

Tool and Guideline # 10

**Practical Tools on
Water Monitoring Methods and
Instrumentation**

**Rwanda Environment Management Authority
Republic of Rwanda
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PREFACE

In 2010, REMA prepared 11 practical technical tools intended to strengthen environmental management capacities of districts, sectors and towns. Although not intended to provide an exhaustive account of approaches and situations, these tools are part of REMA's objective to address capacity-building needs of officers by providing practical guidelines and tools for an array of investments initiatives.

Tools and Guidelines in this series are as follows:

#	<i>TOOLS AND GUIDELINES</i>
1	Practical Tools for Sectoral Environmental Planning : A - Building Constructions B - Rural Roads C - Water Supply D - Sanitation Systems E - Forestry F - Crop Production G - Animal Husbandry H - Irrigation I - Fish Farming J - Solid Waste Management
2	Practical Tools on Land Management - GPS, Mapping and GIS
3	Practical Tools on Restoration and Conservation of Protected Wetlands
4	Practical Tools on Sustainable Agriculture
5	Practical Tools on Soil and Water Conservation Measures
6	Practical Tools on Agroforestry
7	Practical Tools of Irrigated Agriculture on Non-Protected Wetlands
8	Practical Tools on Soil Productivity and Crop Production
9	Practical Technical Information on Low-cost Technologies: Composting Latrines & Rainwater Harvesting Infrastructure
10	Practical Tools on Water Monitoring Methods and Instrumentation
11	11.1 Practical Tools on Solid Waste Management of Imidugudu, Small Towns and Cities : Landfill and Composting Facilities
	11.2 Practical Tools on Small-scale Incinerators for Biomedical Waste Management

These tools are based on the compilation of relevant subject literature, observations, experience, and advice of colleagues in REMA and other institutions. Mainstreaming gender and social issues has been addressed as cross-cutting issues under the relevant themes during the development of these tools.

The Tool and Guideline # 10 provides practical information on water monitoring methods and instrumentation.

These tools could not have been produced without the dedication and cooperation of the REMA editorial staff. Their work is gratefully acknowledged.

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Acronyms

AAS	atomic absorption spectrometry
AES	atomic emission spectrometry
BOD	biochemical oxygen demand
°C	degree Celsius
COD	chemical oxygen demand
CDOM	colored dissolved organic matter
DO	dissolved oxygen
DOC	dissolved Organic Carbon
DDT	dichlorodiphenyltrichloroethane
EC	electrical conductivity
EDTA	ethylene-diamine tetra acetic acid
EMF	electro motive force
FAS	ferrous ammonium sulphate
N	nitrate-N
PCBs	polychlorinated biphenyl
REMA	Rwanda Environment Management Authority
TS	total solids
TSS	total suspended solids
TDS	total dissolved solids
VOC	volatile organic compounds
WHO	World Health Organization

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Practical Tools on Water Monitoring Methods and Instrumentation

1. INTRODUCTION

1.1 Overview

Limited information is available on the extent and quality of surface and groundwater sources in Rwanda. Despite having abundant and good quality water supplies, Rwanda faces a number of challenges in the water sector. The key issues identified in water sector include:

- Massive increases in projected water demand;
- Drinking water crisis, emerging threats to freshwater supplies;
- Water governance; and
- Gender mainstreaming.

How do we get information on the condition of Rwanda's streams, lakes, estuaries, and wetlands? On whether these waters are safe enough to use for drinking? Monitoring provides this basic information.

There are many ways to monitor water conditions. Monitoring specialists sample the chemical condition of water, and sediments to determine levels of key constituents such as dissolved oxygen, nutrients, metals, oils, and pesticides. They also monitor physical conditions such as temperature, flow, sediments, and the erosion potential of stream banks and lake shores and biological conditions and parameters such as *Escherichia coli* and Shigella.

Monitoring can be conducted at regular sites ("fixed stations") on a continuous basis; at selected sites on an as-needed basis, to answer specific questions, or to characterize a watershed; on a temporary or seasonal basis; at random sites throughout an area; or on an emergency basis (such as after a spill). Increasingly, monitoring efforts are aimed at determining the condition of entire watersheds -- the area drained by rivers, lakes, and wetlands. This is because we have come to realize the impact of land-based activities on the waters that drain the land, and the interconnectedness of all types of water bodies, including those beneath the ground.

Monitoring can be conducted for many purposes. Five major purposes are to:

- Characterize waters and identify changes or trends in water quality over time;
- Identify specific existing or emerging water quality problems;
- Gather information to design specific pollution prevention or remediation programs;
- Determine whether program goals -- such as compliance with pollution regulations or implementation of effective pollution control actions -- are being met; and
- Respond to emergencies, such as spills and floods.

1.2 PURPOSE

This technical guideline provides practical information on water monitoring methods and instrumentation. REMA has key monitoring responsibilities and conducts vigorous monitoring programs. Other ministries are also involved in water quality monitoring. Lastly, private entities such as universities, NGOs, environmental groups also conduct water quality monitoring. They may collect water quality data for their own purposes, or to share with government decision makers. Data collected by REMA and other ministries are needed to build the assessments needed to make better pollution control decisions. Without data, REMA cannot know where pollution problems exist, where focus is needed to control pollution.

Although not intended to provide an exhaustive account of approaches and situations, this tool is intended to address capacity-building needs of officers by providing information water monitoring methods and approaches. This tool can be used as field guides or as checklists of elements for discussion during training and during implementation of water monitoring.

This document was produced to address REMA's proposed policy action to strengthen the resource capacity of environmental and related institutions at national and district level for environmental assessment, policy analysis, monitoring, and enforcement.

2. WATER MONITORING PROGRAM

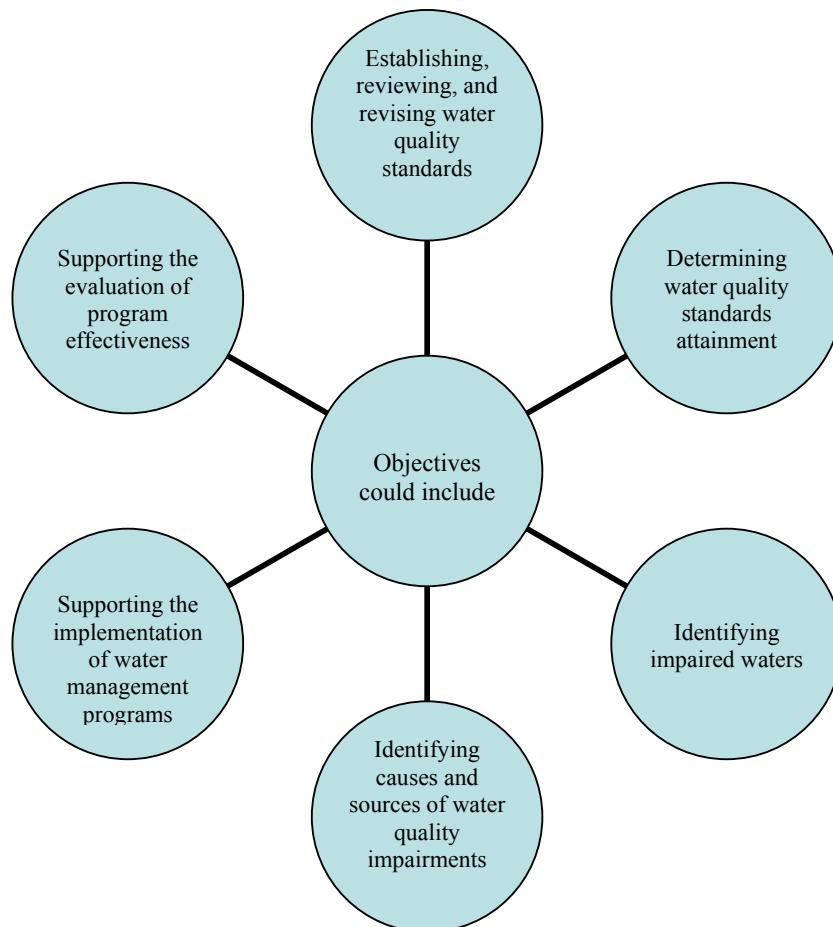
This section describes the operation, methods, systems, and procedures necessary to monitor and to compile and analyze data on the quality of waters in Rwanda and the basic elements of a water monitoring program.

2.1 Monitoring Program Strategy

The monitoring program strategy serves its water quality management needs and addresses all water resources, including streams, rivers, lakes, reservoirs, estuaries, wetlands, and groundwater. The strategy should contain or reference a description of how the province or districts plans to address each of the remaining elements. The monitoring program strategy is a long-term implementation plan and should include a timeline, not to exceed ten years, for completing implementation of the strategy.

2.2 Monitoring Objectives

The monitoring objectives are critical to the design of efficient and effective monitoring program. For example, monitoring objectives could include helping establish water quality standards, determining water quality status and trends, identifying impaired waters, identifying causes and sources of water quality problems, implementing water quality management programs, and evaluating program effectiveness. The monitoring objectives should reflect the decision needs relevant to all types of water resources.



In general, a monitoring program should be able to answer the following five questions:

1. What is the overall quality of waters?

- To determine the extent to which waters meet applicable water quality standards, and provide for the protection and propagation of balanced populations of fish, and wildlife.

2. To what extent is water quality changing over time?

- To assess and report on the extent to which control programs have improved water quality or will improve water quality for the purposes of the protection and propagation of a balanced population of fish, and wildlife and recreational activities in and on the water.
- To assess and report on reductions in nonpoint-source loadings and related improvements in water quality.
- To assess and report on the status and trends of water quality in lakes or wetlands.

3. What are the problem areas and areas needing protection?

- To assess impaired waters.
- To identify waters currently of high quality and should be protected from degradation.
- In order to protect and restore waters, monitoring and assessment programs should identify the causes and sources of impairment.

4. What level of protection is needed?

- To establish the level of protection that is being monitored against. For example, uses of data from monitoring programs to conduct triennial reviews of water quality standards, conduct use attainability analyses, develop and adopt revised designated uses and water quality criteria, establish water quality-based effluent limits, establish total maximum daily loads, and assess which levels of best management practices for nonpoint sources are most appropriate.

5. How effective are clean water projects and programs?

- To evaluate the effectiveness of specific projects and overall programs, including but not limited to nonpoint source control, total maximum daily loads, water quality standards, compliance programs, and generally to determine the success of management measures.

2.3 Monitoring Design

The approach and rationale for the selection of monitoring designs should serve its monitoring objectives. The monitoring program may likely integrate several monitoring designs such as fixed station or intensive and screening-level monitoring to meet the full range of decision needs. The monitoring design should include probability-based networks (at the watershed level) that support statistically valid inferences about the condition of all water types, over time using efficient combination of monitoring designs to meet its objectives.

An integrated design for assessing water quality incorporates multiple tools in a tiered approach to address management decisions at multiple scales. These tools include probabilistic designs, landscape and water quality modeling, and targeted site-specific monitoring. This tiered approach enables to make statistically valid inferences of the extent that waters meet water quality standards, to predict which waters are most likely degraded or at risk for degradation, and to target site specific monitoring needed to address local water

quality concerns. The efficiencies of an integrated design should extend beyond monitoring costs to program costs because it can help prioritize which water bodies need more immediate attention.

The monitoring design should address the objectives outlined in Section 2.2, above. The design should include a comprehensive approach to assessment using multiple indicators for all waters on a continuing basis. The elements of the monitoring design should support the estimation of the amount or percentage of waters that are impaired for each water body type, with a high degree of confidence.

To meet its monitoring objectives, it is suggested that the selected monitoring design yields scientifically valid results and meets the needs of the decision maker. The monitoring design should incorporate appropriate methods to control decision errors and balance the possibility of making incorrect decisions. The levels of precision and confidence should be appropriate to the monitoring objective and the type of data collected.

2.4 Water Quality

Water quality is the physical, chemical and biological characteristics of water. It is most frequently used by reference to a set of standards against which compliance can be assessed. The most common standards used to assess water quality relate to drinking water, safety of human contact, and for health of ecosystems. The vast majority of surface water on the planet is neither potable nor toxic. Another general perception of water quality is that of a simple property that tells whether water is polluted or not. In fact, water quality is a very complex subject, in part because water is a complex medium intrinsically tied to the ecology of the Earth. Industrial pollution is a major cause of water pollution, as well as runoff from agricultural areas, urban storm water runoff and discharge of treated and untreated sewage. The parameters for water quality are determined by the intended use. Work in the area of water quality tends to be focused on water that is treated for human consumption or in the environment.

- *Human consumption:* Contaminants that may be in untreated water include microorganisms such as viruses and bacteria; inorganic contaminants such as salts and metals; pesticides and herbicides; organic chemical contaminants from industrial processes and petroleum use; and radioactive contaminants. Water quality depends on the local geology and ecosystem, as well as human uses. Some people use water purification technology to remove contaminants from the municipal water supply they get in their homes, or from local pumps or bodies of water. For people who get water from a local stream, lake, or aquifer (well), their drinking water is not filtered by the local government.
- *Environmental water quality:* Environmental water quality relates to water bodies such as lakes, rivers, and wetlands. Water quality standards vary significantly due to different environmental conditions, ecosystems, and intended human uses. Toxic substances and high populations of certain microorganisms can present a health hazard for non-drinking purposes such as irrigation. These conditions may also affect wildlife which uses the water for drinking or as a habitat. Modern water quality laws generally specify protection of fisheries and recreational use and require as a minimum, retention of current quality standards.

The complexity of water quality as a subject is reflected in the many types of measurements of water quality indicators. Some of the simple measurements listed below can be made on-site: temperature, pH, dissolved oxygen, conductivity, and oxygen reduction potential, in direct contact with the water source in question. More complex measurements that must be

made in a lab setting require a water sample to be collected, preserved, and analyzed at another location. Making these complex measurements can be expensive. Because direct measurements of water quality can be expensive, ongoing monitoring programs are typically conducted. Tools available are on-site test kits commonly used for water quality testing.

The following is a list of indicators often measured by situational category:

Table 1: Water Quality Standards

<i>Drinking water</i>	<i>Environmental</i>
<ul style="list-style-type: none"> • Alkalinity • Color of water • pH • Taste and odor (geosmin, 2-methylisoborneol (MIB), etc) • Dissolved metals and salts (sodium, chloride, potassium, calcium, manganese, magnesium) • Microorganisms such as fecal coliform bacteria (<i>Escherichia coli</i>), Cryptosporidium, Giardia lamblia and Shigella • Dissolved metals and metalloids (lead, mercury, arsenic, etc.) • Dissolved organics: colored dissolved organic matter (CDOM), dissolved organic carbon (DOC) • Radon • Heavy metals • Pharmaceuticals • Hormone analogs 	<p>Chemical assessment</p> <ul style="list-style-type: none"> • Conductivity • Dissolved Oxygen (DO) • Nitrate-N • Orthophosphates • Chemical oxygen demand (COD) • Biochemical oxygen demand (BOD) • Pesticides <p>Physical assessment</p> <ul style="list-style-type: none"> • pH • Temperature • Total suspended solids (TSS) <p>Turbidity</p>

The Rwanda National drinking water quality standards exist and are the same as the WHO Guidelines. Annex 1 provides the complete WHO Drinking Water Chemical Summary Table for chemicals that are of health significance in drinking-water. Detail information is available in this website. http://www.who.int/water_sanitation_health/dwq/gdwq3rev/en/index.html.

The most undesirable constituents of drinking-water are those capable of having a direct adverse impact on public health. The acceptability of drinking-water is subjective and can be influenced by many different constituents. The next table provides guidance on numbers and problems that may occur because of chemically derived contaminants of water quality

Table 2: Acceptability Aspects of Key Chemically Derived Contaminants

<i>Key contaminants</i>	<i>Acceptability aspects</i>
Ammonia	The threshold odour concentration of ammonia at alkaline pH is approximately 1.5 mg/litre, and a taste threshold of 35 mg/litre has been proposed for the ammonium cation.
Chloride	High concentrations of chloride give a salty taste to water and beverages. Taste thresholds for the chloride anion depend on the associated cation and are in the range of 200–300 mg/litre for sodium, potassium and calcium chloride. Concentrations in excess of 250 mg/litre are increasingly likely to be detected by taste, but some consumers may become accustomed to low levels of chloride-induced taste.
Chlorine	Most individuals are able to taste or smell chlorine in drinking-water at concentrations well below 5mg/litre, and some at levels as low as 0.3 mg/litre. At a residual free chlorine concentration of between 0.6 and 1.0mg/litre, there is an increasing likelihood that some consumers may object to the taste.
Colour	Drinking-water should ideally have no visible colour.

Dissolved oxygen	The dissolved oxygen content of water is influenced by the source, raw water temperature, treatment and chemical or biological processes taking place in the distribution system. Depletion of dissolved oxygen in water supplies can encourage the microbial reduction of nitrate to nitrite and sulfate to sulfide. It can also cause an increase in the concentration of ferrous iron in solution, with subsequent discoloration at the tap when the water is aerated.
Hardness	Hardness caused by calcium and magnesium is usually indicated by precipitation of soap scum and the need for excess use of soap to achieve cleaning. Public acceptability of the degree of hardness of water may vary considerably from one community to another, depending on local conditions. In particular, consumers are likely to notice changes in hardness. The taste threshold for the calcium ion is in the range of 100–300 mg/litre, depending on the associated anion, and the taste threshold for magnesium is probably lower than that for calcium.
Hydrogen sulphide	The taste and odour thresholds of hydrogen sulfide in water are estimated to be between 0.05 and 0.1mg/litre. The “rotten eggs” odour of hydrogen sulfide is particularly noticeable in some groundwaters and in stagnant drinking-water in the distribution system, as a result of oxygen depletion and the subsequent reduction of sulfate by bacterial activity. Sulfide is oxidized rapidly to sulfate in well aerated or chlorinated water, and hydrogen sulfide levels in oxygenated water supplies are normally very low. The presence of hydrogen sulfide in drinking-water can be easily detected by the consumer and requires immediate corrective action.
Iron	Anaerobic groundwater may contain ferrous iron at concentrations of up to several milligrams per litre without discoloration or turbidity in the water when directly pumped from a well. On exposure to the atmosphere, however, the ferrous iron oxidizes to ferric iron, giving an objectionable reddish-brown colour to the water. Iron also promotes the growth of “iron bacteria,” which derive their energy from the oxidation of ferrous iron to ferric iron and in the process deposit a slimy coating on the piping.
Manganese	At levels exceeding 0.1 mg/litre, manganese in water supplies causes an undesirable taste in beverages and stains sanitary ware and laundry. The presence of manganese in drinking-water, like that of iron, may lead to the accumulation of deposits in the distribution system. Concentrations below 0.1 mg/litre are usually acceptable to consumers. Even at a concentration of 0.2 mg/litre, manganese will often form a coating on pipes, which may slough off as a black precipitate. The health-based guideline value for manganese is 4 times higher than this acceptability threshold of 0.1 mg/litre.
pH	Although pH usually has no direct impact on consumers, it is one of the most important operational water quality parameters. Careful attention to pH control is necessary at all stages of water treatment to ensure satisfactory water clarification and disinfection. The optimum pH required will vary in different supplies according to the composition of the water and the nature of the construction materials used in the distribution system, but it is usually in the range 6.5–8.
Sodium	The taste threshold concentration of sodium in water depends on the associated anion and the temperature of the solution. At room temperature, the average taste threshold for sodium is about 200 mg/litre.
Sulfate	The presence of sulphate in drinking-water can cause noticeable taste, and very high levels might cause a laxative effect in unaccustomed consumers. Taste impairment varies with the nature of the associated cation; taste thresholds have been found to range from 250mg/litre for sodium sulfate to 1000 mg/litre for calcium sulfate. It is generally considered that taste impairment is minimal at levels below 250 mg/litre.
Zinc	Zinc imparts an undesirable astringent taste to water at a taste threshold concentration of about 4mg/litre (as zinc sulfate). Water containing zinc at concentrations in excess of 3–5 mg/litre may appear opalescent and develop a greasy film on boiling. Although drinking-water seldom contains zinc at concentrations above 0.1 mg/litre, levels in tap water can be considerably higher because of the zinc used in older galvanized plumbing materials.

The potential waterborne pathogens include bacteria, viruses, protozoa and helminths. The human health effects caused by waterborne transmission vary in severity from mild gastroenteritis to severe and sometimes fatal diarrhoea, dysentery, hepatitis and typhoid fever. Contaminated water can be the source of large outbreaks of disease, including cholera, dysentery and cryptosporidiosis; for the majority of waterborne pathogens, however, there are other important sources of infection, such as person to- person contact and food. Most waterborne pathogens are introduced into drinking-water supplies in human or animal faeces, do not grow in water and initiate infection in the gastrointestinal tract following ingestion.

2.5 Water Quality Indicators

The water quality indicators should also be designated plus supplemental indicators selected according to site-specific or project-specific decision criteria. Core indicators for each water resource type include physical/habitat, chemical/toxicological, and biological/ecological endpoints as appropriate, and can be used routinely to assess attainment with applicable water quality standards throughout Rwanda. Supplemental indicators are used when there is a reasonable expectation that a specific pollutant may be present in a watershed, when core indicators indicate impairment, or to support a special study such as screening for potential pollutants of concern.

Because limited resources affect the design of water quality monitoring programs, it is suggested to use a tiered approach to monitoring that includes a core set of baseline indicators selected to represent each applicable designated use, plus supplemental indicators selected according to site-specific or project-specific decision criteria. Using this tiered approach, REMA should be able to make the best use of its resources to meet water quality decision needs, including assessing water quality standards attainment and designated use support, identifying needed changes to water quality standards, describing causes and sources of impairments, developing water quality-based source controls, and assessing whether physical, chemical, and biological integrity are supported.

The monitoring strategy should define a core set of indicators (e.g., water quality parameters) for each water resource type that include physical/habitat, chemical/toxicological, and biological/ecological endpoints as appropriate, that reflect designated uses, and that can be used routinely to assess attainment with applicable water quality standards throughout the country. This core set of indicators is monitored to provide basin/watershed level information on the fundamental attributes of the aquatic environment and to assess water quality standards attainment/impairment status. Previously, chemical and physical indicators were emphasized; however, biological monitoring and assessment should assume a more prominent role in monitoring.

The strategy should also describe a process for identifying supplemental indicators to monitor when there is a reasonable expectation that a specific pollutant may be present in a watershed, when core indicators indicate impairment, or to support a special study such as screening for potential pollutants of concern. Supplemental indicators are often key to identifying causes and sources of impairments and targeting appropriate source controls. These supplemental indicators may include each water quality criteria in the Rwanda's water quality standards. Table 2 presents examples of recommended core and supplemental water quality indicators.

Table 3: Water Quality Indicators for General Designated Use Categories

	Recommended Core and Supplemental Indicators			
	Aquatic Life & Wildlife	Recreation	Drinking Water	Fish Consumption
Recommended Core Indicators	<ul style="list-style-type: none"> *Condition of biological communities *Dissolved oxygen *Temperature *Conductivity *pH *Habitat assessment *Flow *Nutrients *Landscape conditions (e.g., % cover of land uses) Additional indicators for lakes: <ul style="list-style-type: none"> *Eutrophic condition Additional indicators for wetlands: <ul style="list-style-type: none"> *Wetland hydrogeomorphic settings and functions 	<ul style="list-style-type: none"> *Pathogen indicators (<i>E. coli</i>, enterococci) *Nuisance plant Growth *Flow *Nutrients *Chlorophyll *Landscape conditions (e.g., % cover of land uses) Additional indicators for lakes: <ul style="list-style-type: none"> *depth Additional indicators for wetlands: <ul style="list-style-type: none"> *Wetland hydrogeomorphic settings and functions 	<ul style="list-style-type: none"> *Trace metals *Pathogens *Nitrates *Salinity *Sediments/TDS *Flow *Landscape conditions (e.g., % cover of land uses) 	<ul style="list-style-type: none"> *Pathogens *Mercury *Chlordane *DDT *PCBs *Landscape conditions (e.g., % cover of land uses)
Supplemental Indicators	<ul style="list-style-type: none"> *Ambient toxicity *Sediment toxicity *Other chemicals of concern in water column or sediment *Health of organisms 	<ul style="list-style-type: none"> *Other chemicals of concern in water column or sediment *Hazardous chemicals *Aesthetics 	<ul style="list-style-type: none"> *VOCs (in reservoirs) *Hydrophylic pesticides *Nutrients *Other chemicals of concern in water column or sediment *Algae 	<ul style="list-style-type: none"> *Other chemicals of concern in water column or sediment

2.6 Quality Assurance

Quality management plans and quality assurance program/project plans are established, maintained, and peer reviewed in accordance with REMA policy to ensure the scientific validity of monitoring and laboratory activities, and to ensure that reporting requirements are met.

The Quality Management Plan determines how the monitoring program will plan, implement, and assess the effectiveness of its quality assurance and quality control operations. Quality Assurance Project Plans document the planning, implementation, and assessment procedures for a particular project, as well as any specific quality assurance and quality control activities.

These plans should reflect the level of data quality that is appropriate for the specific uses of the data, such as comprehensive assessment and listing of impaired waters. Data quality and quantity needs are expected to vary according to the consequences of the resulting water quality decisions.

The Quality Assurance Program Plan should provide a description of how:

- Monitoring program objectives are defined in specific qualitative and quantitative terms and linked to an environmental management decision or reporting requirements.
- Selected indicators offer the most direct means of assessing the environmental attribute under study, based upon the associated requirements.
- The uncertainty associated with estimates and conclusions drawn from each component of the monitoring program are understood, quantified, and limited to a reasonable extent.
- The proposed sampling scheme will yield data that are representative of the environmental attribute under study, with consideration of statistical probabilities associated with sampling.
- The quality of the data is assessed and validated to ensure that the data quality objectives of the programs were met.

2.7 Data Analysis, Assessment and Reporting

The methodology for assessing attainment of water quality standards based on analysis of various types of data (chemical, physical, biological, land use) from various sources, for all water body types. The methodology includes criteria for compiling, analyzing, and integrating all readily available and existing information.

The methodology should describe how existing and available data and information relevant to applicable water quality standards, including both core and supplemental indicators, will be compiled and analyzed to make attainment decisions about waters.

The methodology should:

- Identify the required or likely sources of existing and available data and information and procedures for collecting or assembling it;
- Describe or reference requirements relating to data quality and representativeness, such as analytical precision, temporal and geographical representation, and metadata documentation needs;
- Include or reference procedures for evaluating the quality of datasets; and
- Explain data reduction procedures (e.g., statistical analyses) appropriate for comparing data to applicable water quality standards.

Timely and complete water quality reports should be prepared.

2.8 Simple steps in water sampling, analysis and interpretation

In order for water sampling results to be valuable, proper sampling techniques, careful analysis in the laboratory and qualified interpretation of the results are required. Water chemistry compounds present in water are small quantities. These small concentrations--usually measured in parts per million or parts per billion--will determine how the water needs to be treated. To get accurate levels of these compounds it's essential that not only one, but several steps, are carried out with the utmost care and knowledge.

- Step 1: Prepare sample containers for sampling. These containers mustn't contain any of the compounds that samples are to be analyzed for. Sampling bottle material must be suitable for sampling the water without affecting the compound.
- Step 2: The sampling procedure. This must be rigorous, ensuring that a representative sample is collected and at no time is the sample or sample bottle contaminated by the collector. This is no trivial task when it comes to collecting samples with low levels of compounds such as phosphorus. Depending on the compounds to be analyzed, a preservative may be necessary.
- Step 3: Transport to the laboratory for analysis. This needs to be done under appropriate conditions, often in a dark cooler with ice packs.
- Step 4: Processing the water sample. Many samples need to be filtered before testing. In some cases, the filtering step must be done in the field as soon as the sample has been collected. The sample analysis needs to be carried out according to a protocol that doesn't introduce contaminants or otherwise compromise the sample. After suitable processing, the sample is ready to be analyzed.
- Step 5: Analysis. This fifth step can also introduce problems. The laboratory needs to have quality control/assurance procedures in place so analytical values aren't compromised. If the laboratory routinely processes concentrated samples, assurance is needed that water samples will be analyzed in a "clean" fashion. Typically, instruments dedicated for drinking water quality analyses work at lower concentration levels than instruments that are used on every incoming sample. Therefore, when procedures and instruments are subjected to wide ranges of different compounds, the detection of low levels may not be as accurate. Laboratory accreditation can be helpful in dealing with some parameters. One way to determine the accuracy of the work carried out is to include double blind samples (several samples of the same water). The analytical laboratory will determine how much of a particular compound is present in the water.
- Step 6: Interpretation. An institution or individual submitting the sample needs to take a good look at the numbers and try to make sense of them. Because there may have been problems with one or two steps in the sequence, the numbers may make little sense. This is where training in water quality is required.

3. CASE STUDY – MONITORING WATER QUALITY OF WETLANDS

3.1 Objectives

Wetlands can be degraded by both natural and anthropogenic activities, which deteriorate their quality. The degradation of the wetlands can alter their functions, affecting the ecological balance. The objectives of carrying out the physico-chemical and biological analyses these water bodies are as follows:

- Generally, wetland functions directly relate to their physical, chemical and biological integrity. Water quality evaluation for wetlands leads to information about their misuse by indicating the pollution status. Since the quality of aquatic life depends on the water quality, a thorough assessment of the water quality is an integral part of lake or wetland or lake evaluation. The assessment of the chemical criteria of the water body helps in:
 - Evaluating the chemicals that cause toxicity to aquatic life.
 - Studying the long-term effects on the ecosystem.

- Conducting the status and monitoring of wetland resources by studying their physico-chemical and biological parameters.
- Designate uses that protect the structure and function of wetlands for protection of fish, birds, wildlife, and recreation. The baseline values attached to wetlands in terms of designating the viable usage of these water bodies based on established standards protecting their functions is also attempted.
- Analyse the qualitative and quantitative aspects of plankton population of the water bodies. The biological integrity of the wetlands is the driving force for their sound ecological functioning. Wetlands that support a vast diversity of fish, birds, mammals, etc., depend directly on it by supporting vast and diverse forms of plankton providing a nutrient base and a complex food-web. In many cases, planktons also act as the biological indicators of pollution being very sensitive to changes in water quality.

3.2 Hydrological features

A thorough knowledge of the hydrological properties of the water body must be acquired before an effective water quality monitoring system is established. Each of the inland water body is characterised by unique hydrological features such as:

- Rivers: characterised by uni-directional current with relatively high average velocity. In general, thorough and continuous vertical mixing is achieved in rivers due to the prevailing currents and turbulence.
- Lakes: characterised by low, average current giving higher residential time for water. Currents within a lake are multi-directional with mixing regulated by the climatic conditions and lake depth.
- Ground water: characterised by a steady flow pattern both in direction and speed that is largely governed by the porosity of the geological material as a result of which the mixing is poor.
- Reservoirs: intermediate between rivers and lakes.

Large variations in the water residence time occur in different types of inland water bodies. The hydrodynamic characteristics of each type of water body are highly dependent on the size of the water body, climatic conditions and the drainage pattern associated with it. Ground water greatly depends on the recharge regime i.e. infiltration through unsaturated aquifer zone, that allows renewal of the groundwater.

3.3 Physical, chemical and biological properties

The physical and chemical properties of a freshwater body are characteristic of the climatic, geochemical, geomorphological and pollution conditions (largely) prevailing in the drainage basin and the underlying aquifer. The biota in the surface water is governed entirely by various environmental conditions that determine the selection of species as the physiological performance of the individual organisms. The primary production of organic matter, in the form of phytoplankton and macrophytes is more intense in lakes and reservoirs than in rivers. In contrast to the chemical quality of water bodies, which can be measured by suitable analytical methods, biological quality is a combination of both qualitative and quantitative characterisation. This can be carried out in two levels:

- Response of individual species to changes in its environment.
- Response of biological communities to changes in their environment.

The sample collected should be small in volume, enough to accurately represent the whole water body. The water sample tends to modify itself to the new environment. It is necessary to

ensure that no significant changes occur in the sample and preserve its integrity till analysed (by retaining the same concentration of all the components as in the water body). The essential objectives of water quality assessment are to:

- Define the status and trends in water quality of a given water body.
- Analyse the causes for the observed conditions and trends.
- Identify the area specific problems of water quality and provide assessments in the form of management to evaluate alternatives that help in decision-making.

Sampling sites are selected to represent the water quality at different points and depths. Generally three sampling sites are selected for monitoring:

- Inlet: the point where the principal feeder opens into the lake;
- Center: the point that gives the general water quality of the lake;
- Outlet: the place where the overflow occurs.

Generally three types of sampling are adopted for collecting water samples.

- Grab or Catch sampling: the sample is collected at a particular time and place that represents the composition of the source at that particular point and time.
- Composite sampling: a mixture of grab samples is collected at the same sampling point at different time intervals.
- Integrated sampling: a mixture of grab samples collected at different points simultaneously.

The quality of water varies with time in a water body due to various natural and human induced factors. The monitoring has to be done in a way that records all the changes in the quality. The sampling frequencies generally adopted in monitoring are:

- Weekly sampling for one year.
- Consecutive day sampling during study period.
- Hourly sampling for 24 hours.
- Monthly sampling at predefined time.

Variations in water quality are mainly due to changes in the concentrations of the components of the water flowing into the water body. These variations can be man-made or natural and can either be cyclic or random.

- Random variations: due to spasmodic, often unpredictable events such as accidental oil spills, sewage leaks, overflows, etc.
- Cyclic variations: may be a result of regular seasonal changes triggering certain natural processes such as rainfall, snowmelts and seasonal temperature changes, altering the ecosystem. Seasonal growth and decay of vegetation will also rise due to cyclic changes in the composition of water.

3.4 Parameters

The parameters analysed to assess the water quality of wetlands are broadly divided these parameters.

Table 4: Parameters

<i>Parameters</i>	<i>Examples</i>
Physical parameters:	Colour and Temperature
Chemical parameters:	pH, Electrical Conductivity, Total Solids, Total Dissolved Solids, Total Suspended Solids, Total Hardness, Calcium Hardness, Magnesium Hardness, Nitrates, Phosphates, Sulphates, Chlorides, Dissolved Oxygen, Biological Oxygen Demand, Chemical Oxygen Demand

<i>Parameters</i>	<i>Examples</i>
Heavy metals:	Lead, Copper, Nickel, Iron, Chromium, Cadmium and Zinc
Biological parameters:	The biological parameters involved the qualitative analyses of planktons (zooplankton and phytoplankton)

Annex 3 provides detail information on the analyses of physical, chemical and biological parameters.

4. INSTRUMENTATION

The use of laboratory to support and satisfy scientifically documented appropriate methods that meet established criteria for accuracy, sensitivity, bias, and precision and comply with specified data quality needs or requirements is required in some cases.

Portable equipment can also be used to monitor pollution in the water environment, for example in waste water, rivers, lakes, trade effluents and groundwater. Portable field kits are also useful for the field testing of samples in a water quality monitoring programme.

District and sector officers can be equipped with this equipment:

- Surface Water Test Kit, Multi-Parameter (Hach) 245 \$US : Providing economical, easy-to-use tests for ammonia, chlorine, pH, nitrate, dissolved oxygen, phosphorus, and temperature, the Surface Water Test Kit is an ideal tool for both industrial and municipal water treatment plants. The rugged, lightweight kit includes the convenient pH Pocket Pal(TM) Tester and all necessary apparatus and reagents for testing.
- Chlorine, Coliform, and pH Test Kit, Model CEC-2 (Hach) 708 \$US: Coliforms are reliable indicator organisms for testing water quality because they travel with disease-producing microorganisms and are easy to isolate. The presence of coliforms in drinking water indicates the water may not be suitable for drinking and may need to treat with a disinfectant such as chlorine. The coliform test uses tryptose broth and MUG reagent. It provides a reliable, quick way to determine the presumptive presence of coliforms and the specific presence of Escherichia coli, a fecal coliform.
- Wastewater Treatment Plant Laboratory, Model STPL-WRT (Hach) 1835 \$US: A test kit designed as a complete, self-contained portable laboratory provides convenience for wastewater treatment plant operators. Necessary reagents and equipment are supplied to test for temperature, pH, dissolved oxygen, and chlorine.
- Groundwater Multi-parameter water quality tester 2000 \$US: Hand held instrument for the measurement of six different water quality parameters pH, Conductivity, Salinity, Dissolved Oxygen Temperature and Turbidity. All of the six sensors are enclosed inside one probe which can be directly submersed in a river well or other water source with no sample collecting required.
- The descriptions of other portable kits available from some of the major suppliers is found in this WHO web sites: (http://www.who.int/water_sanitation_health/resourcesquality/wqmappendix1.pdf)

Annex 1: WHO Drinking Water Chemical Summary Table

WHO Guideline values for chemicals that are of health significance in drinking-water

<i>Chemical</i>	<i>Guideline value^a (mg/litre)</i>	<i>Remarks</i>
Acrylamide	0.0005 ^b	
Alachlor	0.02b	
Aldicarb	0.01	Applies to aldicarb sulfoxide and aldicarb sulfone
Aldrin and dieldrin	0.00003	For combined aldrin plus dieldrin
Antimony	0.02	
Arsenic	0.01 (P)	
Atrazine	0.002	
Barium	0.7	
Benzene	0.01 ^b	
Benzo[a]pyrene	0.0007 ^b	
Boron	0.5 (T)	
Bromate	0.01b (A, T)	
Bromodichloromethane	0.06 ^b	
Bromoform	0.1	
Cadmium	0.003	
Carbofuran	0.007	
Carbon tetrachloride	0.004	
Chlorate	0.7 (D)	
Chlordane	0.0002	
Chlorine	5 (C)	For effective disinfection, there should be a residual concentration of free chlorine of ≥ 0.5 mg/litre after at least 30 min contact time at pH < 8.0
Chlorite	0.7 (D)	
Chloroform	0.3	
Chlorotoluron	0.03	
Chlorpyrifos	0.03	
Chromium	0.05 (P)	For total chromium
Copper	2	Staining of laundry and sanitary ware may occur below guideline value
Cyanazine	0.0006	
Cyanide 0	0.07	
Cyanogen chloride	0.07	For cyanide as total cyanogenic compounds
2,4-D (2,4-dichlorophenoxyacetic acid)	0.03	Applies to free acid
2,4-DB	0.09	
DDT and metabolites	0.001	
Di(2-ethylhexyl)phthalate	0.008	
Dibromoacetonitrile	0.07	
Dibromochloromethane	0.1	
1,2-Dibromo-3-chloropropane	0.001 ^b	
1,2-Dibromoethane	0.0004 ^b (P)	
Dichloroacetate	0.05b (T, D)	
Dichloroacetonitrile	0.02 (P)	
Dichlorobenzene, 1,2-	1 (C)	
Dichlorobenzene, 1,4-	0.3 (C)	
Dichloroethane, 1,2-	0.03 ^b	
Dichloroethene, 1,2-	0.05	
Dichloromethane	0.02	
1,2-Dichloropropane (1,2-DCP)	0.04 (P)	
1,3-Dichloropropene	0.02 ^b	
Dichlorprop	0.1	
Dimethoate	0.006	
Dioxane, 1,4-	0.05 ^b	
Edetic acid (EDTA)	0.6	Applies to the free acid
Endrin	0.0006	
Epichlorohydrin	0.0004 (P)	

<i>Chemical</i>	<i>Guideline value^a (mg/litre)</i>	<i>Remarks</i>
Ethylbenzene	0.3 (C)	
Fenoprop	0.009	
Fluoride	1.5	Volume of water consumed and intake from other sources should be considered when setting national standards
Hexachlorobutadiene	0.0006	
Isoproturon	0.009	
Lead	0.01	
Lindane	0.002	
Manganese	0.4 (C)	
MCPA	0.002	
Mecoprop	0.01	
Mercury	0.006	For inorganic mercury
Methoxychlor	0.02	
Metolachlor	0.01	
Microcystin-LR	0.001 (P)	For total microcystin-LR (free plus cellbound)
Molinate	0.006	
Molybdenum	0.07	
Monochloramine	3	
Monochloroacetate	0.02	
Nickel	0.07	
Nitrate (as NO ₃ -)	50	Short-term exposure
Nitrilotriacetic acid (NTA)	0.2	
Nitrite (as NO ₂ -)	3	Short-term exposure
	0.2 (P)	Long-term exposure
N-Nitrosodimethylamine (NDMA)	0.1	
Pendimethalin	0.02	
Pentachlorophenol	0.009b (P)	
Permethrin	0.3	Only when used as a larvicide for public health purposes
Pyriproxyfen	0.3	
Pyriproxyfen	0.3	This is not to be used as a guideline value where pyriproxyfen is added to water for public health purposes.
Selenium	0.01	
Simazine	0.002	
Sodium dichloroisocyanurate	50	As sodium dichloroisocyanurate
	40	As cyanuric acid
Styrene	0.02 (C)	
2,4,5-T	0.009	
Terbutylazine	0.007	
Tetrachloroethene	0.04	
Toluene	0.7 (C)	
Trichloroacetate	0.2	
Trichloroethene	0.02 (P)	
Trichlorophenol, 2,4,6-	0.2 ^b (C)	
Trifluralin	0.02	
Trihalomethanes		The sum of the ratio of the concentration of each to its respective guideline value should not exceed 1
Uranium	0.015 (P,T)	Only chemical aspects of uranium addressed
Vinyl chloride	0.0003 ^b	
Xylenes	0.5 (C)	

Footnote:

a	<p>P = provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited;</p> <p>T = provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.;</p> <p>A = provisional guideline value because calculated guideline value is below the achievable quantification level;</p> <p>D = provisional guideline value because disinfection is likely to result in the guideline value being exceeded;</p>
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	C = concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
b	For substances that are considered to be carcinogenic, the guideline value is the concentration in drinking-water associated with an upper-bound excess lifetime cancer risk of 10^{-5} (one additional cancer per 100 000 of the population ingesting drinking-water containing the substance at the guideline value for 70 years). Concentrations associated with upper-bound estimated excess lifetime cancer risks of 10^{-4} and 10^{-6} can be calculated by multiplying and dividing, respectively, the guideline value by 10.

Annex 2: Analyses of Physical, Chemical and Biological Parameters

The parameters analysed to assess the water quality are broadly divided into:

- **Physical parameters:** Colour and Temperature
- **Chemical parameters:** pH, Electrical Conductivity, Total Solids, Total Dissolved Solids, Total Suspended Solids, Total Hardness, Calcium Hardness, Magnesium Hardness, Nitrates, Phosphates, Sulphates, Chlorides, Dissolved Oxygen, Biological Oxygen Demand, Chemical Oxygen Demand
- **Heavy metals:** Lead, Copper, Nickel, Iron, Chromium, Cadmium and Zinc.
- **Biological parameters:** The biological parameters involved the qualitative analyses of planktons (zooplankton and phytoplankton).

Field measurement: The field parameters measured can include pH, conductivity, dissolved oxygen, temperature and transparency.

Physical parameters

COLOUR

In natural water, colour is due to the presence of humic acids, fulvic acids, metallic ions, suspended matter, plankton, weeds and industrial effluents. Colour is removed to make water suitable for general and industrial applications and is determined by visual comparison of the sample with distilled water.

TEMPERATURE

Impinging solar radiation and atmospheric temperature brings about spatial and temporal changes in temperature, setting up convection currents and thermal stratification. Temperature plays a very important role in wetland dynamism affecting the various parameters such as alkalinity, salinity, dissolved oxygen, electrical conductivity etc. In an aquatic system, these parameters affect the chemical and biological reactions such as solubility of oxygen, carbon-di-oxide-carbonate-bicarbonate equilibrium, increase in metabolic rate and physiological reactions of organisms, etc. Water temperature is important in relation to fish life. The temperature of drinking water has an influence on its taste.

Apparatus required: Thermometer- 0.1° C division.

Procedure: Temperature measurement is made by taking a portion of the water sample (about 1litre) and immersing the thermometer into it for a sufficient period of time (till the reading stabilizes) and the reading is taken, expressed as °C.

Chemical parameters

pH:

The effect of pH on the chemical and biological properties of liquids makes its determination very important. It is one of the most important parameter in water chemistry and is defined as $-\log [H^+]$, and measured as intensity of acidity or alkalinity on a scale ranging from 0-14. If free H^+ are more it is expressed acidic (i.e. $pH < 7$), while more OH^- ions is expressed as alkaline (i.e. $pH > 7$).

In natural waters pH is governed by the equilibrium between carbon dioxide/bicarbonate/carbonate ions and ranges between 4.5 and 8.5 although mostly basic. It tends to increase during day largely due to the photosynthetic activity (consumption of carbon-di-oxide) and decreases during night due to respiratory activity. Waste water and polluted natural waters have pH values lower or higher than 7 based on the nature of the pollutant.

* The colorimetric indicator method can be used only for approximate pH values.

Apparatus required:

- **pH indicator (BDH) method:** BDH Indicator (Universal Indicator) and test tubes.
- **Electrometric method:** Glass electrode, reference electrode (mercury/calomel or silver/silver chloride) and pH meter.

Procedure:

Colorimetric method: About 10ml of the sample is taken in a wide mouth test tube, 0.2ml of BDH indicator is added, and shaken gently. The colour developed is matched with the chart and the pH noted.

Electrometric method: The pH is determined by measuring the Electro Motive Force (E.M.F) of a cell comprising an indicator electrode (an electrode responsive to hydrogen ions such as a glass electrode) immersed in the test solution and the reference electrode (usually a mercury/calomel electrode). Contact between the test solution and the reference electrode is usually got by means of a liquid junction, which forms a part of reference electrode. E.M.F of this cell is measured with pH meter, that is a high impedance voltmeter calibrated in terms of pH. The electrode is allowed to stand for 2 minutes to stabilize before taking reading for reproducible results (at least ± 0.1 pH units).

ELECTRICAL CONDUCTIVITY

Conductivity (specific conductance) is the numerical expression of the water's ability to conduct an electric current. It is measured in micro Siemens per cm and depends on the total concentration, mobility, valence and the temperature of the solution of ions. Electrolytes in a solution disassociate into positive (cations) and negative (anions) ions and impart conductivity. Most dissolved inorganic substances are in the ionised form in water and contribute to conductance. The conductance of the samples gives rapid and practical estimate of the variation in dissolved mineral content of the water supply.

Apparatus required: Conductivity meter

Procedure: The electrode of the conductivity meter is dipped into the sample, and the readings are noted for stable value shown as ms/cm.

TOTAL SOLIDS:

Total solids is the term applied to the material residue left in the vessel after evaporation of the sample and its subsequent drying in an oven at a temperature of 103-105°C. Total solids include Total Suspended Solids and Total Dissolved Solids .

Principle: A known volume (50 ml) of well-mixed sample is evaporated in a pre-weighed dish and dried to constant weight in an oven at 103-105°C. The increase in weight over that of the empty dish gives the total solids.

Apparatus: Evaporating dishes-100ml porcelain dish, steam bath, drying oven, desiccator, Monopan balance and measuring jars.

Procedure: A known volume of the well-mixed sample (50ml) is measured into a pre-weighed dish and evaporated to dryness at 103°C on a steam bath. The evaporated sample is dried in an oven for about an hour at 103-105°C and cooled in a desiccator and recorded for constant weight.

TOTAL DISSOLVED SOLIDS

Dissolved solids are solids that are in dissolved state in solution. Waters with high dissolved solids generally are of inferior palatability and may induce an unfavourable physiological reaction in the transient consumer.

Principle: The difference in the weight of total solids and the total suspended solids expressed in the same units gives the total dissolved solids.

Apparatus: Glass-fiber filter disks, membrane filter funnel, filtration apparatus, suction flask and pump, drying oven and Grooch crucible.

Procedure: The difference in the weights of Total Solids and Total Suspended Solids expressed in the same units gives Total Dissolved Solids .

TOTAL SUSPENDED SOLIDS

Suspended solids are the portions of solids that are retained on a filter of standard specified size (generally 2.0 μ) under specific conditions. Water with high-suspended solids is unsatisfactory for bathing, industrial and other purposes.

Principle: A well – mixed sample is filtered through a weighed standard glass fibre filter and the residue that is retained on the filter is dried to a constant weight at 103-105 ° C. The increase in the weight of the filter determines the total suspended solids.

Apparatus: Porcelain dish (100ml capacity), glass fiber filter disk, suction pump and flask, measuring jar, membrane filter funnel, oven and filtration apparatus.

Procedure: The known volume of vigorously shaken sample (50ml) is filtered into a pre-weighed glass fibre filter disk fitted to suction pump, and washed successively with distilled water. The filter is carefully removed from the filtration apparatus and dried for an hour at 103-105 ° C in an oven, cooled in dessicator and weighed for constant weight.

TOTAL HARDNESS

Hardness is predominantly caused by divalent cations such as calcium, magnesium, alkaline earth metal such as iron, manganese, strontium, etc. The total hardness is defined as the sum of calcium and magnesium concentrations, both expressed as CaCO_3 in mg/L. Carbonates and bicarbonates of calcium and magnesium cause temporary hardness. Sulphates and chlorides cause permanent hardness.

Hardness Chart (*for drinking water*):

Soft	0 – 60 mg/L
Medium	60 – 120 mg/L
Hard	120 - 180 mg/L
Very Hard	> 180 mg/L

Principle: In alkaline conditions EDTA (Ethylene-diamine tetra acetic acid) and its sodium salts react with cations forming a soluble chelated complex when added to a solution. If a small amount of dye such as Eriochrome black-T is added to an aqueous solution containing calcium and magnesium ions at alkaline pH of 10.0 ± 0.1 , it forms wine red colour. When EDTA is added as a titrant, all the calcium and magnesium ions in the solution get complexed resulting in a sharp colour change from wine red to blue, marking the end point of the titration. Hardness of water prevents lather formation with soap rendering the water unsuitable for bathing and washing. It forms scales in boilers, making it unsuitable for industrial usage. At higher pH > 12.0, Mg^{++} ion precipitates with only Ca^{++} in solution. At this pH, murexide indicator forms a pink colour with Ca^{++} ion. When EDTA is added Ca^{++} gets complexed resulting in a change from pink to purple indicating end point of the reaction.

Apparatus required: Lab glassware-burette, pipette, conical flask, beakers etc.

Reagents:

- Buffer solution: 16.9 g of ammonium chloride and 1.25g of magnesium salt of EDTA is dissolved in 143ml of concentrated ammonium hydroxide and diluted to 250ml with distilled water.
- Eriochrome black-T indicator: 0.5 g of Eriochrome black-T indicator is dissolved in 100g of triethanolamine.
- Standard EDTA titrant: 0.01M or Ng AR grade EDTA is dissolved in distilled water and diluted to 1000ml and is standardised against standard calcium solution, 1ml = 1mg CaCO_3 .
- Standard Calcium Solution: 1.0g of AR grade CaCO_3 is weighed into a 250ml conical flask, to which 1+1 HCl is added till all CaCO_3 is dissolved completely. 200ml of distilled water is added and boiled to expel carbon-di-oxide, and diluted to 1000ml. 1ml = 1mg CaCO_3 .

Procedure: Exactly 50ml of the well-mixed sample is pipetted into a conical flask, to which 1ml of ammonium buffer and 2-3 drops of Eriochrome black -T indicator is added. The mixture is titrated against standard 0.01M EDTA until the wine red colour of the solution turns pale blue at the end point.

CALCIUM HARDNESS

The presence of calcium (fifth most abundant) in water results from passage through or over deposits of limestone, dolomite, gypsum and such other calcium bearing rocks. Calcium

contributes to the total hardness of water and is an important micro-nutrient in aquatic environment and is especially needed in large quantities by molluscs and vertebrates. It is measured by EDTA titrimetric method. Small concentration of calcium carbonate prevents corrosion of metal pipes by laying down a protective coating. But increased amount of calcium precipitates on heating to form harmful scales in boilers, pipes and utensils.

Principle: When EDTA (Ethylene-diamine tetra acetic acid) is added to the water containing calcium and magnesium, it combines first with calcium. Calcium can be determined directly with EDTA when pH is made sufficiently high such that the magnesium is largely precipitated as hydroxyl compound (by adding NaOH and iso-propyl alcohol). When murexide indicator is added to the solution containing calcium, all the calcium gets complexed by the EDTA at pH 12-13. The end point is indicated from a colour change from pink to purple.

Apparatus required: Burettes, pipette, conical flask, beakers and droppers.

Reagents:

- Sodium hydroxide (8%): 8g of sodium hydroxide is dissolved in 100ml of distilled water.
- Murexide indicator (ammonium purpurate): 0.2 g of murexide is ground well with 100g of sodium chloride thoroughly.
- Standard EDTA titrant, 0.01M: 3.723 g of EDTA (disodium salt) is dissolved in distilled water and made up to 100ml with the same.

Procedure: A known volume (50ml) of the sample is pipetted into a clean conical flask, to which 1ml of sodium hydroxide and 1ml of iso-propyl alcohol is added. A pinch of murexide indicator is added to this mixture and titrated against EDTA until the pink colour turns purple.

MAGNESIUM HARDNESS

Magnesium is a relatively abundant element in the earth's crust, ranking eighth in abundance among the elements. It is found in all natural waters and its source lies in rocks, generally present in lower concentration than calcium. It is also an important element contributing to hardness and a necessary constituent of chlorophyll. Its concentration greater than 125 mg/L can influence cathartic and diuretic actions.

Principle: Magnesium hardness can be calculated from the determined total hardness and calcium hardness.

High concentration of magnesium proves to be diuretic and laxative, and reduces the utility of water for domestic use while a concentration above 500 mg/L imparts an unpleasant taste to water and renders it unfit for drinking. Chemical softening, reverse osmosis and electro dialysis or ion exchange reduces the magnesium hardness to acceptable levels.

NITRATES

Nitrates are the most oxidized forms of nitrogen and the end product of the aerobic decomposition of organic nitrogenous matter. The significant sources of nitrates are chemical fertilizers from cultivated lands, drainage from livestock feeds, as well as domestic and industrial sources. Natural waters in their unpolluted state contain only minute quantities of nitrates. The stimulation of plant growth by nitrates may result in eutrophication, especially due to algae. The subsequent death and decay of plants produces secondary pollution. Nitrates

are most important for biological oxidation of nitrogenous organic matter. Certain nitrogen fixing bacteria and algae have the capacity to fix molecular nitrogen in nitrates. The main source of polluting nitrates is domestic sewage. Nitrates may find their way into ground water through leaching from soil and at times by contamination. They can be measured by the phenoldisulphonic method.

Principle: Nitrates react with phenoldisulphonic acid and produce a nitrate derivative, which in alkaline solution develops yellow colour due to rearrangement of its structure. The colour produced is directly proportional to the concentration of nitrates present in the sample.

Apparatus required: Nessler's tube, pipettes, beakers, spectrophotometer, cuvettes, measuring jar and hot water bath.

Reagents:

- Phenol disulphonic acid: 25 g of phenol is dissolved in 150 ml of concentrated sulphuric acid, to which 85ml of sulphuric acid is further added and heated for about 90 min on a water bath and stored in dark bottles upon cooling.
- Sodium hydroxide: About 50g of sodium hydroxide is dissolved in 150-200 ml of water and cooled.
- Ammonium hydroxide.
- Nitrate solution:
 - Stock nitrate solution: 721.8 mg (0.722g) of AR potassium nitrate is dissolved in distilled water and made up to 100ml for stock solution.
 - Standard nitrate solution: Standard nitrate solution is prepared by evaporating 50ml of the stock solution to dryness in the water bath. The obtained residue is dissolved in 2ml of phenol disulfonic acid and diluted to 500ml, to give 1ml = 10 µg. The solution of various strengths ranging from 0.0 (blank) to 1.0 mg/L at the intervals of 0.2 mg/L is prepared by diluting stock solution with distilled water.

Procedure: A known volume (50ml) of the sample is pipetted into a porcelain dish and evaporated to dryness on a hot water bath. 2ml of phenol disulphonic acid is added to dissolve the residue by constant stirring with a glass rod. Concentrated solution of sodium hydroxide or conc. ammonium hydroxide and distilled water is added with stirring to make it alkaline. This is filtered into a Nessler's tube and made up to 50ml with distilled water. The absorbance is read at 410nm using a spectrophotometer after the development of colour. The standard graph is plotted by taking concentration along X-axis and the spectrophotometric readings (absorbance) along Y-axis. The value of nitrate is found by comparing absorbance of sample with the standard curve and expressed in mg/L.

The high concentration of nitrate in water is indicative of pollution.

PHOSPHATES

Phosphates occur in natural or wastewaters as orthophosphates, condensed phosphates and naturally found phosphates. Their presence in water is due to detergents, used boiler waters, fertilizers and biological processes. They occur in solution in particles or as detritus. They are essential for the growth of organisms and a nutrient that limits the primary productivity of the water body. Inorganic phosphorus plays a dynamic role in aquatic ecosystems; when present

in low concentration is one of the most important nutrients, but in excess along with nitrates and potassium, causes algal blooms. It is calculated by the stannous chloride method.

Principle: In acidic conditions orthophosphate reacts with ammonium molybdate forming Molybdophosphoric acid, reduced further to molybdenum blue by stannous chloride. The intensity of the blue colour is directly proportional to the concentration of phosphate. The absorbance is noted at 690nm using spectrophotometer.

Apparatus required: Spectrophotometer, lab glassware, hot plate and Nessler's tube.

Reagents:

- Ammonium molybdate reagent: 25g ammonium molybdate is dissolved in 175ml distilled water. 280ml concentrated sulphuric acid is added to 400ml distilled water and cooled. Molybdate solution is added and the mixture diluted to 1000ml.
- Stannous chloride reagent: 2.5g fresh stannous chloride is dissolved in 100ml glycerol, heated on water bath and stirred with the glass rod to hasten dissolution.
- Standard phosphate solution: 219.5 mg of dried AR potassium hydrogen phosphate is dissolved in distilled water and made up to 1000ml, where 1ml = 50.0 µg. of phosphate. 10ml of the stock solution is made up to 1000ml to give 1ml = 0.05 mg. Standards of strength ranging from 0 (blank) to 0.05mg/L at intervals of 0.01mg is prepared by diluting the stock with distilled water.

Procedure: To 50ml of the filtered sample, 4ml of ammonium molybdate reagent and about 4-5 drops of stannous chloride reagent is added. After about 10 min but before 12 min, the colour developed is measured photometrically at 690nm and calibration curve is prepared. A reagent blank is always run with same treatment with distilled water as sample. The value of phosphate is obtained by comparing absorbance of sample with the standard curve and expressed as mg/L.

High phosphorus content causes increased algal growth till nitrogen becomes limiting, although blue green algae continues to dominate because of its ability to utilize molecular nitrogen. Besides sedimentation, high uptake by phytoplankton is one of the reasons for fast depletion of phosphorus in water.

SULPHATES

Sulphates are found appreciably in all natural waters, particularly those with high salt content. Besides industrial pollution and domestic sewage, biological oxidation of reduced sulphur species also add to sulphate content. Soluble in water, it imparts hardness with other cations. Sulphate causes scaling in industrial water supplies, and odour and corrosion problems due to its reduction to hydrogen sulphide. It can be calculated by turbidometric method.

Principle: Sulphate ions are precipitated in acetic acid medium with barium chloride to form barium sulphate crystals of uniform size. The scattering of light by the precipitated suspension (barium sulphate) is measured by a Nephelometer and the concentration is recorded.

Apparatus required: Nephelometer, magnetic stirrer, Nessler's tubes and lab glassware.

Reagents:

- Conditioning reagent: 50 ml of glycerol was mixed in a solution containing 30 ml of conc. hydro chloric acid, 300ml distilled water (10% HCl), 100 ml of 95% ethyl alcohol or isopropyl alcohol and 75g NaCl.
- Barium Chloride.
- Standard sulphate solution: 147.9mg of AR grade sodium sulphate was dissolved in distilled water and made up to 1000ml, to give 1ml = 100mg sulphate.

Procedure: 100ml of the sample is filtered into a Nessler's tube containing 5ml of conditioning reagent. About 0.2g of barium chloride crystals is added with continued stirring. A working standard is prepared by taking 1ml of the standard, 5ml of conditioning reagent and made up to 100ml, to give 100 NTU. The turbidity developed by the sample and the standards are measured using a Nephelometer and the results are tabulated.

CHLORIDES

The presence of chlorides in natural waters can mainly be attributed to dissolution of salt deposits in the form of ions (Cl⁻). Otherwise, high concentrations may indicate pollution by sewage, industrial wastes, intrusion of seawater or other saline water. It is the major form of inorganic anions in water for aquatic life. High chloride content has a deleterious effect on metallic pipes and structures, as well as agricultural plants. They are calculated by Argentometric method.

Principle: In alkaline or neutral solution, potassium chromate indicates the endpoint of the silver nitrate titration of chlorides. Silver chloride is quantitatively precipitated before the red silver chromate is formed.

Apparatus required: Lab glassware.

Reagents:

- Potassium chromate indicator solution: 50g of potassium chromate is dissolved in minimum amount of distilled water and silver nitrate is added drop wise till a red precipitate is formed. The mixture is allowed to stand for about 12 hours and diluted to 1000ml with distilled water.
- Silver nitrate solution (0.014N): 2.395g of silver nitrate is dissolved in distilled water and made up to 1000ml.

Procedure: A known volume of filtered sample (50ml) is taken in a conical flask, to which about 0.5ml of potassium chromate indicator is added and titrated against standard silver nitrate till silver dichromate (AgCrO₄) starts precipitating.

DISSOLVED OXYGEN

Oxygen dissolved in water is a very important parameter in water analysis as it serves as an indicator of the physical, chemical and biological activities of the water body. The two main sources of dissolved oxygen are diffusion of oxygen from the air and photosynthetic activity. Diffusion of oxygen from the air into water depends on the solubility of oxygen, and is influenced by many other factors like water movement, temperature, salinity, etc. Photosynthesis, a biological phenomenon carried out by the autotrophs, depends on the plankton population, light condition, gases, etc. Oxygen is considered to be the major limiting factor in water bodies with organic materials. Dissolved oxygen is calculated by many methods.

Method 1: Membrane electrode method

Principle: The membrane electrode has a sensing element protected by an oxygen-permeable plastic membrane that serves as a diffusion barrier against impurities. Under steady conditions the electric current read is directly proportional to the DO concentrations (electric current is directly proportional to the activity of molecular oxygen).

Apparatus required: Oxygen-sensitive membrane electrode and lab glassware.

Procedure: The calibrations are carried out following the manufacturer's calibration procedure. The electrode is dipped into the sample, and the reading noted.

Method 2: Winkler's method

Principle: Oxygen present in the sample oxidizes the dispersed divalent manganous hydroxide to the higher valency to precipitate as a brown hydrated oxide after addition of potassium iodide and sodium hydroxide. Upon acidification, manganese reverts to its divalent state and liberates iodine from potassium iodide, equivalent to the original dissolved oxygen content of the sample. The liberated iodine is titrated against N/80 sodium thiosulphate using fresh iodine as an indicator.

Apparatus required: BOD bottles-300ml capacity, sampling devices, lab glassware - measuring cylinder, conical flasks, etc., and Bunsen burner.

Reagents:

- Manganese sulphate: 480g of manganous sulphate tetrahydrate is dissolved and made up to 1000ml with distilled water (Discarded if it changes colour with starch).
- Alkaline iodide-azide reagent: 500g of sodium hydroxide and 150g of potassium iodide along with 10g of sodium azide (NaN_3) is dissolved and made up to 1000ml with distilled water.
- Conc. sulphuric acid
- Starch indicator: 0.5g of starch is dissolved in distilled water and boiled for few minutes.
- Stock sodium thiosulphate: 24.82g of sodium thiosulphate pentahydrate ($\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$) is dissolved in distilled water and made up to 1000ml.
- Standard sodium thiosulphate (0.025N): 250ml of the stock sodium thiosulphate pentahydrate is made up to 1000ml with distilled water to give 0.025N.

Procedure: The samples are collected in BOD bottles, to which 2ml of manganous sulphate and 2ml of potassium iodide are added and sealed. This is mixed well and the precipitate allowed to settle down. At this stage 2ml of conc. sulphuric acid is added, and mixed well until all the precipitate dissolves. 203ml of the sample is measured into the conical flask and titrated against 0.025N sodium thiosulphate using starch as an indicator. The end point is the change of colour from blue to colourless.

BIOLOGICAL OXYGEN DEMAND

Biological Oxygen Demand is the amount of oxygen required by microorganisms for stabilizing biologically decomposable organic matter (carbonaceous) in water under aerobic conditions. The test is used to determine the pollution load of wastewater, the degree of pollution and the efficiency of wastewater treatment methods. 5-Day BOD test being a bioassay procedure (involving measurement of oxygen consumed by bacteria for degrading

the organic matter under aerobic conditions) requires the addition of nutrients and maintaining the standard conditions of pH and temperature and absence of microbial growth inhibiting substances.

Principle: The method consists of filling the samples in airtight bottles of specified size and incubating them at specified temperature (20 °C) for 5 days. The difference in the dissolved oxygen measured initially and after incubation gives the BOD of the sample.

Apparatus required: BOD bottles - 300ml capacity, air incubator - to be controlled at 20 °C - \pm 1 °C, oximeter and magnetic stirrer.

Reagents:

- Preparation of dilution water: To 1000ml of water, 1ml each of phosphate buffer, magnesium sulphate, calcium chloride and ferric chloride solution is added, before bringing it to 20 °C and aerating it thoroughly.

Procedure: The sample having a pH of 7 is determined for first day DO. Various dilutions (at least 3) are prepared to obtain about 50% depletion of DO using sample and dilution water. The samples are incubated at 20 °C for 5 days and the 5th day DO is noted using the oximeter. A reagent blank is also prepared in a similar manner.

CHEMICAL OXYGEN DEMAND

Chemical oxygen demand is the measure of oxygen equivalent to the organic content of the sample that is susceptible to oxidation by a strong chemical oxidant. The intrinsic limitation of the test lies in its ability to differentiate between the biologically oxidisable and inert material. It is measured by the open reflux method.

Principle: The organic matter in the sample gets oxidized completely by strong oxidizing agents such as potassium dichromate in the presence of conc. sulphuric acid to produce carbon-di-oxide and water. The excess potassium dichromate remaining after the reaction is titrated with Ferrous Ammonium Sulphate (FAS) using ferroin indicator to determine the COD. The dichromate consumed gives the oxygen required for the oxidation of the organic matter.

Apparatus required: Reflux apparatus, Nessler's tube, Erlenmeyer flasks, hot plate and lab glassware.

Reagents:

- Standard potassium dichromate solution (0.250M): 12.25g of potassium dichromate dried at 103 °C for about 2 hours is dissolved in distilled water and made up to 1000ml.
- Standard ferrous ammonium sulphate (FAS) 0.25N: 98g of FAS is dissolved in minimum distilled water to which 20ml of conc. sulphuric acid is added and made up to 1000ml using distilled water to give 0.25N of ferrous ammonium sulphate.
- Ferroin indicator: 1.485g of 1,10-Phenanthroline monohydrate and 695mg of ferrous sulphate is dissolved in 100ml of distilled water.
- Conc. sulphuric acid
- Silver sulphate crystals
- Mercuric sulphate crystals

Procedure: 15ml of conc. sulphuric acid with 0.3g of mercuric sulphate and a pinch of silver sulphate along with 5ml of 0.025M potassium dichromate is taken into a Nessler's tube. 10ml of sample (thoroughly shaken) is pipetted out into this mixture and kept for about 90 minutes on the hot plate for digestion. 40ml of distilled water is added to the cooled mixture (to make up to 50ml) and titrated against 0.25M FAS using ferroin indicator, till the colour turns from blue green to wine red indicating the end point. A reagent blank is also carried out using 10ml of distilled water.

FLUORIDE

Fluorides have dual significance in water supplies. High concentration causes dental fluorosis and lower concentration (<0.8 mg/L) causes dental caries. A fluoride concentration of approximately 1mg/L in drinking water is recommended. They are frequently found in certain industrial processes resulting in fluoride rich wastewaters. Significant sources of fluoride are found in coke, glass and ceramic, electronics, pesticide and fertiliser manufacturing, steel and aluminium processing and electroplating industries. It is calculated by SPADNS method.

Principle: The colorimetric method of estimating fluoride is based on the reaction of fluorides (HF) with zirconium SPADNS solution and the 'lake' (colour of SPADNS reagent), which is greatly influenced by the acidity of the reaction mixture. Fluoride reacts with the dye 'lake', dissociating (bleaching) the dye into a colourless complex anion (ZrF_6^{2-}). As the amount of fluoride increases, the colour produced becomes progressively higher or of different hue.

Apparatus required: Spectrophotometer and lab glassware.

Reagents:

- Standard fluoride solution.
- Stock: 221.0mg of AR grade sodium fluoride was dissolved in distilled water and made up to 1000ml to give 1ml = 100 μ g of F⁻
- Working Standard: 100ml of the stock fluoride was diluted to 1000ml to give 1ml = 10 μ g of fluoride.
- SPADNS Solution: 958mg of SPADNS is dissolved in 500ml of distilled water. [1]
- Zirconyl-acid reagent: 133mg Zirconyl chloride octahydrate ($ZrOCl_2 \cdot 8H_2O$) was dissolved in about 25ml of distilled water. 350ml of conc. HCl was added and diluted to 500ml with distilled water.
- Zirconyl acid-SPADNS reagent: Equal volume of SPADNS and zirconyl acid reagent was mixed.

Procedure: A standard graph is prepared by using fluoride concentrations ranging from 0.005 mg/L to 0.150 mg/L at 570nm. A reference solution is prepared by adding 4ml of acid zirconyl-SPADNS reagent to 21ml of distilled water. A known volume of filtered sample (21ml) is taken in a test tube, 4ml of acid zirconyl-SPADNS reagent is added to the sample along with a reference solution. The mixture is left for about 30 min for complete colour development and the optical density is read at 570nm.

Heavy metals

Heavy metals are elements (properties of metals satisfied) of high atomic numbers. They have high utilities in industrial applications from papers to automobiles, by their very characteristic properties. They are found in the deep bowels of the earth as ores (complexes of mixtures). The metals are segregated from these ores, leaving behind the tailings that find their way into the environment as toxic pollutants. They get into the water bodies directly from point sources as sewage, and non-point sources as runoff and more insidiously as atmospheric deposition that are transported from long distances. Heavy metals affect every level of the food web, from producers in the trophic levels to the highest order carnivore by residing in the system and magnifying at every trophic status.

Atomic absorption spectrophotometer

Working principle: Atomic absorption spectrometer's working principle is based on the sample being aspirated into the flame and atomized when the AAS's light beam is directed through the flame into the monochromator, and onto the detector that measures the amount of light absorbed by the atomized element in the flame. Since metals have their own characteristic absorption wavelength, a source lamp composed of that element is used, making the method relatively free from spectral or radiational interferences. The amount of energy of the characteristic wavelength absorbed in the flame is proportional to the concentration of the element in the sample.

Procedure: The sample is thoroughly mixed by shaking, and 100ml of it is transferred into a glass beaker of 250ml volume, to which 5ml of conc. nitric acid is added and heated to boil till the volume is reduced to about 15-20ml, by adding conc. nitric acid in increments of 5ml till all the residue is completely dissolved. The mixture is cooled, transferred and made up to 100ml using metal free distilled water.

LEAD

Lead is relatively a minor element in the earth's crust but is widely distributed in low concentrations in uncontaminated soils and rocks. Lead concentration in freshwater is generally much higher. High concentration of lead results from atmospheric input of lead originating from its use in the leaded gasoline or from smelting processes. Industrial processes such as printing and dyeing, paint manufacturing, explosives, photography and mine or smelter operations may contain relatively high values in lead. Lead is toxic to aquatic organisms.

Principle: Lead can be determined at a wavelength of 283.3 nm by AAS with aspiration of the sample into the oxidising air-acetylene flame. When the aqueous sample is aspirated, the sensitivity for 1% absorption is 0.5 mg/L and the detection limit is 0.05 mg/L.

Standard lead solution: 1.598g of lead nitrate is dissolved in about 200ml of water containing 1.5ml of conc. nitric acid and diluted to 1000ml of metal free water to give 1ml = 1mg lead. A series of standards ranging from 1mg to 5mg were prepared from the stock and a standard graph was made.

COPPER

Copper is a widely distributed trace element because most copper minerals are relatively insoluble and is sorbed to solid phases, hence only low concentrations are normally present in natural waters. Because of the presence of sulphide, copper would be expected to be even less soluble in anoxic systems. The presence of higher concentrations of copper can usually be

attributed to corrosion of copper pipes, industrial wastes or particularly in reservoirs, which uses copper as algaecides. Copper is an essential trace element in the nutrition of plants and animals including man. It is required for the function of several enzymes and is necessary in the biosynthesis of chlorophyll. High levels are toxic to organisms but the response varies greatly with species.

Principle:

Copper can be determined at a wavelength at 324.7 nm by AAS with aspiration of the sample into an oxidising air-acetylene flame. When the aqueous sample is aspirated, the sensitivity for 1% absorption is 0.1 mg/L and the detection limit is 0.01 mg/L.

Standard copper solution: 1g of copper salt is dissolved in 15ml of 1+1 nitric acid and diluted to 1000ml to give 1ml = 1mg copper. A series of standards ranging from 1mg to 5mg are prepared from the stock and a standard graph prepared.

NICKEL

Standard nickel solution: 1.273g of nickel oxide is dissolved in a minimum quantity of 10% HCl and diluted to 1000ml with distilled water to give 1ml = 1mg of nickel. A series of standards ranging from 1mg to 5mg are prepared from the stock and analyzed.

IRON

Iron is an abundant element in the earth's crust, but exists generally in minor concentrations in natural water systems. Iron is found in the +2 (*ferrous*) and +3 (*ferric*) states depending on the oxidation-reduction potentials of the water. The ferric state of iron imparts orange stain to any settling surfaces, including laundry articles, cooking and eating utensils, and plumbing fixtures.

Principle:

Iron can be determined at a wavelength of 248.3 nm by AAS with aspiration of the sample into an oxidising air-acetylene flame. Under standard conditions, iron produces 1% absorption at 0.12 mg/L and a linear response up to about 5 mg/L.

Standard iron solution: 1g of iron is dissolved in 50ml of 1+1 nitric acid and diluted to 1000ml with distilled water to give 1ml = 1mg of iron. A series of standards ranging from 1mg to 5mg are prepared from the stock and analysed.

CHROMIUM

The concentration of chromium in natural waters is usually very low. Elevated concentrations of chromium can result from mining and industrial processes. Chromate compounds are routinely used in cooling waters to control erosion. Chromium in water supplies is generally found in the hexavalent form.

Principle:

Total chromium can be determined at a wavelength of 357.9 nm by atomic absorption with aspiration of sample into a reducing air-acetylene flame. Under standard concentrations, chromium produces 1 % absorption at 0.25 mg/L and is detectable down to 0.003 mg/L.

Standard chromium solution: 2.828g of AR grade potassium dichromate is dissolved in about 200ml of distilled water, with 1.5ml of conc. nitric acid and made up to 1000ml with the same to give 1ml = 1mg of chromium. A series of standards ranging from 1mg to 5mg are prepared from the stock and analysed.

CADMIUM

Cadmium is largely found in nature in the form of sulphide, and as an impurity of zinc - lead ores. The abundance of cadmium is much less than that of zinc. Cadmium may enter the surface waters as a consequence of mining, electroplating plants, pigment works, textile and chemical industries, and is toxic to man. There is evidence that cadmium affects reproductive organs in humans and is also a potential carcinogen. A specific disease called "itai-itai" has been absorbed in Japan due to excess cadmium. In addition, due to bioaccumulation, certain edible organisms may become hazardous to the ultimate consumer.

Principle: Cadmium can be determined at a wavelength of 228.8 nm by atomic absorption with aspiration of sample into an oxidising air-acetylene flame. When the aqueous sample is aspirated, the sensitivity for 1 % absorption is 25 µg/L and the detection limit is 2 µg/L.

Standard cadmium solution: 1.000 g of cadmium metal is dissolved in minimum volume of 1+1 HCl and made up to 1000ml with distilled water to give 1ml = 1mg of cadmium. A series of standards ranging from 1mg to 5mg are prepared from the stock and analysed.

ZINC

Zinc is an abundant element in rocks and ores and is present in natural waters only as a minor constituent. The main industrial use of zinc is in galvanizing and may enter the drinking waters from galvanized pipes. Another important use is in the preparation of alloys, including brass and bronze. It is an essential element in human nutrition. Food provides the main source of zinc to the body. Zinc may be toxic to aquatic organisms but the degree of toxicity varies greatly depending on water quality characteristics as well as the species being considered.

Principle: Zinc can be determined at a wavelength of 213.9 nm by AAS aspiration of the sample into an oxidizing air-acetylene flame. When the aqueous sample is aspirated, the sensitivity for 1% absorption is 20 µg/L and the detection limit is 5 µg/L.

Standard zinc solution: 1.000g of zinc metal is dissolved in 20ml of 1+1 HCl and diluted to 1000ml in distilled water, to give 1ml = 1mg of zinc. A series of standards ranging from 1mg to 5mg are prepared from the stock and analysed.

Biological parameters

PLANKTON ANALYSIS:

The physical and chemical characteristics of water affect the abundance, species composition, stability and productivity of the indigenous populations of aquatic organisms. The biological methods used for assessing water quality includes collection, counting and identification of aquatic organisms; biomass measurements; measurements of metabolic activity rates; toxicity tests; bioaccumulation; biomagnification of pollutants; and processing and interpretation of biological data. The work involving plankton analysis would help in:

- Explaining the cause of colour and turbidity and the presence of objectionable odour, tastes and visible particles in waters.
- The interpretation of chemical analyses.
- Identifying the nature, extent and biological effects of pollution.
- Providing data on the status of an aquatic system on a regular basis.

Plankton: A microscopic community of plants (phytoplankton) and animals (zooplankton), found usually free floating, swimming with little or no resistance to water currents, suspended in water, nonmotile or insufficiently motile to overcome transport by currents, are called "Plankton".

Phytoplankton (microscopic algae) usually occurs as unicellular, colonial or filamentous forms and is mostly photosynthetic and is grazed upon by the zooplankton and other organisms occurring in the same environment. Zooplankton principally comprise of microscopic protozoans, rotifers, cladocerans and copepods. The species assemblage of zooplankton also may be useful in assessing water quality.

The structure of photosynthetic populations in the aquatic ecosystems is dynamic and constantly changing in species composition and biomass distribution. An understanding of the community structure is dependent on the ability to understand the temporal distribution of the different species. Changes in species composition and biomass may affect photosynthetic rates, assimilation efficiencies, rates of nutrient utilization, grazing, etc.

Plankton, particularly phytoplankton, has long been used as indicators of water quality. Because of their short life spans, planktons respond quickly to environmental changes. They flourish both in highly eutrophic waters while a few others are very sensitive to organic and/or chemical wastes. Some species have also been associated with noxious blooms causing toxic conditions apart from the tastes and odour problems.

Annex 3: References and Useful References

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