PHYSICO-CHEMICAL AND BACTERIOLOGICAL ANALYSIS OF DRINKING WATER OF PESHAWAR CITY

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1- Drinking water

2. water supply - Social services

DEDICATION

This thesis is dedicated to my Father
Who taught me that the best kind of knowledge to have
Is that which is learned for its own sake.
It is also dedicated to my Mother
Who taught me that even the
Largest task can be accomplished
If it is done one step at a time.

ACCEPTANCE BY THE VIVA VOCE COMMITTEE

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ABSTRACT

Water pollution is one of the serious environmental problems, which has impacted human health, ecological system, safe food production and economic status, in general. In term of human health the most dangerous water pollutants are pathogenic microorganisms, i.e., viruses, bacteria and protozoa. It is estimated that 250 million cases of waterborne diseases are reported worldwide each year; and more than 25 million deaths are blamed due to waterborne diseases. In Pakistan, waterborne diseases are also prevalent due to improper water management, lack of water-treatment infrastructure, unhealthy sanitary conditions and poor drinking water quality. It is estimated that 60% Pakistani population have no access to potable drinking water. It has been estimated that due to bad sanitary condition and poor drinking water quality 60% deaths in Pakistan are reported due to use of contaminated water.

Before human consumption drinking water must be treated to ensure absence of disease causing microorganism and other toxic compounds. However, drinking water treatment is rarely done in Pakistan and WHO standards are not followed for its physiochemical and bacteriological analysis. This study was conducted to evaluate physicochemical characteristics and bacteriological analysis of drinking water of old & new Peshawar city. For that purpose, physicochemical parameters, i.e., pH, Turbidity, Electrical conductivity (EC) and Total suspended solids (TSS); and bacteriological parameters, i.e., *Coliform, fecal coliform* and *E.coli* were evaluated (APHA, 2005) by sampling the source of water (tube well), water distribution network (WDN) and storage tanks (ST) of ten (10) selected locations of new and old areas of the city. The samples were collected in triplicate over a period of 6-months and were compared in its water quality.

The data showed a significant variation in physicochemical parameters, i.e., pH: 6.64-8.21, turbidity 2-20 NTU, TSS (2-23 mg/L) and EC (501-897 µs/cm) in all sampling locations. Although, pH of most samples was within the permissible limit of WHO guidelines, EC of all samples was found above the permissible limits. Whereas, TSS of the some 4 locations were found above the permissible limits, while, turbidity of the 3 sampling locations was within permissible limits. In bacteriological analysis except three samples which were collected from the tube well of New Arbab Colony, Hayatabad Phase: 1 and Hayatabad Phase: 4 were found under permissible limit, whereas all others samples were *coliform* positive and exceeded the permissible limits. 12 samples of drinking water were *fecal coliform* positive and 6 samples were *E.coli* positive. It was concluded that drinking water of Peshawar city was highly contaminated with microbes and was not fit for consumption.

DECLARATION

I hereby declare that this thesis, neither as a whole nor as a part thereof has been copied out from any source. It is further declared that I have developed this thesis entirely on the basis of my personal effort made under the sincere guidance of my supervisor *Dr. Syed Shahid Ali,* Foreign Professor (HEC). No portion of the research work presented in this thesis has been submitted in support of any application for any other degree or qualification of this or any other university or institute of learning.

Dated: Jan 12, 2012

Rooh ul Amin
73-FBAS/MSES/F09

FORWARDING SHEET

The thesis entitled "Physico-chemical and bacteriological analysis of drinking water of Peshawar city", submitted by Rooh ul Amin, in partial fulfillment of MS Degree in Environmental Science has been completed under my guidance and supervision. I am satisfied with quality of student's research work and allow him to submit this thesis for further process of as per IIU rules & regulations.

Dated: Jan 12, 2012

Dr. Syed Shahid Ali
Foreign Professor (HEC)

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Rooh Ul Amin

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ACRONYMS & ABBREVIATIONS

β	Beta
%age	Percentage
^{o}C	Degree Celsius/ Centigrade
CaC03	Calcium Carbonate
CO_2	Carbon dioxide
µS/cm	Micro Siemen per centimeter
ml	milliliter
mg	milligram
mg/l	milligrams per liter
NTU	Nephlometere Turbidity Unit
AWWA	American Water Works Association
WHO	World Health Organization
UNICEF	United Nations International Children's Emergency Fund
UN	United Nations
NEQ'S	National Environmental Quality Standard
EPA	Environmental Protection Agency
APHA	American Public Health Association
PCSIR	Pakistan Council of Scientific & Industrial Research
DWQA	Drinking Water Quality Assessment
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
EC	Electrical Conductivity
TSS	Total Suspended Solids
ETEC	Enterotoxigenic *E.coli*
EHEC	Enterohemorrhagic *E.coli*
EIEC	Enteroinvasive *E.coli*
LTB	Lauryl Tryptose Broth
BGBB	Brilliant Green Bile Broth
EMB	Eosin Methylene Blue
PW	Peptone Water
MPN	Most Probable Number
NSDWQ	National Standard of Drinking Water Quality
TWW	Tube Well Water
WDN	Water Distribution Network
STW	Storage Tank Water
UK	United Kingdom
USA	United State of America
WRC	Water Research Commission
WTP	Water Treatment Plant

LIST OF APPENDIX

I. INTRODUCTION

Water is one of the most important natural resource on this universe among all resources provided by the Creator. In Holy Quran it is stated "*we have kept alive everything from water*". It means that water is an essential basic requirement of all living organisms and without water life existence on earth would be impossible.

Pollution of environment and all natural resources is ever-increasing due to anthropogenic activities. Ground water and fresh water resources are equally subjected to contamination due to addition of domestic effluents, industrial discharges, and continuous use of chemicals in agriculture. Water pollutants originate from two main sources, point and non point sources. *Point* sources of water pollution can be identified which include discharge from waste water treatment plants, disposal of effluents, biosolids, human and animal excretory wastes etc. *Non point* sources of water pollution dispersed in environment such as urban and agriculture runoff, construction sites, roads, streets, and parking lots, runoff from farm fields, gardens and lawns. In addition, drinking water resources are also being contaminated by opportunistic disease-causing organisms, e.g., *Legionella pneumophila, Aeromonas, Mycobacterium and Flevobacterium,* that are the part of indigenous microorganisms in soil and environment (Berger and Oshiro, 2002).

Different types of pollutant emit from waste water discharge which include household chemicals such as insect repellents, surfactants and pharmaceuticals. Agricultural runoff includes pesticides and herbicides as well as toxic chemicals waste originating from industries. Pollutants such as pesticides and other industrial toxic chemicals waste are non biodegradable and persist in environment for a long period of time can cause the contamination of both surface and underground water (Eichhorn *et al.*, 2002). Other common sources of water pollution are defective sewerage system, effluent from septic tanks and sewage. In developed countries the industrial pollution is 2-4 times more then sewerage pollution (Waheed and Kausar, 1987). Toxic organic and inorganic compounds, heavy metals, salt, pathogenic microorganism may also be present in water which find their way through industrial and agricultural waste (Knepper *et al.*, 1999).

Improper management of human and livestock waste and their disposal and treatment, infiltration of effluent from septic tanks can cause the contamination of ground water. Furthermore, agricultural runoff of fertilizers and pesticide residuals, and mostly the industrial effluents affects the quality of underground water sources (Singh and Mosley, 2003). Sewage drainage system is one of the most common sources of drinking water pollution since undated sewage and water distribution systems of drinking water comes into contact with each other through leakages and alter the physiochemical properties of drinking water and onset the spread disease causing microorganism.

Drinking water is contaminated by a wide variety of microorganisms. In terms of human health the most dangerous water pollutants are pathogenic microorganisms.

Since the beginning of the recorded history, water contamination played a vital role in the spreading of various bacterial, viral and protozoan diseases. Some of these microbes may be pathogenic and cause different diseases in human. It is also an established fact that drinking water if fecally polluted can spread dangerous diseases like hepatitis, cholera, dysentery, typhoid and diarrhea. In these waterborne diseases the most important one is diarrhea. Recorded history of contaminated drinking water supply has witnessed various bacterial, viral and protozoan diseases, globally. Confirmation of water as a source of spreading diseases came from the studies of John Snow, the father of Epidemiology. The famous outbreak of Cholera in London in 1850s was studied by John Snow and the final report concluded that most of the victims who had drunk water from the same well contaminated from a faulty sewer pipes (Calderon, 2000).

In general term, the greatest microbial risk is associated with ingestion of fecal contaminated water. Waste water discharges, effluent, sewage in fresh water is the well known sources of fecal microbes including disease causing organisms (WHO, 2008; Grabow, 1996). In developing countries one of the major public health problems is viral, bacterial and protozoan diarrheal diseases. Community affected by acute waterborne diarrheal diseases is those with lowest economic resources and bad sanitary and hygienic condition. Children under five year of age, in Asia and Africa are the most affected segment of population due to waterborne diarrheal diseases (Seas *et al.*, 2000).

Diarrheal diseases are transmitted through contaminated drinking water. Each year more than 250 million cases of waterborne diseases are reported globally and above 25 million deaths are blamed due to waterborne diseases. Diarrhea is a major waterborne disease which affect 40% children's under 5 years of age, and it has been reported over 1.5 billion cases of diarrhea occur in children in developing countries in that 4 million ends on death (DWQA, 2005). WHO reported that 80% of all sickness and diseases in developing countries due to waterborne pathogens and inadequate sanitation system. According UN report in developed countries 95% of the population has access to clean and safe drinking water and 90% have adequate, proper mange and safe disposal. In developing countries the situation is different. The UN estimated that at least 2.5 billion populations of the developing countries have no proper manage sanitation system and above half of these people have no access to safe drinking water (Cunningham, 2005).

Although Diarrheal diseases continue to be major health concern in developing countries of Asia, Africa and South America, however developed countries are not privy to this mode of transmission as well. It has been reported that annually 560,000 people suffer from waterborne diseases in a developed country like USA with 7.1 million suffer from a mild to moderate infections; and causing an estimated 12,000 deaths annually. Water sources protection can be accomplished by identifying the contamination / pollutants sources and by taking preventive measures, such as physical barrier to prevent water sources from human and animals excretory wastes, reduce the various activities such as sewage discharge, cattle grazing and restriction on land-use (Robertson and Edberg, 1997).

Pakistan has been facing the similar problem due to improper water management, obsolete water distribution infrastructure, outdated sewage drainage system, bad sanitary conditions in urban and rural areas and poor water quality of drinking water supplies due to microbial contamination. Almost in all of the cities the municipal drinking water does not meet the WHO standards. It is recommended that before human consumption drinking water must be treated, and should be free from toxic chemicals and pathogenic microbes (WHO, 1976), however in Pakistan drinking water treatment is rarely done before consumption and no such international standard are perused for physical, chemical and microbiological limits of drinking water. It is estimated that 60% deaths occur in Pakistan are due to the use of contaminated water (England and Wales, 1956).

In most of larger cities of Pakistan, lack of water treatment plants (WTP), inadequacy or lack of chlorination treatment of drinking water, cross contamination of sewage and water distribution lines, poor maintenance, and illegal connections, are few instances of aggravation and mismanagement. According to recent census, 65% population of Pakistan lives in rural areas and has no proper water supply system. On the other hand, rapid and ill-organized urbanization has also threatened drinking water quality in the major cities of Pakistan. Due to urbanization, safe drinking water availability in cities has been reduced to 40% from previously 60% (Hussain *et al.*, 2007).

Through various mechanisms waterborne diseases can be controlled, such as supply of microbiologically safe drinking water reduce the cases of waterborne diarrheal diseases, improve water sanitation system, hygiene awareness education and household water treatment such as chlorine disinfection process all of these preventive measure are helpful in the reduction of waterborne diseases (WHO, 2004).

Problem Statement

As discussed previously, contaminated drinking water and untreated wastewater is linked with an increased risk of bacterial, viral and protozoan diarrheogenic pathogens all over the world. Ground water is the main source of drinking water in Peshawar. Drinking water quality throughout Peshawar was considered good in the past, however in last few years drinking water contamination has been reported in various location of Peshawar city. Ground water is extracted throughout the metropolitan area and distributed for human use without any prior physio-chemical and microbial analyses. Beside that the water distribution network (WDN) is more that 2 to 3 decade old, depending on locality and area. Situation further aggravates due to leakages in this distribution pipeline network and has been implicated as the main cause of health problem. It is evident that drinking water supply lines and sewerage lines run side by side (Figure 1.1). During drinking water supply waste water and seepage from the surroundings enter the water distribution pipeline through leakages thus contaminate the drinking water.

In addition: there is lack of monitoring of drinking water supply system; absence of water filtration and wastewater treatment plants; and lack of chlorination treatment of drinking water. Such multiple reasons of drinking water contamination are contributing

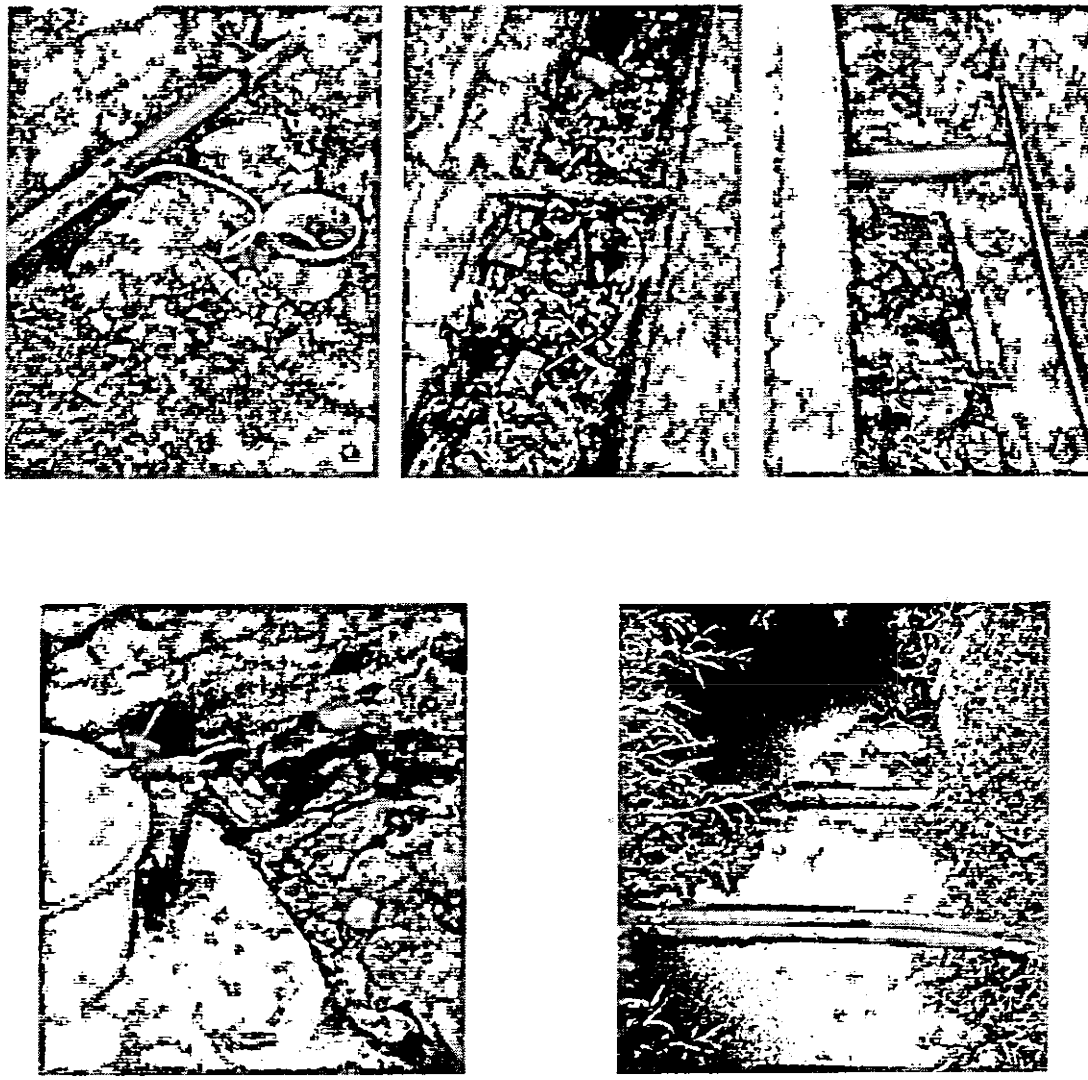


Figure 1.1. Pictorial view of water distribution network and sewage disposal

towards an increase risk of waterborne diseases in population of Peshawar city especially among children. Therefore, the overall objectives of this study were to assess the drinking water quality of Peshawar city. For that purpose, it was imperative for this study to evaluate tube well (TW), water distribution network (WDN) and storage tank (STW) for both old and new Peshawar city with the following objectives.

Objectives of Study

- To investigate the Physico-chemical quality at different points of water resources (Tube Wells), storage reservoirs (water storage tanks), and water distribution system (WDN).
- To estimate bacteriological presence of *Total* and *Fecal Coliform*, and *E.coli* in drinking water samples from all sources.
- To compare physio-chemical properties of drinking water with international or WHO standards and also their effect on water quality.

Significance of Study

Waterborne bacterial diseases are still one of the major problems all over the world especially in developing countries. In Peshawar city ground water is the main source of drinking water. However the water distribution system and water reservoirs are obsolete beside inundated water sewage system this results in underground leakages and contamination of water distribution network. Further more lack of water filtration plant and any chlorination treatment of drinking water aggravate the situation for general population. The present study was designed to identify the water related problems in both old and new urban areas of Peshawar and to propose measures to prevent disease occurrence that originate due to waterborne pathogens.

II. LITERATURE REVIEW

According to the classification of water from a sanitary standpoint, water is classified into three types: *Potable* water, *contaminated* water and *Polluted* water. Potable water is defined as "water free from pathogenic microbes and chemical toxic compounds deleterious to health. Potable water has pleasing taste, odor and appearance (Lamikaran, 1999). On the other hand, contaminated water is unpleasant due to its taste, odor and appearance and could also contain disease-causing microorganism or toxic chemical agents. In addition to unpleasant appearance, taste and odor, polluted water may contain a heavy load of pathogens and toxic chemicals, therefore, make it unfit for consumption as well as for the use of other domestic purposes.

People obtain their drinking water from surface and underground sources. Surface water sources are lakes, river and stream. The quality of surface water rapidly changes as a response to any alterations in the surrounding environment due to industrialization, land use change and other natural calamities. For example, addition of high level of nutrients, i.e., Nitrogen and Phosphorus, cause "*Eutrophication*" in surface water and results in massive growth of algae, also called as *algal bloom*. This process could lead to the growth of other microorganisms beside accumulating chemicals and cause turbidity in surface water. Other contamination sources of surface water are domestic waste water called as sewage, storm water runoff, pesticide and fertilizer runoff, cattle feedlots runoff etc. (Geldreich, 1990). Pollution originating from these sources raises the level of: water turbidity; total suspended solids; biological oxygen demand (BOD), chemical oxygen demand (COD), and propagation of disease-causing microbes and parasites in surface water sources. Whereas, quality of ground water remains consistent throughout in aquifers due to natural sand filtration process which keeps the ground water free from microbial contamination. Although, water quality changes slowly because it is not directly exposed to chemicals and other pollution sources, but in most cases, ground water contamination results due to improper waste disposal from both industry and households and furthermore due to the dwelling of wells and septic tanks (AWWA, 1971).

Drinking water safety is a global concern. Drinking water quality has a strong impact on community health because water play major role in the transmission of disease causing microorganisms which are responsible to cause diseases in people (Howard and Bartram, 2005). In developed regions of the world 90% to 95% people have access to safe drinking water but on the other hand in developing regions people have no access to safe drinking water where waterborne diseases are common. It is estimated that 2.5 billion people do not have access to safe drinking water globally, and more than 1.5 million children in developing countries die from waterborne diarrheal diseases per year (WHO, 2008).

The term "Waterborne disease" describes all types of illness/ infection whose causative agents are transmitted through drinking water. These disease causing pathogenic microorganisms are *Vibrio cholera, E.coli, HAV, Bacillary dysentery, Cryptosporidiosis*

Table 2.1. Waterborne diseases

Causative Agents	Disease
Salmonella typhi	Typhoid Fever
S.enteritidis, S. typhimurium, S .paratyphi and *S.newport*	Salmonellosis.
Shigella dysenteriae, S.boydii and *S.sonnei*	Bacillary dysentery or shigellosis
Vibrio cholera	Cholera
Campylobacter jejuni	Diarrhea
Rotavirus	Winter diarrhea
Hepatitis A Virus [HAV]	Hepatitis A
Polioviruses	Paralytic poliomyelitis
Giardia lambila	Giardiasis
Entamoeba Histolytica	Amoebic dysentery

Source: WHO, 2001

and *Giardiasis* (WHO, 2001). The most common diseases and their disease-causing microorganism are listed in Table 2.1.

WHO has reported that 80% of diseases and one third of mortality cases in developing regions results due to consumption of contaminated drinking water. Untreated drinking water is a major cause of waterborne diseases in developing countries. According to the data collected by WHO, approximately 25,000 persons / day were reported dead during 1980 (near about 9 million/year) as a result of contaminated water consumption. It is still documented that above 5 million deaths are reported due to waterborne diseases annually (WHO, 1996).

Fecal contaminated potable water is responsible for mostly waterborne diarrheal diseases. It is also established fact that drinking water, if fecally contaminated can spread dangerous diseases e.g. cholera, diarrhea and hepatitis. Mostly outbreaks of *E.coli* O157 were documented that occur due to waterborne transmission from source of water, i.e., well's water (Nataro and Kaper, 1998), recreational water (Keene *et al.*, 1994) and community water supply system. Drinking water contamination with untreated human and animal's excretory waste has been responsible for *E.coli* outbreaks (Licence *et al.*, 2000). Beside fecal waste, agriculture waste has been linked to *E.coli* O157 infection in human and such outbreak was found associated with potato fertilized cattle manure (Chapman *et al.*, 1997). In another outbreak in winter 1990 at Cabool, Missouri, *E.coli* outbreaks occurrence was associated with faulty water supply line (Geldreich *et al.*, 1992; Swerdlow *et al.*, 1992).

Shigella species are responsible for more than one million deaths and 163 million cases of dysentery each year, with 99% of these cases reported in developing regions of the world (Torres, 2002). *Shigellosis* outbreak in Florida that involved 1200 people associated with well's water. In Bangladesh from 1972 to 1994, *Shigella* type1 epidemics were extensively reported, and the causative agent was detected and identified in surface water (Faruque *et al*, 2002).

In Pakistan near about 60% deaths are associated with consumption of contaminated drinking water (England and Wales, 1956). Previous study from Punjab revealed that approximately 90% people suffered from waterborne bacterial and protozoan diseases. According to the results 8% of illnesses were due to dysentry, 9% cholera, 11% typhoid, 13% skin, and 17% diarrhea, whereas, malarial disease due to stagnant water in the locality were detected in 32% of the community of the study area (Jehangir *et al.*, 2001).

In another study conducted in Swat, KPK, it was shown that 79% open well's water and 22% hand pumps water samples were found to be unfit for human consumption due to presence of microorganisms, i.e., *Coliform, fecal coliform, E.coli* (Zai and Akhtar, 1996). Similarly, fecal contamination was detected in 57.2% collected water samples from drinking water of Abbottabad, KPK (Rab *et al.*, 1993). In another study conducted at Rawalpindi & Islamabad, It was reported that except spring water all other water samples were found unfit for drinking purpose due to the presence of high amount of suspended solids and divergent group of microorganisms (Khurshid & Bibi, 1991).

Zahoor & Tasleem (2003) reported contaminated water samples from rural Peshawar area. It was found that most of the water samples collected from water source (wells) were 77% unfit for drinking purpose, and contained high amount of TSS, above average EC and pH. In addition, *coliform* bacteria were found significantly higher than benchmark WHO standard for developing countries.

A. Water Quality

Water quality includes Physico-chemical and microbiological properties of drinking water (WRC, 1998). These water properties are altered by dissolved and suspended substances in water. Drinking water quality has a strong impact on community health because water act as a mechanical carrier in the transmission of disease causing microorganisms in human (Howard and Bartram, 2005). Contamination of drinking water with pathogenic microbes and hazardous chemical has detrimental effect on human health around the world, especially in developing countries (WHO, 2003). In order to minimize waterborne diseases and their outbreaks due to polluted and contaminated water, it is important to focus on water quality management (Howard and Bartram, 2005).

a. Physico-chemical characteristics of water

The most important physio-chemical characteristics of water quality are: pH, turbidity, electrical conductivity (EC), and total suspended solids (TSS). These parameters and their impact on water quality are discussed below:

i. pH (Hydrogen ion concentration)

pH is one of the most important chemical parameter of drinking water. The pH range of fresh natural water is between 6.5 to 8.5 (Medera *et al.*, 1982). In most natural waters, this property is controlled by the equilibrium system of carbon dioxide-carbonate-bicarbonate ratios. Any increase or decrease in CO_2 concentration results in increase or decrease in pH value, i.e., increases in CO_2 concentration causes the pH value to decrease, and *vice versa* (Bhatacharya, 1988). Furthermore, any increase or decrease in pH value of drinking water also affects the solubility properties of toxic chemical compounds. It is a general concept that toxicity and solubility of some chemical compounds rises with increase in acidity. For example, Cyanide and sulfides toxicity increase with increase in acidity (Bhatacharya, 1988).

On the other hand, if only small scale increase occur in pH value ammonia could become more toxic. Lowering of pH value (increase in acidity) is the major cause of metal corrosion in water distribution pipes and alters the chlorine disinfectant efficiency (Nold, 2002). Water pH value altered by domestic sewage and industrial waste, to very acidic or very alkaline depends on the type of industry and their effluents. Municipal and industrial waste water discharge may alter the pH of river and well's water, as well. In a study on the effect of pH on the growth of microorganisms, it was indicated that pH value (3 - 10.5) enhanced the growth of indicator microorganisms as well as disease causing organisms in drinking water (Kent, 1998).

ii. Electrical conductivity (EC)

Electrical conductivity is the measurement of water capacity to conduct electricity (Lechevallier *et al.*, 1981). The ions which conduct electricity are negatively and positively charged when dissolved in water come from the breakdown of compounds (Lee *et al.*, 2003). Electrical conductivity has close relationship with total dissolved solids in water such as calcium, magnesium, bicarbonate, nitrogen, phosphorus, iron and sulfur, as well. An increase in the concentration of ions in water causes raises the electrical conductivity of water. For measuring electrical conductivity of drinking water, one indirect measure is to calculate its total dissolved solids concentration. Water with high concentration total dissolved solid has salty taste. The measuring unit of electrical conductivity is micro-siemens/cm (µs/cm). This is the reason that storm water and water from agriculture waste, industrial chemical waste, and domestic waste water and sewage effluents affect electrical conductivity of water.

iii. Turbidity

Turbidity is the measure of suspended solids or the measure of water clarity, transparency and cloudiness. Suspended particles such as clay and silt, organic matters, plankton and other microorganisms are the main sources to cause turbidity in water (Planchere and Cowen, 2007). Other sources of turbidity are soil erosion, urban runoff, domestic sewage, agriculture runoff, road and bridge construction etc (Lechevallier *et al.*, 1981). Turbidity and suspended solids are closely related to each other but the only difference in turbidity includes the presence of microscopic organism and phyto or zoo-plankton (WHO, 2006). Increases in turbidity are often attached to increase in disease causing microbes including cysts or Oocysts. High turbidity in water interferes with treatment and disinfection process especially with chlorine-based chemicals. Turbidity in surface water mostly influenced by high rainfall and massive growth of algae. Ground water have stable turbidity, any alteration in the turbidity of ground water contemplate a major events that required to investigation and correctness. Even relatively small-scale changes in turbidity may be important and outbreak of *Cryptosporidiosis* has been associated with a slight change in turbidity for a short period of time (Waite, 1997). Although turbidity itself not a major health concern, its high level interfere with disinfection process and provide a growth medium to pathogenic microorganism (Murphy, 2007a). Turbidity is also considered as indirect indicator for the presence of microscopic organism in water sources (WHO, 2006).

iv. Total suspended solids (TSS)

Total suspended solids are small, inorganic solid particles (clay and silt) that remain suspended in water due to water motion (McAlister and Ormsbee, 2005). Total suspended solids scattered in water absorbed light, make water turbid and giving murky appearance (Lamb, 1985).

High concentration of total suspended solids in water cause higher its turbidity and reduced the clarity and transparency of drinking water. Total suspended solids most important water pollutants and play major role in the transmission of pathogens, because total suspended solids smaller in size and greater the surface area per unit mass of particles thus provide a medium for pathogens attachment and carry pollutant load on the surface of particles. Number of disease causing microbes and parasites are correlated the high level of turbidity and total suspended solids (Ho *et al*, 2003).

b. Bacteriological characteristics of water

The water quality parameters also depend on the presence of various microorganism in drinking water. The major categories include: *Coliform* group, *Total Coliform, fecal* *coliform,* and *E.coli.* These microorganisms and their impact on water quality are discussed below:

i. *Coliform*

Coliform is a group of bacteria that are Gram-negative, occur independently as short bacilli. They are non-spore forming and non-capsulated bacteria and show true motility due to presence of peritrichous flagella. They are facultative anaerobes and grow at an optimum temperature (35°C to 37°C) on common laboratory nutrient agars. They ferment lactose with production of acid and gas at 35°C within 48 hours and possess β-*galactosidase activity* (WHO, 2008; Grabow, 1996; George *et al.* 2002).

Coliforms bacteria mostly found in the excretory waste of human and animals, soil, aquatic environment and vegetation. *Coliforms* bacteria normally harmless and not cause diseases. These bacteria easy to culture on laboratory medium and their presence indicate the presence of fecal origin disease causing microorganisms. These pathogenic microorganisms are bacteria, viruses, protozoa and other multi-cellular parasites. Mostly *coliform* bacteria belong to family *enterobacterieaceae* and the typical genera include *Klebsiella, Escherichia, Enterobacter, Serratia* (APHA, 1998).

Coliform bacteria are divided into two major groups: (1) *Total coliform (2) Fecal coliform. Total coliform* include the genera *Escherichia, Klebsiella, Serratia* and *Citrobacter* and *fecal coliform* include the genera *Escherichia, Klebsiella* and

Citrobacter. 60 to 90% *coliform* are *fecal coliform* bacteria usually *E.coli* (APHA, 1998). Whereas, *fecal coliforms* are discussed below in separate section.

ii. *Fecal Coliform*

Fecal coliform bacteria are a sub group of *coliform* bacteria. This class of coliform is also termed as Thermo-tolerant bacteria. They are oxidase negative and produce acid and gas from lactose at 44± 0.5°C within 48 hours (Doyle and Erickson, 2006). *Fecal coliform* bacteria include the genera that originate from fecal origin, e.g., (*E.coli*) and the genera that not originate from fecal origin, e.g., *Enterobacter, Klebsiella* and *Citrobacter.* Presence of *fecal coliform* in aquatic environment is the indicator of fecal material of human and other warm blooded animals. *Fecal coliform* can get entrance into surface water through direct discharge of waste from animals, birds, agricultural and storm runoff and domestic sewage (Doyle and Erickson, 2006). Seepage of effluent from septic tanks can allow the flow of *coliform* and *fecal coliform* to underground water sources nearby surface.

iii. *Escherichia coli*

E.coli belong to family *enterobacterieaceae,* posses the enzyme β-galactosidase and β-glucuronosidase. It ferments lactose and mannitol with the production of acid and gas at 44± 0.5°C within 24 to 48 hours. *E.coli* also produces indole from tryptophane. *E.coli* is a sub group of *fecal coliform* bacteria. They are found in large number in the intestine of human and other mammals. *E.coli* abundant in human and other warm blooded animal's excretory waste therefore *E.coli* is the indicator of fecal materials in water (Fujioka *et al.*, 1999).

Most *E.coli* is harmless but some strains are pathogenic and cause diseases in human. The pathogenic strains of *E.coli* are *Enterotoxigenic* (ETEC) (O148), *Enterohemorrhagic* (EHEC) (O157) and *Enteroinvasive* (EIEC) (O124). These are the disease causing strains of *E.coli* and their transmission occurs through fecal contaminated drinking water (Table 2.2) (Scheutz and Strockbine, 2005).

B. Human Health Hazard

Water is a precious resource as it is essential for survival of all kind of living organisms. Apart from its importance as an essential constituent of living organism drinking water act as carrier in the spreading of diseases. It is also established fact that drinking water if fecally polluted can spread dangerous diseases like Cholera, Diarrhea and HAV. The medical history is filled with outbreaks of enteric diseases caused by contaminated drinking water that killed millions of people all over the globe. The World Health Organization (WHO) reported that every year at least 750 million children's suffer from waterborne diarrheal diseases that lead to 4 million deaths.

UNICEF reported that, in 1993, 3.8 million children's under the age of 5 year old died due to waterborne diarrheal diseases worldwide. In India approximately 300,000 children's die annually from waterborne diseases (Reuther, 1996). A total 34 outbreaks

Table 2.2. Diseases caused by pathogenic strains of *E.coli*

Diseases	Causative pathogenic strain
1) **Infantile gastroenteritis** 2) **Profuse watery diarrhea** 3) **Traveler diarrhea**	Entero-toxigenic *E.coli* strain
(Bettelheim, 2003; WHO, 2010)	
1) **Abdominal pain** 2) **Bloody diarrhea** 3) **Hemolytic uremic syndrome** 4) **Acute renal failure**	Entero-hemorrhagic *E.coli* strain
(Bettelheim, 2003; WHO, 2010)	
1) **Abdominal cramps** 2) **Diarrhea** 3) **Vomiting** 4) **Fever, chills**	Entero-invasive *E.coli* strain

Source: (Bettelheim, 2003; Scheutz *et al*, 2005)

were reported in United States in 1991-92, linked with consumption of contaminated drinking water. The etiologic agents of 23 outbreaks were unknown, while remaining outbreaks causative agents are *Giardia, Cryptosporidium, Shigella sonni,* HAV and toxic chemical waste (Moore and Margolin, 1994).

In Pakistan, waterborne diseases are responsible for a substantial percentage of both morbidity and mortality. It is estimated that about 60% deaths associated with consumption of contaminated drinking water and half a million children's die before their first birthday due to waterborne diarrheal diseases each year (England and Wales, 1956). Most of the waterborne pathogens primarily involve gastrointestinal tract and cause diseases that may range from mild such as diarrhea cause by pathogenic strain of *E.coli* to fatal like cholera.

In Peshawar ground water is the main source of drinking water. Drinking water quality throughout Peshawar was considered good in the past, however in last few years drinking water contamination has been reported in various location of Peshawar city. The main reason of drinking water contamination is 2 to 3 decade old water distribution network and lot of leaks in these pipelines. Drinking water supply lines and sewerage line running side by side In Peshawar. During drinking water supply waste water and seepage from the surrounding enter the drinking water distribution pipes through leakages thus contaminate the drinking water.

Drinking water quality has also fallen due to high population growth, urbanization and presence of millions of Afghan refugees in Peshawar which have further increase the burden upon drinking water resources. Satellite towns, i.e., Hayatabad, Defense Officer colony and others, were developed around Peshawar but responsible municipal authorities of different towns have failed to provide safe and clean drinking water to their residents. There is no monitoring of drinking water supply system, beside absence of water filtration plants and wastewater treatment plants and chlorination treatment facility in and around Peshawar. Such multiple reasons of drinking water contamination are contributing toward an increase in waterborne diseases in peoples of Peshawar especially among children's. Therefore, It is important to investigate this problem through water sampling of rural and urban areas of Peshawar. The water sampling methodology in this research study was designed to address both areas and has been discussed in the next chapter.

III. RESEARCH METHODOLOGY

A. Study Area

Peshawar, a historical city, is the provincial capital of *Khyber Pukhtoonkhwa* (KPK) with an estimated population of ~3 million (2010) and a population growth rate of 3.3% per annum. This growth rate is one of the higher than other metropolis of Pakistan. Peshawar City is divided into four towns. Peshawar Town-I, Peshawar Town-II, Peshawar Town-III and Peshawar Town-IV.

An easy access to safe drinking water is one of the basic rights of everyone. Although such facility inside the houses in Peshawar city are slightly higher in urban dwellings as compared to the rural areas. Hand pumps, open well, tube well, pond and tanks are the main sources of drinking water in district Peshawar and It was intimated by City District Government Peshawar (CDGP), a total of 117 tube wells were extracting and supplying water for both domestic and commercial use in district Peshawar while some more were under construction for irrigation purpose (oral communication). The following methods and material used in this study are discussed in the following section.

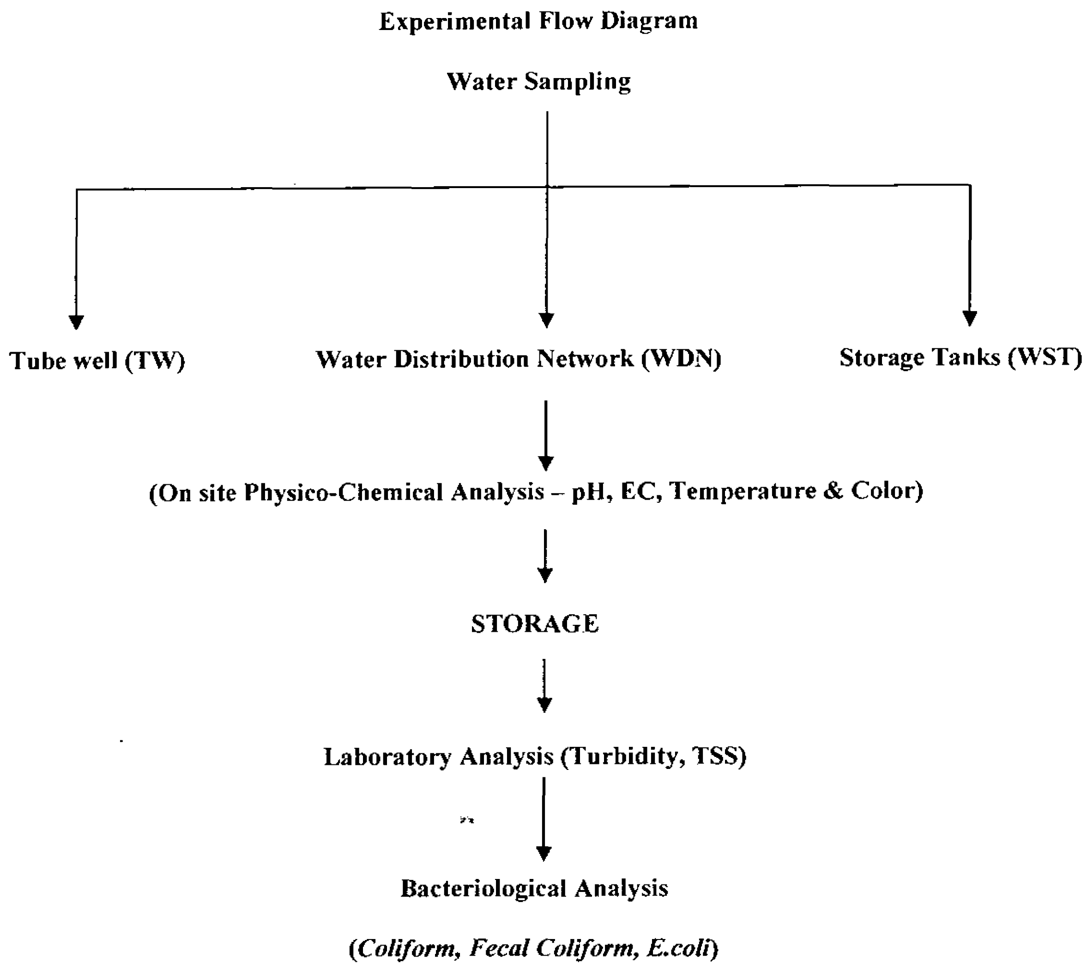


Figure 3.1. Experimental flow diagram

a. Water sampling

The experimental protocol included both chemical and microbial analysis of sampled water from all stake-holders (Figure 3.1).

A total 10 locations for drinking water samples were selected based on new and old areas of Peshawar city represented as A, B, C, D, E, F, G, H, I (Figure 3.2 & 3.3).

Thirty (30) water samples were collected from three different sources i.e. tube wells, water distribution network and overhead storage tank from selected areas of Peshawar city in triplicate. The selected area were University town, Ahmad Abad (Paoka), Academic town, Shaheen town, Tehkal Bala, New Arbab colony (Balil lane), Gulbahar Hayatabad phase # 1, Hayatabad phase # 4 and Sadar Mall Road (Figure 3.4).

b. Water sampling protocol

Water samples collected from each location in the month of August - December-2010 and subject to chemical, physical and microbial analysis.

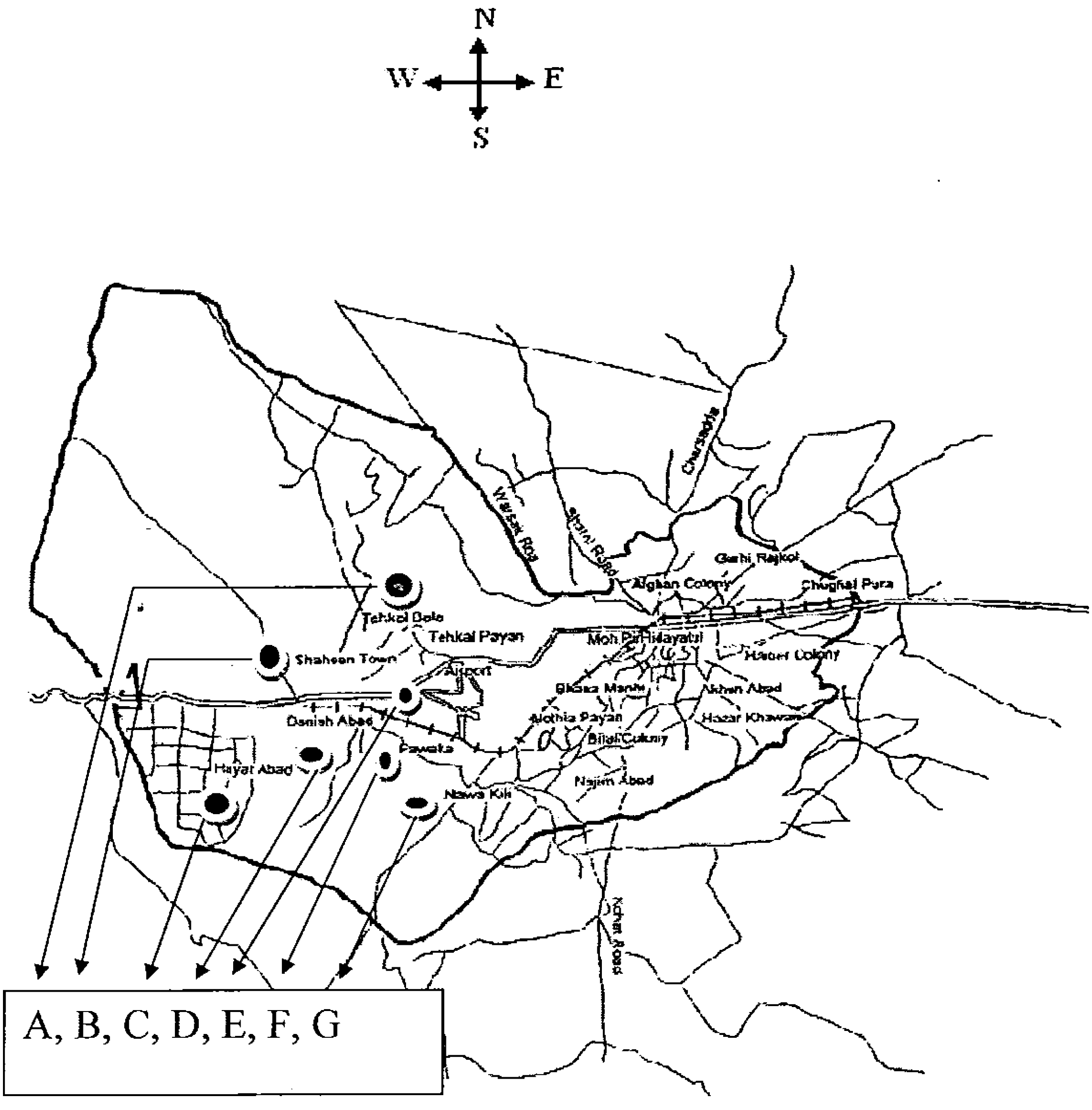


Figure 3.2. Map of District Peshawar

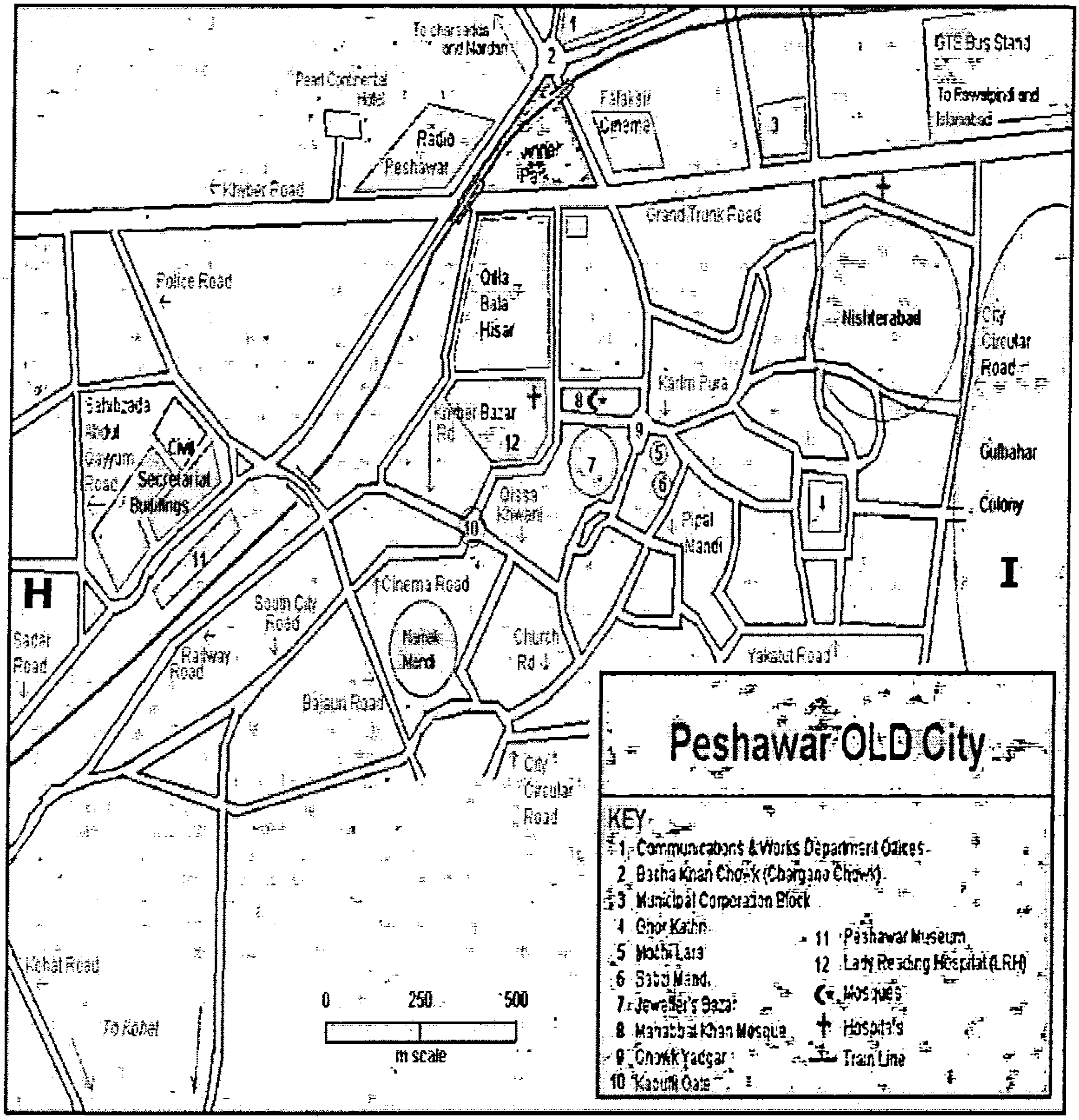


Figure 3.3. Map of Peshawar old city

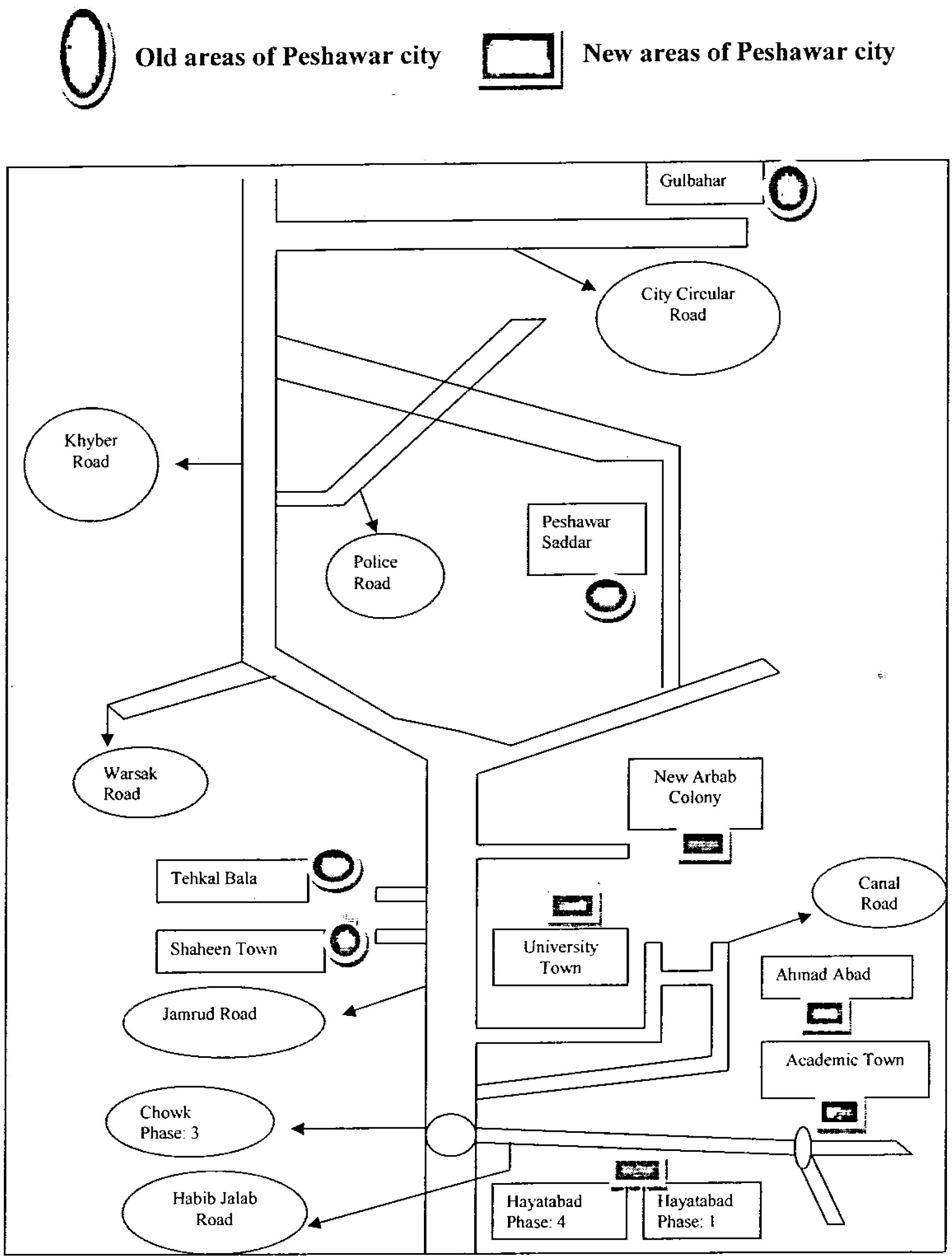


Figure 3.4. Details of sampling locations

B. Material

a. Nature of sample

Total 30 drinking water samples were collected. Each sample with a volume of 500mL and 1000mL, 10 samples each from tube well's, water distribution network and storage tanks were collected for physio-chemical and bacteriological analysis.

b. Instruments/ Equipments

The equipments/ apparatus used for analytical purpose in this research study are: Microprocessor conductivity meter (HANNA Instrument, HI 9932), Turbidimeter (TB 1000), Autoclave Model# KT-30L, Sterilizer, Type E-30, Balance (KERN ALS 220-4), SCHOTT Duran bottles and beakers, Laminar Air Flow Cabinet, Petri/china dishes, filter papers, Inoculums loop, Cold box, test tubes and test tubes stands.

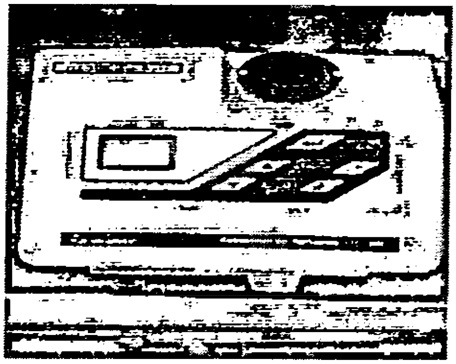
c. Reagents and Media

Lauryl Tryptose Broth (LTB), Brilliant Green Bile (2%) Broth (BGBB), (EC) Broth, Eosin Methylene Blue Agar (EMB), 70% Alcohol, Kovacs reagents and Distilled water.

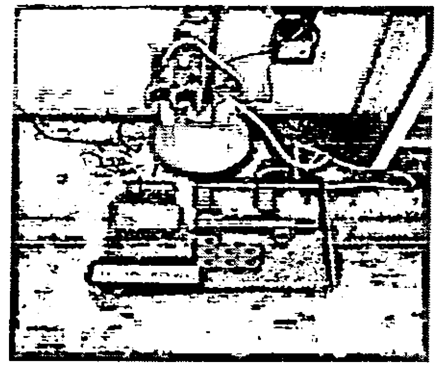
C. Methods

a. Samples collection

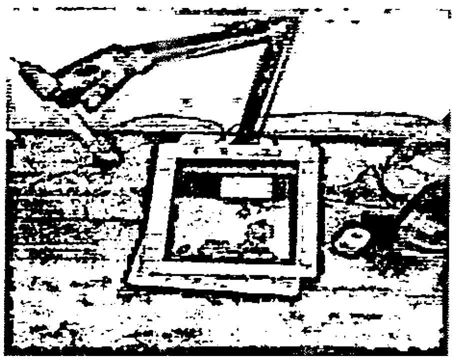
Standard methods for the examination of water and waste water (APHA, 2005) were followed for drinking water samples collection, preservation and transportation. For physiochemical analysis water samples were collected in sterile polyethylene plastic



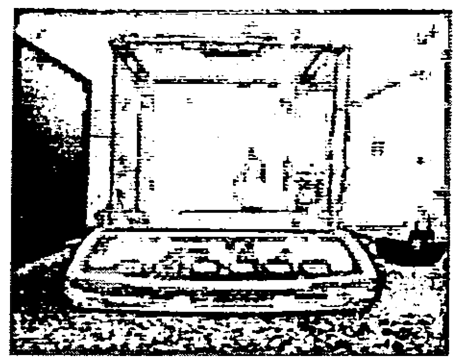
Turbidimeter



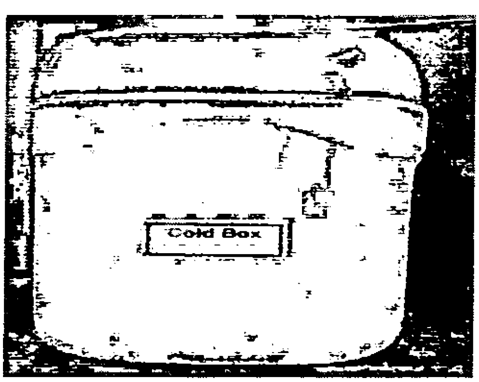
Microprocessor conductivity meter



pH Meter



Balance



Cold Box

SCHOTT Duran bottles

Figure 3.5. Instruments/ Equipments

bottles. Before samples collection bottle were rinsed 2 to 3 times with sample water then water sample collected through grab method.

For bacteriological analysis water samples were collected in sterilized Schott Duran Glass Bottles and properly labeled. In order to prevent from any physio-chemical alteration and unwanted growth of microbes samples were transported in ice box to environment and microbiology section of PCSIR Laboratory complex Peshawar for further bacteriological and physio-chemical analysis. All physio-chemical & bacteriological properties were compared with WHO and National Standards for Drinking Water Quality (NSDWQ) (Table 3.1)

Table 3.1. Physico-chemical drinking water parameters standards

Parameters	WHO, 2008	NSDWQ, 2007
pH	6.5-8.5	6.5-8.5
EC	400 µs/cm	400 µs/cm
TSS	5 mg/l	5 mg/l
Turbidity	≤5 NTU	≤5NTU

D. Analytical Parameters

The following analytical parameters were analyzed for water samples: i. Physio-chemical parameters (pH, Electrical Conductivity (EC), Total Suspended Solids (TSS) and Turbidity. Whereas, Bacteriological parameters were counting of *Coliform, Fecal coliform and E.coli.*

E. Physico-Chemical Parameters Analysis Methods

a. pH: pH of the samples was measured by using digital pH meter. The meter was calibrated with standardized buffer solution of pH 4 and 7. The electrode was removed from the buffer and inserted in the sample water and after adjustment, the pH was recorded.

b. Electrical conductivity: EC was done by conductivity meter (HANNA Instrument HI 9932). The electrode of the conductivity meter was inserted in the standard solution of potassium chloride, whose conductivity was known in order to calibrate the conductivity meter then the electrode was inserted in the sample water and the conductivity of the sample were noted in Micro Siemens per centimeter (μs/cm).

c. Total suspended solid: A filter paper was taken and dried in oven at a temperature 105°C for 10-15 minutes. After drying, cool it to room temperature and weighed (pre-weight) and placed in a funnel standing on a flask then the samples was filtered. Again the filter paper was placed in an oven at temperature of 105°C for an hour. Cooled and weighed again (Post weight). Equation (1):

$$\text{TSS, mg/}= \frac{(A\text{-}B) \times 1000}{\text{mL of sample filtered}} \quad \text{------------------------------} \quad (1)$$

Where: A= pre-weight of filter paper; B= post-weight of filter paper.

d. Turbidity: Wash glass cuvette three times with the sample water. After washing fill cuvette with sample water replace light shield cap and ensure all outside surface are clean, dry and smudge free, then press the enter button and reading was noted.

F. Bacteriological Analysis Methods

Bacteriological analysis of drinking water samples were done by Multi-tube Fermentation Method. The Most Probable Number (MPN) of bacteria present in water sample has been estimated from the specially developed statistical table. Confirmatory test on selective culture medium were also performed. Microbiological data was compared with WHO and National Standards for Drinking Water Quality (NSDWQ) (Table 3.2)

Table 3.2. Bacteriological parameters standards

Parameters	WHO, 2008	NSDWQ, 2007
Coliform	0/100ml	0/100ml
Fecal Coliform	0/100ml	0/100ml
E.coli	0/100ml	0/100ml

A. Multi-tube fermentation method for detection of *coliform* bacteria

a. Presumptive test for *coliform*

1) 10ml water sample was inoculated into tubes containing double strength Lauryl Tryptose Broth and Durham tubes.

2) After inoculation the tubes were kept in incubator at 37°C for 24-48 hours.

3) After incubation period if test tube showing only change in color of the media should be assumed positive presumptive test.

4) Change in color of medium along with gas bubble entrapped in the Durham's tube within 48 hours was the positive indication of *coliform*.

b. Confirmation test for *Coliform*

1) 1ml sample from the positive tube of Lauryl Tryptose Broth was inoculated in Brilliant Green Bile Broth (BGBB) which contains Durham's tubes.

2) Tubes containing Brilliant Green Bile Broth were incubated for 24-48 hours at 37°C.

3) After incubation period presence of gas production in BGBB containing tubes were confirm the presence of *coliform* bacteria.

c. Confirmation test for *Fecal Coliform*

1) 1ml from positive tubes of LTB was inoculated into EC broth which contains Durham's tubes.

2) After inoculation tubes were kept in shaking water bath for 24 hours at 44.5°C

3) After incubation period presences of gas production was confirmed and the presence of *fecal coliform* bacteria in drinking water sample.

d. Completed test for *E.coli*

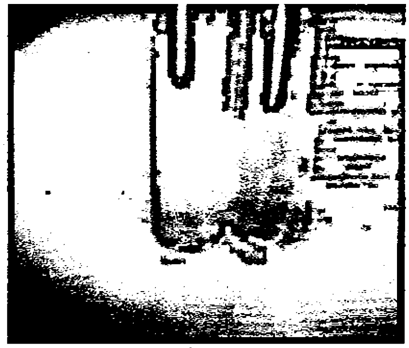
1) Streaking an inoculums loop from positive tubes of EC broth was done EMB agar plates.
2) After streaking EMB agar plates were incubated at 35°C for 24 to 48 hours.
3) After incubation period presence of metallic sheen colonies confirms the presence of *E.coli.*

B. Indole test for *E.coli* confirmation

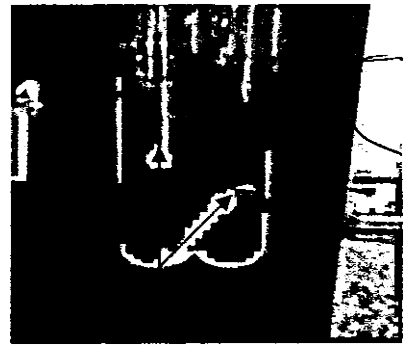
1) *E.coli* colony was inoculated from EMB agar plate into tubes containing 5ml Tryptone Water.
2) Tubes were incubated at 44.5°C for 24 to 26 hours.
3) After incubation period 0.2 to 0.3 ml Kovacs reagents was added to each tube of Tryptone Water.
4) A formation of red color ring in the upper layer was considered as *E.coli* positive.

G. Statistical Analysis

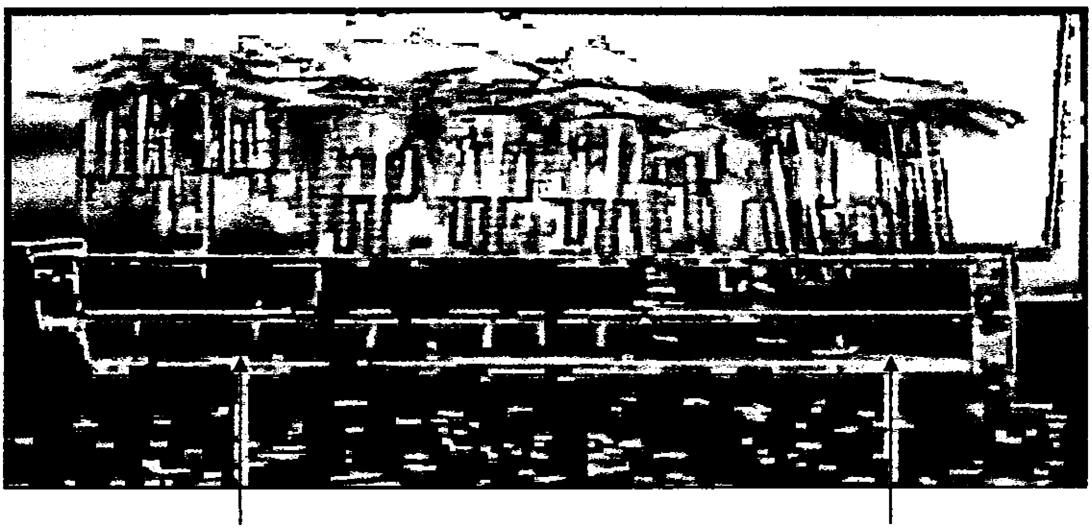
Mean and standard deviation were calculated by using M.S excel (2007) and subject to manual ANOVA (Co-stat Package) for finding significance of difference among different water samples and their types.



Coliform –ive LTB Tubes

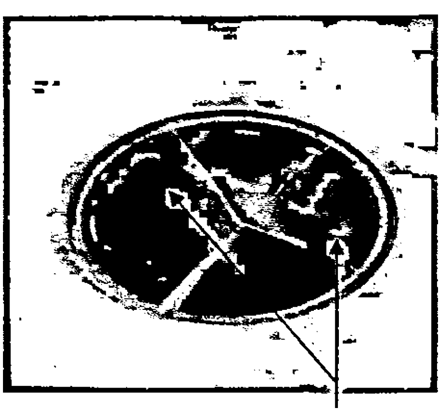


Gas bubble formation in Durham tubes

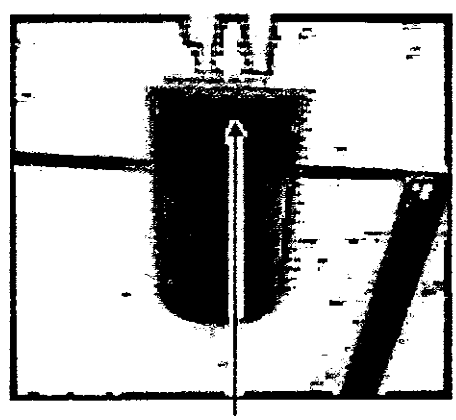


Coliform +ive LTB tubes.

Coliform +ive BGBB tubes



Typical greenish metallic colony of *E.coli*



E.coli Indole-positive tube

Figure 3.6. Pictorial view of bacteriological analysis

IV. RESULTS AND DISCUSSION

To know the drinking water quality, a total of 30 drinking water samples were taken from ten different tube well water (TWW), water distribution network (WDN) and storage tanks (STW) of Peshawar city, and were analyzed for physicochemical and bacteriological parameters.

A. Physico-chemical Analysis of Drinking Water

Drinking water analyze for physio-chemical parameters are (pH, Electrical conductivity, Turbidity and Total suspended solids). Analyzed physio-chemical parameters of drinking water results are listed in Tables 4.1 - 4.4.

a. pH

pH is one of the most important chemical parameter of drinking water and their values extend from 0-14 with a neutral value 7. In present study drinking water samples were collected from three different sources i.e. tube well, water distribution network and storage tanks from selected locations of Peshawar city and were analyzed for pH. Mean pH values of tube well's water samples were found to range from 6.64 to 7.64 (Table 4.1). Lowest pH value (6.64) was recorded in well water sample of Gulbahar whereas; the highest pH value (7.64) was recorded in well water sample of Academic Town (Figure 4.1). However there was no significant difference among all samples. The low pH value of Gulbahar well water samples may be due to large amounts of dissolved

Table 4.1. pH values of water samples of Peshawar City

Area	Sources		
	Tube well	Distribution Networks	Storage Tanks
University Town	06.98 ± 0.151	07.07 ± 0.153	06.65 ± 0.092
Shaheen Town	07.14 ± 0.157	07.20 ± 0.198	07.74 ± 0.230
Tehkal Bala	07.23 ± 0.375	07.48 ± 0.493	07.38 ± 0.156
New Arbab Colony	07.43 ± 0.211	07.40 ± 1.018	07.55 ± 0.543
Ahmad Abad	07.05 ± 0.271	07.92 ± 0.203	07.91 ± 0.253
Academic Town	07.64 ± 0.265	07.22 ± 0.206	07.33 ± 0.212
Sadar Mall Road	07.08 ± 0.302	08.21 ± 0.164	07.89 ± 0.366
Gulbahar	06.64 ± 0.110	06.71 ± 0.117	07.09 ± 0.86
Hayatabad phase 1	06.97 ± 0.273	07.01 ± 0.153	07.34 ± 0.300
Hayatabad phase 4	06.85 ± 0.273	07.08 ± 0.492	07.21 ± 0.111

minerals or due to continuous extraction of water that decrease the dissolved minerals concentration in water cause decrease in the pH of water. Water distribution network samples mean pH values falls within the range 6.71-8.21 with a maximum pH (8.21) recorded in WDN water sample of Sadar Mall Road whereas, the lowest pH value of (6.71) was recorded in Gulbahar WDN sample ((Table 4.1; Figure 4.1). Water with acidic pH value cause corrosion that damage iron made pipes and cause leaching of metals such as zinc, iron, lead and copper from pipes. Therefore a little lower pH in older part of city could be attributed to this phenomenon.

Storage tank water samples mean pH values range from 6.65 to 7.91 (Table 4.1). Water sample collected from the storage tank of University Town had the lowest pH value

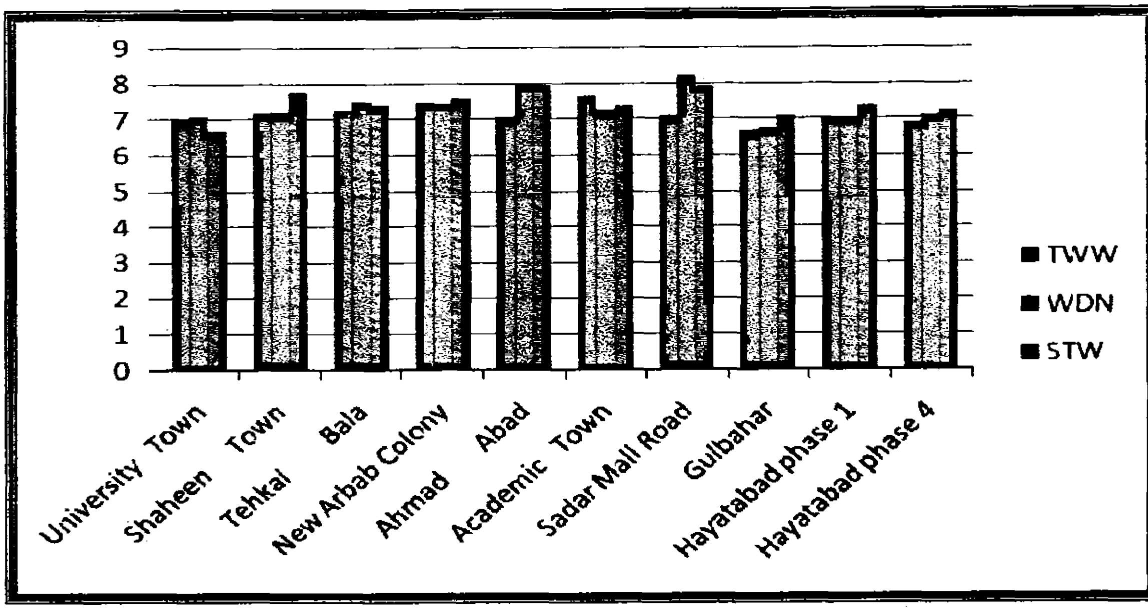


Figure 4.1. Comparison of pH among water collection sources

(6.65) whereas, storage tank water sample of Ahmad Abad, a new area of Peshawar city, was found with the highest pH (7.91)s (Figure 4.1).

However, all these values were not significantly different. It is important to note that water sample collected from storage tanks were made of concrete. Previously, it has been mentioned that concrete storage tank will cause to rise in pH of drinking water due to mixing of cement particles from concrete structure that contains Calcium carbonate ($CaCO_3$) (Quek *et al*, 1993).

Although, fluctuation was recorded in pH values of all water samples. The present study results showed that pH values were almost neutral or close to neutral (pH 7.0) except few water samples. Few variation in pH values and their alkaline nature might be due to increase in temperature that repress the solubility of carbon-dioxide or due to leakage in water distribution network through which domestic wastewater/ sewage and other pollutants enter the water distribution network from the surrounding cause alteration in pH values make them acidic or alkaline. In most of the samples there was no significant variation, only slightly variation in pH values of STW samples. However in some samples the pH was close to (8) that were from Shaheen Town, Ahmad Abad and Saddar Mall Road.

It is important to mention that water with low pH (Acidic) is not a health hazard, but decrease in pH values of drinking water may cause corrosion that damage pipes, water pumps and metallic plumbing fixture. Water with acidic pH have bitter metallic taste, corrosive and soft in nature, while water with alkaline pH have soda taste, slippery feel and hard in nature. WHO specify pH value for drinking water as 6.5 to 8.5, interestingly to say that all pH values of analyzed water sample were within the permissible limits of WHO and fit for drinking purpose (Table 3.1) (WHO, 2008).

b. Electrical conductivity (EC)

EC has a close relationship with total dissolved solids (TDS) and is an indirect measure of dissolved solids in water such as calcium, magnesium, bicarbonate, nitrogen and phosphorus etc. Water with high EC values indicates that there is high concentration of dissolved ions in water (Tchobanoglous and Schroeder, 1985). Water with high electrical conductivity has salty taste. WHO recommended EC value for drinking water is 400 µs/cm, present study results show that all water samples EC values exceeded the

Table 4.2. Electrical conductivity (µs/cm) values of water samples

Area	Sources		
	Tube well	Distribution Network	Storage Tank
University Town	636.0 ± 36.764	716.0 ± 21.029	750.0 ± 44.612
Shaheen Town	750.0 ± 36.576	768.0 ± 19.556	795.0 ± 33.320
Tehkal Bala	560.0 ± 57.248	550.0 ± 39.398	560.0 ± 40.230
New Arbab Colony	643.0 ± 45.658	615.0 ± 33.243	600.0 ± 25.188
Ahmad Abad	670.0 ± 47.731	670.0 ± 45.930	680.0 ± 38.381
Academic Town	690.0 ± 32.239	760.0 ± 30.163	702.0 ± 43.484
Sadar Mall Road	677.0 ± 38.546	695.0 ± 31.918	685.0 ± 29.128
Gulbahar	868.0 ± 16.377	881.0 ± 10.708	897.0 ± 5.487
Hayatabad phase 1	501.0 ± 41.403	519.0 ± 14.732	548.0 ± 28.39
Hayatabad phase 4	545.0 ± 28.371	557.0 ± 30.74	559.0 ± 27.54

permissible limits of WHO standards. Drinking water samples collected from tube well's, mean EC values were found to range from 501 to 868 µs/cm (Table 4.2). Hayatabad phase-1 tube well water sample was lowest EC value (501µs/cm) and Gulbahar tube well water sample was highest EC value of (868 µs/cm) (Figure 4.2).

Mean EC values of water distribution network samples were found within the range between 519 to 881 µs/cm (Table 4.2). The lowest EC values (519 µs/cm) was recorded in water sample collected from distribution network of Hayatabad phase-1 whereas, the highest EC value (881 µs/cm) was recorded in distribution network water sample of Gulbahar (Figure 4.2).

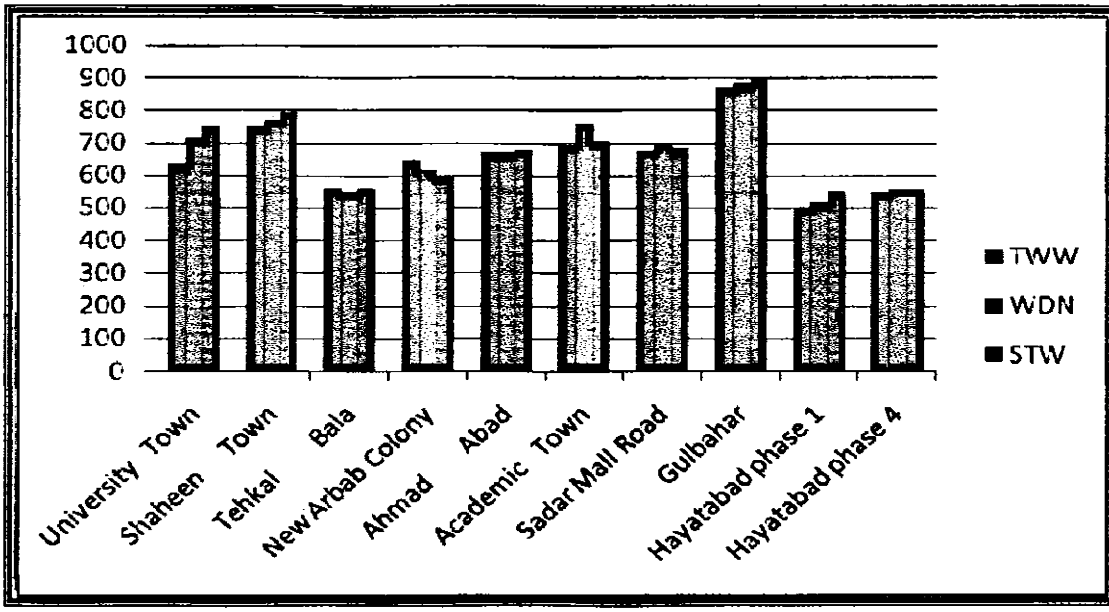


Figure 4.2. Comparison of EC (μs/cm) among water collection sources

In case of, samples from Storage tanks, the mean EC values were found in the range of 548 to 897 μs/cm (Table 4.2). Where the lowest EC value (548 μs/cm) was recorded in water sample collected from Hayatabad phase-1 storage tank and the highest EC value (897 μs/cm) was recorded in STW sample of Gulbahar (Figure 4.2).

The results of present study are comparable with the previous study for evaluation of the aesthetic quality of drinking water of Peshawar valley (Fazlullah and Salim, 1999). Previously, the results from the study revealed that all pH values were within the permissible limit of WHO and EC values of analyzed drinking water samples exceeds the permissible limit of WHO. In present study all collected water samples pH values were within the permissible limit however, EC values of all samples were found above the WHO permissible limit (Table 3.1). The samples collected in this study showed high EC level as compared to WHO Standards. However, few samples were close to WHO standards.

It could be concluded from current study that the EC values of all collected water samples were found above the permissible limits of WHO and NSDWQ. However, as a whole, the EC values of new urban Peshawar were recorded lower than that of old urban Peshawar. The highest EC values were found in water samples of Gulbahar, Shaheen Town and University town while the lowest EC values near the permissible limit of WHO were found in water samples collected from Hayatabad.

Water with high EC is a health hazard and could affect various organ systems. It is evident that intake of drinking water with high EC can have harmful effects on patients with high blood pressure as well as may cause heart problems (DWAF, 1998). In another study it has been reported that drinking water with high EC can also have adverse effects on the blood circulation, nervous conduction and biochemical reaction system (Virkutye and Sillanpaa, 2006).

c. Turbidity

WHO and NSDQW recommended turbidity value for drinking water is 5 NTU. The present study reported the results of 5 tube well's water samples, 7 water distribution network samples and 9 storage tanks water samples with a turbidity values exceeding the permissible limits of WHO and NSDWQ (Table 3.1).

Independently, the drinking water samples collected from tube well's, mean turbidity values were found in the range of 2-12 NTU with the lowest turbidity (2 NTU) was seen in tube well water sample of Hayatabad phase # 1 and the highest turbidity (12 NTU) was observed in tube well water sample of Academic town ((Table 4.3; Figure 4.3). Similarly, the samples from water distribution network (WDN), samples mean turbidity values were found in a range between 3-17 NTU (Table 4.3). Where the lowest turbidity value (3 NTU) was observed in water distribution network samples of Hayatabad phase#1 and the highest turbidity (17 NTU) was seen in water distribution network sample of Sadar Mall Road (Figure 4.3).

In case of mean turbidity values of storage tanks, water samples were found in the range between 5 to 20 NTU (Table 4.3). Where, the lowest turbidity (5 NTU) was noted in storage tank water sample of New Arbab Colony while highest turbidity (20 NTU) was seen in storage tank water sample collected from Sadar Mall Road (Figure 4.3).

Similar study was undertaken previously by Amjad *et al.* (2010) on physical and bacteriological analysis of drinking water of urban and rural Peshawar in 2007. However, it was reported that all physical parameters (pH, EC and Turbidity) values were within the WHO limits and was found fit for drinking. On the contrary, the results of current study do not support this previous report. It could be due to a lot has changed during past few years.

Table 4.3. Turbidity values of drinking water samples

Area	Sources		
	Tube well	Distribution Network	Storage Tank
University Town	3.0 ± 0.942	8.0 ± 03.464	9.0 ± 03.126
Shaheen Town	9.0 ± 04.055	8.0 ± 03.265	12.0 ± 04.082
Tehkal Bala	8.0 ± 02.867	6.0 ± 02.160	8.0 ± 02.708
New Arbab Colony	6.0 ± 01.699	5.0 ± 01.825	5.0 ± 01.885
Ahmad Abad	5.0 ± 01.825	8.0 ± 02.560	9.0 ± 03.091
Academic Town	12.0 ± 02.943	10.0 ± 02.708	8.0 ± 02.494
Sadar Mall Road	9.0 ± 02.624	17.0 ± 05.577	20.0 ± 02.449
Gulbahar	4.0 ± 01.490	7.0 ± 01.943	9.0 ± 01.972
Hayatabad phase 1	2.0 ± 0.942	3.0 ± 01.054	6.0 ± 01.414
Hayatabad phase 4	3.0 ± 01.333	5.0 ± 01.632	9.0 ± 02.943

There was variation in the turbidity values of all collected water samples. Most water samples showed turbidity above the permissible limit of WHO, where the turbidity values of TWW was lower as compared to WDN and STW samples. Highest turbidity value was found in water samples of Sadar Mall Road followed by Academic Town and Shaheen Town.

It is important to mention that turbidity in water reduces the capacity of chlorine based disinfection and provides a growth medium to microbes including pathogens. Therefore, high is an indicator of bacterial load and other pathogenic microbes which cause diarrhea, nausea, vomiting and cramps (EPA, 2002; Schwartz *et al*., 2000).

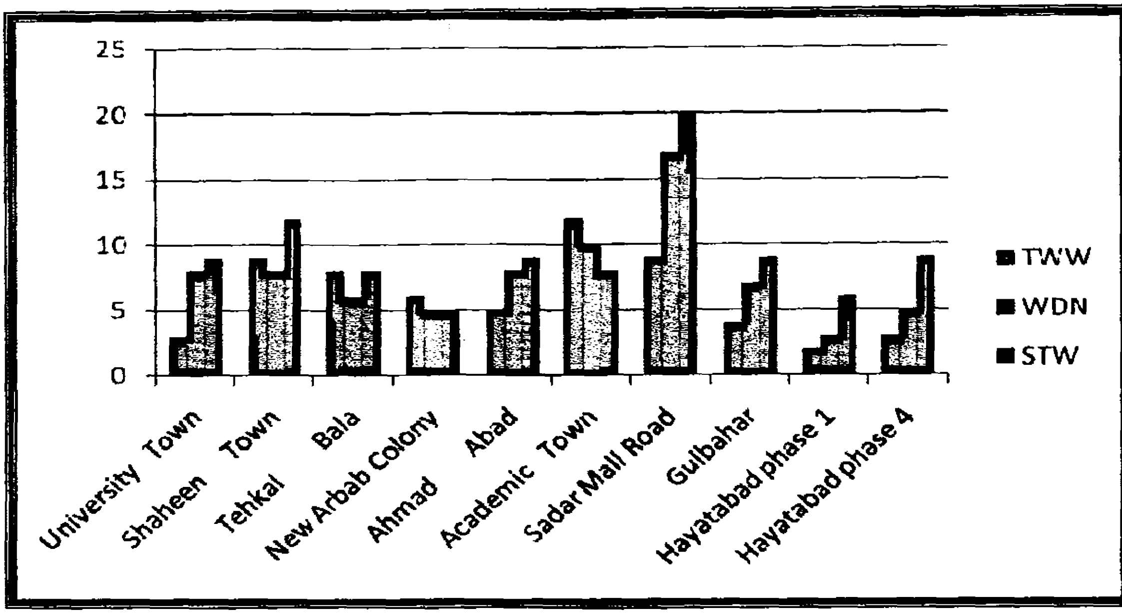


Figure 4.3. Comparison of Turbidity (NTU) among water collection sources

d. Total suspended solids (TSS)

TSS are inorganic in nature with small sized solid particles of silt and clay, and are light in weight remain in suspension in water throughout life due to water motion (McAlister and Ormsbee, 2005). WHO recommends a TSS concentration (5 mg/L) In present study, 10% tube well's water samples, 30% distribution network and 60% storage tanks water samples, the TSS concentration were found above the permissible limits of WHO (Table 3.1). Tube well's water samples mean TSS concentration values were found in the range of 2 to 6 mg/L (Table 4.4). Minimum TSS concentration (2 mg/L) was observed in Hayatabad phase-4 tube well water sample, while maximum TSS concentration 6mg/L was observed in tube well water sample of Sadder Mall Road (Figure 4.4).

Table 4.4. Total suspended solids (TSS) values of drinking water samples

Area	Sources		
	Tube well	Distribution Network	Storage Tank
University Town	4.0 ± 01.414	4.0 ± 02	4.0 ± 01.247
Shaheen Town	5.0 ± 02.170	6.0 ± 03.182	4.0 ± 01.490
Tehkal Bala	4.0 ± 01.563	5.0 ± 01.632	6.0 ± 02.403
New Arbab Colony	3.0 ± 01.247	4.0 ± 01.632	6.0 ± 02.403
Ahmad Abad	3.0 ± 01.563	6.0 ± 01.054	6.0 ± 01.414
Academic Town	4.0 ± 01.247	4.0 ± 01.414	5.0 ± 01.414
Sadar Mall Road	6.0 ± 01.154	11.0 ± 03.527	23.0 ± 03.431
Gulbahar	3.0 ± 01.563	5.0 ± 01.943	10.0 ± 02.357
Hayatabad phase 1	3.0 ± 01.247	3.0 ± 01.154	4.0 ± 01.333
Hayatabad phase 4	2.0 ± 0.816	4.0 ± 01.054	7.0 ± 01.414

Water samples collected from distribution network mean TSS concentration values were found to range between 2 to 11 mg/L (Table 4.4). Highest TSS concentration (11 mg/L) was observed in distribution network samples of Sadar Mall Road and lowest TSS concentration (2 mg/L) was observed in distribution network samples of University town (Figure 4.4).

Mean TSS concentration values in storage tank water samples were found to range between 4 to 23 mg/L (Table 4.4). High TSS concentration (23 mg/L) was found in Sadder Mall Road storage tank water sample and lowest TSS concentration (4 mg/L) was found in storage tank water sample of University Town, Shaheen Town and Hayatabad phase-1 (Figure 4.4).

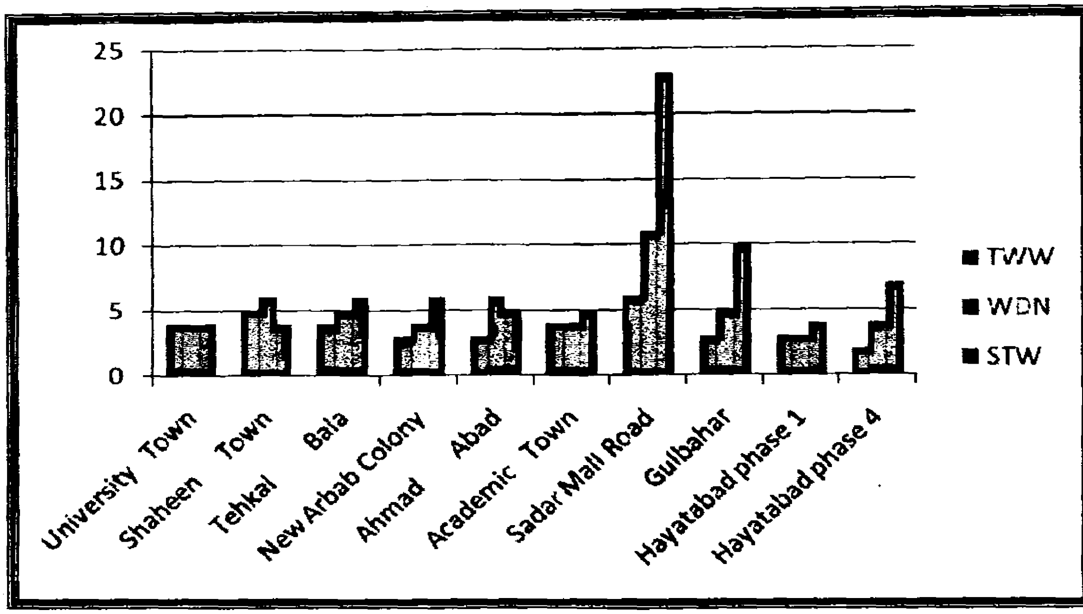


Figure 4.4. Comparison of TSS (mg/L) among water collection sources

Present study results showed that there is no significant variation in TSS values of all collected drinking water samples. Mostly water samples TSS values were found under the specify limit of WHO. TWW samples have lower TSS concentration as compared WDN and STW samples. However water samples collected from Sadar Mall Road was found the highest TSS concentration. However lower TSS concentration was found in drinking water samples collected from new urban Peshawar as compared old urban Peshawar.

In a study conducted to analyze the Physio-chemical and bacteriological quality of drinking water used for drinking and swimming purposes in Abeokuta, Nigeria (Shittu *et al*, 2008), it was reported that pH and turbidity of the well water samples were within the permissible limit and EC values above the permissible limits of WHO. Stream and river water samples pH value were within the permissible limits while EC and turbidity were above the permissible limits. TSS of all the collected samples was above the permissible limits. Similarly, Nasrullah *et al*, (2006) carried out similar studies on underground water quality of Swabi, (KPK). Total three drinking water samples were collected from tube well and were analyzed for physio-chemical parameters, Temperature, pH, EC, TSS and Biological Oxygen Demand (BOD). Their study results show that all physio-chemical parameters of collected water samples were within the permissible limits of WHO and NSDWQ and fit for human consumption.

TSS is one of the well known water pollutant and play important role in the spreading of microbial pathogens. High TSS concentration in water, increase turbidity and reduce the transparency of water. High concentration of TSS in water may be due to domestic sewage, entrance of waste water and effluents into water distribution network through leakages, improper dumping of municipal solids waste and weathering of soil etc.

B. Bacteriological Analysis of Drinking Water

The bacteriological analysis for the presence of *Total Coliforms*, *Fecal Coliform* and *E.coli* was conducted and results are listed in tables 4.5-4.7.

Tube well water samples collected from various location of Peshawar city were analyzed for *Coliform, Fecal Coliform* and *E.coli*. According to the results, tube well's water samples contained *coliform* population in range of 2.2 - 16 MPN/100mL (Table 4.5). Minimum *coliform* population (2.2 MPN/100mL) was detected in tube well water

Table 4.5. Bacteriological analysis of tube well water (TWW)

Area	Parameters		
	Coliform	*Fecal coliform*	*E.coli*
University Town	2.2	-ive	-ive
Shaheen Town	2.2	-ive	-ive
Tehkal Bala	16	+ive	-ive
New Arbab Colony	<1.1	-ive	-ive
Ahmad Abad	16	-ive	-ive
Academic Town	16	-ive	-ive
Sadar Mall Road	12	-ive	-ive
Gulbahar	5.1	-ive	-ive
Hayatabad phase 1	<1.1	-ive	-ive
Hayatabad phase 4	<1.1	-ive	-ive

samples of University town and Shaheen town, whereas, a maximum *coliform* population was detected in tube well water samples of Tehkal Bala, Ahmad Abad and Academic town (Table 4.5). On the other hand, water sample collected from New Arbab Colony, Hayatabad phase-1 and Hayatabad phase-4 were found free from *coliform* contamination.

Fecal coliform bacteria only isolated from well water sample of Tehkal Bala (Table 4.5). Similarly all tube well's water samples were analyzed for detection of *E.coli*. Present studies results showed that all tube well water sample were found free from *E.coli* contamination (Table 4.5).

In Pakistan drinking water quality deteriorate day to day due to improper management, poor sanitary condition and lack of awareness among peoples about drinking water quality. (Najmul *et al,* 2009) studied the quality of bottled water, ground and river water in various parts of Pakistan utilized for drinking purpose. They concluded that 90% well and ground water and 37% bottle water were found contaminated with *coliform* and *fecal coliform* bacteria.

Similarly, Hamida *et al* (2006) studied the bacteriological quality of ground water of Peshawar city in 2005-06, and collected drinking water samples from hand pumps of various schools. It was reported that only 8% samples were found free from bacterial contamination while remaining 92% samples were found positive for bacterial contamination and unfit for drinking. Water samples were analyzed for detection of *coliform, fecal coliform* and *E.coli* independently and revealed that 42% samples contaminated with *coliform* bacteria, whereas, *fecal coliform* were isolated from 33% water samples and *E.coli* was detected in 6% collected water samples of hand pumps.

According to current study, in water WDN samples *coliform* numbers ranged from 1.1 to > 23 MPN/100mL (Table 4.6), where the highest *coliform* count (>23MPN/100mL) were found in WDN of Shaheen Town, Tehkal Bala, New Arbab Colony, Ahmad Abad and Academic Town, while the lowest *coliform* count (1.1 MPN/100mL) was found in WDN samples from Hayatabad Phase-4 (Table 4.6). As a whole, the present study results showed that all WDN samples contaminated with *coliform* bacteria.

Table 4.6. Bacteriological analysis of water distribution network (WDN)

Area	Parameters		
	Coliform	*Fecal coliform*	*E.coli*
University Town	5.1	-ive	-ive
Shaheen Town	>23	-ive	-ive
Tehkal Bala	>23	+ive	+ive
New Arbab Colony	>23	+ive	+ive
Ahmad Abad	>23	-ive	-ive
Academic Town	>23	+ive	+ive
Sadar Mall Road	16	+ive	-ive
Gulbahar	9.2	+ive	-ive
Hayatabad phase 1	2.2	-ive	-ive
Hayatabad phase 4	1.1	-ive	-ive

In case of *Fecal coliform* isolated from WDN samples of Tehkal Bala, New Arbab Colony, Academic Town, Sadar Mall Road and Gulbahar were found positive, (Table 4.6). *Fecal coliform* positive samples were further analyzed for detection of *E.coli*. *E.coli* was detected in water distribution network samples of Tehkal Bala, New Arbab Colony and Academic Town, as well (Table 4.6).

Water samples collected from storage tanks were analyzed for *coliform, fecal coliform* and *E.coli*. Storage tank water samples, *coliform* bacteria counts were within the range between 2.2 to > 23 MPN/100mL (Table 4.7) with minimum *coliform* (2.2 MPN/100mL) was detected in storage tank water samples collected from Hayatabad Phase-4 while maximum *coliform* bacteria were detected in storage tanks water samples of University Town, Shaheen Town, Tehkal Bala, New Arbab Colony, Ahmad Abad

Table 4.7. Bacteriological analysis of storage tanks water (STW)

Area	Parameters		
	Coliform	*Fecal coliform*	*E.coli*
University Town	>23	+ive	-ive
Shaheen Town	>23	-ive	-ive
Tehkal Bala	>23	+ive	+ive
New Arbab Colony	>23	+ive	+ive
Ahmad Abad	>23	-ive	-ive
Academic Town	>23	+ive	+ive
Sadar Mall Road	12	+ive	-ive
Gulbahar	16	+ive	-ive
Hayatabad phase 1	3.6	-ive	-ive
Hayatabad phase 4	2.2	-ive	-ive

and Academic Town (Table 4.7). All collected water samples from storage tanks were *coliform* positive. Previously, (Zahoor and Tasleem, 2003) carried out studies for drinking water quality in rural Peshawar. Tube well and storage tanks water samples were analyzed for bacterial contamination. Their study results showed that only 13% samples were found free from bacterial contamination, 40% were found in the satisfactory level, whereas, 47% samples were found to be highly contaminated with bacteria.

Fecal coliform bacteria were detected in storage tanks water samples collected from University Town, Tehkal Bala, New Arbab Colony, Academic Town, Sadar Mall Road and Gulbahar (Table 4.7). *Fecal coliform* positive samples were further analyzed for detection of *E.coli*. Present study results showed that storage tank water samples of

Tehkal Bala, New Arbab Colony and Academic Town contaminated with *E.coli* (Table 4.7).

Similar studies were carried out by Franciska *et al* (2005) analyzed the quality of drinking water from private water supplies in Netherlands. Total 144 samples were collected for bacteriological analysis. Their results showed that 10.9% samples were contaminated due to *E.coli* and *Enterococci* presence. On the other hand, the present study bacteriological analysis, results showed that 90% drinking water samples were found contaminated due to *coliform* bacteria presence, 40% drinking water samples contaminated with *fecal coliform,* while *E.coli* was detected in 20% collected water samples. These results indicate that drinking water of Peshawar city, a part of a developing country like Pakistan, is highly vulnerable to bacterial contamination. It is due to poor constructed well head, older water distribution network and continuous leakages in these water distribution network, through which seepage from the surrounding enter and contaminate the drinking water during supply, cross contamination with wastewater, short distance between sewage supply line and water supply lines, construction of septic tanks near tube well from which wastewater percolate and contaminate the underground water. In Peshawar city mostly wastewater and drinking water supply lines were found on the surface of ground and running side by side, is one of the major causes of bacterial contamination of drinking water.

V. CONCLUSIONS AND RECOMMENDATIONS

Water consumer can become involved by participating in planning making to maintain and install water pollution protection measures. Whether they are connected to a community water supply or a private domestic well, everyone wants to be assured that their drinking water sources are safe from bacterial contamination, environmental pollution and other risks. This investigation showed much variation among physio-chemical and bacteriological parameters in different location of Peshawar city. Based on the data generated by thorough analysis of source, storage and WDN, the following conclusions were drawn from the results of present study.

A. Conclusions

According to physico-chemical analysis, i.e., pH, EC, TSS, turbidity, most of the samples from old Peshawar city irrespective of source were found above permissible WHO or NSDWQ drinking water quality standards with few exceptions in newer parts of the town. Similarly, the bacteriological analysis, and its results did not show a different overall picture of City, as 20 - 90% drinking water samples were found contaminated due to either *coliform* bacteria or contaminated with *fecal coliform or E.coli*. This result indicates that drinking water of Peshawar city, a part of a developing country like Pakistan, is highly vulnerable to bacterial contamination.

Sewage, domestic waste water, land and urban runoff were normally discharged into water bodies. The presence of *fecal coliform* and *E.coli* presence are indicative, involving a high degree of water receiving sewage effluents and fecal materials. Furthermore, fecal contamination of well, distribution network and storage tanks water was largely due to lack of proper sewage disposal facilities. It was evident that water contamination was mostly due to cross links and leaks in water distribution pipes, absence of an appropriate drainage system for domestic wastewater. Unhygienic conditions were seen during study, as pipelines passing to waste water nallahs, water storage tanks were not properly covered. Pile of garbage was found near tube well without any proper management. No responsible authorities were found, performing their job in proper mean and incompetent individuals, poorly trained staff were employed in water management system. The main problem was lack of financial investment capacity of local, provincial or national government in drinking water sector. In addition on individual basis, the water storage tank and taps in the domestic use or houses were not well protected against bacterial contamination, poorly maintained.

Similar study was undertaken previously by Amjad *et al* (2010) on physical and bacteriological analysis of drinking water of urban and rural Peshawar. However, it was reported that all physical parameters (pH, EC and Turbidity) values were within the WHO limits but bacteriological parameters results reported that 26% water samples were contaminated with *coliform* and *E.coli*. Therefore, it was concluded on the basis of bacteriological parameters drinking water of Peshawar city were highly contaminated and not fit for drinking.

B. Recommendations

Knowing that what can be done to protect water begins with knowing its source, as water is pumped from wells and distributed either through a community supply system or directly to the home from a private well. It is therefore recommended that:

- Cooperation between the government and public must be strengthened to achieve the goal of sustainable development and the responsible authorities are recommended to install new pipelines for distribution of drinking water. Government must established laboratories and required equipments for measurement of contaminant level in water. Water filtration and treatment plants should be installed, and periodically chlorination treatment for distribution of safe drinking water.
- The responsible department should maintain quality of drinking water within the recommended limits of WHO and Environmental protection agency (EPA) should specify criteria for the disinfection of public water supply.
- Proper scientific methods should be followed for waste water disposal.
- Before supplying drinking water to the consumers it should be purified adequately. During rainy season when there is a risk of enteric epidemic drinking water should be boiled before consumption. Municipal water supplies should routinely be examined for *coliform* bacteria, indicator of fecal material in water. Health department should develop a data regarding the epidemiological

aspects of various waterborne diseases. This will help in developing strategy for the control of waterborne diseases in the community.

- Drinking water sources should be protected from wastewater and other pollutant contamination. Drinking water should be stored in properly constructed tanks well protected from seepage of waste water.
- For effective awareness educational institutions, mass media should be used for creating awareness about the importance of water quality among the user.
- Importance of water quality should be addressed, so that peoples could away from the waterborne illnesses.

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APPENDIX

Appendix A. pH values of all triplicates water samples of Peshawar City

Area		Sources		
		TWW	**WDN**	**STW**
University Town	*August*	6.85	7.02	6.58
		6.72	6.83	6.61
		6.91	7.04	6.53
	October	7.09	7.06	6.68
		6.93	6.97	6.75
		6.87	7.08	6.73
	December	7.12	6.98	6.62
		7.16	7.35	6.81
		7.17	7.30	6.54
		TWW	**WDN**	**STW**
Shaheen Town	*August*	7.02	7.14	7.49
		7.23	7.27	7.62
		7.11	7.08	7.96
	October	6.87	6.98	7.84
		6.99	7.35	7.74
		7.37	7.43	7.89
	December	7.09	7.55	7.94
		7.32	6.96	7.93
		7.26	7.04	7.25
		TWW	**WDN**	**STW**
Tehkal Bala	*August*	6.89	7.32	7.14
		7.04	7.73	7.53
		7.11	7.65	7.35
	October	6.97	7.89	7.59
		7.18	7.81	7.43
		6.74	7.88	7.39
	December	7.54	7.82	7.51
		7.65	6.59	7.11
		7.95	6.63	7.37
		TWW	**WDN**	**STW**
New Arbab Colony	*August*	7.35	7.42	7.63
		7.45	7.51	7.81
		7.22	7.35	7.75
	October	7.08	7.28	7.69
		7.29	7.48	7.67
		7.57	7.61	7.74
	December	7.83	7.79	7.83
		7.51	7.03	7.05
		7.57	7.13	6.78

Area		Sources		
		TWW	**WDN**	**STW**
Ahmad Abad	*August*	6.65	7.95	7.91
		6.74	7.85	7.80
		7.36	7.87	7.85
	October	7.26	7.94	7.96
		6.93	7.83	7.87
		7.11	8.39	8.19
	December	7.03	7.98	7.97
		7.18	7.71	7.72
		7.24	7.76	7.92
		TWW	**WDN**	**STW**
Academic Town	*August*	7.53	7.11	7.41
		7.72	7.26	7.58
		7.47	7.32	7.39
	October	7.87	7.59	7.64
		7.92	7.02	7.12
		7.83	7.41	7.53
	December	7.48	6.98	7.10
		7.43	6.93	6.97
		7.51	7.36	7.23
		TWW	**WDN**	**STW**
Sadar Mall Road	*August*	6.67	7.98	7.85
		6.85	7.97	7.87
		7.04	8.19	8.11
	October	7.01	8.21	8.09
		7.35	8.37	8.23
		6.87	8.09	8.13
	December	6.95	8.23	8.20
		6.52	8.42	7.09
		7.46	8.43	7.44
		TWW	**WDN**	**STW**
Gulbahar	*August*	6.51	6.63	6.95
		6.54	6.91	6.97
		6.57	6.82	7.09
	October	6.63	6.67	7.12
		6.68	6.73	7.03
		6.83	6.57	7.21
	December	6.67	6.58	7.19
		6.53	6.63	7.10
		6.80	6.85	7.15

Area		TWW	WDN	STW
Hayatabad Phase-1	*August*	6.73	6.85	6.93
		6.68	6.97	6.94
		7.01	7.09	7.45
	October	7.23	7.18	7.39
		7.48	7.23	7.52
		7.09	6.91	7.12
	December	7.12	6.98	7.19
		6.63	6.74	7.83
		6.76	7.14	7.69
		TWW	**WDN**	**STW**
Hayatabad Phase-4	*August*	6.62	6.97	7.05
		6.59	6.85	7.09
		6.71	7.03	7.13
	October	6.64	6.98	7.23
		6.87	7.12	7.22
		7.01	7.35	7.43
	December	6.98	7.04	7.21
		6.93	7.14	7.20
		7.29	7.24	7.33

Appendix B. Electrical conductivity values of all triplicates water samples of Peshawar City

Area		Sources		
		TWW	**WDN**	**STW**
University Town	*August*	693	702	718
		674	714	728
		675	723	742
	October	587	693	701
		601	699	719
		623	708	763
	December	591	701	798
		633	748	782
		647	756	799
		TWW	**WDN**	**STW**
Shaheen Town	*August*	716	736	758
		730	760	763
		732	772	792
	October	711	743	764
		709	760	779
		773	768	780
	December	789	785	835
		792	793	840
		798	795	844
		TWW	**WDN**	**STW**
Tehkal Bala	*August*	501	503	503
		507	506	505
		507	511	520
	October	525	515	543
		553	550	574
		568	593	590
	December	639	585	595
		613	583	601
		627	604	609
		TWW	**WDN**	**STW**
New Arbab Colony	*August*	597	580	573
		613	602	582
		618	608	603
	October	657	622	619
		670	662	623
		680	680	627
	December	691	587	580
		610	591	585
		651	603	608

Area		Sources		
		TWW	**WDN**	**STW**
Ahmad Abad	*August*	618	625	635
		639	642	645
		664	642	658
	October	628	639	660
		642	645	661
		653	650	675
	December	722	718	720
		720	733	736
		745	735	730
		TWW	**WDN**	**STW**
Academic Town	*August*	645	741	713
		660	765	737
		663	758	750
	October	671	718	720
		687	738	729
		711	742	733
	December	730	789	659
		718	793	627
		725	796	650
		TWW	**WDN**	**STW**
Sadar Mall Road	*August*	641	653	652
		657	663	661
		658	688	675
	October	674	677	660
		685	682	681
		688	698	689
	December	683	713	720
		699	734	722
		708	747	705
		TWW	**WDN**	**STW**
Gulbahar	*August*	868	885	898
		866	880	899
		881	891	897
	October	839	860	893
		854	865	895
		873	884	898
	December	883	889	896
		895	893	899
		853	882	898

Area		TWW	WDN	STW
Hayatabad Phase-1	*August*	479	474	519
		498	493	523
		533	468	538
	October	512	500	543
		535	520	557
		578	540	572
	December	483	563	563
		435	542	572
		456	571	545
		TWW	**WDN**	**STW**
Hayatabad Phase-4	*August*	527	548	541
		543	560	570
		545	565	572
	October	551	552	550
		559	588	586
		568	582	580
	December	530	531	566
		540	528	530
		534	559	536

Appendix C. **Turbidity values of all triplicates water samples of Peshawar City**

Area		Sources		
		TWW	**WDN**	**STW**
University Town	*August*	4	7	7
		3	5	9
		2	6	10
	October	5	11	11
		3	13	9
		2	10	10
	December	3	7	9
		2	6	9
		3	7	7
		TWW	**WDN**	**STW**
Shaheen Town	*August*	7	7	13
		9	8	15
		7	9	14
	October	14	9	12
		12	12	15
		14	10	16
	December	6	5	8
		7	7	8
		5	5	7
		TWW	**WDN**	**STW**
Tehkal Bala	*August*	8	5	7
		7	8	6
		9	7	8
	October	10	7	10
		8	5	8
		9	4	7
	December	8	6	9
		6	5	8
		7	7	9
		TWW	**WDN**	**STW**
New Arbab Colony	*August*	5	4	4
		5	3	6
		6	4	5
	October	5	6	6
		9	7	7
		6	5	4
	December	7	6	5
		6	4	4
		5	6	4

Area		Sources		
		TWW	WDN	STW
Ahmad Abad	August	4	7	10
		5	10	9
		4	9	13
	October	4	8	10
		5	8	9
		5	7	10
	December	7	9	8
		6	7	6
		5	7	6
		TWW	WDN	STW
Academic Town	August	15	10	8
		15	13	9
		14	11	11
	October	11	9	7
		10	8	6
		9	11	9
	December	11	10	8
		13	9	8
		10	9	6
		TWW	WDN	STW
Sadar Mall Road	August	9	12	19
		12	17	21
		12	20	23
	October	8	12	19
		9	14	17
		9	15	20
	December	7	18	20
		7	24	21
		8	21	20
		TWW	WDN	STW
Gulbahar	August	3	7	10
		4	8	11
		3	6	8
	October	5	9	9
		4	6	8
		4	7	6
	December	5	6	11
		5	7	9
		4	7	8

Area		TWW	WDN	STW
Hayatabad Phase-1	*August*	2	3	5
		2	5	7
		3	4	7
	October	2	4	8
		2	2	4
		2	3	7
	December	2	3	5
		1	1	4
		2	2	7
		TWW	**WDN**	**STW**
Hayatabad Phase-4	*August*	4	6	11
		3	4	9
		4	7	13
	October	3	4	7
		2	7	9
		4	3	6
	December	3	5	9
		2	4	8
		2	5	8

Appendix D. Total suspended solids values of all triplicates water samples of Peshawar City

Area		Sources		
		TWW	WDN	STW
University Town	August	4	4	4
		7	5	5
		3	6	4
	October	5	3	5
		2	4	3
		4	4	4
	December	3	3	3
		5	3	4
		3	4	4
		TWW	WDN	STW
Shaheen Town	August	6	6	3
		5	6	4
		7	7	4
	October	4	6	4
		5	7	5
		5	7	5
	December	5	6	3
		4	4	3
		4	5	5
		TWW	WDN	STW
Tehkal Bala	August	4	5	6
		4	6	7
		4	6	9
	October	3	6	6
		4	5	5
		3	5	8
	December	5	4	4
		4	3	5
		5	5	4
		TWW	WDN	STW
New Arbab Colony	August	3	4	6
		3	3	6
		2	3	5
	October	4	7	9
		6	6	7
		2	3	5
	December	3	4	6
		2	2	4
		2	4	6

Area		Sources		
		TWW	WDN	STW
Ahmad Abad	August	2	5	6
		3	4	4
		3	6	8
	October	3	7	5
		4	7	7
		3	6	4
	December	3	7	6
		2	5	6
		4	7	8
		TWW	WDN	STW
Academic Town	August	3	4	4
		4	4	6
		3	6	6
	October	5	5	5
		4	6	7
		6	4	6
	December	3	3	3
		3	2	4
		5	2	4
		TWW	WDN	STW
Sadar Mall Road	August	7	9	19
		5	12	18
		8	13	21
	October	6	8	25
		4	10	24
		6	13	29
	December	8	12	27
		5	10	21
		5	12	23
		TWW	WDN	STW
Gulbahar	August	3	3	7
		3	5	9
		4	7	13
	October	4	9	15
		3	4	10
		3	6	8
	December	2	3	9
		3	5	10
		3	3	9

Area		TWW	WDN	STW
Hayatabad Phase-1	*August*	2	3	3
		4	4	6
		3	3	4
	October	3	2	4
		3	5	3
		2	3	6
	December	3	3	5
		3	2	3
		4	2	2
		TWW	**WDN**	**STW**
Hayatabad Phase-4	*August*	1	4	6
		2	5	6
		2	5	8
	October	3	2	5
		3	3	6
		2	5	9
	December	1	3	6
		2	4	8
		2	5	9