

WATER QUALITY STATUS IN PAKISTAN

Second Report 2001-2003

Dr Muhammad Akram Kahlown
Muhammad Aslam Tahir
Dr Ashfaq Ahmed Sheikh

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LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer	Mg	Magnesium
AF	Acre Feet	MPL	Maximum Permissible Level
Alkal.	Alkalinity	MPN	Most Probable Number
As	Arsenic	$\mu\text{S/cm}$	Micro Siemens Per Centimetre
BOD	Biological Oxygen Demand	N	Nitrate/Normal
Ca	Calcium	Na	Sodium
CDA	Capital Development Authority	ND	No Data
Cl	Chloride	NIH	National Institute of Health
CMH	Combined Military Hospital	Nm	Nanometer
CNS	Central Nervous System	NO_3	Nitrate
CO_3	Carbonate	NTU	Nephelometric Turbidity Unit(s)
COD	Chemical Oxygen Demand	NWQMP	National Water Quality Monitoring Programme
Cr	Chromium	OECC	Overseas Environmental Cooperation Centre
DO	Dissolved Oxygen	PCRWR	Pakistan Council of Research in Water Resources
E	Essential	PINSTECH	Pakistan Institute of Nuclear Science and Technology
E.Coli	Escherichia Coliform	PO_4	Phosphate
EC	Electrical Conductivity/European Community	ppb	Parts Per Billion
EDTA	Ethylenediamine Tetraacetate Dehydrate	ppm	Parts Per Million
EPA	Environmental Protection Agency	PSI	Pakistan Standards Institution
F	Fluoride	RBOD	Right Bank Outfall Drain
FDA	Food Development Authority	RO	Reverse Osmosis
Fe	Iron	Sm^{-1}	Siemens Per Metre
Ft	Foot	SO_4	Sulphate
HCO_3	Bicarbonate	SPADNS	Sodium 2-(parasulfophenylazo) -1, 8-dihydroxy-3, 6-naphthalene disulfonate
HDL	Highest Desirable Level	TCU	True Colour Units
HRD	Human Resource Development	TDS	Total Dissolved Solids
IBWA	International Bottled Water Association	UNICEF	United Nations Children Fund
ICP	Inductive Coupled Plasma Spectrophotometer	UV	Ultra Violet
JICA	Japanese International Cooperation Agency	UV-VIS	Ultra Violet Visible
K	Potassium	WAPDA	Water and Power Development Authority
LBOD	Left Bank Outfall Drain	WASA	Water and Sanitation Authority
M	Molar	WHO	World Health Organization
MAC*	Maximum Acceptable Concentration	WRRC	Water Resources Research Centre
MAC**	Maximum Allowable Concentration	WT	Water Table
MAF	Million Acre Feet	WQP	Water Quality Parameters

EXECUTIVE SUMMARY

Nature has blessed Pakistan with adequate surface and groundwater resources. However, rapid population growth, urbanization and the continued industrial development has placed immense stress on water resources of the country. The extended droughts and non-development of additional water resources have further aggravated the water scarcity situation. Consequently per capita water availability has decreased from 5600 to 1000 cubic meter (m³) per annum. The increasing gap between water supply and demand has led to severe water shortage in almost all sectors. The water shortage and increasing competition for multiple uses of water adversely affected the quality of water. In this regard, the results of various investigations and surveys by several agencies had indicated that water pollution has become a serious problem in Pakistan. Most of the reported health problems are directly or indirectly related to water. The quantitative and qualitative concerns of water call for an action plan for efficient development, utilization and monitoring of the water resources of the country.

Considering the deteriorating water quality status, the Pakistan Council of Research in Water Resources (PCRWR) has launched a National Program for monitoring the quality of water in Pakistan. The main objective of the water-quality monitoring project is to establish a permanent water quality-monitoring network in the country to observe changes in surface and groundwater quality as well as groundwater levels. The monitoring results would lead to remedial measures for improving the quality and sustainable use of the water resources. The project is designed to monitor quality of drinking water from twenty-one cities in the country, out of which 11 cities are from Punjab, 3 from Sind, 4 from Balochistan and 3 from NWFP. Apart from this, six main rivers, five dams, one reservoir, three canals, two natural lakes and two major drains, are also included in the national water quality monitoring network. This gives a reasonable coverage of the country's water resources.

For the collection of water samples, a uniform grid size of 1 km² (for small size cities), 4 and 9 km² (for medium size cities) and, 16 and 25 km² (for big size cities) was used. Permanent points one per grid were selected for collection of water samples. In this regard, preference was given to permanent public water points considering the long term monitoring requirement of the project. The samples were collected before monsoon season. The water samples were collected by the staff of PCRWR stationed at Islamabad and the five Regional Offices.

The sample size, collection, preservations and analysis were conducted according to the standard methods for water quality testing. The sources of water samples were from tap water, tube wells, dug wells, hand pumps, springs, reservoirs, rivers and lakes. The water samples were analyzed for physical, chemical and bacteriological contamination. The physical and aesthetic analysis of water covered color, electrical conductivity, odour, pH, taste and turbidity. The chemical quality included the analysis of water for 76 chemical parameters. The water samples for bacteriological quality was analyzed for coliform and E-Coli contamination. This report presents the results of analysis from sample collected in two consecutive years of water quality monitoring programme i.e. 2001-02 (Phase-I) and 2002-03 (Phase-II).

In general, the both years of sample collection provided almost same findings with respect to physical, chemical and bacterial quality of monitored water sources in all 21 cities. However, some variations in concentration of certain parameters or percentage of samples exceeding recommended safe values were observed which does not have any bearing on the overall conclusions and recommendations of this report.

As a whole, the physical quality of the surface and groundwater was found good except in a few cases where the presence of colour in samples was due to the high level of turbidity and other dissolved and un-dissolved substances. In most of the cities, the value of turbidity in some samples exceeded the WHO standard value of 5 NTU including these from Hyderabad, Karachi, Sukkur, Ziarat, Bahawalpur, Gujrat, Loralai, Khuzdar and Multan. However, the average value of EC in all twenty-one cities during two respective years has been found 827 $\mu\text{S}/\text{cm}$ and 854 $\mu\text{S}/\text{cm}$ with range of values 170-7930 $\mu\text{S}/\text{cm}$ and 236-5300 $\mu\text{S}/\text{cm}$, respectively. Similarly, the pH value of all the collected samples ranged from 6.1-9.0 with average of 7.64 against the recommended WHO guideline range of 6.5-8.5 for drinking water.

The chemical quality of water was found within the recommended level with respect to calcium and chromium. For alkalinity, bicarbonate, carbonate and phosphate, no guideline values have been set by WHO or others. However, higher arsenic contents (WHO limit for arsenic is 10 ppb) were found in some samples collected from 8 cities. The contaminated samples comprised 60% from Bahawalpur, 7% from Gujranwala, 30% from Kasur, 31% from Lahore, 75% from Multan, 45% from Sheikhpura and 6% from Hyderabad. However, increase in percentage samples exceeding the WHO value for arsenic has been observed in most of these reported cities during Phase-II of quality monitoring. Whereas other chemical parameters were found within safe limits, the salt concentrations generally were on the higher side for groundwater as compared to surface water.

Overall the water samples were found bacteriologically contaminated. Almost 50% of the samples in 17 cities were found unfit for human consumption. Whereas all samples in Gujrat, Khuzdar, Loralai and Ziarat were found bacterially contaminated and unsafe for human consumption. However in Phase-II, in some cities the bacterial quality improved such as Islamabad, Rawalpindi, Peshawar, and Khuzdar while further degraded for others especially Gujranwala, Lahore, Sheikhpura, Karachi, and Hyderabad. This highlights the seriousness of bacterial contamination in the drinking water sources perhaps all over the country. Decontamination facilities are generally not present in almost all the cities. The overall deteriorating quality of groundwater may also be associated indiscriminate disposal of sewage and industrial effluents into fresh water bodies along with continuous drop in the watertable besides agricultural activities and the natural condition of aquifers. It has been observed that in most of the cities the water table is falling from one to 10 feet every year. Such alarming conditions lead to the observation that there is a need for a proper and continuous monitoring of the overall water resources of the country.

This investigational study indicates that water in many cities of Pakistan is unsafe for human consumption due to both bacterial and chemical contamination. The monitoring program started by PCRWR will continue to provide the hitherto missing data on important water quality parameters, which will in the long run, help identify water quality problems and issues. Meanwhile, it is suggested that the water supply agencies must take steps to ensure the supply of safe water to the consumers. In this regard, PCRWR has planned a programme to extend the water quality monitoring network to rural areas of the country under which pilot low cost filtration and conditioning units will also be installed in problem areas of 22 districts.

The water supply agencies must adopt appropriate treatment processes such as giving adequate dose of chlorine for bacterial decontamination, addition of alum or ferric chloride *etc.* and/or installation of rapid/slow sand filters for turbidity control. Decontamination by installing ozonators on each tubewell should also be considered where feasible and appropriate. Similarly use of lead pipe or plastic pipe having lead contents must be discouraged.

It is also suggested that the chemicals used in water treatment should be of standard quality, which is possible only through strict quality control by

manufacturers as well as water suppliers. The public should be encouraged in their own interest to clean their domestic underground and overhead tanks. Moreover, no water quality scheme should be approved unless detailed investigation of water quality and quantity of the original source of water is carried out. Above all, there is a need to educate the general public about the importance of water quality and its impacts on their health as well as on the environment where they live.

INTRODUCTION

1.1 Background

Pakistan's current population of 141 million is expected to grow to about 221 million by the year 2025. This increase in population will have direct impact on the water sector for meeting the domestic, industrial and agricultural needs. Pakistan has now essentially exhausted its available water resources and is on the verge of becoming a water deficit country. The per capita water availability has dropped from 5,600 m³ to 1,000 m³. The quality of groundwater and surface-water is low and is further deteriorating because of unchecked disposal of untreated municipal and industrial waste water and excessive use of fertilizers and insecticides. Water quality monitoring and information management is lacking, even though it's crucial to any water quality improvement program.

The Pakistan Council of Research in Water Resources (PCRWR) launched "National Water Quality Monitoring Program" in the country on 17th March 2001. The program aims at undertaking water quality monitoring in 21 major cities, six rivers and 11 storage reservoirs, canal, drains and natural lakes. Previously no consolidated effort was made to monitor quality of drinking water at the national level. As a consequence, no comprehensive data set is available on quality of drinking water. Different organizations including Pakistan Council of Research in Water Resources (PCRWR), Water and Power Development Authority (WAPDA), Environmental Protection Agency (EPA) and some individual consultants have conducted short-term studies on water quality assessment of a few cities.

Results from various investigations and surveys indicate that water pollution has increased in Pakistan. The pollution levels are higher particularly in and around the big cities of the country where cluster of industries have been established. The water quality deterioration problems are caused by the discharge of hazardous industrial wastes including persistent toxic synthetic organic chemicals, heavy metals, pesticide products and municipal wastes, untreated sewage water to natural water bodies. These substances mixed with water then cause widespread water-borne and water-washed diseases.

The World Health Organization (WHO, 1972-73) estimates that 500 million diarrhea cases reportedly take place each year in children less than five years in Asia, Africa and Latin America. The extent of enteric diseases in different areas depends upon the extent to which water is exposed to contamination. The incidence of typhoid fever, bacillary dysentery, infectious hepatitis and other enteric infections are common and are transmitted through contaminated water. Cholera is still a wide spread water borne disease in some developing countries. There are numerous other diseases that are transmitted through polluted water. It has been shown that cancer may be caused by the accumulation of certain materials carried out by water to human organs (DAWN, 1989). The excess of cadmium accumulated in the kidney causes hypertension as is evident from study conducted on animals. The deficiency of chromium in drinking water favour atherosclerotic diseases in human. The compounds of chlorobenzenes and chlorophyll's may affect taste and odor of water.

PCRWR (1985) and WHO (1972-73) reported that after installation of new water supply pipes alone in 30 rural settlements of Japan, communicable intestinal diseases were reduced by 72% and that of trachoma by 64% while the death rate for infants and young children fell by 52%. Similarly in Uttarparadesh (PCRWR, 1985) after carrying out improvements in water works, sewerage, and sanitation, the cholera death rate decreased by 74%, typhoid fever death rate by 63.3%, and dysentery death rate by 23%. Additionally, 10% productive time of each person, wasted due to water-related diseases, can also be saved.

The quality of water supplies in many cities of Pakistan is deteriorating fast. The primary source of these supplies is groundwater. As a result, one hundred million cases of diarrhea are being registered for treatment in hospitals of Pakistan each year (WHO, 1972-73). A survey conducted by PCRWR (Tahir *et al.*, 1994) showed that 81,996 cases of water related diseases were registered in Basic Health Units of Rawalpindi Division alone. According to United Nations Children's Fund (UNICEF), 20 to 40% beds are occupied in the hospitals of Pakistan by patients suffering from water related diseases. Diseases such as cholera, typhoid, dysentery, hepatitis, giardiasis, cryptosporidiosis and guinea worm infections are about 80% (including diseases due to sanitation problem) of all diseases and are responsible for 33% of deaths (Tahir *et al.*, 1994).

Over pumping of groundwater due to extended drought has affected the water quality adversely. According to a recent study about 70% of the 560,000 tube wells of Indus Basin are pumping sodic water. Such water can be highly injurious to soil health creating sodicity problems resulting in reduced permeability and infiltration rates in heavy textured soils. Surface-water from most of our rivers is also polluted. The Kabul River at Nowshera has high coliform content, suspended solids, high Biological Oxygen Demand (BOD) and low Dissolved Oxygen (DO). BOD values are generally above 3 and COD values range between 13 to 744 mg/l. The faecal coliform is high at 1600/100 ml to 1800/100 ml. This water is threatening its use for fish production, irrigation and domestic purposes.

In Jhelum River the DO content remains well above 7 mg/l. The BOD downstream of Jhelum is around 2.2 mg/l. River Chenab receives pollution loads from many industries and cities. As a result the DO is totally depleted in various stretches. The BOD downstream of Faisalabad is 4.2 mg/l. The pollution in River Ravi is the highest of all the rivers in Pakistan. Most waste water discharges in the river reach between Lahore and Balloki, a length of 62 km. The river presently receives 47% of the total municipal and industrial pollution load discharged into all rivers of Pakistan. The BOD in the river after receiving Lahore municipal discharges is estimated to be 77 mg/l on the basis of mean annual flow. Between Lahore and Balloki under low flow conditions, the river is completely devoid of DO and simply acts as a sullage drain.

The BOD in Indus River downstream of Attock is 2.9 mg/l. In Indus River water quality was studied at Dadu Moro Bridge at Kotri Barrage with nitrate levels at 1.1 and 7.5 mg/l, phosphate at 0.02 and 0.3 mg/l, BOD at 2.4 and 4.1 mg/l, faecal coliform at 50 and 400 per ml. Due to industrial waste discharges from Punjab and Sindh, the content of heavy metals such as nickel, lead, zinc and cadmium have also been found in Indus water. This status of water quality calls for regular monitoring for essential information and remedial measures. The national water quality monitoring program of PCRWR aims to establish permanent water quality monitoring network. The information thus generated would be provided to the planners and policy makers to devise strategies and measures to control water quality deterioration in the country.

1.2 Objectives

The general objective of water quality monitoring program is to provide the information on the level of pollution in the water resources of the country. It is expected that this information would help in identifying the problem areas for initiating appropriate corrective solutions. The specific objectives of the water quality monitoring program are:

- To establish a permanent national water quality monitoring network to monitor changes in surface and groundwater quality and groundwater levels;
- To set up a national computer database on water quality for easy access by water users through Internet;
- To prepare national water quality map; and

To suggest remedial measures for improving the water quality.

1.3 Scope of the Study

The national water quality monitoring program covers twenty-one cities all over the country. These cities include Rawalpindi, Islamabad, Gujrat, Lahore, Sialkot, Sheikhpura, Gujranwala, Faisalabad, Kasur, Bahawalpur, Multan, Hyderabad, Karachi, Sukkur, Quetta, Khuzdar, Loralai, Ziarat, Peshawar, Mardan, and Mangora. Apart from these cities, six rivers: Jhelum, Chenab, Ravi, Sutlaj, Indus Hub and Kabul, five dams: Simly, Rawal, Khanpur, Hub, Tarbella, and Mangla, one reservoir: Chashma, two lakes: Manchar, and Hamal and two drains, Left Bank Outfall Drain, and Right Bank Outfall Drain have also been selected for monitoring water quality.

National Drinking Water Quality Map will be prepared on the basis of collected data and data from the previous water quality studies completed by different departments including WAPDA. It is pointed out that presently there is no agency working on national level. The information regarding water quality problems/issues all over the country are available free of cost on Water Quality Website of PCRWR for researchers, policy makers, planners and citizens for utilization in preparation of development schemes on water supply, agriculture, livestock and fisheries *etc.*

1.4 Relationship of the Project to PCRWR

The PCRWR is the national research institute, which is mandated to conduct, organize, coordinate and promote research in all aspect of water resources including drinking water quality. The Council has established six research centers at Quetta, Bahawalpur, Lahore, Peshawar, Islamabad and Tandojam to address problems related with water resources. The center at Islamabad was established to address among other issues related to water quality assessment, water pollution, environmental and wastewater management activities. At present PCRWR have five well-equipped water analysis laboratories at Islamabad, Tandojam, Lahore, Bahawalpur, and Quetta while one at Peshawar is being established. PCRWR has undertaken numerous studies in the past and facilitated different organizations including educational institutes in the area of water quality research.

1.5 Groundwater Availability

Under the crust of the earth, groundwater is found in a very large area, and according to estimates the amount of groundwater in the world is about 500,000 Million Acre Feet (MAF). One fifth of this source lies in the active zone, within a depth of 2,500 feet of the surface. It is more than 30 times the water contained in all fresh water lakes and is more than 3,000 times the average volume of water flowing through rivers and streams (Nazir, 1995).

Pakistan is blessed with extensive groundwater resource, which has been built due to direct recharge from natural precipitation, river flow, and the continued seepage from the conveyance system of canals, distributaries, watercourses and application losses in the irrigated lands during the last 90 years. This groundwater source has a potential of about 55 MAF, out of which about 48.69 MAF is being exploited by over 661,853 private tube wells and about 18,620 public tube wells for domestic, agricultural and industrial purposes (MINFAL, 2003). Province wise groundwater usage is 42.69 MAF in the Punjab, 3.5 MAF in Sindh, 2 MAF in NWFP, and 0.5 MAF in Balochistan. The potential of groundwater exploitation in Azad Jammu & Kashmir is only 16800 AF while existing usage is above 4300 AF. The Northern Areas, the potential for groundwater exploitation is virtually none. Groundwater use is nearing the upper limit in most parts of Pakistan. In Balochistan the watertable has been declining continuously. A number of

studies have estimated that the deficit in Quetta sub-basin is about 21,000 AF per year and that the aquifer storage will be exhausted in 20 years.

For the purpose of drinking water sources, Pakistan can be divided into five major zones: (i) the sweet groundwater areas where water is easily accessible for human consumption; (ii) the brackish groundwater areas where canal or river water is available; (iii) the mountainous and hilly areas in the north where spring water is frequently available; (iv) the eastern desert belt where groundwater may be available only at a greater depth and (v) coastal belt of Pakistan where, generally, saline water is available. However, recent estimates of the availability and use of groundwater of an acceptable quality indicate that this resource has been heavily overexploited affecting both the quality and quantity of the groundwater (Pakistan Water Partnership, 2000).

1.6 Quality of Groundwater

The quality of groundwater is area specific and generally ranges from fresh with Total Dissolved Solids (TDS) less than 1000 mg/l near the major rivers to highly saline with salinity exceeding 3000 mg/l TDS.

In Punjab province about 79% of the area has fresh groundwater as defined above. Some 9.78 million acres are underlain with groundwater of less than 1000 mg/l TDS, 3 million acres with salinity ranging from 1000 to 3000 mg/l TDS and 3.26 million acres are underlain with groundwater of salinity of more than 3000 mg/l TDS. Generally, the saline water is encountered in the middle of Doabs (area between two rivers). Cholistan Desert in the Southern Punjab is well known for highly brackish waters which cannot be used for drinking purposes. Groundwater with high fluoride content is found in the Salt Range, Kasur and Mianwali. There are also reports of high fluoride content, ranging from 65 to 12 mg/l in groundwater in Bahawalpur area. Groundwater samples taken from Jhelum, Gujrat and Sargodha districts have shown concentrations of arsenic well above the WHO guideline value of 50 µg/l. The effluent from tanning industries in Kasur has caused high TDS, chromium, sodium and sulfide contents in groundwater.

In Sindh about 28% of the area has fresh groundwater suitable for irrigation. Close to the edges for the irrigated lands fresh groundwater can be found at 20-25 m depth. Large areas in the province are underlain with groundwater of poor quality. The areas with non-potable highly brackish water include Thar, Nara and Kohistan. In Tharparker, including Umarmkot, the situation is further complicated by the occurrence of high fluoride in some groundwater.

In NWFP abstraction in excess of recharge in certain areas such as Karak, Kohat, Bannu and D.I. Khan has lowered the watertable and resulted in the contamination from the underlying saline water. In Balochistan, the Makran coastal zone and several other basins contain highly brackish groundwater. In the absence of alternative sources of water local communities use groundwater with TDS as high as 3000 mg/l for drinking purposes. In Mastung Valley, groundwater has been found to have high fluoride content.

1.7 Groundwater Fluctuations

A groundwater level, whether it is the watertable of an unconfined aquifer or the piezometric surface of a confined aquifer, indicates the elevation of atmospheric pressure of the aquifer. Any phenomenon, which produces a change in pressure on the groundwater, will cause the groundwater level to change (Tuinzaad, 1954). The change in storage, resulting from difference between supply and withdrawal of water, causes levels to change. Effects of pumping on groundwater level are important in this regard. Other localized storage changes are produced by variation of stream stage and evapotranspiration. External loads, such as tides, trains, atmospheric pressure and earthquakes are borne in part by the water of confined aquifers hence

they affect piezometric levels. Regulation of seepage through earth dams and land drainage as well as an optimistic management of the available water resources both surface and underground can control these fluctuations. The groundwater level fluctuations are mainly of two kinds.

1.7.1 Secular Fluctuation

Secular variations of groundwater levels are those extending over periods of several years. Alternatively, series of wet and dry years in which the rainfall is above or below the mean, will produce long term fluctuation of levels (Fishel, 1956). However, rainfall is not the only indicator of groundwater level changes. Recharge is the governing factor, which depends upon rainfall intensity and distribution, and amount of surface runoff. In over-developed basins where withdrawal exceeds recharge, a downward trend of groundwater level may continue for many years. Due to the continued drought for the last many years, Pakistan is facing such type of fluctuation in groundwater levels in most of the areas (Kahlowan, *et al.*, 2002).

1.7.2 Seasonal Fluctuation

Many groundwater levels show a seasonal pattern of fluctuations. These result from influences such as recharge from rainfall and irrigation, and discharge from pumping which follow well-defined seasonal cycles (Rorabaugh, 1956). The magnitude of the fluctuations, of course, depends upon the quantities of water recharged and discharged, and a fully developed aquifer will have a greater range than one partially developed. These kinds of fluctuations are observed in the Potowar region under the effect of monsoon season.

LITERATURE REVIEW

National and international studies related to drinking water quality conducted by the researchers individually and by various organizations in relation to subject of this report are reviewed and summarized below:

2.1 Studies on Aesthetic and Physical Parameters

Sajjad and Rahim (1998) investigated chemical quality of groundwater of Rawalpindi/Islamabad. Results of electrical conductivity analysis showed increasing trend as water moves from adjoining recharge areas of Margalla and Murree hills towards centre of the basin, which acts as discharge area for groundwater. The electrical conductivity increases from less than 400 $\mu\text{S}/\text{cm}$ near the mountains to a maximum of 1200 $\mu\text{S}/\text{cm}$ in the centre of the basin.

Malick *et.al.* (1998) reported drinking water quality in the city of Karachi. During the study, forty samples were taken from supply lines of different locations of the city originating with waters from the Indus River and Hub sources. These samples were analysed for physico-chemical parameters such as pH, turbidity, EC, TDS, and residual chlorine. Results showed that the treated water from the treatment plants meets WHO guidelines. However, the samples taken from Kemari and Maripur area showed significant TDS increase from the original values of treated water, perhaps due to seepage of brackish water or saline water intrusion.

Kahlowan and Tahir (2001) conducted a research study on quality analysis of bottled/mineral water. A sample of 21 available bottled water brands was collected and analyzed. Aesthetic and physical quality of most brands was found acceptable, whereas many brands of mineral water were found to be bacteriologically contaminated.

2.2 Studies on Chemical and Inorganic Parameters

Sun *et al.* (2001) surveyed drinking water quality of Islamabad in collaboration with National Institute of Health (NIH), Capital Development Authority (CDA) and Environmental Protection Authority (EPA). Out of 271 samples collected, 43.2% were found unsafe for drinking according to Pakistan Standard Institution (PSI) standards and 25.1% by physico-chemical parameters, 10.3% samples contained physico-chemical as well as bacteriological contaminants. Out of 196 CDA samples, 22.4% were unsafe by physico-chemical parameters while 3.6% by both physico-chemical and bacteriological contamination. Dry season samples of Korang stream contained 30.2 NTU turbidity while rainy season samples contained 670 NTU turbidity. Shahdara samples showed 39.4 NTU turbidity and that of Noorpur samples were found polluted with lead (0.15 ppm) but rainy season samples contained no lead. Chlorine was present in rainy season samples of Shahdara. Similarly chlorine was present in dry season samples of Saidpur. Out of 23 CDA samples, 26.1% contained lead in dry seasons, while in rainy season, 9% samples were found chemically polluted, 4.5% each by lead and nitrates. In dry season samples of direct water supply, amount of lead increased from 26.1% to 32%. Two samples were unfit due to colour. In rainy season, lead contamination increased from 4.5 to 23.5%. One sample each was unsafe due to turbidity and colour. Whereas 32% samples of tank water were unfit physico-chemically and 28% were unfit for both physico-chemical and bacteriological parameters. Overall 60% samples were polluted by lead. Among HI series sector samples, 30.8% of direct supply samples and 100% of tank water samples were found polluted by lead.

Tahir (1989) studied pollution problems in water supply systems of Rawalpindi and Islamabad city. The supply systems of both cities were found fit with respect to alkalinity, hardness, TDS, free CO_2 , calcium, ferrous, lithium, manganese, sodium, zinc, nickel, chromium,

potassium, sulfate, phosphates and chlorides. About 25% samples were found unsafe with respect to nitrates and 75% with respect to lead. Out of 53 samples (25 Islamabad, 28 Rawalpindi), 34 were found fit for drinking purpose. Source wise acceptable percentage was 34% of tap water, 0% for cistern, 60% for tubewell, 0% of well and 100% of tank water.

Tahir and Bhatti (1994) carried out a survey of drinking water quality of rural areas of Rawalpindi District. All samples were found fit for physico-chemical parameters. However, in samples of Rawalpindi and Murree, the quantity of manganese was under the desirable level. Further, these samples were unsafe with respect to nitrates content. Two samples were found unsafe with respect to chlorides and seven with respect to sodium. Six water quality parameters were found above the desirable level of WHO.

Din *et al.* (1996) analyzed the quality of drinking water supplied to Islamabad. They found that the chemical quality of most CDA tube-wells was satisfactory during the period of the study (September to December). However, some samples were found with 1.4 ppm strontium concentration.

Tahir *et al.* (1998) analysed the drinking water quality in the rural areas of Rawalpindi district covering Gujar Khan, Kahuta, Murree, Rawalpindi and Taxila tehsils. The results showed higher concentration levels of nitrate, iron and sodium in many water samples.

Sajjad and Rahim (1998) investigated chemical quality of groundwater of Rawalpindi/Islamabad. Results of chemical parameters including nitrate, chloride, sulfate, hardness and sodium showed excessive levels as water moved from adjoining recharge areas of Margalla and Murree hills towards center of the basin, which acts as discharge area for groundwater.

Hussain and Mateen (1998) analyzed the water quality used for daily life in D.G. Khan. The results showed very high level of hardness and sulfate concentration in groundwater. The TDS in canal water was appreciably lower than those found in sub surface water samples.

Sial and Mahmood (1999) evaluated water pollution due to agricultural and industrial activities. They described some aspects of surface and sub-surface water pollution, best management practices and remedial measures required to minimize the environmental hazards.

Latif *et al.* (1999) carried out extensive work on groundwater contamination from nitrate in the irrigated areas of Pakistan. Results showed that the nitrate concentration varied from 0.03 to 3.25 mg/l in the water samples collected from the tile-drainage area, which was below the maximum permissible limit of 10 mg/l of WHO. Whereas the nitrate concentration exceeded the permissible limit in about 15% water samples collected from out side the tile-drainage area. In general, it was concluded that there was no danger of shallow groundwater pollution by nitrate if the agriculture drainage system (Tile Drains) was functioning properly. The groundwater pollution was observed in those areas where there is no drainage system.

Chandio (1999) concluded that nitrogenous fertilizers were responsible for groundwater pollution in irrigated areas. Four sets of experimental fields were selected. In the irrigated fields, 477 samples were collected. Only 3 samples showed NO₃-N concentration between 5 and 10 mg/l and 5 samples had the concentration level above the threshold limit of 10 mg/l. The industrial and municipal wastes had greater contribution into groundwater pollution than the fertilizer pollution. He recommended proper system of monitoring and investigation on groundwater pollution and called executing public awareness and popularization programs for proper field management practices.

Hashmi and Shahab (1999) reported the pollution of groundwater and surface water used by rural and urban areas by both sewage and industrial wastes. The major health risks associated

with poor water quality were outlined. A set of recommendations was given to improve the water quality situation.

Khan (1999) collected and analyzed drinking water samples from restaurants and hospitals of Rawalpindi and Islamabad. In all 105 samples were collected, out of which 48 and 28 samples were collected from restaurants and hotels of Islamabad and Rawalpindi and 14 and 15 samples were collected from hospitals of Islamabad and Rawalpindi respectively. A few samples were found unsafe with respect to TDS and Turbidity.

Ahmed and Ali (2000) investigated pollution in Ravi River and studied the effects of disposal of wastewater on its water quality in relation to various water uses. The flow in the river was highly variable with time during the year, which resulted in variations of different pollution parameters in the river. A decreasing trend in dissolved oxygen and an increasing trend in biological oxygen demand and total dissolved solids were observed over time. The discharges of untreated wastewater from the city and nearby industrial estates into the river were the main causes of water quality deterioration. However, water of Ravi River meets the chemical standards for irrigation purpose.

Tahir (2000) carried out a study to assess arsenic in groundwater of Attock and Rawalpindi district in collaboration with UNICEF. Water samples of both districts showed presence of arsenic ranging from 0-17 ppb, with an average of 5.267 ppb. Eight out of 117 (6.11%) samples were found to exceed the arsenic level recommended by WHO. No distinct correlation between arsenic and other parameters was found. Another set of 47 samples was collected for chloride and 23.4% of them were found unsafe. The range of concentration of fluoride content was 0-1.82 ppm and 2.3% samples were unsafe. The average value of hardness was 358 ppm with a range of 0-1180 ppm and 10.64% samples had exceeded the recommended level. The range of concentration of nitrates was 0-40 ppm with an average of 9 ppm and 23% samples were found unfit. The range of iron concentration was 0-7 ppm with an average of 1.33 ppm. Overall 59.57% samples were found unfit with respect to iron content in water.

Ishaque and Khan (2001) surveyed for the Prevalence of Dental Carries and Oral Hygiene Habits of Children in Quetta. They found a high level of fluorescence in the population due to excessive fluoride through drinking water intake.

Zaman *et al.* (2001) investigated the contamination of toxic substance caused by industries of Karachi in collaboration with Overseas Environmental Cooperation Centre (OECC) and Japanese International Cooperation Agency (JICA). The maximum concentration of lead (0.4 ppm) was found in Liyari River. The highest concentration of chromium of 5.31 ppm was found in Malir River due to discharge of untreated effluent by more than 300 tanneries in the area. It was estimated that coastline of Karachi received 12% share of waste from domestic sewage and 84% from industrial area. The accumulation of nitrate was observed in the top layer of groundwater. The maximum concentration of nitrate was found at shallower groundwater. It further showed that soil texture had significant impact on pollution of groundwater. There was more risk of groundwater pollution in areas occupied by coarse textured soils containing more than 50% sand particles.

Kahlowan and Tahir (2001) conducted a research study on quality of bottled/mineral water. A sample of 21 available mineral water brands was collected and analyzed. Samples were analyzed for 24 water quality parameters. The chemical analysis showed variations ranging from -99 to 1067% of claimed values. Five brands showed more compatibility of labelled with actual parameters ($>\pm 100\%$ variation). In some samples, the variations in labelled and actual values were very high (+300% in some parameters). It was a matter of interest that one brand labelled the concentration of Potassium as 19.10 mg/l, which was much higher than the European Community (EC) standards of 12 mg/l. However, analytical value was 3.2 mg/l, which was

83.25% less than labelled value and also within safe limit. However, analyzed chemical quality of most brands was found within the permissible limits.

2.3 Studies on Microbiological Parameters

Tahir (1989) undertook a study on pollution problems in the water supply systems of Islamabad and Rawalpindi. It was found that 76% samples in Islamabad and 82% samples in Rawalpindi were contaminated due to bacterial presence.

Din *et al.* (1996) reported the quality assessment of drinking water supplied to Islamabad. They found that the water quality of most of the CDA tube-well was satisfactory during the period of their study (September to December) except for seven tube-wells that showed high Coliform levels.

Tahir *et al.* (1998) analyzed the drinking water quality in the rural areas of Rawalpindi. Most of the water samples were found unfit for drinking purpose due to the presence of Coliform and E.coli.

Malick *et al.* (1998) analyzed the drinking water quality in the city of Karachi. Results showed the presence of Coliform bacteria in the main distribution lines. It indicated that water got contaminated from the surrounding leaky sewerage pipelines. Secondly, the presence of faecal Coliform in the water of branch lines feeding to consumers and stand posts, confirmed the mixing of sewage into drinking water lines making it unfit for drinking.

Hashmi and Shahab (1999) reported that the groundwater and surface water used by rural and urban areas were heavily polluted by both sewage and industrial waste.

Ahmed and Ali (2000) studied Ravi River pollution and the effects of waste water discharge on its water quality. Water of Ravi River did not meet the Coliform and faecal Coliform criteria for most water uses.

Kahlowan and Tahir (2001) evaluated the quality of bottled/mineral water. A sample of 21 available brands was collected and analyzed for microbiological indicators. Only 10 brands out of 21 (47.62%) were found fit for drinking purpose with respect to microbiological quality. The remaining 11 brands (52.38%) were found unsafe for human consumption.

Jahangir (2001) found 94% water samples collected from Islamabad/Rawalpindi bacteriologically contaminated and 34% having fecal contaminations.

Sun *et al.* (2001) described that out of 271 samples collected, 77% were unsafe bacteriologically while 10.3% contained both bacteriological and physico-chemical contamination. Among 196 of CDA samples 5.1% were polluted bacteriologically while 3.6% contained both physico-chemical and bacteriological impurities. About 14.7% of tank water samples were found unfit biologically and 28% were found unfit both biologically and physico-chemically. Overall 42.7% samples were bacteriologically polluted, 22.6% of them contained Coliform. Almost all samples from H and I sectors were biologically safe. In tank water samples (Sector H and I), 15.4% were bacteriologically polluted and all contained coliform. Overall 65.5% samples from E and F Sectors were bacteriologically unfit.

2.4 Changes in Groundwater Levels

In Pakistan, groundwater is being utilized through open wells, springs, tube-wells, hand pumps and karezes. Therefore, the quality and quantity of groundwater is important for the sustainability of the resource.

Sajid & Rahim (1998) carried out a study on the chemical quality of groundwater in Rawalpindi/Islamabad area. The results showed that the average depth of water in the study area

was 7 to 15 m. Wells located on the bank of Lei Nullah showed water-table depth between 7 to 10 m, indicating that Lei Nullah served as a source of recharge.

Mashhadi and Muhammad (2000) reported that the water levels in Islamabad were declining in response to groundwater withdrawals. The continuous declining of watertable indicated that the rate of groundwater abstraction was more than the rate of recharge.

Halcrow Rural Management (1996) estimated the groundwater balance for the Quetta sub-basin and found that the total groundwater stored in the top 91 m of saturated aquifer was 2710 million m³ and that 50 percent of this could be safely withdrawn. The above levels of abstraction will increase due to population rise and the remaining groundwater will be exhausted by 2016 if artificial recharge measures are not taken.

Soomro and Hall (1997) investigated the impact of rising groundwater table on the quality of water. It was studied that following the Sukkur Barrage Canal network in the 1930's, groundwater levels in the Left Bank Outfall Drain (LBOD) area risen from 3.7 m to less than 1.5 m over 75% of the irrigated areas and in many areas to just below the surface. The phenomena have been increasing over the years. Similarly, Mashiatullah *et al.* (2002) performed an investigation of shallow groundwater, (8-30 m), groundwater (> 50 m) and deeper groundwater areas (up to 100 m) in Karachi. In general, the results showed that the groundwater was saline and unfit for drinking purposes. The main reason for saline groundwater in Karachi was the salt-water intrusion from sea.

Jensen *et al.* (1998) concluded that in large areas of the Punjab and Sind, groundwater is brackish and cannot be used for domestic purposes including washing. The few water supply schemes that exist in those areas use shallow seepage water. Changes in irrigation water management and more efficient irrigation had caused negative impact by reducing the seepage and by extending canal closure time. In this regard, the continued droughts in the country for the last many years had further deteriorated the quality of water. These findings were confirmed by the investigation carried out by Bhutta *et al.* (2002) in the Indus River Basin.

Abdullah (1996) and PWP (2000) water table in most of the basins is depleting fast with serious consequences. Already the groundwater table has receded to well below 200 m in many areas, making pumping an extremely costly operation. Particularly, in Quetta Valley, groundwater table declined by more than 30 m in recent years. The rate of decline is reported over 2-3 meters per year, which is causing extreme concerns.

Kahlowan *et al.* (2002) while investigating water quality issues in Pakistan found that the groundwater is the major source of drinking and industrial water use. The increased pressure on groundwater has caused the lowering of water table in many cities. The watertable has fallen down by more than 10 feet in many areas. Accordingly, the excessive use of groundwater has also affected its quality.

2.5 Geologic Conditions and Groundwater Quality

All ground waters contain salts, the nature and concentration of these salts depend upon the environment, movement, and source of the groundwater. Ordinarily, higher proportions of dissolved constituents are found in ground water than in surface water because of the greater exposure to soluble materials in geologic strata. Soluble salts found in groundwater originate primarily from solution of rock materials (Foster, 1942). Connate waters are usually highly mineralized as they originate from isolated pockets of residual waters entrapped in sedimentary rocks since geologic times.

Groundwater passing through igneous rocks dissolves very small quantities of mineral matter because of the relative insolubility of the rock composition. Sedimentary rocks are more

soluble than the igneous rocks. Because of their higher solubility, combined with greater abundance in the earth's crust, they furnish a major portion of the soluble constituents to groundwater (Todd, 1959). In areas recharging large volumes of water underground such as alluvial streams or artificial recharge areas, the quality of the infiltrating surface water can have a marked effect on the groundwater. Salts are added to groundwater passing through soils by soluble products of soil weathering and of erosion by rainfall and flowing water. Excess irrigation water percolating to the watertable may contribute substantial quantities of salt (Todd, 1959).

Ahmed (1998) investigated the impact of environmental pollution in Rawalpindi and Islamabad. The results of water samples collected from surface and groundwater sources showed that the levels of Cadmium (Cd) were low in surface water samples as compared to groundwater and it was also expected because the surface water samples have low mineral contents as compared to groundwater.

Qureshi and Barrett-Lennard (1998) reported that out of 560,000 tube-wells in the Indus Basin, about 70% are pumping sodic water. The use of sodic water has, in turn, affected the soil health and decreased the crop yield.

The above presentations lead to the conclusion that the geologic conditions of the area may contaminate the underground water. However, the source of origin as well as recharge is of great importance in groundwater quality investigations.

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.

3.1 WHO Guidelines

A. Bacteriological Qualities

Source/Organisms	Guideline Value
a. All water intended for drinking (E. Coli or thermo tolerant Coliform bacteria)	Must not be detectable in any 100 ml sample
b. 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
c. 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

Inorganic	mg/l	Inorganic	mg/l	Inorganic	mg/l
Antimony	0.005	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	0.300	Lead	0.010	Nitrite(NO ₂)	03.00
Cadmium	0.003	Manganese	0.500	Selenium	0.010
Chromium	0.050	Mercury	0.001		

C. Other Parameters

Inorganic	mg/l	Inorganic	mg/l	Inorganic	mg/l
Colour	15 TCU	1,2 dichlorobenzene	1-10	Hardness,pH, DO	-
Taste, Odour.	-	1,4-dichlorobenzene	0.3-30	Hydrogen sulfide	0.05
Turbidity	5 NTU	Dichlorobenzene	5-50	Iron	0.3
Toluene	24-170	Synthetic detergents	-	Manganese	0.1
Xylenes	20-1800	Aluminum	0.2	Sodium	200
Ethyl-benzene	2.4-200	Ammonia	1.5	Sulfate	250
Styrene	4-2600	Chloride	250	TDS	1000

Monochlorobenzene	10-120	Copper	1	Zinc	3
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D. Disinfectants and Disinfectant by-Products

Name	Value	Name	Value
Chlorine chlorophenol	600-1000	2,4,6-trichlorophenol	2-300
2,4-dichlorophenol	0.3-40	2-chlorophenol	0.1-10

3.2 Standards Drafted by PCRWR*A. Bacteriological Standards (Urban and Rural water supplies)*

Categories	Standards
<i>A. Piped Water Supplies</i>	
A-1 Treated water entering the distribution system <ul style="list-style-type: none"> • Faecal Coliform • Coliform organisms 	0/100 ml 0/100 ml
A-2 Un-treated water entering the distribution system <ul style="list-style-type: none"> • Faecal Coliform • Coliform organisms • Coliform organisms 	0/100 ml 0/100 ml 3/100 ml
A-3 Water in the distribution system <ul style="list-style-type: none"> • Faecal Coliform • Coliform organisms • Coliform organisms 	0/100 ml 0/100 ml 3/100 ml
<i>B. Un-piped Water Supplies</i>	
<ul style="list-style-type: none"> • Faecal Coliform • Coliform Organisms 	0/100 ml 10/100 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 concentrative 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

* Highest Desirable Level.

** Maximum Permissible Level.

C. Other Parameters

Constituent	Unit	HDL*	MPL**	Undesirable Effects
Turbidity	NTU	2.5	5	Un-aesthetic, decrease in efficiency of disinfections
Colour	PCU	5	15	Un-aesthetic
Taste & Odour	-	Unobjectionable		Taste & Odour
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
Magnesium	mg/l	30	150	Stomach disturbances
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

Chloride	mg/l	200	600	Taste, Corrosion
pH	-	7.0-8.5	6.5-9.2	Taste, Corrosion
Hardness	mg/l	200	500	Corrosion or scale formation
Phenolic substances	mg/l	0.001	0.002	Taste

* Highest Desirable Level.

** Maximum Permissible Level.

3.3 Pakistan Standard Institution

Drinking Water Quality Standards

A. Physical Requirements

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

B. Chemical Requirements

1.	Total Dissolved Solids	mg/l	1000	1500
2.	Chloride (Cl)	mg/l	200	600
3.	Sulfate (SO ₄)	mg/l	200	400
4.	Nitrate (NO ₃)	mg/l	-	45
5.	Total Hardness (CaCO ₃)	mg/l	20	500
6.	Nitrite (NO ₂)	mg/l	Nil	Nil
7.	Magnesium (Mg)	mg/l	500	1000
8.	Total Ammonia	mg/l	0.1	0.5
9.	Hydrogen Sulfide	mg/l	Undetectable odour	
10.	Fluoride (F)	mg/l	-	1.5
11.	Iron (Fe)	mg/l	0.3	1.0
12.	Zinc (Zn)	mg/l	5.0	15.0
13.	Manganese (Mn)	mg/l	0.1	0.5
14.	Copper (Cu)	mg/l	1.0	1.5
15.	Calcium (Ca)	mg/l	75	200
16.	Magnesium (Mg)	mg/l	50	150
17.	Phenolic Substances	mg/l	0.001	0.002
18.	Alkyl Benzyl Sulfates	mg/l	0.5	1.0
19.	Carbon Chloroform Extract	mg/l	0.2	0.5

C. Limits of Toxic Substances

1.	Arsenic (As)	mg/l	0.05	-
2.	Cadmium (Cd)	mg/l	0.01	-
3.	Chromium (Cr)	mg/l	0.05	-
4.	Cyanide (Cn)	mg/l	0.20	-
5.	Lead (Pb)	mg/l	0.05	-
6.	Selenium (Se)	mg/l	0.20	-
7.	Radionuclides	Uo/l	1000	-

D. Biological Requirements (Chemical Indicators of Pollution)

1.	Chemical Oxygen Demand (COD)	mg/l	10	-
2.	Biochemical Oxygen Demand (BOD)	mg/l	6	-
3.	Ammonia (NH ₃)	mg/l	0.5	-
4.	Grease	mg/l	1	-

E. Limits for Bacteriological Contaminants

Acceptable bacterial standards for potable water supplies:	
i) Standard plate count (SPC)/mls	No more than 100
ii) Presumptive test for Coliform	Negative
iii) Most probable number (MPN)	< 101 subject to the frequency of opportunity for water analysis.

* Maximum Acceptable Concentration. ** Maximum Allowable Concentration.

3.4 International Bottled Water Association (IBWA) Standards

A. Chemical Quality

Characteristics	Unit	Standard	Characteristics	Unit	Standard
Arsenic (As)	mg/l	0.05	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	-	-	-

B. Microbiological Quality

Total Plate Count/ml	CFU/ml	<200	Escherichia coli	MPN/100 ml	
Coliform (MPN/100 ml)	MPN/100 ml	<220	Salmonella	CFU/100ml	

3.5 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

3.6 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
32.	Chlorine	1.0 mg/l

3.7 Indian Water Quality Standards

A. Physical and Chemical Standards

Sr. #.	Characteristics (mg/l)	Acceptable	Marginal	Sr. #.	Characteristics (mg/l)	Acceptable	Marginal
1	Turbidity	2.5	10	7	Fluoride	1.0	1.5

	(NTU)						
2	Colour (TCU)	5	25	8	Nitrate (N)	45	45
3	Taste & Odour	Unobjectionable		9	Calcium	75	200
4	pH	7-8.5	6.5-9.2	10	Magnesium	30	150
5	TDS	500	1500	11	Iron	0.1	1.0
6	Hardness	200	600	12	Manganese	0.05	0.5
13	Chloride	200	1000	21	Copper	0.05	1.5
14	Sulfate	200	400	22	Zinc	5.0	15
15	Phenolic Compounds	0.001	0.002	23	Lead	0.1	0.1
16	Anionic Detergents	0.2	1.0	24	Selenium	0.01	0.001
17	Arsenic	0.05	0.05	25	Mercury	0.001	0.2
18	Cadmium	0.01	0.01	26	Polynuclear aromatic hydrocarbons (g/l)	0.2	3
19	Chromium	0.05	0.05	27	Gross Alpha Activity	3 (pCi/l)	30
20	Cyanide	0.05	0.05	28	Gross Beta Activity pico curie/l	30 (pCi/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; and
 - 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 below:

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

A. Chemical 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	-	-	0.01	1	-	-
10	Cyanide (CN)	mg/l	0.05	0.01	2	-	0.01	-
11	Fluoride (F)	mg/l	1	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	<0.005
18	Mineral Oil	mg/l	-	ND	ND	-	-	-
19	Nitrate (NO ₃)	mg/l	ND	45	45	4	45	<0.01
20	Nitrite (NO ₂)	mg/l	ND	0.005	0.005	-	0.01	-
21	Organic Matter	mg/l	1	0.003	3	-	5	-
22	Selenium (Se)	mg/l	-	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	CFU/ml	Max 1x10 ⁴	Max.1x10 ⁵	-	-	-	-
2	Coliform (MPN/100 ml)	MPN/100ml	<2.20	0/250 ml	Max.10	<2,20	<2.20	Nil
3	Escherichia coli	MPN/100ml	0	0	0	Negative	-	Nil
4	Salmonella/100 ml	CFU/100ml	-	0	-	-	-	-
5	Staphylococcus Aureus/250 ml	CFU/250ml	-	0	-	-	-	-
6	Pseudomonas Aeruginosa/250 ml	CFU/250ml	0	0	-	-	-	-
7	Faecal Streptococci/20 ml	MPN/20ml	-	-	-	-	1/100 ml	-

3.9 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	CFU/ml	<10	-	100	-	<100	-
2	Coliform (MPN/100 ml)	MPN/100ml	-	<15.100	3	<2.2	0	-
3	Escherichia coli	MPN/100ml	2.2	-	-	-	-	0/100 ml

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

METHODOLOGY

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:

4.1 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; and
- 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 4.1.

Table 4.1: Details of Water Quality Monitoring Network

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	24	12	Hyderabad	HYD	4	15
2	Rawalpindi	RAW	9	14	13	Karachi	KAR	25	28
3	Gujrat	GUT	1	8	14	Sukkur	SUK	1	12
4	Lahore	LAH	16	16	15	Quetta	QUE	4	22
5	Sialkot	SIA	4	10	16	Khuzdar	KHU	Approx.	5
6	Sheikhupura	SHE	4	11	17	Loralai	LOR	1	5
7	Gujranwala	GUJ	4	14	18	Ziarat	ZIA	1	5
8	Faisalabad	FAI	4	14	19	Peshawar	PES	16	13
9	Kasur	KAS	1	10	20	Mardan	MAR	4	10
10	Bahawalpur	BAH	16	25	21	Mangora	MAN	1	10
11	Multan	MUL	16	16	-	-	-	-	-

4.2 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 section 1.3. For water quality data collection purposes, the country has been divided into six 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-I** (WRRC, Islamabad)
Rawalpindi, Islamabad and Gujrat cities, Simly, Rawal and Khanpur dams, Tarbela, Mangla and Chashma reservoirs and Jhelum and Chenab Rivers.
- **Monitoring Station-II** (Regional Office, Lahore)
Lahore, Sialkot, Sheikhupura, 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 Centre, 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.

4.3 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.

4.3.1 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.



Sample Collection from Tap for Microbiological Analysis

4.3.2 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.

4.3.3 Water from Distribution Network

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.



Measurement of Electrical Conductivity in the Field



4.3.4 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).

4.3.5 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.

4.3.6 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.

4.3.7 Dams, Rivers and Lakes

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.

4.3.8 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.



**Microscopic Examination of Isolated Micro-organisms
Water Samples in the Laboratory**

Inoculation of

4.3.9 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+10 ml/litre HNO_3 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.



Types of Samples (A, B, C, D) from Single Source

4.3.10 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, paint, pH-meter and EC-meter.

4.3.11 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.

4.3.12 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.

4.4 Quality Control Measures

Quality control measures were started from the filed. 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 HNO₃ 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 HCO₃ 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 in analytical readings. Cross samples were planned to be sent to some reputable laboratories for comparison. However, due to constraint of time, cross samples could not be carried out in any other laboratory. Therefore, all analysis of field blank, replicate and cross samples for water quality purposes was carried out in PCRWR water quality laboratory at Islamabad by two different teams are shown at Annexure-VII.

Moreover, PINSTECH is now a days analyzing the cross samples of NWQMP (Phase-II) to see the accuracy in analytical results of both laboratories. The comparison of these results will be given in the next report.

4.5 Analytical Methods

The water samples were analyzed for physical, chemical and bacteriological parameters by using standard methods (Table 4.2). The details of the parameters and methods used for their analysis are given below:

Table 4.2: Water Quality Parameters and Methods used for Analysis

S. #	Parameters	Test Method
1.	Alkalinity (m.mol/l as CaCO ₃)	2320, Standard method (1992)
2.	Arsenic (µg/l)	Merck Test Kit (10-500 µg/l) 1.17926.0001, Germany
3.	Bicarbonate	2320, Standard method (1992)
4.	Calcium (mg/l)	3500-Ca-D, Standard Method (1992)
5.	Carbonate (mg/l)	2320, Standard method (1992)
6.	Chloride (mg/l)	Titration (Silver Nitrate), Standard Method (1992)
7.	Chlorine (mg/l)	HACH Test Kit, Model CEC, Cat. No. 22231, USA
8.	Chromium (µg/l)	1,5-Diphenylcarbohydrazide Method (Hach-8023) by Spectrophotometer
9.	Conductivity (µS/cm)	E.C meter, Hach-44600-00, USA
10.	Fluoride (mg/l)	8029, SPADNS Method (Hach) by Spectrophotometer
11.	Hardness (mg/l)	EDTA Titration, Standard Method (1992)
12.	Iron (mg/l)	TPTZ Method (Hach-8112) by Spectrophotometer
13.	Lead (µg/l)	Dithizone Method (HACH-8033) by Spectrophotometer
14.	Magnesium (mg/l)	2340-C, Standard Method (1992)
15.	Nitrate Nitrogen (mg/l)	Cd. Reduction (Hach-8171) by Spectrophotometer
16.	Nitrite Nitrogen (mg/l)	Diazotization (Hach-8507) by Spectrophotometer
17.	pH at 25°C	pH Meter, Hanna Instrument Model 8519, Italy
18.	Phosphate & P (mg/l)	Method (Hach) 8190 & 8048
19.	Potassium (mg/l)	Flame photometer PFP7, UK

Table 4.2- (Contd.)

20.	Sodium (mg/l)	Flame photometer PFP7, UK
21.	Sulfate (mg/l)	SulfaVer4 (Hach-8051) by Spectrophotometer
22.	Total Coliform (MPN/100ml)	407D, Standard method (1971)
23.	TDS (mg/l)	2540C, Standard method (1992)
24.	Turbidity (NTU)	Turbidity Meter, Lamotte, Model 2008, USA

4.5.1 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 colour. The alkalinity to phenolphthalein was considered to be zero in case no colour 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 colour 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.

4.5.2 Arsenic

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.

Merck Test Kit, Cat No. 1.17926.0001, Germany (0.01-0.5 mg/l) was used for arsenic analysis. When zinc and sulfuric acid are added to compounds of arsenic-III and arsenic-V, arsenic hydride is liberated, which in turn reacts with mercury-II bromide contained in the reaction zone of the

analytical test strip to form yellow-brown mixed arsenic mercury halogenides. The concentration of arsenic-III and arsenic-V are measured semi quantitatively by visual comparison of the reaction zone of the analytical test strip with the fields of colour scale. The concentrations of foreign substances given in Table 4.3 lies below the limit at which the determination is interfered with.

Table 4.3: Concentration Levels of Foreign Substance

Al ³⁺	100	Co ²⁺	5	Fe ³⁺	1000	Ni ²⁺	10	SeO ₃ ²⁻	1
Ag ⁺	1	CO ₃ ²⁻	1000	Hg ²⁺	5	NO ₂ ⁻	100	Sn ²⁺	100
Ca ²⁺	1000	CrO ₄ ²⁻	1000	K ⁺	1000	NO ₃ ⁻	100	SO ₃ ²⁻	1
Cl ⁻	1000	Cu ²⁺	0,5	Mg ²⁺	1000	PO ₄ ³⁻	100	SO ₄ ²⁻	1000
ClO ₃ ⁻	25	F ⁻	500	MnO ₄ ⁻	500	S ²⁻	0,5	S ₂ O ₃ ²⁻	0,5
Cn ⁻	1000	Fe ₃ ²⁺	1000	Na ⁺	1000	Sb ³⁺	1	Zn ²⁺	1000
EDTA	1000	-	-	-	-	-	-	-	-

One analytical test strip was removed and the tube was closed immediately. The test strip was inserted with the reaction zone first about halfway through the slot in the stopper of the reaction vessel. A sample of 10 ml was transferred to the reaction vessel by a syringe and added 2 spoonfuls of reagent arsenic-I. Then added 10 drops of reagent arsenic-II rapidly and closed the reaction vessel with the stopper immediately. The sample solution should not come in contact with the test strip while swirling. After 30 minute, the strip was removed and compared the colour on the label/concentration value in mg/l arsenic.

4.5.3 Bicarbonates

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).



Determination of Bicarbonates by Titration Method

The reagent used for this analysis included:

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

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:

R_1 = Volume of acid used for phenolphthalein alkalinity.

4.5.4 Calcium

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 litre, 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 colour 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 4.4.

Table 4.4: Recommended Level 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 = $\frac{\text{ml of standard calcium solution}}{\text{ml of EDTA titrant}}$; and

V= ml of sample.

4.5.5 Carbonate

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; and
- 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”.

Concentration of carbonate mg/l= R₁x20x2.

4.5.6 Chloride

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.

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.

4.5.7 Chromium

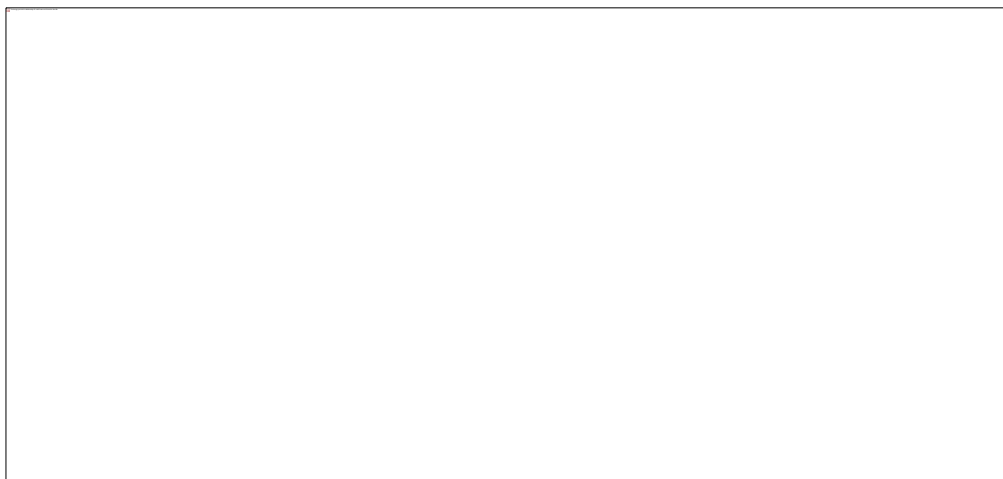
Chromium concentrations in natural waters are usually very small. Elevated chromium concentrations can result from mining and industrial processes. An upper limit of 0.05 mg of chromium per litre is allowed in drinking water in the USA and a similar limit is allowed by WHO. The method used for this analysis was 1,5-Diphenylcarbohydrozide Method (HACH-8023) by Spectrophotometer. The measurements can be made within the accuracy range of 0.0 to 0.60 mg/l.

Hexavalent chromium is determined by the 1, 5 Diphenylcarbohydrozide method using chromium reagent (chroma ver 3). This reagent contains an acidic buffer combined with 1,5-Diphenyl-carbohydrozide when reacts to give a purple colour, which is proportional to the amount of hexavalent chromium present.

Samples were collected in clean plastic bottles, stored at 4°C and analyzed within 24 hours after collection. The contents of one chroma ver 3-reagent powder pillow were added in 10 ml of deionized water. After swirling thoroughly, blank solution was taken in cuvette and placed in cell holder of spectrophotometer adjusted at wavelength of 540 nanometer (nm). Standard chromium solutions of 0.005, 0.02, 0.04, 0.06, 0.08 and 0.1 mg/l were prepared and treated in the same way as deionized water and absorbance were noted. Similarly absorbance of samples was taken and the concentration of chromium was determined with the help of calibrated graph.

4.5.8 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.



Measurement of EC in the Laboratory

The samples were shaken thoroughly before starting measurements and allowed to stabilize till removal of 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 filled with 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.

4.5.9 Fluoride

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 $Abs \times 6.9364 + 0.0425$.

4.5.10 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 litre. 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; and
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.

4.5.11 Iron

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. Colour intensity is proportional to iron concentration. A pH between 2.9 and 3.5 ensures rapid colour 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.



Determination of Iron on Spectrophotometer

4.5.12 Magnesium

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 litre. 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 CaCO_3 .

Concentration of Mg (mg/l) = [total hardness (as CaCO_3 mg/l)–Calcium hardness (as mg CaCO_3 /l) x 0.243].

4.5.13 Nitrate-N

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 ($\text{NO}_3\text{-N}$). 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-coloured product.

A 25 ml of deionized water was taken in a beaker. The contents of 1 NitraVer 5-nitrate reagent pillow 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 (N) were determined with the help of calibrated graph.

4.5.14 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.

4.5.15 Sulfate

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.

4.5.16 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. Flavour 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 sanitarily 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.

4.5.17 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 coloured 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 colour" (water colour) 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:

$$\text{Nephelometric turbidity units (NTU)} = \frac{Ax(BxC)}{C}$$

where;

A= NTU found in diluted samples;

B= Volume of dilution water, ml; and

C= Sample volume taken for dilution, ml.

4.6 Water Table Depth Measurements

Watertable measurements are made to monitor changes in the groundwater under different conditions. Records are required of continuous measurements such as those supplied by an automatic water stage recorder or of periodic measurements with a time interval extending from less than a minute (for a pump test) to 6 months. However, the frequency of measurements should be adjusted to the circumstances. In some instances, only a few measurements over a long period of time may be required. The possibility of error in interpretation decreases as the frequency of measurement and length of record increases. Water level may be measured with a number of different devices. The generally used are:

4.6.1 Chalked Steel Tape

Probably the most common device for measuring static water level is the chalked steel tape which has a weight attached on the lower end. The weight keeps the tape tight and aids in lowering it into the well. The tape is chalked with carpenter's chalk, ordinary blackboard chalk, or dry soil, which changes shade upon becoming wet. The line of the colour change denotes the length of tape immersed in water. Subtracting this length from the reading at the measuring point gives the depth to water. Cascading water in a well may mask the mark of the true water level on the tape, however, this usually occurs only in a well that is being pumped. When this condition is encountered, another method of measuring is used. In small-diameter wells, the volume of the weight may cause the water level to rise in the pipe, and the measurements may need correction.

4.6.2 Electric Sounder (Water Level Indicator)

Electric sounders are also used to measure the depth to water in wells. There are a number of commercial models available, none of which is entirely reliable. Many sounders use brass or other metal indicators clamped around a conductor wire at 5 ft intervals to indicate the depth to water when the metal indicates contact. The spacing of these indicators should be checked periodically with a surveyor's tape to assure accurate and reliable readings. Some electric sounders use a single-wire line and probe, and rely on grounding to the casing to complete the circuit, others use a two wire line and double contacts on the electrode. Most sounders are powered with flashlight batteries and the closing of the circuit by immersion in water is registered on a milliammeter. Experiences have shown the two-wire circuits with a battery are the most satisfactory. Electric sounders are generally more suitable than other devices for measuring the depth to water in wells that are being pumped because they generally do not require removal from the well for each reading. However, when there is oil on the water, water cascading into the well, or turbulent water surface in the well, measuring with an electric sounder may be difficult.

4.6.3 Steel Tape

A simple and reliable method for measuring the depth to water in observation holes between 1½ and 6 inches in diameter is a steel tape with a popper. The popper is a metal cylinder of 1 to 1½ inches in diameter and 2 to 3 inches long with a concave under surface fastened to the end of a steel tape. The popper is raised a few inches and then dropped to hit the water surface, where it makes a distinct "pop". By adjusting the length of tape, the point at which the popper just hits the surface is rapidly determined. Poppers generally are not satisfactory for measuring pumping wells because of the operating noise and lack of clearance. Permanent pump installations should always be required with an access hole for probe insertion or an airline and gauge, or preferably both, to measure draw down during pumping. An airline is accurate only to about 0.5 ft unless calibrated against a tape for various draw downs, but is sufficiently accurate for checking well performance.

4.6.4. Mercury Gauge

Artesian wells with piezometric heads above the ground surface are conveniently measured by capping the well with a cap that has been drilled, tapped and fitted with a plug which is removed for the insertion of a Borden gauge or mercury manometer stem. The static level is determined from the gauge reading of manometer reading after the pressure has stabilized. For continuous records, a recording pressure gauge may be used.

During the present study, the water levels were measured using Water Level Indicator because of its simple and easy use. Secondly the water levels were measured sufficiently after the pumping was stopped to obtain static conditions.

4.7 Data Base

Pakistan Council of Research in Water Resources has developed an integrated website (www.pcrwr.gov.pk) to meet the challenges of digital age. The website contains introduction, organizational structure, facilities at its research centers, collaboration with different international organizations, HRD activities, conferences and seminars held by PCRWR and their proceedings published in addition to other regular and occasional publications such as: newsletter, journal, manuals, research reports, annual progress reports and union list of journals *etc.* Current activities including databases on water quality issues, hydrological statistics, rainfall and river discharge information are also included. Moreover, PCRWR also intends to develop a discussion group of researchers over water research at our website in near future.

The water quality database has been launched for the consumer's awareness and emphasis on water quality issues and analytical results including physico-chemical and microbiological examination. Remedial measures and guidance regarding the protection of source will also be provided in detail about any potential hazard, if present in the source of surveyed area.

The website will be updated periodically to improve the effectiveness of information and its easy access on the suggestions of website visitors and researchers in the field of water sector.

RESULTS AND DISCUSSIONS

This chapter presents the results of 1st and 2nd Phase of water quality data from twenty-one cities, six rivers and eleven storage reservoirs, lakes, canals and drains monitored under the National Water Quality Monitoring Program during 2002 and 2003, respectively. In this chapter health problems caused due to poor water quality are also identified and remedial measures are suggested in the form of recommendations. The details of the results are presented under the three main categories of water quality analysis: (i) Aesthetic and Physical Quality; (ii) Chemical Quality; and (iii) Bacteriological Quality.

5.1 Aesthetic & Physical Quality

The aesthetic and physical parameters provide general information about water quality in qualitative terms and include water quality parameters like colour (appearance, transparency), electrical conductivity, odour, pH, taste, temperature and turbidity. The results of these parameters monitored in all 21 cities are presented at Annexure-II-1(a) to II-21(a) and III-1(a) to III-21(a), and are discussed as under:

5.1.1 Colour

Waters may appear colored or turbid or both. Colour arises from the absorption of visible light by dissolved and un-dissolved substances. Pure water exhibits a light blue colour, which may be changed by the presence of organic/inorganic matter to greenish blue, green, greenish yellow, or brown. Typical colour is mostly due to humic substances or trivalent iron. Generally, the observations of colour are made in qualitative terms. During Phase-I, all drinking water samples collected from Islamabad, Faisalabad, Gujranwala, Gujrat, Kasur, Lahore, Multan, Sheikhpura, Khuzdar, Mangora, Mardan, and Peshawar were found colourless. However, about 13% samples from Rawalpindi, 10% from Sialkot, 13% from Hyderabad, 8% from Sukkur, 9% from Loralai, 5% from Quetta, and 13% from Ziarat had turbidity in colour. About 16% samples from Bahawalpur and 7% samples from Hyderabad are slightly yellowish. Only 12.5% samples from Hyderabad were found of greenish colour.

In the second year of analysis, the results were not significantly different from the 1st year analysis except for few cities (Figure 5.1). In the similar trend, all drinking water samples collected from Islamabad, Rawalpindi, Faisalabad, Gujranwala, Kasur, Lahore, Multan, Sheikhpura, Mangora, Mardan, and Peshawar were found colourless. However, 60% from Hyderabad, 46% from Karachi, 58% from Sukkur, 30% from Loralai, 8% from Quetta, 29% from Ziarat, 10% from Sialkot and 25% samples from Khuzdar were found muddy or turbid in color. However, 16% from Bahawalpur, 11% from Gujrat, 4% from Karachi and 7% from Hyderabad were found yellowish or slightly yellowish, whereas 7% from Hyderabad and 4% from Karachi were greenish in color.

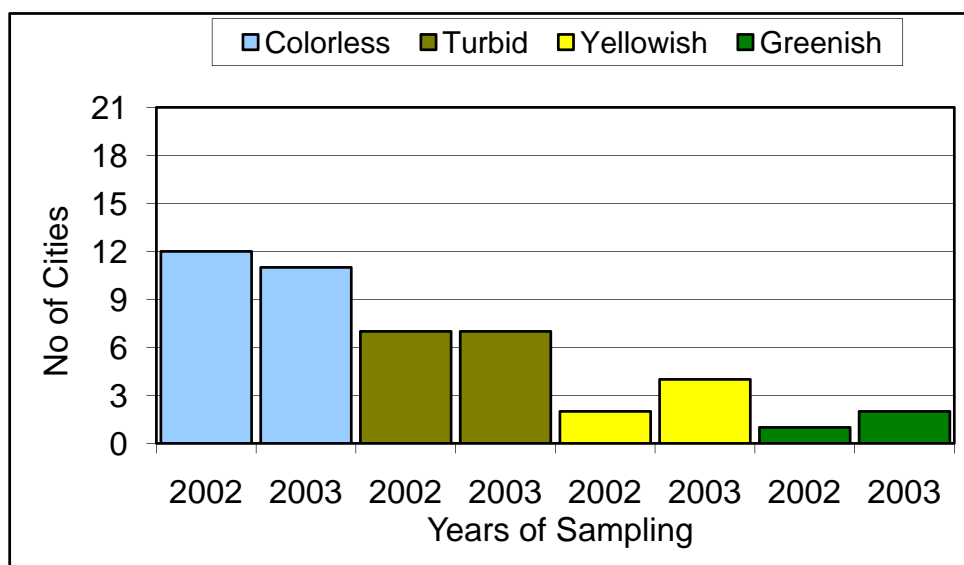


Figure 5.1: Number of cities with different color in drinking water

5.1.2 Electrical Conductivity

Electrical conductivity (EC) depends on the ionic strength of the water and relates to the nature of various dissolved substances, their actual and relative concentration, and the temperature at which the measurement is made. The EC provides a rapid and convenient means for estimating the concentration of electrolytes and gives quick information about all the dissolved minerals. Standard unit of EC is Siemens per metre ($\text{Sm}^{-1}=\Omega^{-1}\text{m}^{-1}$). In order to avoid the expression of results in small decimal fractions, a smaller unit *i.e.* $\mu\text{S}/\text{cm}$ is generally used. The EC of most fresh waters is in the range of 50-500 $\mu\text{S}/\text{cm}$. Groundwater always has higher EC levels when compared with surface water. The values of highly mineralized water go up to 1000 $\mu\text{S}/\text{cm}$ or even more. During year 2002, EC values in all twenty-one urban cities lie in the range of 170-6100 $\mu\text{S}/\text{cm}$ with average of 827. However, few water samples from some cities including Bahawalpur (8%), Faisalabad (36%), Karachi (4%), and Quetta (3%) have EC exceeding 2000 $\mu\text{S}/\text{cm}$.

In year 2003, EC values of all analysed water samples varied from 236 to 5300 $\mu\text{S}/\text{cm}$ with average of 854. However, water samples from some cities including Bahawalpur (4%), Faisalabad (36%), Kasur (20%), Sialkot (10%), Karachi (7%), and Quetta (3%) have EC more than 2000 $\mu\text{S}/\text{cm}$ as observed in year 2002. Some locations having EC higher than 2000 $\mu\text{S}/\text{cm}$ are listed in Table 5.1. In some cases EC did not vary significantly in 2003 in comparison to value in 2002 however in other cases, reasons have been identified for huge difference in EC values between two years of analysis.

5.1.3 Odour

Evaluation of odours is based on the sense of smell similar to evaluation of taste which depends on the sense of taste. Odorous substances are detectable even if present in only a few micro grams per litre, however, some times it is impractical or impossible to identify the odour. The odour tests are useful for evaluating the quality of raw and finished water. A number of organic (mainly) and some inorganic substances contribute to the odour of water. Natural water containing only inorganic matter has usually no odour. For the present analysis, water samples were divided into two groups for odorous evaluation purpose *i.e.* objectionable or unobjectionable. In year 2002, water samples from most of cities were found unobjectionable (odourless) however, 21% samples from Kasur, 10% from

Sialkot and 25% from Hyderabad had objectionable smell. Whereas in year 2003, all collected samples were found odourless.

Table 5.1: Locations of Water Samples Having High EC Values

S. #.	Location	Source	EC ($\mu\text{S}/\text{cm}$)		% Diff.	Remarks
			Yr2002	Yr2003		
1	Govt. High School Hamalton, Bahawalpur	H.Pump	4080	3974	-3	No significant change in EC.
2	Commercial Area, Satellite Town, Bahawalpur	T.Well	2210	621	-72	The reason for this huge difference is that at this site, there are two tubewells at 80 ft apart. When one become out of order the other one is used. During Phase-I, sample was collected from Tubewell No. 1 (300 ft deep), which was out of order during Phase-II. Therefore sample was collected from Tubewell No. 2 (250 ft).
3	Adda Chak 7JB, Sargodha Road, Faisalabad	H.Pump	3000	2940	-2	No significant change in EC.
4	T.Well-3, Canal Bank Rd. Farooqabad, Faisalabad	T.Well	838	1866	122	Tubewell remained closed for last 15 months and reopened after increasing the depth recently.
5	M/C Girls Middle School Samanabad, Faisalabad	Inj. Pump	6100	5300	-13	No specific reason could be identified for this significant reduction in EC.
6	N.C.of Computer Sciences, Faisalabad	Inj. Pump	3790	3100	-18	During Phase-II, the site has been changed nearly 100 m away from where sample was collected in Phase-I due to closure of premises.
7	Muhammadi Masjid, H Area, Khokhrapar, Karachi	H.Pump	3580	1145	-68	The mixing ratio in 2002 was about 50% and due to non-availability of river waters, brakish subsurface water was being used.
8	Muhammadi Masjid Podgali Chowk, Quetta	Well	2970	3011	1	No significant change in EC.
9	Chaki Piyarolal Opp. Railway Station, Kasur	Inj. Pump	1970	2060	5	No significant change in EC.
10	Hotel Sukkur Inn, Clock Tower, Sukkur	H.Pump	280	1780	536	The reason for this charge is that the hotel management has installed donkey pump at 70 ft deep due to shortage of river water.
11	Masjid Kabaturan, Near Ahmadia School, Sialkot	T.Well	1845	2100	14	Due to closure of tubewell, new site was selected some 300 m away in same area
12	Govt. Girls High School Sarfraz Colony, Gujranwala	D. Pump	1600	1897	19	Previous site in the school is closed. New site has been at nearly 75 m opposite to school.

5.1.4 pH

The pH determination is very important as it affects the chemical and biological properties of water. Suitable pH levels are helpful for reducing corrosion and to manage water and waste water treatment processes. It is the logarithm to the base 10 of the reciprocal of the hydrogen ion concentration (most precisely of the hydrogen ion activity) in moles/liter. The practical pH scale extends from 0 (very acidic) to 14 (very alkaline) with the middle value of 7 corresponding to exact neutrality at 25°C. The pH of natural waters is usually due to carbon dioxide/bicarbonate/carbonate equilibrium. WHO has recommended 6.5 to 8.5 pH values for drinking water. The pH of collected samples during year 2002 varied from 6.10 to 9.0 with average of 7.74. The results did not vary significantly during Phase-II of analysis (2003) ranging between 6.78 to 8.54 with average of 7.64 i.e. within recommended range.

5.1.5 Taste

Assessment of taste is based on the sense of taste. For this study, taste tests were performed only on samples that are known to be sanitarly acceptable. The intensity (distinct or indistinct) and specific kinds of taste like metallic, sulfidic and four true taste sensations *i.e.* salty, sweet, bitter and sour were however, not noted. These sensations may be observed in future. Presently, the results of taste examination are described simply in qualitative terms in the forms of two groups *i.e.* objectionable and unobjectionable. In year 2002, water samples from 13 cities including Islamabad, Lahore, Multan, Rawalpindi, Sheikhpura, Sialkot, Karachi, Sukkur, Quetta, Khuzdar, Loralai, Ziarat, and Mangora had unobjectionable taste. Whereas a number of samples from the remaining 8 cities had objectionable taste as detailed in Table 5.2. Whereas in year 2003, a general trend of shift in objectionable samples has been observed to other cities where there were found no objectionable sample last year (2002). All collected samples have unobjectionable taste in Islamabad, Gujranwala, Lahore, Faisalabad, Bahawalpur, Multan, Rawalpindi, Sialkot, Quetta, Ziarat, Mangora, Mardan, and Peshawar. In the remaining 8 cities, objectionable taste of samples has been reported (Table 5.2). It is pointed out that the taste results also depend a lot on individual who tasted the samples.

Table 5.2: Summary of Objectionable Samples for Taste

S. #	City Name	% Samples found Objectionable	
		2002	2003
1	Bahawalpur	4.0	0
2	Faisalabad	29	0
3	Gujranwala	14	0
4	Sheikhpura	0	9
5	Kasur	10	10
6	Hyderabad	27	40
7	Mardan	8	0
8	Peshawar	8	0
9	Karachi	0	32
10	Sukkur	0	42
11	Khuzdar	0	13
12	Loralai	0	9

5.1.6 Turbidity

Turbidity is caused by the scattering of light in all directions due to un-dissolved substances. The turbidity of water is of interest for two main reasons, first, it is an important parameter in water treatment process to calculate the quantity of coagulants, and secondly it gives an estimate of un-dissolved substances. In year 2002, all water samples from Faisalabad, Kasur, Lahore, Sheikhpura,

Sialkot and Mangora were found within WHO guidelines in respect of turbidity (5 NTU). Whereas for the remaining 15 cities, water samples exceeded the WHO guidelines. For some cities, the turbidity values for analysed samples are much higher than 5 NTU such as Rawalpindi, Karachi, Sukkur, and Hydrerabad.

In year, 2003, all water samples from Islamabad, Rawalpindi, Lahore, Faisalabad, Sialkot, Peshawar, Mardan and Mangora were within WHO guidelines. However, turbidity exceeded the permissible limit for the remaining 13 cities. Further increase in percentage of samples exceeding the WHO guidelines has been observed in most of the cases (Figure 5.2). Locations of sites exceeding WHO guidelines in respect of turbidity are given in Table 5.3 which confirm the problem of turbidity at these sites. Although some changes in the turbidity level has been observed between two phases of monitoirng (year 2002 and 2003) however in most of the cases the appropriate reasons could not be identified except at Commercial Area, Satellite Town, Bahawalpur and Hotel Sukkur Inn, Clock Tower, Sukkur which were mainly due to change of water sampling source.

Table 5.3: Locations Where Turbidity Exceeded WHO Guidelines

Location	Turb (NTU)		Location	Turb (NTU)	
	2002	2003		2002	2003
Basti Nayan, Bahawalpur	36	11	Kafe Gulshin, Mani Stop, Karachi	9	37
BWP Victorial Hospital, Bahawalpur	9	3	Masjid Rabani, Mango Pir Road, Karachi	14	40
Commercial Area, S. Town, Bahawalpur	45	1.8	S.U.M Hospital., Shah Faisal Colony-3, Karachi	15	12
Masjid Hasnain Rame Oatak, Bahawalpur	11	14	Masjid, Golimar Road, Sukkur	140	134
Faiz Madina Masjid, Bus Stand, Gujrat	48	45	Rahmania Masjid, Pathan Colony, Sukkur	154	118
Jamia School, Baghdad Colony, Gujrat	19	15	Jamai Masjid, Police Line, Sukkur	110	43
Chah Keemay Wala Opp. B.Z. Univ., Multan	9	8	Dar-Ul-Uloom, Nimash Ground, Sukkur	150	658
Chitti Tanki, Saidpur Rd. Rawalpindi	36	-	Hotel Sukkur Inn, Clock Tower, Sukkur	20	0
T. Well Chaklala R. Station, Rawalpindi	250	0.2	Mustafa-I-Masajid, Nusrat Colony-5, Sukkur	60	44
K.B Fed. Police Station, Hyderabad	160	86	Mosque Near Mukhtiar Kar Office, Sukkur	11	33
City Water Supply Tank Kotri, Hyderabad	60	254	Tajweed-ul-Quran Katan, Khuzdar	13	381
Hussain abad Pacca Tank HDA-8, Hyderabad	63	909	Torkhezai Delay Action Dam, Loralai	966	496
B.I.S.E Hyderabad	11	24	Railway Housing Society, Quetta	45	0
Tayab Masjid Unit-12 L.abad, Hyderabad	12	18	Gugrai Karez Near Kechi Beg, Quetta	36	31
New Wahdat Col., Dasimabad, Hyderabad	24	17	Gawalmandi Chowk, Quetta	96	0
Prit Abad Govt. Hospital, Hyderabad	135	50	Mosque Haji Ghaffar, K. Ahmed Zai, Quetta	60	299
Custom Post Office Pocket Colony, Hyderabad	95	142	Cheena Karez, Ziarat	11	30
Khanpur Rd. Locoshed R. Coly, Hyderabad	31	99	Kwas Water Supply Scheme, Ziarat	21	1
Tando Jehanian Def. Society, Hyderabad	8	7			

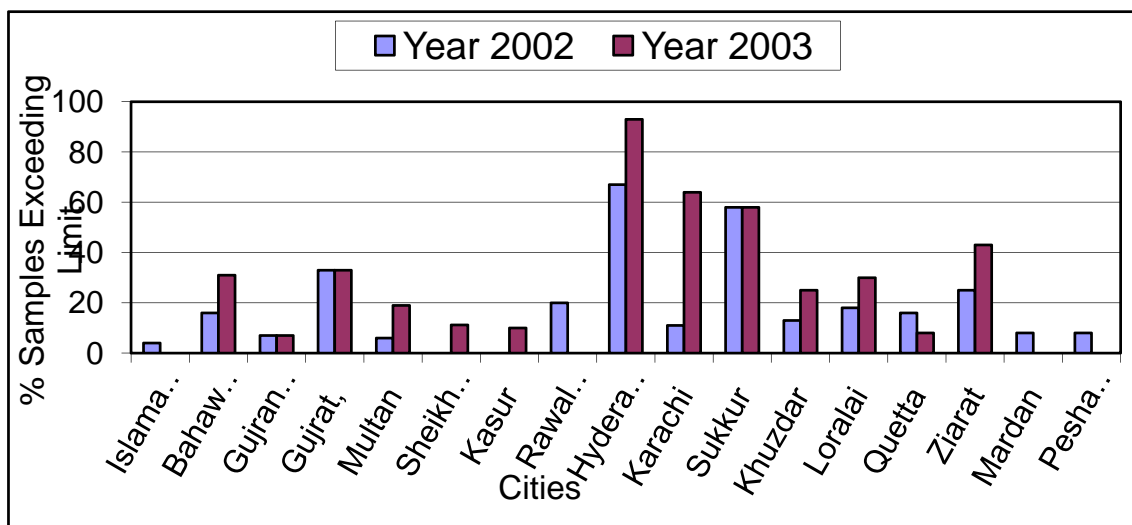


Figure 5.2: Trend of Turbidity in Monitored Cities

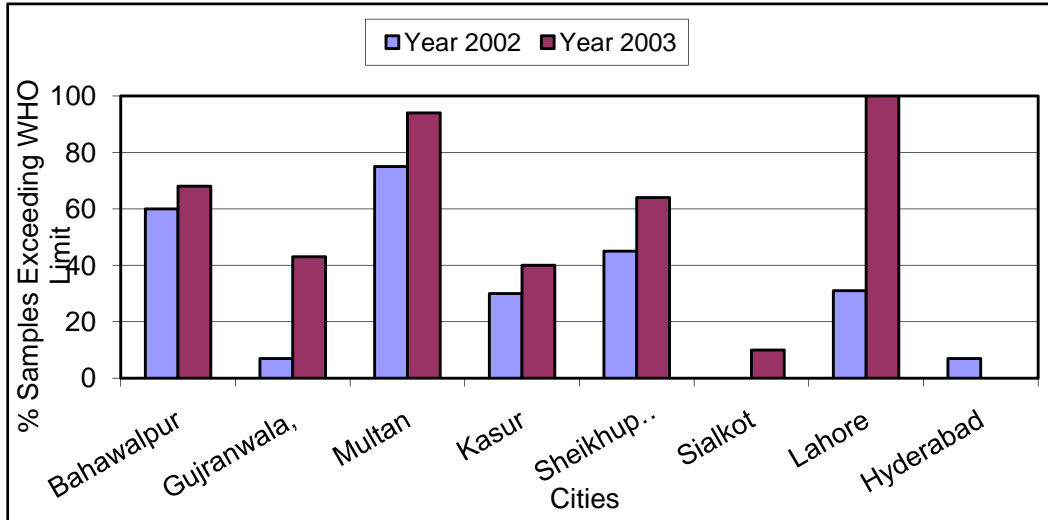
5.2 Chemical Quality

The chemical quality of collected water samples was analyzed for 76 chemical water quality parameters in the laboratories of PCRWR. Water samples from all cities were analysed with respect to guidelines defined by WHO from health point of view. Where not available, other appropriate guidelines including PSI, Canadian Standards etc. were followed. WHO and PSI have not set up guideline values for alkalinity, bicarbonate, carbonate and calcium, however, the Kingdom of Saudi Arabia has documented 75 mg/l as guideline value for calcium. The detailed results are given in Annexures II-1(b) to II-21 (b) and III-1(b) to III-21(b) for important parameters for health whereas results for other parameters are given in Annexures-IV. Significant water quality parameters of common interest are discussed in the following sections:

5.2.1 Arsenic

Arsenic is a non-metallic constituent, present naturally in groundwater due to some minerals and rocks. It has no taste or odor in water. Arsenic is poisonous and severe toxicity has been reported after ingestion of only 100 mg or 100,000 µg/l of the element. Chronic toxicity can result from a build up of lower intakes. Arsenic is not geologically uncommon and occurs in natural water as arsenate and arsenite. Additionally, arsenic may occur from industrial discharge or insecticide application. Results of analysis in year 2002 showed that 60% water samples from Bahawalpur, 7% from Gujranwala, 30% from Kasur, 31% from Lahore, 75% from Multan, 45% from Sheikhupura and 7% from Hyderabad were unsafe due to the contents exceeding the WHO limits. The other cities have arsenic value within permissible limits.

In year 2003 the analysis of collected water samples have shown that 68% water samples from Bahawalpur, 43% from Gujranwala, 40% from Kasur, 100% from Lahore, 94% from Multan, 64% from Sheikhpura and 10% from Sialkot were unsafe due to the contents exceeding the WHO limits. This indicates that the problem of arsenic persists in these cities, and in most of the cases percentage of samples exceeding WHO limit increased as evident from Figure 5.3. The locations where arsenic



exceeds safe limits are given in Table 5.4 where the water sources were mainly tubewells and hand pumps. The comparison of two years data showed general trend of increase in arsenic level in water samples analysed during Phase-II as compared to Phase-I. Any appropriate reason for increase of arsenic may not be identified at this level however in few cases such as Commercial Area, Satellite Town, Bahawalpur and Ch. Med. St, Basti Khudadad, Multan, change in arsenic level has been found due to change in location of sampling source to nearby areas.

Figure 5.3: Cities Exceeding WHO Permissible Limit for Arsenic

Table 5.4: Locations with Arsenic Contents Exceeding WHO Guidelines

Location	As (ppb)		Location	As (ppb)	
	2002	2003		2002	2003
Sutlej Hotel, Bahawalpur	50	76	PCSIR Housing Society, Lahore	20	29
Madrasa, Abbasi Town, Bahawalpur	100	54	LDA Flats Opp. Faisal Town, Lahore	20	23
Madrasa Islampura, Bahawalpur	25	33	Punjab Co-oper. Hous. Soc., Lahore	25	29
Al-Haq Cotton Fac., Bahawalpur	30	52	Chah Keemay Opp. BZU., Multan	40	40
Railway Station, Bahawalpur	40	53	B.Z. Univ., Multan	50	67
Municipal Corp., Bahawalpur	40	52	Punjab Police Line, Multan	40	53
Cooperative Office, Bahawalpur	50	66	Masjid Bilal, Tariqabad, Multan	70	55
Gulzar Saddique Ground, Bahawalpur	30	46	Well-9, Pak Arab Fer. Corp., Multan	40	66
Pump-1, Victorial Hosp., Bahawalpur	40	51	WAPDA, Piran Ghaib, Multan	30	34
One Unit Colony, Bahawalpur	50	53.2	Rukan Alam Coly, G Block, Multan	20	33
Commercial Area, Satellite Town, Bahawalpur	30	1.3	Nishter Hospital, Multan	80	76
Fisheries Department, Bahawalpur	20	44	Cantt Board, Metro Plaza, Multan	60	53
B.I.S.E. Bahawalpur	50	40	Ch. Med. St, Basti Khudadad, Multan	50	73

Pump-16, Cantt. Area, Bahawalpur	50	88	Munir Hotel Solkex Fact., Multan	50	50
Green Town, Bahawalpur	50	40	Ismail Text. Mills Ltd., Multan	70	70
Rehmanpura, Gujranwala	20	38	Nati Pura, Tubewell-12, Sheikhpura	100	53
Chowk Shahedan, Kasur	25	14	T.Well 14, Qadirabad, Sheikhpura	50	40
Kot Mulvi Qadeer, Kasur	15	11	T.Well 15, Bhikhi Rd., Sheikhpura	25	36
Basti Barat Shah, Kasur	15	12	D.H.Q. Hospital, Sheikhpura	40	44
Ali Park, Fort Road, Lahore	20	51	Live Stock Trg. Cen, Sheikhpura	40	40
Goal Bagh, Wahdat Coly, Lahore	30	35	Near Bachal Bhatti Goth, Hyderabad	200	9.2

The maximum arsenic was found up to the range of 100 and 200 ppb in the Punjab and Sindh respectively. The water of all monitoring places of NWFP and Balochistan provinces are within safe limits. PCRWR has also undertaken a program of field-testing for arsenic in drinking water in the rural areas of Pakistan (four provinces) in collaboration with UNICEF. According to their findings, water samples from rural areas of Rahim Yar Khan, Bahawalpur, D.G Khan, Rajanpur, Layyah, Muzaffargarh, Jhang, Toba Tek Singh and Multan in the Punjab and Dadu, Ghotki, Khairpur, Mirpur Khas, Nawabshah and Shikarpur in Sindh were found contaminated with arsenic. The overall arsenic situation in the country (province wise) is categorized into three different ranges and tabulated in Table 5.5.

Table 5.5: Number of Samples Containing Arsenic (ppb) in Pakistan

Sr. #	Province	City	No. of Samples		Number of Samples with Range					
					As (0-10ppb)		As (10-50ppb)		As (>50ppb)	
			2002	2003	2002	2003	2002	2003	2002	2003
1	Capital Territory	Islamabad	27	27	27	27	-	-	-	-
2	Balochistan	Loralai	11	10	11	10	-	-	-	-
3		Quetta	38	38	38	38	-	-	-	-
4		Ziarat	8	8	8	8	-	-	-	-
5		Khuzdar	8	8	8	8	-	-	-	-
6	NWFP	Mangora	10	9	10	9	-	-	-	-
7		Mardan	12	12	12	12	-	-	-	-
8		Peshawar	13	13	13	13	-	-	-	-
9	Punjab	Faisalabad	14	13	14	13	-	-	-	-
10		Gujrat	9	9	9	9	-	-	-	-
11		Rawalpindi	15	15	15	15	-	-	-	-
12		Sialkot	10	10	10	9	0	1	-	-
13		Bahawalpur	25	25	10	8	14	8	1	9
14		Gujranwala	14	14	13	8	1	6	-	-
15		Kasur	10	10	7	6	3	4	-	-
16		Lahore	16	16	11	0	5	15	0	1
17		Multan	16	16	4	1	8	7	4	8
18		Sheikhpura	11	11	6	4	4	6	1	1
19	Sindh	Karachi	28	26	28	26	-	-	-	-
20		Sukkur	12	12	12	12	-	-	-	-
21		Hyderabad	15	15	15	15	-	-	1	0

5.2.2 Chloride

Chloride is widely available in the form of NaCl, KCl, CaCl₂ salts. It is also discharged through effluents of chemical industries, oil well operation, sewage discharge and irrigation leachates.

Daily dietary intake for adults is 9 mg/kg of body weight. Total obligatory loss of chloride per day is approximately 530 mg. About 88% of chloride in the body is extra cellular. A normal 70 kg human body contains about 81.7 gram of chloride and 40 litre of water. Taste threshold levels for NaCl, KCl, and CaCl₂ in water are 210, 310, 222 mg/l respectively. Average intake from drinking water is approximately 100 mg per day. In the first year of sampling, all samples collected from Islamabad, Gujranwala, Gujrat, Kasur, Lahore, Multan, Rawalpindi, Sheikhupura, Hyderabad, Sukkur, Khuzdar, Loralai, Ziarat, Mangora, Mardan, and Peshawar were found within the limit of 250 mg/l of chloride recommended by WHO. However, for other 5 cities few samples did not meet the safe limit levels as shown in Table 5.6.

In second year of sampling, almost similar results have been observed. All analysed samples did not exceed WHO limit for Islamabad, Gujranwala, Gujrat, Kasur, Lahore, Multan, Rawalpindi, Sheikhupura, Hyderabad, Sukkur, Khuzdar, Loralai, Ziarat, Mangora, Mardan, and Peshawar were found within the limit of 250 mg/l of chloride recommended by WHO. However for the same cities as indicated in Table 5.6, few samples exceeded safe limit.

Table 5.6: Cities with Samples Exceeding Safe Limit for Chloride

Cities	Total Samples	No. of Samples Exceeding WHO Limits	
		Year 2002	Year 2003
Bahawalpur	25	1	0
Faisalabad	16	1	5
Sialkot	14	5	1
Karachi	10	1	1
Quetta	38	1	1

5.2.3 Chromium

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. Samples from all cities were found within safe limits for Chromium for both years of sample collection i.e. 2002 and 2003.

5.2.4 Fluoride

Traces of fluoride occur in many water samples and higher concentration is often associated with underground sources that may be present up to 10 mg/l. Fluoride in water results in a substantial reduction of dental carries in both children and adults. High doses of fluoride are acutely toxic to human due to pathological changes in the body. High exposure causes acute effects like crippling, renal disorder and also effecting thyroid in human beings. High concentration of fluoride in water may cause mottling of teeth and skeletal fluorosis. Areas having optimal level of fluoride in water cause dental fluorosis. WHO has recommended 1.5 mg/l threshold value for drinking water. In year 2002, all samples from Islamabad, Gujranwala, Gujrat, Lahore, Multan, Rawalpindi, Sheikhupura, Sialkot, Hyderabad, Sukkur, Khuzdar, Mangora, Mardan and Peshawar were found within the safe limits. However, 4% samples from Bahawalpur, 7% from Faisalabad, 30% from Kasur, 7% from Karachi, 55% from Loralai, 42% from Quetta, and 13% from Ziarat showed excessive fluoride concentration.

During Phase-II of sample collection, the analysis of results showed almost the same trend as observed in year 2002 that all samples from Islamabad, Gujranwala, Gujrat, Lahore, Multan, Rawalpindi, Sheikhupura, Sialkot, Hyderabad, Ziarat, Khuzdar, Mangora, Mardan and Peshawar were found within the safe limits. Whereas 4% samples from Bahawalpur, 8% from Faisalabad, 20% from

Kasur, 8% from Karachi, 8% from Sukkur, 10% from Loralai, 29% from Quetta, showed excessive fluoride concentration. Table 5.7 shows sites having excessive fluoride concentrations (more than 1.5 mg/l). The comparison of two years data showed decreasing trend in fluoride level in later year as compared to results in Phase-I.

It is concluded that severe problem of fluoride lies in three cities out of twenty-one cities *i.e.* Kasur, Loralai and Quetta. However, in isolated places of Bahawalpur, Faisalabad Karachi, and Ziarat, the presence of fluoride was observed.

Table 5.7: Locations with Excessive Presence of Fluoride

Location	Source	Fluoride Level		Location	Source	Fluoride Level	
		2002	2003			2002	2003
G.H. School Hamalton, Bahawalpur	H.P	2.8	2.8	P. Station Ayub Stadium, Quetta	W.S	2.0	0.8
Adda Chak 7JB, Faisalabad	H.P	1.9	0.8	Bolan Medical Complex, Quetta	W.S	2.0	1.6
Chaki Piyarolal, Kasur	Inj.P	1.7	1.63	Gugrai Karez Near Kechi, Quetta	Karez	2.7	1.8
Chowk Shahedan K.M. Khan, Kasur	H.P	2.2	1.8	Lourds Hotel, Quetta	T.W	1.7	0.5
Kot Osman Khan, Kasur	Inj. P	1.7	1.3	Gawalmandi Chowk, Quetta	T.W	3.0	1.3
Masjid Saddique-Akbar Churanghi, Karachi	H.P	2.0	0.4	Khanwari Rd. near Hosp. Quetta	H.P	2.0	2.3
Muhammadi Masjid, Khokhrapar, Karachi	H.P	1.8	1.8	Block-5, Satellite Town, Quetta	T.W	1.7	1.5
Rodlin Village Quetta Road, Loralai	Well	1.8	0.9	Taro Chowk Reservoir, Quetta	W.S	1.9	1.3
Tank Quetta Road, Loralai	W.S	1.6	0.9	Forest Park, Sabzal Rd., Quetta	T.W	2.0	-
P.H.E Pathan Kot, Loralai	T.W	1.7	0.9	Ghaffar Mosque, K A Zai, Quetta	Well	2.0	1.9
OHSR Baloch Colony, Loralai	W.S	1.9	0.8	Irrigation Colony, Quetta	T.W	2.0	2.2
T&T Centre , Loralai	Well	1.9	0.9	Killi Habib, Quetta	T.W	2.3	2.0
Zangi Village, Loralai	Well	1.7	-	Masjid Podgali Chowk, Quetta	Well	3.0	2.3
Agri. Deptt., Rani Bagh, Quetta	T.W	2.8	2.3	Zandra Karez, Ziarat	Karez	2.4	0.5
Railway Housing Society, Quetta	T.W	3.0	1.6				

5.2.5 Hardness

The possible sources of hardness are calcium and magnesium which are present in many minerals like limestone including chalk (CaCO₃), some industrial products and common constituents of food. A minor contribution to the total hardness of water is made by polyvalent ions as zinc, manganese, aluminum, strontium, barium, and irons. Extremely hard water might lead to an increased incidence of utolithiasis. Hard water may possess laxative properties due to association of magnesium with the sulfate ion. A number of studies in various part of the world have demonstrated that there was statistically significant negative correlation between water hardness and cardiovascular disease. However, a variety of other diseases were correlated with hardness of water. These included nervous system defects, anencephaly, prenatal mortality and various types of cancer. In areas with very hard

water, household pipes become choked with deposited material. Hard water also deposits incrustations on kitchen utensils as well as increases soap consumption. Such water can thus be both a nuisance and an economic burden to the consumer. A hardness level of about 100 mg of CaCO₃ per litre provides an acceptable balance between corrosion and problem of incrustation.

The average value of hardness in water samples of all cities is 271 mg/l as CaCO₃, which is within WHO guideline value of 500 mg/l during first year of sample collection and analysis. All water samples from Islamabad, Gujranwala, Gujrat, Kasur, Lahore, Multan, Rawalpindi, Sialkot, Sukkur, Khuzdar and Mangora were found within safe limit. However, 12% water samples from Bahawalpur, 21% from Faisalabad, 9% from Sheikhupura, 6% from Hyderabad, 4% from Karachi, 9% from Loralai, 13% from Quetta, 13% from Ziarat, 8% from Mardan, and 8% from Peshawar exceeded the limit. The range of values for some cities are shown in Figure 5.4.

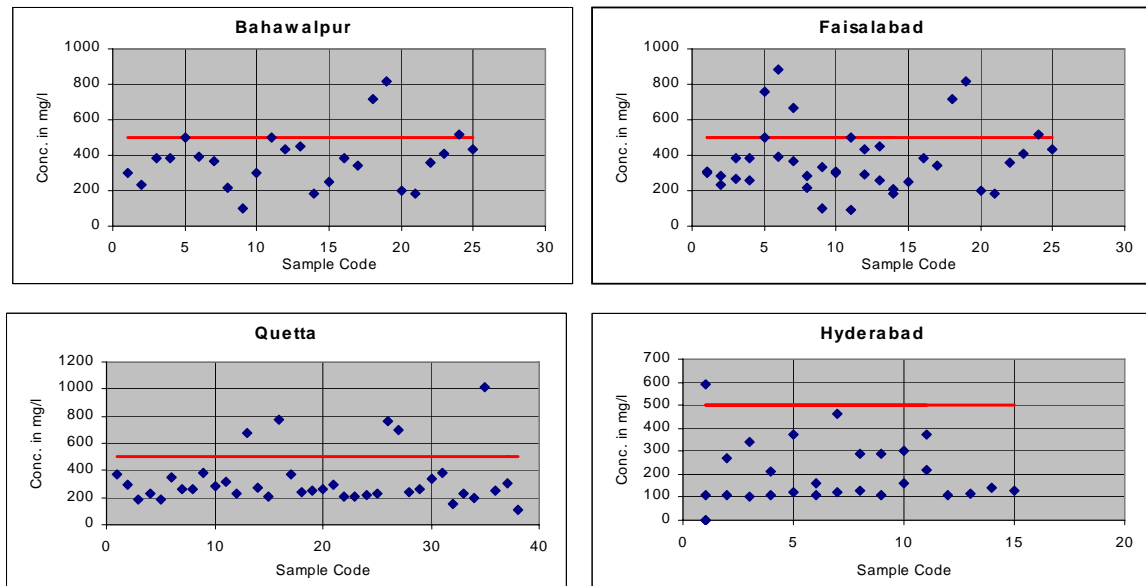


Figure 5.4: Hardness Concentration Exceeding Guidelines in Surveyed Cities during Year 2002

In year 2003, the results from collected samples were more or less same (Figure 5.5). All water samples from Islamabad, Gujranwala, Gujrat, Kasur, Lahore, Multan, Rawalpindi, Sukkur, Khuzdar, Mangora Mardan and Hyderabad were found within safe limit. However, 8% water samples from Bahawalpur, 23% from Faisalabad, 10% from Sialkot, 9% from Sheikhupura, 8% from Sukkur, 4% from Karachi, 8% from Peshawar, 8% from Quetta, 13 from Ziarat, 10% from Loralai exceeded the limit. The showed a similar trend in samples exceeding the limit from these cities during both Phases of sample collection thus further confirming the problem of harness in drinking water of these cities.

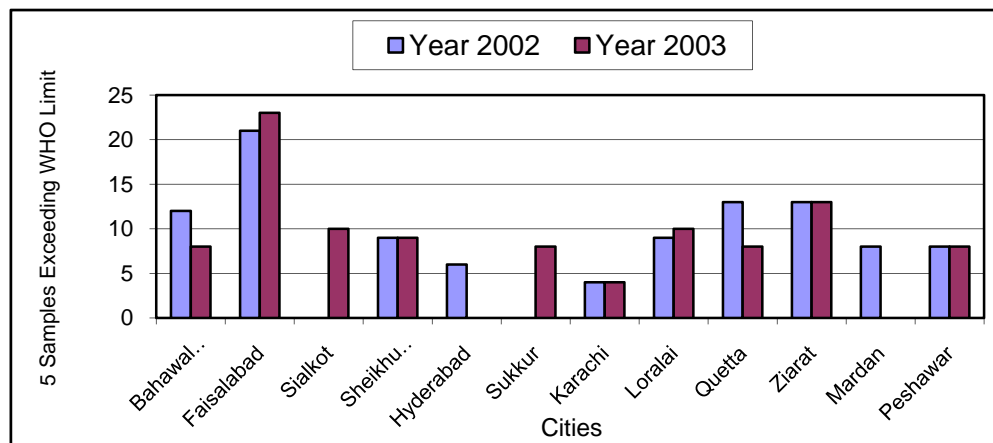


Figure 5.5: Cities exceeding WHO Limit for Hardness

5.2.6 Iron

Iron is an essential element in human nutrition and is generally present in the ferric (III) state. Its presence in natural waters can be attributed to the dissolution of rocks, minerals, acid mine drainage, iron related industries and can be present in the form of rust that precipitated as insoluble ferric hydro-oxide in water. The Minimum daily requirements of iron vary from 7 to 14 mg depending upon age and sex. Excessive iron in water makes the taste unpalatable and also stains laundry and plumbing fixtures. WHO has recommended 0.3 mg/l as guideline values for iron. In Year 2002, all samples collected from urban areas of Faisalabad, Gujranwala, Kasur, Sheikhpura, Sialkot, Khuzdar, Ziarat, Mangora, Mardan and Peshawar were found within safe limit. However, 4% water samples from Islamabad, 60% from Bahawalpur, 33% from Gujrat, 6% from Lahore, 31% from Multan, 7% from Rawalpindi, and 60% from Hyderabad, 21% from Karachi, 75% from Sukkur, 36% from Loralai, and 8% from Quetta exceeded WHO guidelines. The possible source of iron in most places may be rusting. The samples exceeding safe limit for cities are shown in Figure 5.6.

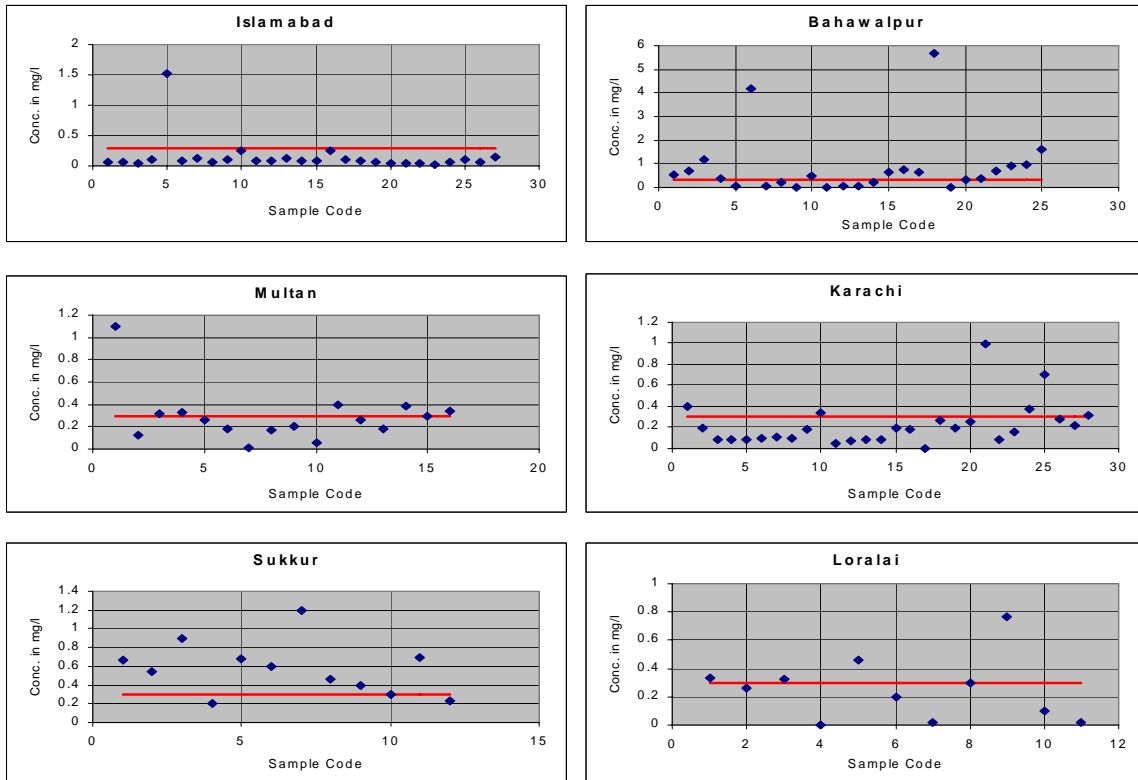


Figure 5.6: Iron Concentration Exceeding Limit in Surveyed Cities (Year 2002)

In Year 2003, all samples collected from urban areas of Faisalabad, Gujranwala, Lahore, Sheikhpura, Khuzdar, Ziarat, Quetta, Loralai, Mangora, Peshawar, Karachi, were found within safe limit. However, 11% water samples from Islamabad, 4% from Bahawalpur, 11% from Gujrat, 30% from Sialkot, 10% from Kasur, 19% from Multan, 7% from Rawalpindi, and 7% from Hyderabad, 17% from Sukkur, and, 13% from Kkuzdar, and 8% from Mardan exceeded WHO guidelines. In general, decrease in percentage of samples exceeding permissible limit has been noted for the second year of sampling with respect to iron concentration in water (Figure 5.7), the reasons however are required to be identified for this significant change.

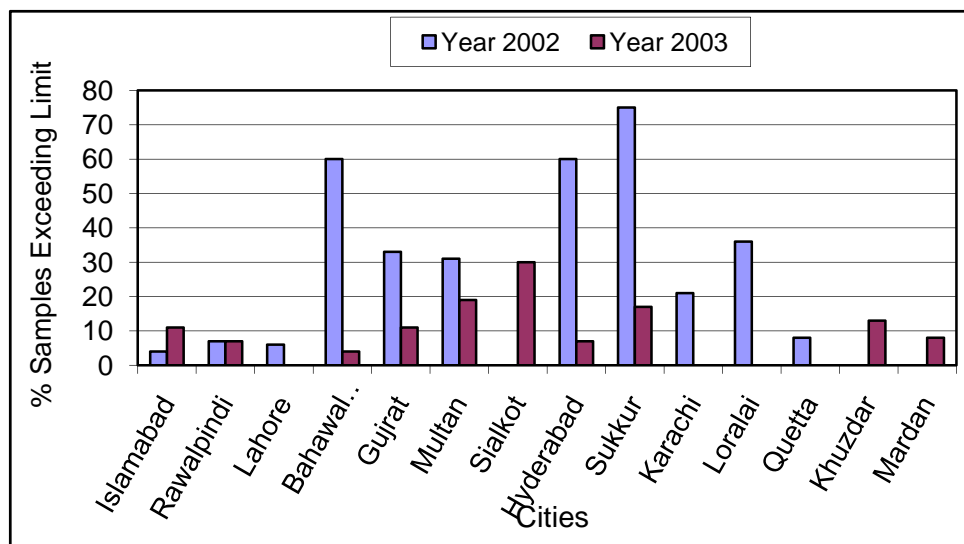


Figure 5.7: Comparison of Cities Exceeding Safe Limit for Iron

5.2.7 Lead

The main sources of lead are paints, lead pipes, wastes of batteries manufacturing industry and leaded gasoline. The reported health effects are mental retardation, constipation, anemia, tiredness, irritability, liver and kidney damage, abnormalities in fertility and pregnancy and effects on central nervous system particularly in children. During first year of project, only fourteen samples were analyzed for lead concentration by Dithyzone method for cities of Islamabad and Rawalpindi due to risky method regarding health point of view, the results of which are given in Table 5.8. Now PCRWR laboratories have been equipped with Atomic Absorption Spectrophotometer (AA) and Inductive Coupled Plasma Spectrophotometer (ICP).

Table 5.8: Lead Concentration in the Cities of Islamabad and Rawalpindi in 2002

S. #	S. Code	Location	Source	Conc. ($\mu\text{g/l}$)
1	ISL-01	TW-193, F-6, Islamabad	T.Well	6
2	ISL-03	Noorpur Shahan, Islamabad	W.Sply	14
3	ISL-06	TW Polyclinic Hostel, Islamabad	T.Well	7
4	ISL-10	TW-2, E-8, GE Navy, Islamabad	T.Well	8
5	ISL-23	7 MGR, F-5/2, Islamabad	Reservoir	9
6	ISL-24	Tap water, MoST, D Block, Islamabad	Tap	11
7	ISL-26	H-63, Gomal Rd., E-7, Islamabad	Cistern	9
8	ISL-28	Simly Dam, Islamabad	Dam	8
9	RAW-01	TW-30, Muslim Town, Rawalpindi	T.Well	7
10	RAW-04	Chitti Tanki, Saidpur Rd., Rawalpindi	W.Supply	11
11	RAW-07	TW-25, Military Hospital, Rawalpindi	T.Well	5
12	RAW-10	TW-53, Afshan Colony, Rawalpindi	T.Well	7
13	RAW-13	TW Chaklala Railway Station, Rawalpindi	T.Well	8
14	RAW-15	Bahria Town, Phase-II, St.49, Rawalpindi	T.Well	5

In Phase-II, water samples were analysed for lead concentration. The results of all analysed samples were however found within permissible value of 10 $\mu\text{g/l}$ except one sample

for Rawalpindi with concentration of 13.69 $\mu\text{g/l}$ and one for Gujranwala with 28.5 $\mu\text{g/l}$. The locations of these samples are given in Table 5.9.

Table 5.9: Samples Exceeding Guideline Value for Lead during Phase-II (2003)

S.#.	Location	Lead ($\mu\text{g/l}$)
1	T. Well-148 Banni Thana, Rawalpindi	13.69
2	Govt. Girls High School Sarfraz Colony, Gujranwala	28.50

5.2.8 Magnesium

Magnesium is a silver white metal, malleable and ductile when heated. Magnesium occurs extensively in the earth crust, ranking 8th among the chemical elements in terrestrial abundance. An average composition of igneous rocks contains 2.09% magnesium. Of the elements present in seawater, magnesium ranks 5th with an estimated 6,125,000 tons of magnesium per cubic mile (1,23,000 metric tons per cubic kilometre) of seawater, its content exceeded only by hydrogen, oxygen, sodium and chlorine. Magnesium is a constituent of over 150 minerals and is an essential element in human, animal and plant nutrition. Magnesium intake from 3.6 to 4.2 mg/kg of body weight is believed to be adequate to maintain magnesium balance, which is closely regulated by the kidneys. An excess of magnesium in the diet is seldom harmful, as it is generally excreted promptly in feces. High concentrations of magnesium sulfate in drinking water have a cathartic effect on new users, but a tolerance is soon acquired. Excessive magnesium in body tissues and extra cellular fluids occurs only as a result of severe kidney malfunction. The PSI and Canadian standards have recommended a maximum level of magnesium of 150 mg/liter.

All samples collected from the urban areas of project cities during year 2002 were found within safe limit in respect of magnesium except for Karachi and Quetta. In both of the cities, one sample each was found with high magnesium contents of 170 and 186 mg/l, respectively as shown in Figure 5.8. The same results have been found in second year (2003) of water sample analysis although with slight variation in magnesium contents. Similarly, one sample exceeded the permissible limit from each Karachi and Quetta city with contents of 165 and 185 mg/l, respectively which are almost same as observed during Phase-I.

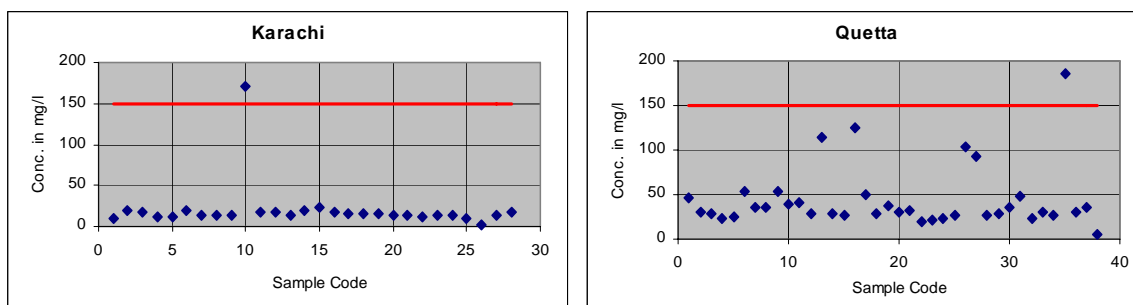


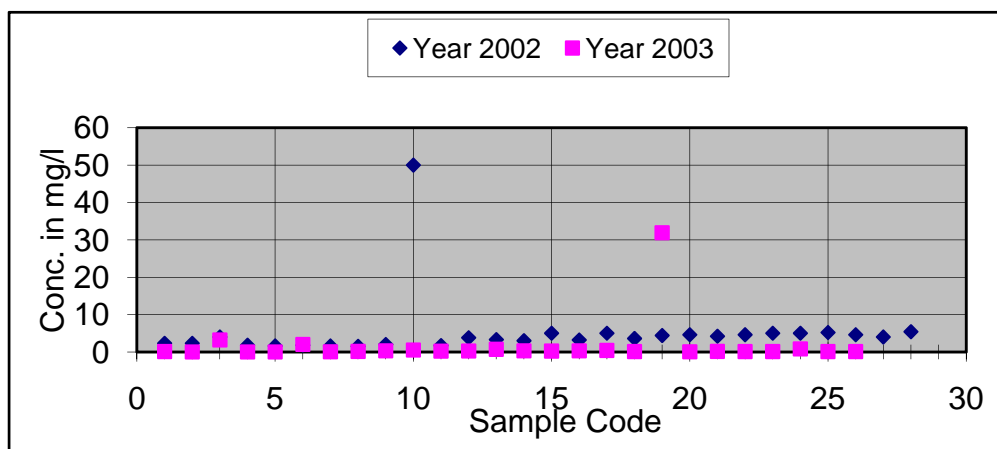
Figure 5.8: Magnesium Concentration Exceeding Guidelines in Surveyed Cities

5.2.9 Nitrate (N)

The fertilizer use, decayed vegetable and animal matter, domestic effluents, sewage sludge disposal to land, industrial discharge, leachate from refuse dumps, and atmospheric washout contribute Nitrate (N) in water. Generally, the higher levels of nitrate (N) are found in ground water. High levels of Nitrate (N) may be responsible for cases of infantile methaemoglobinaemia (30-40% leads to

anoxia), and death. Infants may suffer from gastro-intestinal disturbances. Pregnant women are at greater risk due to Nitrate (N). Nitrate (N) concentration in all cities during year 2002 was found within WHO limits of 10 mg/l except in one place at Muhammadi Masjid, H Area, Khokhrapar, Karachi with nitrogen contents of 50 mg/l from a source of hand pump (Figure 5.9). The analysis of water samples from the year 2003 also confirmed the same results. However, one location namely Kafi Nasir, Gulbai Chowk in Karachi showed high contents of Nitrate i.e. 32 mg/l. These results show that in general the quality of drinking water is safe in the monitored cities with respect to nitrate (N).

Figure 5.9: Nitrate (N) Concentration Exceeding Guidelines in Karachi City

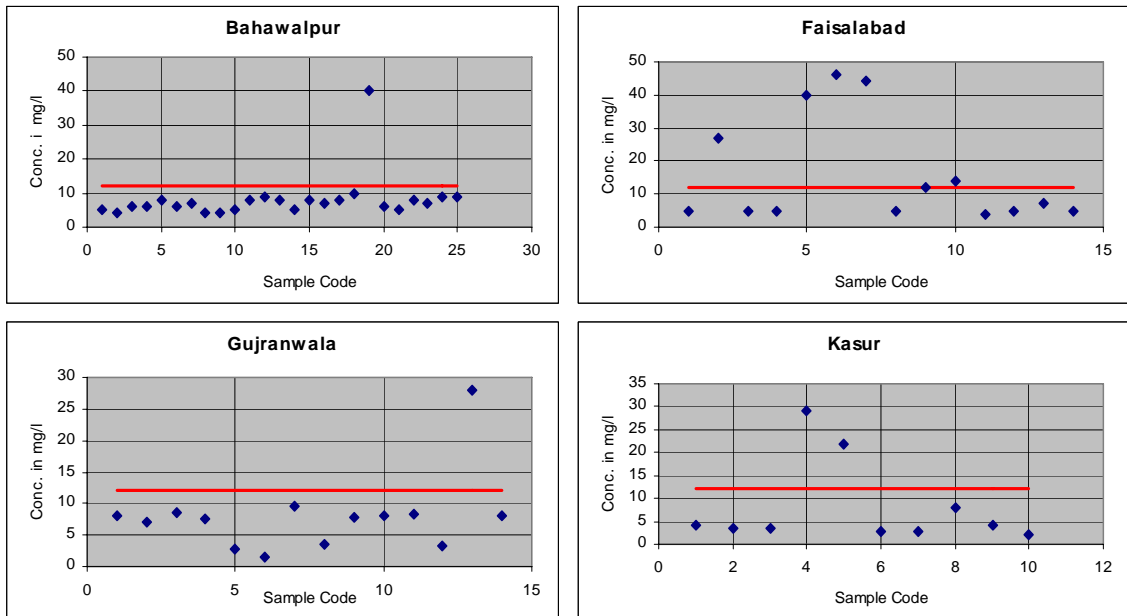


5.2.10 Potassium

Potassium is a silver white metal which can be readily molded and cut by a knife. It oxidizes instantly on exposure to air and reacts with water, yielding potassium hydroxide and hydrogen gas. It is an abundant element, ranking 7th among all the elements in the Earth's crust, 2.59% of which is potassium in combined form. Only oxygen, silicon, aluminum, iron, calcium and sodium are more abundant. Seawater contains 380 parts per million, making potassium 6th most plentiful element in solution, exceeded only by chlorine, sodium, magnesium, sulfur and calcium.

Potassium is essential for all or nearly all forms of life. Potassium plays a major role in biological process and is the principal cation to maintain the osmotic pressure within the cell. Potassium is important for normal muscles, nerve responsiveness, heart rhythm, and intracellular fluid pressure. Therefore, both plants and animals require potassium. Although the total amount of potassium in most soils is usually rather high, the level of available or soluble forms of the element is frequently too low to meet the needs of growing plants. Balance of sodium and potassium is necessary for normal function. Experimental K deficiency in rates results in loss of chloride with hypochloremic acidosis and increase of Na in muscles. In men, disease of gastrointestinal tract, involving loss of secretions through vomiting or diarrhea, may result in serious loss of both sodium and potassium. Trauma, surgery, anoxia, ischemia, shock and any damage to or wasting away of tissues may result in loss of cellular potassium to the extra cellular fluid and plasma. Low extra cellular potassium concentration may cause muscular weakness, changes in cardiac & kidney function, lethargy, and even coma in severe cases.

European Community (EC) has recommended 12 mg/l as guideline value for potassium. In first year of analysis during 2002, water samples from all monitored cities including Islamabad, Lahore, Multan, Rawalpindi, Sheikhpura, Sialkot, Hyderabad, Karachi, Sukkur, Khuzdar, Loralai,



Quetta, Ziarat, Mangora, Mardan and Peshawar were found within safe limit in respect of potassium. However, 4% from Bahawalpur, 36% from Faisalabad, 7% from Gujranwala, 11% from Gujrat, and 20% from Kasur were found with high potassium concentration. The results for some cities are shown in Figure 5.10.

Figure 5.10: Potassium Concentration Exceeding Guidelines in Surveyed Cities in 2002

During year 2003, almost same trend of water samples from all monitored cities was observed as in Phase-I. Out of 21, only four cities including Faisalabad, Gujrat, Kasur and Sukkur, water samples exceeded 46%, 11%, 20% and 8%, respectively limit. The comparison of results from cities exceeding limit during both Phases are given in Table 5.10 which showed general increasing trend of samples exceeding the permissible limit for Potassium.

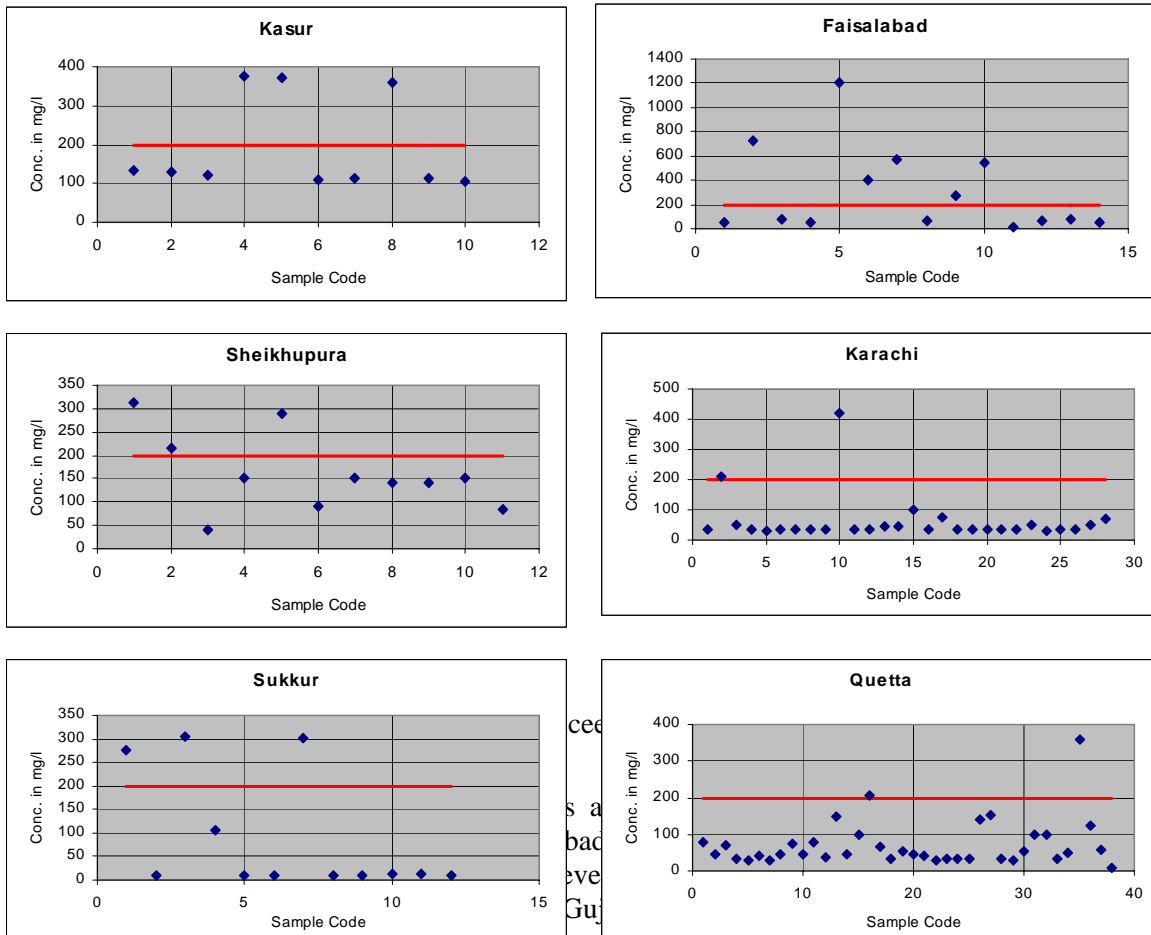
Table 5.10: Percentage of Samples Exceeding Limit in Cities for Potassium

S.No.	Cities	Year 2002	Year 2003
1	Bahawalpur	4	0
2	Faisalabad	36	46
3	Gujranwala	7	11
4	Gujrat	11	20
5	Kasur	20	8

5.2.11 Sodium

Sodium is one of the more abundant elements and is a common constituent of natural water. Surface water contains less sodium whereas relatively higher level of sodium is present in deep groundwater. In general, sodium salts are not acutely toxic substance because of the efficiency with

which mature kidney excretes sodium. Excessive intake of sodium chloride causes vomiting. Acute effects and death have been reported in cases of accidental over dose of sodium chloride in infants. Other effects of excessive intake are hypertension and heart failure. WHO guideline value for this element is 200 mg/l. In year 2002, all water samples from Islamabad, Lahore, Multan, Rawalpindi, Hyderabad, Khuzdar, Loralai, Ziarat, Mangora, Mardan and Peshawar were found within safe limit. However, 8% water samples from Bahawalpur, 43% from Faisalabad, 7% from Gujranwala, 11% from Gujrat, 30% from Kasur, 27% from Sheikhupura, 10% from Sialkot, 7% from Karachi, 25% from Sukkur, and 5% from Quetta exceeded from the safe limits (Figure 5.11).



from Karachi, 17% from Sukkur, and 5% from Quetta exceeded from the safe limits. This shows variation in percentage of samples exceeding permissible limit with respect to results observed in year 2002. The locations with exceeding limit in the monitored cities are shown in Table 5.11 for both Phases of sampling. The results confirm problem of sodium presence at these sites although reduction in concentration has been generally observed during second phase of sampling yet exceeding the permissible limit. However significant change in sodium contents at the location of Satellite Town Bahawalpur during year 2003 is mainly due to change of sampling source i.e. a nearby tubewell located at 80 ft apart from the one sampled in year 2002.

Table 5.11: Sites with Sodium Exceeding WHO Guidelines

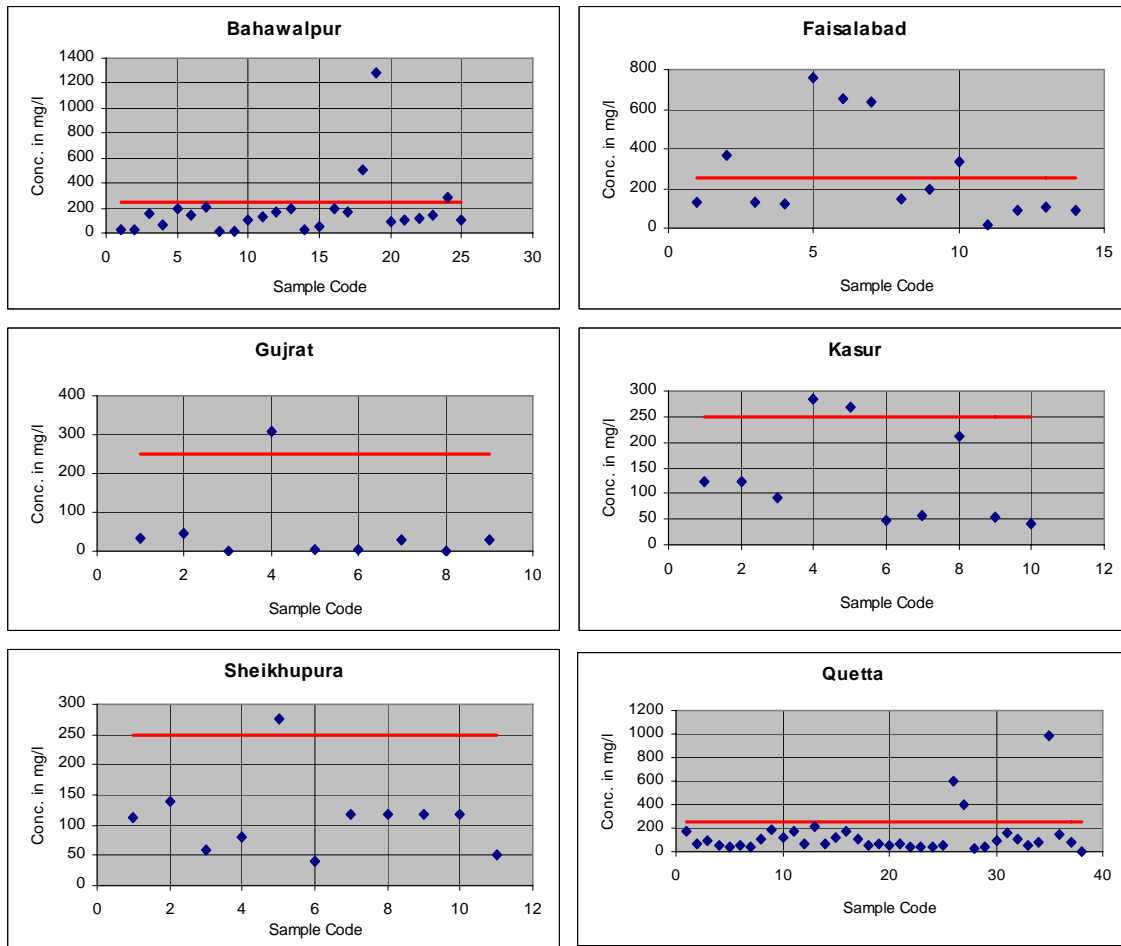
Sr #	Location	Source	Sodium (mg/l)
------	----------	--------	---------------

			Year 2002	Year 2003
1	Satellite Town, Bahawalpur	T.W	280	30
2	GH School Hamalton, Bahawalpur	H.P	760	710
3	Adda Chak 7JB, Faisalabad	H.P	730	630
4	Kot Osman Khan, Kasur	Inj. P	360	360
5	Ghazi Manara, Sheikhpura	H.P	312	300
6	Nati Pura, Sheikhpura	T.W	216	205
7	GMS Samanabad, Faisalabad	Inj. P	1200	1020
8	Gen. Store, Goal Chowk, Faisalabad	Inj. P	400	310
9	N.College of C.S, Faisalabad	Inj. P	575	440
10	Agri. Univ., Faisalabad	Inj. P	275	200
11	Nishatabad, Faisalabad	D. P	550	780
12	GGH Sch. Sarfraz Col, Gujranwala.	D. P	230	224
13	Masjid, Bus Stand, Gujrat	H.P	330	310
14	Chaki Piyarolal, Kasur	Inj. P	375	375
15	Chowk Shahedan, Kasur	H.P	370	360
16	Filling St. F.abad Rd., Sheikhpura	H.P	290	275
17	Near Ahmadia School, Sialkot	T.W	270	180
18	Masjid Saddique-Akbar Churangi, Karachi	H.P	210	123
19	Muhammadi Masjid, Khokhrapar, Karachi	H.P	422	164
20	Maka Goth, Sukkur	T.W	276	204
21	Mastoi Hotel, Sukkur	Tap	306	275
22	Near Al-Habib Hotel, Sukkur	H.P	302	200
23	Children Hospital, Quetta	H.P	208	148
24	Mohammadi Masjid, Quetta	Well	360	330

5.2.12 Sulfate

Sulfate is found almost universally in natural waters in concentration ranging from a few tenths of a milligram/liter to several thousand mg/l. Its main source is air mass in and around metropolitan areas, and is brought down with rains some times at concentrations greater than 10 mg/l. Metallic sulfides, such as iron pyrites, occur in both igneous and sedimentary rocks, they are oxidized to sulfate by moist oxygen during weathering processes. Some sulfate is formed during oxidative decay of organic method. Sulfate may also enter watercourses through waste discharge, household waste including detergents. Tanneries, steel mills, sulfate pulp mills and textile plants are the important industrial sources of sulfate. Once sulfate has been dissolved in water, it becomes a permanent solute except when it is an aerobically reduced to sulfite and precipitated in sediments, released to the atmosphere as H₂S or incorporated in living organic matter. Most inorganic sulfates are quite soluble except for lead and barium salts. Sulfate is not removed from water by any of the common treatment process.

No adverse health effects have been noted for concentrations of sulfate in water less than about 500 mg/l. The only observed physiologically effect at greater concentrations to more than 1000 mg/l has been the induction of diarrhoea. The taste threshold for sulfate in water is between 300 and



400 mg/l for most persons but some individuals are able to detect as little as 200 mg/l. The WHO has recommended 250 mg/l as guideline values. All samples collected in year 2002 from Islamabad, Gujranwala, Lahore, Multan, Rawalpindi, Hyderabad, Karachi, Sukkur, Khuzdar, Loralai, Ziarat, Mangora, Mardan and Peshawar were found within safe limit. However, 12% water samples from Bahawalpur, 36% from Faisalabad, 11% from Gujrat, 20% from Kasur, 9% from Sheikhupura, 10% from Sialkot and 8 from Quetta exceeded WHO limits (Figure 5.12).

Figure 5.12: Sulfate Concentration Exceeding Guidelines in Surveyed Cities (Year 2002)

In Year 2003, the trend was almost similar. All samples collected from Islamabad, Gujranwala, Gujrat, Lahore, Multan, Rawalpindi, Sialkot, Hyderabad, Karachi, Sukkur, Khuzdar, Loralai, Ziarat, Mangora, Mardan and were found within safe limit. However, 12% water samples from Bahawalpur, 46% from Faisalabad, 20% from Kasur, 9% from Sheikhupura, 8% from Peshawar and 5% from Quetta exceeded WHO limits.

The comparison of status from the cities with samples exceeding WHO guidelines is shown in Figure 5.13. In general, a constant trend has been observed except for few cities such as Gujrat, Sialkot and Quetta where no sample or less samples were observed with respect to sulfate contents in year 2003 as compared to year 2002.

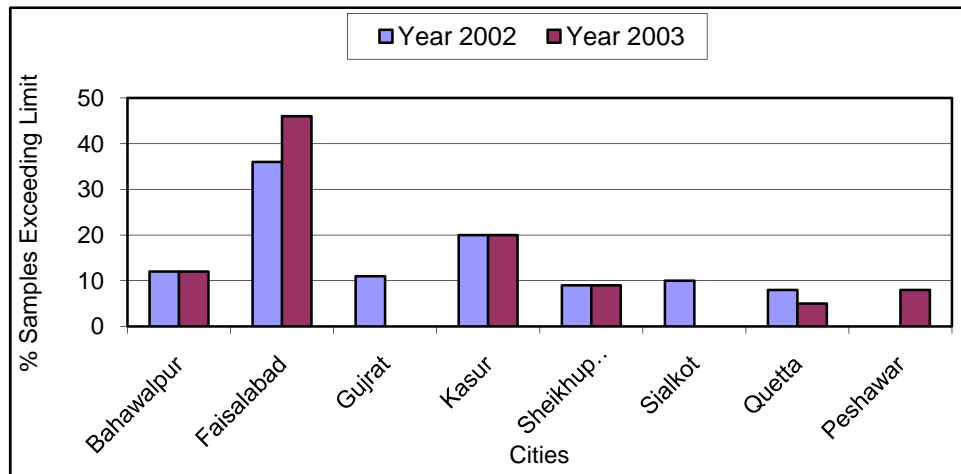


Figure 5.13: Percentage Samples Exceeding WHO Guideline for Sulfate

5.2.13 Total Dissolved Solids (TDS)

The concentration of dissolved solids in water has to be considered for drinking purpose and for many industrial applications. Dissolved solids are those solids capable of passing through a standard filter. In water containing no suspended solids, the dissolved solids are identical to total residue. Bruvold (1967) rated the palatability of drinking water according to total dissolved solids. These levels were as under:

- | | | |
|------|------------------------|--------------|
| i) | Less than 300 mg/l | Excellent |
| ii) | Between 300-600 mg/l | Good |
| iii) | Between 600-900 mg/l | Fair |
| iv) | Between 900-1200 mg/l | Poor |
| v) | Greater than 1200 mg/l | Unacceptable |

Sodium, calcium, magnesium, potassium, (cations), bicarbonates, chloride, sulfate, nitrate (anions) are the main constituents of TDS. There is no evidence of deleterious physiological reactions occurring in person consuming drinking water supplies upto 1000 mg/l. WHO has recommended 1000 mg/l as guideline value for TDS. All samples collected in year 2002 from Islamabad, Lahore, Multan, Hyderabad, Khuzdar, Ziarat, Mangora and Mardan were found within safe limit in respect of TDS. However, 16% water samples from Bahawalpur, 43% from Faisalabad, 7% from Gujranwala, 11% from Gujrat, 30% from Kasur, 7% from Rawalpindi, 18% from Sheikhupura, 10% from Sialkot, 4% from Karachi, 25% from Sukkur, 10% from Loralai, 13% from Quetta, and 8% from Peshawar exceeded WHO limits as shown in Figure 5.14.

In year 2003, no significant difference in the TDS of analysed samples has been observed in all monitored cities as compared with the results of preceding year 2002 except some variation in percentage of samples exceeding permissible limit for few cities (Figure 5.15). All samples collected from Islamabad, Lahore, Multan, Hyderabad, Khuzdar, Ziarat, Mangora and Mardan were found within safe limit in respect of TDS. However, 16% water samples from Bahawalpur, 43% from Faisalabad, 7% from Gujranwala, 11% from Gujrat, 30% from Kasur, 7% from Rawalpindi, 18% from Sheikhupura, 10% from Sialkot, 8% from Karachi, 25% from Sukkur, 10% from Loralai, 8% from Quetta, and 8% from Peshawar exceeded WHO limits.

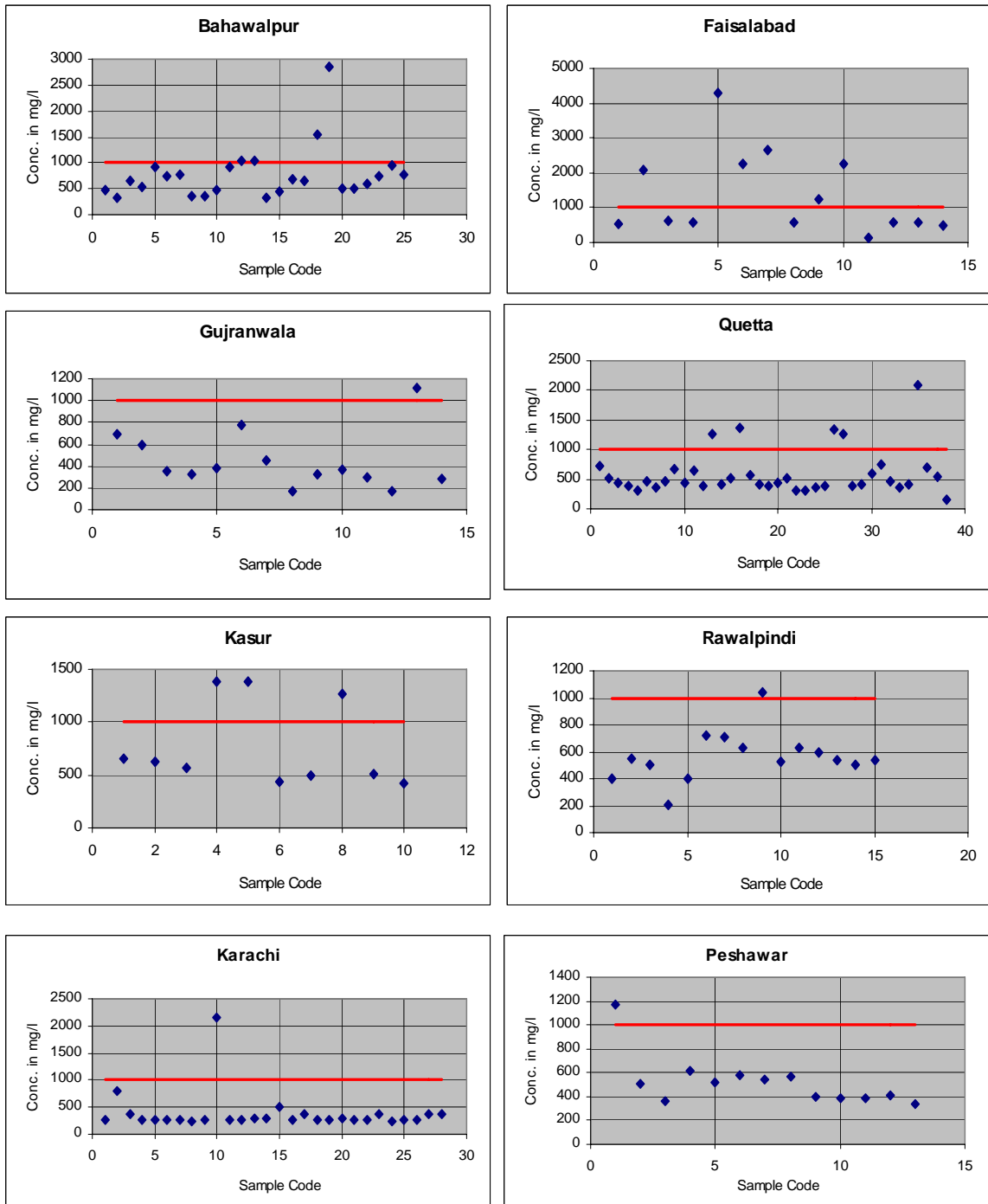


Figure 5.14: TDS Concentration Exceeding Guidelines in Surveyed Cities (Year 2002)

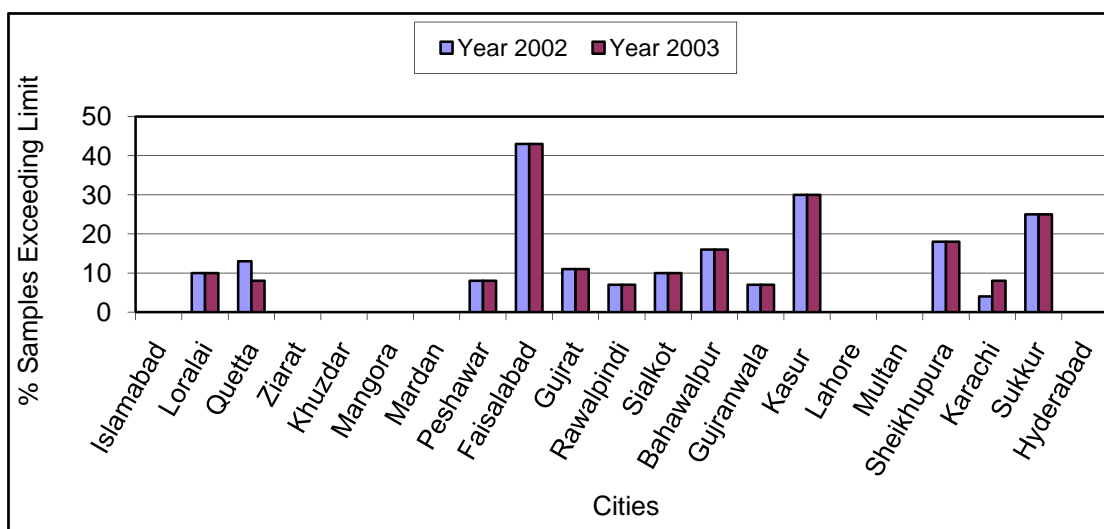


Figure 5.15: Status of Total Dissolved Salts in 21 Monitored Cities

5.3 Bacteriological Quality

Water samples were collected in clean, sterilized containers (200 ml) for bacteriological analysis. Care was taken to ensure that no accidental contamination occurs during sampling. Samples were kept cool and in the dark while transporting to the laboratory. Standard procedures and precautionary measures were adopted while collecting samples from different sources.



Determination of E-Col Count by MPN Method

The collected samples were analyzed in five reputed laboratories in the country. Samples from urban areas of Islamabad, Rawalpindi, Gujrat, Peshawar, Mardan and Mangora were analyzed at PCRWR-Water Quality Laboratory, Islamabad. Bacterial analysis of Lahore, Sialkot, Sheikhupura, Gujranwala, Faisalabad, and Kasur were carried out at Epidemiological Laboratory, Institute of Public Health, Lahore. Facilities of CMH Laboratory, Bahawalpur were utilized to examine the water samples of Bahawalpur, and Multan. Bacterial analysis for Hyderabad, Karachi and Sukkur were completed at Laboratory Unit COD Hills, Water & Sewerage Board, Karachi. Microbiological analysis of Quetta, Khuzdar, Loralai and Ziarat was carried out at CMH Laboratory, Quetta.

The overall drinking water quality in respect of bacterial contamination is found very poor in the first year of sample collection i.e 2002. Details of bacteriological results are presented at **Annexure-II-1 (c) to II-21 (c)**. In all cities, the samples were analysed for Coliform contamination however for few cities E-Coli was also analysed. For Coliform, only 26% samples in Islamabad, 24% in Bahawalpur, 21% in Faisalabad, 71% in Gujranwala, 60% in Kasur, 94% in Lahore, 13% in Multan, 13% in Rawalpindi, 45% in Sheikhpura, 60% in Sialkot, 27% in Hyderabad, 39% in Karachi, 17% in Sukkur, 50% in Quetta, 40% in Mangora, 16% in Mardan, and 31% in Peshawar were found fit for drinking purpose. Unfortunately, all samples from Gujrat, Khuzdar, Loralai, and Ziarat were found unsafe for human consumption.

In second year of monitoring (2003), the water samples were analysed for two variables Coliform and E-Coli in respect of bacteriological quality for all cities (Annexure-III). In case of Coliform, only 60% samples in Islamabad, 36% in Rawalpindi, 63% from Lahore, 62% in Faisalabad, 60% from Kasur, 22% from Gujrat, 29% in Gujranwala, 27% in Sheikhpura, 60% in Sialkot, 32% in Bahawalpur, 31% in Multan, 15% in Karachi, 17% in Sukkur, 51% in Quetta, 38% in Khuzdar, 20% in Loralai, 44% in Mangora, 25% in Mardan, and 54% in Peshawar were found fit for drinking purpose. Whereas, all samples from Hyderabad, and Ziarat were found unsafe for human consumption.

However, in case of E-Coli, only 76% samples in Islamabad, 21% in Faisalabad, 78% from Gujrat, 36% in Rawalpindi, 27% in Sheikhpura, 100% in Bahawalpur, 100% in Lahore, 90% in Kasur, 57% in Gujranwala, 92% in Faisalabad, 80% in Sialkot, 42% in Karachi, 17% in Sukkur, 83% in Quetta, 88% in Khuzdar, 40% in Loralai, 29% in Ziarat, 78% in Mangora, 92% in Mardan, and 54% in Peshawar were found fit for drinking purpose. Whereas, all samples from Hyderabad were found unsafe for human consumption. In Multan, no analysis for E-Coli were available.

The overall comparison of two years of analysis (Table 5.12) shows that the water quality is poor in general in the monitored cities as no city was found with 100% safe samples. However, in some cities the water quality has improved in second year of monitoring in respect of bacteriological contamination (increase of samples with no bacterial contamination) such as Islamabad, Rawalpindi, Kasur, Peshawar, Khuzdar, whereas in some cities it further deteriorated mainly Karachi, Hyderabad, and Sheikhpura. However in some cities no significant change in the results was observed (Sukkur, Quetta and Sialkot). There could be various reasons for the improvement in bacterial quality at some sampled sites mainly due to the dissemination of first year results through this report among the water supply agencies as well as the water users. Further, the end of drought period in first year of sampling (2001-2002) could also be another reason for showing high bacterial contamination, which later improved due to start of relatively high rainfalls in second phase i.e. 2002-2003.

It was found that proper decontamination facilities were either not present or limited in all the surveyed cities. Agencies responsible for water supply should adopt chlorination or ozonization on priority basis. In some cases, microorganisms were found inspite of a little amount of chlorine (0.01mg/l) that may be due to high turbidity level. Disinfections by chlorination may only be effective if proper treatment conditions *i.e.* chlorine dose, appropriate contact time, pH and turbidity are fulfilled adequately *e.g.* a water to be treated having turbidity <1NTU at pH < 8.0 is required chlorine contact time of at least 30 minute for effective chlorination.

Table 5.12: Percentage of Water Samples Found Fit for Drinking Purposes in 21 Cities

S.No.	City	Year 2002		Year 2003	
		Coliform	E-Coli	Coliform	E-Coli

1	Islamabad	26	-	60	76
2	Rawalpindi	13	-	36	36
3	Lahore	94	88	63	100
4	Gujrat	0	-	22	78
5	Gujranwala	71	43	29	57
6	Sialkot	60	60	60	80
7	Multan	13	-	31	-
8	Bahawalpur	24	-	32	100
9	Sheikhupura	45	36	27	27
10	Faisalabad	21	21	62	92
11	Kasur	60	30	60	90
12	Karachi	39	-	15	42
13	Hyderabad	27	-	0	0
14	Sukkur	17	-	17	17
15	Quetta	50	50	51	83
16	Khuzdar	0	0	38	88
17	Loralai	0	0	20	40
18	Ziarat	0	0	0	29
19	Peshawar	31	-	54	54
20	Mardan	17	-	25	92
21	Mangora	40	-	44	78

5.4 Quality of Dams, Rivers, Canals, Lakes and Drains

In the first year of water quality monitoring programme, water samples from three dams, one reservoir, five rivers, one canal, two natural lakes and two drains were collected for getting information about their quality. However in Phase-II, five dams, five rivers, three canals, two lakes and one drain were brought under monitoring network. These samples were analysed from the quality aspects of i) Physical and aesthetic, ii) chemical and inorganic and iii) bacteriological. The results are given in Annexure-V and discussed below:

5.4.1 Physical and Aesthetic

The physical quality has been found varying from source to source. In the first year, the color for reservoirs and rivers was generally muddy whereas for lakes and drains as yellow. The electrical conductivity (EC) for reservoirs, rivers and canals varied from 81 to 1210 with average of 343 $\mu\text{S}/\text{cm}$ which remained within 1000 $\mu\text{S}/\text{cm}$. However, for lakes and drains the results are in the range of 7930 to 138000 $\mu\text{S}/\text{cm}$ as these sources are known highly saline. With respect to odour and taste, samples were generally unobjectionable except for lakes. The pH remained within 7.1 to 8.4 for all cases which is within the recommended range of 6.5-8.5. However, turbidity was quite high with about 86%

sources exceeding the limit of 5 NTU which is obvious due to sediment load to the dams and irrigation network.

In second phase of analysis, more surface water sources were included in the monitoring network totalling five dams, four rivers, three canals, two lakes and one drain. From the analysed samples, in general, little improvement in the physical quality of monitored sources has been observed. The samples are colorless in almost all cases. The EC for dams, rivers and canals varied from 89 to 400 $\mu\text{S}/\text{cm}$ with average of 207 $\mu\text{S}/\text{cm}$ which is less than observed in Phase-I. Whereas for LBOD drain it was 8127 $\mu\text{S}/\text{cm}$. The pH remained within 5.9 to 8.3 with average of 7.6 which is also within limit of 6.5-8.5. However, turbidity is again quite high ranging from 3 to 689 NTU with about 78% sources exceeding the limit of 5 NTU.

However in general, the physical quality of surface sources is more or less comparable with groundwater except for turbidity which is significantly higher for surface water sources.

5.4.2 Chemical and Inorganic Quality

The chemical quality of all analysed samples from the surface sources as a whole was found generally good during both Phases of monitoring (Annexures V-b & V-c). Almost all of the analysed parameters were within their permissible limits especially for dams, rivers and canals. However, for lakes and drains few cases of exceedance were observed and these are generally highly saline sources or carrying saline drainage effluents.

This lead to conclusion that the chemical quality of surface sources is generally good in comparison to groundwater sources in the country.

5.4.3 Bacteriological Quality

The quality of all monitored surface water sources in terms of microbiological contamination is generally poor during both years of sampling (Annexure V-d) which is mainly due to indiscriminate disposal of domestic/industrial waste directly or indirectly into surface drains and irrigation network.

5.5 Quality Control Protocol

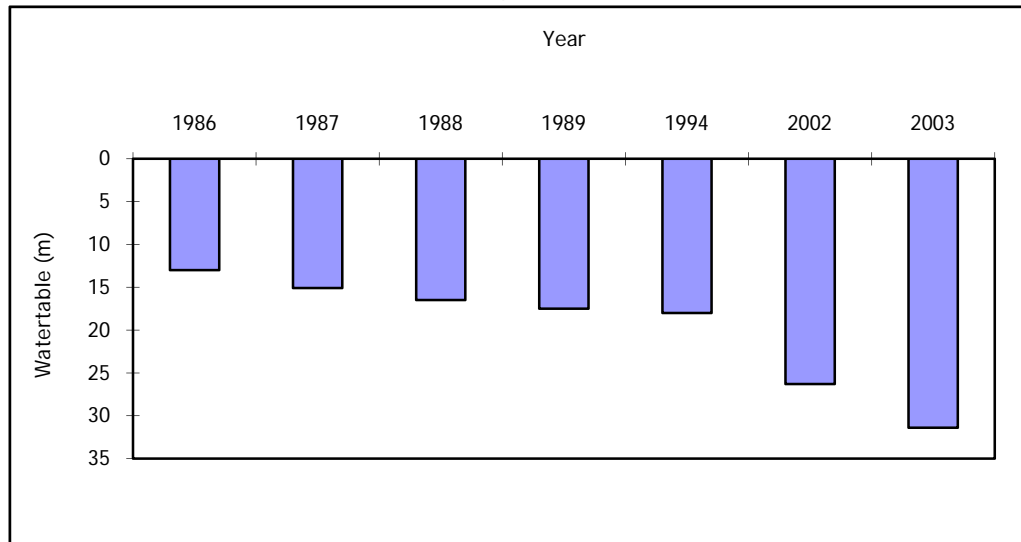
Quality control protocols were followed both at the field and laboratory levels by adopting standard sampling methods, instrumental calibration with known standards prepared at reputed ISO-9000 certified laboratories, known standards addition, reproducibility and cross checks. For this purpose, quality control measures were taken at the beginning of sample collection. Four types of samples (bacterial samples in sterilized bottles, nitrate (N) & trace elements with appropriate preservatives and other water quality parameters without preservatives) were collected from each site. Cross, field blank and replicate samples for quality control purposes were also collected. Standardization of equipment and calibration for each water quality parameter was carried out with known standards purchased from reputed laboratories. Sites for cross samples, field, blank and replicates were selected owing to site number divisible by 10 or 20. Field blank, replicate and cross samples were analyzed at PCRWR Water Quality Laboratory, Islamabad. However, analysis of cross samples were carried out by two different laboratory teams (Phase-I) due to constraints of time. Based on experience, it has been decided that water samples will be sent to another laboratory like PINSTECH for cross analysis for comparison in Phase-II. Furthermore, the comparison of results (water quality parameters) in second year were carried out on different state of art equipment like ICP-AES and AAS especially purchased to improve analytical capabilities and accuracy issues. The results

of field blanks, replicate and cross analysis are shown in Annexure-VI for year 2002 whereas in Annexure-VII for year 2003.

5.6 Ground Water Level and Quality

As a part of the monitoring program, watertable was measured from the same points where the water quality samples were collected following the same grid system as adopted in water quality sampling. During field investigation, it was learnt that there was no historical record of groundwater levels available with the most of the concerned agencies including WASA which are the leading organizations dealing with water supply in the cities. Moreover, there was no network available for continuous monitoring of groundwater fluctuations. Therefore, to initiate the activity, the water levels were measured during sampling of the monitoring period. For groundwater quality monitoring, the samples were collected from open wells, tube wells, bores, and hand pumps located in the respective grids of the cities. Accordingly, the watertable from the same sources were measured using water level indicator (as described in Section 1.6). In order to get representative observations and given the limitations discussed above, the water levels measurements were taken in almost static conditions of the groundwater sources (sufficient time after pumping is stopped). The water-level readings from the respective grids of all projected cities are given in Annexure-II-1(a) to II-21 (a). and III-1(a) to III-21(a).

The results of water level monitored for each grid in Islamabad shows that water-level varied in year 2002 from 9.8 to 37.1 m with an average of 26.1 m whereas in the year 2003 it ranged from 22 to 41 m with average of 31.4 m, indicating drop in watertable. In adjoining city of Rawalpindi, the variations in water level are 10.2 to 54.4 m with an average of 40.8 m. This showed that the water level was about 15.2 m deeper in Rawalpindi than Islamabad. However, variations in water level from grid to grid are mainly related to the elevation of the respective points. The historical record (1986-2003) of average draw down in watertable for Islamabad is



shown in Figure 5.16.

Figure 5.16: Historical Variation in groundwater level of Islamabad (1986-2003)

This showed that there is continuous decline in groundwater levels in response to groundwater withdrawals. The continuous declining trend of water table

indicates that the rate of groundwater abstraction is higher than the rate of groundwater recharge.

The average water-level in other cities of Punjab (Sr. # 3 to 11 in Table 4.1) varied from 6.6 to 21 m. However, the point-to-point variations within the cities are relatively small which is mainly due to the plane areas. Out of the projected cities in Punjab, the average water level in Lahore and Gujrat are deeper which is 21 to 18.8 m, respectively. The historical record (1993-2003) for groundwater level in Lahore (Figure 5.17) shows that watertable is also continuously falling and the trend is almost similar to Islamabad.

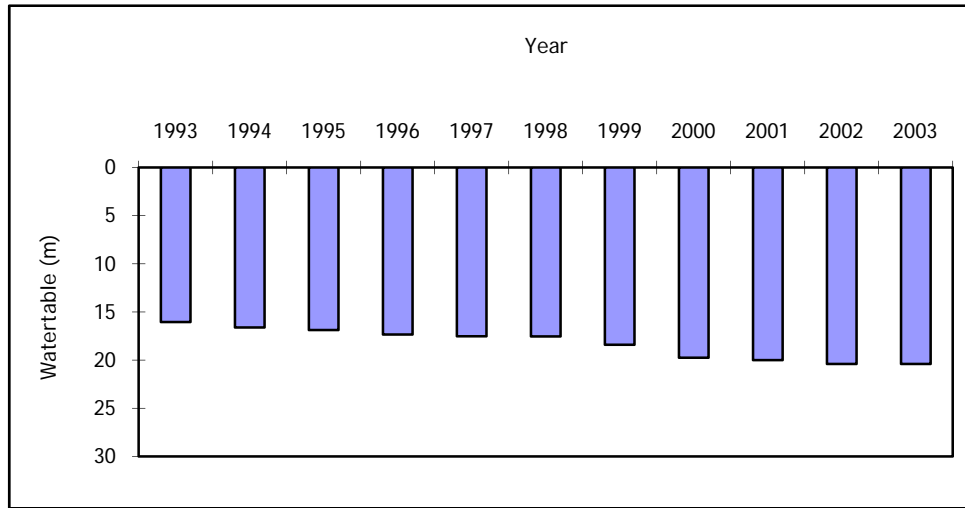


Figure 5.17: Historical Variation in groundwater level of Lahore (1993-2003)

In Balochistan during Phase-I of monitoring, the average water level in the cities being monitored varies from 15.8 to 40.2 m. In Quetta, water level varies over a wide range from 9 to 91.5 m with an average of 33.8 m, whereas in other areas including Khuzdar, Loralai, and Ziarat, the water level ranges from 9 to 23.5, 13.7 to 54.9 m and 15.2 to 76.2 m, respectively. The comparison of water table data with the Phase-II in year 2003, showed general trend of drop in ground water table (Figure 5.18).

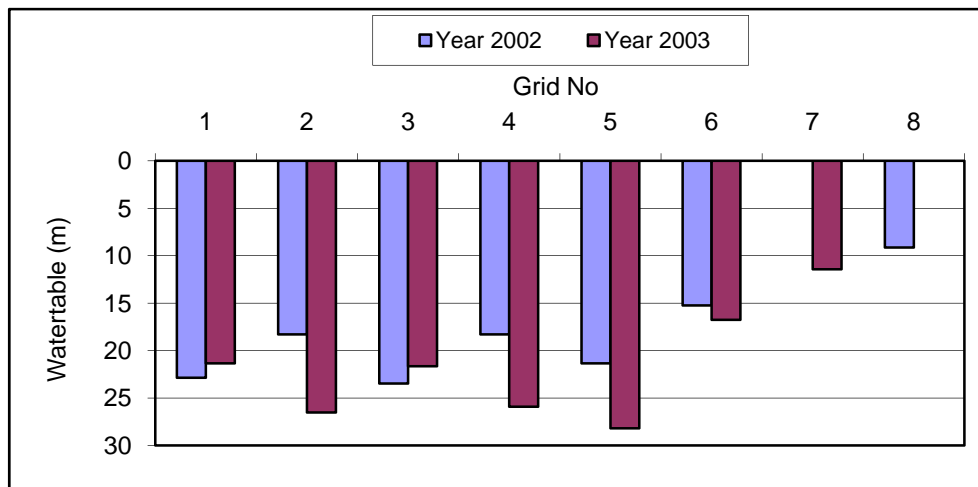


Figure 5.18: Ground water table behaviour in Khuzdar (2002 to 2003)

In NWFP Province, the average waterlevel in Peshawar, Mardan and Mangora varied from 11.4 to 19.6 m during Phase-I. The waterlevel in these areas varied from 4.6 to 47.9 m, 7.6 to 13.7 m and 9.8 to 36.6 m, respectively. However, the point-to-point variation in waterlevel is significant for these cities. In Sindh Province, however sufficient water-level record could not be collected as most of the water supply in the areas of Karachi, Hyderabad and Sukkur is from surface sources. The average water depth in these cities however varied from 3.3 to 4.6 m as shown in Annexure-II-1(a) to II-21 (a). However in Phase-II, no significant change in watertable (Annexure-III-1(a) to III-21 (a)) has been observed with respect to values in first year of monitoring.

Though limited inferences can be made on the basis of two years data on groundwater behaviour, the historical trends, where available showed declining of groundwater storage.

5.6 Water Treatment Process

Various water treatment processes are being used in the country depending upon the source of water. In semi-hilly areas, rainwater is stored and is used for drinking after simple filtration. In mountainous areas, springs water is mainly used for drinking without any treatment. In the irrigated areas where groundwater is brackish or not available, canal water is used for drinking purposes after treatment through slow or rapid sand filter, which removes suspended solid materials only.

Surface water is filtered by rapid sand filtrations and then chlorinated in treatment plants to reduce the suspended bacterial load in some urban areas of Pakistan like Karachi, Faisalabad, Rawalpindi and Islamabad. In these treatment plants, raw water is received in a distribution chamber for pre-chlorination, which neutralizes organic and bacterial load as well as optimizes the pH value for chemical treatment. Aluminium potassium sulfate (Alum) is being used as a coagulating agent, which is added in the raw water before a flash mixer for uniform distribution of the coagulant. The chemically mixed water is then conveyed to a flocculation chamber until a thick floc of settle-able matter is formed which is removed in sedimentation basins. The clear water is then filtered through rapid sand filter beds. In some cases post chlorination is also practiced. In some urban areas like Peshawar and Hyderabad no exhaustive treatment are carried out and water is simply chlorinated before its use.

The selection of water treatment technology for the provision of safe drinking water is not an easy choice. The decision requires information and knowledge about the water to be treated. Information includes complete analysis of the water sample to be treated, available amount of water, purpose and requirement of the treatment, capacity of the plant *etc.* In brief, rapid sand filtration and slow sand filtration technologies are used for the removal of turbidity, dust and rust *etc.* Granular activated carbon filtration is in practice for the improvement of taste, removal of toxic and odor producing elements. Chlorination is usually used for decontamination purpose. Ultra Violet (UV) disinfection technology and ozonization is not commonly used at water treatment plants being used for the community in the country. The recommended water treatment processes based on sources of water are given in Table 5.13.

Table 5.13: Water Treatment Process Based on Source of Water

Type of Source	Screening	Pre-Chlorination	Aeration	Plain Sedimentation	Flocculation	Coagulation and Setting	Filtration	Post Chlorination	Iron Removal	Fluoride Removal	Desalination
i) Surface-water											
a) Storage	E	O	E	E	O	O	E	E	O	-	-
b) River	E	O	E	O	E	E	E	E	O	-	-
c) Canal	E	O	E	E	O	O	E	E	-	-	-
d) Hilly region	E	O	-	O	-	-	-	E	-	-	-
ii) Groundwater											
a) Dug wells	-	-	O	-	-	-	O	E	O	O	O
b) Infiltration Galleries Radial Collector Well	-	-	-	-	-	-	-	E	-	-	-
iii) Rain-water	E	-	-	-	-	-	-	E	-	-	-
iv) Spring	-	-	-	-	-	-	-	E	-	-	-

Note: E= Essential .

O= Optional.

CONCLUSIONS & RECOMMENDATIONS

6.1 Conclusions

Based on the results of data analyzed during both Phases of water quality monitoring (2001-02 and 2002-03) and presented earlier, the following conclusions are drawn:

- The results of water samples collected during Phase-I and Phase-II provided in general same findings however, some variations in percentage samples exceeding permissible limits for certain analysed parameters have been observed in some cities.
- Most of the drinking water samples in the surveyed cities are found fit for consumption with respect to physicochemical and aesthetic water quality parameters;
- Analysis of data indicates that the situation of drinking water quality due to bacterial contamination in the country is generally poor. In none of the cities all samples were safe from bacterial contamination. In some cities all the samples were found contaminated with coliform and E.Coli bacteria during Phase-I of water quality monitoring during 2001-2002. These cities are: Gujrat, Khuzdar, Loralai, and Ziarat. Cities with bacteriological contamination in 75-100 percent water samples are (in descending order of percentage samples found contaminated) Bahawalpur, Multan, Rawalpindi, Mardan, Sukkur, Faisalabad, and Hyderabad. Cities in the range of 50-74 percent contaminated samples include Islamabad, Peshawar, Karachi, Mangora, Sheikhupura, and Quetta. Similarly, during Phase-II, in none of the cities all samples were found safe in respect of bacterial contamination. However some improvement has been observed for few cities in terms of more safe samples specifically Islamabad, Rawalpindi, Gujrat, Faisalabad, Khuzdar and Peshawar in comparison to Phase-I. Whereas in some cases, the situation further deteriorated e.g. Gujranwala, Sheikhupura, Karachi and Hyderabad. This highlights the seriousness of bacterial contamination in the drinking water sources in the country. This may be due to many reasons including intermittent water supply, leakage of pipes, pollution from sewerage pipes (problem within the distribution system), and contamination of shallow water tables due to human activities. However some relative improvements in second phase of monitoring may mainly be attributed to the dissemination of the report's findings among water supply agencies and users as well.
- Excess of Arsenic and fluoride concentrations beyond safe limits in water are also a cause of major concern in some areas. For Arsenic these include (in descending order of percentage samples found with Arsenic contamination) Lahore, Multan, Bahawalpur, Sheikhupura, Gujranwala, Kasur and Sialkot. Low cost technologies for arsenic treatment have been introduced by the Council with collaborated efforts and which would soon be soon extended to the problem areas.
- For fluoride hazard in water, the cities are (in descending order of percentage sample found with fluoride contamination) Quetta (29%), Kasur (20%), Loralai (10%), Karachi (8%), Faisalabad (8%) and Bahawalpur (4%);
- Iron is another element, which was found in excess of safe limits in samples collected from some of the cities in Phase-I. These cities are (in descending order of percentage sample contaminated) Sukkur (73%), Bahawalpur (60%), Hyderabad (60%), Loralai (36%), Multan (31%), Quetta (8%) and Lahore (6%). However in Phase-II (2002-03), some changes have been observed. The cities exceeding recommended level for iron

include Sialkot (30%), Multan (19%), Sukkur (17%), Khuzdar (13%), Gujrat (11%), Islamabad (11%), Mardan (8%) and Rawalpindi (7%);

- Nitrate (N) was not found to be a problem in any of the cities except Karachi where 4 percent samples were detected to have this parameter in excess of safe limits;
- Lead was also not found to be a problem in any of the cities except Rawalpindi and Gujranwala where 7% samples in each city were detected to have this parameter in excess of safe limits. However, presence of lead contents in the air may not be ignored especially for metropolitan cities like Karachi, Rawalpindi, Lahore etc. needing air pollution investigations.
- Turbidity of water was another parameter, which was exceeding recommended levels in almost all the cities except Faisalabad, Kasur, Lahore, Sheikhupura, Sialkot, and Mangora. However in Phase-II (2002-2003), in some cities turbidity increased whereas in few cities no turbidity was found as compared to analysis of Phase-I. The cities where no turbidity was found include Islamabad, Rawalpindi, Lahore, Faisalabad, Sialkot, Mardan and Mangora whereas in remaining 14 cities turbidity was found with different levels.
- Other problem parameters detected in water samples are: (i) Sodium (exceeding safe limits in Faisalabad, Kasur, Sheikhupura, Sukkur, Gujrat, Bahawalpur, Gujranwala, Karachi, and Quetta); (ii) Sulfates (Faisalabad, Kasur, Bahawalpur, Sheikhupura, Peshawar and Quetta); and (iii) Total Dissolved Solids (Faisalabad, Kasur, Sukkur, Sheikhupura, Bahawalpur, Gujrat, Sialkot, Loralai, Quetta, Karachi, Peshawar, Gujranwala, Rawalpindi).

The details of major problem parameters in the surveyed cities are given in Table 6.1 showing percentage of samples exceeding their permissible guideline values in each city.

Table 6.1: Major Problem Parameters Detected in Water Samples of Surveyed Cities

S. #	City	Problem Parameters with Percentage Samples Exceeding Guidelines	
		Phase-I (2001-02)	Phase-II (2002-03)
1	Islamabad	Bacterial contamination (74) & turbidity (3.7)	Bacterial contamination (40), Iron (11)
2	Bahawalpur	Bacterial contamination (96), arsenic (60), iron (60), sodium (8), fluoride (4), Sulfate (12), turbidity (16), hardness (12) & TDS (16)	Bacterial contamination (68), arsenic (68), iron (4), sodium (8), fluoride (4), Sulfate (12), turbidity (31), hardness (8) & TDS (16)
3	Faisalabad	Bacterial contamination (79), fluoride (7), sodium (43), potassium (36), sulfate (36), hardness (21), taste (29) & TDS (43)	Bacterial contamination (38), fluoride (8), sodium (43), potassium (46), sulfate (46), hardness (23), taste (29) & TDS (43)
4	Gujranwala	Bacterial contamination (29), taste (14), arsenic (7), potassium (7) sodium (7), turbidity (7) & TDS (7)	Bacterial contamination (71), taste (14), arsenic (43), sodium (7), & TDS (7)
5	Gujrat	Bacterial contamination (100), iron (33), turbidity (33), potassium (11), sodium (11), sulfate (11) & TDS (11)	Bacterial contamination (78), turbidity (33), potassium (11), iron (11), sodium (11), TDS (11)
6	Kasur	Bacterial contamination (40), odour (21), taste (10), arsenic (30), fluoride (30), sodium (30), potassium (20), sulfate (20), & TDS (30)	Bacterial contamination (40), turbidity (10), odour (21), taste (10), arsenic (40), iron (10), fluoride (20), sodium (30), potassium (20), sulfate (20) & TDS (30)
7	Lahore	Bacterial contamination (13), arsenic (31) & iron (6)	Bacterial contamination (37), and arsenic (100)
8	Multan	Bacterial contamination (87), arsenic (75), iron (31) & turbidity (6)	Bacterial contamination (69), arsenic (94), iron (19), turbidity (19)
9	Rawalpindi	Bacterial contamination (87), iron (7), turbidity & TDS (7)	Bacterial contamination (64), iron (7), TDS (7)
10	Sheikhupura	Bacterial contamination (55), arsenic (45), sodium (27), hardness (9), sulfate (9) & TDS (18)	Bacterial contamination (73), turbidity (9), arsenic (64), sodium (18), hardness (9) sulfate (9), & TDS (18)
11	Sialkot	Bacterial contamination (40), odour, sodium (10), sulfate (10) & TDS (10)	Bacterial contamination (40), arsenic (10%), Iron (30), odour, hardness (10), & TDS (10)
12	Hyderabad	Bacterial contamination (73), turbidity (67), hardness (6), iron (60), odour, taste (25) and arsenic (7)	Bacterial contamination (100), turbidity (93), iron (7), odour, and taste (25)
13	Karachi	Bacterial contamination (61), iron (21), turbidity (11), fluoride (7) sodium (7), nitrate (N) & TDS (4)	Bacterial contamination (85), turbidity (64), fluoride (8), sodium (7), & TDS (8)
14	Sukkur	Bacterial contamination (84), iron (75), turbidity (58), sodium (25) & TDS (25)	Bacterial contamination (83), fluoride (8), iron (17), turbidity (58), hardness (8), potassium (8), sodium (17) & TDS (25)
15	Khuzdar	Bacterial contamination (100) & turbidity (12)	Bacterial contamination (62), iron (13), turbidity (25)
16	Loralai	Bacterial contamination (100), fluoride (55), iron (36), turbidity (18), hardness (9) & TDS (9)	Bacterial contamination (80), fluoride (10), turbidity (30), hardness (10), & TDS (10)
17	Quetta	Bacterial contamination (50), fluoride (42), turbidity (16), iron (8), sodium (5), sulfate (8), hardness & TDS (13)	Bacterial contamination (49), fluoride (29), turbidity (8), sulfate (5), hardness (8), & TDS (8)
18	Ziarat	Bacterial contamination (100), turbidity (25), hardness (13), & fluoride (13)	Bacterial contamination (100), turbidity (43), hardness (13), & fluoride (12)
19	Mangora	Bacterial contamination (60)	Bacterial contamination (56)
20	Mardan	Bacterial contamination (84), turbidity (8) & hardness (8)	Bacterial contamination (75), iron (8),
21	Peshawar	Bacterial contamination (69), turbidity, hardness (8) & TDS (8)	Bacterial contamination (46), turbidity (8), sulfate (8), hardness (8), & TDS (8)

6.2 Recommendations

There is no doubt that majority of the population of the country is exposed to the hazard of drinking unsafe and polluted water. As is evident from the data presented, the water supplies in all the surveyed cities, some of which are metropolitan and cosmopolitan with expected better delivery of civic amenities and service, are found microbiologically unfit for human consumption. It is therefore no surprise that the inhabitants of these cities frequently suffer from the incidence of waterborne diseases like Typhoid, Gastro-enteritis, Cholera, Hepatitis, *etc.* in the spread of which contaminated water has now been accepted as the main source. It also gives indications of the very serious extent of the problem that could be prevalent in much greater proportions in smaller towns and rural areas of Pakistan. So far as health concerns of citizens are concerned after bacterial contaminations, the other problem parameters, except for Arsenic, Fluoride, and Iron, are of minor significance. It is essential that solution should be found to ameliorate these problem areas by undertaking crash program.

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

1. Water supply agencies not only in the surveyed cities but elsewhere in the country must ensure that the supply of water to the consumers is of safe quality particularly with respect to bacterial contamination. It is their civic duty to ensure that the water is given appropriate dose of chlorine and provided adequate contact time with maintenance of proper pH and reduction the turbidity of water to permissible limits by providing adequate filtration facilities;
2. A very effective and economical way to decontaminate bacterially affected water is ozonation. For this, the civic bodies and concerned agencies should be made to install ozonators on tube wells supplying drinking water to citizens;
3. The departments responsible for water supply in urban areas in particular should replace age-old leaking pipes in their water supply systems. These pipes are not only a source of wastage of scarce water but are also a major cause of bacterial contamination in the distribution system;
4. 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;
5. 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;
6. The National Drinking Water Quality Standards, promulgated by Pakistan Standards Quality Control Authority should be enforced immediately and made applicable to both private and public bodies and entrepreneurs in the Water Sector;
7. The public should be encouraged to periodically clean all domestic undergrounds and overhead tanks (cistern system) in their house. For this well-planned awareness campaigns should be initiated;
8. 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;
9. Most of the industries in the country are indiscriminately discharging harmful toxic

elements into water bodies. The Environmental Protection Agency should become more active and strictly enforce laws and regulations preventing industrial entrepreneurs from discharging their effluents directly into open water bodies and groundwater;

10. 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;
11. 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. There are reported cases of Arsenicosis from many areas in central Punjab and Sindh. These wells should be abandoned and new sources identified. Similarly there are other problem parameters as well;
12. Low cost household level water treatment technologies with low technical input to use them should be developed using indigenous material and expertise particularly for controlling and treating water with biological, arsenic, and fluoride contamination.
13. 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;
14. For effective awareness, educational institutions & mosques including mass media should be used for creating awareness about the importance of water quality among the users; and
15. Seminars and workshops should be frequently arranged to disseminate the findings of the water quality monitoring results.

The details regarding problem parameters, health effects and possible solution for the rectification for each city is shown at Annexure-I.

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