SURVEY AND ANALYSIS OF GROUNDWATER CONTAMINATION IN WASA SUPPLIED WATER WITHIN HOTSPOT AREAS OF RAWALPINDI CITY

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It is certified that the contents and form of the thesis entitled

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Syed Daniyal Ali

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I certified that this research work presented in the thesis titled ***"Survey And analysis of groundwater contamination in WASA supplied water within hotspot areas of Rawalpindi city"*** is my own work. Thesis has significant new work/knowledge as compared to already published or under consideration to be published elsewhere. No sentence, equation, diagram, table, paragraph or section has been copied verbatim from previous work unless it is placed under quotation marks and duly referenced. The thesis has been checked using TURNITIN and found within limits as per HEC plagiarism Policy and instructions issued from time to time

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To My Beloved Parents,

And Respectful Teachers

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SYED DANIYAL ALI

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LIST OF ABBREVIATIONS/ KEYWORDS

APHA	American Public Health Association
BGLB	Brilliant Green Bile Broth
$CaCO_3$	Calcium Carbonate
CDA	Capital Development Authority
Cl_2	Chlorine
°C	Degree Celsius
DBP	Disinfectant By-Products
DO	Dissolved Oxygen
DWDS's	Drinking Water Distribution Systems
EC	Electrical Conductivity
EC broth	Escherichia coli broth
E. coli	Escherichia coli
EPA	Environmental Protection Agency
FBS	Federal Bureau of Statistics
GDP	Gross Domestic Product
GPS	Global Positioning System
HCO_3	Bicarbonate ion
HDR	Human Development Report
IDW	Inverse Distance Weighted
K	Potassium
Km^2	Square Kilometer

L	Litre
m^3	Meter cube
mg	Milligram
ml	Milliliter
mm	Millimeter
MS	Microsoft
MPN	Most Probable Number
NO_3	Nitrate ion
NTU	Nephelometric Unit
PCRWR	Pakistan Council of Research in Water Resources
pH	Power in terms of hydrogen ions concentration
SD	Standard Deviation
r^2	Coefficient of Correlation
RDA	Rawalpindi Development Authority
SO_4^{-2}	Sulphate ion
TDS	Total Dissolved Solids
UC	Union Council
UNICEF	United Nations Children’s Fund
WASA	Water and Sanitation Agency
WHO	World Health Organization
WQI	Water Quality Index

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ABSTRACT

With the advent of 21st century, rapid industrialization and population growth has resulted in deterioration in quality of natural water reservoirs at global level, thus imposing high human health risks. Accordingly, the accessibility of safe drinking water to common public has become one of the major challenges in developing countries like Pakistan. The major aim of current research was to collect groundwater samples from four zones of Water And Sanitation Agency (WASA) in subdivision of Rawalpindi city (also termed as Rawal Town). Furthermore, eight physicochemical parameters and one microbiological analysis were conducted across 20 hotspots (populated) areas covering forty-six Union Councils (UC) devised by Tehsil Municipal Administration (TMA), Rawalpindi. The results indicated that only 1% of total samples exceed threshold turbidity limit in UC 37, while 5% of total samples for hardness and 7% of total samples for alkalinity in UC 14 were found above national and international standards of water quality namely Pakistan Standard for Drinking Water Quality (PSDWQ) and World Health Organization (WHO) permissible limits respectively. However, other physicochemical parameters including pH, electrical conductivity (EC), total dissolved solids (TDS), chlorides and dissolved oxygen were found within allowable levels for all studied areas. In contrast, fecal contamination was observed for all water samples, as indicated by most probable number test, rendering it unfit for human consumption. Pearson correlation matrix was developed to monitor the relationship between water quality parameters with results indicating strong correlation between "EC with TDS", "pH with hardness and alkalinity" and "chlorides with EC" at p value less than 0.05. At the end, water quality index (WQI) was developed with results showing excellent rating at UC 29 "Khurram Colony" and UC 30 "Chah Sultan" and poorest rating at UC 37 "Dhoke Dalal" across all studied sample sites. Overall, our findings revealed that microbial contamination in drinking water pose a serious threat to residence of Rawalpindi city and needs special attention to ensure public health safety

Chapter # 01

INTRODUCTION

1.1 Background Information

Water is mandatory for the continued survival of the living race. About 71% of our earth's surface is covered with freshwater resources, it is found to be the most valuable asset to the human race for its consumption. 96.5% of the overall water reserves of the earth belong to oceans (USGS, 2011) Water consumption is mandatory for domestic, commercial, and industrial usages. Statistics depict that in 2020, around 22.69% of GDP of Pakistan belongs to agricultural sector (O'Neill, 2021). The accessibility of water becomes one of the major hindrances in the country's prosperity to acquire its domestic, agricultural, and industrial growth particularly in the outlook of overpopulation and urbanization (Bashir et al., 2020). As water is a universal solvent so it can easily be contaminated by anthropogenic activities of all living organisms near its vicinity making it unfit and unsafe for human consumption.

1.2 Water Quality

Drinking, residential usage, food production, irrigation, recreational purposes, all your daily lives tasks would be possible by safe and hygienic water supply. Water quality is of supreme importance worldwide. The maximum risk factors associated with the health of the public are microbes and their active participation in deteriorating water quality characteristics and its consumption. Although other routes and sources would be significant but water route being essential to humans is a very easy and accessible one. According to WHO and UNICEF 2017, drinking water sources containing fecal pollution affected 2000 million people worldwide. People consuming fecally polluted water sources are widely affected by water-borne diseases like diarrhea, cholera, dysentery, typhoid, and polio. The bacterial death toll due to the consumption of polluted drinking water is projected to be up to 502,000 every year. In underdeveloped countries, 38% of medical facilities require an advanced water source (water quality safe from diseases), 19% have bad quality sanitation services, and 35% lack water and soap for handwashing (water scarcity). According to Pak-EPA, human waste containing contaminants in terms of viruses and bacteria being discharged in water bodies to deteriorate its characteristics and quality turned out to be a vector for water-related diseases.

1.3 Surface Water Quality

Water present in lakes, rivers, streams, wetlands belong to *surface water*. It is the most effective factor in the hydrological cycle which includes the passage of water from the earth surface to the atmosphere, back to earth, and vice versa, ensuring the sustainability of water for future generations. Precipitation and water runoff feeds surface water bodies. It is very easy for contaminators to contaminate surface water bodies as they are easily accessible to approach. COVID-19 originally initiated from Wuhan, China in late December 2019 caused a worldwide impact of overall 2 million cases of this viral infection spread rapidly from person to person whenever two people came in contact via sneezes, talks, and coughs. This forces different countries to be in complete lockdown for any domestic (Home Isolation) and international purposes (borders state boundaries sealed). Anthropogenic activities are imperative for all types of pollution in the environment (Yunus et al., 2020). Since public movement in different sectors halted because of Coronavirus, the load of pollution and contamination levels of different types also get decreased. This study draws our attention to the fact that how with the aid of remote sensing illustrations, we could see the healing (improvement) in surface water value in terms of suspended particulate matter (SPM) in the Vembanad Lake in India. The major objective of this study is to assess the status of water quality in a freshwater asset like Vembanad Lake. The study explains that the SPM concentration (produced by sedimentation, siltation, sewage disposal, and bacteria results in high turbidity) for the duration of the lockdown span decreased by 15.9% on average compared with the prelockout period (Yunus et al., 2020). Humans and animals intervening in the sources of water through artificial and anthropogenic activities must lead to its progression to decline its water characteristics and to negate the option for the supply of water in safe and secure conditions. Due to this reason, about 80% of freshwater systems are going through water security issues. Protected water supplies, aquatic ecosystems are known to be cost-effective ways to improve and ensure the characteristic of safe water as it is (Vörösmarty et al., 2021).

1.4 Ground Water Quality

Water present under the layers of earth in between the cracks and spaces of soil, sand and rocks. It is collected in between the geological surfaces of soil and rocks and move slowly through them to form aquifers. Water table is termed as the level of water underground present in fts (feets). Groundwater can be found anywhere (Foundation, 2021). In Pakistan, the major source for drinking water consumption is groundwater and it is highly varied in different parts of countries because of their relevant water tables in every zone for domestic usage. Rainfall and temperature are also the contributing factors for variability in water space. Ground water contamination poses severe threats to the health and hygiene of public. A study conducts by (Jamal et al., 2020) illustrated that about 30% of disease outbreaks are from water distribution deficiencies. She used QMRA and GIS mapping of water distribution system to identify potential locations and to carry out corrective actions to achieve distribution system rehabilitation. About 20-40% of all diseases outbreaks are from drinking water pollution which result in loss of national income in this regard is huge i.e., PKR 24-59 thousand million annually which is about 0.60 to 1.44 % of Pakistan's GDP approximately. About 72% of water supply distribution networks were in functional state and 84% of those schemes supply drinking water to public were unfit for consumption and usage. Groundwater and metropolitan water in Kallar Syedan were analyzed by considering water samples from five various stations for their physicochemical and microbial analysis. The study carried out revealed that underground water was polluted at sampling points namely Tayala and Luni. Fecal coliforms were present due to leakage of pipelines and sewage ponds which are closed to sampling sites (Ahmed & Shafique, 2019)

1.5 Water Distribution Network and Schematics

Hydraulic and hydrological features include pumping stations, storage tanks, valves, pipelines, treatment plants etc. are utilized to outsource the water supply to consumers and public. To ensure a steady supply or conveyance of water to all segments, positive pressure in the pipelines must be maintained throughout the schematics. High pressure pumps are being used to pressurized water into overhead storage tanks, mainly established at the summit point in the network. Microbial regrowth in watershed supply networks is a vital issue that can adversely impact water supply utilities. Disinfected water enters the distributive system of water supply for consumption with a very few microscopic species leads to regrowth of bacteria (Salam et al., 2021). (Khan et al., 2021) presented her research work by focusing on water quality assessment on different water sources and their direct and indirect impacts on human health and hygiene in study area of district Bajaur, Pakistan. Water samples in total of n= 331 taken from hand pumps, open wells, and tube wells being investigated for various tests of physical, chemical, and microbial analysis to assess the water quality reported that TSS and E.coli contamination exceeds the permissible limits of given standards indicated poor quality of water for human consumption across all three sources of drinking water supply. In terms of pollution source indication stats showed that anthropogenic and human activities are responsible for water pollution in that study area.

1.6 Study Area

Rawalpindi district is also known as *"Pindi"* situated in the northern part of Punjab province and encompasses a region of 5286 km^2. Belongs to one of the 36 districts of the province Punjab; it is 290 km northwest of the city Lahore (capital of Punjab) and 11 km southwest of the national capital Islamabad. It is situated at Long/Lat 73.0500° E and 33.6000° N. Rawalpindi is the 4th major city of Pakistan. It is administratively divided into 8 Towns (Tehsils) namely Rawal Town, Potohar Town, Gujar Khan, Murree, Kallar-Syeda, Kahuta, Kotli-Satiyan Taxila (Shabbir & Ahmad, 2015). According to the organizations concerned with the census population, the yearly growth rate of Rawalpindi in 2018 was 2.13%. It reduces to 1.97% in 2021 as shown in Figure 1.1. Rawal Town is known for its hustle and bustle and its congestion of people as everyone who lives here are well connected to each other. It comprises of 46 Union Councils (UC) which are being govern by Tehsil Municipal Administration (TMA) as given in Figure 1.3. Municipal department gives the following services: water supply, sanitation and conservancy, transfer and transport of waste and garbage to dumping site, sewer or storm water disposal, infrastructure formation of solid or liquid waste removal and drainage. Water and Sanitation Agency (WASA) being the government sector organization provides services & is accountable for providing safe and secure water supply and sanitation and ensure the health and hygiene of public. It gives a helpline of 1134 to all the residents of Rawal town. (WASA, 2018).

Surface water being supplied through Rawal dam and Khanpur dam whereas groundwater being available by the support of tube wells, dug wells, handpumps and filtration plants installed across area to facilitate the residents for safe water quality as in Figure 1.2 (WASA, 2018).

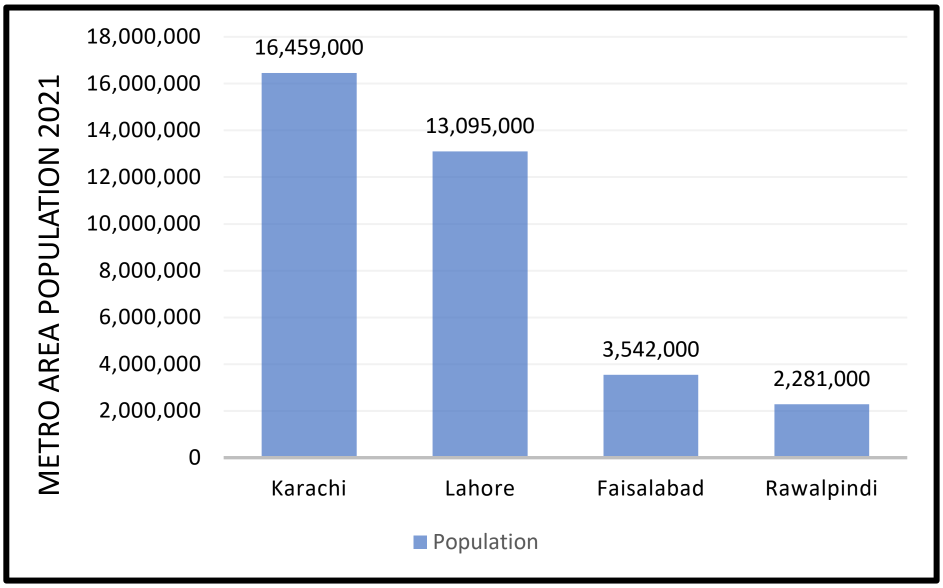

Figure 1.1: Metropolitan area population of major cities of Pakistan for the year 2021 (O'Neill, 2021)

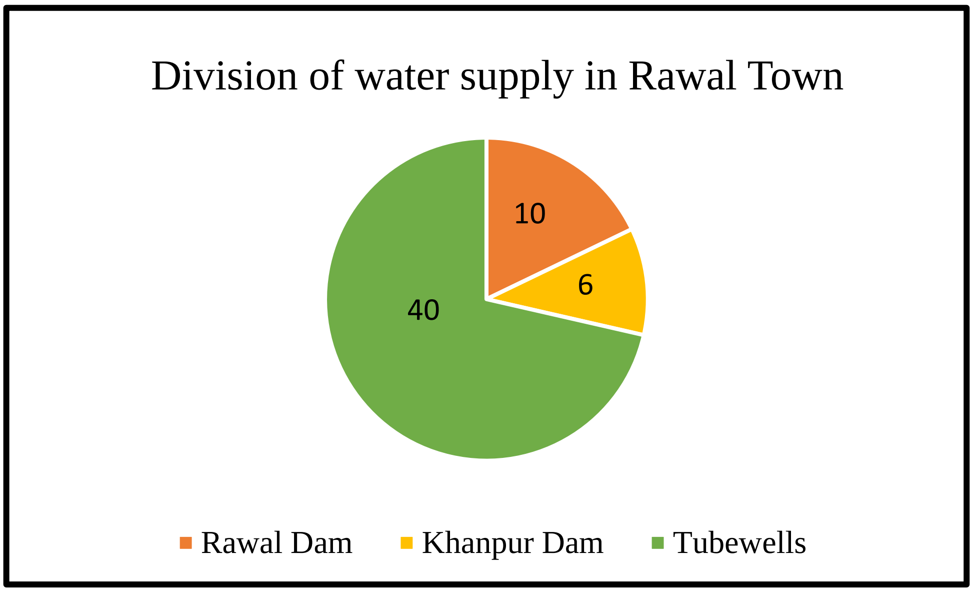

Figure 1.2: WASA divisions water supply in Million Gallons per day (MGD) to residents of Rawal Town (WASA, 2018)

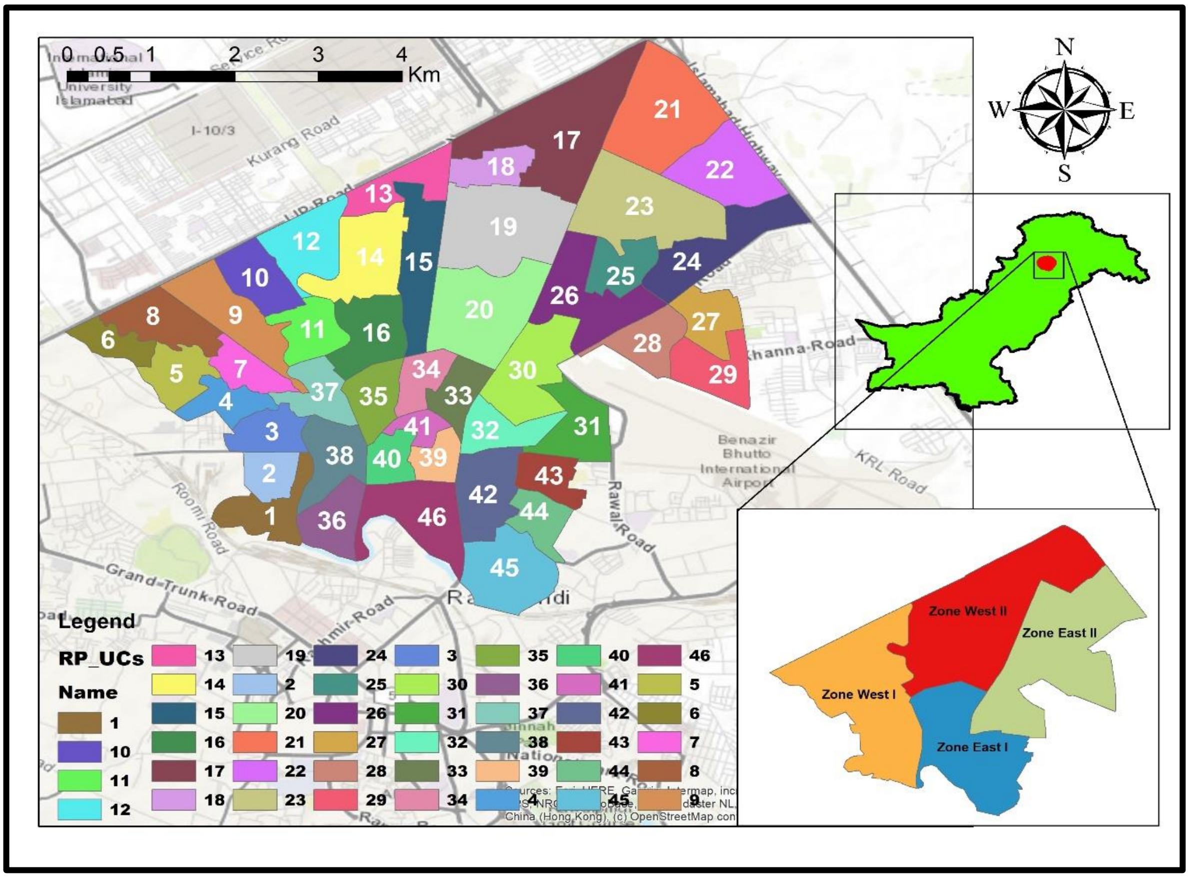

Figure 1.3: Study area based on Union council divisions of Rawal town Rawalpindi city. (Data-Shapefiles taken from Albayrak SWM)

1.7 Aims and objectives of research study

Based on the current scenario issue particularly with Rawalpindi city, following aims have been deduced to properly address and to provide particular and relevant recommendations to minimize and rectify the present practices in the field of water supply and sanitation.

1. Survey of drinking water quality in hotspot areas of WASA Rawalpindi.
2. Drinking water quality assessment by physicochemical and microbial parameters.
3. Estimating Water Quality Index (WQI) for all four zones of Rawal town Rawalpindi.

Chapter # 02

LITERATURE REVIEW

This chapter depicts the methods and techniques to carry out different approaches for effective research in recent years in relevance with the aims and objectives of this study. Various domestic and international research articles were conducted to review how water resources and streams are affected via anthropogenic activities by humans.

2.1 Groundwater: A major source of drinking water

Ground water is one of the main sources for drinking water trade to public especially in state like Pakistan which is highly stressed in clean and pure surface water supply due to poor infrastructure development and lack of proper regulations in water development sector. It's consumption and exploitation vary with respect to different zones and areas of our country. Existing ground water levels and weather conditions defines the availability of water to a specified region for consumption. It is highly variable in Punjab. There's no proper water balance in underdeveloped countries. Water level decreases as its exploitation increases while very minimal water recharge from surface water resource forces any country to be represented as water scarce state. Groundwater used for any residential and commercial purposes is very dynamic for hydrochemistry to be implemented on. Subsurface soil environments in which groundwater considered to be presented in can be effectively evaluated by water chemistry (Abbas et al., 2021). Anthropogenic activities and natural processes define groundwater quality anywhere in the world. Groundwater quality deteriorates due to overexploitation, industrialization, urbanization, and poor management in the field of water supply and control. About 70-90 % of untreated commercial wastewater effluent have been dumped in natural water streams that destroys aquaculture and pollute our environment (Bashir et al., 2020). Groundwater suitability in terms of geochemical factors in specified area can be examined by considering various components and chemical species such as nitrates, phosphates, chlorides etc. (Iqbal et al., 2022). To reach the consumption demand of limited supply for water, it is readily approachable within shallow depths of 40-50 feet, but it cannot fulfill long term goals. Potable water source that can considered to be safe and available in adequate amount is found to be existing in the depth ranging from 350 to 500 feet water wells (Yar et al., 2022).

Groundwater quality is much better than surface water conditions due to availability of fewer contaminants and pathogens under the cover of land enhance its originality in terms of exploitation and consumption. Groundwater must have a defined geological and chemical arrangement and the change in its composition totally depends on temperature, mineral dissolution, weathering of rocks, lithology, slope and mutual interaction between water and soil structure present beneath the ground (Mukhopadhyay et al., 2022).

2.2 Water quality Parameters

2.2.1 pH

pH scales expressed the amount of hydrogen ion (H^+) concentration in any given solution. Acidic, basic, or neutral nature of any solution can be found out by its pH scale ranges from (0-14). 7 being the neutral range zone. Although human health based being set by WHO (World Health Organization) does not involve pH, still it is one of the vital field parameters for water quality and its respective impacts on human consumption. Corrosion of metals being done if pH of water becomes less than 7 and it may have adverse effects on health if water being supplied to public and can exceeds the limits set by relevant standards. In water treatment facilities and distribution networks, pH should be maintained to ensure the validation of clean water supply chain for the people of Bihar, India. If it falls below 4, it can cause irritation (Logeshwaran et al., 2018) in eyes and skin infections. It is most prominent in people with sensitive diseases.

A study conducted by (Adimalla, 2021) assessed the quality of ground water in semi-arid region of India by using Pollution Index of groundwater. pH of groundwater samples was found to be in range of 7.33-8.75 shows that groundwater in the region is neutral to alkaline in nature. The factors of slightly higher pH may be the strata, geogenic and anthropogenic sources of contamination to direct water sources. Most of the water samples were marginally suitable for drinking water purposes. Another research conducted by (Ali et al., 2021) examined the groundwater quality of Nala Lai stream of Pakistan revealed that the pH of various sampling locations near the stream was being elevated to 8.9 due to excessive growth of microbial contamination which encourages the growth of algae, which increases the amount of carbon dioxide, consumed and elevates the pH levels. Humans also could increase the pH limits by the initiation and production of chemical fertilizers which added to water runoffs in higher concentrations (Ali et al., 2021).

Usually, the solutes cause alkalinity in the water and being responsible for the buffering action (Solanki et al., 2012) in Uttarpardesh, India . During summer, the pH is on the higher side, whereas it remains on lower side during winter season. Chemical buffering and discharge of bicarbonate and carbonate ions might be responsible for the alkaline state of pH (Solanki et al., 2012). High pH during summer season might be attributed to the high decomposition activities, whereas build up organic matters and decomposition of vegetation which produces CO_2 on biological oxidation might be responsible for the low value of pH in winter season. External factors such as respiration, photosynthesis, exposure to air, dumping of industrial waste etc. cause disturbance in pH (Solanki et al., 2012).

2.2.2 Turbidity

Muddy appearance exists in water because of existence of significant concentration of suspended particles ranges from 10nm to 0.01mm give rise to turbid water and if it is being supplied, that will rise the gastrointestinal diseases. Suspended particles such as clay, silt, sand, and other particulate materials in water are not only the main cause of turbidity but also play vital role in absorbing heat which increases temperature and reduces light for photosynthesis to take place (Review, 2020). Study conducted in different rural villages in southeastern Nigeria by (Tyopine et al., 2022) examined the drinking water samples revealed that high turbid water was found in various samples indicating its poor consumption. Values varied from 0.5 NTU to 68.2 NTU indicates higher distribution of metals in examined water which ultimately leads to hard water, scale buildup and metal corrosion. Various reasons include decay of plants and animal materials, erosion, runoff, and debris of waste material. Diarrhoea, abdominal pain, and hypertensive disorders were in majority of people who consumed that high turbid water in that examined region.

Turbidity can enhance the cost of water treatment to quite an extent depending on its usage (Yunus et al., 2020). Particles in suspension in water provides suitable conditions to interfere with the process of chlorine residual concentration. It can also affects the odor and taste of water and can become breeding ground for the growth of viruses and bacteria (Rashid et al., 2019). It states extent of cloudiness in water for supply and consumption. If turbidity exceeds 5 NTU then it becomes detectable to the naked eye. It messes with disinfection procedure and can be rectify by using a process called filtration which reduces turbidity to less than 1 NTU.

Microbes include viruses, bacteria and various pathogens attached to suspended particles entered in water systems and human health indices would deteriorate considering the poor water quality status.

During summer season in Ahmedabad lake India, turbidity is on the higher side whereas, in winter season it reduces to quite an extent (Solanki et al., 2012). The greater quantity of sewage water and contaminations from the surroundings might be responsible for the high turbidity during summer season. Aquatic vegetation might also be responsible for the increase in turbidity. Higher turbidity affects the process of photosynthesis, thereby, indirectly affecting the life of plants (Solanki et al., 2012).

2.2.3 Electrical Conductivity

It is one of the main contributing parameters of field survey monitoring of water samples. It depends upon ionic solution present in water sources. Conductivity meter used to measure EC of water and other specified solutions. It can be used to measure TDS indirectly by considering ionized chemicals and species in water. Dissolved inorganic substances is the major reason of high amount of EC. Corrosivity of water sample and its significant impact on solubility of compounds being the major contributing factors to study the rise of EC in water samples in Uttar Pradesh, India suggests the mixing of sewage of ground water as the examined sites were near dense urbanization (Kim et al., 2021). A sudden increase or decrease in water body could indicate pollution. An oil spill and addition of other organic compounds would decrease conductivity as these elements won't break down in ions.

(Kükrer & Mutlu, 2019) examined the ground water quality of Sinop provincial borders in Turkey and revealed that the range of EC varied across different months. High EC values were associated with household wastes, waste disposal, chemical influents from agricultural fields and stock farming activities. Increased values of EC were observed in summer times due to evaporation phenomenon which ultimately leads to higher salinity. EC values in drinking water varies from source to source in examined area which may be due to infiltration of sewerages near populated areas of Swat, Pakistan. Its range varied from 127-791 µS/cm (Khan et al., 2018).

Electrical conductivity is observed to be on the higher side during summer season in study area of Punjab, India whereas, it is reduced during monsoon season (Singh et al., 2022). Tropic levels of water body and the contamination condition can be reflected by the high value of conductivity. The seasonal variation in the conductivity is attributed to the changing concentration of salt as evaporation directly influences it. Dilution of water takes place during monsoon season which results in reducing the electrical conductivity as the addition of water occurs during monsoon (Atique et al., 2021).

2.2.4 Total Dissolved Solids

Total dissolved solids define as dissolution of total inorganic matter and salts in water sample. It includes inorganic constituents like sulphates, carbonates, chlorides, bromides, potassium, calcium and many more. TDS contributors involves both organic and inorganic matter, but the concentration of organics was very limited as in relation with inorganics. The TDS limit exceeds than permissible limits don't have adequate consequences on human health and hygiene (Khan et al., 2021). The amount of TDS recorded during summer season was greater as compared to amount recorded during monsoon season. The higher value of TDS might be attributed to polluted domestic wastewater, trash, fertilizer etc. Higher concentration of TDS helps in enriching the nutrient condition of water body which eventually caused eutrophication of aquatic habitat (Pourfaraj & Mokhtari, 2021).

High flow rates, urban runoffs, septic systems, rotting plants and soil erosion all are the major contributing factors in high TDS concentrations. A study conducted by (Chakraborty et al., 2019) in different areas of Bangladesh examined the water quality and its relevant health implications. This study concludes that people consuming water for drinking with high TDS values (1560-1734 mg/L) and high salinity were exposed to diarrheal and abdominal pain in different hospitals. Low-cost adaptation strategies for providing fresh and safe water like rainwater harvesters installations were recommended to safe more people from all viral diseases. Microbial infections were also found in most of the water samples.

2.2.5 Total Hardness

Water hardness is the prevalent parameter and one of the most influential factors in drinking water supplies. Generically, hardness exceeds more than 200mg/L can be found satisfactory but its sources initiate early to deteriorate water quality but values higher than 300mg/L cannot be taken lightly as it will starts causing turbidity in water supplies and become hosts for different types of pathogens, viruses and bacteria (Hailu et al., 2019). Hydrochemistry of water being influenced by calcium (Ca^{+2}) and magnesium (Mg^{+2}) ions in a specified region. Hardness is due to bivalent ions of calcium and magnesium present in water sample. The types depend upon degree of hardness being involve in ecological water cycle. Temporary and permanent hardness being in water resources can be rectify by boiling or usage of specified process to ensure water purity in the environment.

Research conducted by (Liyanage et al., 2022) for examining the water borne issues in various farming communities of Sri Lanka. Preference was given to this project for finding the possible linkage between water quality and diseases prevalence within examined area. For that, 60 ground water samples were analyzed for source detection. Results reveal that 87% of all water samples exceeded the permissible limits for hardness in drinking water. Due to excessive consumption of hard water ions by public could impact the kidneys. Prolonged drinking of fluoride and hard water increase the injury leading to end-stage kidney diseases. Reasons of presence of hard water in examined area may be the geological conditions and anthropogenic activities. Total hardness is directly proportional to the temperature as the study conducted by in the water of Chandola lake was very much evident of this (Vasistha & Ganguly, 2022). The greater hardness during summer may be attributed to the greater evaporation rate of water and inclusion of calcium and magnesium salts through plants and living organism. These observations were very well supported by the study conducted in J.N.U lake in Delhi and in several aquatic habitats of Tamil Nadu (lakshmi et al., 2018).

In Japan, tap water quality and its relation with pipe distribution networks was analyzed to monitor the scaling impacts on the surface of distribution pipes in different areas (Hori et al., 2021). Results showed that 55% of total water distribution networks were clogged with hard water. Scaling was the major issue across all networks. In addition, many of the water pipelines were out of the durable time and needed to be replaced. In many of the states, water purifiers and water softeners were used to tackle this issue. 82% of total pipelines were badly affected by scaling and hard water excessive supply. Hard water value ranges from 560-875 mg/L across all states showing the alarming situation for public.

2.2.6 Alkalinity

Carbonates (CO_3^{-2}), bicarbonates (HCO_3^-), and hydroxides (OH^-) are the major reasons to cause alkalinity in water resources. Carbon dioxide reacts with alkaline part of soil causing the bicarbonates to generate, being the primary constituent along with borates, phosphates. The most influential species for alkalinity are also hydroxides which can level up the alkaline dissolution in water (Zhang et al., 2021). The arid and semi-arid region mostly relied on groundwater to meet the domestic demands due to absence of alternative water resources and inconsistent rainfall. Groundwater was assessed for drinking and irrigation in various arid regions in Saudi Arabia. Random sampling of 62 water samples was conducted in the study area. Results showed that the alkalinity in all water samples were found to be exceeding permissible limits due to extreme arid climatic conditions and impact of sewage discharge eventually deteriorated the water quality status (Mallick et al., 2021). Elevated levels of alkalinity range may result in gastric cancer, hypertension and drop in blood pressure.

Most alkalinity represented as mg/L of $CaCO_3$ as most of the rocks and salts are because of weathering, provides carbonates and bicarbonates in water domain. Other processes to initiate alkalinity are through soil, ion exchange methods, evaporation and precipitation methods (Islam et al., 2020). Alkalinity during winter season is on the lower side whereas, during summer season, it enhances to the maximum possible level in rural state of Karnataka, India. This elevation of alkalinity during summer may be attributed to the decomposition of dead living organisms and release of CO_2 causing the inclusion of bicarbonate and carbonate. Identical results were observed in water bodies of Dharwad, Karnataka. Increase in alkalinity might be the result of constant degradation of plants and living organisms which impacts the ecosystem (Malik & Rathi, 2022).

2.2.7 Chlorides

The inorganic salts include various types of species and chlorides are one of them. Drinking water would not be the only major contributor of chlorides intake by humans rather home salt usage also shows its significance to human exposure by eating it. Normally, the groundwater shows high levels of concentration of chlorides rather than surface water supplies due to weathering phenomenon of salts and minerals during evaporation and precipitation. High chlorides concentration results in higher intrusion of metals due to corrosiveness in pipelines and water supply networks (Overbo et al., 2021). Corrosivity and chlorides concentration both have a positive correlation with each other. Pakistan Environmental Protection Agency (Pak-EPA) have set a limit of chlorides for not having more than 250mg/L. Although, it has not health-based impacts, but it can alter the taste of drinking water to be saltier, can damage boilers and can provide hindrance to growth of vegetation if used in agricultural sector for irrigation purposes. The concentration of chlorides in water bodies during summer is generally on the higher side as compared to that in winter. The high concentration of chlorides in water bodies might be the result of higher rate of evaporation which is observed during summer, or this might also be attributed to the organic waste in general across Karnataka India (Derrik et al., 2021).

GIS based water quality index study was established by (Banerjee et al., 2021) to examined the water samples in Buddh Nagar district of Noida U.P., India. Total of 51 water samples were collected and exposed to various physicochemical parameters to assess its consumption quality. Results indicated the presence of high chloride levels across all samples. This is due to oil well wastes and intrusion of wastewater from nearby industries and commercial sector due to which it gave salty taste to water and laxative effect to humans. Chlorides excessive presence could contaminate human's food chain and could impact on ecosystem's sustainability.

2.2.8 Dissolved Oxygen

It is the measure of health indicator showing how good or bad the water capability to support aquatic life. Dissolved oxygen should be present in water ranges from 6.5-8 mg/L would consider healthy water quality (Maiolo & Pantusa, 2021). Levels of oxygen can be incremented by absorption from the atmosphere, and it can be deteriorated in water bodies by disintegration of organic matter.

(Gawle et al., 2021) while his survey in Surat, India stated that the quantity of dissolved oxygen is on the higher side during winter whereas, during summer seasons, it reduces to the minimum level. Level of dissolved oxygen in water is directly affected by the process of active photosynthesis since it elevates the amount of dissolved oxygen. Temperature and microbial activity are directly proportional to the amount of dissolved oxygen in water.

2.3 Microbial Contamination

Gastroenteritis also known as Gastro or infectious diarrhea involves diseases concerns with stomach or small intestine. They always caused via oral route by drinking or eat something. Water borne diseases are the initiators to cause gastroenteritis diseases like diarrhea, vomiting, stomachache, nausea, and abdominal pain. Lack of body fluids make a patient weaker and thirstier. This "Stomach flu" ranks 5^{th} in Pakistan in which 73% of deaths were due to diarrheal symptoms and diseases (Mzi et al., 2021). It is the second most general cause of deaths among adults.

For microbes, the drinking water environment functions as an ecological niche (Wang et al., 2014). Biofilms in distribution pipelines were considered as harbors for potential pathogens, such as fecal indicator bacteria (Escherichia coli), opportunistic bacteria from environmental source (like Pseudomonas aeruginosa, Legionella spp. etc.), obligate bacterial pathogens having originated from a fecal source (like Campylobacter spp. etc.), protozoa (like Cryptosporidium parvum etc.) and enteric viruses (like rotaviruses, adenoviruses, noroviruses etc.). These pathogenic organisms adhere to already existing biofilms and live and grow there for days, weeks or even longer based on the environmental conditions and the biology and ecology of the pathogenic organism to deteriorate the water quality (Javed et al., 2021).

In 2019, four major hospitals of twin cities (Rawalpindi and Islamabad) reported that over 13000 patients had been affected by gastroenteritis diseases (Qasim et al., 2019). Poor infrastructure, old rusty water supply pipelines, leakages in different network designs and untreated wastewater discharges from industrial zones allow various unknown diseases to prosper in the vicinity of water supply for public. Stringent actions should be taken against the violators of our society which endangers our lives. There exists a very strong and significant relationship between water quality and hygienic risk factors. In the recent times, there’s exists talks of pathogenic contamination known as feacal contamination which exists or initiate by the excreta of humans or animals and destroys our ecosystem by slowly entering in water transmission routes. Their presence is an indication of sewage or animal waste contamination (Salam et al., 2021). Bacterial or microbial contamination hurdles or provides hindrances to safe and secure drinking water consumption. Different epidemic episodes could be potentially activated whenever microbes or pathogens entered in water supply chains and networks. So precautionary measures must be accounted for to avoid or rectify it on priority basis (Rashid et al., 2021)

Chapter # 03

METHODS AND MATERIALS

Methodology is the organized, academic evaluation of the procedures being implemented to the field of study. Water quality monitoring is one of the most challenging procedures to assess the quality and to figure out the sources of contamination by the field phenomenon of sampling in a specified defined region or study area. It involves preliminary planning, equipment, manpower, resources and most importantly the methodological flow chart of steps that we follow to ensure quality research work. To study the trend, specific significant pollutant flux, their harmful impacts on our lives, the precision and accuracy of existing equipment, designated time frames of trends, monitoring of all these factors can be done by authentic water quality studies, procedures, and evaluations

3.1 Study Design

In this study, the research work is divided into six major phases involving field work, laboratory work and software work to achieve our basic aims and objectives.

1. SURVEY OF STUDY AREA (RAWAL TOWN RAWALPINDI)
2. SAMPLING FROM FOUR ZONES OF WASA RAWALPINDI
3. ANALYSIS OF PHYSICOCHEMICAL PARAMETERS
4. ANALYSIS OF MICROBIAL PARAMETER BY MPN
5. STATISTICAL ANALYSIS BY PEARSON'S CORELATION MATRIX
6. ESTIMATING WQI BY WEIGHTED ARITHEMATIC INDEX METHOD

Figure 3.1: Research schematics study flow design

3.2 Description of Study Area

Rawalpindi district is also known as *"Pindi"* lies in the northern part of Punjab province and covers an area of 5286 km^2. It is one of the 36 districts of the province Punjab; it is 290 km northwest of the city Lahore (capital of Punjab) and 11 km southwest of the national capital Islamabad. It is situated at Long/Lat 73.05° E and 33.60° N. Rawalpindi is the 4th largest city of Pakistan. It is administratively divided into 8 Towns (Tehsils) namely Rawal Town, Potohar Town, Gujar Khan, Murree, Kallar-Syeda, Kahuta, Kotli-Satiyan, Taxila (Shabbir & Ahmad, 2015). Rawal Town consists of 46 union councils as devised by Tehsil Municipal Administration (TMA) as in Figure 3.2. The total population reported 1.4 million people in 2020 as surveyed by Albayrak solid waste management company in collaboration with semi government body "Rawalpindi waste management company (RWMC)". Table 3.1 showing major public service departments and their respective services to public. Union Council names of Rawal Town along with their respective numbers given in Table 3.2. Rawalpindi lies in semi- arid to sub-tropical region in terms of climate category. Temperature ranges from 12 degree to 48 degree centigrade & the average rainfall is about 1000 mm. The surface water is mainly recharged by Haro and Soan rivers which are under Rawal and Khanpur Dam.

Table 3.1: Names of major public service departments of Rawal town

MAJOR DEPARTMENTS / ORGANIZATIONS IN RAWAL TOWN RWP		
Name	**Abbreviation**	**Services/Fields**
TMA	Tehsil Municipal Administration	Zoning, master planning, land use control, urban infrastructure development
RDA	Rawalpindi Development Authority	Enable provision and improving metropolis-wide development works for commercial outlets in the city
PHA	Parks and Horticulture Authority	Creation and maintenance of parks, gardens and nurseries, plantation, and land scaping on available lands.
WASA	Water And Sanitation Agency	Planning, development and maintenance of water supply, sewerage, and drainage system.

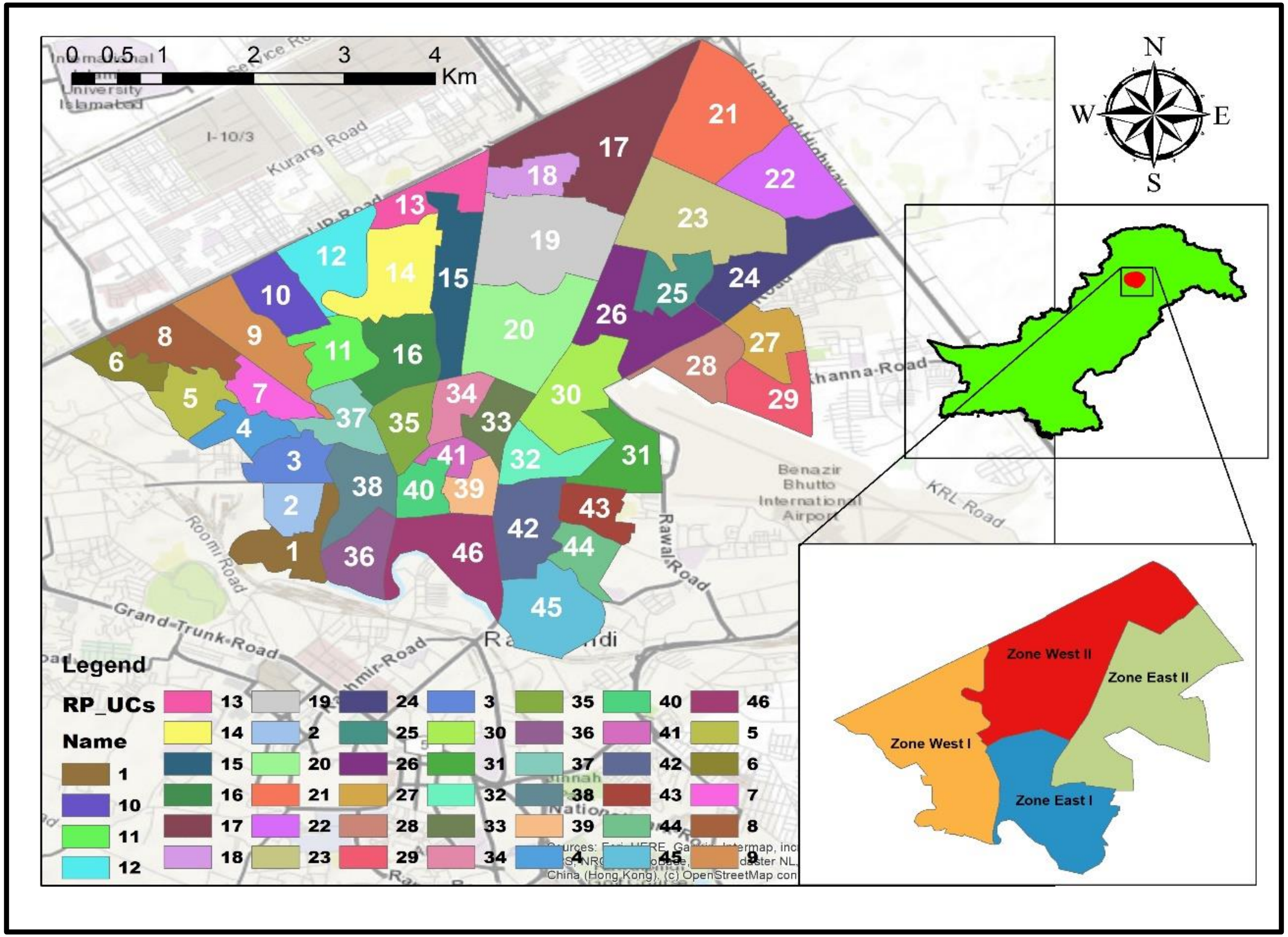

Figure 3.2: Study area based on Union council divisions of Rawal town Rawalpindi city. (Data-Shapefiles taken from Albayrak SWM)

Table 3.2: Names of 46 union councils of Rawal Town.

UC No.	UNION COUNCILS NAME	UC No.	UNION COUNCILS NAME
01	Ratta Amral	24	Dhoke Ali Akbar
02	Dhoke Ratta	25	Sadiqabad
03	Hazara Colony	26	Afandi Colony
04	Dhoke Mangtal	27	Muslim Town(East)
05	Dhoke Hassu (North)	28	Muslim Town(West)
06	Dhoke Hassu (South)	29	Khurram Colony
07	Pir Wadhahi	30	Chah Sultan
08	Fauji Colony	31	Dhoke Hukam Daad
09	Bangash Colony + GBS	32	Amarpura
10	Khayban-e-Sir Syed(North) (N)	33	Kartar Pura
11	Khayban-e-Sir Syed(South) (S)	34	Banni
12	Dhoke Najju	35	Mohallah Imam Bargah
13	New Katarian	36	Mohan Pura
14	F-Block Satellite Town	37	Dhoke Dalal
15	Saidpur Scheme	38	Ganj Mandi
16	Mohallah Eidgah	39	Waris Khan
17	Dhoke Babu Irfan	40	Purana Qila
18	Pindora	41	Shah Chan Chiragh
19	Satellite Town	42	Millat Colony
20	Asghar Mall Scheme	43	Dhoke Khabba
21	Dhoke Kala Khan	44	Dhoke Farman Ali
22	Qayyum Abad	45	Chamanzar Colony
23	Dhoke Kashmirian	46	City (Urban)

3.3 Survey of Study Area

3.3.1 GPS coordinates of tube wells

To plot the coordinates of 375 tube wells of Rawal Town across 46 union councils, a GPS field survey was conducted during the time span of October 2020 to December 2020 using GNSS Version 3.2.1 (Global Navigation Satellite system) mobile application as in Figure 3.3. The coordinates of groundwater sources used to generate a geodatabase feature classes for ArcGIS. The accuracy was excellent in narrow streets and dark alleys.

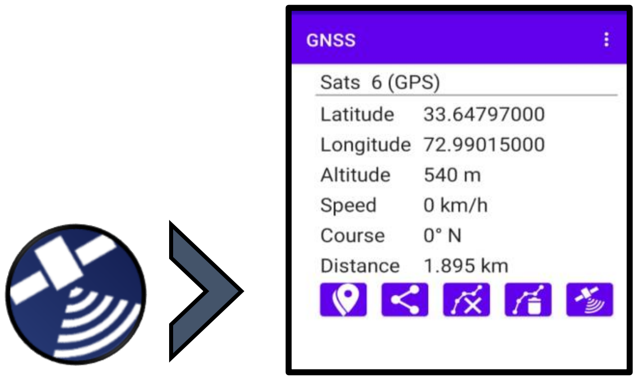

Figure 3.3: GNSS Application icon and user interface display

Data obtained from WASA Rawalpindi was being verified by the field survey across overall study area. In addition to tube wells, filtration plants also being installed over the period to ensure safe and secure water consumption available to the residents of Rawal town Rawalpindi. Almost 125 plants ensuring the drinking water needs of people across all four zones. Different locations of tube well positions in Rawal Town can be seen in Figures 3.4 & 3.5. Table 3.3 showing data sources and their respective descriptions.

Table 3.3: Data sources and its specifications for Rawal Town study area.

DATA TYPE	DESCRIPTION	DATA SOURCE
Field Data	Coordinate points of Tube wells	Survey by GNSS Mobile App
Population Data	UC Population of 2020	Albayrak- SWMC
Water Parameter Data	pH, Turbidity, EC, TDS, Hardness, Chlorides, Alkalinity, MPN, DO	IESE- Laboratory Analysis
UC Boundary	Shapefiles on ArcGIS	Albayrak- SWMC/ WASA

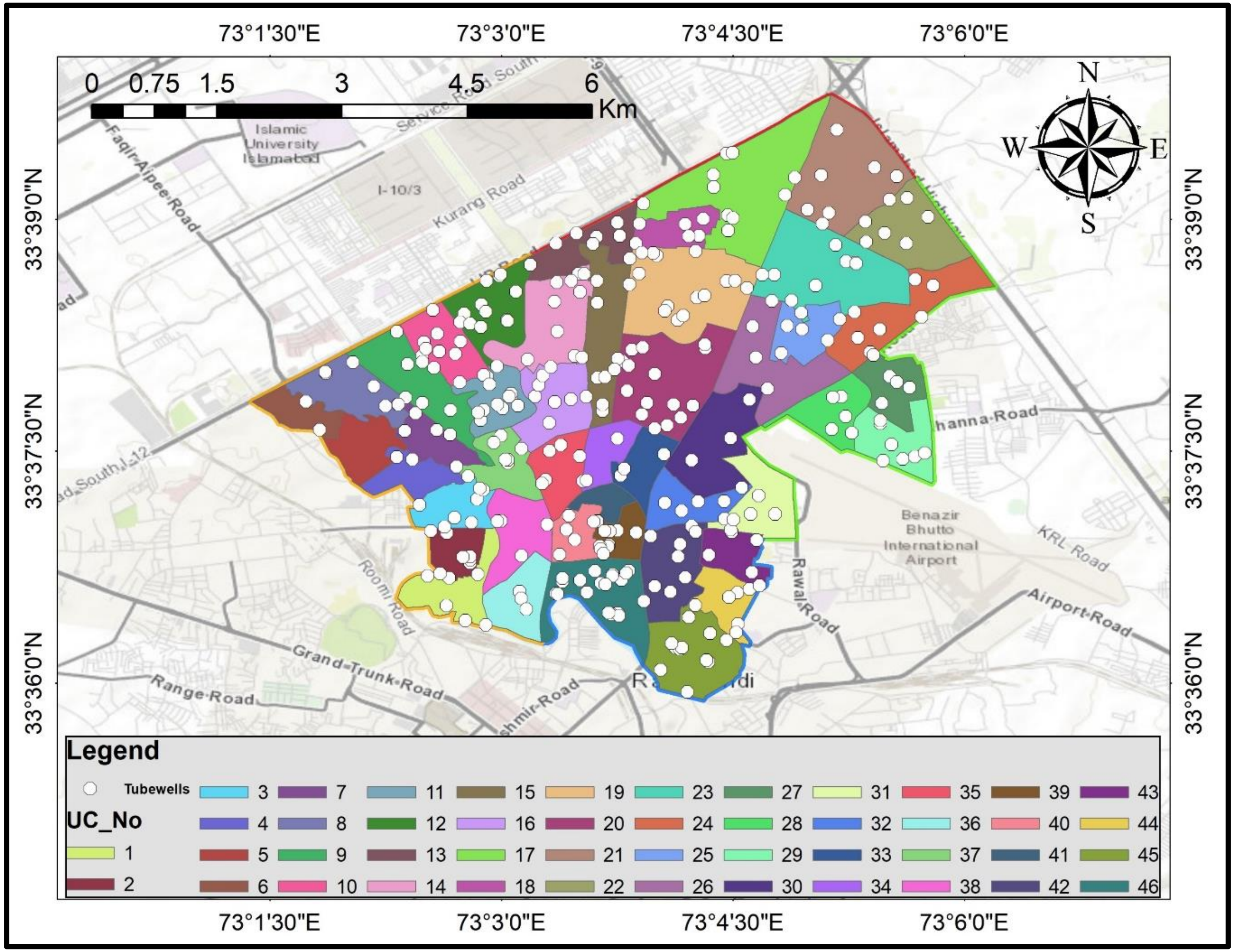

Figure 3.4: Geodatabase displayed of tube wells in Rawal town using ArcGIS software

Figure 3.5: Different locations of tube wells in different Union Councils of Rawal town Rwp.

3.3.2 Water Regulating Body (WASA)

Water regulating authority (WASA) is being established by the local government to launch national and international recognized standards of water supply qualifications and to commit consistence compliance with them by providing excellent services relevant to water supply, drainage systems etc.

WASA focuses on two main aims; to meet community needs to support sustainable development through development and maintenance of effective services in field of water supply & to supply good quality water to the residents of community complying with national (PSDWQ) and international (WHO) drinking water quality standards (WASA, 2018).

WASA divides study area of Rawal town in four different zones namely, Zone West I, Zone West II, Zone East I and Zone East II as shown in Table 3.4 & illustrated in Figure 3.6. Figure 3.7 represents zonal divisions in Rawal town.

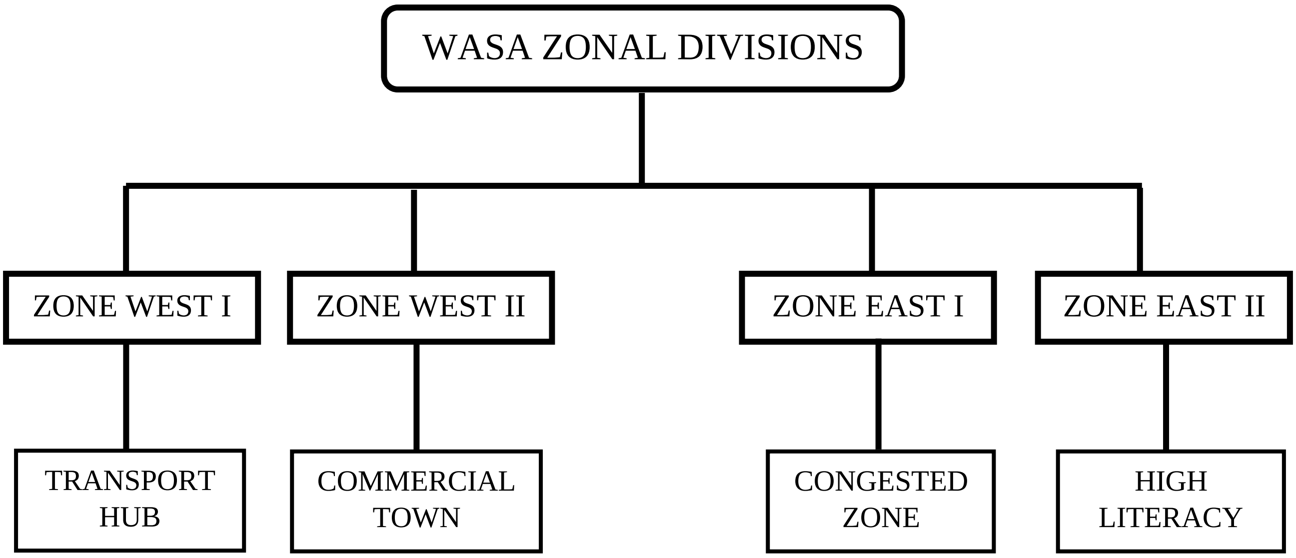

Figure 3.6: Flowchart of WASA Zonal divisions and their respective characteristics.

Table 3.4 WASA zonal divisions by union council wise classification

WASA ZONAL DIVISIONS IN TERMS OF UNION COUNCILS	
Names	Union Councils
ZONE WEST I	1,2,3,4,5,6,7,8,9,10,11,12,36,37,38
ZONE WEST II	13,14,15,16,17,18,19,20,21
ZONE EAST I	33,34,35,39,40,41,42,43,44,45,46
ZONE EAST II	22,23,24,25,26,27,28,29,30,31,32

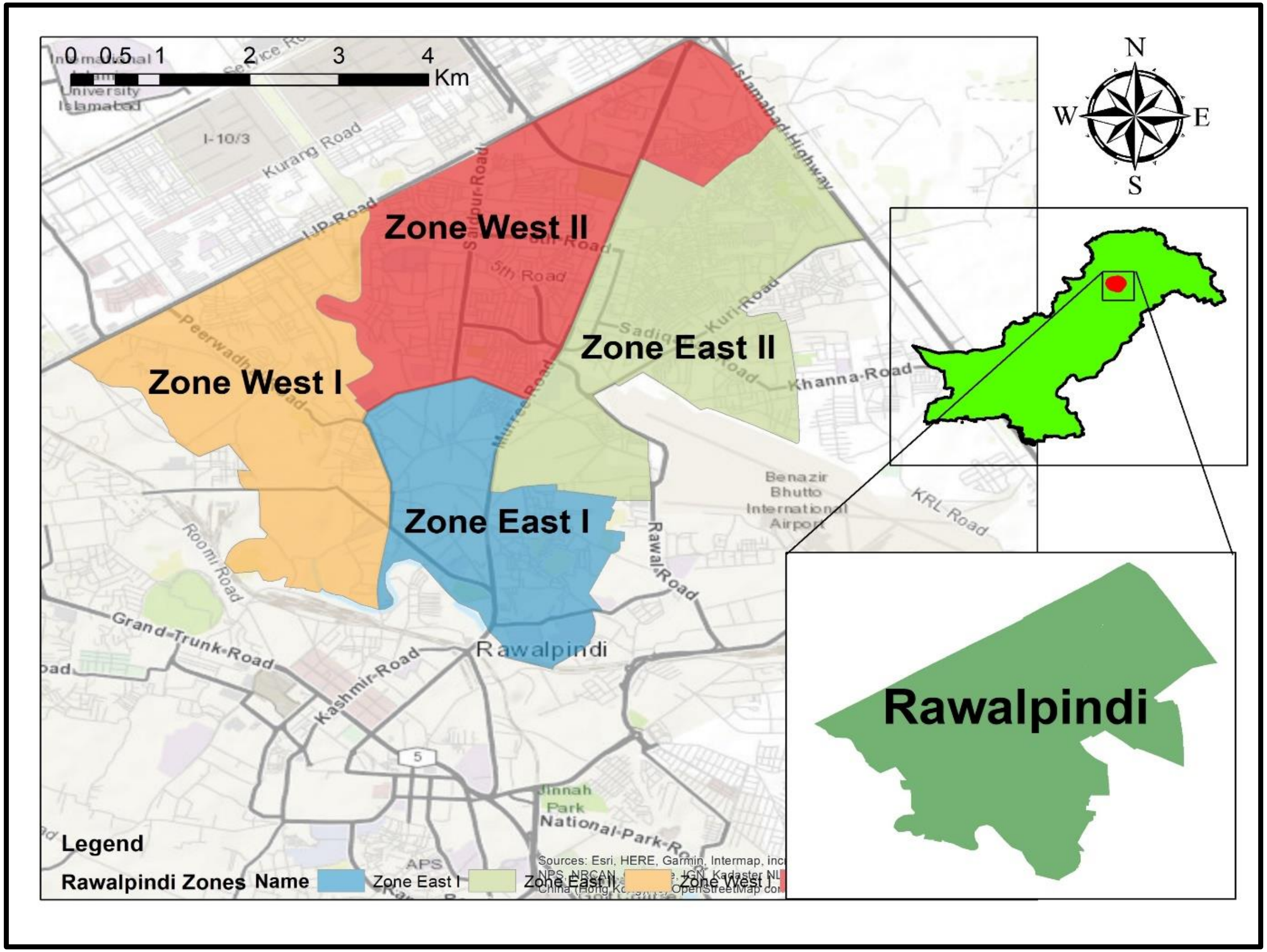

Figure 3.7: Geodatabase depiction of WASA zonal divisions in Rawal Town RWP

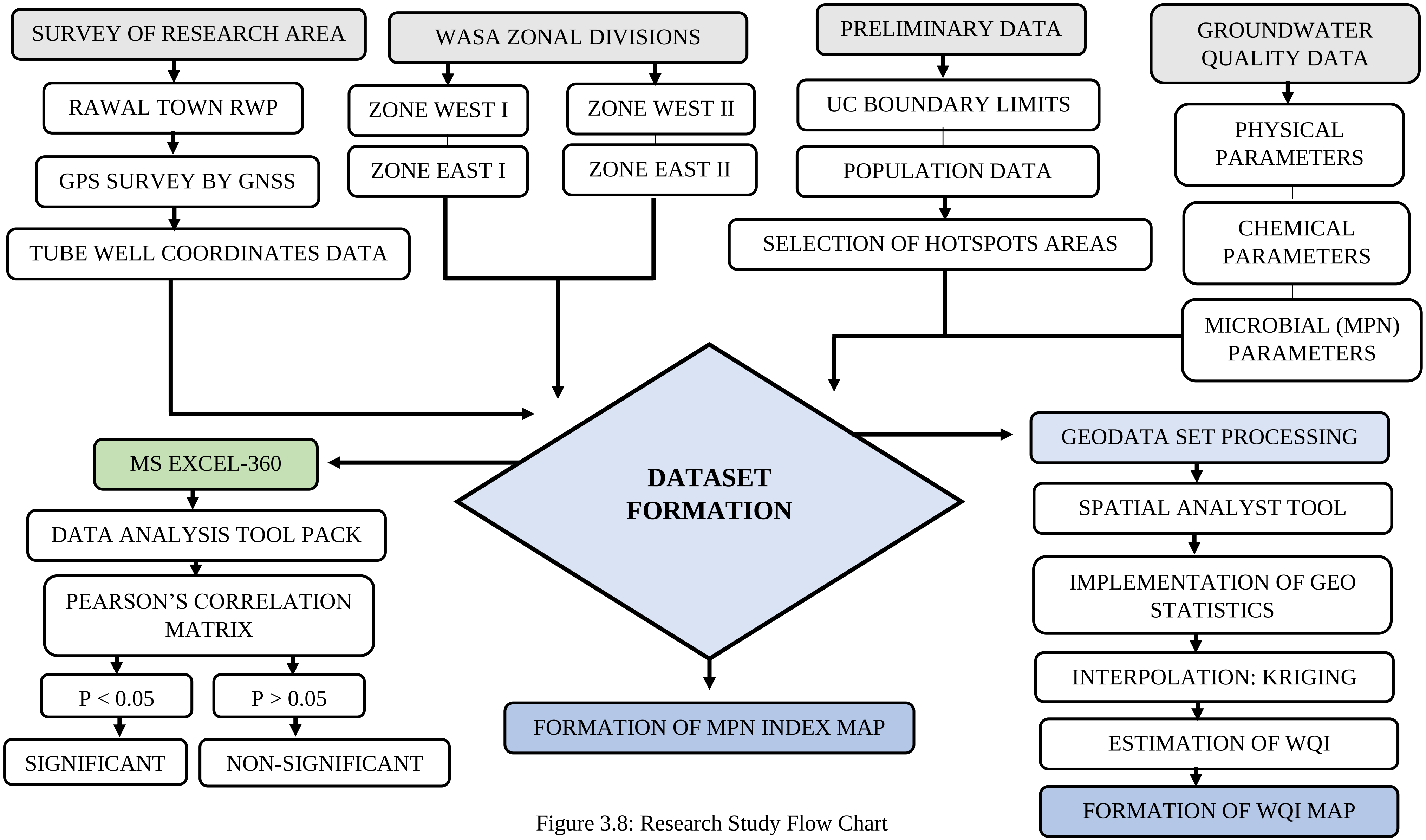

Figure 3.8: Research Study Flow Chart

3.4 Selection of hotspot areas & tube wells

To filter out hotspot areas from Rawal town, populated areas whose population is greater than 30,000 persons were selected as data by Albayrak 2020. The major research methodology flowchart can be seen in Figure 3.8. Tube well selection from each hotspot area is based on the basic factors includes major water supply in that area., serving maximum number of homes, have greater pumping hours and have overhead tank for water supply.

As WASA zones divided into four divisions. So, by considering the data of population from Albayrak-SWM company of year 2020. We selected five hotspot areas from four zonal divisions on basis of population. Following tables represents my hotspot areas in bold letters across all four zones in Rawal town Rawalpindi. UC Populations with Zonal divisions reported in Tables 3.5, 3.6, 3.7 & 3.8.

Table 3.5: Union Council names and population in Zone West I

ZONE WEST I		
UC NO	**UC'S NAMES**	**POPULATION (2020)**
01	Ratta Amral	29,551
02	**Dhoke Ratta**	**34,236**
03	Hazara Colony	26,110
04	Dhoke Mangtal	29,579
05	Dhoke Hassu (North)	24,351
06	**Dhoke Hassu (South)**	**30,682**
07	Pir Wadhai	28,395
08	Fauji Colony	29,008
09	**Bangash Colony**	**35,216**
10	Khayban-e-Sir Syed (N)	27,079
11	Khayban-e-Sir Syed (S)	28,900
12	**Dhoke Najju**	**33,369**
36	Mohan Mura	28,929
37	**Dhoke Dalal**	**30,816**
38	GanjMandi	29,194

Table 3.6: Union Council names and population in Zone West II

ZONE WEST II		
UC NO	UC'S NAMES	POPULATION (2020)
13	**New Katarain**	**31,712**
14	**F block**	**30,366**
15	**Saidpur Scheme**	**31,161**
16	Eidgah Muhalla	27,268
17	**Dhoke Babu Irfan**	**36,080**
18	Pindora	29,621
19	**Satellite Town**	**34,170**
20	Asghar Mall Scheme	29,866
21	Dhoke Kala Khan	28,964

Table 3.7: Union Council names and population in Zone East I

ZONE EAST I		
UC NO	UC'S NAMES	POPULATION (2020)
33	**KartarPura**	**30,898**
34	**Banni**	**30,255**
35	**Mohalla Imam Bargah**	**31,822**
39	Waris Khan	26,569
40	Purana Qila	27,049
41	Shah Chan Chiragh	25,916
42	**Millat Colony**	**32,662**
43	Dhoke Khabba	29,562
44	Dhoke Farman Ali	29,030
45	Chamanzar Colony	29,593
46	**City (Urban)**	**33,063**

Table 3.8: Union Council names and population in Zone East II

ZONE EAST II		
UC NO	**UC'S NAMES**	**POPULATION (2020)**
22	Qayyumabad	29,567
23	Dhoke Kashmirian	28,206
24	Dhoke Ali Akbar	28,717
25	Sadiqabad	29,716
26	**Afandi Colony**	**32,031**
27	Muslim Town (East)	27,342
28	**Muslim Town (West)**	**33,705**
29	**Khurram Colony**	**32,190**
30	**Chah Sultan**	**36,190**
31	**Dhoke Hukam Dad**	**35,742**
32	Amarpura	29,251

3.5 Sampling from Zones

The time span for sampling in this research is from August 2021 to November 2021 across all four zones of Rawal town starting from Zone West I till Zone East II. To consider the complete representative of the sample, five water samples were taken from each UC designated as shown in Table 3.9. One from tube well & four from residential taps. Total no of samples from each hotspot area/UC are 05. Total no of samples from each zone are 25. Total no of samples across my research study are 100.

Grab sampling method was selected as it is simpler and permits measurement of unpredictable constraints such as pH, DO and temperature. This method is suitable for small operating facilities for designated areas for continuous sample monitoring of groundwater. Five samples were taken from selected tube wells and residential taps to achieve an overall water quality profile across selective hotspot areas. WASA tube well operators have a significant role in my field survey of sampling. Designated timings for water supply to public were generally in two shifts. Morning shift timing was from 8am to 10am. Evening shift timing was from 4pm to 6pm. Sampling was done in the morning due to availability and convenience of laboratories to conduct valuable research.

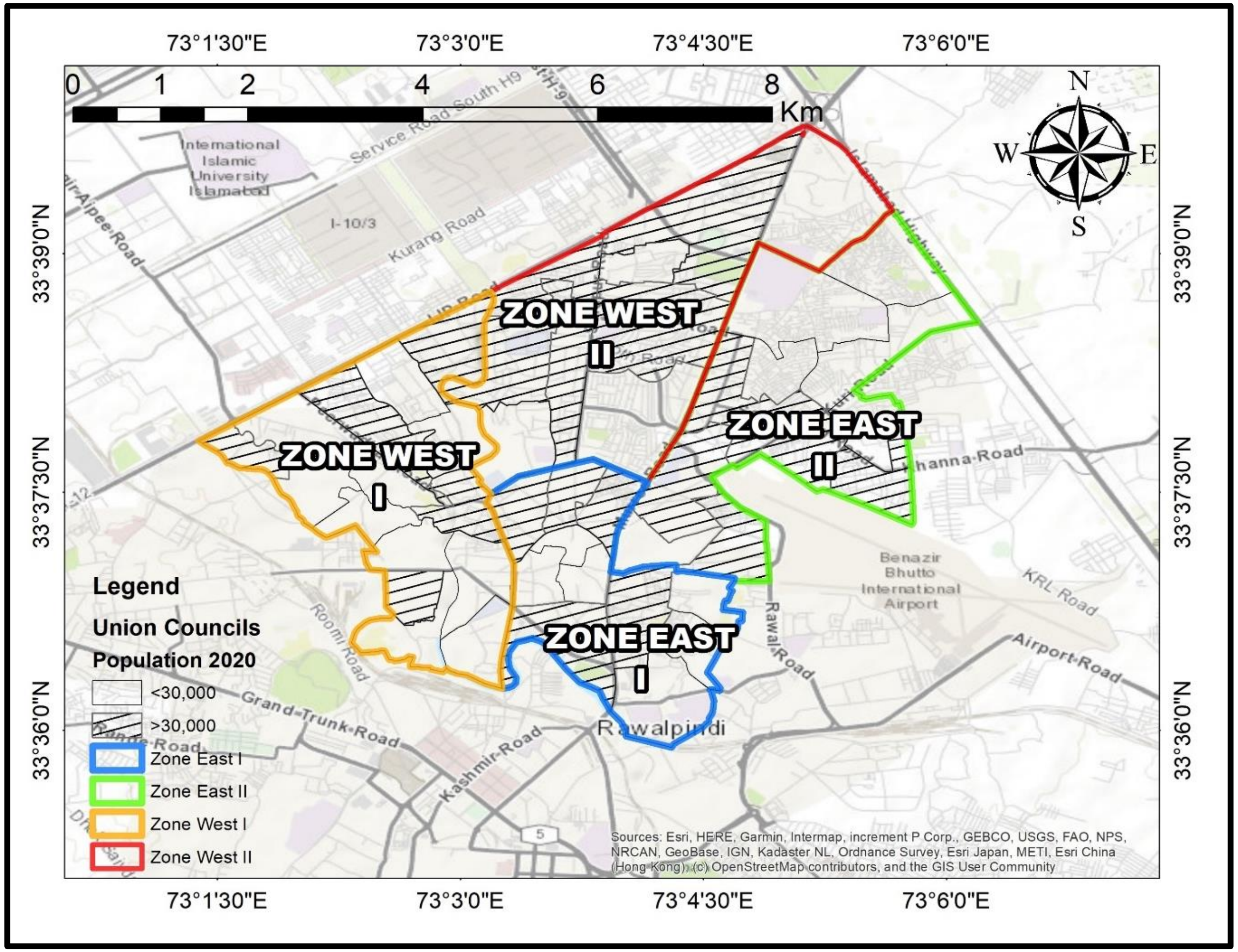

Figure 3.9: Selection of hotspot areas in WASA divisional zones Rawal town RWP

Table 3.9: Different tube well & residential tap locations in hotspot areas

UC NO.	UC NAME	No. of Samples	Tube well Coordinates		TW Number by WASA
			Latitude X	Longitude Y	
02	Dhoke Ratta	05	33.6156700	73.0458900	79-D
06	Dhoke Hassu	05	33.63022167	73.02863667	87-A
09	Bangash Colony	05	33.63248667	73.04145667	95-C
12	Dhoke Najju	05	33.63900167	73.04886333	101-A
37	Dhoke Dalal	05	33.62472333	73.05163833	146-B
13	Katarian	05	33.647199	73.057171	03-A
14	F block	05	33.63930167	73.0551850	108-A
15	Saidpur Scheme	05	33.63491333	73.058555	110-C
17	Dhoke Babu Irfan	05	33.65029000	73.07468000	08-B
19	Satellite Town	05	33.64044167	73.06527167	116
33	Kartar Pura	05	33.62324000	73.06505000	131-A
34	Banni	05	33.62417167	73.05899667	155-A
35	Imam Bargah M	05	33.62273333	73.05399833	154-C
42	Millat Colony	05	33.611107	73.068843	50-A
46	City (Urban)	05	33.612059	73.063536	69
26	Afandi Colony	05	33.630553	73.079205	35-A
28	Muslim Town (W)	05	33.62775	73.084708	31-C
29	Khurram Colony	05	33.624808	73.090678	33-B
30	Chah Sultan	05	33.623952	73.071154	38-A
31	Dhoke Hukam Dad	05	33.6198645	73.0775709	45-A

Residential water samples were taken in nearby vicinity of tube wells, so their locations are the same as tube well respective locations. Sampling locations (Clustering) of respective tube wells shown in Figure 3.10.

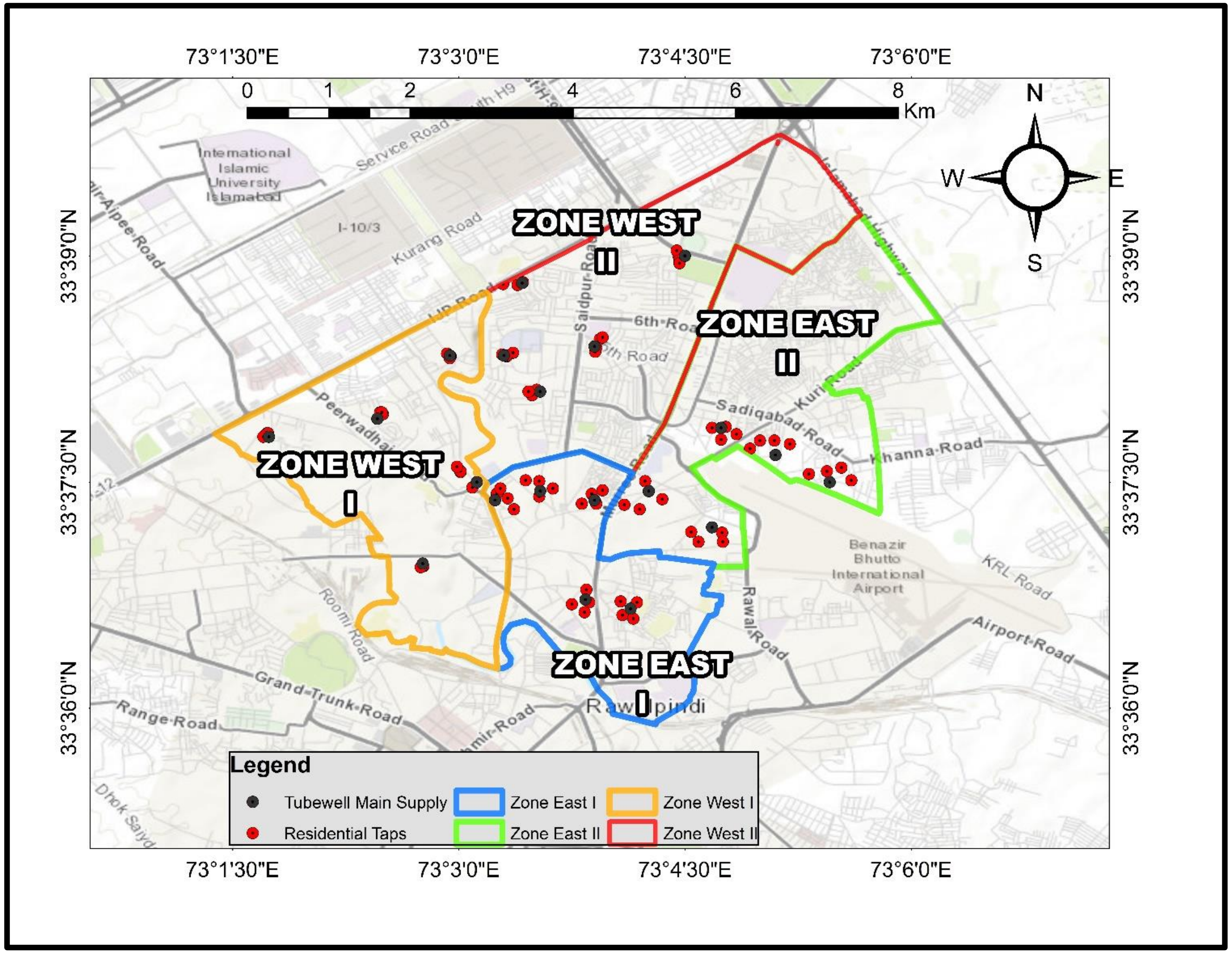

Figure 3.10: Sampling locations (Clustering) of respective tube wells and residential taps across hotspot areas of Rawal town.

3.6 Sampling

3.6.1 Preparation of glassware

500ml Schott bottles were provided for sampling. All the sampling bottles were rinsed with detergent and then with distilled water and autoclaved at 121ºC, 15 psi for 15 minutes time. Then the autoclaved bottles were oven dried for two hours at 105ºC. After this the bottles were tightly capped and wrapped.

3.6.2 Sample Collection, Transportation and Storage

Samples were collected carefully to avoid any sort of contamination. Tap water (samples) and tube well samples were collected in autoclaved bottles. After all the bottles were marked, water samples were transported to the laboratory in an ice box. After collection, they were examined directly or within 1 hour of their collection. All the procedures were conducted out as recommended in the Standard Methods for the Examination of Water and Wastewater (APHA 2017).

3.7 Physicochemical Analysis

A lot of research has been made on effects of ground water quality on human health and its approval threshold for physical attributes. Based on these studies, the World Health Organization (WHO) has established regulations to assist nations to establish quality guidelines with which local water supplies should comply. The water samples from hotspot areas were analyzed for physical parameters including pH, temperature, electrical conductivity etc.

3.7.1 pH

pH meter was used by company OAKTON® pH/DO meter, model: WD-35632-02 and it was regulated with standard pH buffers of pH 4,7 and 10 before use (APHA, 2012).

3.7.2 Turbidity

Turbidity was determined by HACH turbidity meter 2100P and its efficiency was examined by analyzing the turbidity of secondary standards i.e., gel solutions having known turbidity (APHA, 2012) as shown in Figure 3.11.

Figure 3.11: Turbidity meter used in Environmental Chemistry laboratory

3.7.3 EC & TDS

Both parameters were determined using HACH Sens Ion 5 TDS meter. It was standardized using a solution of sodium thiosulfate having known conductivity and TDS. The measuring probe was stabilized prior to taking the reading of each parameter.

3.7.4 Total Hardness

Total hardness was measured by titration. An ammonia buffer and EDTA color indicator are added to a volume of sample water. An acid is then added to water, and it reacts with Ca^{+2} and Mg^{+2} in the water. The volume of acid required to change the color of the sample reflects the Ca^{+2} and Mg^{+2} concentration of sample. More the acid needed, more will be the Ca^{+2} and Mg^{+2} in the sample. Hardness is generally described as an equivalent quantity of $CaCO_3$ and is generally expressed in (mg/L) or (ppm) of $CaCO_3$. In the EDTA titration method, a 25 ml sample of water was taken in 250 Erlenmeyer flask. 1-2 ml of buffer was added to adjust the pH of sample. Two drops of EBT indicator were added in the sample water that changed the color to purple. EDTA acid was dispensed in the burette and sample was titrated till end point was attained where sample color changed from purple to blue (APHA, 2012).

$$\text{Total hardness (EDTA) as mg/L of } CaCO_3 = \frac{A \times B \times 1000}{25}$$

Where;

A = ml of EDTA used for sample – ml of EDTA used for blank.

B = mg/L as $CaCO_3$ equivalent to 1.00 ml EDTA titrant.

3.7.5 Total Alkalinity

Titration is used to measure the total alkalinity in water samples. An acid of known strength (titrant) is added to a volume of sample water. The volume of acid required to bring the sample to a specific pH level reflects alkalinity of a sample. The pH end point is indicated by a colour change. Alkalinity is expressed in units of milligrams per liter (mg/L) of $CaCO_3$. In this study, titration method was used by taking 0.02N H_2SO_4 (sulfuric acid) in the burette and 50 ml water sample in the flask. Two drops of methyl orange added in the flask which change the colour of water sample to orange for finding the endpoint. On titrating with H_2SO_4, colour changes from orange to pink indicating end point (APHA, 2012). Alkalinity is determined using the following formula:

$$\text{Alkalinity (mg/L)} = \frac{\text{Volume of Acid} \times \text{Normality of Acid} \times 5000}{\text{Volume of water sample}}$$

3.7.6 Dissolved oxygen

Dissolved oxygen can be examined by using an electrode meter. It does not measure oxygen levels directly. It makes use of electrode to measure partial pressure of oxygen in water, which can be converted into oxygen mass weight concentration. The amount of oxygen dissolved in water can be expressed as the concentration in milligrams per liter (mg/L) of water sample.

3.7.7 Microbial Analysis by Most Probable Number

The method used for microbial contaminants examination for all water samples is Most Probable Technique (MPN). It is Multiple Tube Fermentation Technique. This technique has been done in Environmental Microbiology Laboratory at IESE, NUST. To ensure whether water is safe for pathogenic bacteria’s present in it or not, it can be used as a fecal coliform indicator for detection. Fewer organisms exist in water indicates no diseases causing species and it is safe for consumption. It's a three-day test with one day of preparation of media.

MPN procedure uses three types of media broths for the detection of microbial contamination,

- Lauryl Tryptose Broth (LTB)
- Brilliant Green Bile Lactose Broth (BGLB)
- EC Broth (selective for fecal coliforms)

It involves beakers, flasks, test tubes, durham tubes and sampling bottles. All glassware should be autoclaved and sterilize before initiating this method. Autoclaved for temperature of 121^{o} C at a pressure of 15psi for approximately 15 mins and then, oven dried for two hours will destroy any harmful microbes attached on the glassware surfaces.

For a single water sample, 10 tubes of LTB broth (Lauryl Tryptose Broth), BGLB (Brilliant Green Bile Lactose Broth) & EC broth (Escherichia coli) each were formed in microbiology laboratory for water testing for coliforms detection. 36.7g of LTB media, 40g of BGLB media and 37g of EC media each were diluted in 1L of distilled water after gone through the process of 10 mints on hotplate for attaining homogenous mixture. 10ml mixture of each of the media broths were transfer to 10 tubes for each broth glassware respectively containing inverted durham tubes up to one half or two third limit. Capping all the test tubes containing media and autoclave them for 121^{o} C for two hours. After that, place them in incubator for 24 hours to check sterility across all test tubes (APHA, 2012). It involves three basic phases.

3.7.7.1 Presumptive Test for Coliforms

Phase by phase procedure of MPN detects total coliform and E. coli. It involves first phase as presumptive test in which 10 fermentation test tubes containing 10ml of LTB broth and inverted durham tubes were utilized. After shaking gently, 10 ml drinking water sample was added to each test tube containing media. After that, all 10 test tubes were put in incubator at 37^{o}C for 24 hours. Production of bubble in durham tube and cloudiness in media showed positive test reaction and indication of presence of total coliforms.

3.7.7.2 Confirmatory Test for Coliforms

The next phase in continuation with previous one is confirmatory test in which positive LTB tubes were shaken lightly and a small inoculum of hot wire loop was shifted to BLGB broth containing tubes. After that, all tubes were put in incubator at 37^{o}C for 24 hours. Production of bubble in durham tube and cloudiness in media revealed positive test reaction and confirmation of presence of total coliforms.

3.7.7.3 Complete Test for Coliforms

The last phase is known as completed test for coliform detection in which positive BGLB tubes were shaken lightly, and a small inoculum of hot wire loop was shifted to EC broth containing tubes. After that, all tubes were put in incubator at 37ºC for 24 hours. Production of bubble in durham tube and cloudiness in media revealed positive test reaction and confirmation of presence of fecal coliforms (E coli) (APHA, 2012) as shown in Figure 3.12.

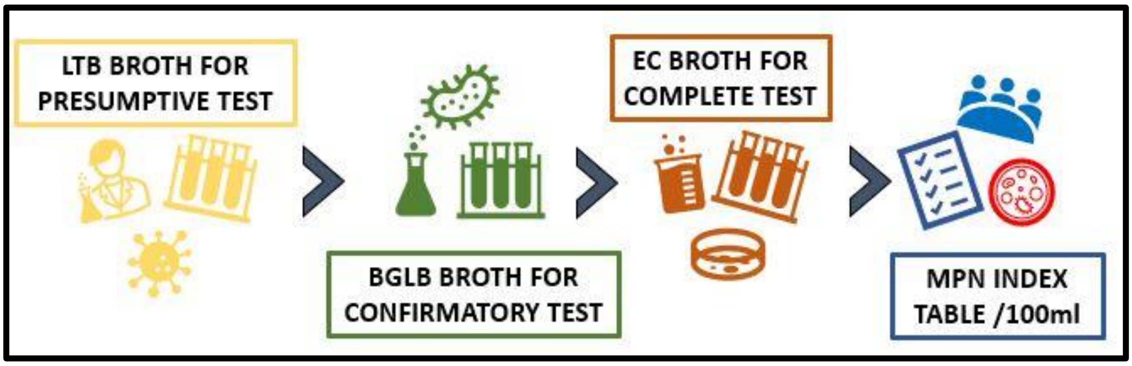

Figure 3.12: MPN method process diagram

3.8 Statistical Analysis

For better understanding of patterns and trends, statistical tools were used by Microsoft Excel 360. This analysis was very important for samples size of 100 (n = 100). These analyses were of very significance as we can find relations between different physicochemical and microbial parameters. Different descriptive statistics includes mean, maximum, minimum values, range, standard deviation, and p-values among different parameters were calculated.

3.8.1 Pearson Correlation Matrix

Pearson correlation shows the prediction among two variables using average values. Data analysis tool pack was utilized to depict the relation and coherence between parameters selected for highlighting their importance in water supply networks with significance level of 0.05.

3.9 Formation of Water Quality Index

For the formation of WQI rating, Weighted Arithmetic Index method was used to identify and predict the water quality of Rawal Town Rawalpindi. It was developed by Brown et al. 1972. WQI summarizes large amount of water quality data into simple terms. Water quality index described below used to investigate the existing groundwater fitness in terms of its consumption and drinking purposes, by using twenty selective hotspot area's tube wells and their respective residential taps of Rawal town.

It involves six major steps includes selection of water quality parameters, followed by calculation of Unit Weight Factors (W_n), calculation of Sub-index rating value and its respective aggregation to get final value result. Calculation of WQI values at all sampling sites would be done to map or overlay the results of overall Water Quality Index by Arc-GIS.

$$\mathbf{WQI} = \frac{\Sigma\,(\mathrm{Wn} \times \mathrm{Qn})}{\Sigma\,\mathrm{Wn}}$$

Where:

Weightage factor (W_n) is designed as an equation:

$$\mathbf{Wn} = \frac{\mathrm{K}}{\mathrm{Sn}}$$

Unit weight (W_n) of different available water quality parameters were inversely proportional to recommended standards of water quality for respective parameters (Brown et al., 1972)

And K is proportionality constant derived from,

$$\mathbf{K} = \frac{1}{\Sigma\,(\frac{1}{Sn})}$$

Where, Sn are the standard values of selected parameters given by national and international standards (WHO & PSDWQ). Sub index rating values gives the basic formula to provide answers for different parameter ranges and their respective rating.

Quality Rating is given by formula,

$$\mathbf{Qn} = \frac{(\mathrm{Vn} - \mathrm{Vo})}{(\mathrm{Sn} - \mathrm{Vo})} \times 100$$

Where:

Q_n = Quality rating for all water quality parameters

V_n = Value of water quality parameter obtained from laboratory analysis

V_o = Ideal value of parameter in pure water

S_n = Standard values

Vo for pH is 7 while all other parameters, it is equal to zero

The groundwater was then announced as excellent, good, poor, very poor and unfit for consumption by public based on WQI rating values from 0-25, 26-50, 51-75, 76-100 and value above 100 respectively (Brown et al., 1972). To generate WQI map in GIS, “Spatial Analyst Tools” were used. The “point to Raster tool” to” conversion tool” was used to generate rasters of all physicochemical and microbial parameters of all 100 samples collected from hotspot areas of Rawal town. Ideal best value for pH in drinking water is 7, so the “Minus Tool” being applied to reduce 7 from all the values in pH raster domain. After this, use “Divide Tool” to divide each raster parameter with its recommended standard values data. Every raster was multiplied by 100 to find values of Q_n for each parameter to evaluate and calculate. After that, WQI formula was applied by using “Math Tool” to calculate overall values in each cell (Ram et al., 2021).

Chapter # 04

RESULTS AND DISCUSSIONS

This chapter simplifies and objectively reports how the water quality in Rawal town have been found by our designed research schematics and by applying analysis on different physical, chemical, and microbial parameters. All samples collected from distribution network of hotspot areas of Rawalpindi city compared with authentic standards of World Health Organization (WHO) and Pakistan Standards of Drinking Water Quality (PSDWQ).

Table 4.1: Water quality standards for WHO and PSDWQ

PARAMETERS	UNIT	WHO	PSDWQ
pH	----	6.5-8.5	6.5-8.5
Turbidity	NTU	<5	<5
Dissolved Oxygen	mg/L	6-8	6-10
EC	µS/cm	750	1000
TDS	mg/L	500	1000
Alkalinity	mg/L of $CaCO_3$	500	500
Hardness	mg/L of $CaCO_3$	500	500
Chlorides	mg/L	200	200
Coliform	0/100ml	0	0
Source: (EPA, 2008)			

Overall, 100 samples analyzed in laboratory to give an overview of the area. Zone wise sampling was done to compare the quality rating of drinking water across Rawal town Rawalpindi. Observe their values with national and international standards to check the permissible limits as given in Table 4.1. This study may be very useful any water regulating authority.

4.1 Box Plots Profiling

A box plot is a graphical data analysis showcasing overall trend in a data series. It is used as a substitute to ANOVA. Following is the detailed analysis of physicochemical parameters using box plots.

4.1.1 pH

The pH represents the instantaneous hydrogen ion activity in water sample. It gives an idea about the acidic and alkaline conditions of water bodies in specified area (Bhardwaj & Giri, 2019). When pH of drinking water escalates towards basicity, taste of water may become bitter. With pH range greater than 8.5, it may cause skin to become dry, itchy, and irritated and could be a reason of calcium and magnesium carbonates buildup in your distribution networks (Gawle et al., 2021). Human body is made up of 70% of water so it helps stabilizing our natural pH. Too much acidic or alkaline water can disrupt the body's balance that leads to development of bacteria , fungi and parasite (Tariq et al., 2021).

The values of tube well and respective tap water samples after examining the pH were found in variance with different zones of study area. pH of all water at all sampling stations was within the WHO acceptable limit. pH of all collected samples were above 7 (neutral) which can be found by the cause of mixing of carbonates and bicarbonates of alkaline metals in supplied water. All samples were found within allowable limits set by World Health Organization (WHO) and Pakistan Standards for Drinking Water Quality (PSDWQ) which are in range of 6.5-8.5 as illustrated in Figure 4.1.

In Zone West I and II of western side, all the examined samples were in range of 7.05-8.3 showing slight alkaline water in results of UC 37 "Dhoke Dalal" due to elevated levels of alkalinity in that hotspot area. In Eastern Zones I and II, the range of assessed water samples were found in between 7.1-7.8 indicating neutral zone in pH terms.

According to similar research conducted by (S. Khan et al., 2017), physicochemical parameters were examined by collecting 22 water samples from different sites in Peshawar. pH was found to be in range of 6.6-7.6 indicating all samples from wells and springs were within range set by WHO and PSDWQ. Similar study conducted by (Akhtar et al., 2019) examined the water quality of residential taps in Mianwali, Punjab, Pakistan. pH range was found to be in accessible limits provided with sample size of 235 and mean value of 7.6.

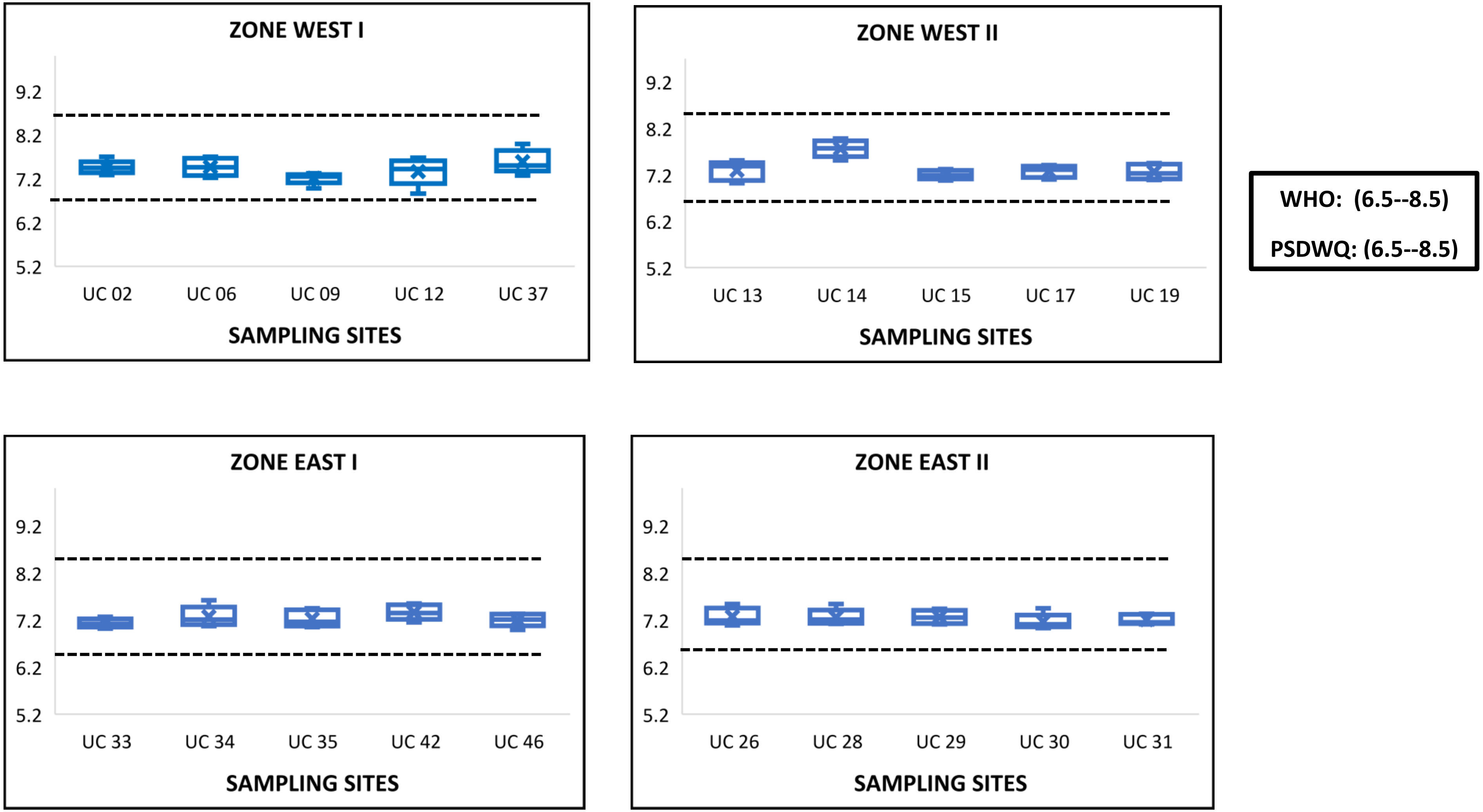

Figure 4.1: pH profile variation of all four zones of Rawal town Rawalpindi.

4.1.2 Turbidity

Physical parameter which is a measure of relative clarity in water bodies is known as turbidity. It can also be known as "Cloudiness in water sample". It is the measurement of the scattering of light by suspended particles whenever the light shined through the sample. Higher the scattered light's intensity, higher will be the turbidity (Rashid et al., 2019). High turbidity in water samples can shield microorganisms so that the disinfection or chlorination would be ineffective in those water suppliers and would be difficult for public consumption. Water with higher amount of turbidity would lead humans to diseases like nausea, headaches, and cramps. Turbidity should ideally be less than 1 NTU for effective disinfection at all source water supplies (Salam et al., 2021). Growth rate of algae and other aquatic plants in streams and lakes have been affected by turbidity. Turbidity can also increase water temperature because suspended particles absorb more heat (Ali et al., 2019).

Out of 100 water samples examined, only one sample found to be violating the permissible standard. This shows that all water samples were cleared in study area. Overall, water samples collected from 4 zones were found to be in allowable limits prescribed by WHO and PSDWQ that is <5NTU as shown in Figure 4.2. The reason of a single sample violating the set standard was due to scaling in that water distribution pipelines. Other reasons may be the leakages in supply networks or accelerated process of corrosion in pipes leads to supply more particulate matter in supply chains for public.

(Ali et al., 2021) conducted research work to test water quality in different areas of Rawalpindi. 12 physicochemical parameters were assessed from 8 selective locations found that the maximum value of turbidity was 3 NTU which was in permissible limit comfortably as set by WHO guidelines. (Rashid et al., 2019) investigated the ground water quality by taking 22 samples from Chitral District, northern Pakistan and found that turbidity ranges from 3.9 to 4.7 NTU representing safe limits of samples.

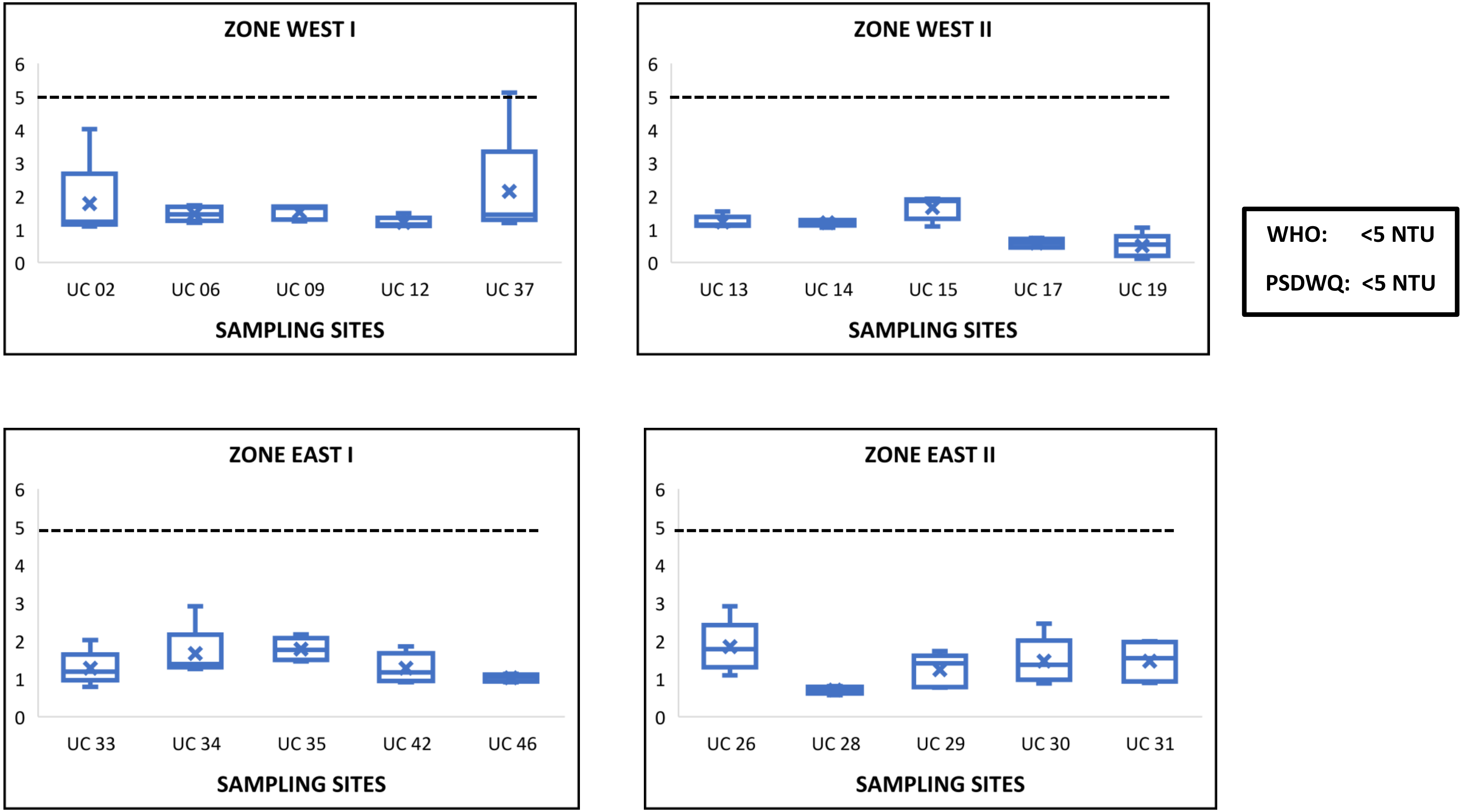

Figure 4.2: Turbidity variation profiles of all four zones of Rawal town Rawalpindi.

4.1.3 Electrical Conductivity

Electrical conductivity measures the ability of water to transport through it. It is an estimation parameter of how many dissolved ionic species exists in water sample so that we may get the idea of total dissolved solids (TDS) present in water. It is basically an indirect measure of TDS (Singh et al., 2022). Water samples collected for estimating EC from overall Rawal town study area varied across different union councils. As an overview, all water samples were fall in permissible category designed by WHO and PSDWQ which is 2500µS/cm as shown in Figure 4.3. The trend throughout the sampling time frame remains consistent across all four zones of Rawalpindi.

Similar study conducted by (Abbas et al., 2021) examined 120 water samples from Tehsil Kot Addu, southern Punjab Pakistan. Samples examined for EC displays the range of 692-898 µS/cm which were under the allowable limits of WHO. This study matches the current research study. EC have a significant impact on water quality. Values higher than the recommended limit results in hypertensions, kidney failures and kidney stones. Therefore, not suitable for public consumption (Mzi et al., 2021)

4.1.4 Total Dissolved Solids

TDS can be stated as inorganic salts and small amount of organic matter present in solution of water. The primary constituents includes calcium, magnesium, sodium, potassium, chlorides, carbonates and nitrate ions (Gawle et al., 2021). All water samples assessed for TDS were found to be in permissible limits prescribed by WHO and PSDWQ which is <1000mg/L as shown in figure 4.4. This limit would generally be acceptable for drinking water consumption by public. Zone West I and II illustrated that TDS amount would be in 495-635mg/L range in collected water samples with UC 02 “Dhoke Ratta” showed the peak value in overall west zone. Zone East I and II provides TDS concentration range 384-459 mg/L in overall collected water samples with UC 46 “City” showed the highest value in overall eastern side.

Similar study was carried out by (Khalid et al., 2018) aimed to examine water quality by collecting 41 samples from three tehsils of district Vehari based on occurrence of water borne diseases reported that TDS were within the range of acceptable WHO limits (123-890ms/L). Excessive TDS concentration could cause extreme scaling in water distribution pipes and networks and can shorten up the service life (Gupta et al., 2021).

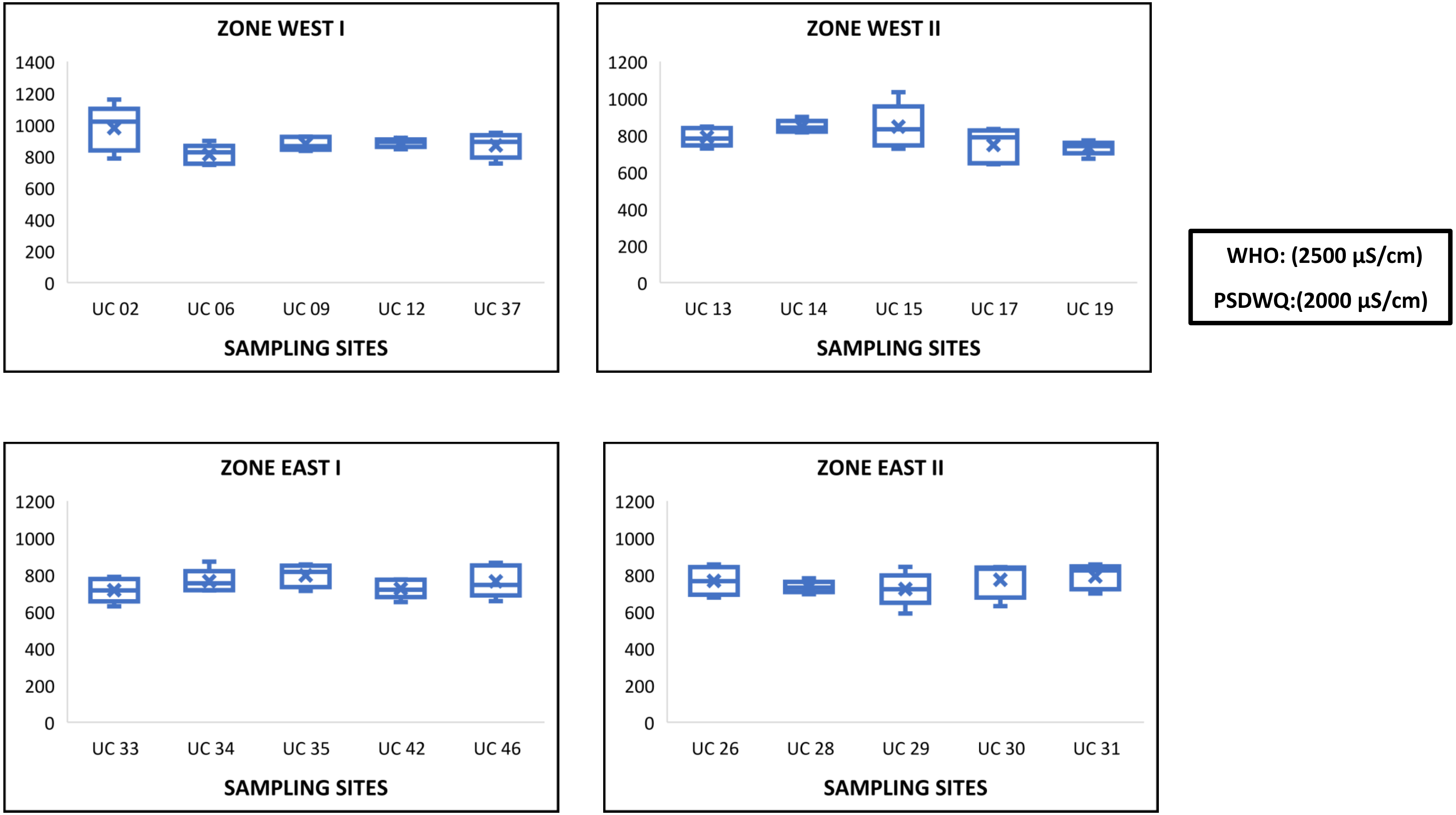

Figure 4.3: EC variation profiles of all four zones of Rawal town Rawalpindi.

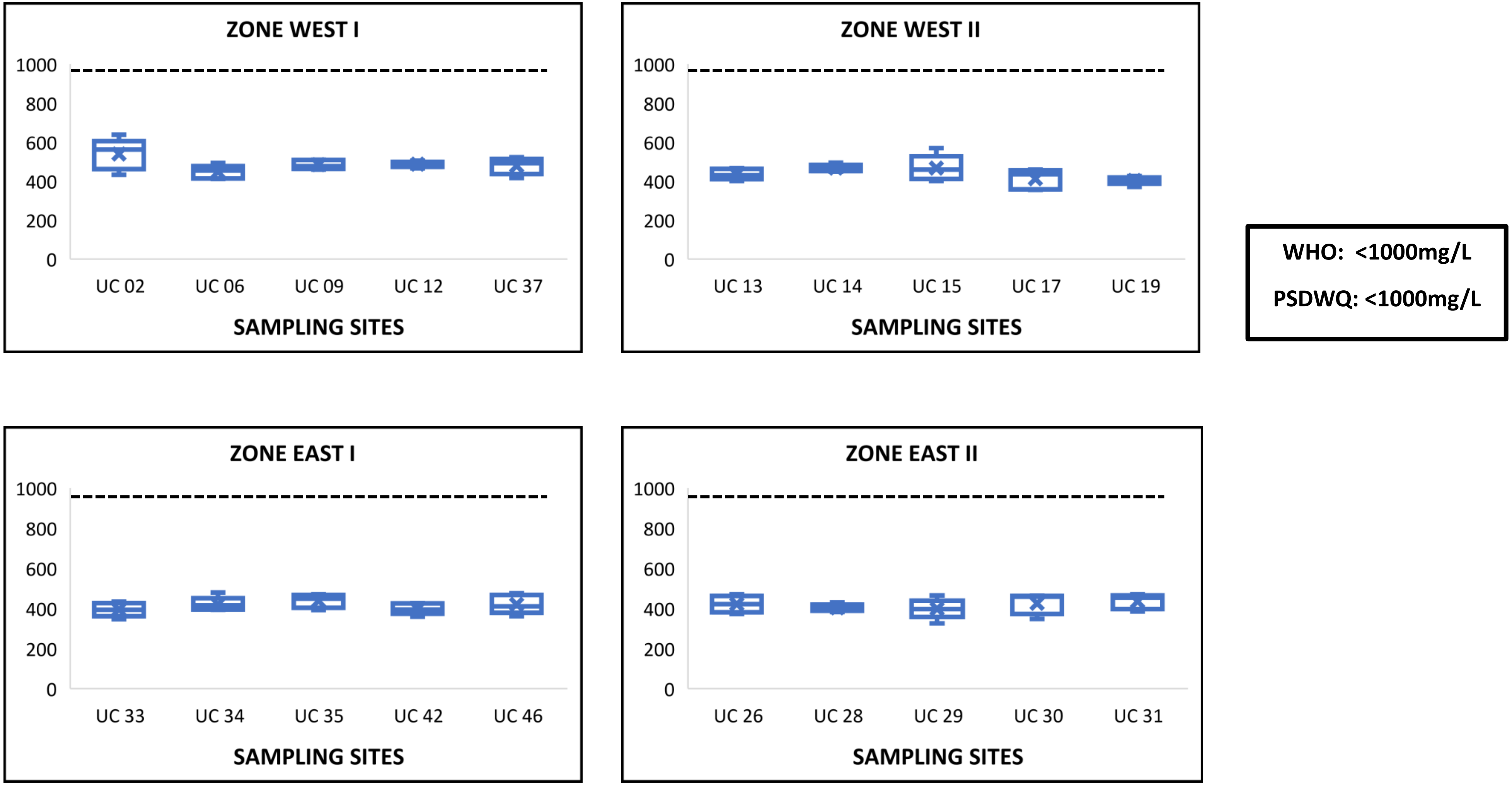

Figure 4.4: TDS variation profiles of all four zones of Rawal town Rawalpindi.

4.1.5 Total Alkalinity

Alkalinity is water’s capability to withstand acid changes in pH. Sometimes, it is known as buffering capacity (Jalees et al., 2021). Alkalinity is very important for ecosystem as it protects or buffers against rapid pH changes. Excess of alkalinity in human body may cause gastrointestinal issues and skin irritation. It elevates body’s normal pH leading to metabolic alkalosis causing nausea, vomiting, and muscle twitching. Decrease in free calcium in a body leads to bone issues due to alkalosis. So, it’s compulsory to keep alkalinity within permissible limits set by national and international standards (Mulk et al., 2015).

The alkalinity measured from tube wells and tap water for all twenty hotspot areas vary in between union councils. Apart from the results of alkalinity examined in the UC 37 “Dhoke Dalal” i.e., 500mg/L and UC 14 “F block Satellite Town” i.e., 510 mg/L, the alkalinity of all water samples across all zones in every selected month were found within the limits prescribed by WHO and PSDWQ which is <500mg/L as shown in Figure 4.5. The major reason of exceeded values of alkalinity in two hotspots could be the higher levels of calcium carbonates ($CaCO_3$) which may be present in the composition of soil, rocky areas with lot of calcite and dolomite concentration from where the water supply initiates.

(Bhardwaj & Giri, 2019) examined the physicochemical parameters of tap water from Himachal Pradesh, India. The average result of alkalinity was assessed to be 285.17mg/L which was in the permissible limit. Another relevant study conducted by (H. Ali et al., 2019) in Rawalpindi by examining 10 sampling sites from Rawal and Potohar town and found average value of alkalinity to be 147mg/L which is in range with recommended limits.

Related study by (Sailaja et al.,2015), examined the alkalinity of residential tap water of 37 wards of Kavali Municipality, SPSR Nellore district, India. The mean alkalinity was 120mg/L, which was also within the set permissible limit by WHO thus supporting the present study. Drinking water having alkalinity greater than the recommended value of 500mg/L is reported to have unpleasant taste (Pandey et al., 2020).

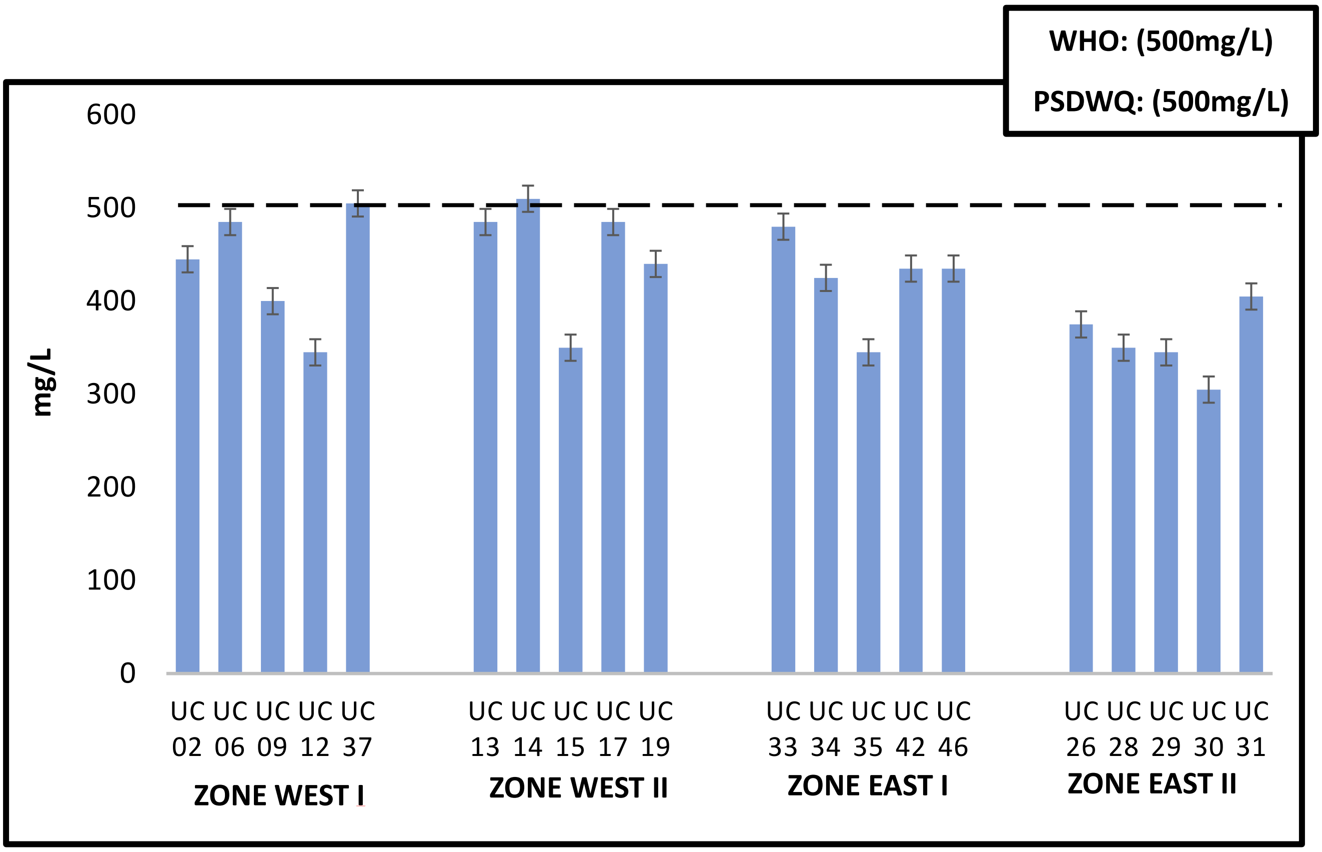

Figure 4.5: Alkalinity variation in bar chart of all four zones of Rawal town Rawalpindi.

4.1.6 Chlorides

Chloride is a natural existing element that is commonly found in nature in the form of sodium chloride as a table salt or in a combined form with calcium and magnesium. Intrusion of salty water from oceans into groundwater sources, the process of weathering in bedrocks and soil, salt bearing geological formations are the main sources of presence of chlorides in groundwater. The level of concentration of chlorides can be elevated near the coast lines where the salts concentration are on peak levels (Rehman et al., 2018). High levels of chloride concentration don't have a direct impact on humans rather it can corrode and weaken metallic piping and fixtures, give a salty taste to drinking water, damage household appliances. If the water used for irrigation, it may inhibit the growth of vegetation (Khan et al., 2017).

All the water samples collected from four zones for examining the chlorides varies in between hotspot areas and were in permissible range as suggested by WHO and PSDWQ. 24.99-75.68 mg/L range with standard deviation of 15.87 shows how chlorides concentration in water samples were in normal range. The results in Figure 4.6 illustrated chlorides concentration in study area.

Same type of study conducted in Lahore by (Ali et al., 2021) to examine water quality from eight different locations conclude that chlorides concentration were within safe limits which matches my research study results.

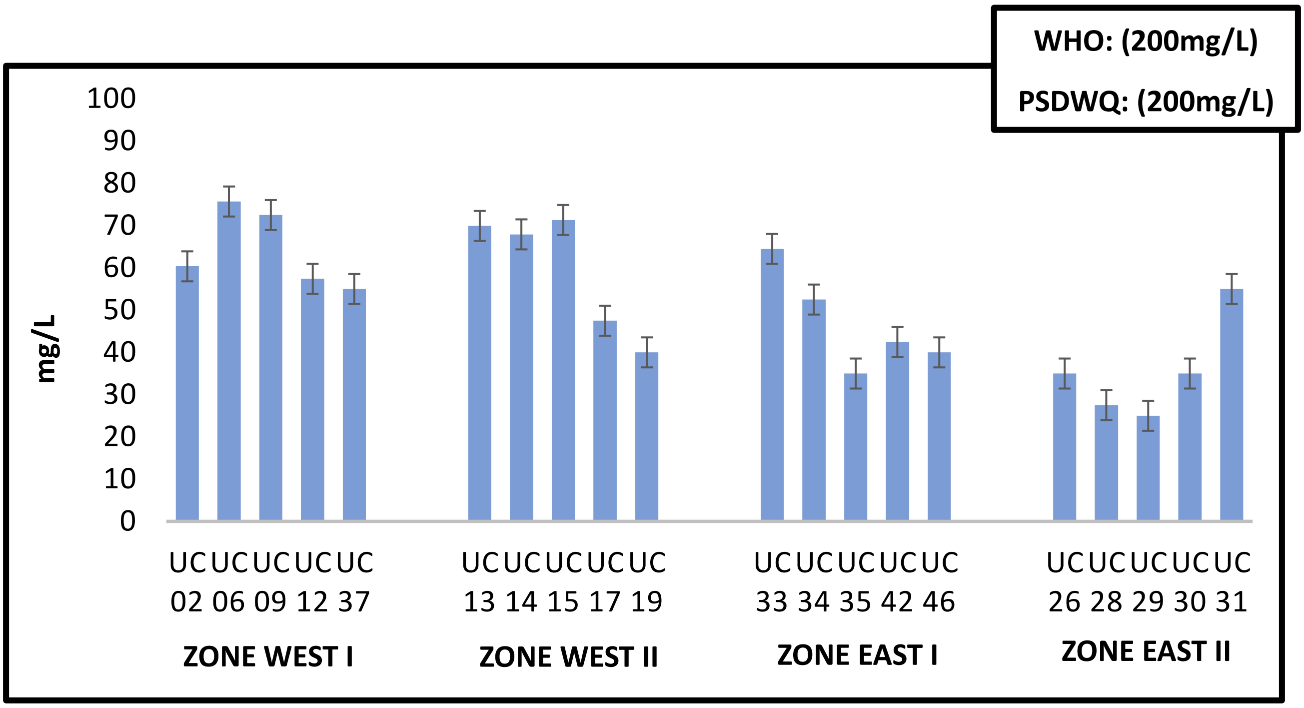

Figure 4.6: Chlorides variation in bar chart of all four zones of Rawal town Rawalpindi.

4.1.7 Dissolved Oxygen

Dissolved oxygen in drinking water is a primary parameter to examine water quality, it is a marker that give the reflection of physical and biological processes taking place in water. DO required by microbes such as bacteria and fungi to decompose organic material in water bodies (Aleem et al., 2018). The effect of low dissolved oxygen concentrations upon fishes and other aquatic culture would be highly dependent on sensitivity of individual species (Singh et al., 2022).

The tube well and residential tap water DO for all hotspot areas vary and selected months of sampling were from August 2021 to November 2021. Almost all the samples were found exceeding the permissible limit set by WHO that is 6-8mg/L as shown in Figure 4.7. The existence of dissolved oxygen in water is essential to keep water sources healthy and to negate out potential threats to water bodies in terms of pollution. DO have an inverse relationship with temperature. Low temperature shows higher values in terms of oxygen in water. As the time span of sampling covers the start and mid of winter season. This could confirm the exceeded values of DO in overall study area. Lower values of DO in few areas were due to bacterial actions and respective organics decay.

Same set of scenario in terms of DO limits could be seen in Iran conducted by (Mohammadi et al., 2019) which shows that DO limits were higher in cold seasons thus supporting the present research work.

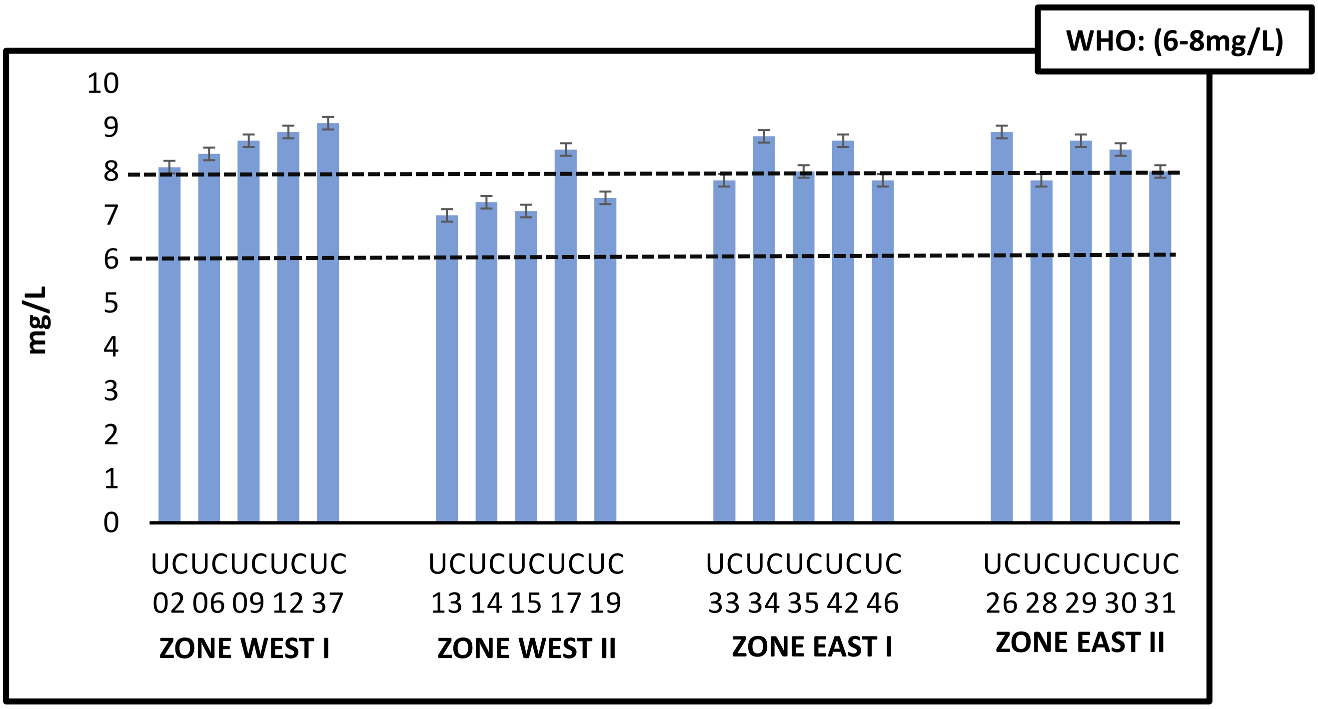

Figure 4.7: DO variation in bar chart of all four zones of Rawal town Rawalpindi.

4.1.8 Total Hardness

Existence of hardness in groundwater is of natural occurrence primarily due to weathering of limestones, sedimentary rocks and calcium bearing minerals in earth strata from where the water supply is possible (Arain et al., 2014). Hard water has several impacts on the human body. Hair and skin are the most common issues by the impact of hard water. As hard water dries, it leaves behind tiny amount of hard minerals on skin which clog pores and upset the natural pH which leads to dry, irritated skin (Jha et al., 2020). The minerals will be left behind on your hair too results in dry out your hair. This occurs because the coating doesn't allow moisturizers and conditioners to penetrate the hair follicle (Jha et al., 2020).

Samples collected from two hotspot areas were examined for water hardness found to be vary across each area. Most of the samples were found in the limit set by WHO that is <500 mg/L as shown in Figure 4.8. These examined results illustrate that water in Rawal town was soft in nature. Samples collected from UC 37 "Dhoke Dalal" were found to be exceeding the allowable limit of 500mg/L shows that hard water being supplied to public in that hotspot area. The reason of this exceeding values would be the rocky materials and presence of marble shops in the vicinity of sample collection from tube well and taps. Persistent flow of hard water in water pipelines would be the major cause of scaling on the surfaces of these water distribution pipelines.

According to similar study organized by (Mulk et al., 2015) aims to find the hardness impacts on water quality stated the range between 260-530mg/L of hardness found in Buner district, Pakistan. It represents most of the water samples were found to be in allowable range apart from few samples exceeding the permissible range matches the current study report.

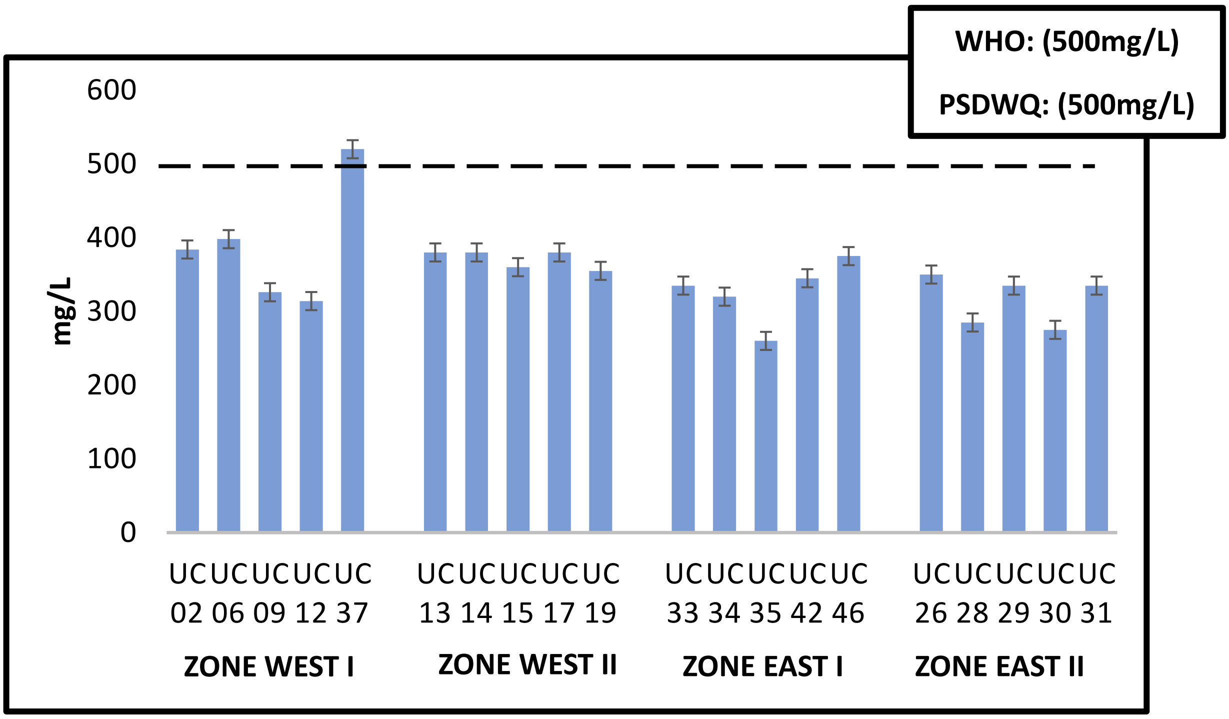

Figure 4.8: Hardness variation in bar chart of all four zones of Rawal town Rawalpindi.

4.2 Fecal Coliform by Most Probable Number

The existence of Escherichia coli (E. coli) and total bacteria with fecal coliform in drinking water are the major contributors that have significant potential to lead epidemics of waterborne diseases (Salam et al., 2021). These are disease causing water vectors which derives from feces of humans and animals, directly or indirectly contaminate the true nature of water (Fatima et al., 2021). The permissible limit of total and fecal coliform in drinking water as set by WHO and PSDWQ is 0 MPN/100ml. However, the results obtained from MPN procedure indicates that all water samples across four zones exceeds the permissible limit ranges from 5 to >23 and were unfit for human consumption. The results differ in all four zones of Rawal town Rawalpindi indicates the efficiency of chlorinators across different hotspot regions in research area. As given in Figure 4.9, overall fecal coliform found in drinking water samples collected from tube wells and residential taps were in the order of Zone West I > Zone East I > Zone West II > Zone East II. The maximum contamination shown in "red color" observed in Zone West I and minimum contamination shown in "green color" was found to be in Zone East II as per stated by MPN indices.

Major reasons of deterioration of ground water quality may be the cross contamination and intermixing due to leakages in water supply joints and pipes, unhygienic conditions at tube wells and other water distribution installations, pipe networks passed through sewage drains and flaws in water and sewage design networks (Fatima et al., 2021). Recharge mechanism of Nullah Lai which considered to be the carrier of wastewater of twin cities could be the contributing factor in contamination of potable water.

The difference in contamination level is majorly due to disinfection via chlorination. Some tube wells have chlorinators in working condition but in supply lines, lack or minimum concentration of chlorine residual leads to microbial activity to rise and their direct impact on human health by consuming drinking water.

According to a similar study conducted by (Javed et al., 2021) to evaluate water quality in a area of Saggiya Lahore. 95% water samples were found contaminated with fecal coliforms through MPN index technique, which supported my findings as it also exceeded permissible limits set by WHO and PSDWQ.

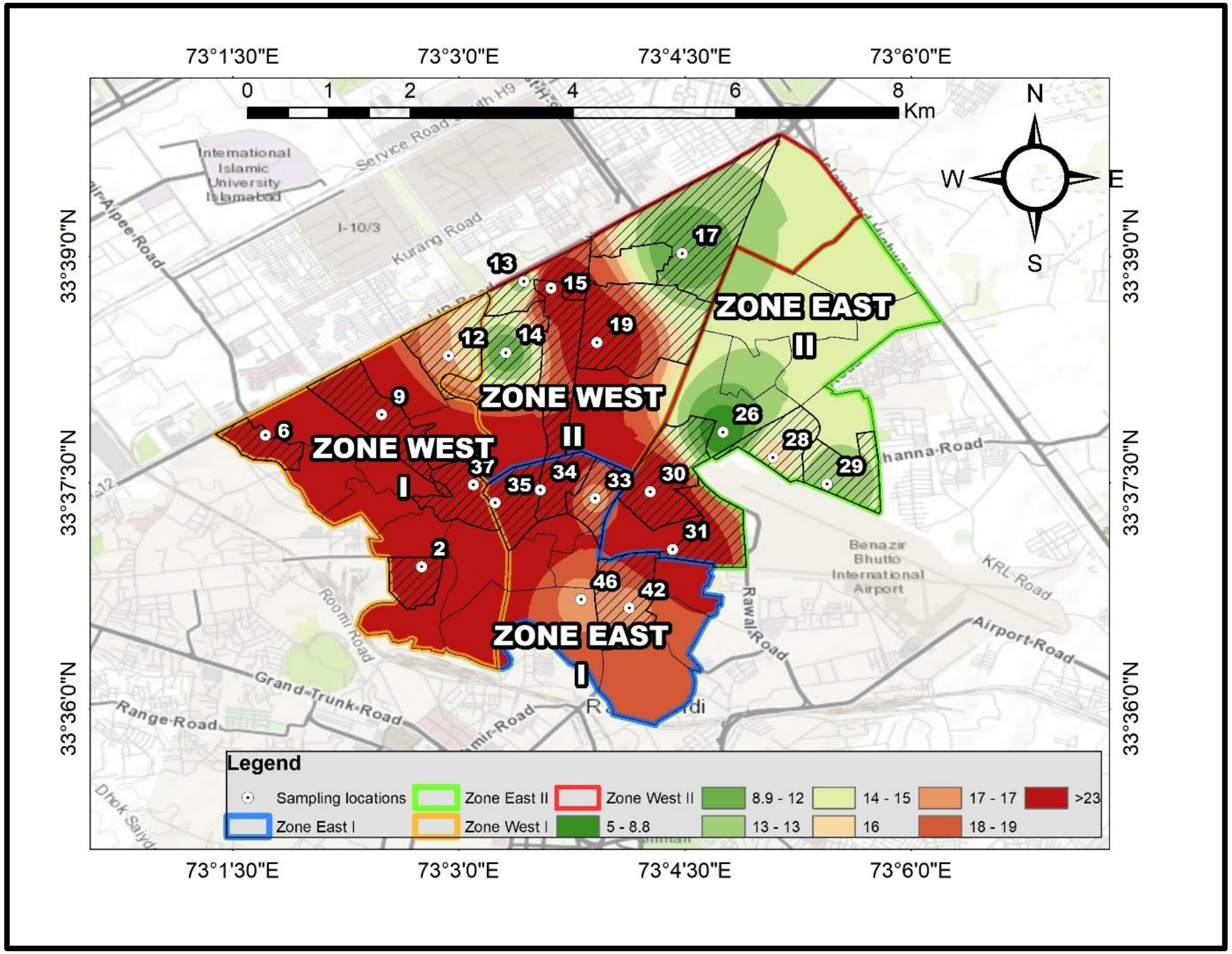

Figure 4.9: Fecal contamination by MPN indices in all four zones of Rawal town Rawalpindi.

4.3 Pearson Correlation Matrix

In statistics, it is a relation of linear correlation among two data constraints. This matrix has two absolute values or correlation coefficients of +1 and -1. +1 coefficient of correlation indicates strong positive direct relation between two parameters with 0 represents no correlation. -1 coefficient tells us the strong inverse relation which indicates one element dependency on another (Maiolo & Pantusa, 2021).

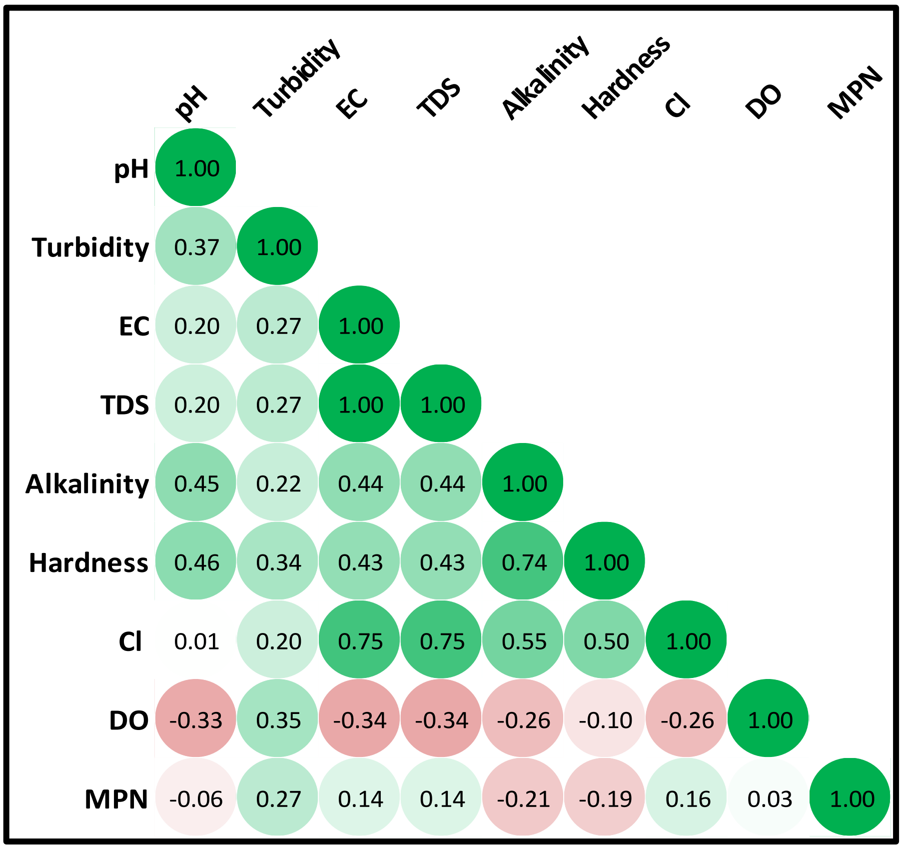

Figure 4.10: Pearson correlation matrix of all water samples in terms of all parameters

EC & TDS have the perfect correlation with each other having p value 0.0002 which is less than 0.5 indicates significant relation. Conductivity increases in water samples as the concentration of all dissolved constituents/ions increases. Color illustrates strength of relation & symbol shows direction from direct to inverse. All ions have a common source and geochemical process.

Alkalinity and water hardness are similar in terms of their origin as they both come from sources in nature in form of dissolution of carbonate salts and nutrients in water sources. When limestone and dolomite dissolve in water, calcium and carbonates concentration rises. This means that the level of water hardness and alkalinity in a place will be very similar which indicates positive strong relation of 0.73 having p value less than 0.05 indicates it has significant relationship.

Chlorides boosts the electrical conductivity of water and thus increases its corrosivity. In metal pipes, chloride alters with metal ions to form soluble salts. As EC directly related to TDS, so both parameters show direct relation with chlorides. pH has the strong relation with hardness and alkalinity with p-value less than 0.05 shows significantly strong as shown in Figure 4.10.

Turbidity has a weak correlation value of 0.27 with MPN as high turbid water were more susceptible to microbiological contamination since the pathogens attached themselves to the suspended particles in turbid drinking water would be of higher probability. These suspended particles then safeguard pathogens from disinfectants and interfere with the disinfection process. This relation has a p value greater than 0.05 which shows relation is non-significant as only one water sample exceeded the permissible limit set by WHO and PSDWQ.

The similar study conducted by (Solangi et al., 2019) in Thatta district states the positive correlation between EC and TDS. TDS showing significant positive relation with chlorides concentration of 0.71, weak turbidity relation with fecal coliform count which supports my work.

4.4 Water Quality Index

Water Quality index (WQI) is valuable and distinctive technique to illustrate an overall quality of water for a specific study area in a single term or quality rating that can be helpful to understand and to select appropriate treatment technique in order to meet the relevant concerns. The selected eight physicochemical parameters were utilize to form water quality index ratings for Rawal town Rawalpindi. According to the results of water quality index, overall hotspot areas provide good quality water with indices ratings lie in the range of 26-50 indices as given in Table 4.2. Two areas i.e., UC 29 “Khurram Colony” and UC 30 “Chah-Sultan” provides excellent quality of water rating in the range of 0-25 indices. Only on area i.e., UC 37 “Dhoke Dalal” have shown poor water quality rating with 62.4 index. The reason of this poor quality supply in UC 37 was higher values of turbidity, alkalinity and hardness present in sampled water which exceeded the WHO and PSDWQ drinking water quality limits. From 100 samples collected, 5% of samples rated poor, 10% of samples rated excellent and 85% of samples rated good by WQI using weighted arithmetic index method.

The point values of specified locations were interpolated by kriging to classify area wise water quality situation in research study. The union councils present in western zones like Dhoke Ratta, Dhoke Mangtal, Bangash Colony, Dhoke Hassu had excellent water quality in terms of physicochemical parameter analysis and were fit for drinking as shown in Figure 4.11. Only Dhoke Dalal was found to be exceeding water quality protocols. The eastern parts like Muslim Town, Afandi Colony, Chah Sultan and Dhoke Hukamdad were also having good to excellent water quality rating formed by using (Brown et al., 1972).

The similar study conducted by (Bashir et al., 2020) having an aim to assess the water quality of Jhelum canal reveals that most of the water falls under excellent quality rating using WQI by similar approach to figure out the water quality situation prevalent in research study zones.

Ground water quality assessment conducted by (Ram et al., 2021) in Uttar Pradesh India illustrated that WQI of overall area was safe and potable apart from few sensitive localized areas which supports the present study.

Table 4.2: WQI ratings for all zones of Rawalpindi

WATER QUALITY INDEX RATING	
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very. Poor
100 >	Unfit for human consumption
Source: (Brown et al., 1972)	

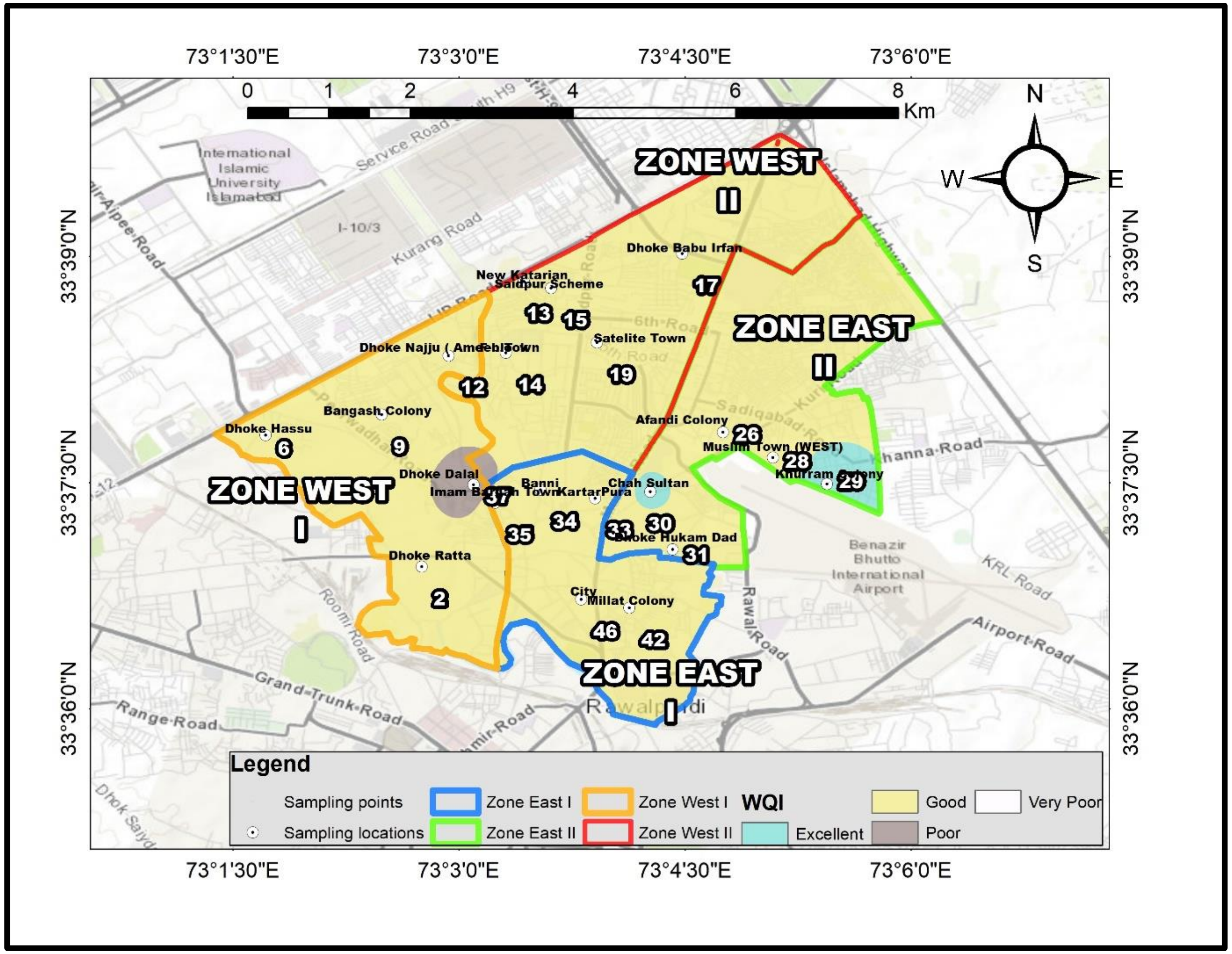

Figure 4.11: Water Quality Index Map of overall Rawal town Rawalpindi.

Chapter # 05

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions have been formed from the present research:

- Surface water supplied in Rawal town is already contaminated according to previous studies conducted, groundwater being the other source is reasonably satisfactory in physicochemical parameters in most of the areas of my study.
- Research reveals that 1% samples of turbidity, 5% of hardness & 7% samples of alkalinity for evaluating ground water were above WHO & PSDWQ permissible limits.
- At most of the sampling sites of Zone West I & Zone East I, E. coli have the highest count of >23 MPN/100ml. Lowest count observed at different hotspots sites of UC 26 named Afandi colony, UC 28 Muslim Town & UC 29 Khurram Colony i.e.,5.1 MPN/100ml.
- Mapping shows that maximum samples are physiochemically fit but microbially unfit for consumption.
- The survey of sampling sites revealed that chlorinators installed at most of the major tube wells were not functional.
- The preparation of Geographical Information System (GIS) in forming of water quality index map (WQI), spatial distribution maps can help WASA identifying the sources in affective areas and to limit the risk of water related diseases to the minimum to ensure safe water supply networks and to improve public management.

5.2 Recommendations

Following research suggestions are illustrated:

- Further study may be done on small scale to explore correlation between groundwater quality & gastroenteritis patients (1 major hospital with 10-15 Union Councils in the vicinity).

- As GIS provides more options to improve the given data in coordinates form, we can also include the patient's residential addresses to add in map for clustering out the density of people suffering from water related diseases and match that information with water supply network designs provided by WASA to identify the source of contamination in specified UC area.
- Regular monitoring of quality of drinking water supply and maintenance of suitable disinfectors should be implemented before distribution across town.
- Site investigation studies can be improved by including geological factors i.e., type of soil, rainfall, water table depth, elevation, lithology of rocks.
- Effects of heavy metals on ground water quality can also be assessed to make it more comprehensive & to increase accuracy level of your research.
- Chlorinators positioned at tube wells should be regularly monitored and proper maintenance shall be done to eliminate the risks associated with water quality.

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