

WATER QUALITY PROFILE OF PAKISTAN (22 CITIES)



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EXECUTIVE SUMMARY

The National Water Quality Monitoring Program is executed at 22 major cities of Pakistan including federal city of Islamabad. The province wise distribution is **Punjab**: Bahawalpur, Faisalabad, Gujranwala, Gujrat, Kasur, Lahore, Multan, Rawalpindi, Sargodha, Sheikhpura, Sialkot; **NWFP**: Mangora, Mardan, Peshawar; **Balochistan**: Khuzdar, Loralai Quetta, Ziarat; **Sindh**: Hyderabad, Karachi, Sukkur. The water sources in all cities were selected from where the people are getting water mainly for drinking purposes. The water samples for analysis were collected from overall 344 different water sources. The analytical parameters were divided into Physical and Aesthetic, Major Components (Chemicals), Trace & Ultra Trace Elements and Bacteriological (Coliform, *E.Coli*) parameters. The overall profile of drinking water quality was described on city level instead of parameter. **Federal Area Islamabad**, out of 26 locations 01 water source is safe for drinking. The 65% samples were contaminated with Coliform bacterium and 23% polluted with *E.Coli*, 73% samples have excess of Ca. **Punjab Province, Bahawalpur** out of 25 locations no water source was safe for drinking. 24% samples were polluted with *E.Coli*, 52% was contaminated with Coliform bacterium, 76% samples possessing excess Arsenic (As). High concentration of Iron (Fe) was found in 64% samples. **Faisalabad** 15% samples polluted with *E.Coli*, 38% samples contaminated with Coliform, out of 13 sources 03 were safe for drinking. **Gujranwala** out of 14 locations 04, sources were safe for drinking. The 14% polluted with *E.Coli*, 64% contaminated with Coliform, 43% samples having the Arsenic level beyond permissible limits. **Gujrat** out of the 9 locations 02 water sources were safe for drinking. The 33% samples were polluted with *E.Coli* and 78% were contaminated with Coliform. **Kasur** out of 10 locations no source was safe for drinking, 10% samples polluted with *E.Coli* and 50% contaminated with Coliform organisms. The level of As (10 ppb) in 80% samples were beyond permissible limits. **Lahore** out of 16 locations no source is safe for drinking, 100% samples possessing high concentrations of As and 43% samples were polluted with Coliform and less percentage (11%) of samples was observed contaminated with *E.Coli* bacterium. **Multan** out of 16 locations no source is safe for drinking, 31% samples contaminated with Coliform. A quite high percentage (88%) of water samples were showing more concentration of As and 50% samples were found with high concentration of Fe. **Rawalpindi** out of 15 locations 2 sources found safe for drinking, 40% samples were found polluted with *E.Coli* and 73% contaminated with Coliform, 60% samples possessing high concentration of Ca. **Sargodha** out of 24 locations 01 source was safe for drinking, 38% samples polluted with *E.Coli* and 75% contaminated with Coliform. The high level of TDS was observed in 62% samples. **Sheikhpura** out of 11 locations 01 source was safe for drinking, 9% samples were polluted with *E.Coli*, 36% contaminated with Coliform, 45% samples possessing higher levels of As. **Sialkot** out of 10 locations no source was safe for drinking, 30% samples polluted with *E.Coli* and 70% contaminated with Coliform. **Province of NWFP, Mangora** out of 10 locations 02 are safe for drinking, 10% samples contaminated with *E.Coli*, 40% contaminated with Coliform. **Mardan** out of 12 locations no source was safe for drinking water, 8% samples polluted with *E.Coli* 75% contaminated with Coliform, 67% samples have concentrations of Fe beyond the permissible limits. **Peshawar** out of 13 tubewells, only 03 tubewells were pumping safe drinking water, 15% samples contaminated with *E.Coli* and 31% polluted with Coliform. The Fe concentration was high in 62% samples. **Province of Balochistan, Khuzdar** out of 11 locations no source was safe for drinking. Dominant sources of water are contaminated with fecal organisms *E.Coli* (55%) and Coliform (91%). **Loralai** out of 10 locations 03 sources are safe for drinking, 70% samples contaminated with *E.Coli* and Coliform microorganisms. **Quetta** out of 34 locations 12 sources were safe for drinking, 23% samples were polluted with *E.Coli*, 50% contaminated with Coliform, 23% samples have NO₃ 2+3 Fe and Floride in higher concentrations. **Ziarat** out of 10 locations no source is safe for drinking, 100% samples polluted with *E.Coli* and Coliform. **Province of Sindh, Hyderabad** out of 15 locations no source is safe for drinking, 93% samples polluted with *E.Coli* and 100% contaminated with Coliform, 80% have the Turbidity level beyond the permissible limits. **Karachi** out of 28 locations no source was safe for drinking, 86% samples polluted with *E.Coli* and 100% contaminated with Coliform. **Sukkur** out of 12 locations 02 sources were safe for drinking, 67% samples polluted with *E.Coli* and 75% contaminated with Coliform, 58% samples containing the non-acceptable level of suspended earth materials in the form of high Turbidity.

For the first time in Pakistan, about 54 numbers of trace and ultra trace elements were detected in the water quality laboratory of PCRWR, Islamabad by using high tech lab. instrument viz. ICP (Inductive Coupled Plasma Spectrometry). In general, majority of the water samples collected from 344 locations distributed in 22 major cities of Pakistan were found contaminated and polluted with both or single organisms of Coliform or *E.Coli*. It has been observed that almost all surface water sources usually contaminated with bacteria while deep groundwater sources have been found generally free of bacteria due to least seepage influence. However, both surface and groundwater sources/locations had been found contaminated lying in the urban areas of dense population. The report was based on Phase-III (summer) water quality monitoring through collection of water samples and subsequent field and lab. analysis. Contrary to previous two reports on water quality status of Pakistan; in this report a different pattern of results presentation is adopted on city level basis instead of parameters, which is more appropriate and easy in understanding for policy makers, city Nazims and water supply managers to adopt future line of actions on the important issue of water quality.

INTRODUCTION

Water is a source of life creation and survival of mankind on the earth. At the same time water has become a source of multiple problems to human health. Water quality is linked to the density of population, where population is dense it is susceptible to have more pollution. According to a UN study while the world population continues to surge, the availability of freshwater is on the decline and in the next two decades, many of the countries in South Asia, Middle East and Africa would face a crunch. Water contaminated with fecal bacteria, parasites and other microbes, causes about 6,000 deaths of adults and children every day. In developing countries, environmentally water quality issues were on the top followed by air pollution and solid water disposal problems. With the passage of time, water quantity is becoming scarce and the quality is deteriorating due to urbanization, industrialization, deforestation, land degradation, global warming, increasing of population, diversified domestic uses. The public health decision-makers in the developing countries are not well aware of the severity of the situation. Even if they were, the lack of good management and professionalism, together with financial constraints, contributed significantly to the water-borne health risks. The population of Pakistan is now estimated to be more than 140 million. With the present growth rate of 2.1% the population of the country is expected to be doubled by the year 2025. It is estimated that in Pakistan around 30% and 40% of all reported diseases and deaths are attributed to poor water quality respectively. Moreover, the leading cause of deaths in infants and children up to 10 years age as well as mortality rate of 136 per 1,000 live births due to diarrhea is reported while every fifth citizen suffers from illness and disease caused by polluted water. In Karachi only, more than 10,000 people die annually of renal infection due to the polluted drinking water. The budget of majority of the poor people was often consumed by water-borne diseases owing to which they had little money left for improving their life standard (*Dawn April 5, 2004*).

To tackle the alarming scenario of water quality concerns, previously in Pakistan only piecemeal attempts to determine and monitor the drinking water quality of a few selected areas without taking into consideration of ecological zones have been made so far, the holistic approach to monitor the chronic problem was not followed properly. After observing the gravity of the water quality problem at national level, the Pakistan Council of Research in Water Resources (PCRWR) had launched “National Water Quality Monitoring Program” in the country on March 17, 2001. The Phase-I & Phase-II of the program has been completed in 21 major cities of the country. In this report the Phase-III (summer water samples collection and analysis) water quality monitoring field as well as lab. Analytical data has been incorporated and presented covering 22 major cities of Pakistan covering Federal area and cities of all provinces viz. Islamabad, Bahawalpur, Faisalabad, Gujranwala, Gujrat, Kasur, Lahore, Multan, Rawalpindi, Sargodha, Sheikhpura, Sialkot, Mangora, Mardan, Peshawar, Khuzdar, Loralai, Quetta, Ziarat, Hyderabad, Karachi, Sukkur. The city-wise results of different water quality parameters have been discussed instead of parameters.

REVIEW OF LITERATURE

The water quality parameters being studied by PCRWR for National Water Quality Monitoring Program are reviewed mainly focused on natural resources, contaminations and health effects in respect of various Physical & Aesthetic, Chemical, Trace & Ultra Trace Elements including Microbiological parameters.

NATURAL SOURCES, CONTAMINATIONS AND HEALTH EFFECTS

In under developed and developing countries of the world; most of communicable diseases are water borne due to drinking of unsafe water and these diseases cause morbidity and mortality. In developing countries, the mortality rate especially in the infants is very high. This is due to lack of monitoring facilities of water quality as well as improving facilities like treatment plants. Unfortunately public and decision makers of the most developing world are not well aware of the gravity of the situation. In all developed countries drinking water quality is considered a very serious issue and improvement measures were taken about a century ago. For the evaluation of water pollution, water quality parameters are used for analytical purpose and also provision of safe drinking water to the citizens or public. The general public of these countries are aware of water quality impacts on human health, hence they are very conscience about it. For the reduction of pollution or improvement in quality of water used for human consumption depend on reliable analytical measurements. So analytical water quality parameters are utmost important and are playing a key role for water pollution assessment. The prime objective of this chapter is to know about natural sources, contaminations, health effects and guideline values of some basic drinking water quality parameters.

PHYSICAL AND AESTHETIC PARAMETERS

pH

The pH of an aqueous system is measure of acid-base equilibrium achieved by various dissolved compounds and in most natural water is controlled by the carbon dioxide-bicarbonate-carbonate equilibrium system. The pH of most raw water sources lies within the range 6.5-8.5. Chlorination tends to lower the pH, where as water softening using the excess lime/soda ash process raises the pH level. A direct relationship between human health and the pH of drinking water is impossible to ascertain because pH is so closely associated with other aspects of water quality. In so far as pH affects the various processes in water treatment that contribute to the removal of viruses, bacteria and other harmful organisms, it could be claimed that pH has an indirect effect on health. WHO Guideline (1984) recommended guideline value for pH is 6.5-8.5, although it is recognized that some problems could arise within a distribution system with pH level below 7.0. Sawyer & Mccary (1967) explained that efficiency of coagulation and flocculation process is markedly dependent on pH. Smith (1973) found that the metal ion stability and solubility in water solutions when they are in low concentration are affected very much by pH. EPA, USA (1977) claimed that at high pH levels drinking water acquires a bitter taste.

Electrical Conductivity (EC)

A measure of the ability of an aqueous solution to carry an electric current is called as conductivity. This ability depends on the presence of ions, their total concentration, mobility, and valence and on the temperature of measurement. Solutions of most inorganic compounds are relatively good conductors. Conversely molecules of organic compounds do not dissociate in aqueous solution. The determination of electrical conductivity provides a rapid and convenient means of estimating the concentration of electrolytes in water containing mostly mineral salts.

Turbidity

Turbidity in water is caused by the presence of suspended matter, such as clay, silt colloidal organic particles, Plankton and other microscopic organisms. Turbidity is an expression of certain light scattering and light-absorbing properties of water. Turbidity is an important parameter for characterizing the water quality. Public health services drinking water standards (1962) documented that turbidity excess of the guideline value of 5 NTU is generally objectionable to consumers. The perception of higher turbidity in water at the consumer's tap than in that entering the distribution system may indicate post-treatment contamination, corrosion, or other distribution problems. Consequently, as excessive turbidity can protect micro-organisms from the effects of disinfection, stimulate the growth of bacteria in the water and itself exert a significant chlorine demand, it is vitally important in producing safe drinking water.

Color

WHO (1984) and the Water Clinic (2003) reported that color in drinking water may be due to the presence of colored organic substances, usually humus, metals such as iron and manganese, colored industrial wastes. Danamenk (2003) reported that organic color and staining usually occur in areas with poor drainage, and sometimes it combines with iron to form "heme-iron" which is difficult to remove. Ronald (2003) found that USEPA and the Washington Administrative Code for Public Water Supplies has set limits for physical characteristics of water under general use color of drinking water should not exceed 15 units. WHO (1996) has recommended 15 TCU as the level, above which likely to give rise to consumer complaints because of appearance.

Taste

Taste refers only to gustatory sensations called bitter, salty, sour and sweet that result from chemical stimulation of sensory nerve endings located in the papillae of the tongue and soft palate as reported by APHA, *et al.*, (1992). Taste threshold in distilled water for the major cations of drinking water i.e. calcium, magnesium, sodium and potassium have been reported to be approximately 100,30,100 and 300 mg/l respectively (National Academy of Sciences, 1973). Michael (1981) reported that there are only four true taste sensations; salty, sweet, bitter and sour.

Odor

Michael (1981) reported that a great number of organic and some inorganic substances contribute to the odor of waters. The non-specific fishy, grassy and musty odors normally associated with biological growth tend to occur most frequently in warm surface water in the warmer months of the year. Odor in potable water is almost invariably indicative of some form of pollution of the water source or of malfunction during water treatment or distribution. Drinking water should have no observable odor to any consumer (WHO, 1984).

CHEMICAL PARAMETERS

Alkalinity (Alk)

The principal anions for producing Alkalinity of fresh water are bicarbonate, sulphate and chloride. The Alkalinity may be defined as, the capacity of some of its components to accept protons i.e. to bind an equivalent amount of a strong acid. The total contents of negative ions and other substances which react to neutralize the H⁺ ion. Jaffer *et.al* (1985) gave maximum permissible level/range of alkalinity as 50 to 500 mg/l as CaCO₃.

Bicarbonate (HCO₃)

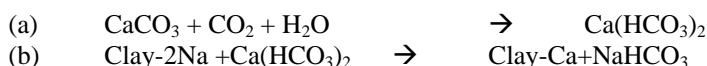
Bicarbonates are the dominant anion in most surface and ground waters. The weathering of rocks contributes to bicarbonate content in water. Mostly bicarbonates are soluble in water and concentrations in water are related

to the pH. Bicarbonates are usually less than 500 mg/l in groundwater. They also influence the hardness and alkalinity of the water. The good quality canal and tube-well water contains small amounts of NaHCO_3 .

Carbonate (CO_3)

In Pakistan the sodic lands develop mainly under the influence of Na_2CO_3 and NaHCO_3 and saline sodic lands contain NaHCO_3 in medium to low amounts, Rafiq (1980) categorized the salt-affected lands into lands containing Na_2CO_3 and CaSO_4 ; the presence of Na_2CO_3 indicated low amounts of Ca^{2+} and Mg^{2+} ions, Ansari *et al.* (1979) reported that the lands of the Punjab (Upper Indus Basin) had high concentrations of Na_2CO_3 and NaHCO_3 but the lands of Sindh province (Lower Indus Basin) were mostly free from Na_2CO_3 .

Saline waterlogged lands in Pakistan usually contain high levels of CaCO_3 . Native CaCO_3 could be solubilized and convert to $\text{Ca}(\text{HCO}_3)_2$ and then soluble NaHCO_3 .



Calcite (CaCO_3) and dolomite are called rock-forming minerals on the earth. Calcite is the most common and widespread of the carbonate minerals. Great masses of calcite occur in limestone. Small crystal masses are present in rock openings. Calcite also occurs as a vein mineral in almost all rocks. Crystals are common. Cleavage is perfect.

Calcium (Ca)

Calcium is a mineral need for numerous functions, including blood clotting, the transmission of nerve impulses and the regulation of the hearts rhythm. The presence of calcium in water supplies results from deposits of limestone, dolomite, calcite, gypsum and gypsiferous shale. The Calcium minerals and compounds are not easily soluble in pure water, the presence of carbon dioxide readily increases their solubility and sources of water containing up to 100 mg of calcium per liter are fairly common in arid regions having pH above 7.0. WHO (1996) and PSI (1987) recommended 75 mg/l as permissible amount of calcium in drinking water, whereas PSQCA (2002) has recommended the revised water quality standard for calcium as 200 mg/l.

Magnesium (Mg)

The magnesium is a common constituent of natural water. Michael (1981) found that magnesium and calcium both produce the property of hardness in water. Acu-Cell (2003) had reported that about 19g of magnesium per 70kg human body weight is involved in the synthesis of protein as well as acts as co-factor in 300 enzymatic reactions.

Hardness

Hard water forms precipitates on boiling or when soap is added to it. Hardness is due to the presence of calcium, magnesium or ferrous (iron salts) as chloride, sulphate or bicarbonates. The terms "hard water" and "soft water" are still in use. The degree of hardness is equivalent to CaCO_3 concentration and designated as soft (0-60 mg/l), medium hard (60-120 mg/l), hard (120-180 mg/l), very hard (>180 mg/l). Bokina (1965) found increased incidence of urolithiasis due to hard water in the USSR where the local tap water contained 300-500 mg of calcium per litre. Guidelines for Canadian drinking water quality (1979) documented that there is no firm evidence that water hardness causes ill effects in man. Marier (1979) observed that there is a close association between death rates from strokes and the acidity of river derived drinking water. Since that time, a number of studies in various parts of the world have demonstrated that there is high statistically significant negative association between water hardness and cardiovascular disease. In most studies, the Calcium concentration has shown the strongest co-relation. The co-relation with hardness and the calcium content of water was high, although other water parameters, many of which are Interco-related with hardness, also provided strong statistical associate ion. Very hard water can cause household pipes choking, scaling, incrustations on kitchen utensils and increasing soap consumption. Hard water can create both nuisance and

economic burden to community. A hardness level of about 100 mg of CaCO₃ per litre provides an acceptable balance between corrosion and the problems of incrustation, although, from aesthetic considerations 500 mg/l is recommended as a guideline value.

Sodium (Na)

Sodium is present in abundance or in less quantity in natural waters. Seawater contains relatively high levels of sodium about 10 g of sodium per litre (WHO, 1979). The sodium salts are highly soluble in water and found abundance in mineral deposits. Sodium is the principal cation (Na⁺) in the extra-cellular fluid (ECF) and it has several physiological roles including maintaining acid-base balance, generating transmembrane gradients (which allow cells to take up nutrients) maintenance of ECF volume and osmotic pressure and in the electrophysiology of nerve and muscle cells (Healthnet, 2003). Acu-Cell (2003) reported that deficiency of sodium in the body may appear as mental apathy, low blood pressure, fatigue, depression, seizures, dehydration etc., whereas overdose can cause edema, hypertension, stroke, headaches, kidney damages, stomach problems and nausea. WHO (1984) reported that in most countries, the majority of water supplies contain less than 20 mg of sodium per liter but in some countries sodium levels can exceed 250 mg/l. According to WHO (1979) water treatment chemicals such as sodium fluoride, sodium silico fluoride, sodium hydroxide, sodium carbonate, sodium bicarbonate and sodium hypochlorite can add significant amounts of Na (30 mg/l) in drinking water. WHO (1996) recommended the 200 mg/l as the guideline value for sodium in drinking water.

Potassium (K)

The potassium content of drinking water varies greatly depending on its source and it tends to be larger in mineral and seawaters than ordinary tap water. However, on average the daily water consumption by adults, the K intake is less than 0.1%. Potassium abundance in drinking waters can reach upto 20 mg/l (APHA, *et al.*, 1992). The potassium is very significant body mineral important to both cellular and electrical function. The total potassium in the body and blood serum varies from 4-5 mg/100 ml. An amount of 1600 to 3500 mg of potassium consumption per day has been recommended by Anderson & Young (2002). Potassium deficiency causes irregular and rapid heart beat, hypertension, muscle weakness, bladder weakness, kidney disease and asthma whereas over dose may appear as irregular/rapid heart beat, cystitis, bladder infection, ovarian cysts, and weakened immune system (Acu-Cell, 2003). An increased level of potassium in the blood is known as hyper-kalemia appear as reduced renal function, an abnormal breakdown of protein and severe infection (Aparna, 2001).

Chloride (Cl)

Chloride high concentration occurs from chloride containing geological formation, pollution by sewage, industrial waste, intrusion of seawater and other saline water. It is widely distributed in nature in the form of NaCl, KCl and CaCl₂ salts. Chloride is present at low concentration in natural surface water as compared to ground water. Chloride is the abundant anion in human body and contributes significantly, along with its associated cations for maintaining the osmotic activity of extra cellular fluids (88%). A normal 70 kg human body weight contains about 81 g of chloride in 45 liters of drinking water. One gram table salt (NaCl) per person per day is essential for normal health. For children up to 18 years of age, a daily dietary intake of 45 mg chloride per kg of body weight is sufficient. The salty taste produced by chloride depends on the chemical composition of the water. The salty taste with concentration of 250 mg/l may be detectable in water containing sodium ions. On the other hand, the typical salty taste may be absent in water containing 1000 mg/l chloride when calcium and magnesium ions are predominant. A high chloride content has a deleterious effect on metallic pipes and structures. WHO (1984) had recommended 250 mg/l as guideline value.

Sulphate (SO₄)

Dissolved sulphate is considered to be permanent solute of water. The majority of sulphate compounds are soluble in water, the exception being the sulphates of lead, barium and strontium. It may however be reduced to sulfide, volatilized to the air as H₂S precipitated as an insoluble salt or incorporated in living organisms. Sulphates are used in the manufacturing of numerous chemicals, dyes, glass, paper, soaps, textiles, fungicides,

insecticides, astringents and cosmetics. Sulphate levels in Canadian lakes range from 3 to 30 mg/l Katz (1977). Finding of National Water Quality Monitoring Program (NWQMP) have revealed that water samples of various cities of Punjab and Balochistan provinces have sulphate concentration exceeding WHO limits (Kahlown, *et al.*, 2001). No symptoms of sulphate deficiency have been reported in humans. No optimum dietary intake for inorganic sulphate has been suggested. Fingl (1980) reported the dehydration as a common side effect due to the ingestion of large amounts of magnesium or sodium sulphate. The taste threshold concentrations of sulphate salts are 250-500 mg/l for sodium sulphate, 250 to 900 mg/l for calcium sulphate and 400 to 600 mg/l for magnesium sulphate NRC (1977). WHO (1996) has set the sulphate level of 250 mg/l in drinking water above which consumer may feel problem in taste.

Nitrate (NO₃)

Nitrate is a very important water quality parameter regarding health point of view. It comes into water from fertilizer use, decayed vegetable and animals matter, domestic effluent, sewage sludge, industrial discharges, farm leachates, atmospheric washout. U.S. EPA (1977) documented that water supply in some countries containing high levels of nitrate have been responsible for cases of infantile Methaemoglobinaemia and death. Xu Guang Wei (1981) had diagnosed gastric cancer in China in the areas where high levels of both nitrate and nitrite were found in drinking water and found the high mortality rate from this disease. Data showed that in this area the levels of both nitrate and nitrite in drinking water and in vegetables were higher than in the low-risk areas. WHO (1978) has documented that the pregnant women are at greater risk than the general adult population due to nitrate induced Methaemoglobinaemia. Guidelines for drinking water by WHO (1984) recommended 10 mg/l as nitrate nitrogen.

Methaemoglobinaemia: The extent of the worldwide problem has been reviewed by WHO (1984). It has been well documented that in some countries water supplies containing high levels of nitrates were responsible for cases of infant Methaemoglobinaemia and death. It was recommended that water supplies containing high levels of nitrate should not be used by child and for the preparation of infant foods. The problem of Methaemoglobinaemia does not arise in adults. Increased sensitivity may also occur when infants suffer from gastrointestinal disturbances which increase the number of bacteria that can convert nitrate to nitrite. Prolonged boiling of water may increase the problem by increasing the nitrate levels owing to evaporation. Cases of infant Methaemoglobinaemia have not been reported in areas where the drinking water contains less than 10 mg of nitrate-N per litre, only 2.3% of all cases appear to be associated with nitrate levels between 10-20 mg of nitrate-N per litre of water.

Carcinogenicity of Nitrosamines: Nitrosamines will be produced which may be carcinogenic. It has been shown that the formation of nitrosamines may be increased in individuals with bladder infections which would be ultimately absorbed into the blood. Although tests on animals have shown that a number of nitrosamines are carcinogenic, there is no direct evidence of their carcinogenicity in man. In a review of gastric cancer in China, the Putian Prefecture of the Fujian Province was found to have the highest mortality from this disease. The levels of both nitrate and nitrite in drinking water and in vegetables were higher in this area. Evidences of carcinogenicity from nitrate via the formation of nitrosamines rests with epidemiological studies (WHO 1984).

Phosphorus (PO₄)

Phosphorus occurs in natural waters and in wastewaters almost solely as “phosphates” classified as orthophosphates, condensed phosphates (pyro, meta, and polyphosphates) and organic phosphates. Water Shedss (2003) reported that phosphorus plays a role in deoxyribonucleic acid (DNA), ribonucleic acid (RNA), adenosine diphosphate (ADP) and adenosine triphosphate (ATP) and required for these necessary components of life to occur. Generally, phosphorus (as orthophosphate) is the limiting nutrient in freshwater and aquatic system. The natural total phosphorus are generally less than 0.03 mg/l whereas the natural levels of orthophosphate usually range from 0.005 to 0.05 mg/l. No guideline values suggested by WHO for drinking water, however the EPA water quality criteria state that phosphates should not exceed 0.05 mg/l if streams discharge into lakes or reservoirs, 0.25 mg/l within a lake or reservoir and 0.1 mg/l in streams or flowing waters (USEPA, 1986).

Total Dissolved Solids (TDS)

Total dissolved solids (TDS) in water are inorganic salts and small amounts of organic matter. The principal ions contributing to TDS are carbonate, bicarbonate, chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium. TDS in water may be originated from natural sources, sewage effluent discharges, urban runoff and industrial discharges. TDS is linked to taste, hardness, corrosion properties and tendency to incrustation. There is no evidence of deleterious physiological reactions have TDS levels in excess of 1,000 mg/l Dufor (1972). TDS in drinking water may even have beneficial health effects. Bruvold *et al.*, (1967) have rated the palatability of drinking water due to the TDS level i.e. Excellent (<300 mg/l), Good (300-600 mg/l), Fair (600-900 mg/l), Poor (900-1200 mg/l), Unacceptable (>1200 mg/l). Water with extremely low TDS levels may also be unacceptable because of its flat, insipid taste. WHO recommended 1000 mg/l TDS as guideline values.

TRACE AND ULTRA TRACE ELEMENTS

Lead (Pb)

The main sources of lead are paints, pipes, wastes of batteries, manufacturing industries and gasoline. Lead is a serious cumulative body poison. The natural lead content of lake and river water worldwide has been estimated to be 1-10 µg/l WHO (1973). Michael (1981) had reported 0.03 µg/l in seawater but near the surface and shore the concentration may be as much as 10 times more. SDWF (2003) had given the possible chronic health effects as brain and nerve damage, kidney damage, digestive disturbances, blood disorders and hypertension. The symptoms of acute poisoning i.e. tiredness, lassitude, slight abdominal discomfort, irritability, anemia and in case of children, behavioral changes were also diagnosed. Guideline value for lead is 0.01 mg/l or 10 µg/l (10 ppb) recommended by WHO (1984).

Arsenic (As)

Arsenic (As) is an inorganic element has no taste, smell, color in water. As is a naturally occurring element found in soils, surface water and groundwater, highest in areas of geothermal activity. As is used in the production of pesticides and herbicides. As is ingested by drinking contaminated water. As is known carcinogenic and poisoning element either acute or chronic. It can enter the metabolic system of unborn babies. Ingestion of large quantities resulting in stomach pain, nausea, vomiting, diarrhea which may lead to shock, coma and even death. Higher rates are linked to produce cancer of the lungs, bladder, kidney, liver and skin, particularly in young age children and elder old age human. The unborn babies and people with long illnesses are at greater risk of As poisoning (USDI, 2001). The permissible limits of WHO (1984) are 10 ppb to As concentration in drinking water.

Iron (Fe)

Iron is also an abundant element by weight on the earth's crust. In water it occurs in the divalent and trivalent (ferrous and ferric) forms. The solubility in natural waters is dependent upon the pH and the oxidation-reduction potential. In reducing conditions; iron exists in the ferrous state. On exposure to air oxidized to the ferric form and with water hydrolyzes to insoluble hydrated ferric oxide that makes iron-laden waters objectionable. Iron in water can cause staining of laundry and porcelain, deposit a slimy coating on the piping. A bittersweet astringent taste is detectable at level above 1 mg/l. Iron is an essential element in human nutrition. It is contained in a number of biologically significant proteins as hemoglobin and cytochromes. Iron also promotes the growth of "iron bacteria" which derive their energy from the oxidation of ferrous iron to ferric iron. Iron deficiency causes anemia and symptoms of fatigue appeared. The higher iron intake through drinking water/food may produce symptoms of anorexia, dizziness, nausea, vomiting, headache, weight loss, shortness of breath and possibly a graying color to the skin. WHO (1996) have recommended the guideline value for iron in drinking water as 0.3 mg/l.

Fluoride (F)

Traces of fluorides occurrence are widespread in waters and higher concentrations are often associated with groundwater sources in areas where fluoride-bearing minerals are common. Edmunds and Smedley (1996) have found high fluoride concentrations in groundwater from calcium-poor aquifers and where exchange of sodium for calcium occurs. In areas that are rich in fluoride containing minerals e.g. fluorapatite, the groundwater may contain up to 10 mg of fluoride per liter or even more (Bulusu et al, 1979). According to WHO (1970) most of the waters contain below 1 mg of fluoride per liter. Drinking water is typically the largest single contributor to the daily fluoride intake (WHO, 1986). However, this is not necessarily true in every case. British Geological Survey (2003) has found a significant mitigating effect against dental caries as minor concentrations in drinking water is beneficial. Optimal concentrations are 1 mg/l, however, chronic ingestion greater than 1.5 mg/l (WHO guideline value) is linked with development of dental fluorosis and in extreme cases, skeleton fluorosis. High doses have been linked to cancer.

Chromium (Cr)

Chromium concentrations in natural waters are usually very small. Elevated chromium concentrations can result from mining and industrial processes. An upper limit of 0.05 mg of chromium per liter is allowed in drinking water in the USA and a similar limit is allowed by WHO. Natural water contains only traces of chromium as cation. Chromium under strongly oxidizing conditions may be converted to hexavalent state and occurs as chromate anion. Its presence indicates pollution by industrial wastes. Liver necrosis, nephritis, G.I. mucosa irritation, prostrate, digestive track and lung cancers are reported in the literature due to excessive intake of chromium. The WHO has recommended 50 µg/l as the maximum permissible limit for this element. Chromium exists in trivalent state, which is stable form, and other one is hexavalent chromium, which is readily reduced by a variety of organic species. Trivalent form rarely occurs in potable water. According to APHA, *et al.*, (1992), the hexavalent chromium concentration of U.S drinking waters has been reported to vary between 3 and 40 µg/l with a mean of 3.2 µg/l. The hexavalent chromium (at 10 mg/l of body weight) could cause liver necrosis, nephritis and death in man, lower doses also cause irritation in gastrointestinal mucosa. Liver, kidney and lungs damage as the possible chronic health effects. The levels in water are usually low (9.7 mg/l) because of the low solubility of chromium. He also determined that the drinking water normally contains very low concentrations of chromium (5 µg/l or less) and the chromium levels as high as 20 g/l in tap water are found very rare. Chromium plays a vital role in glucose metabolism through its influence on glucose tolerance. Chromium in water is absorbed at approximately 5% of the dose as compared to food which is 0.5-1% (WHO, 1973).

Manganese (Mn)

The manganese is a mineral that naturally occurs in rocks and soil and is the normal constituent of the human diet. Manganese may become noticeable in water at concentrations greater than 0.05 mg/l of water by imparting a color, odor or taste to the water. APHA, *et al.*, (1992) found that there is evidence that manganese occurs in surface waters both in suspension in the quadrivalent state and in the trivalent state in a relatively stable, soluble complex. Manganese intake through drinking water can vary considerably, normally being substantially lower than intake from food. Available data indicate that exposure via this source would normally be less than 0.1 mg/day, but can be an order of magnitude higher, exposure to high concentrations of manganese over the course of years has been associated with toxicity to the nervous system (USEPA, 1977). Acu-Cell (2003) reported that manganese deficiency in the body may appear as hypoglycemia, joint discolorations, asthma, migraine, osteoporosis and gastrointestinal disorders whereas manganese toxicity due to over dose cause muscle tremors, dizziness, liver disease, high risks to several cancers, fibroid tumors, edema and colitis. WHO (1996) has recommended 0.1 mg/l as the guideline value for drinking water.

Molybdenum (Mo)

Molybdenum is generally present at very low concentrations in water. It's concentration in surface water is normally less than 7 µg/l. The molybdenum plays a vital role in everyday life, particularly in relation to many aspects of the protection of human health and the environment. The essential metal is found mainly in the liver,

kidney and adrenal gland. Its functions in the body as a component of three main enzymes such as sulphate oxidase, xanthine oxidase and aldehyde oxidase. Deficiency of this element is very rare. In the body deficiency will manifest as abnormal excretion of sulphur metabolites, low concentration of uric acid in the urine and increased excretion of hypoxanthine and xanthine excretion. The molybdenum in drinking water has been recommended 0.07 mg/l by WHO (APHA *et al.*, 1992; WHO, 1996)

Nickle (Ni)

The nickel compounds are found in many ores and minerals and nickel salts are quite soluble, may contribute to water pollution through municipal or industrial waste discharges. About 1 mg/l level of nickel in surface water has been reported in the literature. The nickel is relatively non toxic to man. The toxicity of nickel to aquatic life varies generally with the species, pH and water hardness. Plasma nickel is a constituent of the circulating proteins nickeloplasmin and albumin and it is thought to be factor in hormone, lipid and cell-membrane metabolism. Skin reactions such as itching, burning, redness or other rashes are the most common symptoms of nickel sensitivity; however asthma attacks are another but less frequent possibility. WHO has recommended guideline value for nickel as 0.02 mg/l (Acu-Cell, 2003; WHO 1996; USEPA, 1977).

Aluminum (Al)

Aluminum is distributed widely in nature and is a constituent of all soils, plants and animal tissues. As a consequence of this wide natural distribution and the activities of man, aluminium is present in air, food and water, both natural and polluted. The salts of aluminum are used extensively in water treatment for the removal of color and turbidity. The level of aluminum in water varies considerably and may exceed 10 mg/l in the vicinity of aluminum processing plants. The aluminum has been associated with certain neurological disorders such as dialysis, dementia and Alzheimer's disease. Aluminium present in drinking water contributes only a small proportion of the estimated daily human intake i.e. less than 4% of the normal daily intake. Aluminum does not appear to be an essential nutrient in man. The chronic use of large quantities of aluminum hydroxide in the form of "antacids" can lead to excessive loss of phosphate from the system. However, it is not clear, whether the presence of aluminum causes such conditions or is simply an indicator of other factors (APHA *et al.*, 1992; WHO, 1996).

Selenium (Se)

The selenium concentrations usually found in water are of the order of a few micrograms per liter, but may reach 50-300 µg/l in seleniferous areas and have been reported to reach 1 mg/l in drainage water from seleniferous irrigated soils. The data from different parts of the world indicated that the selenium contents in most surface water samples analyzed was well below 10 µg/l. It is reported that the sources of contamination of selenium are discharges from petroleum refineries, corrosion deposits and discharge from mines. The selenium concentration of most drinking waters and natural waters is less than 10 µg/l. According to Acu-Cell (2003) deficiency of selenium leads to lowered glutathione peroxidase activity and it is implicated with a higher risk for cancer of the liver lungs, colon, rectum and prostate. Whereas over dose or selenium toxicity may appear as nerve degeneration, osteoporosis, cystadenoma, shingles, loss of hair, garlic breath and death (NRC, 1977; National Academy of Sciences, 1973; USEPA, 1986; APHA, *et al.*, 1992). Possible chronic health effects produce by selenium toxicity reported by USEPA (1986) as growth inhibition, skin discoloration, dental and digestion problems, liver damage and psychological disorders and possible health effects may be the hair or fingernail loss, numbness of fingers or toes and circulatory problems. According to WHO (1984) guideline value for selenium in drinking water is 0.01 mg/l.

BACTERIOLOGICAL PARAMETERS

Coliform

Total coli form bacteria, a particular group of waterborne microbiological contaminants is the most common indicator organism applied to drinking water. Total coliform bacteria and fecal coli form *Escherichia Coli*

(*E.Coli*) are two types of fecal indicator bacteria. Several bacteria can be classified as coliform, and are commonly found in soil, on the surface of leaves, in decaying matter, and can grow in water distribution mains. These types of coliform bacteria aren't fecal contamination related and do not necessarily indicate unsafe water. Almost all surface waters contain some bacteria while groundwater's are generally free of bacteria unless under the direct influence of surface water. Surface and groundwater contamination can occur as a result of surface runoff through urban areas, pastures, feedlots, on-site septic tank/sewage disposal system leakage, sewage treatment plant/disposal system overload, raw sewage deep well injection, improper coagulation, use of recycled, concentrated backwash water. Distribution system contamination can occur as a result of cross-connection, broken or leaking waterlines, or back-siphonage. Effects of bacterial ingestion include abdominal cramps and diarrhea. WHO standards require zero Coliform to be found per 100 ml of safe drinking water (*USDI; 2001*).

Escherichia Coli (*E.Coli*)

Fecal bacteria are single-celled microorganisms, virtually always associated with fecal contamination of water, but not always harmful. Fecal indicator bacteria are used in determining (indicating) the microbial quality of water. Fecal coliform known as Escherichia Coli (*E.Coli*) are fecal indicator bacteria. Escherichia Coli (*E.Coli*) is the fecal coliform group of bacteria contaminated in much higher level than coliforms. *E.Coli* appears as straight rods, single or in pairs forms, can grow on simple nutrient media. Chiang (2003) found that Escherichia coli is a specific subset of thermotolerant coliform bacteria which possess the enzymes B-galactosidase, B-glucuronidase and hydrolyzes 4-methyl-umbelliferyl-B-D-glucuronidase. Waite (1985) had estimated that 95% of all coliform found in human feces could be *E.Coli*. Sewage, treated effluents, all natural water which are subjected to recent fecal contamination from humans or wild animals will contain *E.Coli*. Usually *E.Coli* cannot multiply in any natural water environment and they are, therefore, used as specific indicator for fecal contamination (WHO, 1996). The presence of *E.Coli* can cause diarrhea, nausea and other problems especially for infants, children and those with weak immune systems, cause infantile diarrhea and acute diarrhea that may be fatal. Hemorrhagic colitis (HC) is the acute disease caused by E-Coli. HC results in severe abdominal cramps, watery diarrhea, and lower intestinal bleeding; with occasional vomiting and fever. In some cases, hemolytic uremic syndrome or renal failure can occur. Although not life threatening to healthy adults, these diseases can be fatal to young children. E-Coli is transmitted through fecal-oral ingestion of the bacteria by direct ingestion (i.e. drinking), primary contact recreation (i.e. swimming), or secondary contact (i.e. fishing). WHO standards require zero *E.Coli* to be found per 100 ml of safe drinking water (*USDI; 2001*).

CAUSES OF WATER POLLUTION

Leakage of pipe lines:

The water at the source is usually potable, fit and good quality for human consumption but got contaminated and polluted when pipelines were cut for illegal connections. The old and rusted distribution pipeline system was the main cause of micro holes and crakes and mixing of sewerage water.

Location of pipelines:

The authorities responsible for supply of potable water to the public in cities, usually layout the freshwater pipes at parallel or beneath the sewerage pipes or channels. The seepage of sewerage polluted water is towards lower levels causing the mixing of waste effluent in freshwater.

Clogging of sewerage system:

In most of the cities, more than 50% of sewerage channels and pipelines are overloaded and remained in most cases blocked due to poor maintenance and plugging with plastic bags & bottles and, therefore, much of the sewage overflows into surface drains and natural water channels.

Mixing of untreated contaminated water:

The overall cities in Pakistan are producing wastewater estimated at 4.43 billion cubic meters. The total wastewater finding its way to the major rivers is estimated at about 1.782 billion cubic meters, which includes municipal and industrial effluents. The river Indus and its tributaries have been heavily polluted with agricultural, human, hospital and industrial wastes. About 60% of the Karachi city's untreated sewage is being flushed into the Arabian Sea. It means that over 300 million gallons of untreated water going in the sea daily (*Dawn, March 18-24, 2004*) (*Dawn, March 16, 2004*).

Growing of field crops and vegetables:

It is common practice in urban adjoining agricultural fields to irrigate the field crops and vegetables with untreated wastewater because of its high fertility and reliable supply in spite of the health risks involved. Farmers prefer to use untreated wastewater when there is opportunity for direct economic benefits and especially in cases when there is lack of access to other sources of irrigation water.

Groundwater pollution in:

Consolidated Rocks: The polluted and contaminated poor quality water can percolate and mix in the groundwater sources even in areas of hard rock formations. Because even the hard rocks zones are capable of producing joints, fractures, fissures, lineaments, caverns, cavities, splitting, broken layers, fault zones, curved faces, cleavages, cracks, cones, pores, openings, veins, capillaries etc. These open spaces acts as water movement capillaries facilitating the mixing of surface and groundwater.

Unconsolidated Rocks: If the land surface contains layers of loess it can store a huge amount of contaminated and polluted water and can release it slowly toward the aquifer even in the dry periods. At the land surface, the layers of gravels, pebbles, boulders, coarse grained sands, loamy soils, fine sands, sandy loam, silt are permeable enough to produce acceptable infiltration rates for mixing of polluted water into the fresh aquifers.

WATER QUALITY STANDARDS

The basic purpose of making guidelines or standards is to provide safe drinking water to all the citizens. The World Health Organization (WHO) has provided guidelines for drinking water, which are advisory in nature, and are based on scientific research and epidemiological findings. The values of various water quality parameters recommended by WHO are the general guidelines. That is why, different countries have established their own water quality standards to meet their national priorities taking in to account their economic, technical, social, cultural, and political requirements. The PCRWR and Pakistan Standard Institution (PSI) have already drafted drinking water quality standards; however, the enforcement of these standards is still pending. This matter needs to be addressed on top priority basis. The WHO guidelines and standards proposed by national agencies like PCRWR, Pakistan Standard Institution (PSI), International Bottled Water Association (IBWA), Food Development Authority (FDA), Environmental Protection Agency (EPA) and other countries are given in this chapter.

WHO Guidelines

A. Bacteriological Qualities

<i>Source/Organisms</i>	<i>Guideline Value</i>
All water intended for drinking (E. Coli or thermo tolerant Coliform bacteria)	Must not be detectable in any 100 ml sample
Treated water entering the distribution system (E. Coli or thermo tolerant coliform and total coliform bacteria)	Must not be detectable in any 100 ml sample
Treated water in the distribution system (E. Coli or thermo tolerant coliform and total coliform bacteria)	Must not be detectable in any 100 ml sample In the case of large supplies, where sufficient samples are examined, must not be present in 95% of samples taken throughout any 12-month period.

B. Chemicals of Health Significance

<i>Inorganic</i>	<i>mg/l</i>	<i>Inorganic</i>	<i>mg/l</i>	<i>Inorganic</i>	<i>mg/l</i>
Antimony	0.05	Copper	2.000	Molybdenum	0.070
Arsenic	0.010	Cyanide	0.070	Nickel	0.020
Barium	0.700	Fluoride	1.500	Nitrate(NO ₃)	50.00
Boron	0.500	Lead	0.010	Nitrite(NO ₂)	03.00
Cadmium	0.003	Manganese	0.500	Selenium	0.010
Chromium	0.050	Mercury	0.001	Uranium	0.002

C. Other Parameters

<i>Parameter</i>	<i>mg/l</i>	<i>Parameter</i>	<i>mg/l</i>	<i>Parameter</i>	<i>mg/l</i>
Color	15 TCU	1,2 dichlorobenzene	1	Hardness, pH, DO	-
Taste, Odor.	-	1,4-dichlorobenzene	0.3	Hydrogen sulfide	0.05
Turbidity	5 NTU	Tetrachlorethene	0.04	Iron	0.3
Toluene	0.70	Ethylbenzene	0.3	Sodium	200
Xylenes	0.5	Aluminum	0.2	Sulfate	250

Ethyl-benzene	0.3	Ammonia	1.5	TDS	1000
Styrene	0.02	Chloride	250	Zinc	3
Monochlorobenzene	0.3	Copper	1		

D Pesticides

Pyradite	0.1	Chlorotoluron	0.03
1,2-dichloropropane	0.04	Bentazon	0.3

US-EPA Guidelines for Drinking Water

B. Inorganic Chemicals

<i>Inorganic</i>	<i>mg/l</i>	<i>Inorganic</i>	<i>mg/l</i>	<i>Inorganic</i>	<i>mg/l</i>
Antimony	0.006	Copper	1.0	Molybdenum	0.070
Arsenic	0.010	Cyanide	0.2	Zinc	5
Barium	2	Fluoride	2	Nitrate(N)	10.00
Beryllium	0.004	Lead	0.015	Nitrite(N)	01.00
Cadmium	0.005	Manganese	0.050	Selenium	0.050
Chromium	0.10	Mercury	0.002	Aluminum	0.05-0.2

C. Other Parameters

<i>Parameter</i>	<i>mg/l</i>	<i>Parameter</i>	<i>mg/l</i>	<i>Parameter</i>	<i>mg/l</i>
Color	15 TCU	1,2 dichloropropane	Zero	pH	6.5-8.5
Atrazine	0.003	o-Dichlorobenzene	0.6	Sulfate	250
Toluene	1	p-Dichlorobenzene	0.075	Iron	0.3
Xylenes (total)	10	Endrin	0.002	Sodium	200
Ethyl-benzene	0.7	Ethylbenzene	0.7	Sulfate	250
Styrene	0.1	Methoxychlor	0.04	TDS	1000
Chlorobenzene	0.1	Vinyl chloride	0.002	Corrosivity	Non-corrosive
Benzene	Zero	Chloride	250		
Oxamyl	0.2	Glyphosate	0.7		

D Disinfectants

Chloramines	4	Chlorine dioxide	0.8
Chlorine	4	Chlorite	1

Standards Drafted by PCRWR

A. Bacteriological Standards Urban and Rural (piped and up piped) water supplies

Categories	Standards
A: Piped Water Supplies	
A-1 Treated water entering the distribution system	
Faecal Coliform	0/100 ml
Coliform organisms	0/100 ml
A-2 Un-treated water entering the distribution system	
Faecal Coliform	0/100 ml
Coliform organisms	0/100 ml
A-3 Water in the distribution system	
Faecal Coliform	0/100 ml
Coliform organisms	0/100 ml
B. Un-piped Water Supplies	
Faecal Coliform	0/100 ml
Coliform organisms	0/100 ml

B. Standards for Inorganic Health Related Constituents

Constituent	Unit	HDL*	MPL**	Toxic Effects
Fluoride	mg/l	1.000	1.500	Dental fluorosis in children, excessive concentration may cause crippling skeletal fluorosis.
Nitrate (NO ₃)	mg/l	45.000	45.000	Infantile methaemoglobinaemia.
Lead	mg/l	0.050	0.050	Children particularly susceptible to effects of lead on central nervous system
Mercury	mg/l	0.001	0.001	Neurological effects

C. Other Parameters

Constituent	Unit	HDL	MPL	Undesirable Effects
pH	-	7.0-8.5	6.5-9.2	Taste, Corrosion
Turbidity	NTU	2.5	5	Un-aesthetic, decrease in efficiency of disinfections
Colour	PCU	5	15	Un-aesthetic
Taste & Odour	-	Unobjectionable		Taste & Odour
Magnesium	mg/l	30	150	Stomach disturbances
Hardness	mg/l	200	500	Corrosion or scale formation
Chloride	mg/l	200	600	Taste, Corrosion
TDS	mg/l	500	1500	Fault or salty taste, corrosion or instruction
Iron	mg/l	0.1	1.0	Taste, discoloration
Manganese	mg/l	0.05	0.5	Taste, discoloration
Copper	mg/l	0.05	1.5	Taste, corrosion of pipes and utensils taste
Zinc	mg/l	5	15.0	Taste
Sulfate	mg/l	200	400	Corrosion, Laxative effect
Phenolic substances	mg/l	0.001	0.002	Taste

* Highest Desirable Level

** Maximum Permissible Level

Pakistan Standards and Quality Control Authority (PSQCA)
Drinking Water Quality Standards

A. Physical Requirements

S. #.	Characteristics	Unit	MAC*	MAC**
1	pH	-	7.0-8.5	≥ 6.5- ≤ 9.2
2	Turbidity	NTU	5	25
3	Colour	TCU	5	50
4	Taste & Odor	-	Unobjectionable	

B. Chemical Requirements

1	Alkyl Benzyl Sulfates	mg/l	0.5	1.0
2	Calcium (Ca)	mg/l	75	200
3	Total Hardness (CaCO ₃)	mg/l	20	500
4	Chloride (Cl)	mg/l	200	600
5	Sulfate (SO ₄)	mg/l	200	400
6	Nitrate (NO ₃)	mg/l	-	10
7	Total Dissolved Solids	mg/l	1000	1500
8	Iron (Fe)	mg/l	0.3	1.0
9	Fluoride (F)	mg/l	-	1.5
10	Nitrite (NO ₂)	mg/l	Nil	Nil
11	Total Ammonia	mg/l	0.1	0.5
12	Hydrogen Sulfide	mg/l	Undetectable odor	
13	Zinc (Zn)	mg/l	5.0	15.0
14	Manganese (Mn)	mg/l	-	0.5
15	Copper (Cu)	mg/l	-	1.0
16	Magnesium (Mg)	mg/l	50	150

C. Limits of Toxic Substances

1	Arsenic (As)	mg/l	0.01	
2	Cadmium (Cd)	mg/l	0.003	
3	Chromium (Cr)	mg/l	0.05	
4	Cyanide (Cn)	mg/l	0.07	
5	Lead (Pb)	mg/l	0.01	
6	Selenium (Se)	mg/l	0.01	

E. Limits for Bacteriological contaminants

Acceptable bacterial standards for potable water supplies are as follows:	
Escherichia coli	0/250 ml
Total Coliform	0/250 ml
Enterococci	0/250 ml
Pseudomonas aeruginosa	0/250 ml

* Maximum Acceptable Concentration ** Maximum Allowable Concentration

International Bottled Water Association (IBWA) Standards

A. Chemical Quality

Characteristics	Unit	Standard	Characteristics	Unit	Standard
Arsenic (As)	mg/l	0.01	Mercury (Hg)	mg/l	0.001
Barium (Ba)	mg/l	1	Nitrate (NO ₃)	mg/l	10
Cadmium (Cd)	mg/l	0.005	Nitrite (NO ₂)	mg/l	1
Chromium (Cr)	mg/l	0.05	Selenium (Se)	mg/l	0.01
Chloride (Cl)	mg/l	250	Silver (Ag)	mg/l	0.025
Copper (Cu)	mg/l	1	Sulfate (SO ₄)	mg/l	250
Cyanide (Cn)	mg/l	0.1	Phenolic	mg/l	0.001
Fluoride (F)	mg/l	4	PCB	mg/l	0.0005
Iron (Fe)	mg/l	0.3	TDS	mg/l	500
Lead (Pb)	mg/l	0.005	Zinc (Zn)	mg/l	5
Manganese (Mn)	mg/l	0.05	Turbidity	NTU	0.5

B. Microbiological Quality

Escherichia coli	Not detectable in 100ml
Coliforms	Not detectable in 100ml

Food Development Authority (FDA) Water Standards

Characteristics	Unit	Standard	Characteristics	Unit	Standard
Arsenic (As)	mg/l	0.05	Nitrate (NO ₃)	mg/l	10
Barium (Ba)	mg/l	1	Selenium (Se)	mg/l	0.01
Cadmium (Cd)	mg/l	0.01	Silver (Ag)	mg/l	0.05
Chromium (Cr)	mg/l	0.05	Sulfate (SO ₄)	mg/l	250
Chloride (Cl)	mg/l	250	Phenolic	mg/l	0.001
Copper (Cu)	mg/l	1	Ra 226 activity (pCi/l)	-	5
Iron (Fe)	mg/l	0.3	Total Beta activity (pCi/l)	-	8
Lead (Pb)	mg/l	0.05	TDS	mg/l	500
Manganese (Mn)	mg/l	0.05	Zinc (Zn)	mg/l	5
Mercury (Hg)	mg/l	0.002	Coliform (MPN/100 ml)		<2,20

National Environmental Quality Standards by EPA (Liquid Industrial Effluents)

Sr.#	Parameter	Standards
1	Temperature	40 C
2	pH Value (acidity/basicity)	6-10 pH
3	5-day Biochemical Oxygen Demand (BOD) at 20 ⁰ C	80 mg/l
4	Chemical Oxygen Demand (COD)	150 mg/l
5	Total Suspended Solids	150 mg/l
6	Total Dissolved Solids	3500 mg/l
7	Grease and Oil	10 mg/l
8	Phenolic Compounds (as phenol)	0.1 mg/l
9	Chloride (as Cl)	1000 mg/l
10	Fluoride (as F)	20 mg/l
11	Cyanide (as Cn)	2 mg/l
12	An-ionic detergents (as MBAS) ³	20 mg/l
13	Sulfate (SO ₄)	600 mg/l
14	Sulfide (S)	1.0 mg/l
15	Ammonia (NH ₃)	40 mg/l
16	Pesticides, herbicides, fungicides and insecticides	6.15 mg/l
17	Cadmium	0.1 mg/l
18	Chromium (trivalent and hexavalent)	1.0 mg/l
19	Copper	1.0 mg/l
20	Lead	0.5 mg/l
21	Mercury	0.01 mg/l
22	Selenium	0.5 mg/l
23	Nickel	1.0 mg/l
24	Silver	1.0 mg/l
25	Total Toxic Metals	2.0 mg/l
26	Zinc	5.0 mg/l
27	Arsenic	1.0 mg/l
28	Barium	1.5 mg/l
29	Iron	2.0 mg/l
30	Manganese	1.5 mg/l
31	Boron	6.0 mg/l

Indian Water Quality Standards

A. Physical and Chemical Standards

Sr. #.	Characteristics (mg/l)	Accept-able	Marginal	Sr. #.	Characteristics (mg/l)	Accept-able	Marginal
1	Turbidity (NTU)	2.5	10	15	Copper	0.05	1.5
2	Colour (TCU)	5	25	16	Zinc	5.0	15
3	Taste & Odor	Unobjectionable		17	Phenolic Compounds	0.001	0.002
4	pH	7-8.5	6.5-9.2	18	Anionic Detergents	0.2	1.0
5	TDS	500	1500	19	Arsenic	0.05	0.05
6	Hardness	200	600	20	Cadmium	0.01	0.01
7	Chloride	200	1000	21	Chromium	0.05	0.05
8	Sulfate	200	400	22	Cyanide	0.05	0.05
9	Fluoride	1.0	1.5	23	Lead	0.1	0.1
10	Nitrate (N)	45	45	24	Selenium	0.01	0.001
11	Calcium	75	200	25	Mercury	0.001	0.2
12	Magnesium	30	150	26	Polynuclear aromatic hydrocarbons (g/l)	0.2	3

13	Iron	0.1	1.0	27	Gross Alpha Activity	3 (pCi/l)	30
14	Manganese	0.05	0.5	28	Gross Beta Activity (pCi/l)	30 pico curie/l	

- The figures indicated under the column “Acceptable” are the limits up to which the water is generally acceptable to the consumers.
- Figures in excess of those mentioned under “acceptable” render water not acceptable, but still may be tolerated in absence of alternative and better source but up to the limits indicated under column “Marginal” above which the supply will have to be rejected.

B. Bacteriological Standards

- i) Water entering the distribution system coliform count in any sample of 100 ml should be zero.
- ii) Water in the distribution system shall satisfy all the three criteria indicated below;
 - *E.Coli* count in 100 ml of any sample should be zero
 - Coliform organisms no more than 10 per 100 ml shall be present in any sample
 - Coliform organisms should not be detectable in 100 ml of any two consecutive samples or more than 50% of the samples collected for the year.
- iii) Individual or small community supplies.
 - *E.Coli* count should be zero in any sample of 100 ml and coliform organisms should not be more than 3 per 100 ml.

• C. Virological Aspects

- i) A level of 0.5 mg/l of free chlorine residual for one hour is sufficient to inactivate virus, even in water that was originally polluted. This free chlorine residual is to be insisted in all disinfected supplies in areas suspected of endemicity of infectious hepatitis to take care of the safety of the supply from virus point of view, which incidentally takes care of the safety from the bacteriological point of view as well. For other areas 0.2 mg/l of free chlorine residual for half an hour should be insisted.

The water quality standards developed and enforced by various countries are given in the tables from 3.8 to 3.10.

Water Quality Standards of Indonesia, Singapore, Malaysia, Thailand, Philippines and Brunei.

A. Chemically Quality

S. #	Substances	Unit	Indonesia	Singapore	Malaysia	Thailand	Philippines	Brunei
1	Arsenic (As)	mg/l	0.05	0.05	0.05	0.05	0.05	<0.003
2	Barium (Ba)	mg/l	-	1	-	1	-	<0.02
3	Borate (BO ₃)	mg/l	-	0.03	30	-	-	0.2
4	Cadmium (Cd)	mg/l	0.1	0.01	0.01	0.005	0.01	<0.002
5	Chromium (Cr)	mg/l	-	0.05	0.05	0.05	0.05	<0.01
6	Chloride (Cl)	mg/l	250	0.05	-	250	-	-
7	Chlorine (Cl ₂)	mg/l	-	-	1	1	-	-
8	Copper (Cu)	mg/l	0.5	-	-	0.1	1	<0.01
9	COD	mg/l	-	-	-	1	-	-
10	Cyanide (CN)	mg/l	0.05	0.01	0.01	-	0.01	-
11	Fluoride (F)	mg/l	1	2	2	-	2	0.09
12	Hardness (CaCO ₃)	mg/l	170	-	-	100	-	-
13	Iodine (I)	mg/l	-	1	-	0.3	-	-
14	Iron (Fe)	mg/l	0.1	-	-	0.05	1	-
15	Lead (Pb)	mg/l	0.05	0.05	0.05	0.05	0.05	<0.01
16	Manganese (Mn)	mg/l	0.05	2	2	0.002	0.1	0.01
17	Mercury (Hg)	mg/l	0.001	1	0.001	-	0.001	<0.001
18	Mineral Oil	mg/l	-	ND	ND	-	-	-
19	Nitrate (NO ₃)	mg/l	ND	45	45	4 (N)	45	<0.05
20	Nitrite (NO ₂)	mg/l	ND	0.005	0.005	-	0.01	<0.005
21	Organic Matter	mg/l	1	0.003	3	-	5	-
22	Selenium (Se)	mg/l	-	0.01	0.01	0.01	0.01	<0.01
23	Silver (Ag)	mg/l	-	-	-	0.05	-	-
24	Surfactant	mg/l	-	ND	ND	-	2	-
25	Sulfide (S)	mg/l	ND	0.05	0.05	-	-	-
26	Sulphate (SO ₄)	mg/l	200	-	-	250	-	-
27	Phenolic	mg/l	-	ND	ND	0.001	0.001	-
28	Ra 226 activity	pCi/l	-	30	-	-	-	-
29	Total Beta activity	pCi/l	-	1	-	-	-	-
30	TDS	mg/l	500	-	-	500	-	-
31	Zinc (Zn)	mg/l	-	-	5	5	5	-

B. Microbiological Quality

1	Total Plate Count/ml		Max 1x10 ⁴	Max.1x10 ⁵	-	-	-	-
2	Coliform (MPN/100 ml)		<2.20	0/250 ml	Max.10	<2,20	<2.20	Nil
3	Escherichia coli		0	0	0	Negative	-	Nil
4	Salmonella/100 ml		-	0	-	-	-	-
5	Staphylococcus Aureus/250 ml		-	0	-	-	-	-
6	Pseudomonas Aeruginosa/250 ml		0	0	-	-	-	-
7	Faecal Streptococci/20 ml		-	-	-	-	1/100 ml	-

Water Quality Standards of Vietnam, Japan, China, Hong Kong, Korea and Taiwan

A. Chemical Quality

Sr.#	Substances	Unit	Vietnam	Japan	China	H. Kong	Korea	Taiwan
1	Arsenic (As)	mg/l	0.05	<0.2	0.05	0.01	0.05	0.05
2	Ammonium (NH ₄)	mg/l	-	<0.5	-	1.5	0.5	-
3	Barium (Ba)	mg/l	-	-	-	0.7	-	-
4	Borate (BO ₃)	mg/l	10	-	-	0.3	-	-
5	Cadmium (Cd)	mg/l	0.01	<0.05	0.01	0.003	0.01	0.01
6	Chromium (Cr)	mg/l	-	<0.05	0.05	0.05	0.05	0.05
7	Chloride (Cl)	mg/l	-	<350	250	250	150	250
8	Chlorine (Cl ₂)	mg/l	-	-	-	-	-	1
9	Copper (Cu)	mg/l	1	<0.05	1	2	1	0.01
10	COD	mg/l	-	-	-	-	-	0.8
11	Cyanide (CN)	mg/l	0.01	<0.01	0.01	0.07	ND	-
12	Fluoride (F)	mg/l	2	<1.5	0.8	1.5	1	-
13	Hardness (CaCO ₃)	mg/l	-	100-500	250	-	300	250
14	Iodine (I)	mg/l	-	-	-	-	-	0.3
15	Iron (Fe)	mg/l	-	<0.1	0.3	0.3	0.3	0.05
16	Lead (Pb)	mg/l	0.05	<0.1	0.05	0.01	0.1	0.05
17	Manganese (Mn)	mg/l	2	<0.1	0.05	0.5	0.3	0.001
18	Mercury (Hg)	mg/l	-	-	0.001	0.001	ND	-
19	Nitrate (NO ₃)	mg/l	45	<5.0	10	50	10	10
20	Nitrite (NO ₂)	mg/l	-	-	ND	3	-	ND
21	Organic Matter	mg/l	3	-	0.1	-	-	0.1
22	Selenium (Se)	mg/l	-	<0.05	0.01	0.01	0.01	0.01
23	Silver (Ag)	mg/l	0.01	-	0.05	-	-	0.05
24	Sulphate (SO ₄)	mg/l	-	<250	250	250	200	250
25	Phenolic	mg/l	-	<0.001	-	-	0.005	-
26	Total Beta activity	pCi/l	-	-	-	1.0 Bq/l	-	-
27	TDS	mg/l	-	<1000	500	1000	-	500
28	Zinc (Zn)	mg/l	5	<5	5	3	1	5

B. Microbiological Quality

1	Total Plate Count/ml		<10	-	100	-	<100	-
2	Coliform (MPN/100 ml)		-	<15.100	3	<2.2	0	-
3	Escherichia coli		2.2	-	-	-	-	0/100 ml

Water Quality Standards of Saudi Arabia, Guam, Australia, Argentina, Mexico and Canada

A. Chemical Quality

Sr.#	Substances	Unit	S. Arabia	Guam	Australia	Argentina	Mexico	Canada
1	Arsenic (As)	mg/l	0.05	0.05	0.05	0.05	0.05	0.025
2	Ammonium (NH ₄)	mg/l	-	-	-	0.2	0.5	-
3	Barium (Ba)	mg/l	1	1	1	-	0.7	1
4	Borate (BO ₃)	mg/l	-	-	30	-	-	5
5	Cadmium (Cd)	mg/l	0.01	0.01	0.005	0.01	0.005	0.005
6	Chromium (Cr)	mg/l	0.05	0.05	0.05	0.05	-	0.05
7	Chloride (Cl)	mg/l	250	250	-	350	250	-
8	Chlorine (Cl ₂)	mg/l	-	-	0.01	0.5	0.1	-
9	Copper (Cu)	mg/l	1	1	1	2	1	-
10	COD	mg/l	-	-	3	-	-	-
11	Cyanide (Cn)	mg/l	0.05	-	0.1	0.10	-	0.2
12	Fluoride (F)	mg/l	-	-	1.5	2	2	-
13	Iron (Fe)	mg/l	0.3	0.3	-	2	0.3	-
14	Lead (Pb)	mg/l	0.05	0.05	-	0.05	0.02	0.01
15	Manganese (Mn)	mg/l	0.05	0.05	2	0.1	0.05	-
16	Mercury (Hg)	mg/l	-	0.002	0.001	0.001	0.001	0.001
17	Nitrate (NO ₃)	mg/l	-	10	45	45	10	45
18	Nitrite (NO ₂)	mg/l	-	-	0.01	0.1	-	3.2
19	Selenium (Se)	mg/l	-	0.01	0.01	-	0.05	0.01
20	Silver (Ag)	mg/l	0.05	0.05	-	0.05	-	-
21	Surfactant	mg/l	-	-	-	-	0.5	-
22	Sulfide (S)	mg/l	-	-	0.05	-	-	-
23	Sulphate (SO ₄)	mg/l	250	250	-	500	250	-
24	Phenolic	mg/l	0.001	0.001	-	-	0.001	-
25	Ra 226 activity	pCi/l	3	5	1	-	-	-
26	Total Beta activity	pCi/l	-	8	-	-	-	-
27	TDS	mg/l	-	500	-	1500	500	-
28	Zinc (Zn)	mg/l	5	5	5	5	3	-

B. Microbiological Quality

1	Total Plate Count/ml	-	-	-	<1	500	100	100
2	Coliform (MPN/100 ml)	-	-	<2.20	Max.10	3	<2	-
3	Escherichia coli	-	-	-	-	Negative	-	0
4	Pseudomonas Aeruginosa/250 ml	-	-	-	-	Negative	-	0

Permissible Limits of different Water Quality Parameters adopted for National Water Quality Monitoring Program

S.No.	Parameters	Unit	Permissible Limit	Set By
1	pH	-	6.5 - 8.5	WHO
2	EC	uS/cm	-	NGVS
3	Turbidity	NTU	5	WHO
4	Alk	mg/l	50-500	Jaffar et. al., (1985)
5	HCO ₃	mg/l	-	NGVS
6	CO ₃	mg/l	-	NGVS
7	Ca	mg/l	75	PSI
8	Mg	mg/l	150	WHO
9	Hard	mg/l	500	WHO
10	Na	mg/l	200	WHO
11	K	mg/l	12	EC
12	Cl	mg/l	250	WHO
13	SO ₄	mg/l	250	WHO
14	NO ₃ (N)	mg/l	10	WHO
15	PO ₄	mg/l	-	NGVS
16	TDS	mg/l	1000	WHO
17	Pb	µg/l	10	WHO
18	As	µg/l	10	WHO
19	Fe	mg/l	0.3	WHO
20	F	mg/l	1.5	WHO
21	Coliform	MPN	Nil	WHO
22	<i>E.Coli</i>	MPN	Nil	WHO
23	Chromium (Cr)	ppb	50	WHO
24	Manganese (Mn)	ppb	500(p)	WHO
25	Molybdenum (Mo)	ppb	70	WHO
26	Nickel (Ni)	ppb	20	WHO
27	Aluminum (Al)	ppb	200	WHO
28	Selenium (Se)	ppb	10	WHO

MATERIALS AND METHODS

General methodology adopted for National Water Quality Monitoring Program consisted of establishing network for collection of water sample, monitoring stations, sample size and frequency of sample collection, details of analysis, recording of groundwater level *etc.* The details of these components are given below:

Grid Size and Number of Samples

A uniform site selection criterion was adopted and a grid size of 1 km² (for small cities) 4 and 9 km² (for medium cities) and 16 and 25 km² (for big cities) was established. Preference was given to permanent public points considering the long term monitoring requirement of the project. Geology and depth of aquifers was also considered. A minimum distance of 1 km was maintained between the two monitoring points. Site identification was marked on each city map according to the grid. Sample ID for monitoring purpose was marked on the basis of actual sampling visit sequence of various sites. Following identifications were also marked on every sample of each site:

- A for Bacterial analysis
- B for Trace element analysis
- C for Nitrate (N) analysis
- D for Other water quality parameters

Cross, field blank and replicate samples for quality control purposes were also collected. Sites for cross samples were selected owing to site number divisible by 10. Sites for Field Blank and Replicates were on the basis of site number divisible by 20. The details regarding grid size and sampling points (number) are shown in Table.

Details of Water Quality Monitoring Network Table-1

Sr. #	City Name	City Code	Grid Size (km ²)	Total Sample Points	Sr. #	City Name	City Code	Grid Size (km ²)	Total Sample Points
1	Islamabad	ISL	4	26	12	Sialkot	SIA	4	10
2	Bahawalpur	BAH	16	25	13	Mangora	MAN	1	12
3	Faisalabad	FAI	4	13	14	Mardan	MAR	4	10
4	Gujranwala	GUJ	4	14	15	Peshawar	PES	16	13
5	Gujrat	GUT	1	9	16	Khuzdar	KHU	Approx.	11
6	Kasur	KAS	1	10	17	Loralai	LOR	1	13
7	Lahore	LAH	16	18	18	Quetta	QUE	4	25
8	Multan	MUL	16	16	19	Ziarat	ZIA	1	11
9	Rawalpindi	RAW	9	15	20	Hyderabad	HYD	4	15
10	Sargodha	SAR		24	21	Karachi	KAR	25	28
11	Sheikhupura	SHE	4	11	22	Sukkur	SUK	1	12

Monitoring Domains

The national water quality-monitoring program covers twenty-one main cities, 11 in Punjab, 3 in Sindh, 4 in Balochistan, and 3 in NWFP. The detail of cities is available in table-1. For water quality data collection purposes, the country has been divided into five zones namely Capital Territory Area, Punjab (two zones), Sindh, Balochistan, and NWFP. The field teams of the sub offices were assigned the task in the respective zones of the country and were mobilized for field data collection. Details of the Monitoring Stations (MS) and their areas of responsibility for collection of water samples for water quality monitoring are as under:

- *Monitoring Station-1* (WRRC, Islamabad)

- Rawalpindi, Islamabad and Gujrat cities, Simly, Rawal and Khanpur dams, Tarbella, Mangla and Chashma reservoirs and Jhelum and Chenab Rivers
- **Monitoring Station-II** (Regional Office, Lahore)
Lahore, Sialkot, Sheikhpura, Gujranwala, Faisalabad and Kasur cities and Ravi River
 - **Monitoring Station-III** (Regional Office, Bahawalpur)
Bahawalpur and Multan cities and Sutlaj River
 - **Monitoring Station-IV** (Drainage Research Center, Tandojam)
Hyderabad, Karachi and Sukkur cities, Manchar and Hamal lakes, LBOD, RBOD and Hub dam and Indus River
 - **Monitoring Station-V** (WRRC, Quetta)
Quetta, Khuzdar, Loralai and Ziarat cities and Hanna Lake
 - **Monitoring Station-VI** (WRRC, Peshawar)
Peshawar, Mardan and Mangora cities and Indus and Kabul Rivers

Sample Collection and Preservation

Water samples for physico-chemical analysis were collected in polystyrene bottles of 0.5 and 1.5 liter capacities. Before collecting the samples, the bottles were washed properly and rinsed thoroughly several times first with water and then with distilled water. For bacterial analysis, samples were collected in sterilized containers (200 ml). Hydrochloric acid and boric acid were used as preservatives in the sampling bottles for trace elements and nitrate nitrogen respectively before going to field. The first set of water samples was collected after monsoons rains. The sampling team comprised of a Deputy Director as Incharge assisted by a Laboratory Assistant, a supervisor, and a driver. Following procedure and precautionary measures were followed while collecting samples from the field.

Tap Water

Un-rusted taps were selected for collection of water samples. These taps were properly cleaned and allowed to flow for a few minutes before collecting the sample.

Tubewell Water

The water samples from tube wells were collected after allowing them to flow for at least 10 minutes to get representative sample of the groundwater. Depth of groundwater level and location of the tubewell was properly marked on the topographic survey sheet.

Water from Distribution Networks

The water samples from the distribution network were collected from the source of supply (as closely as possible) to minimize the effects of pollution in the distribution system and from consumers end to evaluate the actual quality of water being used. All water sample containers were filled slowly to avoid turbulence and air bubbles after flushing the system for sufficient time.

Hand Pump/Dug Well Water

Water samples were collected from hand pumps or dug wells after purging of the hand pump or well. The purging was carried out by making one stroke for every foot of depth (A hand pump or dug well having 30 feet of depth, needs 30 strokes for its purging).

Stream Water

Water samples were collected from the centre by standing in the middle of the stream. Care was taken to keep the bottle well above the bed of the stream to avoid unwanted bed material going into the sample.

Spring Water

Water samples were collected directly from the spring in sterilized sampling bottles for microbiology and bottles used with or without preservatives for other water quality parameters.

Dam, River and Lake

It is difficult to obtain a truly representative sample when collecting surface water samples. Sampling point was selected carefully (near to bank in case of river) to avoid any kind of debris in the water. Considerable variations like seasonal stratification, runoff, rainfall and wind were also documented while collecting water sample especially from lake.

Microbiological Samples

The water samples for microbiological contamination were collected in clean, sterile plastic bottles (200 ml). The care was taken to ensure that no accidental contamination occurs during sampling. Samples were not taken from those taps, which were leaking between the spindle and gland to avoid outside contamination. The samples were kept cool and in the dark while transporting to the laboratory.

Type of Water Samples and Preservatives

Samples were collected for microbiological analysis, for trace elements, for Nitrate (N) and general water quality parameters. The details of these samples and preservative used for each sample are given below:

Type A – All sites – Sterilized sampling bottles for microbiological analysis;

Type B – All sites – 2 ml/liter HNO₃ as preservative for trace elements;

Type C – All sites – 1 ml/100 ml, 1 M Boric acid as preservative for Nitrate (N); and

Type D – All sites – No preservative for other water quality parameters.

Check List of Items/Activities Needed Before Going To Field

- Number of bottles required for sampling.
- An appropriate preservative filling in the sampling bottles.
- Calibration of field equipment (if necessary).
- General items required for sampling *e.g.*, sampling forms, equipment, markers, ballpoints, distilled water and paint *etc.*

Check List of Items/Activities Needed During Collection of Samples

- City map with grids and identified ID site. During site finalization, ensure that site selection meets the criteria of representative sample. Filling site and sample ID in the form.
- Sample bottle with date and sample ID with indelible ink.
- Sample bottles preserved with appropriate preservative.
- Finalization of method for sample collection.
- Ensuring at four water quality samples.
- Confirm cross, field blanks and replicate samples from suitable sites.
- Marking of (P) on site after collecting sample for future reference and use red paint.

Check List Items/Activities after Collection of Samples

- Samples are transported to the laboratory within the recommended time period.
- That the water samples are not filtered.
- Purpose of water testing to the communities is properly explained.

Quality Control Measures

Quality control measures were started from the field. Standard sampling methods were adopted to collect the samples. Four types of samples were collected for monitoring purpose where as three kinds of samples were collected for quality control. The detail of these samples is as under:

i) Samples for Monitoring Purposes

- a) Samples for microbiological examination in sterile bottle.
- b) Samples for the analysis of trace elements by addition of HNO_3 as preservative.
- c) Samples for the analysis of Nitrate (N) by addition of boric acid as preservative.
- d) Samples without preservative for the analysis of EC, pH, Hardness, Ca, Mg, Na, K and HCO_3 etc.

ii) Samples for Quality Control Purposes.

- a) Samples for cross analysis (10%).
- b) Samples to check reproducibility (10%).
- c) Samples for field blank (10%).

Field blank and replicate samples were planned to be analyzed in the same laboratory to see the quality of distilled water and reproducibility of analytical results. The reproducibility of the results was found within satisfactory limits, the results of replicate samples are given in (*annexure-27*). Cross samples were planned to be sent to some reputable laboratories for comparison. The PINSTECH is now a days analyzing the cross samples of NWQMP (Phase-III) to see the accuracy in analytical results of both laboratories. The comparison of these results will be given in the next report.

Analytical Methods

The water samples were analyzed for physical, chemical and bacteriological parameters by using standard methods. The details of the parameters and methods used for their analysis are given below:

Water Quality Parameters and Methods used for Analysis

S. #	Parameters	Test Method
	pH at 25C°	pH Meter, Hanna Instrument Model 8519, Italy
	Conductivity (µS/cm)	E.C meter, Hach-44600-00, USA
	Turbidity (NTU)	Turbidity Meter, Lamotte, Model 2008, USA
	Alkalinity (m.mol/l as CaCO ₃)	2320, Standard method (1992)
	Bicarbonate (HCO ₃)	2320, Standard method (1992)
	Carbonate (CO ₃) (mg/l)	2320, Standard method (1992)
	Calcium (Ca) (mg/l)	3500-Ca-D, Standard Method (1992)
	Magnesium (Mg) (mg/l)	2340-C, Standard Method (1992)
	Hardness (mg/l)	EDTA Titration, Standard Method (1992)
	Sodium (Na) (mg/l)	Flame photometer PFP7, UK
	Potassium (K) (mg/l)	Flame photometer PFP7, UK
	Chloride (Cl) (mg/l)	Titration (Silver Nitrate), Standard Method (1992)
	Sulfate (SO ₄) (mg/l)	SulfaVer4 (Hach-8051) by Spectrophotometer
	Phosphate & P (mg/l)	Method (Hach) 8190 & 8048
	TDS (mg/l)	2540C, Standard method (1992)
	Lead (Pb) (µg/l)	Dithizone Method (HACH-8033) by Spectrophotometer
	Arsenic (As) (µg/l)	Merck Test Kit (10-500 µg/l) 1.17926.0001, Germany
	Iron (Fe) (mg/l)	TPTZ Method (Hach-8112) by Spectrophotometer
	Fluoride (F). (mg/l)	8029, SPADNS Method (Hach) by Spectrophotometer
	Total Coliform & <i>E.Coli</i> (MPN/100ml)	407D, Standard method (1971)
	Chromium (Cr), (ppb)	Atomic absorption spectrometric method for low levels of total chromium and inductive coupled plasma spectrometric method (ICP – see detection limits on next page)
	Manganese (Mn), (ppb)	Standard Method of atomic absorption spectrometric and Inductive Coupled Plasma Spectrometric methods for direct determination.
	Molybdenum (Mo), (ppb)	Standard Method of atomic absorption spectrometric and Inductive Coupled Plasma Spectrometric technique
	Nickel (Ni), (ppb)	Standard Method of atomic absorption spectrometric and Inductive Coupled Plasma Spectrometric technique
	Aluminum (Al), (ppb)	Atomic absorption spectrometric and inductive coupled plasma methods
	Selenium (Se). (ppb)	Hydride generation systems of atomic absorption spectrometric and inductive coupled plasma spectrometric methods

**Detection Limits Capability of ICP
(Inductive Coupled Plasma Spectrometry)
against different elements**

Sr. #	Element	Symbol	Detection Limit (ppb)
1	Silver	Ag	4.5
2	Aluminum	Al	2.3
3	Arsenic	As	18
4	Gold	Au	8.3
5	Boron	B	2.3
6	Barium	Ba	0.1
7	Beryllium	Be	0.3
8	Bismuth	Bi	18
9	Calcium	Ca	0.045
10	Cadmium	Cd	2.3
11	Cerium	Ce	11.3
12	Cobalt	Co	7.5
13	Chromium	Cr	6
14	Cesium	Cs	4800
15	Copper	Cu	3
16	Dysprosium	Dy	0.45
17	Erbium	Er	1.0
18	Europium	Eu	0.45
19	Iron	Fe	2.3
20	Gallium	Ga	9.8
21	Gadolinium	Gd	3.75
22	Germanium	Ge	20
23	Hafnium	Hf	6
24	Mercury	Hg	13
25	Holmium	Ho	0.75
26	Indium	In	27
27	Iridium	Ir	5.25
28	Potassium	K	15
29	Lanthanum	La	0.03
30	Lithium	Li	0.9
31	Lutetium	Lu	0.075
32	Magnesium	Mg	0.15
33	Manganese	Mn	0.45
34	Molybdenum	Mo	6
35	Sodium	Na	1.5

Sr. #	Element	Symbol	Detection Limit (ppb)
36	Niobium	Nb	6
37	Neodymium	Nd	3
38	Nickel	Ni	9
39	Phosphorous	P	27
40	Lead	Pb	21
41	Palladium	Pd	10.5
42	Praseodymium	Pr	1.2
43	Platinum	Pt	30
44	Rubidium	Rb	4.5
45	Rhenium	Re	16.5
46	Rhodium	Rh	7.5
47	Ruthenium	Ru	9
48	Sulphur	S	30
49	Antimony	Sb	27
50	Scandium	Sc	0.6
51	Selenium	Se	55.5
52	Silicon	Si	7.5
53	Samarium	Sm	10.5
54	Tin	Sn	22.5
55	Strontium	Sr	0.03
56	Tantalum	Ta	13.5
57	Terbium	Tb	7.5
58	Tellurium	Te	40.5
59	Thorium	Th	25.5
60	Titanium	Ti	0.9
61	Thallium	Tl	24
62	Thulium	Tm	2.3
63	Uranium	U	27
64	Vanadium	V	3
65	Tungsten	W	25.5
66	Yttrium	Y	0.3
67	Ytterbium	Yb	0.45
68	Zinc	Zn	1.35
69	Zirconium	Zr	2.3

pH

For most practical purposes the pH of an aqueous solution can be taken as the logarithm to the base 10 of the reciprocal of the hydrogen ion concentration (more precisely, of the hydrogen ion activity) in moles/litre. The practical pH scale extends from 0 to 14 with the middle value of 7 corresponding to exact neutrality at 25 °C. The pH of natural waters is usually governed by the carbon dioxide/bicarbonate/ carbonate equilibrium and lies in the range between 4.5 and 8.5. Humic substances may affect it by changes in the carbonate equilibrium due to bioactivity of plants, in some cases by hydrolysable salts *etc.* Waste waters and polluted waters may have pH values much lower or higher.

On site determination of pH of the samples was done in most of the cases. In other cases where pH meter was not available samples were collected and transferred in a completely filled, well stopper bottles to prevent changes in its composition especially in carbon dioxide. The method used for this analysis was Electrometric Method (Reference method). The pH meter was standardized according to the manufacturer's instructions. Before measuring the pH of the test samples, the electrode was washed thoroughly first with distilled water and then with the sample water. Then the electrode was dipped into the sample and system was allowed to stabilize before making the final reading. Determination was made in unstirred solutions to avoid loss of carbon dioxide or other volatile components.

Conductivity

Conductivity is a measure of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions, their total concentration, mobility, valence and on the temperature of measurement. Solutions of most inorganic compounds are relatively good conductors. Conversely molecules of organic compounds do not dissociate in aqueous solution. The determination of electrical conductivity provides a rapid and convenient means of estimating the concentration of electrolytes in water containing mostly mineral salts. The apparatus used for this analysis was EC meter, HACH-44600, USA.

The samples were shaken thoroughly before starting measurements and allowed to stabilize till removal of attain air bubbles. EC meter was standardized with the help of standard solution of potassium chloride, 0.01 M at a constant temperature of 25 °C. Then conductivity cell was thoroughly rinsed with distilled water as well as a small amount of sample. The cell was then completely dipped in sample. The EC of the samples was noted from the screen of EC meter. Temperature affects conductivity that varies by about 2% per 1 °C. The temperature of 25 °C is taken as standard. Dissolved carbon dioxide increases conductivity without increasing the mineral salt content. The same is true for a sample with a low pH value, owing to the high equivalent conductivity of the hydrogen ion. However, the effect is not large and the removal of carbon dioxide from hard water cannot be achieved without a risk of precipitating calcium carbonate.

Turbidity

Turbidity is an expression of the optical property that causes light to be scattered and absorbs rather than transmitted in straight line through the sample. Suspended matter such as clay, silt, fine organic, inorganic substances, soluble colored organic compounds, plankton and other microscopic organisms causes turbidity in water. Correlation of turbidity with the weight concentration of suspended matter is difficult to derive due to the size, shape and refractive index of the particulates that affect the scattering properties of the light in the suspension. Optically black particles (activated carbon) may absorb light and effectively increase turbidity measurements. The turbidity is of interest for two main reasons. First, turbidity is an important parameter for characterizing the water quality. Water treatment plants need its values for the treatment of surface water. Secondly, knowledge of the turbidity allows an estimate to be made of the concentration of un-dissolved substances.

The samples were collected in plastic bottles. Turbidity of the samples was measured just after their collection as irreversible changes may occur in turbidity as a result of long period storage. The method used for this analysis was Nephelometric method. The apparatus consisted of Turbidity meter, Lamotte, Model 2008, USA. This turbidity method is based on a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension under the same conditions.

The higher the intensity of scattered light, the higher the turbidity. Formazin polymer is used as the reference turbidity standard suspension. Turbidity determination is applicable to a water sample that is free from debris and rapidly settling coarse sediments. Dirty glassware, the presence of air bubbles, and the effects of vibrations that disturb the surface visibility of the sample will give false results. "True color" (water color) due to dissolved substances may absorb light and cause low turbidity values. This effect usually is however not significant in the case of treated water.

a) Measurement of turbidity less than 40 NTU.

The samples were vigorously shaken till the disappearance of air bubbles. The sample was then poured into the turbidity meter tube. The turbidity was read directly from the instrument scale.

b) Turbidity exceeding 40 NTU

The samples were diluted with one or more volumes of turbidity free water to fall below 40 NTU. Then calculated the turbidity values by using following equation.

$$\text{Nephelometric turbidity units (NTU)} = \frac{A \times (B \times C)}{C}$$

Where;

- A= NTU found in diluted samples
- B= Volume of dilution water, ml and
- C= Sample volume taken for dilution, ml

Taste

Taste refers only to gustatory sensations called bitter, salty, sour and sweet that result from chemical stimulation of sensory nerve endings located in the papillae of the tongue and soft plate. Flavor refers to complex of gustatory, olfactory and trigeminal sensations resulting from chemical stimulation of sensory nerve endings located in the tongue, nasal cavity and oral cavity. Water samples taken into the mouth for sensory analysis always produce a flavor, although taste, odor or mouth-feel may predominate, depending on the chemical substances present. Taste tests were performed only on samples that were known to be sanitarly acceptable for ingestion. The method used for this analysis was that sample taste was carried out at the original temperature of the sample after rinsing the mouth with a portion of sample for some seconds on the tongue. The result of a sample test was described only qualitatively. The person tasting water must avoid eating, drinking or smoking before making a test. Only 4 true taste sensations, salty, sweet, bitter and sour were used for reporting taste results.

Alkalinity

Alkalinity of water is its acid-neutralizing capacity. The measured value may vary significantly with the end point pH used. The alkalinity is primarily a function of carbonate, bicarbonate and hydroxide contents. The measured values may also include contributions from borates, phosphate, silicates or other bases if present. Alkalinity measurements are used in the interpretation and control of water and waste water treatment processes. Raw domestic waste water has an alkalinity less than or slightly greater than that of the water supply. The method used for this analysis was 2320 Standard Method (1992). The chemicals used for this analysis included:

- i) Carbon dioxide free distilled water;
- ii) Sodium carbonate solution, 0.05 mol/l;
- iii) HCl 0.02 M;
- iv) Phenolphthalein indicator; and
- v) Methyl orange indicator.

A 100 ml sample was mixed with 2 or 3 drops of phenolphthalein indicator in a conical flask. The phenolphthalein alkalinity of the sample was determined by titrating with standard acid (HCl 0.02 M) until the disappearance of pink color. The alkalinity to phenolphthalein was considered to be zero in case no color was

produced after addition of few drops of phenolphthalein. The methyl orange alkalinity of the sample was determined by titrating with standard acid (HCl 0.02 M) until the color changes from yellow to orange.

$$\text{Total alkalinity as CaCO}_3 \text{ (m.mol/l)} = \frac{1000 \times B \times C}{V}$$

Where;

- B= ml of standard acid solution to reach the end point of methyl orange;
- C= Concentration of acid in mol/l; and
- V= ml of sample.

Using 100 ml of sample and 0.1 mol/l standard acid solutions, the numerical value of alkalinity is directly expressed in m.mol/l by the number of ml of titrant consumed.

Bicarbonate (HCO₃)

Bicarbonates are the dominant anion in most surface and ground waters. The weathering of rocks contributes to bicarbonate content in water. Mostly bicarbonates are soluble in water and concentrations in water are related to the pH. Bicarbonates are usually less than 500 mg/l in groundwater. They also influence the hardness and alkalinity of the water. No guidelines values are recommended by WHO. The method used for this analysis was 2320 Standard Method (1992).

The reagent used for this analysis included:

- i) Methyl orange indicator; and
- ii) Standard acid (HCl) 0.02N.

A 50 ml of sample was taken in flask and added one drop of methyl orange. Then titrated it against the standard acid until the colour changed from yellow to orange and recorded the volume of acid used as “R₂”.

$$\text{Bicarbonate mg/l} = R_2 \times 20 - R_1 \times 20 \times 2$$

Where:

R₁= Volume of acid used for phenolphthalein alkalinity.

Carbonate (CO₃)

The method used for this analysis again was 2320 Standard Method (1992). The reagents used for this analysis included:

- i) Standard solution 0.02 N HCL;
- ii) Phenolphthalein indicator.

A 50 ml of sample was taken in flask and added one drop of phenolphthalein indicator. The carbonate was considered to be zero in case of no pink colour. If the sample turned into pink colour, the sample was titrated against the standard acid until it became colourless. The volume of acid used was noted as “R₁”.

$$\text{Concentration of carbonate mg/l} = R_1 \times 20 \times 2$$

Calcium (Ca)

The presence of calcium in water supplies results from passage through or over deposits of limestone, dolomite, gypsum and gypsiferous shale. The calcium content may range from zero to several hundred milligrams per liter, depending on the source and treatment of the water. Small concentrations of calcium carbonate combat corrosion of metal pipes by laying down a protective coating. Appreciable calcium salts, on the other hand, precipitate on heating to form harmful scale in boilers, pipes and cooking utensils. Chemical softening, reverse osmosis, electro dialysis, ion exchange is used to reduce calcium and the associated hardness.

Samples were collected in plastic bottles without the addition of preservative. The samples were re-dissolved by the addition of nitric acid in case of precipitation of calcium carbonate produced during sample storage before analysis. The method used for this analysis was Disodium Ethylenediaminetetraacetate dehydrate (EDTA) titration method (reference method). When EDTA is added to water containing calcium and magnesium ions, soluble EDTA chelates are formed. The stability constant for the calcium chelates is larger than that for the magnesium chelate consequently, in a titration, calcium reacts before the magnesium. Calcium can be determined in the presence of magnesium by EDTA titration when an indicator is used that reacts with calcium only *e.g.* Murexide gives a color change when all of the calcium has been complex by EDTA at a pH of 12 to 13.

Orthophosphate precipitates calcium at the pH of the test and, therefore, produces low results. Strontium and barium interfere with the calcium determination by virtue of the fact that they also form EDTA chelates and alkalinity in excess of 30 mg/l may cause an indistinct endpoint with hard water. The concentration levels of ions which cause interference with the calcium hardness are given in Table.

Recommended Levels of Concentrations of Ions for Non-Interference of Calcium

Copper	2 mg/l	Ferrous iron	20 mg/l	Zinc	5 mg/l	Tin	5 mg/l
Manganese	10 mg/l	Ferric iron	20 mg/l	Lead	5 mg/l	Aluminum	5 mg/l

The reagents used for this analysis included:

- i) Sodium hydroxide (NaOH), 1N;
- ii) Murexide indicator; and
- iii) Standard EDTA titrant, 0.01 M.

A sample of 50 ml was used, or a smaller portion diluted to 50 ml so that the calcium content was about 5-10 mg. Then added 2 ml of NaOH solution or a volume sufficient to obtain a pH of 12-13. After stirring well, 0.1-0.2 gm of the Murexide indicator was added. Then EDTA titrant was added slowly, with continuous stirring until the proper end point reached.

$$\text{Concentration of Ca (mg/l)} = \frac{A \times B \times 400.8}{V}$$

Where

A= ml of EDTA titrant used for titration of sample;

B= ml of standard calcium solution; and
ml of EDTA titrant

V= ml of sample.

Magnesium (Mg)

Magnesium ranks eighth among the elements in order of abundance and is the common constituent of natural water. Waters associated with granite or siliceous sand may contain less than 5 mg of magnesium per liter. Water containing dolomite or magnesium-rich limestone may contain 10-50 mg/l and several hundred mg/l may be present in water that has been in contact with deposits containing sulfates and chlorides of magnesium. Magnesium by a similar action to calcium, imparts the property of hardness to water. This may be reduced by chemical softening or ion exchange methods. The method used for analyzing magnesium concentration was 2340-C, Standard Method (1992). Magnesium was estimated as the difference between hardness and calcium as CaCO₃.

$$\text{Concentration of Mg (mg/l)} = [\text{total hardness (as CaCO}_3 \text{ mg/l)} - \text{Calcium hardness (as mg CaCO}_3\text{/l)} \times 0.243].$$

Hardness

Originally, water hardness was understood as a measure of the capacity of water to precipitate soap. In conformity with current practice, total hardness is defined as the sum of the calcium and magnesium concentrations, both expressed as calcium carbonate, in milligram per liter. The hardness may range from zero to hundreds of milligrams per litre, in terms of calcium carbonate, depending on the source and treatment to

which the water has been subjected. Samples were collected in plastic bottles without the addition of preservative. The method used for this analysis was EDTA Titration Standard Method (1992).

EDTA forms soluble chelates of calcium and magnesium ions. When a small amount of Eriochrome Black T indicator is added to a solution containing calcium and magnesium ions at pH 10.0 ± 0.1 , the solution became wine-red in colour. When the solution is titrated with EDTA the calcium and magnesium are complexed and at the end point the colour of the solution changes from wine-red to blue. Several metal ions can interfere with the titration by producing fading or indistinct endpoints. To minimize these interferences, sodium sulfide solution is added. The approximate concentration of various ions can be tolerated if sodium sulfide is added. Interfering substances are aluminum 20 mg/l, cadmium 10 mg/l, cobalt 0.3 mg/l, copper 20 mg/l, ferrous ions 5 mg/l, lead 20 mg/l, manganese ion 1 mg/l, nickel 0.3 mg/l, polyphosphate 10 mg/l, zinc 200 mg/l.

A 25 ml of sample was taken and diluted to 50 ml with distilled water in a conical flask. One ml of buffer solution and 1-2 drop of Eriochrome Black T indicator was added. Then the standard EDTA titrant was added slowly with continuous stirring, until last radish tinge colour disappeared from the solution. The end point of the solution was normally blue. The duration of the titration was not extended beyond 5 minutes measured from the time of addition of buffer.

$$\text{Hardness as CaCO}_3 \text{ (mg/l)} = \frac{(A-B) \times C \times 1000}{V}$$

Where;

A= ml of EDTA for titration of sample;

B= ml of EDTA for titration of blank;

C can be calculated from the standardization of the EDTA titrant and equivalent to
ml of standard calcium solution; and
ml of EDTA titrant

V= ml of sample.

Chloride (Cl)

Chloride (Cl) ion is one of the major inorganic anions in water and waste water. In potable water, the salty taste produced by chloride concentrations is variable and dependent on the chemical composition of water. Some waters containing 250 mg Cl/ l may have a detectable salty taste if the cation is sodium. On the other hand the typical salty taste may be absent in water containing as much as 1000 mg/l when the predominant cations are calcium and magnesium. The chloride concentration is higher in waste water than in raw water. Along the seacoast, chloride may be present in high concentration because of leakage of saline water into water bodies directly or indirectly. Industrial processes may also increase chloride. High chloride content can harm metallic pipes and structures, as well as growing plants. The method used for this analysis was Titration (silver nitrate) standards method.

Representative samples were collected in clean and chemically resistant plastic bottles. The maximum sample portion required was 100 ml. No special preservative was necessary for the storage of samples. Chloride is determined in a natural or slightly alkaline solution by titration with standard silver nitrate using potassium chromate as indicator. Silver chloride quantitatively precipitates before red silver chromate is formed.

Bromide, iodide and cyanide are measured as equivalents of chloride ion. Main interferences are the contents of thiosulfate, thiocyanate, cyanide, sulfite, sulfide, Iron (if present >10 mg/l) and orthophosphate (if present >25 mg/l.) The pretreatment of highly colored or turbid samples is required. The reagents used for this analysis included:

- Standard silver nitrate solution (0.02 M);
- Potassium chromate indicator; and
- Aluminum hydroxide suspension.

A 20 ml sample was taken in a conical flask and adjusted the pH range 7 to 10 with H₂SO₄ or NaOH. A few drops of K₂CrO₄ indicator solution was added and titrated against standard solution of AgNO₃ (titrant) up to pinkish yellow end point. 100 ppm NaCl standard was used to confirm accuracy.

$$\text{Concentration of Cl mg/l} = \frac{(A-B) \times M \times 35.45 \times 1000}{V}$$

Where:

A and B are the volumes of silver nitrate solution required by the sample and blank respectively;
M=Concentration (mol/lit) of AgNO₃; and
V= ml of sample.

Sodium (Na) & Potassium (K)

Sodium ranks sixth among the elements in order to abundance and is present in most natural waters. The level of Na may vary from less than 1 mg/l to more than 500 mg /l. Whereas potassium ranks seventh among the elements in order of abundance, yet it's concentration in most drinking waters seldom reaches 20 mg/l. Samples for analysis of sodium and potassium were collected in polyethylene bottles to eliminate the possibility of sample contamination, due to leaching of glass container. The method used for analysis of sodium and potassium was same emission photometric method (Model: PFP-7, JENWAY, UK). Principle of the Flame photometer operation is that compounds are thermally dissociated and further excited to high energy level, when these atoms return to ground state they emit radiation which lies mainly in the specific visible region of the spectrum. Light emitted is proportional to sample concentration. Detection limits of the instrument for sodium and potassium is <0.2 mg/l. After ignition, the filter select control is set at proper position. Suction rate of distill water should be 2-6ml/minute. Blank and standard solutions of various concentrations were aspirated and fine control was adjusted to have stable positive reading. After blank and standards, samples were aspirated and results are noted.

Sulfate (SO₄)

Sulfate is an abundant ion in the earth's crust and light concentrations may be present in water due to leaching of gypsum, sodium-sulfate and shale. High concentrations of sulfate may be due to oxidation of pyrite and mine drainage. Sulfates also come from sulfur containing organic compounds and industrial waste discharge. Sulfate concentrations in natural water range from a few mg to several hundred mg per litre. The WHO has established 200 mg/l as the highest desirable level of sulfate and 400 mg/l as the maximum permissible level in water for domestic use. Samples were collected in clean plastic bottles and were stored at 4°C in order to reduce the possibility of bacterial reduction of sulfate to sulfide in polluted or contaminated samples. The method used for this analysis was Sulfa Ver 4 HACH Method (8051) (powder pillows). The range of measurement was 0 to 70 mg/l.

Sulfate ions in the sample react with barium in the sulfa ver 4-sulfate reagent and form insoluble barium-sulfate turbidity. The amount of turbidity formed is proportional to the sulfate concentration. The following elements interfere at levels above those concentrations listed below:

Calcium	20,000 mg/l as CaCO ₃	Chloride	40,000 mg/l as Cl.
Magnesium	10,000 mg/l as CaCO ₃	Silica	500 mg/l as CaCO ₃

UV-VIS Spectrophotometer (U-1100), HITACHI apparatus was used for analysis. A 25 ml of deionized water was taken in a beaker. The contents of sulfa ver 4 sulfate reagent powder pillows were added and swirled to dissolve. The beaker was placed undisturbed for 5 minute to reach its reaction period. The contents of beaker were taken in a reference cell and placed into the cell holder of UV-VIS spectrophotometer adjusted at wavelength of 450 nm. The button zero was pressed to display zero reading. Then the standard solutions of 5,10,20,30,40,50,60 and 70 mg/l sulfate were prepared into separate beakers and the contents of sulfa ver 4-sulfate reagent powder pillows were added and swirled to dissolve. After 5 minutes (reaction period) the absorbance were taken and a graph was plotted between concentration of the sulfate standard solution and their

representative absorbance. Similarly the water samples were treated and their absorbance was compared with graph in order to determine their concentrations.

Nitrate (NO₃)

Nitrate, highly oxidized form of nitrogen is commonly present in natural water due to end product of the aerobic decomposition of organic nitrogenous matter. Significant sources of nitrate are fertilizers from cultivated land, drainage from livestock feed lots and domestic and some industrial waste water. Unpolluted natural water usually contains only minute amounts of nitrate. Excessive concentrations in drinking water are considered hazardous for infants. In their intestinal tract nitrates are reduced to nitrites, which may cause methaemoglobinaemia.

Samples were collected in plastic bottles with the addition of boric acid (2 ml/l sample) and stored at 4°C. Before analysis, the samples were warmed to room temperature and neutralized with 5.0N sodium hydroxide standard solution. The method used for this analysis was Cadmium Reduction Method (HACH-8171) by Spectrophotometer.

The range of measurement for Nitrate (N) in drinking waters falls between 0 to 4.5 mg/l (NO₃-N). The possible interferences are strong oxidizing and reducing substances. Ferric (iron) causes high results and must be absent. Chloride conc. above 100 mg/l may also cause low results. Cadmium metal reduces nitrate presence in the sample to nitrite. The nitrite ion reacts in an acidic medium with sulfamic acid to form an intermediate diazonium salt, which couples to gentisic acid to form an amber-colored product.

A 25 ml of deionized water was taken in a beaker. The contents of 1 NitraVer 5-nitrate reagent were added and swirled to dissolve. The beaker was placed undisturbed for 5 minutes to allow for the chemical reaction to complete. The contents of beaker were taken in a reference cell and placed into the cell holder of UV Visible spectrophotometer adjusted at wavelength of 400 nm. The zero button was pressed to display zero reading. Then the standard nitrate (N) solutions of 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0 mg/l were prepared in separate beakers and their absorbance were noted. Similarly absorbances of samples were measured and the concentrations of nitrate (NO₃) were determined with the help of calibrated graph.

Phosphate

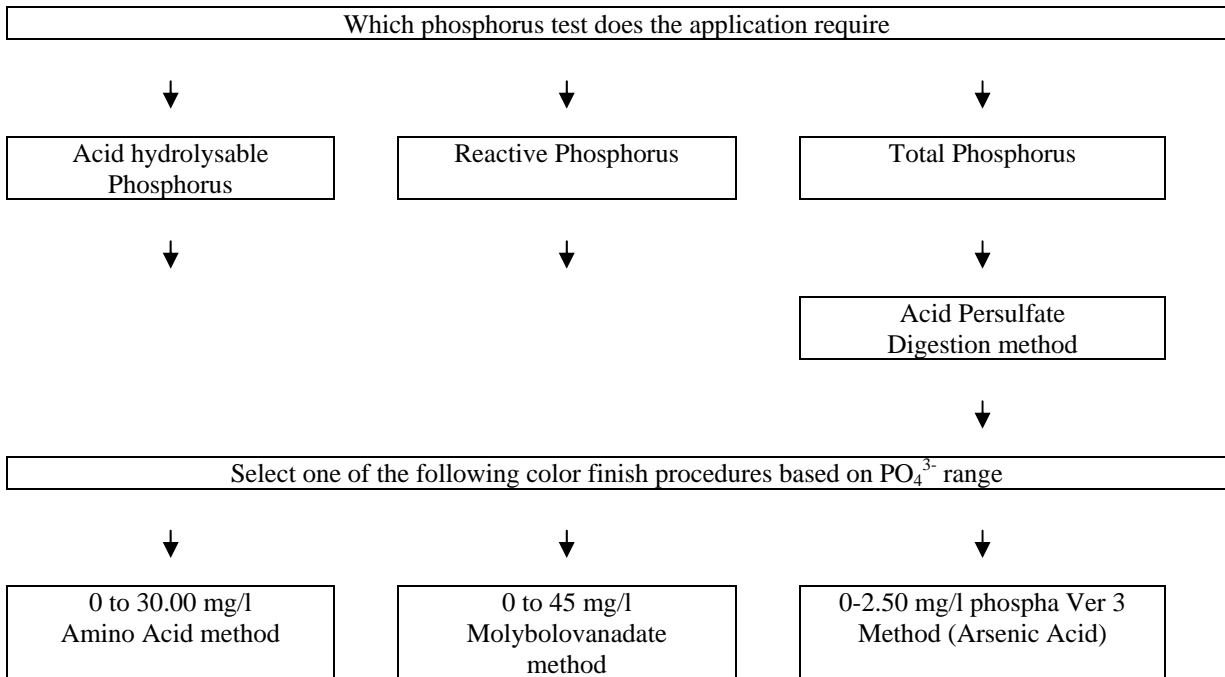
It occurs in natural waters and waste waters almost so leys as “Phosphates”. These are classified as

- Orthophosphates
- Condensed phosphates (pyro, meta & other polyphosphates)
- Organically bound phosphates

Phosphate occurs in bottom sediments and in biological sludges, both as precipitated inorganic forms and incorporated into organic compounds. Total Phosphorus can be divided analytically into three chemical types that have been described.

- i) Reactive
- ii) Acid Hydrolyzable
- iii) Organic phosphorus

Methods to Determine Phosphate are briefed as following;



The method used for phosphate analysis is Molybolovondate Method.

Following reagents were prepared and used for the analysis;

1. Amino Solution: 3.7 gram sodium sulphite (Na₂SO₃). 0.1 g Amino-2-naphthol-4 (sulphuric acid). 6.2 g Na metabolisulphurous (Na₂S₂O₅). Dissolved in 100 ml water (stored in Amber colored bottle).
2. Ammonium Molybedate: 4.8 g Ammonium molybedate dissolved in 80 ml. of distill water. 0.25 g or 0.25 ml concentrated ammonium hydroxide added and diluted up to 100 ml distill water. Heated solution until solution cleared.
3. Bismuth Nitrate Solution: 37 ml H₂SO₄ + 63 ml distill water, cool it and dissolve 0.48 g bismuth nitrate.
4. Standard Phosphate Solution: 1.4328 g of potassium dihydrogen phosphate dissolved in one litre of distilled water. This solution equal to 1000 ppm PO₄.

A series of standard phosphate solution ranging from 0 to 10 ppm by diluting the stock solution of phosphate are prepared. 5 ml sample (as standard) + 1 ml amino solution + 1 ml bismuth nitrate + 1 ml ammonium molybedate solution allowed to stand for 10 minute to develop color and measure the color at 650 nm wavelength after setting the spectrophotometer according to instrument instruction manual.

If absorbances are noted, curve between absorbance and concentration is drawn by MS-Excel and regression equation is drawn, which gives the concentration of samples. If spectrophotometer is giving concentration, then there is no need of regression equation and standard curve. Now take actual samples and add all the reagents, give 10 minutes as reaction time and note absorbance of each sample on spectrophotometer and draw concentration from regression equation.

Total Dissolved Solids (TDS)

Measurement for total dissolved solids is a procedure to check the correctness of analyses and is applicable specifically to water samples for which relatively complete analyses are made. This check does not require additional laboratory analyses. TDS of the water samples was measured in following way:

$$\text{Total dissolve solids (TDS)} = 0.6 (\text{alkalinity}) + \text{Na} + \text{K} + \text{Ca} + \text{Mg} + \text{Cl} + \text{SO}_4 + \text{NO}_3 + \text{F}$$

If the ratio of calculated TDS to conductivity falls below 0.55, the lower ion sum is suspect and needed to reanalyze it. If the ratio is above 0.7, the higher ion sum is suspect and needed to reanalyze it. The acceptable criterion is as follows.

Calculated TDS/Conductivity = 0.55 – 0.70

If the ratio of TDS to EC is outside these limits, measured TDS or measured conductivity is suspect and needed to reanalyze.

Trace and Ultra Trace Elements

Fifty eight different trace and ultra trace elements such as Lead, Arsenic, Iron, Fluoride Beryllium, Cadmium, Cerium, Cesium, cobalt, Chromium, Copper, Niobium, Neodymium, Nickel, Palladium, Praseodymium, Rhodium, Ruthenium, Scandium, Selenium, Samarium, Tin, Strontium, Tantalum, Thallium, Vanadium, Tungsten, Yttrium, Ytterbium, Zinc, Zirconium, Silver, Aluminum, Bismuth, Dysprosium, Erbium, Europium, Gallium, Germanium, Gadolinium, Hafnium, Mercury, Holmium, Indium, Iridium, Lanthanum, Lithium, Lutetium, Manganese and Molybdenum were analyzed. Fifty four of the trace and ultra-trace elements were analyzed on state of art equipment i.e. Inductive Coupled Plasma Spectrometer (ICP Vista Pro). Analytical procedure includes following steps;

1. Torch alignment using standard solution of manganese with concentration of 5 ppm.
2. Wavelength calibration using multielement standard having 50 ppm potassium and 5 ppm other elements i.e. Al, As, Ba, Cd, Co, Cr, Cu, Mn, Mo, Ni, Pb, Se, Sr, Zn.
3. Creation of new worksheet with the selection of required elements.
4. Calibration with various multielement standards solutions having desirable concentrations.
5. Analysis of actual water samples.

Distill-dionized water of high quality ($EC < 0.3 \mu S/cm$) is used to prepare blank solution. Volume of concentrated Nitric Acid (65%) is added to distill water in a ratio to have blank solution with 2% concentrated HNO_3 . This blank solution is used for washing as well as for calibration. Samples to be analyzed are prepared using some concentrated nitric acid to have 2% adjusted ratio of acid in the sample. Reliability and reproducibility of analysis were checked by analyzing, blank, standard and pre-analyzed sample after every ten samples.

Lead (Pb)

Natural Water contains more than 5 $\mu g/l$. Lead in a water supply may come from industrial, mine and smelter discharges or from the dissolution of old lead piping. Sample was acidified by the addition of 2 ml of concentrated HNO_3 per liter of sample prior to storage in a plastic container. Lead was analysed by Atomic Absorption Spectrometric method using Graphite mode (AAS Vario 6 Analytik Tena AG) using argon gas at a pressure of 3-5 Bars. Graphite tube technique includes steps i.e. Installation of graphite tube furnace unit in the sample chamber; Installation of autosampler (MPE 50); and Formation of graphite tube. Optical parameters include wavelength adjustment at 217 nm. After ensuring the conditions for lead analysis method was loaded. Conditions were given to autosampler having Diluents (0.5% HNO_3) at position 41 and stock (lead standard of 100 ppb at position 42) solutions of $Pb(NO_3)_2$ with 8 ppb concentration and $Mg(NO_3)_2$ with 5 ppb concentration were used as Analyt modifier. Temperature of instrument was 900 C° whereas atomization takes place at 1800 C° . Calibration was performed with number of standards of known concentration using the stock solution of 100 ppb or as required will be given. Working area for samples were at positions 1-40 on autosampler. Sample name and sample positions were feeded into software and analysis was performed.

Arsenic (As)

Arsenic is a non-metallic element, present naturally in surface and ground water due to erosion of rocks. It is concentrated in shale, clays, phosphorites, coals, sedimentary iron ore and manganese ores. Aqueous arsenic in the form of arsenite, arsenate and organic arsenicals may result from mineral dissolution, industrial discharges or the application of herbicides. The chemical form of arsenic depends on its source. Inorganic

arsenic may originate from minerals, industrial discharges and insecticides, whereas organic arsenic may come from industrial discharges, insecticides and biological action on inorganic arsenic. The toxicity of arsenic depends on its chemical form.

Atomic Absorption Spectrometer (Hydride Generation mode) was used for the analysis of arsenic in water samples. All samples were analysed on HS 55 Mercury/Hydride system, an accessory (AAS, Vario 6 Analytik Jena AG) for the matrix free determination of the hydride forming elements such as As, Bi, Sb, Se, Sn and Te.

The Hydride technique makes use of fact that hydrogen liberated in the reaction of the weakly acidic sample solutions with sodium boro-hydride which combines with metal ions to form gaseous hydrides. These are carried to the hot quartz cell by the carrier gas and decomposed by collision processes in a series of steps, until free As atoms were obtained.

For the analysis of arsenic the Atomic Absorption Spectrophotometer (AAS Vario 6 Analytik Jena AG), Mercury/Hydride System HS55 (Analytik Jena AG), and Argon Gas with 99.99% purity were used. The following common reagents were used for the analysis;

- i. Sodium borohydride (NaBH_4 , 98% purity)
- ii. Sodium hydroxide, NaOH
- iii. Hydrochloric Acid (Concentrated 37% HCl)
- iv. Arsenic Standard (1007 $\mu\text{g/ml}$, As in 2% HNO_3 , BDH)

In order to make reducing solution (Reductant), 15 g sodium borohydride (NaBH_4) and 5 g of sodium hydroxide were dissolved in 500 ml distilled water. This reagent was used as reducing agent for Arsenic analysis.

The HS 55 Mercury/Hydride system consisting of a basic unit and the cell unit was operated and controlled from PC. Basic unit consists of three accessories. These include batch module, single channel-peristaltic pump and gas valve box. The gas valve box supplied argon gas for scavenging and for transporting the metal hydrides to the system.



Fig.-1: Mercury Hydride System of Atomic Absorption Spectrophotometer (AAS)

Pressure of the argon gas cylinder was adjusted at 3-5 bars. After attaining the necessary temperature (950 °C) reducing agent was fed by the peristaltic pump. A 10 ml sample was taken into reaction cell and 0.8 ml of concentrated HCl was dispensed into sample and reaction cell was adjusted properly at its place. Calibration standards of arsenic with concentrations (0,10,20,30,40,50 ppb) and (50,60,70,80,90,100 ppb) were prepared. New method of calibration was developed using these standards under the operation of software, and then the method developed was loaded for analysis of actual samples. HS 55 hydride system analyzes the water samples in the following sequences:

- Pre-wash time
- Reaction time
- Rewash time

The detection limit of this method is 0.1 ppb.

Iron (Fe)

Iron is an abundant element in the earth's crust, but exists generally in minor concentrations in natural water system. Surface water in a normal pH range of 6 to 9 rarely carries more than 1 mg of dissolved iron per liter. The formation of hydrated ferric oxide makes iron-laden waters objectionable. This ferric precipitate imparts an orange stain to any setting surface including, laundry articles, cooking and eating utensils and plumbing fixtures. Additionally, iron imparts a yellowish colour and bitter taste to water. This coloration along with associated taste and odors can make the water undesirable for domestic use. WHO has established 0.3 mg/l as the highest desirable level for iron in water and 1.0 mg/l as the maximum permissible level in water intended for domestic use.

In the sampling and storage process, iron in solution may undergo changes due to oxidation and it can readily precipitate on the sample container walls or a partially settle-able solid suspension. For total iron measurement, precipitation can be controlled in the sample containers by the addition of 1.5 ml of concentrated nitric acid per liter of sample immediately after collection. The method used for this analysis was Photometric Phenanthroline Method.

Ferrous (iron) chelates with 1, 10-phenanthroline to form an orange-red complex. Color intensity is proportional to iron concentration. A pH between 2.9 and 3.5 ensures rapid color development in the presence of an excess of phenanthroline. The interfering substances are cyanide, nitrate, phosphate, chromium, zinc, iron, cobalt and copper (in excess of 5 mg/l), nickel (in excess of 2 mg/l), Bismuth, cadmium, mercury, molybdate and silver.

The concentration of iron was measured at 510 nanometer on Spectrophotometer, Model U-1100, HITACHI. The reagents used for this analysis included:

- i) Iron standard solutions;
- ii) Phenanthroline solution; and
- iii) Ammonium acetate buffer solution.

A 5 ml of deionized water was taken in a beaker. Its pH was adjusted between 3 and 4 and 1 ml of buffer solution with 0.2 ml of phenanthroline solution was added. After 10-15 minute, the contents of beaker were taken in a culet and placed in cell holder of the spectrophotometer at wavelength of 510 nm and the zero button was pressed. The standard solutions from 0.1 to 1.0 mg/l were prepared and their absorbances were taken. Similarly the absorbance of samples was taken and their concentrations were determined with the help of calibrated graph.

Fluoride (F)

A fluoride concentration of approximately 1.0 mg/l in drinking water effectively reduces dental caries without harmful effects on health. Fluoride may occur naturally in water or it may be added in controlled amounts. Some fluorosis may occur when the fluoride level exceeds the recommended limits. The method used for analyzing was 8029, SPADNS (Hach) by Spectrophotometer. The range of analysis is about 0.0 to 2.00 mg/l. Samples were collected without preservative in polythene bottles and analyzed within 28 days.

The SPADNS colorimetric method is based on the reaction between fluoride and a zirconium-dye lake. Fluoride reacts with the dye lake, dissociating a portion of it into a colorless complex anion (ZnF_6^{-2}) and the dye. As the amount of fluoride increases, the color produced becomes progressively lighter. Thus bleaching the red color is an amount proportional to the fluoride concentration.

A 10 ml sample and deionized water was measured into two dry sample cells. Then two ml of SPADNS reagent was added into each cell and swirled to mix. After one-minute reaction period, the blank was placed into the cell holder of spectrophotometer adjusted at 580 nm and pressed the zero button. Then the prepared sample was placed into the cell holder and their absorbance was noted. Similarly, all the samples were treated

and their absorbances were noted. The concentration of fluoride in samples was determined with the help of regression model. Concentration of F ion mg/l equals $\text{Abs.} \times 6.9364 + 0.0425$.

Chromium (Cr)

Chromium exists in trivalent state, which is stable form, and other one is hexavalent chromium, which is readily reduced by a variety of organic species. Trivalent form rarely occurs in potable water. According to APHA, *et al.*, (1992), the hexavalent chromium concentration of U.S drinking waters has been reported to vary between 3 and 40 $\mu\text{g/l}$ with a mean of 3.2 $\mu\text{g/l}$. According to Michael (1981) samples should be collected in polyethylene bottles and acidified (1.5 ml of concentrated HNO_3 per liter of sample) immediately after collection to prevent chromium loss on the walls of the sample container. Analytical methods given in Standard Methods (APHA, *et al.*, 1992) are colorimetric method for determination of hexavalent chromium. Atomic absorption spectrometric method for low levels of total chromium and inductive coupled plasma spectrometric method. Guideline value recommended by WHO (1984), PSQCA (2002) and Canadian Bottled Water Federation (1989) for chromium is 0.05 mg/l, whereas MCL and MCLG set by EPA (1986) is 0.1 mg/l.

Manganese (Mn)

Joxel (2001) reported that manganese is a mineral that naturally occurs in rocks and soil and is normal constituent of the human diet. Manganese may become noticeable in water at concentrations greater than 0.05 mg/l of water by imparting a color, odor or taste to the water. APHA, *et al.*, (1992) found that there is evidence that manganese occurs in surface waters both in suspension in the quadrivalent state and in the trivalent state in a relatively stable, soluble complex. Manganese intake through drinking water can vary considerably, normally being substantially lower than intake from food.

Michael (1981) has recommended the acidification of water samples by the addition of 1.5 ml of concentrated HNO_3 per liter of sample prior to storage in a plastic container whereas Standard Methods (APHA, *et al.*, 1992) has recommended the atomic absorption spectrometric and Inductive Coupled Plasma Spectrometric methods for direct determination of manganese of the various colorimetric methods, the persulphate method is preferred because the use of mercuric ion can control interferences from a limited chloride ion concentration. WHO (1996) has recommended 0.1 mg/l as the guideline value for drinking water.

Molybdenum (Mo)

Molybdenum is generally present at very low concentrations in water. It's concentration in surface water is normally less than 7 $\mu\text{g/l}$ as reported by Michael (1981). APHA *et al.*, (1992) in standard method has referred to flame atomic absorption spectrometric and inductive coupled plasma methods for analysis of molybdenum in drinking water. WHO (1996) has recommended the 0.07 mg/l as the guideline value of molybdenum in drinking water.

Nickel (Ni)

Michael (1981) found that nickel compounds are found in many ores and minerals and as most nickel salts are quite soluble, they may contribute to water pollution through municipal or industrial waste discharges. Michael (1981) has recommended acidification of water samples by the addition of 1.5 ml of concentrated HNO_3 per liter of sample prior to storage in a plastic container. The Atomic Absorption Spectrometric and Inductive Coupled Plasma Spectrometric methods are the methods of choice for all samples as recommended by standard methods (APHA, *et al.*, 1992). WHO (1996) has recommended guideline value for nickel as 0.02 mg/l whereas USEPA (1986) has recommended MCL and MCLG as 0.1 mg/l.

Aluminium (Al)

Aluminium is distributed widely in nature and is a constituent of all soils, plants and animal tissues. As a consequence of this wide natural distribution and the activities of man, aluminium is present in air, food and water, both natural and polluted (Sorensen *et al.*, 1974 and Monier Williams, 1935). The salts of aluminum are used extensively in water treatment for the removal of color and turbidity. The level of aluminium in water

varies considerably and may exceed 10 mg/l in the vicinity of aluminum processing plants (Sylvester, *et al.*, 1967).

APHA, *et al.*, (1992) in the “Standard Methods for the examination of water and wastewater” have recommended to use separate clean bottle for water sampling and acidified with nitric acid to a pH below 2.0 to minimize precipitation and adsorption on container walls. The Atomic Absorption Spectrometric and Inductive Coupled Plasma methods are free from such interferences as fluoride and phosphate and are preferred. The Eriochrome cyanine R colorimetric method provides a means for estimating aluminium with simpler instrumentation. The automated pyro-catechol violet method is a highly sensitive flow injection or continuous flow analysis technique (APHA, *et al.*, 1992).

Selenium (Se)

The selenium concentrations usually found in water are of the order of a few micrograms per liter, but may reach 50-300 µg/l in seleniferous areas (WHO, 1972) and have been reported to reach 1 mg/l in drainage water from seleniferous irrigated soil as reported by Hem (1970). Several reviews (Rosenfield, 1964; NRC, 1977; Muth, 1967, National Academy of Sciences, 1976; USEPA, 1980; Ermakov and Kovalskij, 1974 and NRC, 1980) of data from different parts of the world indicated that the selenium contents in most surface water samples analyzed was well below 10 µg/l. APHA, *et al.*, (1992) have reported that the selenium concentration of most drinking waters and natural waters is less than 10 µg/l. However the pore water in seleniferous soils in semiarid areas may contain up to hardness or thousands of microorganisms dissolved selenium per liter. SDWF (2003) has reported that the sources of contamination of selenium are discharges from petroleum refineries, corrosion deposits and discharge from mines. According to WHO (1984) guideline value for selenium in drinking water is 0.01 mg/l. Canadian Bottled Water Federation (1989), PSQCA (2002), Health & Welfare Canada (1987), Ontario Ministry of the Environment (1983), USEPA (1986) have also reported the same value i.e. 0.01 mg/l for selenium. Selenium in concentrations of around 1 µg/l has been found to be adsorbed on pyrex glass and on polyethylene container (Shendrikar & West, 1975). Therefore, Michael (1981) has recommended collecting the samples in a polyethylene bottle and acidifies by the addition of 1.5 ml of concentrated HNO₃ per liter if the sample is to be stored. Reference methods for determination of selenium in water are hydride generation systems of atomic absorption spectrometric, inductive coupled plasma spectrometric methods and by chemical methods involving derivatification of selenite and determination of the organic derivative by colorimetry or fluourometry (APHA, *et al.*, 1992).

Total Coliforms & E.Coli

Bacteriological Testing of water samples was performed by “Defined Substrate Technology (Colilert) Method” which is a standard method for enumeration of Total Coliforms and *E.Coli* simultaneously in the water and wastewater. Five number of colilert tubes containing colilert reagent were inoculated for each sample under aseptic conditions. After an incubation period of 24 hours at 35±0.5 C°, observations were made for color change and inflorescence. Presence of yellow color indicates the presence of total coliforms, whereas fluorescence is checked by placing the UV lamp (3-5 inch in size) in front of the tubes in a dark environment. Presence of fluorescence in the tubes indicates the presence of *E.Coli*. Density of Total Coliforms and *E.Coli* was determined with reference to the standard Most Probable Number (MPN) probability chart as given below. Results have been expressed as MPN/100 ml for both Total Coliforms and *E.Coli*.

Maximum Probable Number of Organisms per 100ml Sample

<i>No. of +ve Tubes</i>	<i>MPN Organisms/100ml</i>
0	0
1	2
2	5
3	9
4	16
5	>16

RESULTS & DISCUSSIONS

The National Water Quality Monitoring Program is executed in 22 major cities of Pakistan including federal area of Islamabad city. The province wise distribution of cities is Punjab (11), NWFP (3), Balochistan (4), Sindh (3), i.e. **Punjab**: Bahawalpur, Faisalabad, Gujranwala, Gujrat, Kasur, Lahore, Multan, Rawalpindi, Sargodha, Sheikhpura, Sialkot; **NWFP**: Mangora, Mardan, Peshawar; **Balochistan**: Khuzdar, Loralai Quetta, Ziarat; **Sindh**: Hyderabad, Karachi, Sukkur. The water sources/locations in all cities were selected from where the people are getting water mainly for drinking purposes. The water samples for analysis were collected from overall 344 different water sources/locations showing distribution as Islamabad (26), Punjab (163), NWFP (35), Balochistan (65) Sindh (55). The source wise detail is Tubewells (176), W. Supply (23), Cistern (2), Bore (12), Tap (60), Well (5), Karez (2), Spring (5), Windmill (1), Hand Pump (48), Injection Pump (7), Donkey Pump (3). The province wise water sources/locations distribution is Islamabad: Tubewell (19), W.Supply (2), Cistern (1), Bore (1), Tap (3); **Punjab**: Tubewell (90), W.Supply (5), Bore (9), Tap (7), Hand Pump (42), Injection Pump (7), Donkey Pump (3); **NWFP**: Tubewell (33), and Bore (2). **Balochistan**: Tubewell (31), W.Supply (13), Cistern (1), Tap (4), Well (5), Karez (2), Spring (5), Windmill (1), Hand Pump (2); **Sindh**: Tubewell (3), W.Supply (3), Tap (45), Hand Pump (4).

The analytical parameters are divided into **Physical and Aesthetic**:- pH, Electrical Conductivity (EC), Turbidity, Color, Taste, Odor. **Major Components Chemicals**:- Alkalinity (Alk), Bicarbonate (HCO_3), Carbonate (CO_3), Calcium (Ca), Magnesium (Mg), Hardness, Sodium (Na), Potassium (K), Chloride (Cl), Sulphate (SO_4), Nitrate (NO_3), Phosphate (PO_4), Total Dissolved Solids (TDS). **Trace and Ultra Trace Elements**:- Lead (Pb), Arsenic (As), Iron (Fe), Fluoride (F), Chromium (Cr), Manganese (Mn), Molybdenum (Mo), Nickle (Ni), Aluminum (Al), Selenium (Se) have been included out of 58 determined elements. **Bacteriological Parameters**:- Coliform and Escherichia Coli (*E.Coli*). The terminologies for differentiating safe and unsafe drinking water parameters in the report are used: - (i) guideline values; (ii) water quality standards; (iii) permissible limits; (iv) acceptable standards. The PCRWR has adopted WHO, PSQCA (Pakistan Standard and Quality Control Authority), and EC (European Commission) set standards for comparison. The report is based on Phase-III (summer) water quality monitoring through collection of water samples and subsequent field and lab. analysis. Contrary to previous two reports on water quality status of Pakistan; in this report a different pattern of results presentation is adopted on city level basis instead of parameters, which is more appropriate and easy to understand for policy makers, city Nazims and water supply managers to adopt future line of actions.

* *The numbers of cities and water source are given in brackets.*

FEDERAL AREA ISLAMABAD

The water samples were collected from 26 locations covering the whole city and all possible drinking water sources i.e. Tubewell (19), Water Supply (2), Bore (1), Tap (3) and Cistern (1). Out of 26 locations only at 01 location the water source was safe for drinking. After processing the analytical data. 65% samples were found contaminated with Coliform bacterium and 23% were polluted with *E.Coli*, whereas 73% samples were identified having excess of Ca and 12% possessing excess of Fe and 8% showing high Turbidity levels when the data was compared with WHO and PSI set guideline values (*Annexure-1*). The water quality was deteriorated may be due to much older water pipes leakages, allowing seepage of sewerage water and the sources like tubewells, water supplies, cistern, bore, taps were extracting the groundwater contaminated by industrial waste or polluted streams and tributaries. The overall scenario of drinking water quality status was very much discouraging and alarming because the Islamabad is considered the most beautiful and hygienic city of Pakistan, but the water quality picture is otherwise. The agencies responsible to supply and manage the water resources of Islamabad were not transmitting the true picture to the public. For example, the National Institute of Health (NIH) declared that the water being supplied to the residents of the capital was fit for human consumption. A bacteriological examination report released by the institute said the water being supplied to the residents was free of various types of bacterium. The NIH analyzed the water samples after reports appeared in the newspapers that the quality of drinking water being supplied by the respective departments throughout the country was unhygienic. On the basis of this analysis, the Capital Development Authority (CDA) had assured the residents of Islamabad that they should not be scared of any water-borne disease because the water being supplied to them was completely safe for drinking (*Dawn; March 27, 2004*). The news published by the CDA was not supported by any data.

Safe Water Source

There is only 01 tubewell No.200 installed at Fatima Jinnah Park supplying safe water free of all microbial contaminations and possessing less and acceptable concentrations of soluble macro and micro inorganic ions as well as physical and esthetic parameters compared with international water quality standards. Hence, the water could be supplied and used for drinking purposes from this tubewell in the city. (*Annexure-23*)

Safe Water Sources with Slight Problems

There are only 02 water sources viz. Tubewell No.193, F-6, NEFDEC Cinema and Tubewell No.37, G-5 (both had excess of Ca) supplying safe drinking water with slight water quality problems not so adversely affecting the human health in general. Hence, the water could be supplied and used for drinking purposes from these tubewells in the city (*Annexure-24*).

PROVINCE OF PUNJAB

BAHAWALPUR

The water samples were collected from 25 locations covering the whole city and all possible sources i.e. Tubewell (13) and Hand Pump (12). Out of the 25 locations none of the source is supplying safe drinking water to the people living in the city. After processing the analytical data it was estimated that 24% were polluted with *E.Coli*; 52% samples were found contaminated with Coliform bacterium; 76% possessing excess Arsenic (As) most of the samples containing more than 50 ppb which is 5 times more than WHO set limits; 4% having more Lead (Pb), 4% samples with more Nitrate (NO₃) and K 12% with high Total Dissolved Solids (TDS), 32% water samples possessing excess level of Turbidity and the tubewell water of Commercial Area, Satellite Town has extreme levels of Turbidity may be due to damaged strainer pipes. 60% samples have higher concentration of Calcium (Ca) and the tubewell of Commercial Area, Satellite Town is pumping the water with more soluble ions of Ca (188 mg/l) may be due to underground more calcareous mineral rocks; the hardness was observed beyond permissible limits in 16% water samples; the Sodium (Na) ions are high in 8% water samples but the hand pump water is highly brackish possessing high levels of both cations and anions as well as Arsenic. The hand pump is located at Govt. High School, Hamatian; while 4% were found with more Potassium (K) level; the anions like Sulphate (SO₄) are also found beyond acceptable limits in 20% water

samples; the micro element i.e. Iron (Fe) was on higher side in 64% samples. 4% samples were found contaminated with Al and Mo (*Annexure-2*). The data was compared with WHO and PSI set guideline values.

FAISALABAD

The water samples for analysis were collected from 13 locations covering the whole city and all possible sources i.e. Tubewell (2), Taps (5), Hand Pump (1), Injection Pumps (4), Donkey Pump (1). The overall supply of potable water is satisfactory because out of 13 sources 3 are supplying safe drinking water and 2 delivering safe water with slight problems (excess Fe). After processing the analytical data it was estimated that 15% samples were polluted with *E.Coli*, 38% water samples were found contaminated with Coliform bacterium and the same %age of water samples had been identified possessing the excess concentrations of Na, Ca, Cl, SO₄ and Fe. 8% samples having more F and Pb levels; 31% having excess NO₃. 23% water samples possessing hardness beyond acceptable limits, 46% samples had higher concentration of K and high level of TDS (*Annexure-3*).

Safe Water Source

There were 03 water sources i.e. 01 Tubewell No.3, installed at Canal Bank Road, Farooqabad; 02 Taps located at Baghdadi Chowk Sidupur Near Noori Masjid and Makhdoom Road, Khalil Abad were supplying safe water free of all microbial contaminations and possessing acceptable concentrations of soluble macro and micro inorganic ions as well as within limits of physical and esthetic parameters. Hence, the water could be supplied and used for drinking purposes from these sources safely. (*Annexure-23*).

Safe Water Sources with Slight Problems

There are 02 water sources viz. taps provided at Shadab Colony, Shadab Park and Awan Chowk, Sadar Bazar (both had excess of Fe) were supplying safe drinking water with slight water quality problems not so adversely affecting the human health in general. Hence, the water could be supplied and used for drinking purposes from these sources safely. (*Annexure-24*).

GUJRANWALA

The water samples were collected from 14 locations covering the whole city and all possible sources i.e. Tubewells (9), Hand Pumps (2), Injection Pump (1), and Donkey Pumps (2). Out of the 14 locations the 04 sources i.e. 3 tubewells and 1 Donkey Pump were supplying safe drinking water. After processing the analytical data it was calculated that 14% water samples were polluted with *E.Coli* and 64% water samples were found contaminated with Coliform bacterium. 43% water samples were found having the As beyond permissible limits, while 7% water samples had excess of NO₃ anions. The 2 number of water samples (14%) contain excessive amount of Ca ions (*Annexure-4*).

Safe Water Source

There were 04 sources i.e. 3 tubewells installed at Tanki No.1, Peoples Colony Taqirpura, Saghir Park Badri Chowk, Govt. P. Graduate College Pasroor Road and 1 donkey pump located at Govt. Girls High School Sarfraz Colony were supplying safe water free of all microbial contaminations and possessing less concentrations of soluble macro and micro inorganic ions as well as acceptable levels of physical and esthetic parameters compared with international accepted water quality standards. Hence, the water could be supplied and used for drinking purposes from these sources (*Annexure-23*).

GUJRAT

The water samples were collected from 9 locations covering the whole city and all possible sources i.e. Tubewells (7), Hand Pumps (2). Out of the 09 locations only 02 water sources viz. tubewells were supplying safe drinking water. After processing and computation of the analytical data it was revealed that 33% water

samples were polluted with *E.Coli* while 78% samples were found contaminated with Coliform microorganisms; 22% or 02 number of water samples are turbid; whereas 01 sample out of 09 samples were investigated to have excess concentration of various ions compared with WHO and PSQCA set guideline values i.e. As, TDS, Ca, Na, SO₄ and Fe (*Annexure-5*).

Safe Water Source

There were 02 tubewells installed at Mohalla Meanabad Sargodha Road and Municipal Corporation are supplying safe water free of all microbial contaminations and possessing less concentration of soluble macro and micro inorganic ions as well as with less values of physical and esthetic parameters compared with international accepted water quality standards. Hence, the water could be supplied and used for drinking purposes from the tubewells (*Annexure-23*).

KASUR

The water samples were collected from 10 locations covering the whole city and possible representative sources i.e. Tubewells (7), Hand Pump (1), and Injection Pumps (2). Out of 10 locations none of any source was supplying safe drinking water. In each case one or more parameter(s) was falling under non-acceptable guideline values. After compiling and processing the field and lab. analytical data it was recorded that 10% samples were polluted with *E.Coli* and 50% water samples were found contaminated with Coliform bacterium. The level of as in 80% water samples was found beyond WHO permissible limits (10 ppb). Only 01 (10%) sample collected from the tubewell installed at Govt. Primary School, Muhalla Qadir was found with higher concentration of Selenium (Se). The %age of various non-acceptable parameters like Fluoride and Nitrate (20%), Na, TDS and Fe (40%), K and SO₄ (30%) was identical (*Annexure-6*).

LAHORE

The water samples were collected from 16 locations covering the major part of the city area and sources i.e. Tubewells (16). Out of the 16 locations none of any source was supplying safe drinking water. In each case one or more parameter(s) was falling under non-acceptable guideline values. The data was computed and processed which showed that 43% samples were polluted with Coliform Bacterium. None of the sample showing E-coli contamination. The overall picture of other parameters was depicted as 100% water samples were possessing higher concentrations of As compared to WHO guide line values. The higher concentration of Fe was found in 50% water samples. 6% samples were found with high concentration of Na & TDS (*Annexure-7*).

MULTAN

The water samples were collected from 16 locations covering the city and major water sources i.e. Tubewells (7), Water Supplies (2), and Hand Pumps (7). Out of the 16 locations none of any source was supplying safe drinking water. In each case one or more parameter(s) were falling under non-acceptable guideline values. After processing the analytical data it was estimated that 31% samples were found contaminated with Coliform bacterium; and surprisingly no sample was polluted with *E.Coli* organism. A quite high %age (88%) of water samples were showing high concentration of As, whereas 50% water samples were possessing the concentration of Fe beyond the permissible limits. The Ca and turbidity were found in high concentrations in 38% and 19% water samples respectively (*Annexure-8*).

Safe Water Source with Slight Problem

There was only one water source tubewell installed at 132 KV Grid Station, Vehari Road was supplying safe drinking water with slight water quality problems (excess of Ca and Fe) not so adversely affecting the human health in general. Hence, the water could be supplied and used for drinking purposes from this tubewell (*Annexure-24*).

RAWALPINDI

The water samples were collected from 15 locations covering the major water supply sources of the city i.e. Tubewell (13), W.Supply (1), and Bore (1). Out of 15 locations only 2 sources (tubewells) were supplying safe drinking water. The data was computed and processed which shows that 40% water samples were polluted with *E.Coli* and 73% samples were found contaminated with Coliform bacterium, whereas 60%, 20%, 13%, and 7% water samples had been identified possessing higher levels of Ca, Turbidity, Fe, and TDS respectively compared with international permissible water quality standards (*Annexure-9*). The more recent survey of hospitals, basic health units (BHUs), clinics and medical care centers conducted by Nespak it was reported in the news media that more than 82,000 cases of water related diseases were recorded annually in Rawalpindi. Almost 40 % of all reported diseases and 30% of all reported deaths in Rawalpindi were attributed to E-Coli, bacteriological and fecal contamination of drinking water. It was further asserted that about 45% of the total infant deaths occur due to water-borne diseases while inadequate supply of safe and credible potable water and unhygienic sanitation conditions were responsible for as many as 80% of all morbidity. The epidemic of hepatitis that appeared in Rawalpindi in 1993 and resulted in 4,000 cases was mainly due to water source pollution by faeces and inadequate water treatment. The data also reveals that the water provided to the residents did not meet the World Health Organization (WHO) standards (*Dawn; April 5, 2004*).

Safe Water Source

The 02 sources i.e. Tubewell No.30 and Tubewell No.4 installed at Muslim Town Haji Chowk and PAF Base, Minhas Camp respectively were supplying safe water free of all microbial contaminations and possessing less concentrations of soluble macro and micro inorganic ions as well as acceptable level of physical and esthetic parameters compared with international accepted water quality standards. Hence, the water could be supplied and used for drinking purposes from these tubewells in the city (*Annexure-23*).

Safe Water Source with Slight Problems

There were 02 water sources (tubewells) viz. Tubewell No.42 installed at Football Ground Westridge (excess Ca, Fe) and Tubewell No.41 installed at Dehri Hasanabad (excess Ca); supplying safe drinking water with slight water quality problems not so adversely affecting the human health in general. Hence, the water could be supplied and used for drinking purposes from these tubewells as well in the city (*Annexure-24*).

SARGODHA

The water samples were collected from 24 locations covering the major part of the city and all possible drinking water sources i.e. Tubewell (1), Water Supply (2), Bore (8), Hand Pumps (13). Out of 24 locations only 01 location had the facility to supply safe drinking water. After computing and processing of the field and lab. analytical data it was estimated that about 38% water samples were polluted with *E.Coli* and 75% samples were found contaminated with Coliform bacterium. The high concentration of As, Na, Cl, SO₄, Ca and Mg ions were found beyond the permissible limits in 13%, 54%, 42%, 46%, 50% and 17% water samples respectively but the water sample collected from Govt. Poly Technic Institute has shown extreme high level of As (182 ppb) when the WHO acceptable limits is 10 ppb and the threshold value is 10 ppb whereas, followed by the Pakistan Standard Quality Control Authority. High level of TDS and Turbidity was observed in 63% and 4% samples respectively. A similar and identical 33% water samples had been found containing high level of Hardness, NO₃ and K. High concentration of Fe was found in 4% samples (*Annexure-10*).

Safe Water Source

There was 01 source (Hand Pump) located at M. Mumtaz Chak No.9, Jhang Road; supplying safe water free of all microbial contaminations and possessing less concentrations of soluble macro and micro inorganic ions as well as acceptable levels of physical and esthetic parameters compared with international accepted water quality standards. Hence, the water could be supplied and used for drinking purposes without using any treatment process (*Annexure-23*).

Safe Water Source with Slight Problems

There were 02 water sources viz. Bore drilled at Haji Saifullah, Chak No.47 NB (posses excess Ca) and Hand Pump located at Mosque Chak No.87, Nikki (excess of Ca and K) ; supplying safe drinking water with slight water quality problems not so adversely affecting the human health in general. Hence, the water can be supplied and used for drinking purposes (*Annexure-24*).

SHEKHUPURA

The water samples were collected from 11 locations covering the major localities of the city and all possible sources i.e. Tubewells (6), Tap (1), and Hand Pumps (4). Out of 11 locations only 01 source (tubewell) was supplying safe and potable drinking water. After compiling and processing the field and lab. analytical data it was observed that 9% water samples were found beyond the permissible limits in parameters i.e. *E.Coli*, Turbidity, SO₄, Ca and Hardness, while 36% samples were found contaminated with Coliform bacterium. A reasonable percentage (45%) of water samples have been found possessing higher levels of As, even 66 ppb was determined in water taken from the tubewell installed at Nati Pura near Yamin Madran Tubewell-12. The 27% samples found with high level of NO₃ & TDS while 18% samples having Na & K beyond the permissible limits (*Annexure-11*).

Safe Water Source

There was only 01 source i.e. Tubewell No.18 located at Housing & Physical Colony; supplying safe and potable water free of all microbial contaminations and possessing less concentrations of soluble macro and micro inorganic ions as well as below levels of physical and esthetic parameters compared with international accepted water quality standards. Hence, the water can be supplied and used for drinking purposes from this tubewell without involving any treatment process (*Annexure-23*).

Safe Water Source with Slight Problem

There was one hand pump located at Kohistan Rehman Hotel near G.M. Rice Mill; supplying safe drinking water with slight TDS problem not considered so much adverse on the human health in general perspective. Hence, the water can be supplied and used for drinking purposes from this hand pump (*Annexure-24*).

SIALKOT

The water samples were collected from 10 locations covering the major parts of the city and water supply sources i.e. Tubewells (9) and Tap (1). Out of 10 locations no source was supplying perfect potable and safe drinking water. After compiling and processing the field and lab. analytical data it was found that 30% water samples were polluted with *E.Coli* and almost double %age (70%) of water samples were contaminated with Coliform organism. The 20% water samples are possessing slightly higher concentration of As (11-14 ppb) compared with WHO acceptable standards. However, 10% samples were found containing high level of Turbidity, Ca and Fe (*Annexure-12*).

Safe Water Source with Slight Problems

There were 02 tubewells located at Allama Iqbal Memorial Hospital (excess Turbidity) and Fetch Garh Road near Grave Yard (excess Ca); supplying safe drinking water with slight water quality problems not so adversely affecting the human health in general perspective. Hence, the water can be supplied and used for drinking purposes by the communities (*Annexure-24*).

PROVINCE OF NWFP

MANGORA

The water samples were collected from 10 locations covering the major localities of the city and sources i.e. Tubewells (10) (*Annexure-13*). Out of the 10 locations only 02 tubewells were supplying potable safe drinking water. After processing the field and lab. analytical data it was revealed that 10% water samples were found contaminated with *E.Coli* and 40% samples were found contaminated with Coliform bacterium. 20% samples having high level of NO₃ and 70% Ca ions may be due to lime containing aquifers.

Safe Water Source

There were 02 water sources viz. Shagi Tubewell and Tubewell located in Sector-C, Kanju Township area; supplying quite potable and safe water free of all microbial contaminations and possessing less concentrations of soluble macro and micro inorganic ions as well as low levels of physical and esthetic parameters compared with international accepted water quality standards. Hence, the water can be supplied and used for drinking purposes from these tubewells without any treatment processes (*Annexure-23*).

Safe Water Source with Slight Problem

There were 02 tubewells installed at DHDC Hospital and TW-1, Amankot, Chinar Colony,; supplying water having slightly higher concentration of Ca ions hence the water was safe for drinking not to be considered so adversely affecting the human health in general perspective. Hence, the water can be supplied and used for drinking purposes by the communities (*Annexure-24*).

MARDAN

The water samples were collected from 12 locations covering the major parts of the city and most of the water supply sources i.e. Tubewells (10), Bores (2) (*Annexure-14*). Out of the 12 locations no source is found satisfactory for supplying potable and safe drinking water. The compilation and computation of the field and lab. analytical data had shown that 8% water samples were polluted with *E.Coli* and majority of the water samples (75%) were contaminated with Coliform bacterium. The 67% of the water samples have concentrations of Fe beyond permissible limits of WHO standards whereas 01 sample (8%) has slightly more concentration of NO₃ anions (above 20 mg/l) as 10 mg/l is the acceptable level of WHO. In the tested water samples the major problem identified was the presence of Coliform bacteria.

Safe Water Source with Slight Problem

There were 02 water sources viz. Tubewell No.12, Dang Baba and Bore at Hujra Haji Zareen Khan which had been found possessing high concentration of Iron (Fe) may be considered the sources supplying safe drinking water with slight water quality problem not so adversely affecting the human health in general perspective. Hence, the water can be supplied and used for drinking purposes from the tubewell and the bore (*Annexure24*).

PESHAWAR

The water samples were collected from 13 locations covering the major parts of city and water supply sources 13 number of Tubewells. Out of the 13 tubewells 03 were pumping hygienic and safe drinking water. The data was processed and found that 02 water samples (15%) were contaminated with *E.Coli* and double numbers (04) and identical %age (31%) of the samples were contaminated with Coliform bacterium. One sample (8%) out of 13 water samples had excessive water quality parameters i.e. Hardness, TDS, Cl and SO₄ compared with WHO permissible values. The Fe concentration was found slightly on higher side in 62% water samples (*Annexure-15*).

Safe Water Source

Out of 13, the 03 tubewells installed at Nothia Road Gulberg No.1; Agriculture University Campus, and 7-D-4/Phase-1, Super Market; are supplying very good quality potable and safe water free of all microbial contaminations and possessing less concentrations of soluble macro and micro inorganic ions as well as low levels of physical and esthetic parameters compared with international adopted water quality standards. Hence, the water can be supplied and used for drinking purposes from these tubewells without any treatment process (*Annexure-23*).

Safe Water Source with Slight Problem

The 05 numbers out of 13 tubewells installed at Khattak Chowk; Soraizai Payan Inqilab Road; Ahmad Khail; Afghan Colony Latif Abad; and TW-2, St.4, Kacha Garhi; have been identified the water sources possessing slightly above concentrations of Iron (Fe) (0.34-0.46 mg/l), the acceptable value of Fe is 0.3 mg/l as per WHO standard. Hence, these tubewells are extracting and supplying very near to safe water quality suitable for drinking not so adversely affecting the human health in general perspective. Consequently, the water can be supplied and used safely from these tubewells (*Annexure24*).

PROVINCE OF BALOCHISTAN

KHUZDAR

The water samples were collected from 11 locations covering the major areas of the city and all possible sources i.e. Tubewells (4), Water Supplies (2), Cistern (1), Tap (1), Well (1), Spring (1), Hand Pump (1). In upland Balochistan, the groundwater was dependable source of water because surface water liable to runoff within shortest period in the streams and tributaries after precipitation. Out of the 11 locations not even a single source was supplying safe potable drinking water. The field and lab. analytical data had shown that dominant sources of water were contaminated with feacle organisms *E.Coli* (55%) and Coliform (91%). The Turbidity level is higher in 36% water samples, whereas the inorganic constituents like NO₃ and Ca were found at higher levels in 18% and 27% water samples respectively compared with WHO guideline values. Out of 11 analyzed water samples, 02 (18%) samples collected from the tubewell installed at Irrigation Colony and hand pump located at Madrisa Jamai-e-Rizvia Khalilia Khund had shown more levels of Chromium (Cr), whereas, 03 (27%) water samples collected from a well (Madrisa Tajweed-ul-Quran Katan), a spring (Pir Umer Mazar) and a tap (Super Shashan Hotel on Karachi Road) were found beyond permissible limits of Alluminium (Al) levels (*Annexure-16*).

LORALAI

The water samples were collected from 10 locations covering the major localities of the city and possible surface and groundwater sources i.e. Tubewells (3), Water Supplies (3), Tap (1), Wells (2), Spring (1). Out of the 10 locations 03 sources (1 water supply & 2 tubewells) are supplying fit and safe potable drinking water. After processing the analytical data it was concluded that 70% water samples were contaminated and polluted with *E.Coli* and Coliform micro organisms, whereas 01 sample comprising 10% of the total samples had been declared unfit for human ingestion due to presence of Hardness, NO₃, TDS and SO₄ above the permissible limits. High concentration of Fe was found in 1 sample contributing 10% of the total samples and the same percentage had high level of Turbidity. However, 40% water samples have high concentrations of Ca ions.

Safe Water Source

There are 03 water sources i.e. one public Water Supply scheme in the form of Army Water Purification Plant; and two Tubewells installed at Commissioner Office; and PHE Pathan Kot; supplying potable fit and safe water free of all microbial contaminations and possessing less concentrations of soluble macro and micro inorganic ions as well as less physical and esthetic parameters compared with international accepted water quality standards. Hence, the water can be supplied and used for drinking purposes from these water sources without any treatment process (*Annexure-23*).

QUETTA

The water samples were collected from 34 locations covering the major civil residential and cantonment areas of the city and all possible sources i.e. Tubewells (22), Water Supplies (6), Tap (1), Well(1), Karez (1), Spring (2), and Hand Pump (1). Out of 34 locations 12 sources are supplying fit, potable and safe drinking water. The data was compiled and processed which revealed that 8 samples (24%) were polluted with *E.Coli* and possessing more concentration of Fe, at the same time, 17 samples (50%) were contaminated with Coliform bacterium. Out of total samples 8 numbers (24%) have soluble ions of NO₃ and F⁻ in higher concentrations, whereas 5 water samples (15%) have more Turbidity level and 3 samples (9%) has Hardness. TDS and SO₄ values beyond the permissible limits were found in 6% of the samples, while 12% samples have high level of Ca and 3% with high level of Mg and As. 05 (15%) samples collected from a spring (Met. Office Braway), a karez (Gujrai Karez near Kechi Beg), two tubewells (Jamia Masjid Nawan Killi and Quetta Airport), a spring (Urak Spring Cantt.) and a lake (Hanna Lake) were found possessing higher concentration of Aluminum (Al) than permissible limits (*Annexure18*).

Safe Water Source

The Quetta valley dominant population is using groundwater for drinking and domestic needs. The most of the alluvium aquifers have been exhausted and consequent groundwater extraction by B-WASA is concentrated on 1000-1200 feet deep hard rock aquifers due to which the groundwater is saved from the contamination of sewerage effluent, commercial and domestic waste water. The Quetta Metropolitan is fortunate because out of 13 tubewells 09 are pumping fit, potable and safe drinking water. Similarly out of 05 water supply schemes 03 are providing the safe good water quality free of all microbial contaminations and possessing less concentrations of soluble macro and micro inorganic ions as well as lower physical and esthetic parameters compared with international accepted water quality recognized standards. Hence, the water can be supplied and used for drinking purposes from these sources without any treatment process. The list of tubewells and high up water supply tanks is given for the awareness of general public and other safe water consumers particularly the mobile water tanker owners supplying the potable water to the houses on payment (*Annexure-23*).

Tubewell Location

- 1) Nasir Abad Maidani, Mariabad
- 2) Haji Ghaibi Road,
- 3) Kharot Abad-I, Smungly Road,
- 4) Khilli Khaizy, Smungly Road,
- 5) Gwalmandi Chowk,
- 6) Rehmat Colony, Gali No.1, Sirki Road,
- 7) Staff College near Purification Plant,
- 8) Staff College Urak Road,
- 9) Govt. Girls College Cantt.

Water Supply Location

- 1) Pumping Station Ayub Stadium,
- 2) Taro Chowk, Pashtoon Abad
- 3) Chiltan Booster near Cavalry Zamzama Road,

ZIARAT

The water samples were collected from 10 locations covering the major parts of the city and all possible sources i.e. Tubewells (2), Water Supplies (2), Tap (2), Well (1), Karez (1), Spring (1), Windmill (1). Out of 9 locations no source is supplying safe drinking water. After compiling and processing the field and lab. analytical data it was estimated that all water samples (100%) were found polluted with *E.Coli* and Coliform bacterium. The physical and chemical analysis of water has indicated the high level of Turbidity and NO₃ concentration in 2 samples (20%) and in 1 sample (10%) the hardness was also above the acceptable limit. The Ca ions were in high concentration in 5 water samples (50%) may be due to the presence of Chiltan and Ziarat limestone rocks in the area. 05 (50%) samples collected from a spring (P.H.E. Water Supply Scheme), two

water supplies (PHE Water Supply near Jinnah Top and Faran Tangi Water Supply Scheme Killi Pechi), a well (Jamia Masjid) and a Karez (Cheena Karez) were found possessing higher concentration of Alluminium (Al) than permissible limits (*Annexure-19*).

PROVINCE OF SINDH

HYDERABAD

The water samples were collected from 15 locations covering the main localities of the city and possible sources i.e. Tubewell (1), Water Supplies (2), Taps (12). Out of 15 locations no source was identified which supplied safe drinking water. After compilation and processing of the field and lab. analytical data it was found that 93% water samples were polluted with *E.Coli* and 100% samples were found contaminated with Coliform bacterium, whereas, out of 15 water samples, 12 samples (80%) have the Turbidity level beyond the permissible limits because major water supply is from Indus river and more turbidity was observed in tap and water supply distribution system; only the water from tubewell and two taps were observed free of suspended sediments; 7 samples (47%) contained excess Fe contents and 1 sample (7%) has high concentration of Ca, Pb and Hardness (*Annexure-20*).

KARACHI

The water samples were collected from 28 locations covering the major parts of the metropolitan and possible sources i.e. Taps (26), Hand Pumps (2). Out of 28 locations no source was identified which supplied safe drinking water. The field and lab. analytical data was compiled and processed, it was noticed that 86% water samples were polluted with *E.Coli* and 100% samples were found contaminated with Coliform bacterium, consequently all water sources were switched over to unsafe drinking water. Amongst the tested water samples 2 samples (7%) were high in Hardness, Na and K ions, similarly 1 sample (4%) were found with high ionic concentration of Ca, Mg, SO₄, NO₃ & F and 3 samples (11%) have high level of Cl & TDS, whereas 12 samples (43%) contained Fe beyond WHO guideline values. The high Turbidity was observed in 5 samples (18%) out of 28 water samples. 02 (7%) samples collected from a tap (Jamia Masjid Fazyan Al-Tegia), a hand pump (Café Nasir Gulbheri) have been found possessing higher concentration of Nickel (Ni) than acceptable limits (*Annexure-21*).

In the news print media, a number of information about water quality was published which showed the gravity of the poor quality of water being supplied and used in the city. Karachi was provided with about 550 million gallons of water every day from two major surface water sources - Indus River and Hub reservoir. The Malir and Lyari rivers were blatant examples of rivers that have been converted into sewerage drains and there was no sign of aquatic life other than pollutants. The city Nazim had presented a gloomy picture of the quality of water and informed that more than 10,000 people in the city die annually of renal infection due to the polluted drinking water (*Dawn March 16,2004*). Karachi Water Supply Board (KWSB) was the sole water supply agency in the city, supply water through underground pipe network and ultimately the people are using Tap water because groundwater was highly saline due to the Arabian seawater intrusion. KWSB had claimed that safe and fit drinking water was supplied for human consumption after chlorine treatment. The decreased rate of downstream Kotri Barrage Indus river flow, the total dissolved solids (TDS) in Indus water increased steeply and reached the limits of 3200 mg/l at Sujawal Bridge. The Sindh Environmental Protection Agency (SEPA) had reported the diseases like diarrhea, dysentery, cholera, viral hepatitis, respiratory infections and cabbies at hospital in a considerable number which appeared a source of poor water quality. The agency had also managed the water quality analysis and estimated that 87% of tap water samples collected from 18 different localities of Karachi were unsatisfactory for drinking purpose. All samples were contaminated with E-Coli fecal organism and one could imagine what havoc the water could play with the health of patients undergoing routine dialysis due to kidney problems (*DawnMarch16&22,2004*).

SUKKUR

The water samples were collected from 12 locations covering the major localities of the city and possible sources i.e. Tubewells (2), Water Supply (1), Taps (7), Hand Pumps (2). Out of 12 locations only 2 sources were supplying safe drinking water. The field and lab. analytical data was compiled and processed, it was

estimated that 67% water samples were polluted with *E.Coli* and 75% samples were found contaminated with Coliform bacterium, consequently most of the water sources were switched over to unsafe drinking water. Out of 12 samples, 7 samples (58%) were containing the non-acceptable level of suspended earth materials in the form of high Turbidity level. The highest %age of turbidity was observed in tap and water supply distribution system because the major source of water supplied to the city was drawn from the Indus River containing suspended colloidal materials. Two samples had been found possessing the ionic composition in the rage of 17% determined as Ca, K, SO₄ & TDS. Similarly, 1 sample (8%) had shown the Hardness, Na, Cl & As above the permissible limits as per WHO guideline values. 04 (33%) samples collected from two tubewells (Maka Goth near Sheraz Hospital and Water Supply Scheme Barrage Colony), a tap (Hamayoon Gymkhana), and a hand pump (Hotel Sukkur Inn, Clock Tower) were found possessing higher concentration of Aluminium (Al) than permissible limits (*Annexure-22*).

Safe Water Source

There are 02 sources i.e. Tubewell installed at Makka Goth, Near Sheraz Hospital (possessing only excess Aluminium ultra trace element) and Hand Pump located at Khalil Photo near Al-Habib Hotel; supplying potable good quality safe water free of all microbial contaminations and possessing less concentrations of soluble macro and micro inorganic ions as well as lower level of physical and esthetic parameters compared with international accepted water quality recognized standards. Hence, the water can be supplied and used for drinking purposes without any treatment process (*Annexure-23*).

SURFACE WATER

Samples were collected from 20 different sources i.e. Dams (07), Rivers (08), Canal (01), and Lakes (04). After the compilation of field and lab. data it was found that 100% samples were contaminated with Coliform and *E.Coli*. Out of 20 samples 17 (85%) samples have high level of turbidity. 30% samples found with high level of Al, whereas 15% samples having high concentration of Pb. Hamal Lake was found with high level of Ca, Mg, Hardness, Cl, Na, K, SO₄, and TDS. 20% samples were contaminated with Ni and Cd whereas 5% having high concentration of Cr, Hg, Mn and As. 25% samples found with high concentration of Fluoride and 40% with high level of Fe (*Annexure-26*).

CONCLUSIONS

The water sources in all cities were selected from where the people were getting water mainly for drinking purposes. The water samples for analysis were collected from overall 344 different water sources (locations) showing distribution as **Islamabad** (26)*, **Punjab** (163), **NWFP** (35), **Balochistan** (65) **Sindh** (55). The source wise detailed was Tubewells (176), W. Supply (23), Cistern (2), Bore (12), Tap (60), Well (5), Karez (2), Spring (5), Windmill (1), Hand Pump (48), Injection Pump (7), Donkey Pump (3). On overall Pakistan basis, out of 344 water samples, 65% samples had been diagnosed as polluted with Coliform and 35% were contaminated with *E.Coli*. The 28% water samples had excessive concentration of Ca ions may be due to calcareousness of land parent materials in Pakistan, whereas, 27% water samples had been contaminated with excess Fe and similarly 22% water samples had, as levels beyond WHO permissible limits. The Turbidity level is found on higher side in 17% water samples as a whole; on the same pattern 12% samples had been identified with high level of TDS. More or less 9% to 10% water samples had more ionic concentrations of Na, SO₄ and NO₃ than permissible limits. Similarly, ranging from 6% to 8% water samples had contained excessive levels of Hardness, Cl and K contents. The higher levels than acceptable standards 1% samples respectively. 5% samples were contaminated with high level of Al and 0.3 to 1% samples had high concentration of Cr, Mo, Se and Ni.(Annexure-25).

The water samples were collected from different 344 water sources located in 22 important cities of Pakistan. Out of 344 water sources, 36 sources were delivering potable, fit, hygienic and safe good quality drinking water free from microbial contaminations and possessing less concentrations of soluble macro and micro inorganic ions as well as low levels of physical and esthetic parameters compared with international accepted water quality standards. Hence, the water can be supplied and used for drinking purposes from these sources without any treatment processes. At the same time 21 water sources were supplying safe drinking water with slight 1 to 5 problem parameters (Turbidity, Ca, K, TDS & Fe), not so adversely affecting the human health in general perspective. Consequently, the water can be supplied and used for drinking from these sources after simple treatment processes.

For the first time in Pakistan, about 54 numbers of trace and ultra trace elements were determined in the water quality laboratory of PCRWR, Islamabad by using high tech lab. instrument viz. ICP (Inductive Coupled Plasma Spectrometry). In general, majority of the water samples collected from 343 locations distributed in 22 major cities of Pakistan were found contaminated and polluted with both or single organisms of Coliform or *E.Coli*. It has been observed that almost all surface water sources usually contaminated with bacteria while deep groundwater sources had been found generally free of bacteria due to least seepage influence. However, both surface and groundwater sources/locations had been found contaminated lying in the urban areas of dense population.

* The number of water sources/locations are given in brackets.

The report is based on Phase-III (summer) water quality monitoring through collection of water samples and subsequent field and lab. analysis. Contrary to previous two reports on water quality status of Pakistan; in this report a different pattern of results presentation is adopted on city level basis instead of parameters, which is more appropriate and easy in understanding for policy makers, city Nazims and water supply managers to adopt future line of actions on the important issue of water quality.

RECOMMENDATIONS

Based on the data presented earlier, the following specific recommendations are made:

1. Safe water sources identified in different cities must be publicized and informed to the city Nazims so that maximum number of peoples could be benefited from these potable good quality water sources.
2. Low-cost kits and reliable simple methods of water quality testing system which can be handled by lay household individuals be developed and encouraged in the country.
3. Comprehensive plans should be made and implemented to meet the human needs of safe drinking water and to prevent the occurrence of all water-borne diseases.
4. The water supply and management agencies should feel the responsibility to maintain water quality in the water distribution system up to the consumers' level for which booster chlorination be ensured at different pumping stations.
5. Household water reservoirs are not cleaned periodically, these should be cleaned and disinfected regularly.
6. Water theft and wastage through leakages should be properly monitored by concerned authorities and remedial action be taken timely.
7. Appropriate measures, especially by civil bodies, need to be taken to discourage use of suction pumps on the supply lines. The consumers must be warned about the health consequences associated with contaminated drinking water.
8. Acceptable parameters levels set by the World Health Organization (WHO) for the purity of potable safe drinking water should be fully adopted in the country.
9. There is need for evolving a regular and fool-proof method to ensure that the drinking water must be free from E-Coli and Coliform responsible for various water-borne diseases.
10. Strict compliance of environmental protection legislations and arrangements be made for treatment of huge quantity of toxic waste industrial and domestic sewage water prior to runoff into the natural freshwater rivers, streams, tributaries, canals and other water channels as well as sea.
11. Simple technologies and low cost treatment plants may be developed indigenously and make efforts to arrange for the recycling of wastewater to make it reusable for agricultural, domestic and industrial purposes.
12. Chlorination, ozonation and solar radiation treatment for water disinfection in rural areas, including deserts should be introduced where potable water is available in very little quantity and that, too contaminated most of the time.
13. Baseline data bank on the quality of piped and groundwater being consumed by citizens be established for comparative water quality monitoring studies in future at national level.
14. Leakages and wastage of water must be minimized causing 30-50 % loss of the total water supply. The water supply agencies should install meters to charge the consumers on the basis of "pay as you use".
15. Health education should include the subject of water quality, safety and associated hazards.
16. Prevention of cross-contaminations should be controlled by not passing pipelines along or across the sewerage lines.

17. Water distribution network is grossly overloaded and has outlived its economic design life in most of the cities which needs replacement with high quality pipes.
18. There is need to clean and improve the sewage system and to rehabilitate the outlived or undersized sewers, as well as it should be extended upto the *kaichi abadis* and other slum areas where they are absent. However, an efficient sewage system, which can safeguard groundwater and rivers from getting contaminated be installed.
19. The government should provide treatment facilities at low cost to the farmers as well as small industrialist for reducing the risks of using effluents.
20. Awareness must be propagated to minimize the thoughtless and wasteful activities like using running tap water to wash cars or irrigating the lawns and home garden unnecessarily. Each of us has to realize that less water used means less wastewater produced.
21. Proper scientific solid waste management system must be evolved to reduce the flow of pollutants into the fresh surface and groundwater sources.
22. It should be mandatory on the agencies responsible to regularly monitor quality of water being supplied to the consumers through analysis done at their own laboratories or other accredited laboratories of repute.
23. Regular monitoring of all water resources and water points at the national level should be ensured to help identify problem areas, causes of contamination, and design a framework of corrective plans.
24. Lead absorbed by water bodies from atmosphere can be quite injurious to health. Use of lead free gasoline for vehicles should be encouraged in the country, particularly in those areas where surface water is the main source of drinking water like Karachi, Islamabad, and Rawalpindi to avoid contamination.
25. It has been observed that sub-standard chemicals containing impurities are used in water treatment plants. Such chemicals can produce different kinds of contaminants, causing health hazards. It is strongly recommended that strict quality control must be ensured in the treatment plants.
26. Alternate sources of water should be identified in areas where the quality of source of existing water supply is questionable. Examples for such cases are wells from which water with high concentrations of Arsenic is pumped for drinking purposes.
27. No new water supply scheme should be approved unless detailed investigations of water quality, quantity, possible sources of local contamination, and its sustainability have been carried out.
28. For effective awareness, educational institutions & mosques including mass media should be used for creating awareness about the importance of water quality among the users.
29. Seminars and workshops should be frequently arranged to disseminate the findings of the water quality monitoring results.

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