within the permissible limit of Pak EPA (30°C).

3.6 Turbidity

Turbidity is the cloudiness or haziness of water caused by suspended individual particles, which are normally invisible to the human eye and do not easily settle down or may be caused by phytoplankton development. The higher the turbidity level of drinking water, the greater the chance that people could develop gastrointestinal diseases (Azis, et al., 2015). Turbidity must not exceed 5 NTU, according to the Pak EPA, and water with turbidity less than 1.00 NTU is excellent for domestic use. No turbidity was found in the collected samples of groundwater from Sector I-9, Tele Gardens, Zaraj housing scheme, and River Gardens. Only the turbidity of groundwater sample GW-22 of Multi Gardens (11.2 NTU) exceeded the permissible limit of Pak-EPA which is 5 NTU.

3.2 Results of physical parameters of wastewater samples

The wastewater samples of five sewage treatment plants were assessed for physical parameters i.e., pH, temperature, electrical conductivity (EC), turbidity, salts, and total dissolved solids (TDS). The results of the physical parameters of all wastewater samples before and after treatment are discussed below.

3.2.1 pH

According to Pak EPA guidelines, the pH value must be in the range of 6-9 for wastewater (Akan, et al., 2017). According to the results of pH for wastewater samples before and after the treatment, the pH values of the samples exceeded the lower range of recommended limit 6.

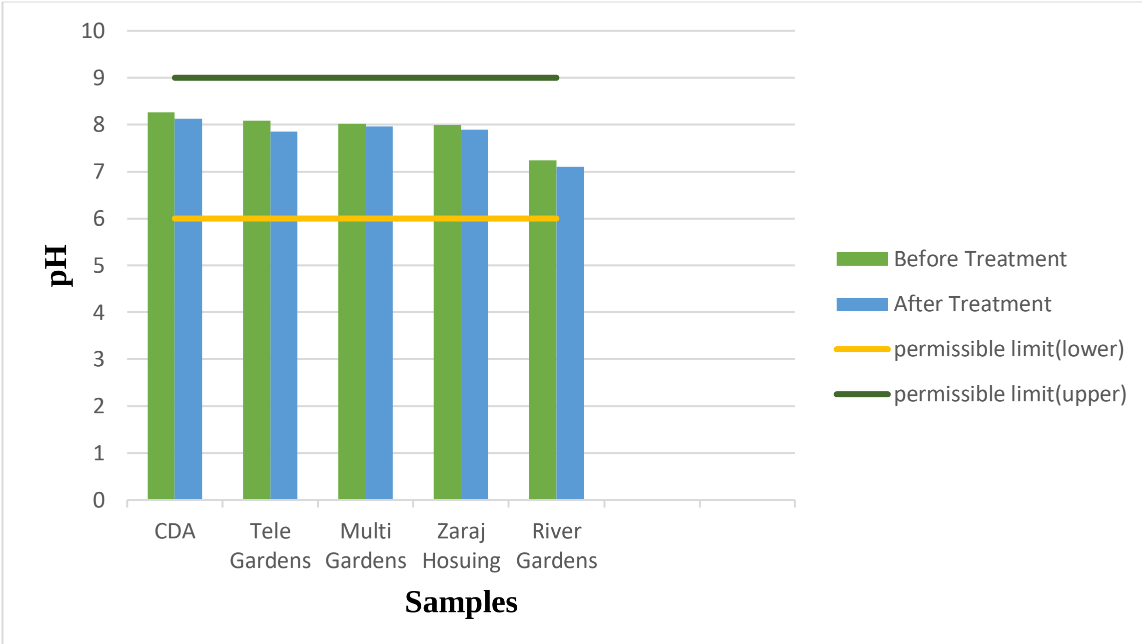

Figure 3.7(a): Levels of pH in collected wastewater samples

3.2.2 Electrical Conductivity

According to the Pak EPA's guideline, the acceptable limit for electrical conductivity for wastewater is 3000 µS/cm^3 (Iram, et al., 2013). The results of wastewater samples for the electrical conductivity of all STPs were within the recommended limit.

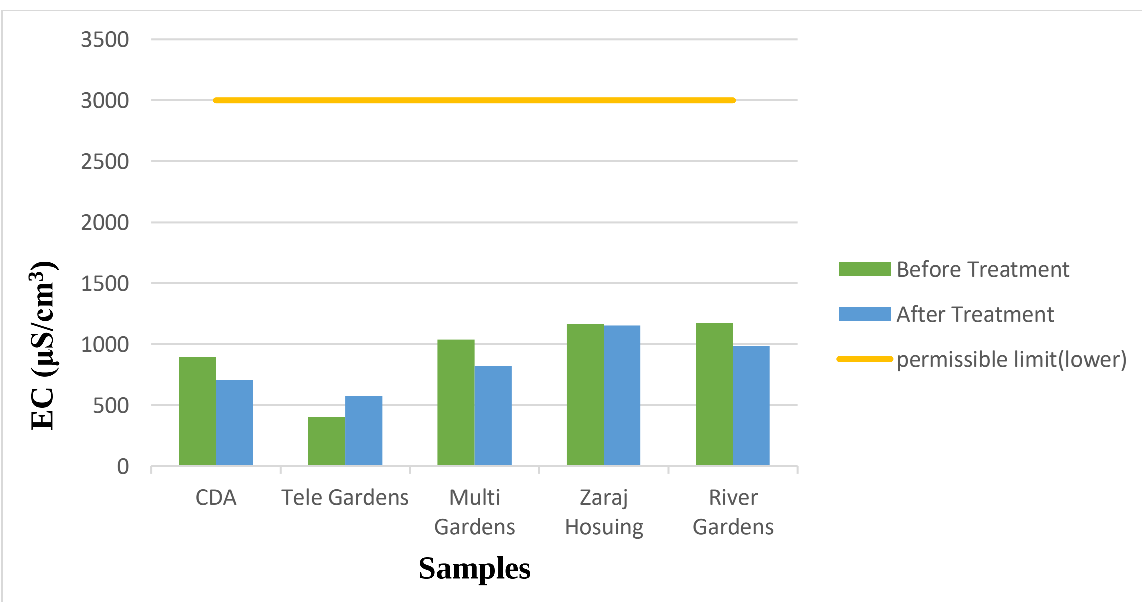

Figure 3.7(b): Levels of EC in collected wastewater samples

3.2.3 Total dissolved solids (TDS)

According to the Pak EPA's guideline, the acceptable limit for total dissolved solids (TDS) for wastewater is 3500 mg/l (Halliwell, et al., 2015). The results of wastewater samples before and after treatment were within the recommended limit.

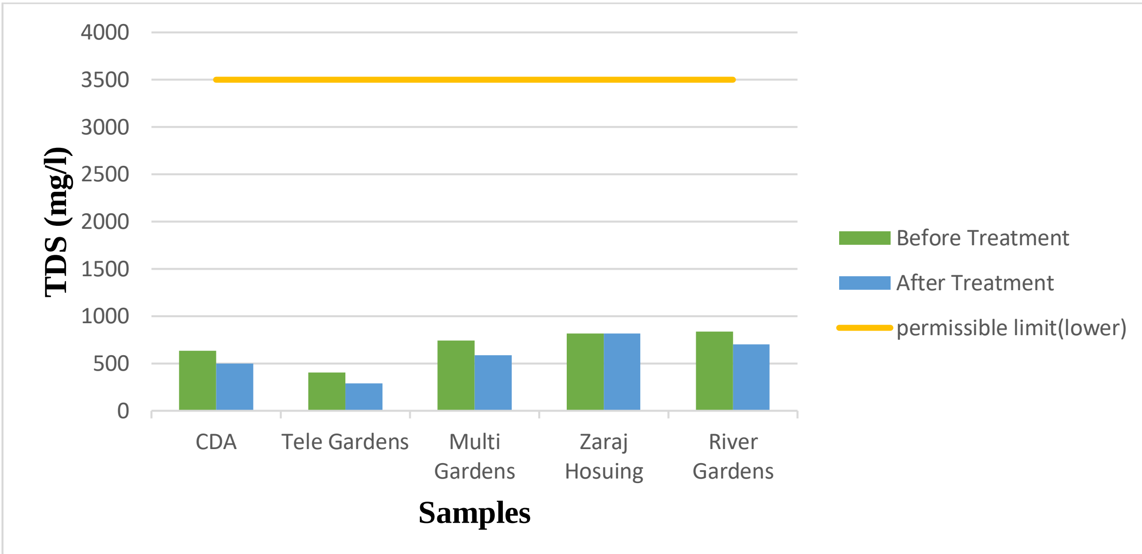

Figure 3.7(c): Levels of TDS in collected wastewater samples

3.2.4 Salts

According to the Pak EPA's guidelines, the acceptable limit for salts for wastewater is 200 mg/l. The results of all water samples before and after the treatment exceeded the recommended limit except for one sample after the treatment of Tele Gardens which was within the recommended value.

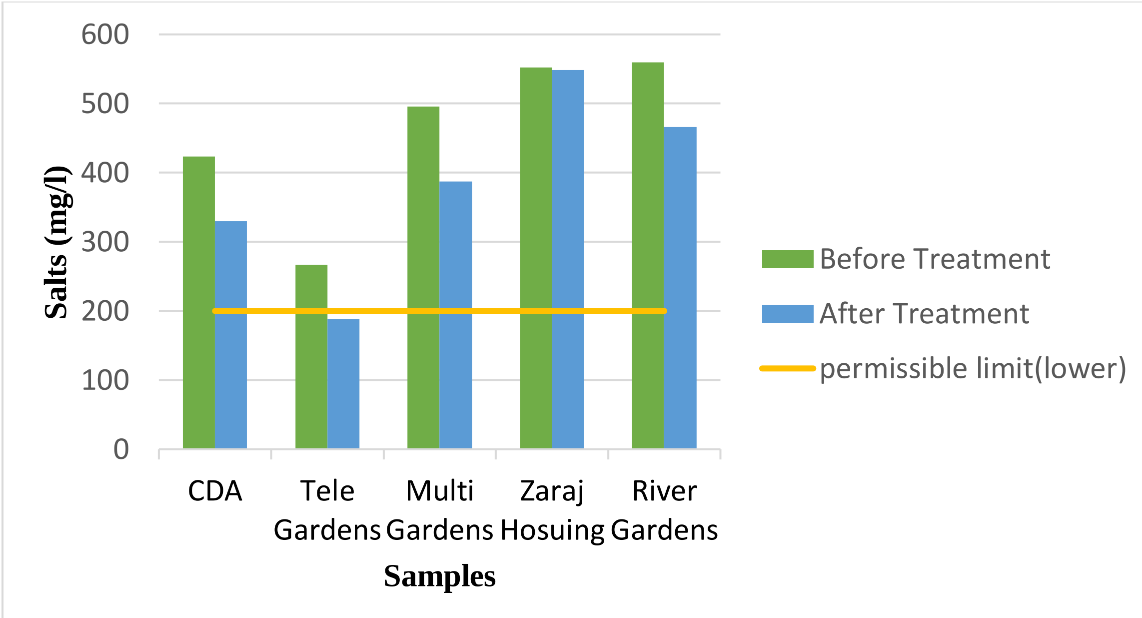

Figure 3.7(d): Levels of salts in collected wastewater samples

3.2.5 Temperature (°C)

According to the Pak EPA's guideline, the acceptable limit for levels of temperature in wastewater is <3°C. The results of wastewater samples, before and after the treatment were above the recommended limit. There was no major difference between the temperature of wastewater before and after the treatment.

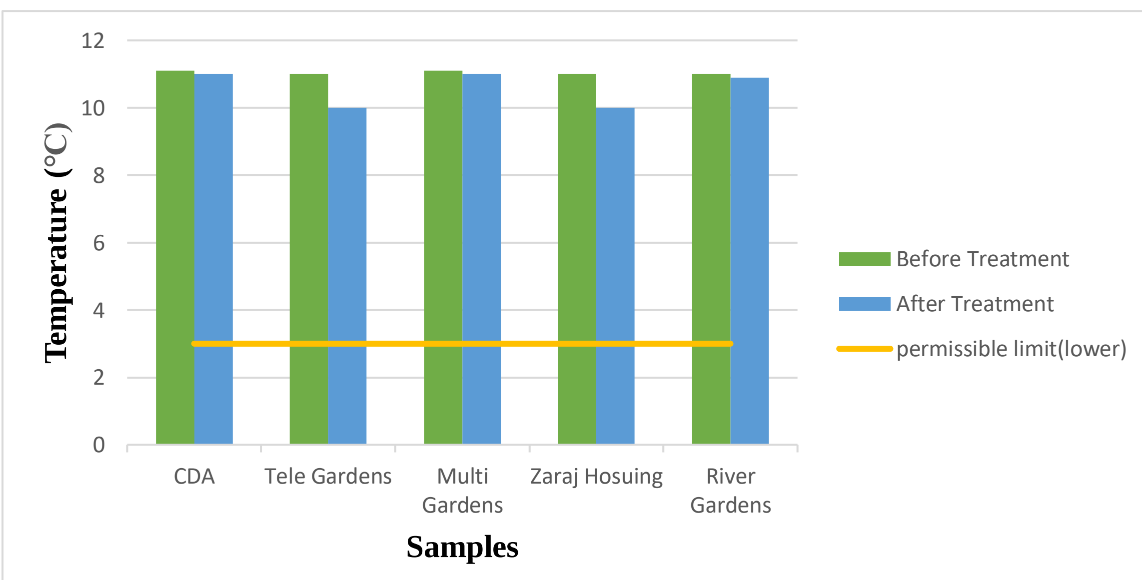

Figure 3.7(e): Levels of temperature in collected wastewater samples

3.3.6 Turbidity

Turbidity must not exceed 5 NTU, according to the Pak EPA guidelines. All the wastewater samples had turbidity higher than the permissible limit of Pak EPA before the treatment. And it significantly reduces to below the permissible limit of 5 NTU after the treatment except in the wastewater sample of Zaraj Housing Scheme STP which had the highest turbidity before the treatment.

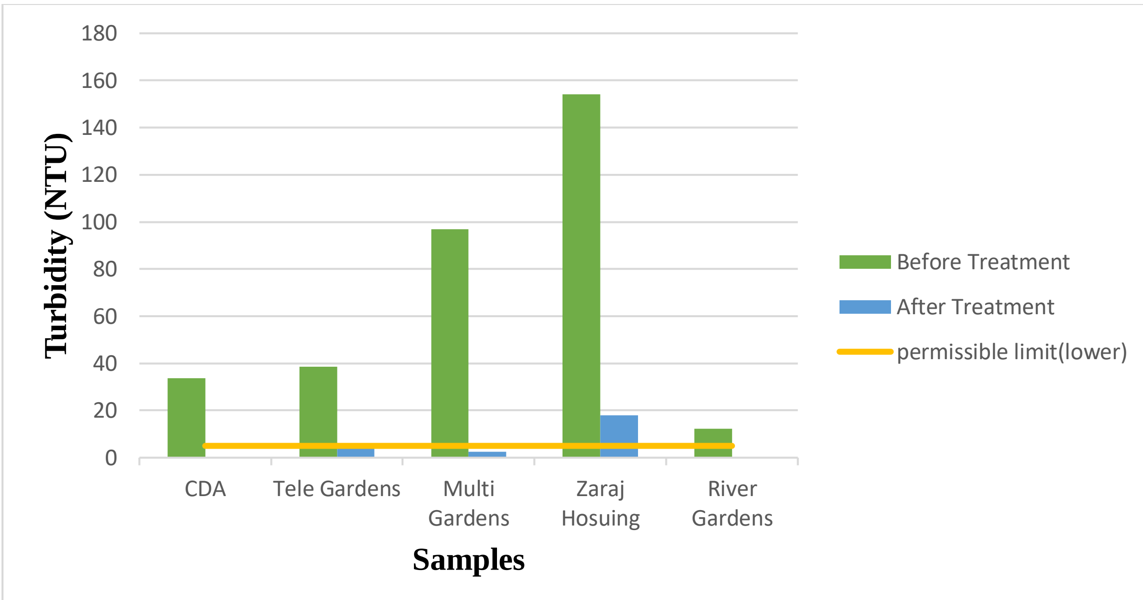

Figure 3.7(f): Levels of turbidity in collected wastewater samples

3.3. Results of Biological Parameters of Groundwater

The table below shows the CFU counts of microbial growth on two different media, namely nutrient and MacConkey agar after incubation for 24 hours. The microbial counts ranged from 0 to numerous counts in different water samples. The CFU count on Nutrient Agar (NA) was overall higher than the other media (Mac). Overall, the groundwater samples that were collected had shown microbial contamination. The highest count of coliforms was found in groundwater samples from the Tele Gardens and then some counts were also found in groundwater samples from the Multi Gardens sewage treatment plant. According to Pak EPA standards, the recommended value of total coliforms is supposed to be nil or negative in water and >500 CFU/ml for total bacteria.

Table 3.1: Results of microbial analysis of water samples collected from five sewage treatment plants

Sample ID	**Microbial growth on Nutrient Agar (NA)** (CFU/ml)	**Microbial growth on MacConkey Agar (Mac)** (CFU/ml)
Sector I-9		
GW-1	120	0
GW-2	390	0
GW-3	210	0
GW-4	150	0
GW-5	280	0
GW-6	40	0
GW-7	25	0
GW-8	640	0
GW-9	75	0
GW-10	89	0
Tele Gardens		
GW-11	90	25
GW-12	300	215
GW-13	120	82
GW-14	30	11
GW-15	175	26
GW-16	290	82
GW-17	360	152
GW-18	196	137
GW-19	90	11
GW-20	180	100
Multi Gardens		
GW-21	41	5
GW-22	34	4
GW-23	7	0
GW-24	55	0
GW-25	90	6
GW-26	118	0
GW-27	80	0
GW-28	55	2
GW-29	66	4
GW-30	74	5
Zaraj Housing Scheme		
GW-31	540	0
GW-32	260	0
GW-33	192	0
GW-34	165	0

GW-35	45	0
GW-36	80	0
GW-37	90	0
GW-38	240	0
GW-39	170	0
GW-40	640	0
River Gardens		
GW-41	36	0
GW-42	340	0
GW-43	231	0
GW-44	210	0
GW-45	430	0
GW-46	690	0
GW-47	63	0
GW-48	580	0
GW-49	35	0
GW-50	720	39
Permissible limits of Pak EPA	>500 CFU/ml	0 CFU/ml

The results of total bacteria in water samples collected from Sector I-9 showed that only one sample, GW8, had exceeded the permissible limit of less than 500 CFU/ml with a count of 640 CFU/ml. The coliform results of water samples showed that all samples had no presence of coliforms. The results of total bacteria in water samples collected from Tele Gardens showed that all samples, GW11, and GW20, had values within the permissible limit of less than 500 CFU/ml. The coliform results of water samples showed that all samples had values exceeding the permissible limit for coliforms which is 0 CFU/ml. Residents of Tele Gardens use that water for drinking purposes as well. The presence of coliforms in water samples indicates the poor quality of water and it cannot be used for drinking purposes because it is harmful for the health. The results of total bacteria in water samples collected from Multi Gardens showed that all samples, GW21, and GW30, had values within the permissible limit of less than 500 CFU/ml. The coliform results of water samples showed that six samples GW21, GW22, GW25, GW28, GW29, and GW30, samples had shown the presence of coliforms, indicating the poor quality of water. The results of total bacteria in water samples collected from the Zaraj Housing Scheme showed that two samples, GW31, and GW40, had exceeded the permissible limit of less than 500

CFU/ml. The coliform results of groundwater samples showed that all samples had no presence of coliforms.

The results of total bacteria in water samples collected from the River Gardens showed that three samples, GW36, GW38, and GW50, had exceeded the permissible limit of less than 500 CFU/ml. The coliform results of water samples showed that all samples had no presence of coliforms except for GW46, GW48 and GW50 where it was 39 CFU/ml, exceeding the acceptable limit which is 0 CFU/ml as given by the Pak EPA.

3.4 Results of chemical parameters of groundwater samples

The groundwater samples collected from the surrounding areas of five sewage treatment plants in Islamabad were analyzed for chemical parameters i.e., total hardness, alkalinity, chlorides, carbonates, and nitrates. The results of all chemical parameters are discussed below.

3.4.1 Chlorides

Chloride is an anion that originates primarily from the dissociation of hydrochloric acid salts such as NaCl, KCl, and $CaCl_2$ from geological formations. It is also added by sewage contamination, industrial waste, and intrusion of seawater or saline water. Surface water usually has a low chloride content compared with groundwater. Chloride is a chemical for metabolism that the human body requires. It also helps preserve the acid-base equilibrium of the body (Nasir, et al., 2012). The Pak EPA proposed a maximum allowable chloride value of 250 mg/L for groundwater. The chlorides of all the water samples were within the permissible limits.

3.4.1.1 Sector I-9

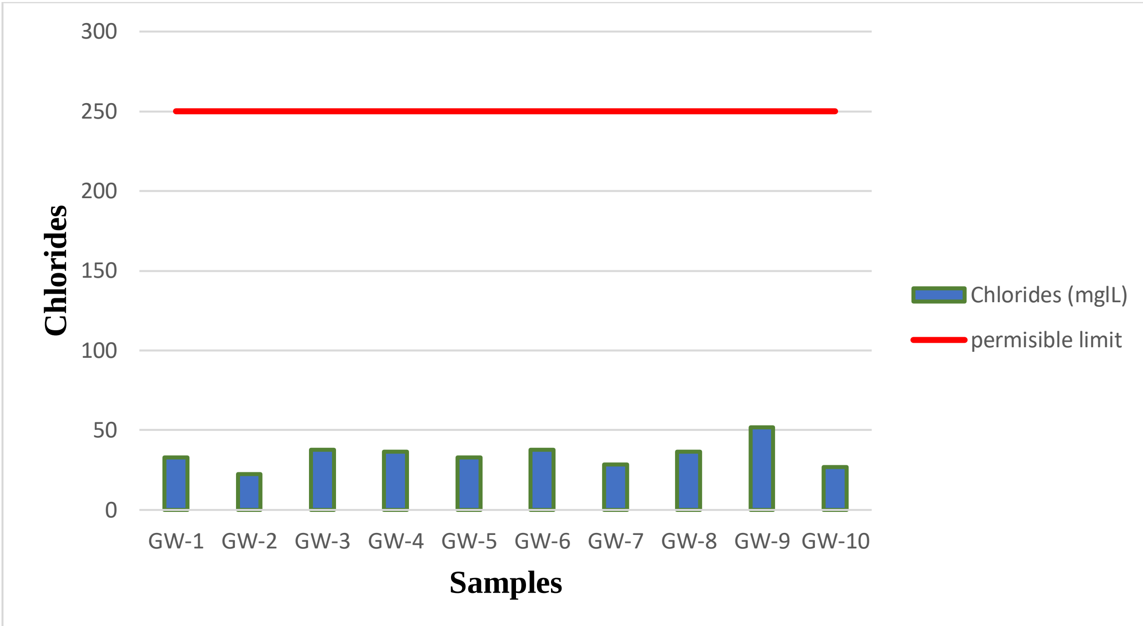

Figure 3.8(a): Levels of Chlorides in collected water samples from I-9

3.4.1.1 Tele Gardens

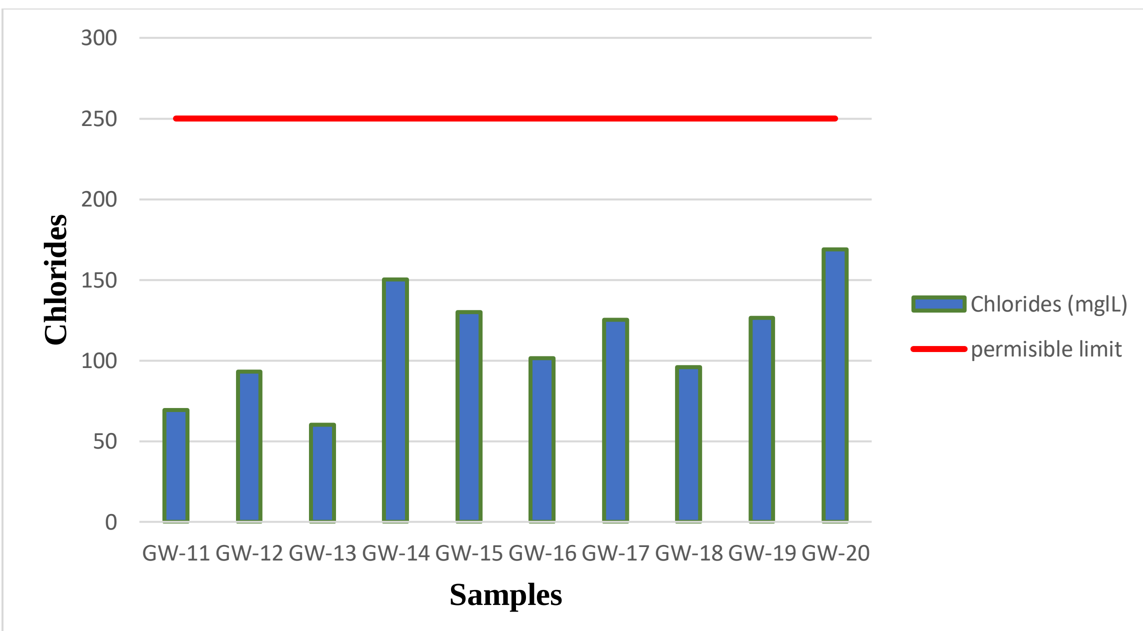

Figure 3.8(b): Levels of Chlorides in collected water samples from Tele Gardens

3.2.3 Multi Gardens

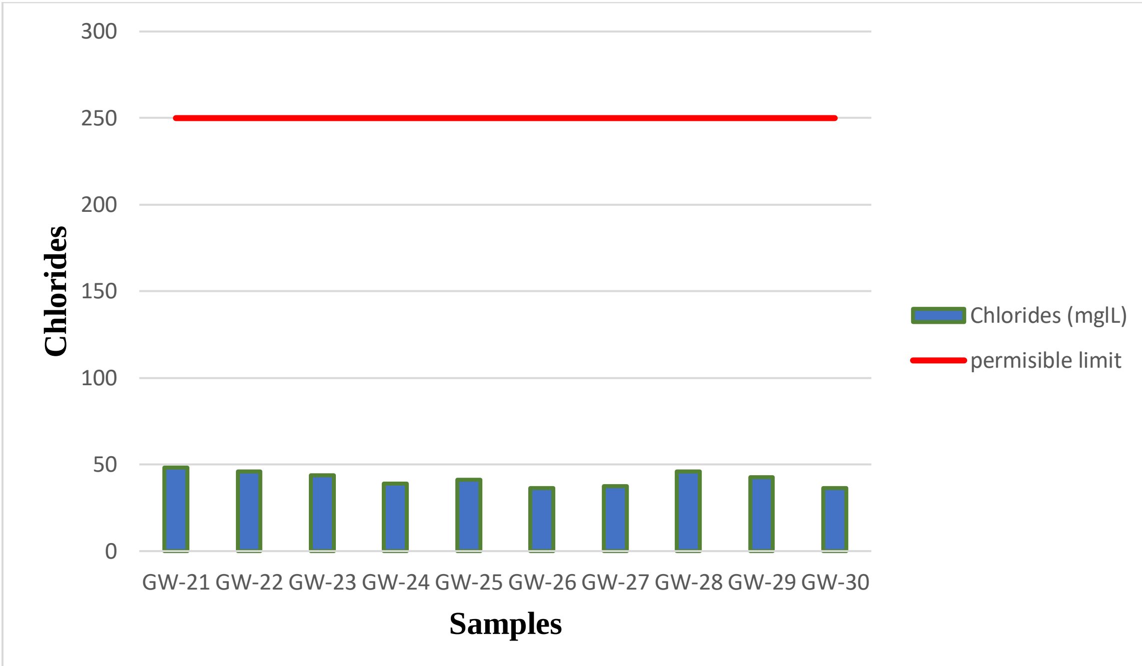

Figure 3.8(c): Levels of Chlorides in collected water samples from Multi Gardens

3.2.4 Zaraj Housing Society

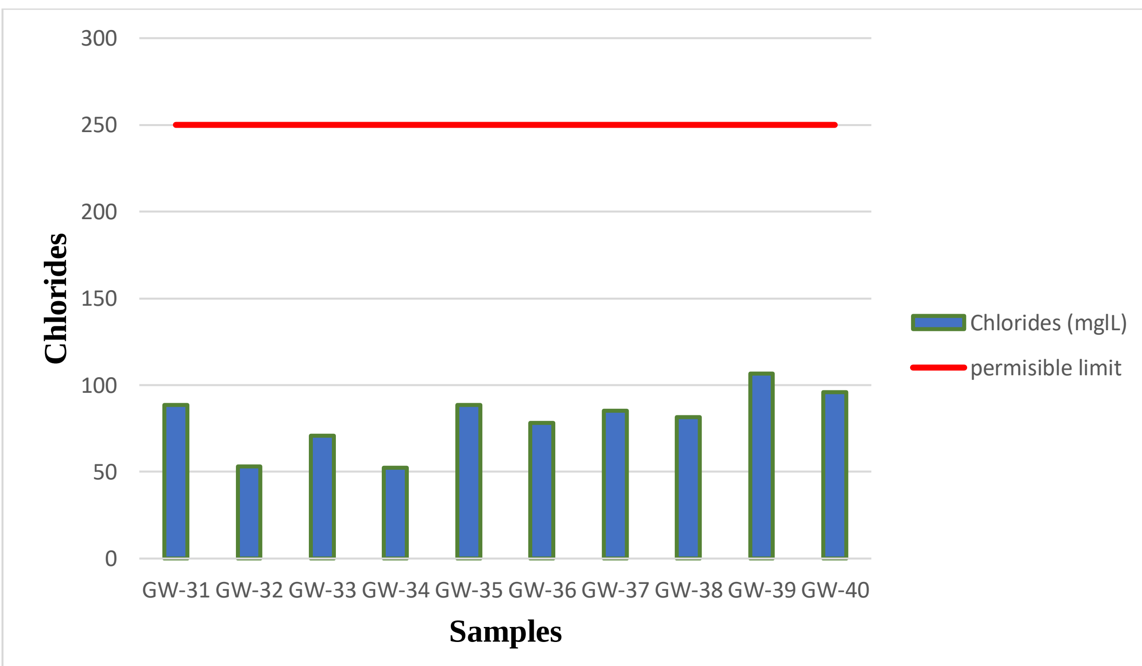

Figure 3.8(d): Levels of Chlorides in collected water samples from Zaraj Housing Scheme

3.2.5 River Gardens

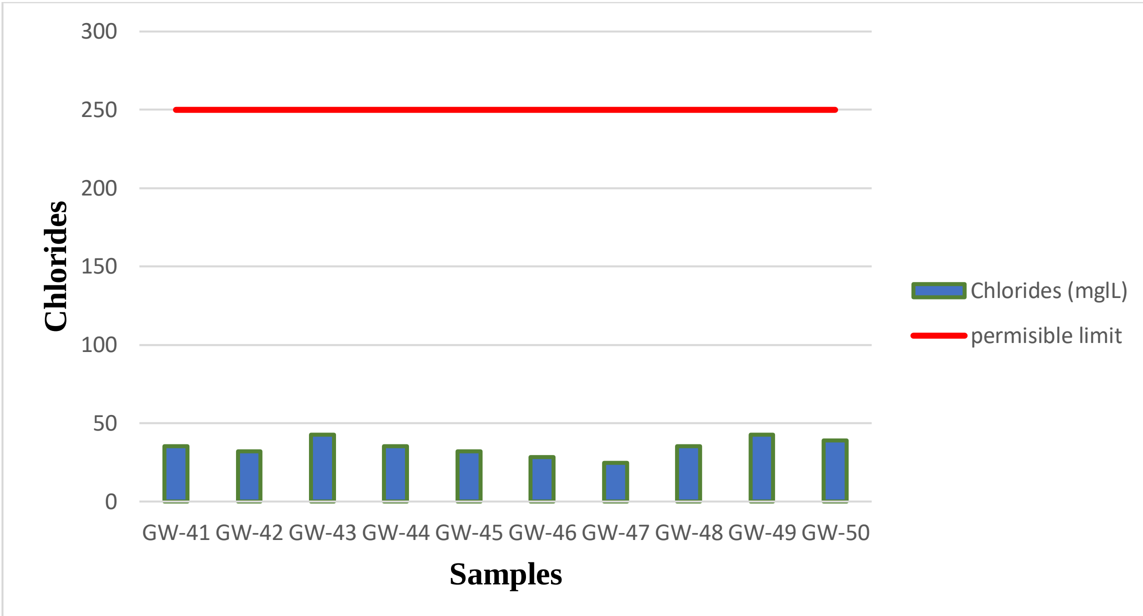

Figure 3.8(e): Levels of Chlorides in collected water samples from River Gardens

3.4.2 Sodium

The results of all groundwater samples were within the permissible limit of Pak EPA i.e., 200mg/l. Sodium is required for the normal functioning of the human body but, if the concentration of sodium exceeds the defined limit it causes harmful effects on human health. Sodium is required for the normal functioning of the human body. Whereas, if the concentration of sodium exceeds it can cause health-related issues like blood pressure, strokes, and cardiovascular diseases (Iqbal, et al., 2023). Sodium in all the groundwater samples (GW-1 to GW-50) was within permissible limit of Pak EPA.

3.4.2.1 Sector I-9

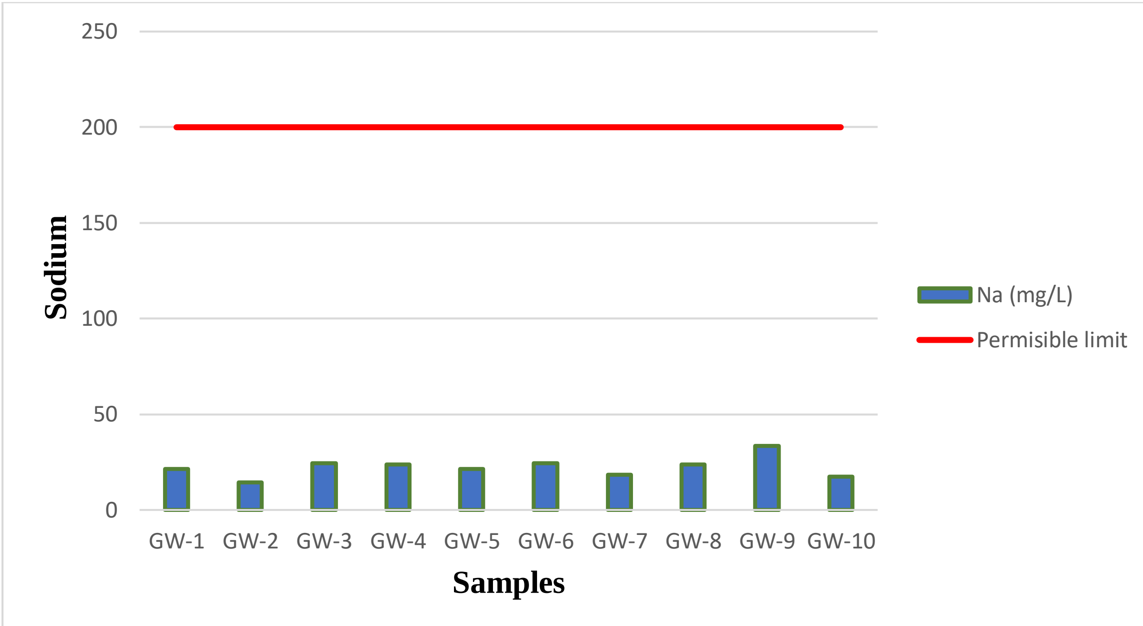

Figure 3.9(a): Levels of sodium in collected water samples from I-9

3.4.2.2 Tele Gardens

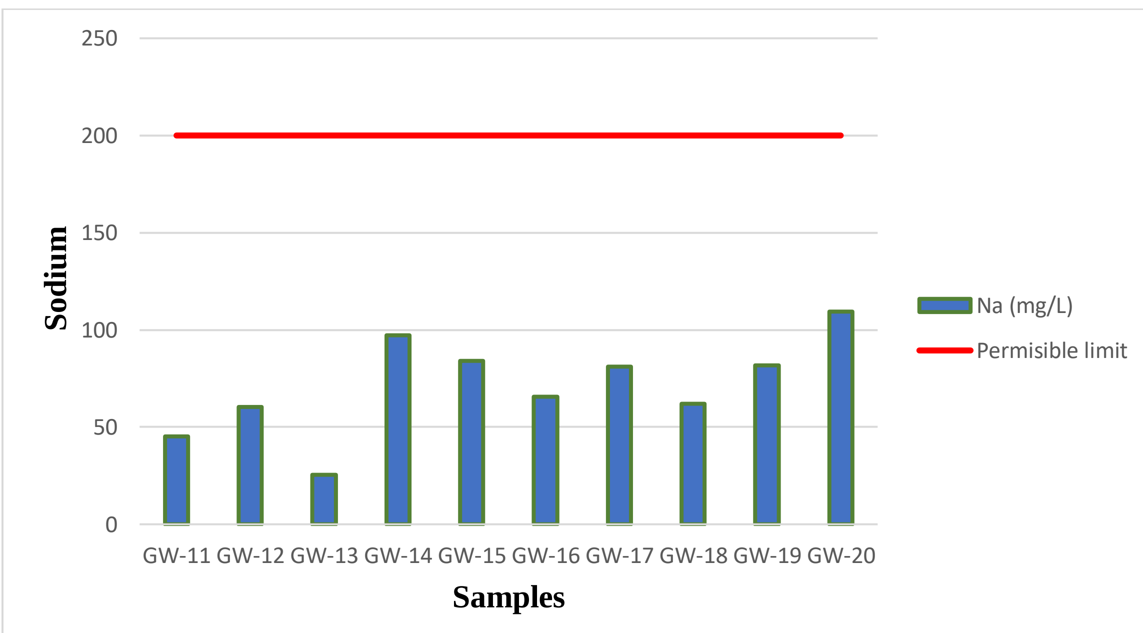

Figure 3.9(b): Levels of Sodium in collected water samples from Tele Gardens

3.4.2.3 Multi Gardens

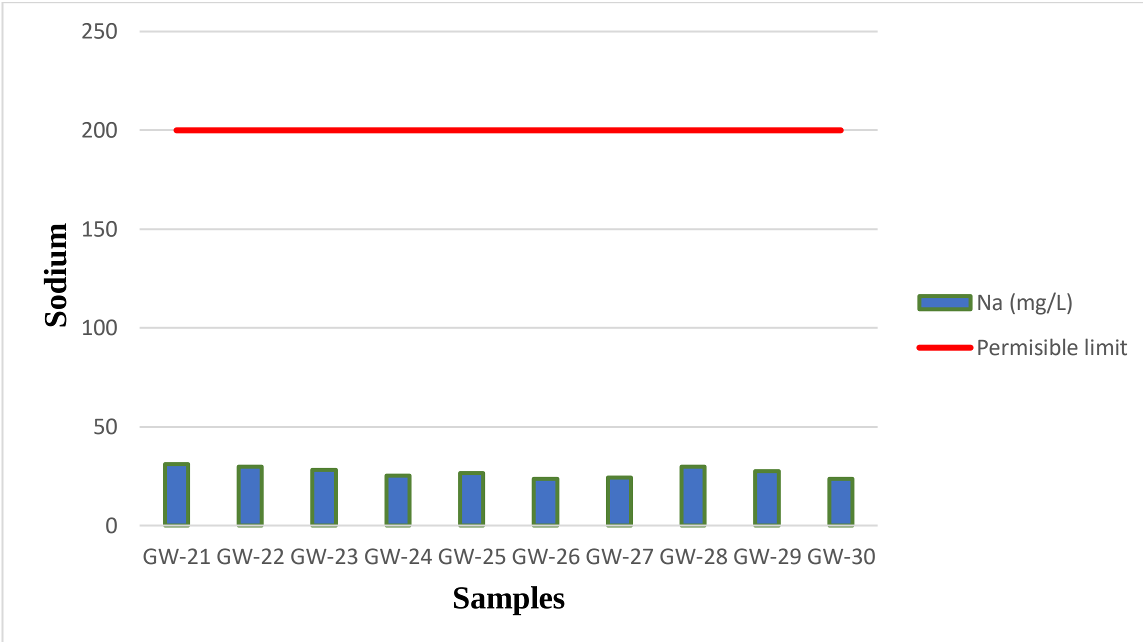

Figure 3.9(c): Levels of Sodium in collected water samples from Multi Gardens

3.4.2.4 Zaraj Housing Scheme

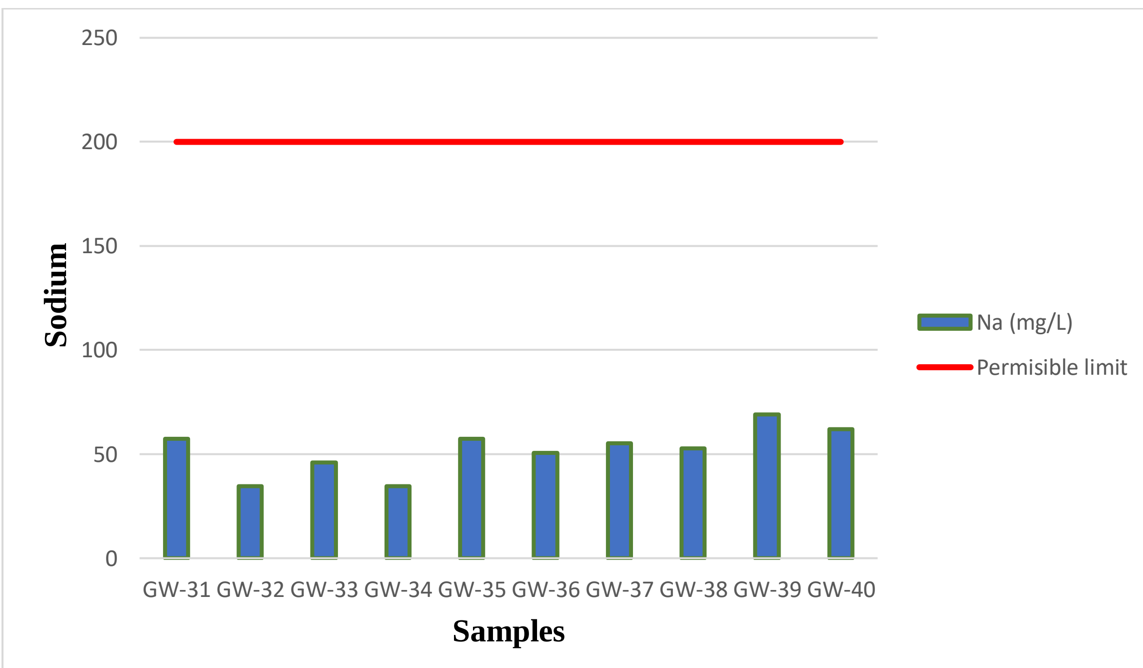

Figure 3.9(d): Levels of Sodium in collected water samples from Zaraj Housing Scheme

3.4.2.5 River Gardens

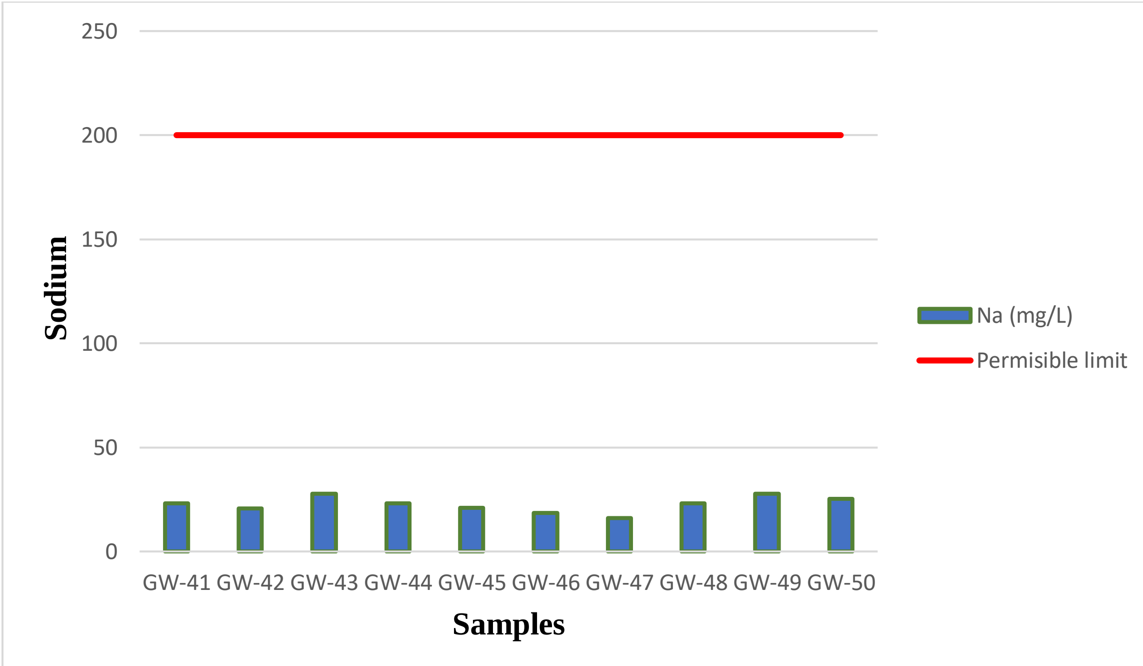

Figure 3.9(e): Levels of Sodium in collected water samples from River Gardens

3.4.3 Total Hardness

3.4.3.1 Sector I-9

The highest allowable level in groundwater is 500 ppm, according to Pak-EPA and PCRWR. The hardness of all the groundwater samples was within permissible limits.

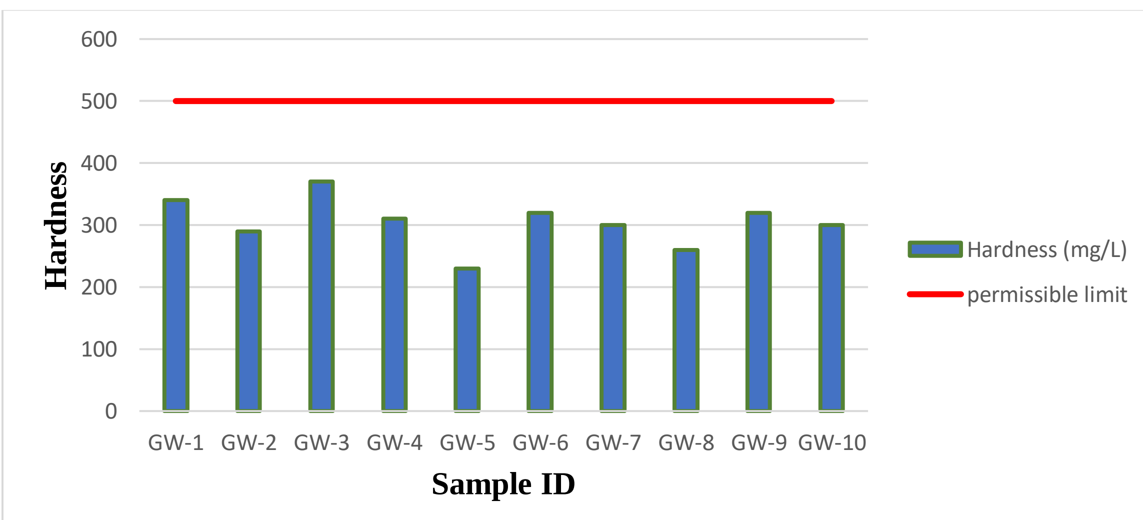

Figure 3.10(a): Levels of Hardness in collected water samples from I-9

3.4.3.2 Tele Gardens

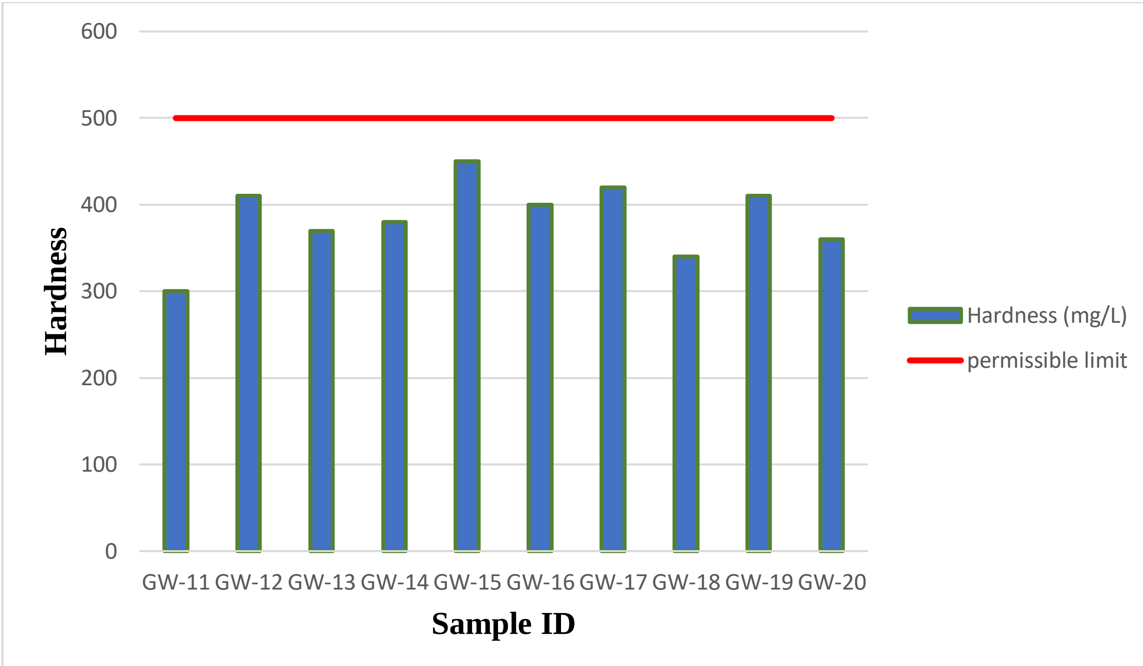

Figure 3.10(b): Levels of Hardness in collected water samples from Tele Gardens

3.4.3.3 Multi Gardens

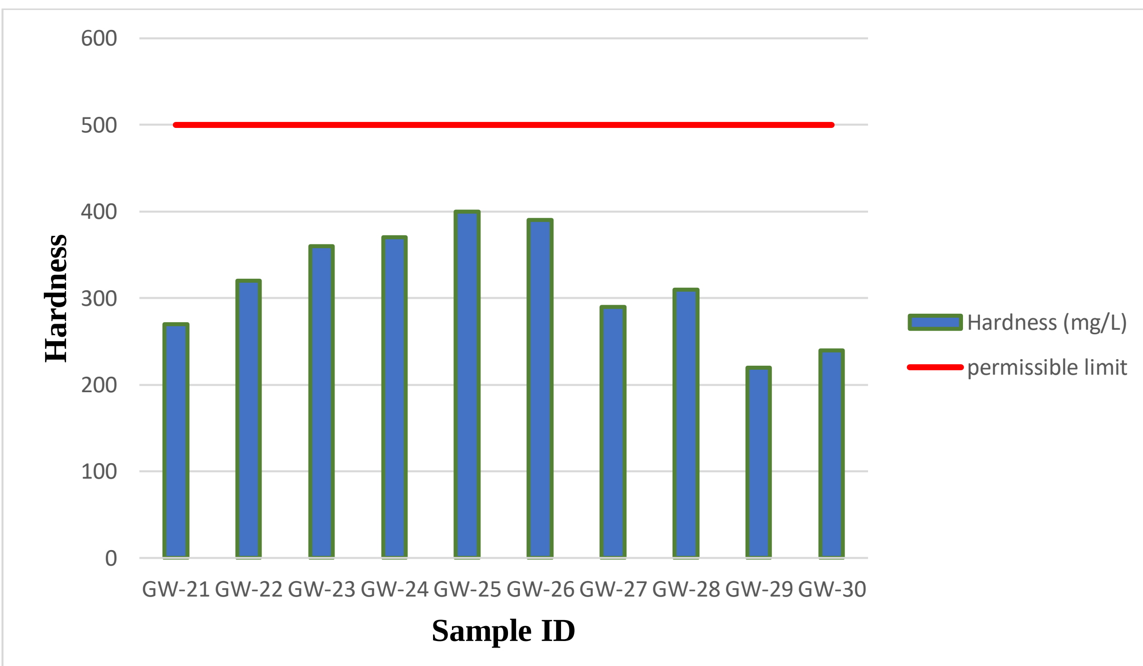

Figure 3.10(c): Levels of Hardness in collected water samples from Multi Gardens

3.4.3.4 Zaraj Housing Scheme

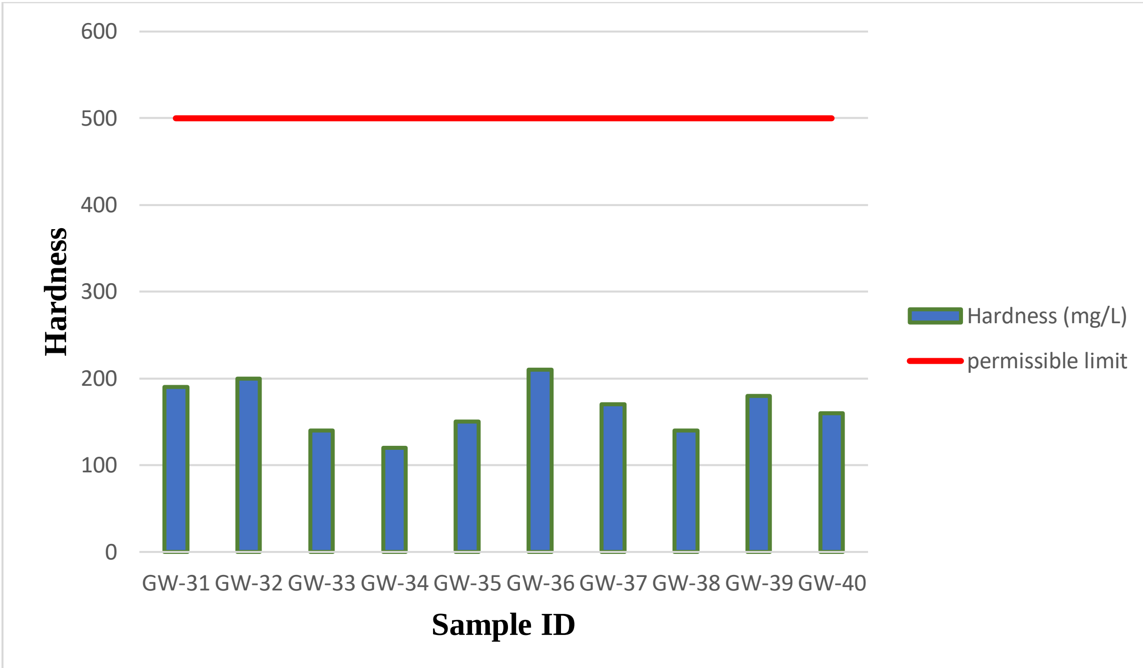

Figure 3.10(d): Levels of Hardness in collected water samples from Zaraj housing

3.4.3.5 River Gardens

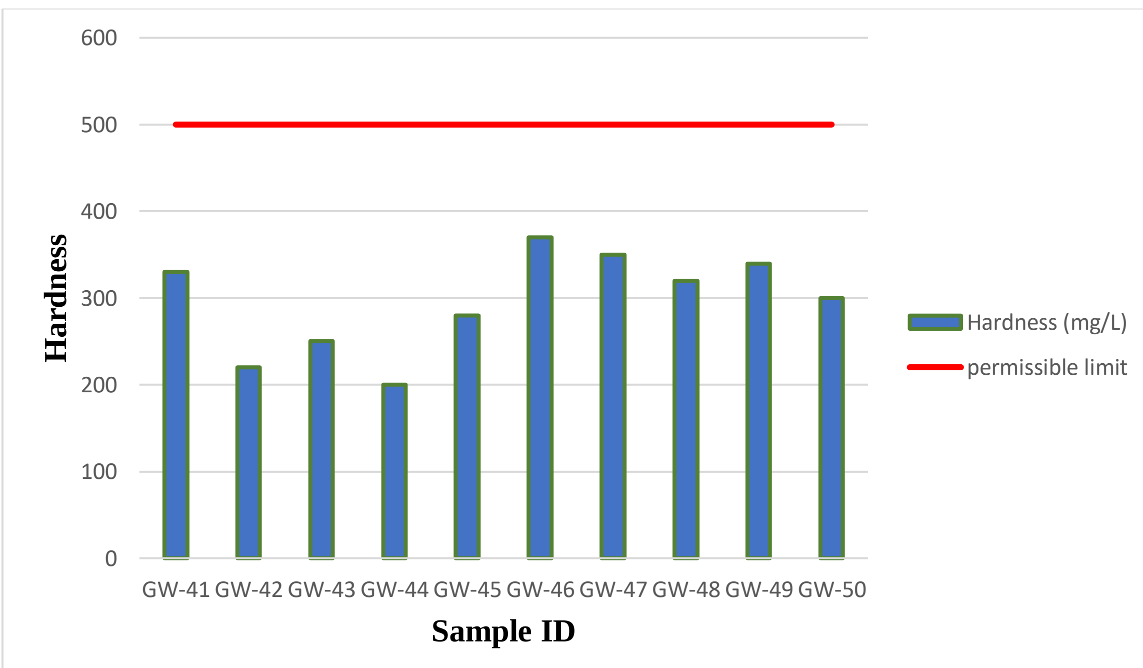

Figure 3.10(e): Levels of Hardness in collected water samples from River Garden

3.4.4 Alkalinity

Alkalinity is the waterpower neutralizing the acid. The chlorides, bicarbonate, and sulfate are the ions mainly contributing to alkalinity. Water system alkalinity is derived from many sources, soil ion exchange reactions, mineral and rock weathering, mineral precipitation and evaporation, biological receipt, decrease of strong acid anions, and deposition of atmospheric dust particles (Qureshi, et al., 2021). The permissible limit of alkalinity recommended by Pak EPA is 200 mg/L. The alkalinity of all the groundwater samples was within the permissible limit except for the GW-17, GW-18, and GW-19 samples of Tele Gardens where the value exceeded the permissible limit of Pak EPA which is 200 mg/l.

3.4.4.1 Sector I-9

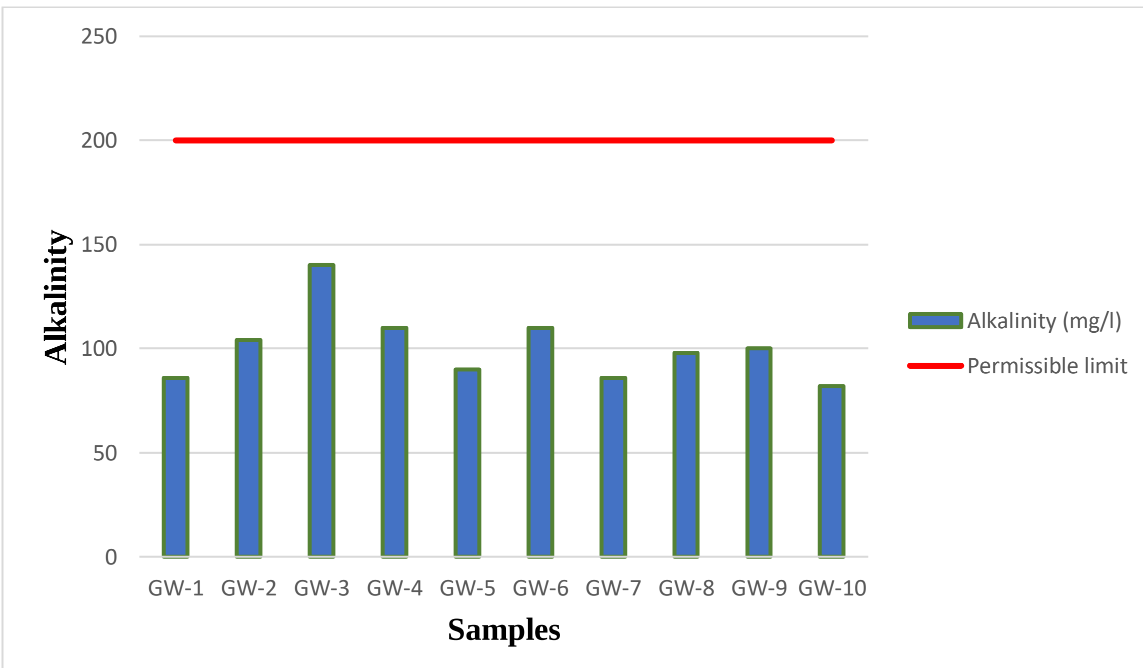

Figure 3.11(a): Levels of Alkalinity in collected water samples from I-9

3.4.4.2 Tele Gardens

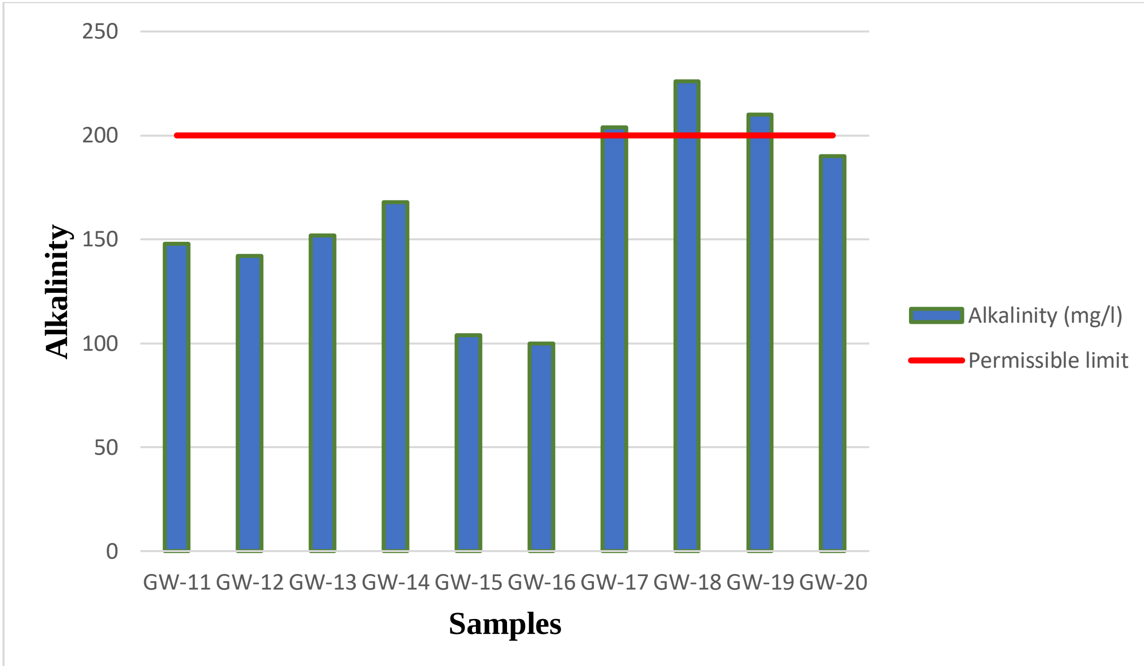

Figure 3.11(b): Levels of Alkalinity in collected water samples from Tele Gardens

3.4.4.3 Multi Gardens

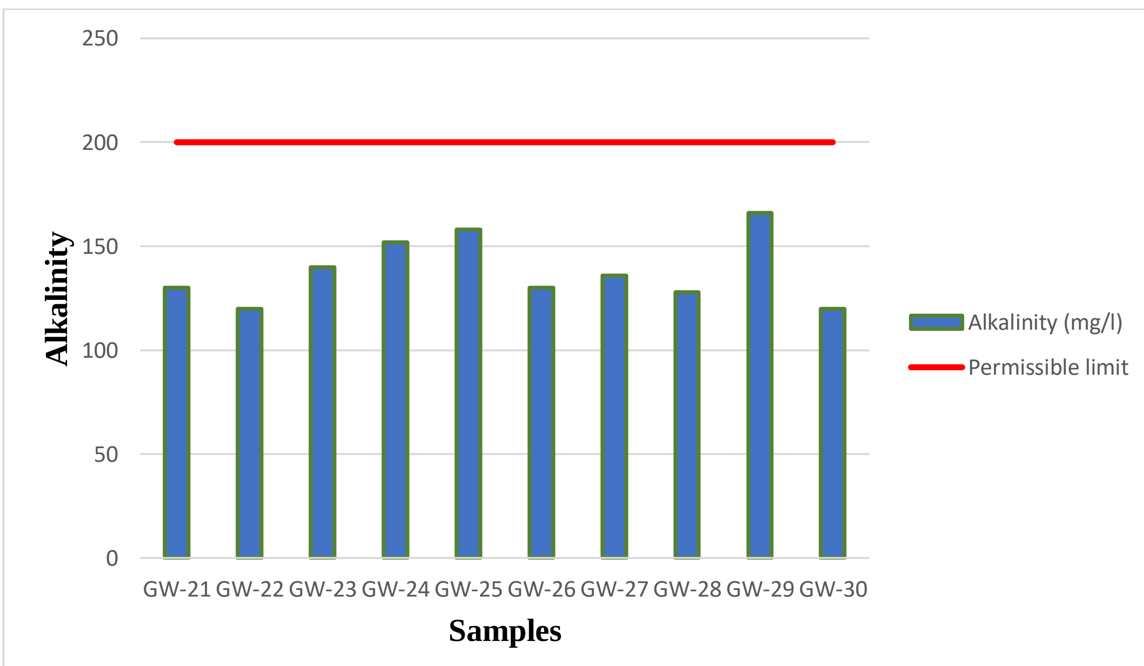

Figure 3.11(c): Levels of Alkalinity in collected water samples from Multi Gardens

3.4.4.4 Zaraj Housing Scheme

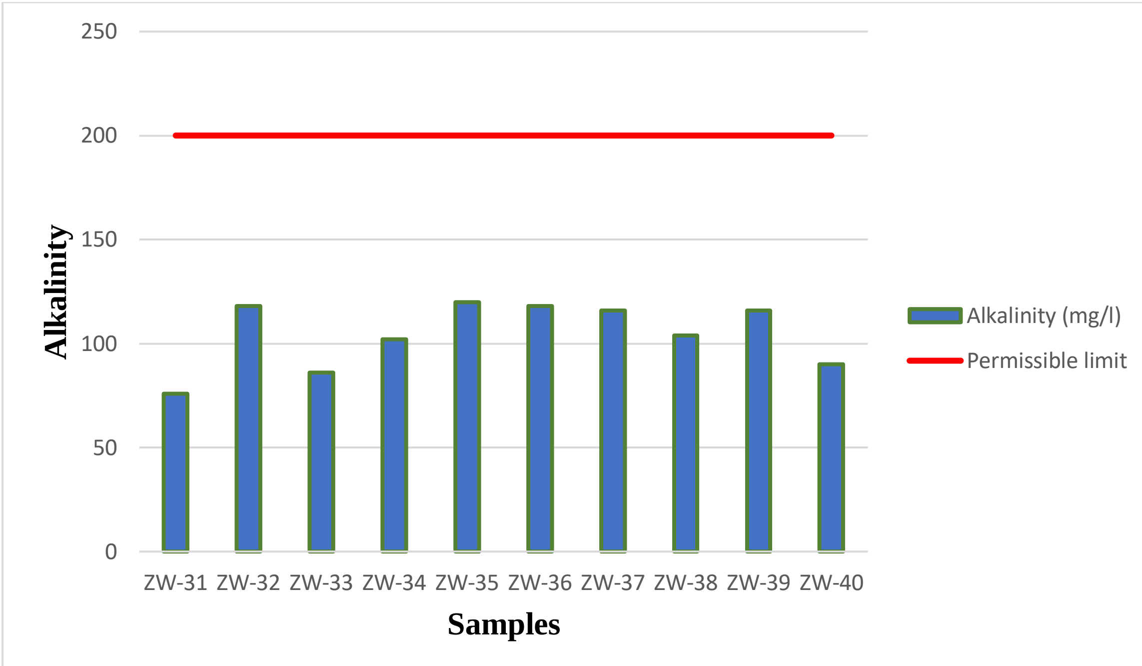

Figure 3.11(d): Levels of Alkalinity in collected water samples from Zaraj housing scheme

3.4.4.5 River Gardens

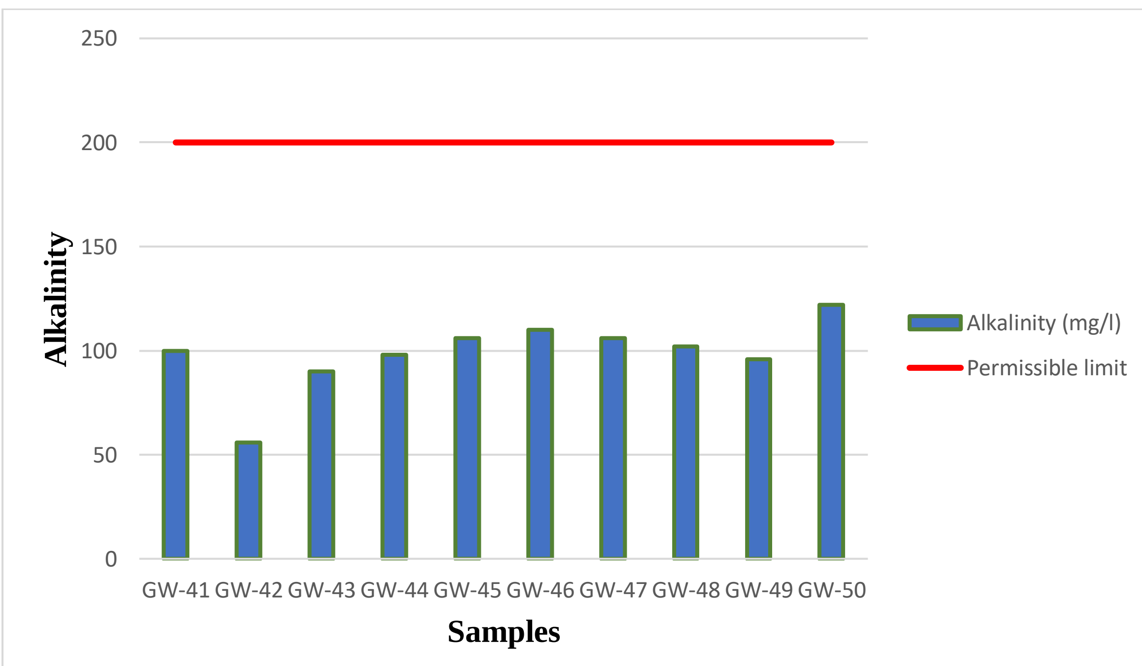

Figure 3.11(e): Levels of Alkalinity in collected water samples from the River Gardens

3.4.5 Nitrates

The results of groundwater samples GW1-GW50 were within the permissible limit of Pak EPA 50 mg/l. If the value of nitrate in water increases above the recommended limit it can cause fatigue, muscle aches, weakness, dizziness, and excess heart rate (Alahi & & Mukhopadhyay, 2018). The results of Nitrates for all samples are shown in the table below.

Table 3.2: Results of Nitrates in groundwater samples collected from areas surrounding treatment plants

Sample ID	**Nitrates** (mg/l)
Sector I-9	
GW-1	0.491
GW-2	0.621
GW-3	3.210
GW-4	1.032
GW-5	0.535
GW-6	0.389
GW-7	0.567
GW-8	0.481
GW-9	0.297
GW-10	0.508
Tele Gardens	
GW-11	9.535
GW-12	9.318
GW-13	8.881
GW-14	10.94
GW-15	10.68
GW-16	5.4
GW-17	1.194
GW-18	0.459
GW-19	10.03
GW-20	2.324
Multi Gardens	
GW-21	2.010
GW-22	1.789
GW-23	2.216
GW-24	0.886
GW-25	0.891
GW-26	2.281
GW-27	1.113
GW-28	1.545
GW-29	1.043
GW-30	

Zaraj Housing Scheme	
GW-31	0.005
GW-32	0.048
GW-33	0.043
GW-34	0.043
GW-35	0.097
GW-36	0.021
GW-37	0.021
GW-38	0.064
GW-39	0.010
GW-40	0.005
River Gardens	
GW-41	0.048
GW-42	0.048
GW-43	0.043
GW-44	0.010
GW-45	0.075
GW-46	0.021
GW-47	0.005
GW-48	0.005
GW-49	0.043
GW-50	0.043
Permissible limit of Pak EPA	**50 mg/l**

3.4.6 Carbonates

The results of groundwater samples collected from the surrounding areas of five sewage treatment plants (i.e., Sector I-9, Tele Gardens, Multi Gardens, Zaraj, and River Gardens) were assessed for carbonates. The results of carbonates are shown in the table below. There is no recommended limit for carbonates in water given by the Pak EPA or any other international standard.

Table 3.2: Results of Carbonates in groundwater samples collected from areas surrounding treatment plants

Sample ID	$NaHCO_3$	Na_2CO_3	HCO_3	CO_3
Sector I-9				
GW-1	2.9	3.6	2.1	2.1
GW-2	2.5	3.1	1.8	1.8
GW-3	3.1	3.8	2.2	2.2
GW-4	2.3	2.9	1.7	1.7
GW-5	2.1	2.6	1.5	1.5

GW-6	5.1	6.3	3.6	3.6
GW-7	2.1	2.5	1.4	1.4
GW-8	2.3	2.7	1.5	1.5
GW-9	2.4	2.8	1.6	1.6
GW-10	1.9	2.4	1.4	1.4
Tele Gardens				
GW-11	3.5	4.4	2.5	2.5
GW-12	2.6	3.3	1.9	1.9
GW-12	3.3	4.2	2.4	2.4
GW-14	3.6	4.6	2.6	2.6
GW-15	3.8	4.8	2.8	2.7
GW-16	3.2	4.1	2.3	2.3
GW-17	3.9	4.9	2.7	2.9
GW-18	4.1	5.1	2.9	2.8
GW-19	3.7	4.7	2.6	2.7
GW-20	3.5	4.4	2.5	2.5
Multi Gardens				
GW-21	3.3	4.2	2.4	2.4
GW-22	2.7	3.4	2.1	2.1
GW-23	3.2	4.1	2.3	2.3
GW-24	3.5	4.4	2.5	2.5
GW-25	3.1	3.8	2.2	2.2
GW-26	3.1	3.7	2.1	2.1
GW-27	3.3	4.2	2.4	2.4
GW-28	3.1	3.8	2.2	2.2
GW-29	4.4	5.5	3.2	3.2
GW-30	3.3	4.2	2.4	2.4
Zaraj Housing Scheme				
GW-31	0.6	0.8	0.4	0.4
GW-32	0.5	0.7	0.4	0.4
GW-33	0.7	0.9	0.5	0.5
GW-34	0.3	0.5	0.3	0.3
GW-35	0.5	0.7	0.4	0.4
GW-36	0.4	0.5	0.3	0.3
GW-37	0.8	1.05	0.6	0.6
GW-38	0.2	0.3	0.1	0.1
GW-39	0.6	0.8	0.4	0.4
GW-40	0.9	1.1	0.6	0.6
River Gardens				
GW-41	0.5	0.7	0.4	0.4
GW-42	0.3	0.4	0.2	0.2
GW-43	0.5	0.7	0.4	0.4
GW-44	0.5	0.6	0.3	0.3
GW-45	0.6	0.7	0.4	0.4
GW-46	0.7	0.6	0.3	0.3

GW-47	0.5	0.6	0.3	0.3
GW-48	0.6	0.8	0.4	0.4
GW-49	0.4	0.5	0.5	0.5
GW-50	0.2	0.3	0.1	0.1

3.5 Results of chemical parameters of wastewater samples before and after treatment

The wastewater samples were collected before and after treatment and were analyzed for chemical parameters i.e., alkalinity, total hardness, chlorides, carbonates, and nitrates. The results of all parameters are discussed below.

3.5.1 Chlorides

The chlorides of the wastewater samples were within the permissible limit of 1000mg/l by Pak EPA before and after the treatment.

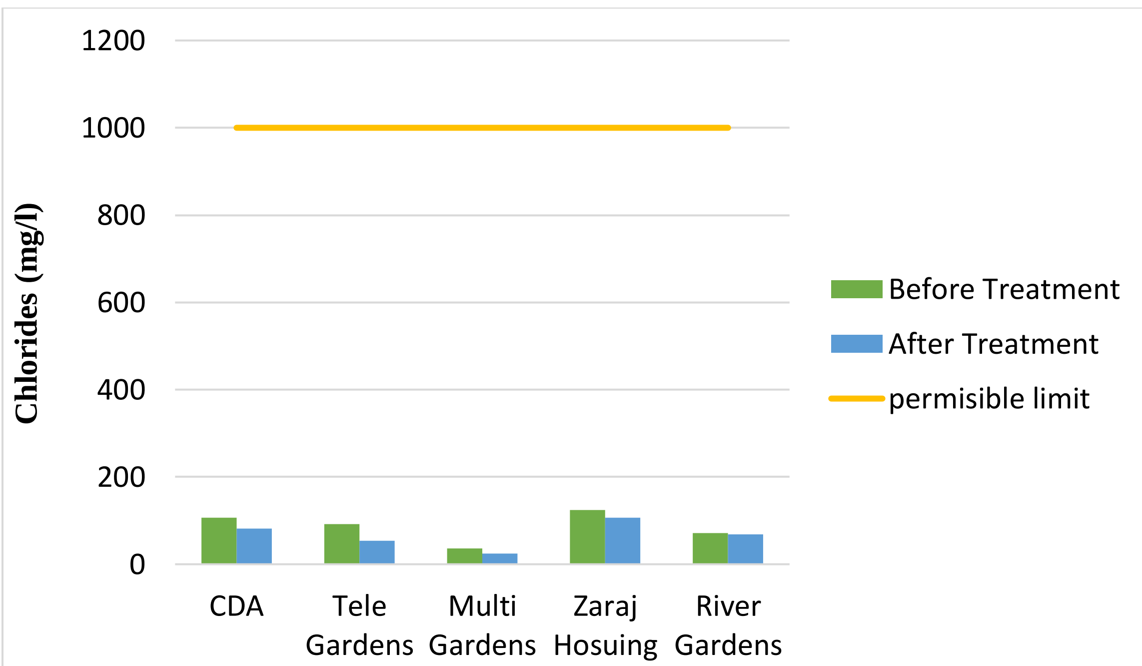

Figure 3.12: Levels of Chlorides in wastewater samples from 5 STPs

3.5.2 Sodium

The results of wastewater samples were within the permissible limit of Pak EPA i.e., 200mg/l.

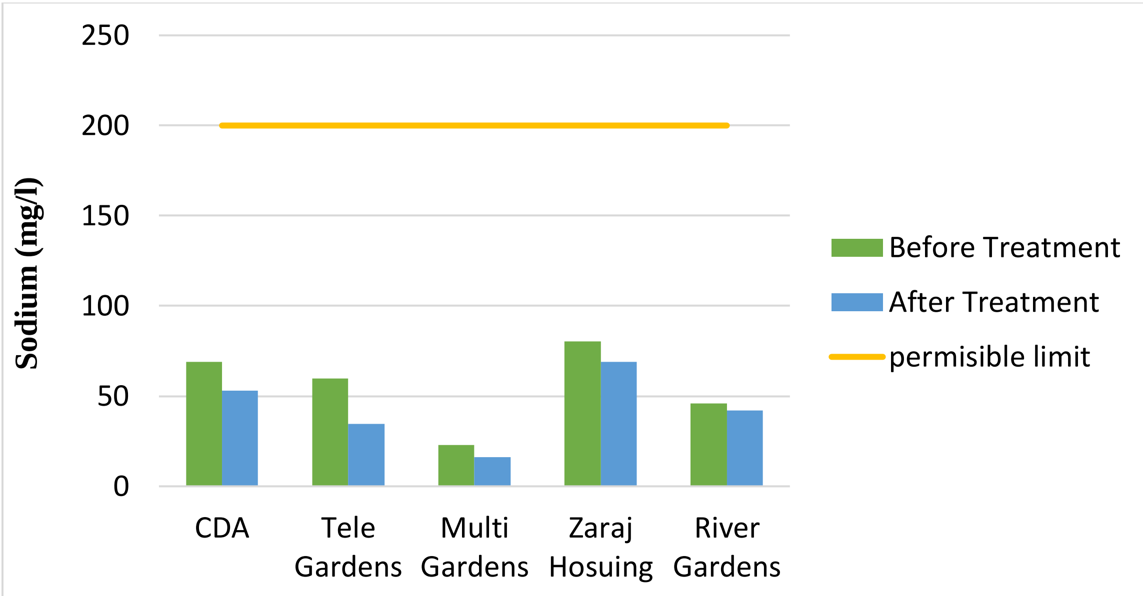

Figure 3.13: Levels of Sodium in wastewater samples from 5 STPs

3.5.3 NaCl

There is no permissible or recommended limit for NaCl in wastewater by Pak EPA. However, there is recommended limit for sodium and chlorine separately. So, all the wastewater samples have NaCl below the permissible limit, before and after the treatment.

Table 3.3 Results of NaCl in wastewater samples collected from 5 STPS

Sample ID	NaCl
CDA Sewage Treatment Plant	
BT	175.5
AT	134.5
Tele Gardens Sewage Treatment Plant	
BT	152.1
AT	87.7
Multi Gardens Sewage Treatment Plant	
BT	58.5
AT	40.9
Zaraj Housing Scheme Sewage Treatment Plant	
BT	204.7
AT	175.5
River Gardens Sewage Treatment Plant	
BT	117
AT	117

3.5.4 Alkalinity

The permissible limit of alkalinity recommended by Pak EPA is 200 mg/l. The alkalinity of the wastewater samples exceeded the limit for CDA, Multi Gardens, Zaraj, and River Gardens before treatment and after treatment.

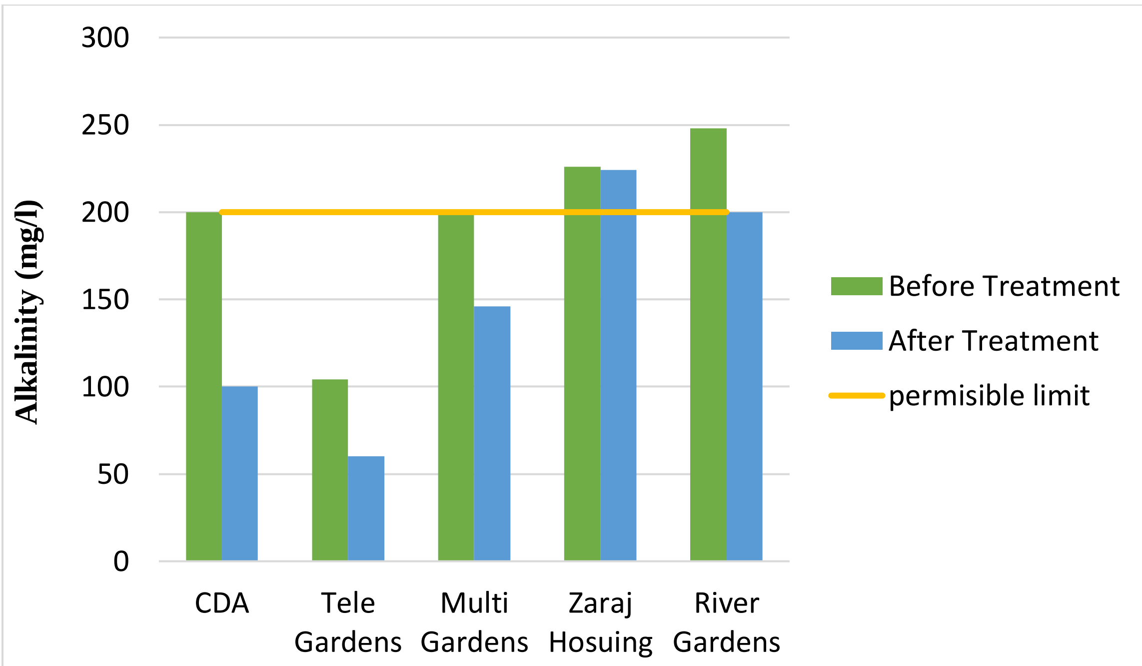

Figure 3.14: Levels of Alkalinity in wastewater samples from 5 STPs

3.5.5 Total Hardness

The highest allowable level in drinking water is 500 ppm, according to Pak EPA and PCRWR. The hardness of all the wastewater samples was within permissible limits except for one sample from the CDA sewage treatment plant where the value exceeded after treatment.

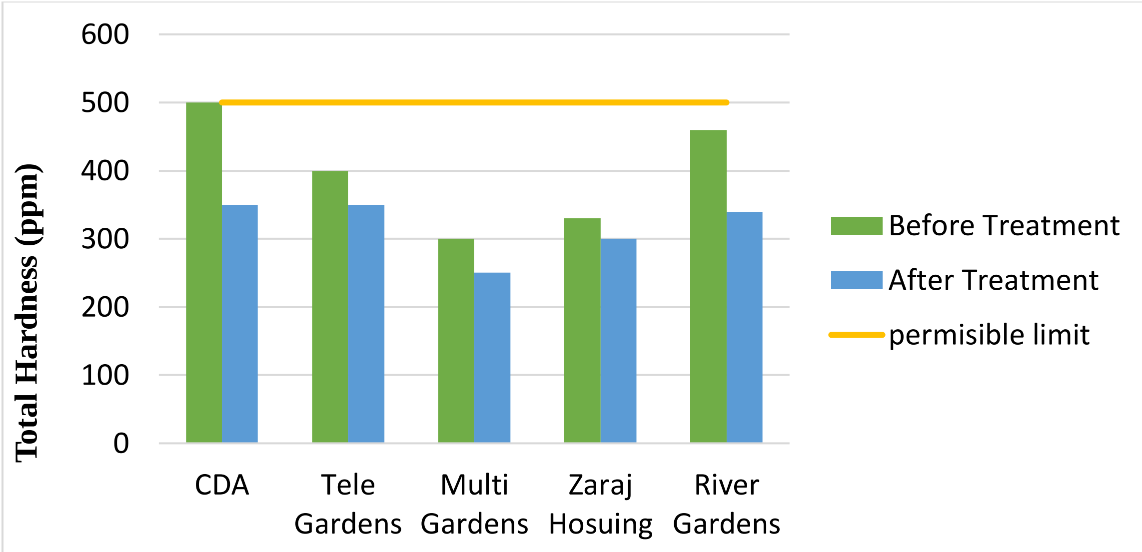

Figure 3.15: Levels of hardness in wastewater samples from 5 STPs

3.5.6 Nitrates

The results of wastewater samples before and after treatment were within the permissible limit of Pak-EPA 50 mg/l. The results of nitrates for all wastewater samples are shown in the table below.

Table.3.4: Results of Nitrates in Wastewater samples before and after treatment

Sample ID	**Nitrates** (mg/l)
CDA Sewage Treatment Plant	
BT	0.686
AT	0.724
Tele Gardens Sewage treatment plant	
BT	0.848
AT	0.821
Multi Gardens Sewage treatment plant	
BT	0.237
AT	0.529
Zaraj Housing Scheme Sewage Treatment Plant	
BT	1.427
AT	1.281
River Gardens Sewage Treatment Plant	
BT	1.318
AT	1.567
Permissible limit of Pak EPA	**50 mg/l**

3.5.7 Carbonates

The results of carbonates in wastewater samples of all the treatment plants showed that there is no significant difference in the values of carbonates before and after the treatment. Also, there is no recommended limit for carbonates given by any national or international organization.

Table 3.5: Results of carbonates in wastewater samples collected from 5 STPS

Sample ID	$NaHCO_3$	Na_2CO_3	HCO_3	CO_3
CDA Sewage Treatment Plant				
BT	1	1.2	0.7	0.7
AT	0.5	0.7	0.4	0.4
Tele Gardens Sewage treatment plant				
BT	1	1.3	0.7	0.7
AT	0.6	0.8	0.4	0.4
Multi Gardens Sewage treatment plant				
BT	0.3	0.4	0.2	0.2
AT	0.5	0.7	0.4	0.4
Zaraj Housing Scheme Sewage Treatment Plant				
BT	1.2	1.5	0.9	0.9
AT	1.1	1.4	0.8	0.8
River Gardens Treatment Plant				
BT	1.5	1.8	1	1
AT	1.1	1.4	0.8	0.8

3.5.8 Chemical Oxygen Demand (COD)

According to the Pak EPA, the chemical oxygen demand (COD) in wastewater should not be more than 400mg/l. The result of all wastewater samples had values within the permissible limit before and after the treatment as shown in Figure 3.16.

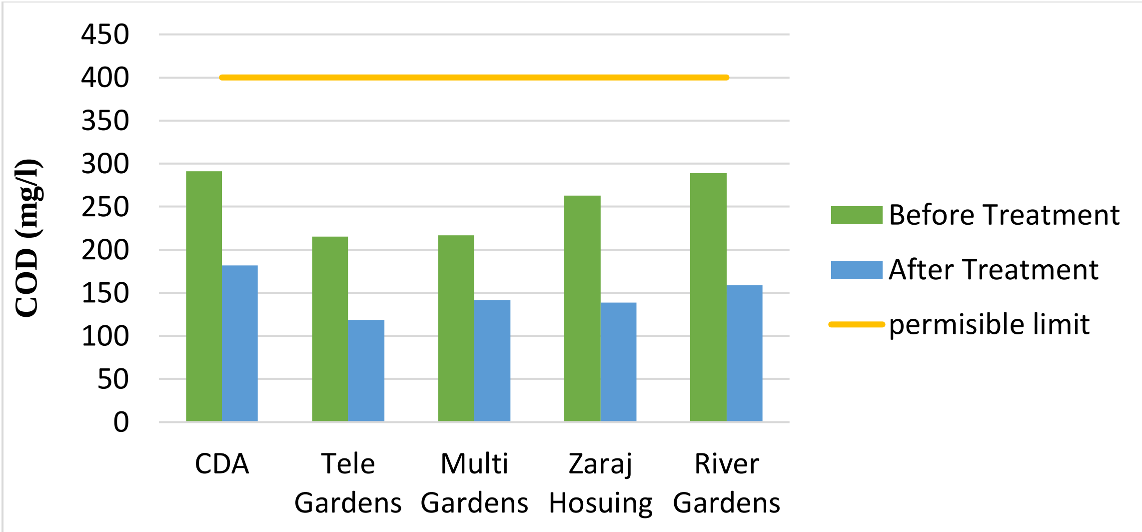

Figure 3.16: COD of collected wastewater samples

3.5.9 Biological Oxygen Demand (BOD)

According to the Pak EPA, the biological oxygen demand (BOD) in wastewater should not be more than 80mg/L. Before the treatment, the result of all wastewater samples had values above the permissible limit and after the treatment, the values of CDA, Multi, and River Gardens exceeded the limit as shown in Figure 3.17.

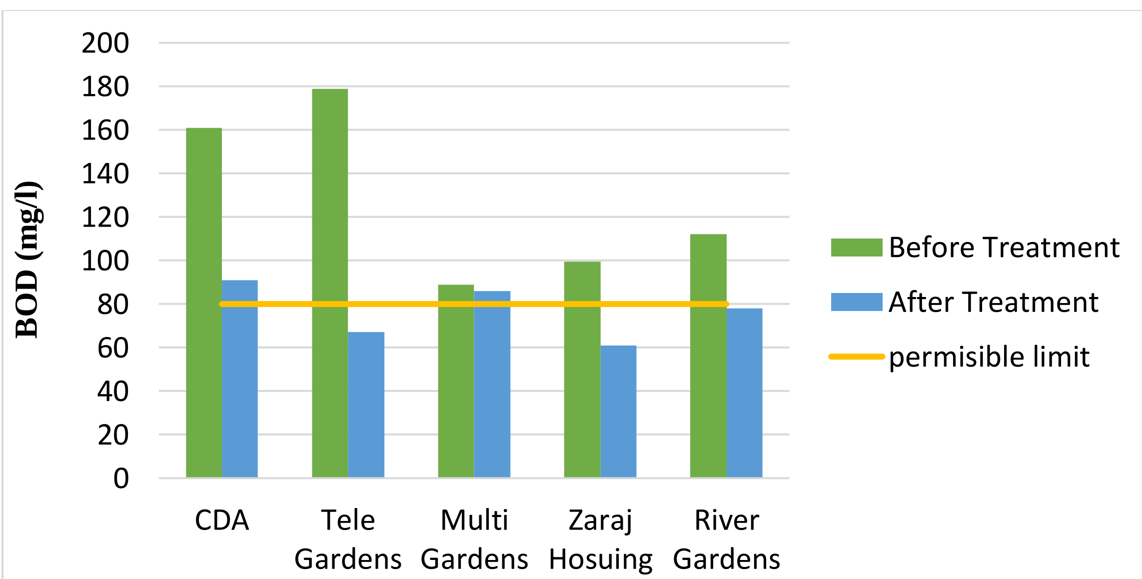

Figure 3.17:BOD of collected wastewater samples

3.6 Results of heavy metals

The water samples collected from five sewage treatment plants before and after treatment and the groundwater samples collected from the respective sectors of treatment plants were subject to heavy metal analysis from the Pak EPA laboratory. The heavy metals including Iron (Fe), Cadmium (Cd), Chromium (Cr), Lead (Pb), Arsenic (As), and Manganese (Mn) were analyzed in collected water samples. Arsenic (As) was absent in all water samples.

3.6.1 Results of heavy metals in groundwater samples

Table 3.4: Results of heavy metals in groundwater samples

Sample ID	Fe	Cr	Cd	Mn	Pb
Permissible Limits of Pak-EPA (mg/l)	**0.3**	**0.05**	**0.003**	**0.1**	**0.01**
Sector I-9					
GW-1	0.151	BDL	BDL	0.131	BDL
GW-2	BDL	BDL	0.002	0.251	BDL
GW-3	0.188	BDL	BDL	0.092	BDL
GW-4	0.095	BDL	BDL	0.091	BDL
GW-5	BDL	BDL	BDL	0.058	BDL
GW-6	BDL	BDL	BDL	BDL	0.081
GW-7	0.312	BDL	BDL	0.122	BDL
GW-8	0.135	BDL	0.001	0.071	BDL
GW-9	BDL	BDL	BDL	0.068	0.011
GW-10	0.331	BDL	BDL	0.117	BDL
Tele Gardens					
GW-11	BDL	BDL	BDL	BDL	BDL
GW-12	0.085	BDL	BDL	BDL	BDL
GW-12	BDL	BDL	BDL	0.191	BDL
GW-14	BDL	BDL	BDL	0.217	0.013
GW-15	0.118	BDL	BDL	0.074	BDL
GW-16	BDL	BDL	BDL	BDL	BDL
GW-17	0.221	BDL	BDL	0.312	BDL
GW-18	BDL	BDL	BDL	0.059	BDL
GW-19	0.312	BDL	BDL	BDL	BDL
GW-20	BDL	BDL	0.002	0.188	BDL
Multi Gardens					
GW-21	BDL	BDL	BDL	0.098	BDL
GW-22	BDL	BDL	BDL	0.211	BDL
GW-23	0.113	BDL	0.0011	0.117	BDL
GW-24	BDL	BDL	BDL	0.048	BDL

GW-25	0.251	BDL	BDL	0.321	BDL
GW-26	0.121	BDL	BDL	0.129	BDL
GW-27	BDL	BDL	BDL	BDL	BDL
GW-28	0.321	BDL	BDL	0.127	BDL
GW-29	BDL	BDL	BDL	BDL	BDL
GW-30	BDL	BDL	BDL	0.073	BDL
Zaraj Housing Scheme					
GW-31	BDL	BDL	BDL	0.15	0.035
GW-32	0.136	BDL	BDL	0.103	BDL
GW-33	0.0122	BDL	BDL	BDL	BDL
GW-34	BDL	BDL	BDL	0.122	BDL
GW-35	BDL	BDL	BDL	0.051	0.012
GW-36	BDL	BDL	0.001	0.121	BDL
GW-37	BDL	BDL	BDL	0.098	BDL
GW-38	0.215	BDL	BDL	0.081	BDL
GW-39	BDL	BDL	BDL	0.087	BDL
GW-40	BDL	BDL	BDL	0.091	BDL
River Gardens					
GW-41	BDL	BDL	BDL	0.098	BDL
GW-42	BDL	BDL	BDL	0.199	0.011
GW-43	BDL	BDL	BDL	0.217	BDL
GW-44	0.301	BDL	BDL	0.081	BDL
GW-45	0.211	BDL	BDL	BDL	BDL
GW-46	0.121	BDL	BDL	0.317	BDL
GW-47	BDL	BDL	BDL	0.218	BDL
GW-48	BDL	BDL	BDL	0.011	BDL
GW-49	BDL	BDL	BDL	BDL	BDL
GW-50	BDL	BDL	BDL	BDL	BDL

3.6.2 Results of heavy metals in wastewater samples

The results of all tested parameters are shown in the graphs. Arsenic was not detected in any of the collected wastewater samples before and after treatment.

3.6.2.1 Iron (Fe)

According to the Pak EPA guidelines, the concentration of Iron (Fe) in wastewater should not be more than 8mg/L. The collected wastewater had values before treatment and after treatment which were within the recommended limit.

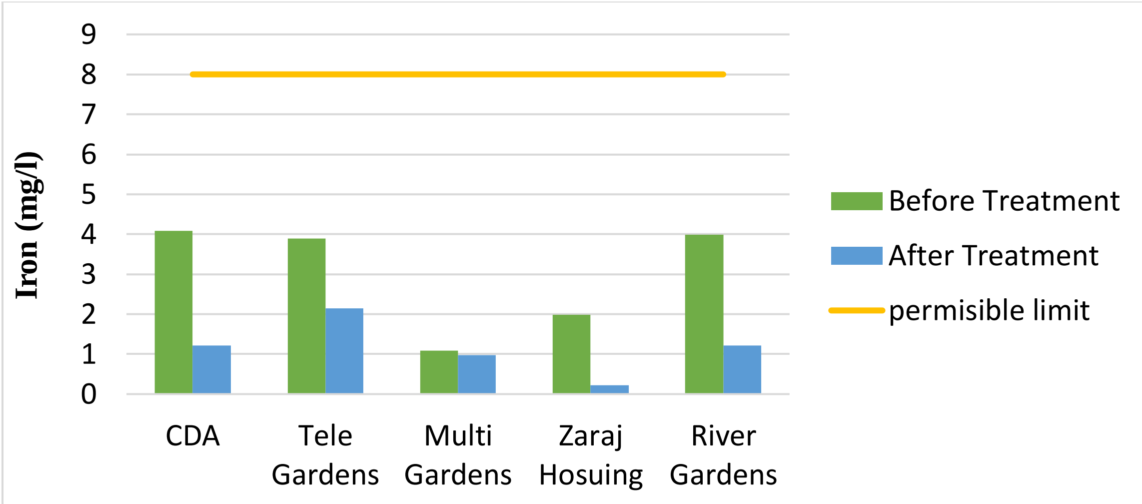

Figure 3.18(a): Levels of Iron in wastewater samples from 5 STPs

3.6.2.2 Chromium (Cr)

According to the Pak EPA guidelines, the concentration of Chromium (Cr) in wastewater should not be more than 1mg/L. The collected wastewater had values before treatment which surpassed the permissible limit except for Zaraj Housing. After treatment values of Tele Gardens, and Zaraj were within the limit compared to the rest of the plants.

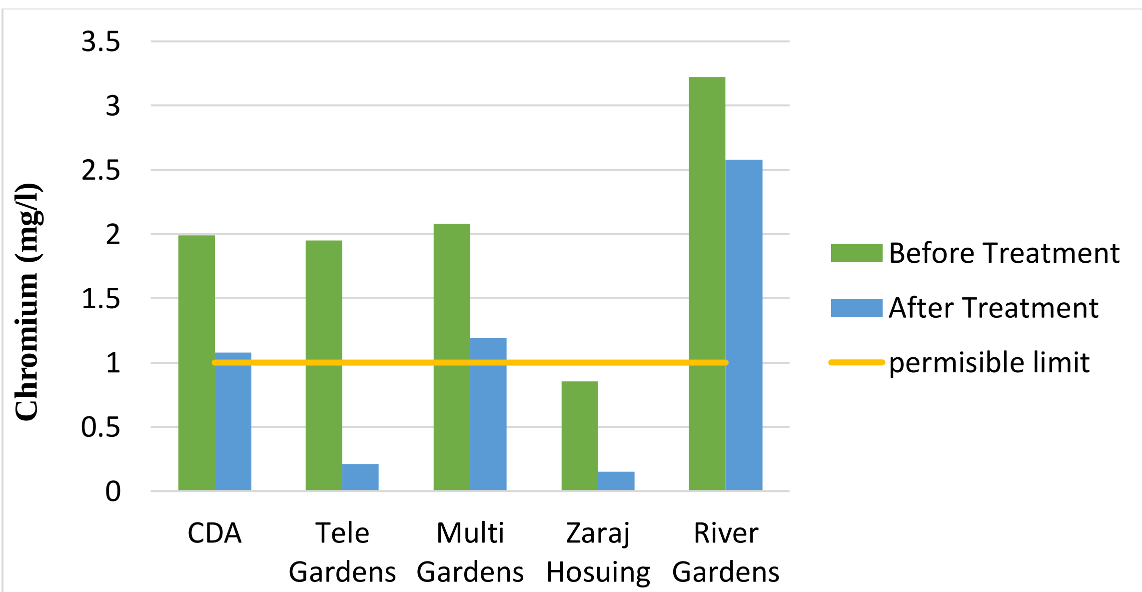

Figure 3.18(b): Levels of Chromium in wastewater samples from 5 STPs

3.6.2.3 Cadmium (Cd)

According to the Pak EPA guidelines, the concentration of Cadmium (Cd) in wastewater should not be more than 0.1mg/L. The before-treatment results of all collected wastewater samples surpassed the permissible limit. After treatment, only Tele Gardens had a value below the limit after treatment compared to the rest of the plants.

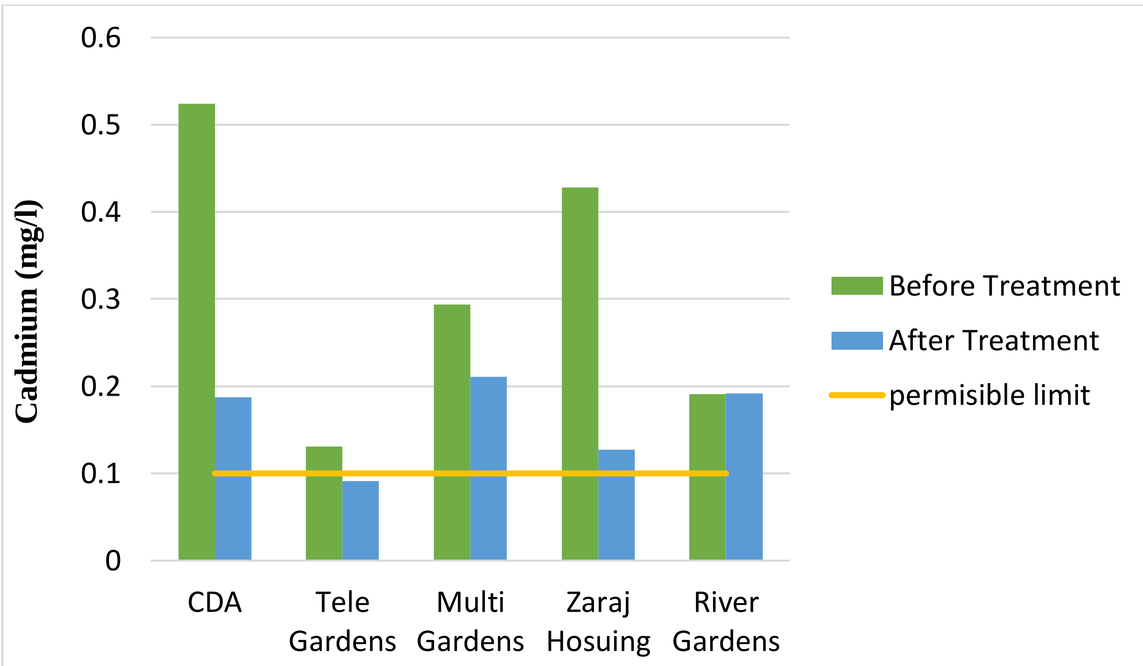

Figure 3.18(c): Levels of Cadmium in wastewater samples from 5 STPs

3.6.2.4 Manganese (Mn)

According to the Pak EPA guidelines, the concentration of Manganese (Mn) in wastewater should not be more than 1.5mg/L. The before-treatment results of all collected wastewater samples surpassed the permissible limit. After treatment, only Tele Gardens and Zaraj housing plants had values below the limit after treatment compared to the rest of the plants.

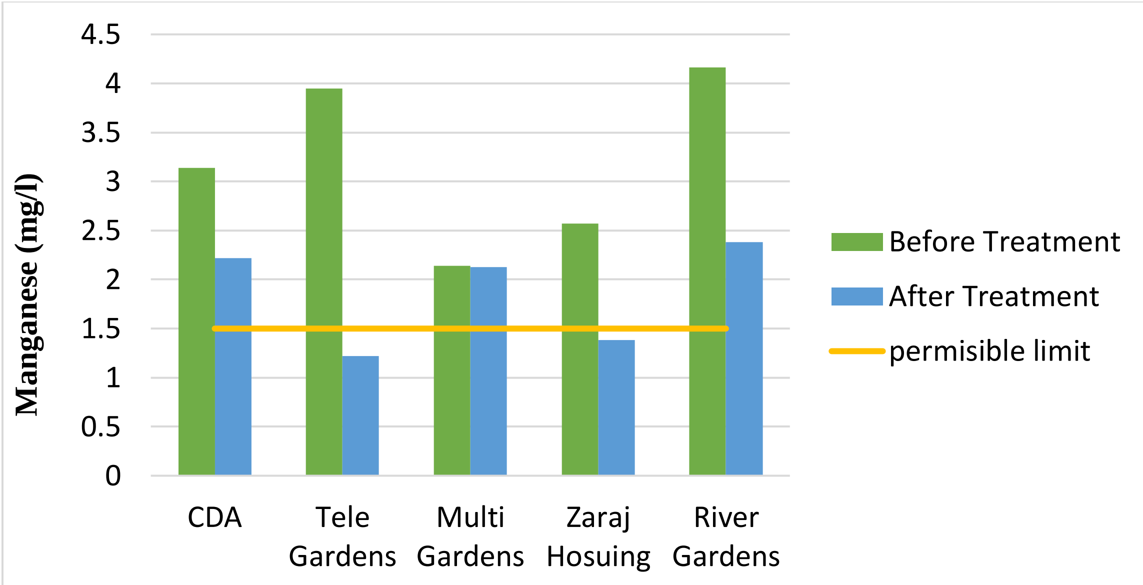

Figure 3.18(d): Levels of Manganese in wastewater samples from 5 STPs

3.6.2.5 Lead (Pb)

According to the Pak EPA guidelines, the concentration of Lead (Pb) in wastewater should not be more than 0.5mg/L. The collected wastewater samples had chromium values within the permissible limit.

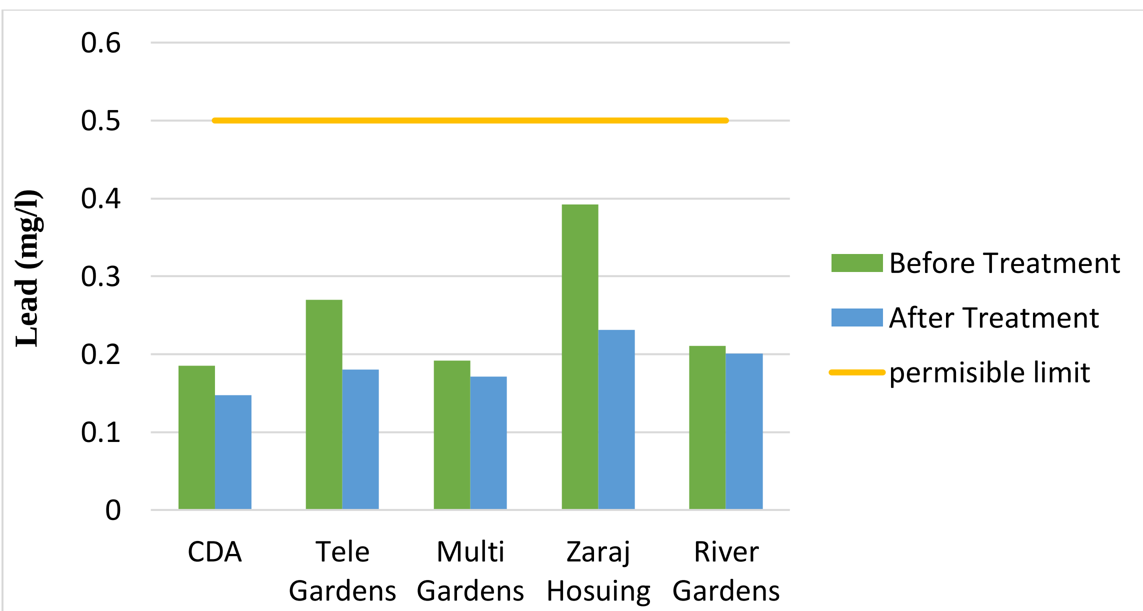

Figure 3.18(e): Levels of Lead in wastewater samples from 5 STPs

3.7: Removal Efficiency of Sewage Treatment Plants (STPs)

Treatment efficiency of the sewage treatment plants CDA, Tele Gardens, Multi Gardens, Zaraj, and River Gardens Housing scheme was carried out concerning the parameters (i.e. BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), pH, Turbidity, TDS (Total Dissolved Solids), Chromium, Cadmium, Manganese, Iron, Lead, etc.). The removal efficiency for all the wastewater parameters was calculated using the formula.

$$\text{Efficiency (\%)} = \frac{Con_{in} - Con_{out}}{Con\ in} \times 100$$ (Qasim, et al., 2017)

The results offer insights into the efficacy of each treatment facility in eliminating certain chemical elements from wastewater. Multi Gardens STP has high removal efficiencies for nitrates, but River Gardens STP has limited to no removal efficiencies for chlorine, sodium, and NaCl. Comprehending these differences is essential for evaluating the overall efficiency and environmental impact of any treatment facility. CDA STP has lower removal efficiencies for pH, but Multi Gardens STP exhibits greater removal efficiencies for turbidity in terms of physical characteristics. Comprehending these differences is essential for evaluating the overall efficiency and ecological footprint of any treatment facility. Various physical and chemical parameters show inferior removal efficiency in different sewage treatment plants due to multiple variables. Insufficient buffering capacity in treatment processes can impede the adjustment of pH levels to the desired ranges. Inadequate monitoring and control during treatment operations can cause fluctuations in pH levels, which can impact overall efficiency. Alkaline or acidic pollutants in the influent water can hinder treatment operations and reduce removal efficiency. Inadequate filtration or separation procedures within treatment processes can lead to restrictions in removing dissolved salts and minerals, as shown by electrical conductivity (EC) and total dissolved solids (TDS. Elevated saline levels from industrial discharges or natural sources could aggravate the issue, surpassing treatment capacities and decreasing overall effectiveness. Specific salt ions, including chloride and sulfate, resistant to treatment, can impair removal efficiency. Regulating temperature in treatment procedures is crucial for reaching peak performance (Gai & Deng, 2021).

Regulating temperature in treatment procedures is crucial for reaching peak performance. The inability to adjust temperature significantly because of the huge volume and flow rates can restrict the effectiveness of treatment operations in reducing temperature. Partial degradation pathways or the presence of resilient organic compounds might decrease the efficiency of pollution removal, such as turbidity. Inadequate retention time or contact with microbial populations in treatment systems might worsen these difficulties, leading to reduced overall efficiency. To address these problems, a complete approach is needed, which involves enhancing treatment technologies, improving monitoring and control mechanisms, and considering fluctuations in influent water quality. Sewage treatment plants can improve their wastewater treatment operations by identifying and resolving the underlying reasons for reduced removal efficiency. Many treatment plants showed higher removal efficiencies for some parameters. Higher removal efficiencies are typically attained by employing efficient treatment procedures, ensuring adequate contact time for treatment, eliminating easily degradable contaminants, maintaining stable influent water quality, and enhancing the ability to target specific pollutants (Mahfooz, et al., 2020).

Table 3.5: Removal Efficiencies of chemical parameters of wastewater samples

Wastewater Samples	**Cl**	**Na**	**NaCl**	**Alkalinity**	**Hardness**	**Nitrates**
CDA Sewage Treatment Plant						
Before	106.5	69	175.5	200	500	0.724
After	81.6	52.9	134.5	100	350	0.686
Removal Efficiency	29%	23%	23%	50%	30%	5%
Tele Gardens Sewage Treatment Plant						
Before	92.3	59.8	152.1	104	400	0.848
After	53.2	34.5	87.7	60	350	0.821
Removal Efficiency	42%	41%	42%	42%	13%	3%
Multi Gardens Sewage Treatment Plant						
Before	35.5	23	58.5	200	300	0.529
After	24.8	16.1	40.9	146	250	0.237
Removal Efficiency	30%	30%	30%	27%	17%	55%

Zaraj Housing Scheme Sewage Treatment Plant						
Before	124.2	80.5	204.7	226	330	1.427
After	106.5	69	175.5	220	300	1.281
Removal Efficiency	14%	14%	14%	3%	9%	10%
River Gardens Sewage Treatment Plant						
Before	71	46	117	248	460	1.567
After	71	46	117	200	340	1.318
Removal Efficiency	0%	0%	0%	19%	26%	15%

Table 3.6: Removal Efficiencies of Carbonates of wastewater samples

Wastewater Samples	**$NaHCO_3$**	**Na_2CO_3**	**HCO_3**	**CO_3**
CDA Sewage Treatment Plant				
Before	1	1.2	0.7	0.7
After	0.5	0.7	0.4	0.4
Removal Efficiency	50%	41%	42%	42%
Tele Gardens Sewage Treatment Plant				
Before	1	1.3	0.7	0.7
After	0.6	0.8	0.4	0.4
Removal Efficiency	40%	38%	42%	42%
Multi Gardens Sewage Treatment Plant				
Before	0.5	0.7	0.4	0.4
After	0.3	0.4	0.2	0.2
Removal Efficiency	40%	42%	50%	50%
Zaraj Housing Scheme Sewage Treatment Plant				
Before	1.2	1.5	0.9	0.9
After	1.1	1.4	0.8	0.8
Removal Efficiency	8%	7%	11%	11%
River Gardens Sewage Treatment Plant				
Before	1.5	1.8	1	1
After	1.1	1.4	0.8	0.8
Removal Efficiency	27%	22%	20%	20%

Table 3.5: Removal Efficiencies of physical parameters of wastewater samples

Wastewater Samples	PH	EC	TDS	Salts	Turbidity
CDA Sewage Treatment Plant					
Before	8.27	894	635	423	33.63
After	8.13	707	501	330	0
Removal Efficiency	2%	21%	21%	22%	100%
Tele Gardens Sewage Treatment Plant					
Before	8.09	574	408	267	38.57
After	7.86	404	287	188	4.75
Removal Efficiency	3%	30%	30%	30%	88%
Multi Gardens Sewage Treatment Plant					
Before	8.02	1040	744	496	97
After	7.97	824	585	387	2.45
Removal Efficiency	0.6%	21%	21%	22%	97%
Zaraj Housing Scheme Sewage Treatment Plant					
Before	7.99	1165	818	552	154
After	7.89	1151	816	548	18.06
Removal Efficiency	1%	1%	0.2%	0.7%	88%
River Gardens Sewage Treatment Plant					
Before	7.24	1174	834	560	12.13
After	7.20	984	699	466	0
Removal Efficiency	0.5%	16%	16%	17%	100%

Table 3.6: Removal efficiencies of heavy metals for five STPS

Wastewater Samples	Fe	Cr	Cd	Mn	Pb
Tele Gardens Sewage Treatment Plant					
Before	3.89	1.95	0.131	3.95	0.27
After	2.15	0.21	0.091	1.22	0.18
Removal Efficiency	45%	89%	31%	69%	33%
Zaraj Housing Scheme Sewage Treatment Plant					
Before	1.991	0.855	0.428	2.571	0.392

After	0.218	0.15	0.127	1.385	0.231
Removal Efficiency	89%	82%	70%	46%	41%
River Gardens Sewage Treatment Plant					
Before	3.991	3.221	0.192	4.161	0.211
After	1.218	2.58	0.191	2.385	0.201
Removal Efficiency	69%	20%	0.5%	43%	5%
CDA Sewage Treatment Plant					
Before	4.08	1.99	0.524	3.147	0.185
After	3.121	1.081	0.187	2.227	0.147
Removal Efficiency	24%	46%	64%	29%	21%
Multi Gardens Sewage treatment plant					
Before	1.08	2.08	0.294	2.147	0.192
After	0.985	1.191	0.211	2.133	0.171
Removal Efficiency	9%	43%	28%	0.6%	11%

The results show the varying efficiency of each sewage treatment plant in eliminating heavy metals from wastewater. Zaraj Housing Sewage Treatment Plant demonstrates high removal rates for heavy metals compared to other treatment plants, although Multi Gardens Sewage Treatment Plant normally displays lower removal rates. Comprehending these differences is essential for assessing the overall efficiency and ecological footprint of each sewage treatment facility.

Table 3.7: Removal efficiencies of COD and BOD for five STPS

Wastewater Samples	**COD**	**BOD**
CDA Sewage Treatment Plant		
Before	291	161
After	182	91
Removal Efficiency	37%	43%
Tele Gardens Sewage Treatment Plant		
Before	215	179
After	119	67
Removal Efficiency	34%	63%
Multi Gardens Sewage Treatment Plant		
Before	217	89
After	142	86
Removal Efficiency	35%	3%

Zaraj Housing Scheme Sewage Treatment Plant		
Before	263	99.5
After	139	61
Removal Efficiency	47%	39%
River Gardens Sewage Treatment Plant		
Before	289	112
After	159	78
Removal Efficiency	45%	30%

The results offer an understanding of the capacity of each sewage treatment plant to reduce the amounts of organic pollutants, as measured by COD and BOD. Tele Gardens STP and Zaraj Housing STP show greater removal efficiency for both parameters than River Gardens, CDA, and Multi Gardens STPs. CDA STP shows significant effectiveness in removing BOD compared to the others. Comprehending these differences is crucial for analyzing the effectiveness of each Sewage Treatment Plant (STP) and evaluating their impact on enhancing overall water quality.

CONCLUSION

Managing wastewater contamination from industrial and municipal sources is a crucial issue for policymakers and the government in water-stressed countries. This study examined the quality of wastewater in the five sewage treatment plants and the groundwater quality of surrounding areas in Islamabad by analyzing heavy metals, and biological, chemical, and physical factors. Excessive levels of pollutants (physiochemical, biological, and metals) were detected in the sewage wastewater, and groundwater beyond the limit allowed by the Pakistan EPA. The groundwater samples from different sectors showed varying levels of bacterial contamination. In some sectors, total bacteria count exceeded permissible limits while in others, coliform presence indicated poor water quality. Regular monitoring and remedial actions are necessary to ensure groundwater quality meets safety standards across different sectors. The results of the physical parameters of groundwater showed that the pH values of samples exceeded the lower range. EC and temperature were within the limit for all samples. Some samples for TDS exceeded the permissible limit. The levels of salts also exceeded the limit in all water samples. Turbidity for just one sample of Multi Gardens exceeded the limit whereas it was zero for all other samples. The results of physical parameters for wastewater showed that pH, salts, turbidity, and temperature exceeded the permissible limit as given by the Pak EPA. However, all values showed a slight decrease after the treatment, compared to the results before the treatment. The results of chemical parameters for groundwater samples showed that all parameters were within the recommended limit of Pak EPA. For wastewater, the values of sodium, Chlorides, NaCl, Nitrates, COD, and carbonates were within the recommended limit, but the values of Alkalinity and BOD surpassed the acceptable limit by Pak EPA. The results of heavy metals for groundwater showed varying results with most of the samples bearing values below the detection limit. However, in some samples, the values of Mn and Fe surpassed the acceptable limit. For wastewater samples, the value of Cr, Cd, and Mn exceeded the limit before treatment and showed a decreasing trend in values after the treatment. Pb and Fe were within the recommended limit. The analysis of removal efficiencies across different sewage treatment plants revealed variations in the effectiveness of treatment processes. Zaraj Housing STP demonstrated relatively high removal efficiencies for heavy metals and some chemical parameters, while Multi Gardens

STP generally exhibited lower removal efficiencies. In terms of heavy metals, Tele Gardens STP showed notable removal efficiencies for Cr and Cd. CDA STP showed high removal efficiency regarding chemical parameters. However, River Gardens STP displayed lower removal efficiencies across multiple parameters, indicating potential challenges in treatment effectiveness. These results underscore the importance of continued monitoring and improvement efforts to ensure consistent water quality standards are met across sewage treatment plants.

RECOMMENDATIONS

1. Regular assessment and monitoring of the Sewage treatment plants' intake, outflow, and groundwater of nearby areas is necessary. This involves considering fluctuations in flow rates and seasonal variations. Ensure that all maintenance and technical repairs are properly addressed.
2. Future research should employ sophisticated techniques to analyze physical, chemical, biological, and heavy metal factors to guarantee consistency with previous studies and regulatory guidelines.
3. There should be thorough study designs in place to gather data over a longer period to encompass changes in water quality metrics throughout time, including daily and seasonal variations.
4. Conducting studies under controlled settings to evaluate the removal efficiency of different treatment procedures used by the treatment plants.
5. Regular assessments of groundwater contamination should be conducted to evaluate the quality of groundwater in areas near treatment plants and determine any potential effects of effluent discharge on groundwater resources.
6. Risk assessment should be conducted to evaluate the potential health and environmental risks linked to the reported water quality parameters, especially heavy metals, in both treated effluents and groundwater samples.
7. Disseminating results to pertinent stakeholders, such as local communities, government and regulatory bodies, and policymakers, to increase knowledge and guide decision-making on water resource management and pollution control strategies.

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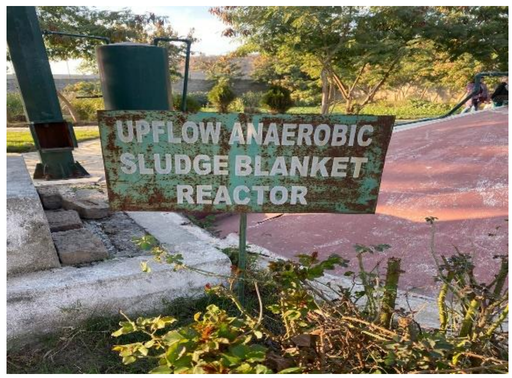
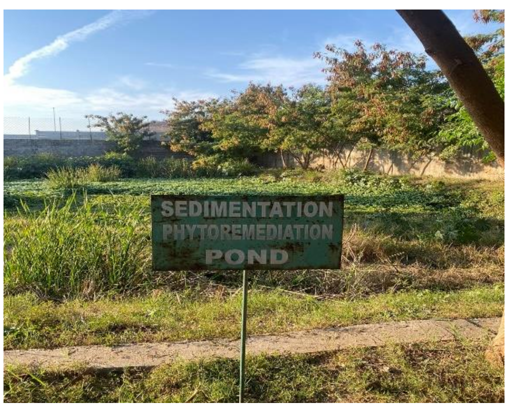
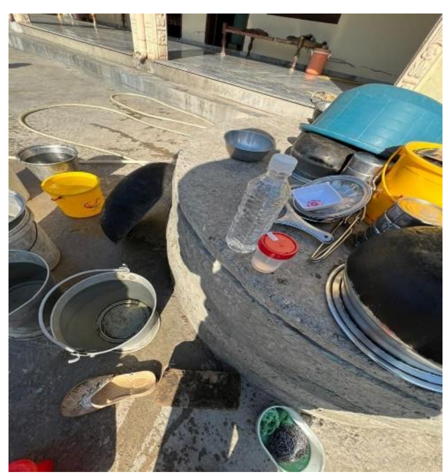
APPENDICES

Sewage Treatment Plants





Sample Collection



Lab Analysis