CHAPTER 7

7.Water Quality Testing and Laboratory Facilities

CHAPTER 7: WATER QUALITY TESTING AND LABORATORY FACILITIES

7.1 Introduction

Water quality is typically categorised into physical, chemical, microbiological, and radiological parameters. As the water comes into contact with various substances in different phases of the hydrologic cycle, such as rainfall, runoff, infiltration, impoundment, use, and evaporation, many substances are dissolved and suspended. Drinking water quality is influenced by source water, efficacy of water treatment plants, integrity, and condition of the water distribution system, and, as importantly, the condition of service lines to households.

Focused attention on water quality is critical to all design aspects of various components of the water supply system. The raw water quality of source water is an important aspect of the detailed engineering design of the components throughout the system, e.g., intake arrangements, treatment process, boosting/correcting measures needed in the transmission of treated water, for delivering quality water to all the consumers. The design should therefore take into consideration the physical, chemical, biological, and radiological water quality parameters associated with the source water, which may, at present, be within the permissible limits, but could have increasing trends and might change during the design period and make the water unfit for drinking unless specific treatment is installed before it can be delivered to the consumers.

The primary purpose of water quality monitoring in the water supply system is to ensure compliance with water quality criteria and standards stipulated by the concerned agencies, assess the state of water and determine trends. Strategies need to be developed for undertaking monitoring and surveillance, collecting and analysing data and delineating preventive and remedial actions for the provision of safe water, which are explained in detail in Chapter 8: Drinking Water Quality Monitoring and Surveillance of Part B of the Manual.

7.2 Health Effects of Unsafe Drinking Water

Water is necessary for survival, and everyone should have access to an adequate, safe, and reliable water supply. In terms of quantity and quality, water profoundly affects the health and well-being of individuals and the community. Pathogens in drinking water are likely to result in infectious diseases. In addition, chemical contaminants are increasing in the water, posing health risks when their presence is above stipulated standards and consumed without treatment. Many factors, such as the type of contaminant and concentration in water, the quantity of water consumed, duration of exposure and individual susceptibility, largely govern the severity of the impact of the disease. Inadequate management, monitoring and surveillance of urban, industrial, and agricultural water and sanitation services contaminate or chemically pollute the drinking water, exposing individuals to preventable health risks.

Diseases like cholera, diarrhoea, dysentery, hepatitis A, typhoid and polio have been linked to contaminated water and poor sanitation. Tables 7.1 give details of the diseases likely to be caused by chemical contaminants (if exceed the limits stipulated in drinking water standards IS 10500:2012). Table 7.2 provide details of diseases mainly gastrointestinal diseases due to pathogens in drinking water.

Table 7.1: Water Contaminants and Associated Diseases

S. No.	Contaminants	Diseases or Impacts
1	Alkalinity	Gastrointestinal irritation and irritation to the eyes, skin, and mucous membranes

S. No.	Contaminants	Diseases or Impacts
2	Hardness	Eczema, in addition to this it causes scaling and inability to form lather
3	Copper	Vomiting, diarrhoea, stomach cramps, nausea, liver damage, and kidney disease
4	Chloride	Chloride toxicity has only been observed rarely in impaired sodium chloride metabolism cases, such as congestive heart failure
5	Fluoride	Weakness, shallow respiration, spasms and convulsions, jaundice and urine suppression, discoloration of teeth, mottling in infants, and fluorosis
6	Nitrates as NO_3	Methaemoglobinaemia and congenital malformations
7	Sodium	Nausea, vomiting, muscular twitching and rigidity, convulsions, and cerebral and pulmonary oedema
8	Arsenic	Fatigue, nausea, vomiting, stomach pain, bloody diarrhoea, thickening or discoloration of the skin leading to skin cancer, numbness in hands and feet
9	Cadmium	Bone disease, osteomalacia, choking, vomiting, diarrhoea, abdominal pain, anaemia, renal dysfunction
10	Cyanide	Unresponsive hypotension, slow respiration and gasping, cyanosis at high levels and finally, death

(Source: World Health Organisation, 2017)

Table 7.2: Microorganisms and Associated Diseases

S. No.	Microorganism	Diseases or Impacts
Pathogenic protozoans		
1.	*Cryptosporidium hominis, C. parvum*	Gastroenteritis
2.	*Acanthamoeba castellanii*	Amoebic meningoencephalitis
3.	*Entamoeba histolytica*	Amoebic dysentery
4.	*Balantidium coli*	Dysentery
5.	*Giardia lamblia*	Giardiasis (gastroenteritis)
Pathogenic bacteria		
6.	*Shigella spp.*	Bacillary dysentery
7.	*Salmonella typhi*	Typhoid fever
8.	*Salmonella paratyphi*	Paratyphoid fever
9.	*Vibrio cholerae*	Cholera
10.	*Leptospira spp.*	Leptospirosis
11.	*E. coli O157:H7 (Pathogenic E. coli)*	Gastroenteritis, ear and eye infections, diarrhoea, urinary tract infections, skin diseases
Enteric Viruses		

S. No.	Microorganism	Diseases or Impacts
12.	Polio viruses	Poliomyelitis
13.	Rotaviruses	Gastroenteritis
14.	Hepatitis A virus	Infectious hepatitis, jaundice
15.	Hepatitis E virus	Infectious hepatitis, jaundice, miscarriage, and death

(Source: World Health Organisation, 2017)

Legislative Provision

Article 21 of 'The Constitution of India', 1949 states "Protection of life and personal liberty: No person shall be deprived of his life or personal liberty except according to procedure established by law". Thus, the right to access to drinking water is fundamental to life and there is a duty on the State under Article 21 to provide safe and clean drinking water to its citizens.

India is a party to the Resolution of the UNO passed during the United Nations Water Conference in 1977: "All people, whatever their stage of development and their social and economic conditions, have the right to have access to drinking water in quantum and of a quality equal to their basic needs."

The United Nations (UN) has determined that access to clean water and sanitation facilities is a fundamental human right. Sustainable Development Goal 6 is about "clean water and sanitation for all".

7.3 Standards and Guidelines

There are various standards and guidelines published by the Bureau of Indian Standards (BIS), Ministry of Environment, Forests and Climate Change (including Central Pollution Control Board) and Ministry of Jal Shakti from time to time, which form the basis of planning the Water Quality Testing requirements and laboratory facilities to be provided, to provide safe drinking water to all residents, at all times.
The Standards and Guidelines applicable are:

1. IS 10500: 2012 Drinking Water - Specifications (second revision)
2. IS 3025: 2019 Methods of Sampling and Test (Physical and Chemical) for Water and Wastewater
3. CPCB Water Quality Standards - Designated Best Use Water Quality Criteria
4. Drinking Water Quality Monitoring & Surveillance Framework, Jal Jeevan Mission, Ministry of Jal Shakti, October 2021

7.4 Water Quality Regulations

Water that is fit for human consumption (drinking water) must meet specific criteria/guidelines values/standards to avoid adverse health effects as mentioned in the above paragraphs. For design purposes, contaminants that can be treated with the same technique are usually grouped. In most cases, it is impossible to address each contaminant in terms of treatment. However, specific contaminants (e.g., fluoride, arsenic, iron etc.) must be removed and require specific treatment.

7.4.1 Raw Water Quality Criteria

The criteria applicable for the surface water source, are prescribed by Central Pollution Control Board (CPCB) as 'Water Quality Criteria' which are based on the designated use. The water quality criteria are stipulated to define the goals and aspirations for the usage of each water body. Typical examples of designated uses include fish and wildlife conservation and propagation, recreation, water supply (as source) to the general public, agricultural, industrial, navigational, and other applications.

Water quality criteria of CPCB, based on designated use, are given in Table 7.3, which indicates that criteria provided against Class A and Class C apply to water supply schemes with surface water sources. ULBs can use criteria A and C for selecting appropriate surface water source for water supply schemes.

Table 7.3: Surface water quality criteria for designated best use

Designated Best Use	Class of water	Criteria
Drinking water source without conventional treatment but after disinfection	A	• Total coliforms organism MPN/100ml shall be 50 or less • pH between 6.5 and 8.5 • Dissolved oxygen 6 mg/L or more • Biochemical oxygen demand five days 20 °C, 2 mg/L or less
Outdoor bathing (organized)	B	• Total coliforms organism MPN/100ml shall be 500 or less • pH between 6.5 and 8.5 • Dissolved oxygen 5 mg/L or more • Biochemical oxygen demand five days 20°C, 3 mg/L or less
Drinking water source after conventional treatment and disinfection	C	• Total coliforms organism MPN/100 ml shall be 5,000 or less • pH between 6 to 9 • Dissolved oxygen 4 mg/L or more • Biochemical oxygen demand five days 20°C, 3 mg/L or less
Propagation of wildlife and fisheries	D	• pH between 6.5 to 8.5 • Dissolved oxygen 4 mg/L or more • Free ammonia (as N) 1.2 mg/L or less
Irrigation, industrial cooling, controlled waste disposal	E	• pH between 6.0 to 8.5 • Electrical conductivity at 25°C micro mhos/cm Max.2250 • Sodium absorption ratio max. 26 • Boron max. 2 mg/L

(Source: Central Pollution Control Board guidelines, 2019)

7.4.2 Drinking Water Specification (IS 10500:2012)

Water, an excellent solvent, ensures the solubility of chemicals from natural and anthropogenic sources. There can be several constituents in water which may adversely affect water quality. In providing safe drinking water, determining the water quality parameters is essential to avoid adverse health effects on consumption. All water quality constituents (parameters) do not have adverse health effects and their determination has implications ranging from water treatment to aesthetic value.

The Bureau of Indian Standards (BIS) prescribes the tests for assessing water quality and standards that must be met for making the water potable in IS 10500:2012 and subsequent amendments and IS 3025:2019 - Methods of Sampling and Test (Physical and Chemical) for Water and Wastewater.

In the absence of an alternate source, the standard specifies acceptable and permissible limits. It is recommended that the acceptable limit be implemented, as values above those listed under 'Acceptable' render the water unfit for consumption. Such a value may be tolerated in the absence of an alternative source. However, if the value exceeds the 'permissible limit in the absence of an alternate source' limits, the water must be rejected for drinking.

IS 10500:2012 - Drinking Water - Specification has the following categories of water quality parameters for which limits (standards) are provided:

i) Organoleptic and physical parameters
ii) General parameters concerning substances undesirable in excessive amounts (chemical parameters)
iii) Parameters concerning toxic substances (chemical parameters)
iv) Pesticide residues (chemical parameters)
v) Parameters concerning radioactive substances
vi) Microbiological parameters namely indicator bacteria, viruses, protozoa, and helminths
vii) Biological parameters namely algae, zooplankton, flagellates

Drinking water shall comply with the requirements given in Tables 7.4 to Table 7.9. The methods of sampling and testing have been explained in relevant parts of IS 3025.

It is further mentioned that water quality parameters once introduced by BIS as part of IS 10500:2012 should be mandatorily monitored by ULBs. There are emerging contaminants such as pharmaceutical and personal care products (PPCPs), persistent organic pollutants (POPs), per and poly fluoroalkyl substances (PFAS), etc., which also have health concerns, and are being monitored in developed countries. Monitoring these emerging contaminants will also be mandatory once they are part of IS 10500:2012. It is suggested to large and medium ULBs to collate data of emerging contaminants of water sources if available through reliable references such as research and academic institutions.

Table 7.4: Organoleptic and Physical Parameters

S. No.	Characteristic	Requirement (Acceptable Limit)	Permissible Limit in the Absence of Alternate Source	Method of Test, Ref to Part of IS 3025	Remarks
1	2	3	4	5	6
i)	Colour, Hazen units, Max	5	15	Part 4	Extended to 15 only, if toxic substances are not suspected in absence of alternate sources
ii)	Odour	Agreeable	Agreeable	Part 5	a) Test cold and when heated b) Test at several dilutions
iii)	pH value	6.5-8.5	No relaxation	Part 11	-

S. No.	Characteristic	Requirement (Acceptable Limit)	Permissible Limit in the Absence of Alternate Source	Method of Test, Ref to Part of IS 3025	Remarks
iv)	Taste	Agreeable	Agreeable	Parts 7 and 8	Test to be conducted only after safety has been established
v)	Turbidity, NTU, Max	1	5	Part 10	-
vi)	Total dissolved solids, mg/L, Max	500	2000	Part 16	-

NOTE - It is recommended that the acceptable limit is to be implemented. Values in excess of those mentioned under "acceptable" render the water not suitable, but still may be tolerated in the absence of an alternative source but up to the limits indicated under permissible limit in the absence of alternate source in col. 4, above which the sources will have to be rejected.

Table 7.5: General Parameters Concerning Substances Undesirable in Excessive Amounts

S. No.	Characteristic	Requirement (Acceptable Limit)	Permissible Limit in the Absence of Alternate source	Method of Test, Ref to	Remarks
1	*2*	*3*	*4*	*5*	*6*
i)	Aluminium (as Al), mg/L, Max	0.03	0.2	IS 3025 (Part 55)	-
ii)	Ammonia (as total ammonia N), mg/L Max	0.5	No relaxation	IS 3025 (Part 34)	-
iii)	Anionic detergents (as MBAS) mg/L, Max	0.2	1	Annex K of IS 13428	-
iv)	Barium (as Ba), mg/L, Max	0.7	No relaxation	Annex F of IS 13428* or IS 15302	-
v)	Boron (as B, mg/L, Max	0.5	2.4**	IS 3025 (Part 57)	Permissible value changed from 1 to 2.4 mg/L
vi)	Calcium (as Ca), mg/L, Max	75	200	IS 3025 (Part 40)	-
vii)	Chloramines (as Cl_2), mg/L, Max	4	No relaxation	IS 3025 (Part 26)* or APHA 4500-Cl G	Chloramines are used as disinfectant and a minimum residual level should be maintained but it

S. No.	Characteristic	Requirement (Acceptable Limit)	Permissible Limit in the Absence of Alternate source	Method of Test, Ref to	Remarks
1	*2*	*3*	*4*	*5*	*6*
					should be ensured that maximum level doesn't exceed 4.0 mg/L
viii)	Chloride (as Cl), mg/L, Max	250	1000	IS 3025 (Part 32)	-
ix)	Copper (as Cu), mg/L, Max	0.05	1.5	IS 3025 (Part 42)	-
x)	Fluoride (as F), mg/L, Max	1	1.5	IS 3025 (Part 60)	-
xi)	Free residual chlorine, mg/L, Min	0.2	1	IS 3025 (Part 26)	Chlorine is used as disinfectant. This is applicable only when water is chlorinated. Tested at consumer end. When protection against viral infection is required, it should be minimum 0.5 mg/L.
xii)	Iron (as Fe), mg/L, Max	1**	No relaxation	IS 3025 (Part 53)	Total concentration of manganese (as Mn) and iron (Fe) shall not exceed 1 mg/L which was increased from 0.3 mg/L.
xiii)	Magnesium (as Mg), mg/L, Max	30	100	IS 3025 (Part 46)	-
xiv)	Manganese (as Mn), mg/L, Max	0.1	0.3	IS 3025 (Part 59)	Total concentration of manganese (as Mn) and iron (Fe) shall not exceed 0.3 mg/L
xv)	Mineral oil, mg/L, Max	1**	No relaxation	Clause 6 of IS 3025 (Part 39) Infrared partition method	Permissible value increased from 0.5 to 1mg/L
xvi)	Nitrate (as No_3), mg/L, Max	45	No relaxation	IS 3025 (Part 34)	-
xvii)	Phenolic compounds (as	0.001	0.002	IS 3025 (Part 43)	-

S. No.	Characteristic	Requirement (Acceptable Limit)	Permissible Limit in the Absence of Alternate source	Method of Test, Ref to	Remarks
1	*2*	*3*	*4*	*5*	*6*
	C_6H_5OH), mg/L, Max				
xviii)	Selenium (as Se), mg/L, Max	0.01	No relaxation	IS 3025 (Part 56) or IS 15303*	-
xix)	Silver (as Ag), mg/L, Max	0.1	No relaxation	Annex J of IS 13428	-
xx)	Sulphate (as SO_4), mg/L, Max	200	400	IS 3025 (Part 24)	May be extended to 400 provided that Magnesium do not exceed 30
xxi)	Sulphide (as H_2S), mg/L, Max	0.05	No relaxation	IS 3025 (Part 29)	-
xxii)	Total alkalinity as calcium carbonate, mg/L, Max	200	600	IS 3025 (Part 23)	-
xxiii)	Total hardness (as $CaCO_3$), mg/L, Max	200	600	IS 3025 (Part 21)	-
xxiv)	Zinc (as Zn), mg/L, Max	5	15	IS 3025 (Part 49)	-

NOTES:

1. Approved and validated international test methods from ISO/ APHA/ ASTM/ AOAC/ EPA/ EN may also be followed.
2. In case of dispute, methods given at column 5 and wherever indicated by '*'shall be the referee method. **as per latest amendments.
3. It is recommended that the acceptable limit is to be implemented. Values in excess of those mentioned under 'acceptable' render the water not suitable, but still may be tolerated in the absence or an alternative source but up to the limits indicated under 'permissible' limit in the absence or alternate source' in col. 4, above which the sources will have to be rejected.

Table 7.6: Parameters Concerning Toxic Substances

S. No.	Characteristic	Requirement (Acceptable Limit)	Permissible Limit in the Absence of Alternate Source	Method of Test, Ref to	Remarks
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
i)	Cadmium (as Cd), mg/L, Max	0.003	No relaxation	IS 3025 (Part 41)	-
ii)	Cyanide (as CN), mg/L, Max	0.05	No relaxation	IS 3025 (Part 27)	-
iii)	Lead (as Pb), mg/L, Max	0.01	No relaxation	IS 3025 (Part 47)	-
iv)	Mercury (as Hg), mg/L, Max	0.001	No relaxation	IS 3025 (Part 48)/Mercury analyser	-
v)	Molybdenum (as Mo), mg/L, Max	0.07	No relaxation	IS 3025 (Part 2)	-
vi)	Nickel (as Ni), mg/L, Max	0.02	No relaxation	IS 3025 (Part 54)	-
vii)	Pesticides, µg/L, Max	See Table 7.8	No relaxation	See Table 7.8	-
viii)	Polychlorinated biphenyls, mg/L, Max	0.0005	No relaxation	ASTM 5175* Or APHA 6630	-
ix)	Polynuclear aromatic hydrocarbons (as PAH), mg/L, Max	0.0001	No relaxation	APHA 6440	-
x)	Total arsenic (as As), mg/L, Max	0.01	No relaxation**	IS 3025 (Part 37)	Permissible value changed from 0.05 to no relaxation
xi)	Total chromium (as Cr), mg/L, Max	0.05	No relaxation	IS 3025 (Part 52)	-
xii)	Trihalomethanes:				
	a) Bromoform, mg/L, Max	0.1	No relaxation	ASTM D 3973-85* Or APHA 6232	-
	b) Dibromochloromethane, mg/L, Max	0.1	No relaxation	ASTM D 3973-85* Or APHA 6232	-
	c) Bromodichloromethane, mg/L, Max	0.06	No relaxation		-

S. No.	Characteristic	Requirement (Acceptable Limit)	Permissible Limit in the Absence of Alternate Source	Method of Test, Ref to	Remarks
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
	d) Chloroform, mg/L, Max	0.2	No relaxation	ASTM D 3973-85* Or APHA 6232 ASTM D 3973-85* or APHA 6232	-
xiii)	Uranium, mg/L, max	0.03***	No relaxation	IS 3025 (Part 65*) or IS 14194 (Part 3)	***New addition

NOTES:

1. Approved and validated international test methods from ISO/ APHA/ ASTM/ AOAC/ EPA/ EN may also be followed.
2. In case of dispute, methods given at column 5 and wherever indicated by '*'shall be the referee method. **as per latest amendments. ***New addition.
3. It is recommended that the acceptable limit is to be implemented. Values in excess of those mentioned under 'acceptable' render the water not suitable, but still may be tolerated in the absence or an alternative source but up to the limits indicated under 'permissible' limit in the absence or alternate source' in col. 4, above which the sources will have to be rejected.

Table 7.7: Parameters Concerning Radioactive Substances

S.No.	Characteristic	Requirement (Acceptable Limit)	Permissible Limit in the Absence of Alternate Source	Method of Test, Ref to Part of IS 14194	Remarks
(1)	(2)	(3)	(4)	(5)	(6)
i)	Radioactive materials:				
	a) Alpha emitters Bq/L, Max	0.1	No relaxation	Part 2	-
	b) Beta emitters Bq/L, Max	1.0	No relaxation	Part 1	-

NOTE - It is recommended that the acceptable limit is to be implemented. Values in excess or those mentioned under 'acceptable' render the water not suitable, but still may be tolerated in the absence of an alternative source but up to the limits indicated under permissible limit in the absence or alternate source' in col. 4 above which the sources will have to be rejected.

Table 7.8: Pesticide Residues Limits and Test Method

S. No.	Pesticide	Limit µg/L	Method of test, Ref to	
			USEPA	AOAC/ ISO
(1)	*(2)*	*(3)*	*(4)*	*(5)*
i)	Alachlor	20	525.2, 507	-
ii)	Atrazine	2	525.2. 8141 A	-
iii)	Aldrin/Dieldrin	0.03	508	-
iv)	Alpha HCH	0.01	508	-
v)	Beta HCH	0.04	508	-
vi)	Butachlor	125	525.2, 8141 A	-
vii)	Chlorpyriphos	30	525.2. 814 1 A	-
viii)	Delta HCH	0.04	508	-
ix)	2.4-Dichlorophenoxyacetic acid	30	515.1	-
x)	DDT (*o, p* and *p, p* - Isomers of DDT, DDE and DDD)	1	508	AOAC 990.06
xi)	Endosulfan (alpha, beta, and sulphate)	0.4	508	AOAC 990.06
xii)	Ethion	3	1657 A	-
xiii)	Gamma -HCH (Lindane)	2	508	AOAC 990.06
xiv)	Isoproturon	9	532	-
xv)	Malathion	190	8141 A	-
xvi)	Methyl parathion	0.3	8141 A	ISO 10695
xvii)	Monocrotophos	1	8141 A	-
xviii)	Phorate	2	8141 A	-

NOTE - Test methods are for guidance and reference for testing laboratory. In case of two methods. USEPA method shall be the reference method.

Table 7.9: Bacteriological Quality of Drinking Water[1)]

S. No.	Organisms	Requirements
(1)	**(2)**	**(3)**
i)	All water intended for drinking: a) E. coli or thermotolerant coliform bacteria[2), 3)]	Shall not be detectable in any 100 ml sample
ii)	Treated water entering the distribution system: a) E. coli or thermotolerant coliform bacteria[2)] b) Total coliform bacteria	Shall not be detectable in any 100 ml sample Shall not be detectable in any 100 ml sample
iii)	Treated water in the distribution system: a) E. coli or thermotolerant bacteria b) Total coliform bacteria	Shall not be detectable in any 100 ml sample Shall not be detectable in any 100 ml sample

1) Immediate investigative action shall be taken if either E. coli or total coliform bacteria are detected. The minimum action in the case of total coliform bacteria is repeat sampling; if

these bacteria are detected in the repeat sample, the cause shall be determined by immediate further investigation.

2) Although E. coli is the more precise indicator of faecal pollution, the count of thermotolerant coliform bacteria is an acceptable alternative. If necessary, proper confirmatory tests shall be carried out. Total coliform bacteria are not acceptable indicators of the sanitary quality of rural water supplies, particularly in tropical areas where many bacteria or no sanitary significance occur in almost all untreated supplies.
3) It is recognised that, in the great majority of rural water supplies in developing countries, faecal contamination is widespread. Under these conditions, the national surveillance agency should set medium term targets for progressive improvement of water supplies.

7.5 Water Quality Data

The water quality data of surface raw water source and ground water source are very crucial for designing and implementing the water supply systems. Thus, the water quality data should be collected from the government agencies such as Central Pollution Control Board (CPCB), Central Water Commission, and State Pollution Control Board, so as to design the treatment system. The available data with these agencies will cater to all quality fluctuations and shocks during the design period as these agencies collect data in various seasons. However, it is always a good practice to collect samples from the proposed water supply source as detailed in subsequent section. Hence, samples should also be collected from the prospective water source in addition to referring the data available with these agencies.

7.5.1 Surface Water Quality Data

In 1978, the Central Pollution Control Board began monitoring national water quality as part of the Global Environmental Monitoring System (GEMS) Water Programme. With 24 surface water and 11 groundwater stations, the monitoring programme was off to a start. In addition to GEMS, in 1984, a system for Surface Water, viz., a National Programme of Monitoring of Indian National Aquatic Resources (MINARS) was launched, with 113 stations spread across ten river basins. This monitoring network has been further expanded to many surface water sources including major lakes/ponds.

The monitoring activities carried out as part of the national network serves various assessment objectives as given below in determining:

- Natural freshwater characteristics without direct human influence,
- Long-term trends in critical water quality indicators in freshwater resources,
- Organic matter, suspended solids, nutrients, toxic chemicals, and other pollutants that flow from river systems to the sea/coastal interfaces.

A selective network of strategically vital monitoring stations has been established to achieve the earlier objectives. It is being operated in the country's major, medium, and minor watersheds of rivers, lakes, ponds and storage tanks, bodies of water, drains, water channels, and subsoil aquifers. Three types of stations are set up for monitoring: baseline, trend and flux stations. Periodic water quality monitoring is being undertaken by CPCB with assistance from State Pollution Control Boards. The water quality data of surface water sources are available on the website of CPCB.

7.5.2 Ground Water Quality Monitoring (GWQM)

GWQM is a co-ordinated effort to collect and analyse data on groundwater's physical, chemical, and biological characteristics, aquifer conditions, and designated ground use. Groundwater is characterised by contrasting aquifer and geologic features, limited accessibility (i.e., groundwater must be sampled through an existing or newly drilled well or spring), and 3-D distribution movement within a geologic framework. Central Ground Water Board (CGWB) co-ordinates GWQM through a network of observation wells spread across the country. Water quality along with water level data of these sources (observation wells) are periodically published in the form of reports by CGWB.

If any new water source/s is/are identified for water supply schemes and water quality data are not available for these sources, detailed analysis should be undertaken by analysing the parameters as specified in Table 8.1: Frequencies and parameters for analysis of surface water and groundwater sources (Part B of the Manual).

7.5.3 Water Quality Assessment

Assessment is the systematic documentation and study of the quality phenomenon to take decisions in designing the water supply system components, mainly intake and treatment processes. The assessment should take into account the following parameters:

(a) Where to sample: Locating the sampling point;

(b) What to measure: Define the parameters to be monitored;

(c) When to observe (how often): Frequency of observation.

After commissioning of the water supply system, it is vital to monitor the water quality parameters to ensure the proper functioning of the system. Water quality data collected during the water supply system operation should help to take any corrective changes required to deliver ‘Drink from Tap’ with 24×7 pressurised water supply. Refer Chapter 8 in part B of this Manual for detailed deliberation on monitoring aspects.

7.5.4 Critical Water Quality Assessment/Assurance Points

The quality of water being supplied through the water supply system has to be monitored to ensure conformance with the desired drinking water standard. The facility has to be in place to carry out these water quality tests at the critical points and transmit the data to the central unit to make positive changes in the design of various components to optimise the system.

These critical points must be carefully selected to capture variations in water quality in the water supply system. It is recommended to provide the following critical points to assess the water quality:

i) At the intake/tube well (water source);
ii) At the inlet and outlet of the treatment plant;
iii) At the inlet and outlet of service reservoirs such as ESRs/MBRs/GSRs;
iv) Inlet and at the farthest point in each District Metered Area (DMA);
v) At discrete locations in the network/DMA.

The emerging technologies, e.g., IoT and related instrumentation, can be used for efficient water quality monitoring at few of these critical points. Water quality data being collected by using emerging technologies should be connected to SCADA and analysed with digital twin technology for taking decisions and implementing corrective measures. The water quality data should be mapped on GIS.

Case Study

Digital Monitoring of 24×7 Water Supply (Drink from Tap Mission) in Puri and other Cities of Odisha

In the Indian context, intermittent water supply systems have several issues, including inefficient and poor design, concerns with maintenance and operation, financial instability, etc. Throughout the decades, urban Odisha was under great difficulty in terms of water supply infrastructure such as inadequate service coverage, poor drinking water quality, discontinuous supply and high-water losses, and could not keep up with the rate of expanding urbanisation. To tackle this problem, Government of Odisha initiated 'Drink from Tap' Mission, during October 2020 to provide good quality piped drinking water to approximately 2.5 lakh consumers of Puri city on a 24×7 basis. The objective of the mission was to make available sufficient quantity and good quality water directly from the tap. Water supply management was achieved through a community partnership known as "Jalsathi", which provided equitable, sustainable, and people-centred service provisions. It also focused on 100% coverage of both household connections and metering to avoid non-revenue water (NRW) and quality assurance through third-party quality monitoring and laboratories. Jal Sathis contributed to a change in the situation on the ground and increased public trust in the water supply system. The "Smart Water Management System" under "Drink from Tap Mission" was created and had initially been implemented in four pilot zones of Puri City to enable real-time data collecting, analysis, decision making, and public reporting (Figure A). Now it has been upscaled for pan city for Puri and additional 7 cities in Odisha.

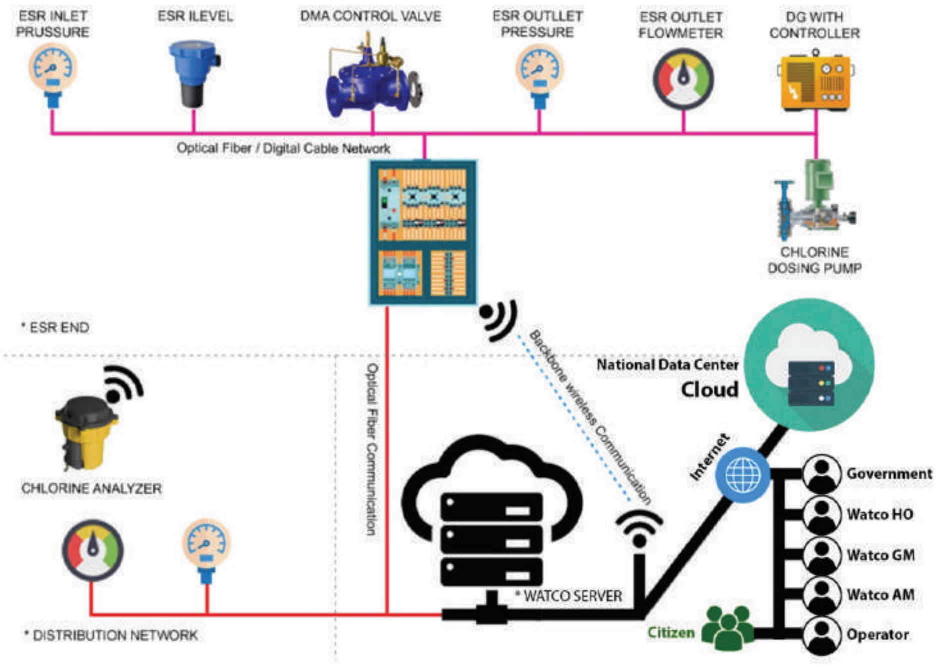

Figure A: System Architecture of Smart Water Management System in Puri

It aims to build public trust in the public water supply system so that individuals can drink from the tap instead of relying on the current delivery systems. In order to increase customer confidence, real-time online water quality data is broadcast on LCD panels in public areas (Figure B). For better water quality monitoring of essential parameters and effective incident management, mobile van laboratories have been deployed. The main difficulty has been reducing non-revenue water usage. To reduce leakage, a special cell with a committed crew has been developed, with implementation targeted at NRW reduction. The NRW is now less than 15%, down from a high of 54%. Special

Mobile Team have been established for speedy reaction to water supply-related incidents and immediate maintenance of leaks.

Figure B: Digital display board mounted at public places

The public and communities now have more faith in government because each home has access to high-quality water around-the-clock (24/7), there is no need for household storage, pumping, or treatment, house connections are simple, water is conserved through metering, production costs are reduced, issues and complaints are resolved quickly and, above all, end-to-end services are provided right at the doorstep.

7.6 Establishing Testing Mechanism

Several institutions are catering to water testing requirements. An institutional mechanism of laboratories is proposed below that can be made functional at different levels, e.g., at National, State, and ULB level. Water quality laboratories are also the backbone of water quality monitoring and surveillance programme. Well-located and well-equipped analytical laboratories with competent staff are essential to evaluate water utility services' efficiency in terms of water quality. Therefore, the provision of safe drinking water warrants a strong laboratory network within the state and ULB for water quality assessment.

7.6.1 Proposed institutional mechanism of laboratories

As explained earlier, an institutional mechanism exists for water quality monitoring and surveillance at various levels. To synchronise water quality monitoring and surveillance and have a similar template for the data collection, compilation and analysis, existing mechanisms need strengthening.

Strengthening of the network of water quality assessment laboratories is based on a state laboratory and a series of laboratories at the ULB, including mobile and basic laboratories at the water treatment plant level (Figure 7.1). The laboratory at the water treatment plant can also serve the entire water supply system, including the function of the basic laboratory. ULB can have any of the following laboratory systems:

i) Two laboratories separately catering to (a) the source and distribution system and (b) the basic laboratory at water treatment plant;

ii) Single laboratory catering to the entire water supply system including water treatment plant.

In addition to ULB laboratories, a state laboratory is also proposed which may co-ordinate activities of all the ULB laboratories in the state. The state laboratory should be accredited by National Accreditation Board for Testing and Calibration Laboratories (NABL). The laboratory should be well-equipped to deal with the parameters identified in the Bureau of Indian Standards on quality standards for drinking water (IS 10500:2012). It is recommended that ULB laboratories should be subsequently accredited by NABL. It is required to perform external control on the quality of the analysis performed by ULB laboratories. State and large ULBs should also have mobile laboratories.

The ULB-level laboratories should be capable of carrying out a moderate series of physical, chemical, and microbiological analysis, which must be subject to quality assurance programmes to guarantee their quality. In addition, they should be able to offer support services to the field staff carrying out tests using portable equipment.

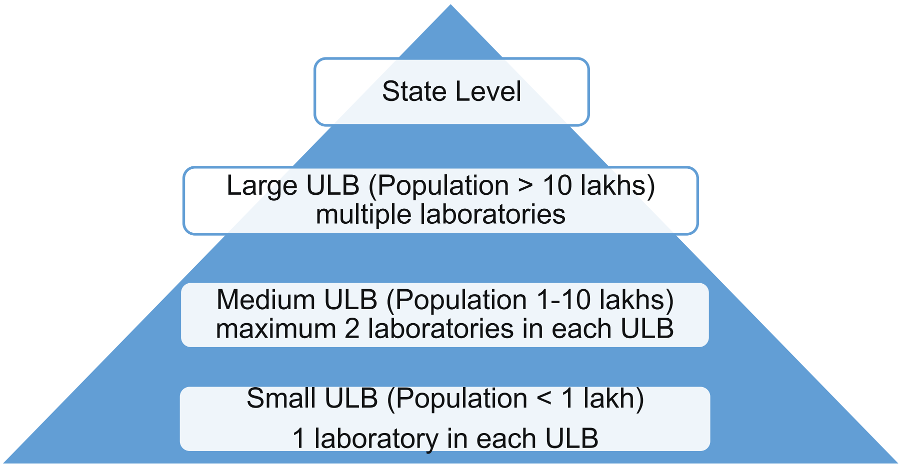

Figure 7.1: Laboratory Network for Water Quality Assessment

A minimum of one water testing laboratory should be established in each ULB. The State Laboratory of the concerned State Government Department (e.g., Urban Development Department) can co-ordinate with any of the laboratories being operated by other State and Central Government agencies (Public Health Engineering Department (PHED), Central Ground Water Board (CGWB), Central Water Commission (CWC), etc.) to optimise available resources.

Following guidelines can be adopted while locating water testing laboratories:

i. Only one water testing laboratory should be established in Small ULBs (Population <1 lakhs). Wastewater analysis should be undertaken in the same laboratory, however, proper precautions (such as microbiological analysis in separate rooms for water and wastewater analysis) should be undertaken to avoid cross-contamination. Similarly, specific water testing parameters such as Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Kjeldahl Nitrogen (TKN), etc., should preferably be analysed in a separate laboratory room.
ii. Maximum of two water testing laboratories can be established in a Medium ULB (Population 1-10 lakhs).
iii. Large ULBs (>10 lakhs population) can have multiple laboratories, however, attempts should be made to minimise number of laboratories.

iv. Water testing laboratories should be in government-owned buildings.

v. It is a practice to locate water testing laboratory in the premises of water treatment plants. While the practice can be continued in locating the laboratory in water treatment plant premises, water testing laboratory can also be located in prominent location in the city/urban area to have better accessibility to the citizens. Establishing a water testing laboratory in the premises of Incharge of water supply in ULB will also help in providing prominence to these laboratories and also assist in better co-ordination between engineers and analysts/chemists.

vi. Location of water testing laboratory should be prominently displayed in busy public areas by using sign boards, wall paintings, etc., so that the community in general can be aware of laboratory facilities.

vii. Location of water testing laboratories should also be geo-tagged and displayed in the ULB website.

viii. It is a common practice to locate water testing and wastewater (sewage) testing laboratories in the premises of a water treatment plant and sewage treatment plant respectively. This helps in optimising time for collection and analysis of water and wastewater samples from the treatment plants. While this practice can be continued if separate laboratories are already existing in the water treatment and wastewater treatment plant premises.

ix. Joint or separate laboratories for water and wastewater analysis can be planned and operationalised. If it is proposed to have water testing and wastewater testing laboratories in the same premises/buildings, microbiology sections for water and wastewater analysis should be separate to avoid cross-contamination. Similarly, specific water testing parameters such as Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Kjeldahl Nitrogen (TKN), should preferably be analysed in a separate laboratory room.

x. Staff for wastewater analysis should be separate and same guidelines available for water quality analysis can be adopted for engagement of staff.

xi. Major equipment such as Atomic Absorption Spectrophotometer (AAS) with Electrode Lamp, Inductively Coupled Plasma - Optical Emission Spectrometry (ICP-OES)/Inductively Coupled Plasma - Mass Spectrometry (ICP-MS), Gas Chromatograph - Mass Spectrometry (GC-MS), Liquid Chromatograph - Mass Spectrometry (LC-MS), Ion Chromatograph (IC) and PCR machine should be shared between large laboratories for water and wastewater analysis. Only one set of these equipment should be procured in large ULB (population >10 lakhs) and in the State Laboratory even if there are multiple water testing laboratories in any ULB.

xii. State laboratory should preferably be located in the capital city of the State.

7.6.2 Functions of Water Quality Testing Laboratories

Within the proposed hierarchy, the basic laboratory at WTP controls and optimises the treatment process. In case of a plant of greater capacity (>50 MLD), all the additional parameters shall be monitored in the ULB laboratory.

In general, the critical function of a water testing laboratory is to determine the water quality for drinking and domestic use. To undertake this function, the following activities are involved, viz.:

(i) Collection of water samples from the field with suitable preservation

(ii) Sanitary surveillance

(iii) Water sample storage with suitable preservation

(iv) Requisite data analysis

(v) Other functions would include:

- Delineating the potential areas of water contamination (health-based parameters like excess of salinity, fluoride and metals such as iron, manganese, arsenic, etc.);

- Determining the risk of pollution from various sources like agricultural practices (pesticides and fertilisers), industrial discharges, municipal sewage disposal and disposal of solid wastes;
- Communicating the results to concerned officials for corrective actions;
- Follow-up water quality monitoring after implementation of corrective actions, mainly if the source is bacteriologically contaminated;
- Identifying sampling stations and frequency; and
- Providing reference/critical points to monitor improvement or deterioration in water quality.

The concerned authorities in ULBs will carry out the following activities:

i.) Set up/strengthen ULB-level laboratories.

ii.) Upgrade existing water quality testing laboratories, including procurement of equipment, instruments, chemicals/reagents, glassware, consumables, etc.

iii.) Procure special vehicles for transportation of water samples from the field to the laboratory.

iv.) Conduct Information, Education and Communication (IEC) activities on the importance of consuming safe drinking water, capacity building, and training various stakeholders.

v.) Seek accreditation for ULB-level laboratories through the NABL.

The envisaged functions of different laboratories within the proposed hierarchy and requisite staffing shall be as given below in Table 7.10.

Table 7.10: Envisaged Functions of Various Laboratories

Laboratory	Envisaged Functions
State level Laboratory and large ULB (10 lakhs or greater)	It will be a well-equipped laboratory capable of: • Analysing the physico-chemical and microbiological parameters of water and wastewater • Supervising and assisting medium and small laboratories in the state on sampling, water quality analysis, data analysis, and crosschecking of standards • Preparing and implementing water safety plan • Undertaking routine monitoring and surveillance of the water supply system and suggest corrective actions based on water quality analysis data • Routine monitoring of identified control measures within the water supply system • Identifying contamination points within water supply systems and control • Validating and entering data in a standard database • Undertaking analysis of all routine water quality parameters, viz., heavy metals, pesticides, bacteriological, and biological analysis with sophisticated instruments as detailed in Chapter 8 of Part B Manual • Taking up independent public health surveillance for water safety • Carrying out community awareness programmes • Collaborating with similar water testing laboratories in the State, e.g., State Laboratory of Rural Water Supply Agency (PHED)

Laboratory	Envisaged Functions
Medium (1-10 lakhs) and small ULB (<1 lakh) laboratory, and basic laboratory at WTP	It will be a well-equipped laboratory capable to: • Analyse specified required water quality parameters, as mentioned in Chapter 8 - Part B Manual • Undertake routine monitoring and surveillance of the water supply system • Prepare and implement water safety plan • Enter data in a standard database • Carry out community awareness programmes • Collaborate with similar water testing laboratories in the State, e.g. District Laboratory of Rural Water Supply Agency (PHED)

7.6.3 Mobile Drinking Water Quality Testing Laboratory

ULBs can procure mobile water quality testing laboratories to test specified endemic parameters, local communities' congregation areas, and inaccessible parts of the city. This type of mobile laboratory may be needed in areas where water samples cannot be transported to the designated laboratories on time. The mobile laboratories should be fully equipped to conduct on-the-spot water analysis concerning drinking water sources' safety. The results of the tests will help determine strengthening of preventive measures, treatment needed and warning to consumers to make the contaminated water safe to drink. They play a significant role during calamities/disasters as they can reach these areas quickly, i.e., cyclone and flood-prone areas, landslides, and earthquake-prone areas, etc. The primary functions of a mobile laboratory include:

i. Water quality testing, monitoring and surveillance in remote areas/hot spots/disaster-prone areas;
ii. Cross-verification of results with other laboratories;
iii. Water quality testing and management during disasters and natural calamities;
iv. Awareness generation amongst the community.

7.6.4 Staffing

Staff requirements for water quality testing varies widely according to the population of ULB, number of water samples to be collected and analysed, number of water sources, treatment plant size, and financial resources. A suggestive staff requirement for various levels of laboratories is given below in Table 7.11 and Table 7.12. The requisite qualification of all staff can be based on the concerned State Government guidelines. The position of Chief Water Analyst should be held by chemist/microbiologist/environmental scientist having experience in water quality analysis and surveillance. The staff of the laboratories namely chemists, analysts, microbiologists, bacteriologists, and laboratory assistants should have expertise and experience, and must understand the principles and know how to operate the equipment/instruments available in the laboratory.

Table 7.11: State/ULB-Level Water Quality Testing Laboratory

S. No.	Position	Numbers			
		State Laboratory	ULB		
			Large ULB (population >10 lakhs)	Medium ULB (1-10 lakhs)	Small ULB (<1 lakh)
1.	Chief Chemist/Water Analyst	01	01	01	-
2.	Senior Chemist/Water Analyst	02	01	01	-
3.	Environmental Engineer	02	01	01	-
4.	Chemist/Water Analyst	03	02	01	01
5.	Microbiologist/Bacteriologist	02	02	01	01
6.	Laboratory Assistant	04	03	02	01
7.	Lab Attendant	06	04	03	02
8.	Data Entry Operator	02	02	01	01
9.	Field Assistant/sample collector (task/need-based field staff)	06	04	03	02

Table 7.12: Mobile Water Testing Laboratory

S. No.	Position	Numbers
1.	Chemist/Water Analyst/Microbiologist	01
2.	Field Assistant (task/need-based field staff)	01
3.	Driver	01
4.	Helper	01

7.7 Laboratory Facilities and Equipment

7.7.1 Facilities

At the time of construction of water works assets, it is critical to provide testing laboratories and procure applicable standard instruments and equipment. The laboratory's layout will be determined by the various analytical work that must be completed. When choosing the required space, consideration should be given to the space needed for permanently installed equipment and the efficient completion of analytical work by laboratory workers. Future growth should be considered while building the new laboratory or retrofitting the old laboratory. Urban areas for developing separate structures of laboratory facilities are categorised as follows:

i) Large ULB (Metropolitan areas having a population >10 lakhs).

ii) Medium ULB (Municipal Corporations having a population 1-10 lakhs).

iii) Small ULB (Municipalities having a population <1 lakh).

Although these laboratories will be operated and maintained by individual ULBs, cross-linkages among laboratories should be encouraged in a State for optimising resource availability. Table 7.13 lists the necessary laboratory equipment.

Table 7.13: Facilities Required in a Laboratory

S. No.	Infrastructure	State or Large ULB Laboratory (population > 10 lakhs)	Medium ULB Laboratory (population 1-10 lakhs)	Small ULB Laboratory (population <1 lakh)
1.	Space for Analysis (minimum area)	80 m^2 (including 20 m^2 biological)	60 m^2 (including 20 m^2 for biological testing)	50 m^2 (including 10 m^2 for biological testing)
	Space for storage (in m^2)	45	25	20
	Space for office & library (in m^2)	45	15	10
	Total space req. (in m^2)	170	100	80
2.	No. of Computers	03 (include one system for library)	01	01
3.	Internet facility	Yes	Yes	Yes
4.	No. of UPS	02	01	01
5.	Inverters (back up time - 3 hrs.)	02	02	01
6.	Printer	02	01	01
7.	Telephone Facility	Yes	Yes	Yes
8.	Fax	Yes	Yes	Yes
9.	A.C.	Yes	Yes	Yes
10.	Provision for Fume hood	Yes	Yes	May not be needed at this level
11.	Biosafety cabinet	Yes	Yes	Yes
12.	Provision for gas connection	Yes	Yes	Yes (Only LPG)

Additional space for wastewater treatment/ spent water generated from the laboratory should be provided.

(Source: Drinking Water Quality Monitoring & Surveillance Framework, 2021 of GOI)

7.7.2 Equipment

Water quality testing equipment are staple in environmental laboratories. Various types of water quality testing equipment are used to test water for physical, chemical, and microbiological contaminants. These equipment can be used to test a variety of parameters in water. Equipment to be procured by municipal corporations and other ULBs should be decided by the concerned ULB based on water quality parameters to be analysed. It is recommended that the state and large ULBs should have facilities to analyse all the water quality parameters, as mentioned in Table 7.14. The laboratory should cater to other ULBs (particularly medium and small ULBs) in case episodic monitoring needs to be carried out and other laboratories don't have facilities to analyse the concerned water quality parameters. The equipment listing below is based on the incremental approach for choosing the parameters to be tested at each level of laboratories. Each ULB should ensure that an appropriate laboratory infrastructure as recommended by NABL should be first created before procuring the equipment. Moreover, qualified and experienced/trained staff availability should also be ensured before procurement of the equipment. However, non-availability of trained staff should not be an excuse to avoid carrying out water quality analysis. The water quality analysis of the listed parameters is essential and services of any other NABL accredited laboratories as detailed out in Section 8.5 (Part B Manual - Chapter 8) should be utilised.

Table 7.14: Equipment/Instrument in water testing laboratories (Indicative numbers given against each equipment)

S. No.	Item	State	Large ULB	Medium ULB	Small ULB
1.	pH meter (each laboratory based and portable type)	2	2	1	1
2.	TDS/Conductivity meter (each laboratory based and potable type)	2	2	1	1
3.	Nephelometer (Turbidimeter) (each laboratory based and potable type)	2	2	1	1
4.	Digital balance	2	2	1	1
5.	UV-Visible spectrophotometer	2	2	1	1
6.	Refrigerator	2	2	1	1
7.	Water still	2	2	1	1
8.	Voltage stabiliser/Inverters	3	3	2	2
9.	Hot Plate	2	2	1	1
10.	Heating mantle	2	2	1	1
11.	Water bath	2	2	1	1
12.	Hot air oven	4	4	2	2
13.	Bacterial incubator	3	3	2	1
14.	Membrane filtration unit	2	2	1	1
15.	Autoclave	2	2	1	1
16.	Magnetic stirrer	2	2	1	1
17.	Microscope	1	1	1	1
18.	UV laminar air flow chamber for bacteriological analysis	1	1	1	1
19.	Plate count and colony counter	1	1	1	1
20.	Arsenic testing instrumentation (portable) - only in affected states	1	1	1	1
21.	Hydride generator with all accessories	Yes	Yes	Yes	Yes
22.	DO meter	1	1	1	1

S. No.	Item	State	Large ULB	Medium ULB	Small ULB
23.	Specific ion meter along with electrodes (for fluoride)	1	1	1	1
24.	Fume cupboard	2	2	1	1
25.	Auto burette and auto pipette (numbers can be decided as per requirements)	Yes	Yes	Yes	Yes
26.	Thermometers (numbers can be decided as per requirements)	Yes	Yes	Yes	Yes
27.	Double distillation apparatus/Ultrapure water purification system to provide type I/type II water for sophisticated instruments	2	2	1	1
28.	Argon, Nitrogen, Hydrogen Helium and Oxygen Gas Cylinders (for AAS/Advanced Spectro-photometer) / ICP-MS/OES	Yes	Yes	Yes	No
29.	Kjeldal distillation apparatus	Yes	Yes	Yes	No
30.	Pressure pump	Yes	Yes	Yes	No
31.	Deep freezer (-20 °C)	1	1	No	No
32.	Micropipette	Yes	Yes	No	No
33.	Centrifuge	2	2	1	1
34.	Reflux apparatus/COD digester	1	1	1	No
35.	Ion chromatograph	1	1	No	No
36.	Atomic absorption spectrophotometer (AAS) with electrode lamp	1	1	No	No
37.	Inductively coupled plasma- optical emission spectrometry (ICP-OES)/mass spectrometry (MS)	1	1	No	No
38.	Gas chromatograph-mass spectrometry (GC-MS)	1	1	No	No
39.	Liquid chromatograph-mass spectrometry (LC-MS)	1	1	No	No
40.	PCR machine	1	1	No	No

Required laboratory consumables (glassware and accessories) and chemicals in the required quantity should also be maintained in stores of each laboratory.

7.8 Water Quality Index (WQI)

A water quality index provides a single number (like a grade) that expresses the overall water quality of a particular water sample (location and time specific) for several water quality parameters. Developing an index aims to simplify the complex water quality parametric data into comprehensive information for easy understanding. A water quality index based on important parameters provides a simple indicator of water quality which gives a general idea of the possible problems with the water in the region and across the stretch of the river/stream, helping in deciding the best alternative location of intake. Hence, water quality index should be determined water sources to be used for water supply. Water quality parameters, namely, dissolved oxygen, faecal coliforms, pH and BOD (as mentioned in Table 7.15) should be used to determine water quality index.

The WQI has been determined based on the formula developed by National Sanitation Foundation (NSF) and modified by Central Pollution Control Board (CPCB), which depicts the water quality simply and easily for utilities and the general public at large. To maintain uniformity while comparing the WQI across the nation, the NSF-developed WQI has been modified, and CPCB has assigned relative weights. The modified weights are given in Table 7.15. The formula and classification of water quality indices for surface and groundwater are given in Table 7.16. The water quality is described upon determining the water quality index for easy understanding and interpretation.

Table 7.15: Modified Weights for Computation of WQI based on DO, FC, pH and BOD

Parameters	Original Weights from NSF WQI	Modified Weights by CPCB
Dissolved oxygen (DO)	0.17	0.31
Faecal coliform (FC)	0.15	0.28
pH	0.12	0.22
BOD	0.1	0.19
Total	0.54	1

Table 7.16: Formula and Classification of Water quality indices for Surface and Groundwater

<table>
<tr><th colspan="2">Surface Water Quality</th><th colspan="2">Ground Water Quality</th></tr>
<tr><td colspan="2">$WQI = \sum_{i=1}^{P} W_i I_i$</td><td colspan="2">$WQI = \sum_{i=1}^{n=9} q_i . W_i$</td></tr>
<tr><td colspan="2">Where:
I_i = sub-index for water quality parameter,
Where,
sub-index = monitored concentration/water quality standard
W_i = weight (in terms of importance) associated with water quality parameter
P = number of water quality parameters</td><td colspan="2">Where:
q_i = quality rating, $= \frac{C_i}{S_i} \times 100$
W_i = the relative weight $= \frac{w_i}{\sum_{i=1}^{n} w_i}$
w_i = the weight of each parameter or relative of each weight
C_i = the concentration of each chemical parameter in each water sample in mg/L
S_i = the Indian drinking water standard for each chemical parameter in mg/L according to the guidelines of the BIS 10500, (2012)</td></tr>
<tr><th>WQI</th><th>Quality classification</th><th>Remarks</th><th>Colour code</th></tr>
<tr><td colspan="4">Surface Water Quality</td></tr>
<tr><td>63-100</td><td>Good to Excellent</td><td>Non-polluted</td><td></td></tr>
<tr><td>50-63</td><td>Medium to Good</td><td>Non-polluted</td><td></td></tr>
</table>

WQI	Quality classification	Remarks	Colour code
38-50	Bad	Polluted	
38 and less	Bad to Very Bad	Heavily polluted	
Ground Water Quality			
<50	Excellent	Non-polluted	
50-100	Good Water	Non-polluted	
100-200	Poor Water	Polluted	
200-300	Very Poor	Polluted	
>300	Water unsuitable for drinking	Heavily polluted	

7.8.1 Advantages of WQI

The following are the advantages of WQI:

- Reduces the number of parameters needed to compare water quality for a specific application.
- Provides a single number that represents overall water quality to a particular location and time.
- Identifies water quality in terms of time and space dynamics.
- Assures water body's safety to users, such as aquatic life habitat and drinking water supplies.
- Serves as a great way to monitor water quality.
- Allows comparisons between various rivers and sampling sites.
- Simplifies complex dataset into information that is simple to comprehend and use.
- Provides a single-value output derived from several parameters as well as important information about water quality that the general public and non-technical population can understand.
- Serves as a valuable tool for disseminating information about water quality to the general public and legislative decision-makers.

7.8.2 Limitations of WQI

Despite the many benefits of the WQI, it is beset by specific challenges.

- The WQI is not an absolute standard of pollution or water quality.
- There is a lack of precision and accuracy in the classification method of the significance of parameter evaluation.
- It is ineffective in mitigating risk and subjective experience in a complex environmental problem, such as observation incompatibility, uncertainty, and criteria imprecision.
- There is a lack of a standardised method for measuring biological parameters in water pollution.
- The transfer of critical environmental data into meaningful information is insufficient.

7.9 Sanitary Surveillance

The sanitary surveillance (survey) should include the location of all potential and existing health hazards. The information obtained from a sanitary survey is essential for evaluating the microbiological and chemical water quality data. It is desirable to:

i) Identify potential hazards;

ii) Determine factors that affect water quality.

The sanitary survey is elaborately discussed in section 8.7 in Part B of this manual.

The following are some factors that should be investigated in a sanitary survey:

7.9.1 Surface Water

i. Proximity to watershed and character of sources of contamination, including industrial wastes, oil field brines, acid waters from mines, sanitary landfills and agricultural drain waters.

ii. Population and wastewater collection, treatment, and disposal in the watershed.

iii. Closeness of sources of faecal pollution to intake of water supply.

iv. Wind direction and velocity data, the drift of pollution, and algae/aquatic growth potential in case of lake or reservoir supplies.

v. Character and quality of raw water.

vi. Protective measures in the watershed to control fishing, boating, car washing, swimming, wading, ice cutting and permitting animals on shoreline areas.

vii. Efficiency and constancy of surveillance on the watershed and around the surface water source.

7.9.2 Ground Water

i. Nature, distance, and direction of local sources of pollution including pit latrines, twin pits, etc.

ii. Possibility of surface-drainage water entering the supply and of wells becoming flooded.

iii. Drawdown when pumps are in operation, recovery rate when pumps are off.

iv. Methods for protecting the water supply against contamination from wastewater collection, treatment facilities, and waste disposal sites.

v. The presence of an unsafe supply nearby and the possibility of cross-connections cause a danger to public health.

vi. Occurrence of geogenic contaminants such as arsenic, fluoride, etc.

vii. Disinfection: equipment, supervision, test kits, or other types of laboratory control.

7.10 Water Safety Plan (WSP)

"The most effective means of consistently ensuring the safety of a drinking water supply is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in water supply from catchment to consumer." In the Guidelines for Drinking Water Quality, Fourth Edition, published by the World Health Organisation (WHO) in 2011, such an approach is termed a ‘Water Safety Plan’ (WSP).

The purpose of a WSP is to consistently ensure the safety and acceptability of a drinking water supply by adopting principles of preventive management. This is done by eliminating/minimising potential sources of contamination in the catchment, raw water sources, water treatment plants, distribution network, storage, collection, and handling. The concept was drawn from traditional multiple-barrier risk management techniques and the Hazard Analysis at Critical Control Point (HACCP) approach, which has been applied in the food manufacturing industry for several decades. This forms the basis of the development of the WSP approach. WSP can be developed for and applied to a large, piped drinking water supplies, small community supplies and household systems.

Over the last decade, WSPs have gained acceptance as an essential framework for achieving water quality and health-based targets. Public water utilities in Australia, the United Kingdom, Latin America and the Caribbean, Bangladesh and Uganda have successfully developed and implemented WSPs for their water supply systems. Case studies document increased compliance with drinking water quality regulations, improved watershed management practices, reduced cost of operation and significant cost savings as a result of implementing WSPs.

A practical risk management approach is required to resolve the issues of urban water, particularly with respect to inferior water quality. WSP will help in implementing 'Drink from Tap' initiative.

7.10.1 Preparation and Implementation of Water Safety Plan

There are five key components to any WSP:

(i) *System assessment*, which determines if the drinking water supply system, from catchment to consumer, is capable of supplying water of sufficiently high standards to meet regulatory targets. A thorough understanding of the supply system is necessary before the WSP can be developed. For this, a multidisciplinary team familiar with the drinking water supply system should be formed to carry out risk assessment and hazard identification at each process step.

(ii) *Operational monitoring*, to define and validate the monitoring of water quality parameters at each process step and the control measures associated with them. This is done to identify any failures in the system as soon as they occur so that corrective actions can be taken without delay.

(iii) *Management plans*, which include supporting programmes, describe actions taken during normal and incident operational conditions and define a schedule for review of the WSP. This ensures the correct implementation and continued effectiveness of the WSP in meeting water quality standards.

(iv) Management and communication.

(v) WSP review and improvement.

It is recommended that ULBs should prepare and implement water safety plans. Preparing and implementing a water safety plan will help to ensure water safety in the water supply system and match International best practices. World Health Organisation (2023), Water safety plan manual: step-by-step risk management for drinking water suppliers, Second Edition should be used to prepare WSP:

There are 10 modules (Table 7.17) in the Manual which will help in preparing water safety plan document by ULB.

Table 7.17: Water Safety Planning: Overview of the 10 Modules

WSP Component	Module No.	Title	Addresses
Preparation	1	Assembling the WSP Team	Who will lead WSP development and implementation?
System Assessment	2	Describing the System	How does the system deliver drinking water from catchment to consumer?

WSP Component	Module No.	Title	Addresses
	3	Identifying hazards and hazardous events	What could go wrong?
	4	Validating existing control measures and assessing risks	How effective are the control measures and how important are the risks?
	5	Planning for improvement	What needs to be improved to ensure the supply of safe drinking water, and how?
Monitoring	6	Monitoring control measures	Are the control measures operating as intended?
	7	Verifying the effectiveness of water safety planning	How do we know that the WSP is working and effective?
Management and Communication	8	Strengthening management procedures	What management procedures should be used for normal and abnormal conditions?
	9	Strengthening WSP supporting programmes	What is the best way to support the implementation of water safety planning?
WSP review and improvement	10	Reviewing and updating the WSP	How will the WSP be kept up to date?

Case studies from India are presented below which can be referred while preparing water safety plan:

Case Study

Hazard in the catchment and implementation of control measures

Figure 1: Ash Pond in the Catchment of Kanhan River

(Intake well of Kanhan WTP encircled, and change in colour of water due to overflow of breached ash pond in February 2017)

Kanhan river is a major source of water supply to Nagpur, India. A water safety plan was prepared in 2011 and updated in 2014. The ash pond of Koradi/Khaparkheda thermal power plants upstream of the intake point in the catchment was identified as a major hazard. Supernatant/overflow from the ash pond to the intake point in Kanhan River was identified as a major hazardous event in WSP-2011. In contrast, the breach is identified as another hazardous event in WSP-2014 (this was missed in earlier WSP). Although existing control measures, such as a bund around the ash pond, were in place, the residual risk was identified as high. Control measures like co-ordination among thermal power plant authorities, water suppliers and statutory authorities were also recommended. Another measure was a stoppage of the intake well pumping if there was the slightest evidence of ash in the river water. Water suppliers implemented these measures. There was an accidental breach in the ash pond in February 2017 (Figure 1), and because of the control measures in place, the water supply from Kanhan river could be normalised in a couple of days which otherwise could have taken weeks.

Case Study

Hazard Identification and implementation of control measures in Master Balancing Reservoir

The Master Balancing Reservoir (MBR), with a capacity of about 2.5 million litres located in Seminary Hills, was in a state of disrepair. Leakage was observed at its inlet valve (Figure 2), which was identified as a major hazard during the WSP preparation in 2011. The slabs of the inlet chamber were in need of repair and the iron reinforcement rods were corroded. Control measures included the replacement of the valve as the risk was very high. The water supplier implemented and replaced the valve (Figure 3).

Figure 2: Leaking valve identified as a very high risk during WSP preparation

Figure 3: Replacement of leaking valve (an example of control measure implementation)