Assessment of eco-environment quality and monitoring & maintenance of ecosystems

The learning objectives

1. The objective of the module is to make participants aware of techniques to assess the quality of water, sediment and biota.
2. It would expose them to various standard operating protocols for sampling, laboratory analysis, data handling, reporting and information generation and use. It would also give exposure to how the monitoring data can be used for formulation of ecosystem restoration and maintenance program.

The learning outcomes

This session would essentially bring out the following

1. a brief understanding on components of aquatic ecosystem including biotic and abiotic, techniques to assess the quality of these components including standard operating procedures and protocols;
2. how to design a network for sampling in different types of water bodies, optimum number of samples for representative sampling, different types of sampling e.g. grab, composite, integrated etc, sample preservation, transport, laboratory analysis, quality control and quality assurance in analysis;
3. data handling techniques including scrutiny of data, data validation, sources of errors, data analysis including identification of outliers, statistical tools, various methods of data presentation, reporting, conversion of data into information;
4. understanding on setting environment quality goals and comparison of existing quality with the desired quality as per the set goals to identify the gaps;
5. understanding on how to prepare restoration and maintenance plan after the gaps are identified including identification of nature and magnitude of pollution, sources of pollution, various options for control of such pollution and preparation of action plan for combating such pollution.

Introduction

For rational planning of any eco-restoration program, adequate knowledge of existing status of quality of eco-environment is pre-requisite. It helps in identification of nature and magnitude of pollution control required, prioritization of pollution control efforts and evaluation of effectiveness of pollution control programs. The ultimate goal of combating water pollution is to restore the quality of water in all the natural water bodies to a level which can support human use and functions of the ecosystems that depend directly or indirectly on them. In order to achieve this goal, it is important to keep watch on level of degradation of aquatic ecosystem and effectiveness of restoration efforts.

Eco-environment quality management is for a great deal controlled by authorization of discharges of dangerous substances for which monitoring of discharges, effluents and influenced surface water is essential. On a national and regional level, countries have issued several laws and directives related to water management and pollution control, including the prescription of monitoring activities. Examination of the water management approaches applied in different countries shows great similarity, although the emphasis may differ because of geographical or institutional reasons.

Water quality monitoring is one of the first steps required in the rational development and management of water resources. In the field of water quality management, there has been a steady evolution in procedures for designing systems to obtain information on the behaviour of water quality in the environment. In this way, 'monitoring' comprises all activities to obtain 'information' with respect to the water system.

Water quality monitoring is a complex subject, and the scope of it is both deep and wide. Its proper study has a direct relation and interface with chemistry, biology, physics, statistics and also economics. Its scope is also related to the types of water-uses which are manifold and the nature of the sources of water such as surface water (rivers and lakes), sea water and groundwater.

What is monitoring?

Webster's dictionary defines monitoring as (1) to check and sometimes to adjust for quality or fidelity, (2) to watch, observe or check, especially for a special purpose, (3) to keep track of, regulate or control (as a process for the operation of a machine). Note that both (1) and (3) involve adjustment, regulation, or control, which fit well with the various types of monitoring information. A distinction can be made between different monitoring activities:

Survey: an exercise in which a set of standardised observations is taken from a single station or a set of stations within a short period of time to furnish qualitative or quantitative descriptive data;

Surveillance: a continued programme of surveys systematically undertaken to provide a series of observations in time;

Monitoring: surveillance undertaken to ensure that previously formulated standards are being met.

In the present context the word monitoring is defined in a less strict way to encompass all three types of activities.

Why monitoring ?
Clearly environmental monitoring must have a purpose and a function in the process of risk assessment and pollution control. In risk management, monitoring is essential in the stage of problem recognition (indication of water quality deviations), the stage of analysis (with respect to the expected changes) and the stage of management (verification or control of strategy results).
A number of purposes for monitoring can be discerned:

- **The signal or alarm function** for the detection of suddenly occurring (adverse) changes in the environment. Preferably the monitoring system should be designed to immediately enable the tracing of causes;
- The **control function** to assess the general quality of water in relation to adopted water quality requirements or objectives, and for verification on the effectivity of pollution control strategies as well as a check on permitted effluent quality compliance;
- The **trend (recognition) function** based on time series analysis to enable the prediction of future developments;
- The **instrument function** to help in the recognition and clarification of underlying processes.

Ecological risk assessment will take place on a regional or even on a local scale. Regional aquatic risk assessment is concerned with describing and estimating risks for impairment of designated water uses resulting from specific regional or local-scale pollution and/or physical disturbance. The outcome of these risk assessment efforts will result in proposals for risk reduction, which are to be embedded in a suitable legislative framework.

Ecological risk assessments begin with activities that define the nature of the problem, followed by an integration of exposure assessment and effects assessment in order to estimate the probability and level of effects possibly occurring in receiving water bodies. In a process called risk management, the results of the risk assessment are considered along with economic, technological, social and political considerations to arrive at a control strategy. In this process, monitoring is essential in the following stages:

- **During problem formulation**; chemical and biological monitoring of surface waters may indicate deviations from the normal (alarm and trend function), triggering problem recognition;
- **During the stage of analysis**; chemical monitoring of receiving waters as well as selected effluents will help in exposure characterization, while biological monitoring of the same will enlighten on the ecological effects to be expected (instrument function);
- **During the stage of risk management**; monitoring will help in the verification of control strategy results, and in checking compliance (control function).

It is stressed that in environmental control, monitoring should be applied as an instrument and not as an objective itself. The main reason for monitoring is to detect changes in the state and functioning of ecosystems in a stage that early, that counteractive measures can timely be initiated, developed, and evaluated. Sampling is only the first step in the monitoring process, that should be followed by analysis and interpretation and evaluation of the monitoring results, to be concluded with a timely reporting of the achieved results. The generation of tables of analytical data in itself is not providing pollution control information. The period between sampling and reporting is often considerable, thereby devaluating the monitoring results for their intended use.

Monitoring objectives

Water quality monitoring is carried out for various reasons and the objectives of a particular monitoring programme have a direct bearing on the costs of carrying out the programme. The most important objectives of surface water and effluent quality sampling programmes include:

- identification of state and trends in water quality, both in terms of concentrations and effects;
- identification of the mass flow of contaminants in surface water and effluents;
- formulation of standards and permit requirements;
- testing of compliance with standards and classifications for surface waters and effluents;
- early warning and detection of pollution.

In practise, data from routine monitoring programmes are generally used for a variety of purposes in addition to those for which the programmes were designed. Identification of the state and trends in water quality is mainly important for policy and management, while the identification of the mass flow in rivers and waste water discharges is of particular importance at the boundaries between countries, districts or water systems. Mass flows are subject of international negotiations and are an input for mass balances for specific substances. Testing of compliance with standards (control) is related to the water quality objectives for surface water as prescribed in both national and international standards. The early warning monitoring programme to signal pollution due to (accidental) spills by industry and ships is especially important if surface water of that particular river or water system is used for public water supply. Finally, data will be used for various projects including research.

Water quality monitoring is an important aspect of overall water quality management and water resources development. A well planned and well managed water quality monitoring system is required to signal, control or predict changes or trends of changes in the quality of a particular water body, so that curative or preventive measures can be taken to restore and maintain ecological balance in the water body. Monitoring is essential for the succesful implementation of environmental legislation: to ensure that standards and criteria set by the regulatory agencies are maintained on a continuing basis.

Due to economic and practical considerations, monitoring network design, sampling frequencies, choice of variables and frequency of laboratory analysis should be determined on the basis of the information requirements, the hydraulic and hydrologic constraints, variability in water body characteristics, the end-use of water that drains to and from the water body, the overall objectives of the monitoring programme, and finally of course on costs involved and budgets allocated to the programme.

Monitoring techniques

Traditionally, pollution control agencies all over the world relied on chemical-specific approaches to regulate discharges of toxic pollutants. This approach involved specification of standards and limits to loads and concentrations of a number of priority pollutants in surface water and waste water, among others based on their potential toxicity**.**

In the European Inventory of Existing Commercial Substances (EINECS) about 100.000 chemicals have been identified. From these compounds the concentrations of approximately 30-40 chemicals are more or less regularly monitored in important European aquatic ecosystems. The major proportion of chemicals can not reliably be quantified in surface water and effluent due to unavailability of analytical methods, or due to the costs of sampling and laboratory analysis. Properly evaluated data on chemicals with respect to their long-term (eco)toxicity and environmental fate are also relatively scarce. Furthermore, data on the projected effects of individual compounds do not account for the interactions among pollutants or the combined effects of pollutants that may occur in the complex mixture of toxicants that comprise many industrial and municipal effluents as well as diffuse inputs to surface waters. This implies that the likelihood of NOT managing the environmental impact of important chemicals is high. It is therefore understandable that water control authorities are taking a keen interest in developing both physico-chemical monitoring techniques including the development of mixture toxicity variables, and biological monitoring methods (toxicity studies and biomonitoring techniques) for the prediction and detection of ecological effects of waste loads to receiving water bodies.

Design of eco-environment quality monitoring programme

- If the water quality is same every where, we can do away with one measurement. But it varies with time and space. Thus, need for larger measurement over a spatial and temporal to ascertain the quality in accordance to our requirement.
- As we know all form of life dependant on water, and thus, they need water of definite quality and hence one has to ascertain if the quality is in according to requirement.
- Water quality monitoring is a programmed process of sampling, measurement and reporting of water characteristics for specific objective(s).

Components of eco-environment quality monitoring programme

- Objectives
- Preliminary survey
- Monitoring network design
- Resource estimation
- Field work
- Laboratory work
- Analytical quality assurance
- Data management and reporting
- What information should the monitoring programme generate and for what purpose – Objective(s)
- What is to be measured? – parameters
- What is to be sampled? – water, sediment or biota
- Where is to be sampled – location
- When and how often to be sampled? – frequency and time of sampling
- A clear statement of the objective is necessary to avoid:

Needless and wasteful expenditure of time, effort and money. The importance of the use of information should be stressed. There is little point in generating monitoring data unless they are to be used. It is essential that the design, structure, implementation and interpretation of monitoring systems and data are conducted with reference to the final use of the information for specific purposes.

Definition and types of biomonitoring

The introduction of biological variables in environmental monitoring activities added the terms biomonitoring or biological monitoring to our vocabulary. Different interpretations of what is considered to be a biological variable or biological observation caused a lot of confusion on which activities belong to biomonitoring. In the medical world, biomonitoring is solely defined as the concentration measurement of pollutants inside the human body. Naturalists generally also include measurements of the direct effects of disturbances on physiological processes in organisms. Measurements on the responses on a higher level of biological integration (populations, communities and ecosystems) naturalists classify as inventories. Finally, according to environmentalists, all varieties of biologically oriented measurements, as long as they are performed with the objective of protecting, preserving and correcting the biological integrity of natural systems, fall under the reign of biomonitoring. In this respect, biological integrity may be defined as "the maintenance of community structure and function characteristic of a particular locale" [].

There are following main types of biomonitoring used all over the world:

1. - **Bioaccumulation monitoring** for measurements on chemical concentrations in biological material.
2. - **Toxicity monitoring** for measurements on the direct biomolecular and physiological responses of individual organisms towards toxicants in an experimental setup, including bioassays and biological early warning systems.
3. - **Ecosystem monitoring** for measurements on the integrity of ecosystems which is in many cases diffusely related to all kinds of environmental perturbations. This type of biomonitoring will include inventories on species composition, density, diversity, availability of indicator species, rates of basic ecological processes, etc.

The word **integrated monitoring** will be reserved for coordinated monitoring activities comprising chemical and biological measurements in a variety of environmental media or compartments.

Possibilities of biomonitoring

Both the occurrence of bioaccumulation and the occurrence of biological effects often have demonstrated to provide useful and reliable information on the state of the environment. However, it is essential to realize that a biological response will only fully express if the amplitude and exposure duration of the disturbing factor is matched with the sensitivity and response rate of the disrupted biological process. In Figure 1 the response rates of important biological processes are globally indicated. The slower response rates of processes on higher levels of biological organization are quite evident.

Spatial gradients in physico-chemical variables and biological interactions are the cause for differences in populations of species and community structure. Depending on the tolerance, size, mobility and the radius of action of exposed species, these gradients can have a size varying between a single millimetre and several thousands of kilometres. As a consequence, specific types of environmental problems are related to their specific scales. As an example:

the problems arising from the increased production of CO_2 are exerted on a global scale, while the effects of soil pollution caused by chemical dumping ("valleys of drums") are only expressed locally.

It will be obvious that the differences in time, space and organizational scaling have important implications for the applicability of biomonitoring techniques. Especially with the design of monitoring networks (frequency, grid density and variable selection) these aspects are essential to be considered with great care.

The use of biomonitoring methods in the control strategies for chemical pollution may have several advantages over chemical monitoring. Firstly, these methods reflect effects in which the bioavailability of the compound(s) of interest is also incorporated next to the concentration of the compounds and their intrinsic toxicity. Secondly, most biological measurements form the only way of integrating the effects on a large number of individual and interactive processes.

Over time, it has become apparent that a chemical-specific approach, by itself, cannot adequately serve to provide the information to protect surface waters from pollution effects. The ultimate goal of environmental protection for aquatic systems is to warrant the sustainability of the ecosystem as a whole, including flora and fauna, public health and to safeguard the specific uses such as public water supply, recreation (fishing, swimming), nature conservation, etc. In other words; we should not solely be interested in concentrations of pollutants, but in the effects possibly occurring.

Often biomonitoring methods are cheaper, more precise and more sensitive than chemical analysis to detect adverse conditions in the environment. This is due to the fact that the biological response is very integrative and accumulative in nature, especially at the higher levels of biological organization. This may lead to a reduction of the number of measurements both in space and time.

As a disadvantage of biological effect measurements it can be stated that it is sometimes very difficult to relate the observed effects to specific aspects of pollution. In view of the present chemical oriented pollution abatement policies and to reveal chemical specific problems, it is clear that biological effect analysis will never totally replace chemical analysis. However, in some situations the number of standard chemical analysis can be reduced, by allowing bioeffects to trigger chemical analysis (integrated monitoring), thus buying time for more elaborate analytical procedures.

The environmental science literature is replete with examples of effects on variables that were measured in the laboratory or in the field, but that can not be explicitly translated into a societally or biologically important environmental value. These monitoring efforts generally only result in the question "So What?" without any action taken. If monitoring variable selection is guided by first specifying assessment endpoints according to ecological objectives, the translation or extrapolation possibilities are built-in. The process is easily understandable with the examples given in table 1.

Table 1: Examples of corresponding assessment and measurement endpoints

REGION	ECOLOGICAL OBJECTIVE	ASSESSMENT ENDPOINT	CAUSES	MEASUREMENT ENDPOINT
Wadden sea	Retain function as breeding ground for marine species	Presence of a balanced population of healthy harbour seals	PCB	Hepato-enzymatic reactions in fish
			Heavy metals	Metallothioneine masking reactions in mollusca
Rhine river	Ecological rehabilitation	Presence of an endogenous population of salmonids	Eutrophication	Biomass algae
			Heavy metals	Bioaccumulation in mollusca
			Toxicity	Sediment bioassays
Local industrial effluent discharge in river	No impairment of local biota, water supply function, and fisheries downstream Fish edible without health risk	1) No increased human health risk allowed after treatment to drinking water 2) No reduction allowed of fisheries volume and public demand	Toxicants in general	Effluent toxicity tests
				Bioaccumulation in fish
				Tests for persistence of toxicity
				Mutagenicity tests
				Food chain inventories in receiving water

Some of the requirements for monitoring variables are mutually exclusive. It is generally accepted that ecological relevance is inversely related to criteria like sensitivity and specificity. Effects on a higher level of biological organisation (population, community, etc.) are highly biologically relevant, but may be insensitive (due to the availability of alternative pathways in an ecosystem, and complex regulating mechanisms) and are normally a-specific in their response to many perturbations. For bio-molecular and physiological effects, the order of their compliance to the criteria mentioned above will be reversed.

Variables with a response that is restricted to only one type or group of pollutants or a specific type of perturbation are generally associated with processes having a low rank in the chain of causality. This type of monitoring variables (measurement endpoints) have a high problem/solution directed bio-indicative capacity. Due to their distinct relation to specific aspects of pollution, they can be fruitfully used for control.

The indicative value of ecological (assessment) endpoints on a higher level of integration is to be found in signalling trends in combined ecosystem performance. However, this type of evaluation, in general, lacks the possibility to direct counter-active measures. In many cases it will only reveal the need for process studies on the underlying causes.

Biological monitoring

All natural waters contain living organisms. Each of these organisms has particular requirements with respect to the physical, chemical and biological condition of its habitat. Changes in these conditions can result in reduction in species numbers, a change in species dominance or total loss of sensitive species by death or migration. The presence or absence of certain species in relation to particular water quality characteristics has been used for biological monitoring of water quality based on "indicator species". The fluctuations in diversity and numerical abundance of species have also been used for biomonitoring of water quality. Macro-invertebrates are particularly suitable for such methods.

There are as many methods as the number of scientific groups working on biomonitoring in the world. The details of these methods are widely referred in the literature. Thus it becomes difficult to select appropriate method for a situation. In order to find suitable method for Indian conditions and within capability of Indian regulatory authorities, Central Pollution Control Board has carried out a three year pilot study on the Yamuna river under Indo-Dutch collaborative project and developed a method for evaluation of water quality combining both the chemical and biological evaluation to make it more scientific and useful for the pollution control agencies in India. The method integrates the individual parameters in an index. The methodology developed involves large number of physico-chemical measurements, although it has a flexibility to be used even if limited parameters of local importance are measured. For any beginner measurement of all the parameters used in the above methodology may be difficult. The complete details of the methodology is available elsewhere (de Kruijf, de Zwart and Trivedi, 1992, Trivedi, de Zwart & de Kruijf, 1993, de Zwart & Trivedi, 1995). A brief description is provided below:

The Yardstick:
The adopted river water quality yardstick is based on measured chemical, bacteriological and ecological data. The individual measurement are integrated to a number of indices which are graphically presented in a so called AMOEBA - figure. The AMOEBA (abbreviation for a method of ecological and biological assessment) depicts the actual quality status, together with the deviation from target objectives. The individual indices are related to identifiable aspects of pollution, and therefore they can be used for water quality management. For the time being 8 different indices are specified:

Pollution Load (strain) Indices:

- Bacterial Pollution Index (BPI)
- The Nutrient Pollution Index (NPI)
- The Organic Pollution Index (OPI)
- The Industrial Pollution Index (IPI)
- The Pesticide Pollution Index (PPI)

Effect (stress) Indices:

- The Benthic Saprobity Index (BSI)
- The Biological Diversity Index (BDI)
- The Production Respiration Index (PRI)

Each of these indices are derived from a set of one or more water quality monitoring parameters which may vary according to regional requirements. The details of the methodology is described elsewhere (Trivedi et al 1993, de Zwart and Trivedi, 1995)

Amoeba Presentation
All the eight individual indices as explained earlier are expressed on a scale from 0 to 100, where 0 indicates the worst imaginable condition and 100 stands for a totally natural environment. The target level does not necessarily be 100 since compromise between

development and environmental protection leads to the acceptance of some degree of deterioration. For each index a different target value may be selected, depending on local conditions. The targeted values of each individual indices is rescaled so as to fall on a circle, "AMOEBA" (Ten Brink et al 1991). Thus one can immediately see which index is falling short of or exceeding the target.

The sector size can also vary according to the weightage of the corresponding index, and may depends on the local regional or national values and views. For the time being the weightage of the indices are kept equal.

Application of Amoeba in water Pollution Control:
Rational formulation of any pollution control program for a water body needs to define water quality objectives (target) for that water body in a sound scientific manner. These objectives are used as yardstick to identify the areas in need of restoration, extent of pollution control needed, prioritization of pollution control programme and effectiveness of pollution control efforts. Using the Yamuna River's 3 years data on the water quality the indices are calculated and presented in the "AMOEBA" form. The suggested target values for NPI, OPI, IPI, PPI, BSI, BDI and PRI are 90, 80, 60, 80, 80, 70, 70 and 80 respectively. These targets are suggested based on various water quality objectives identified by the CPCB under its various pollution control programmes. An example of how the proposed yardstick can be applied in the field of pollution control is given in Table 2.

Table 2. Example of Application of Yardstick in Pollution Control

Stretch	Value not fulfilling the target	Major cause for degradation	Action Required
Palla to Wazirabad	BPI	Faecal coliform	Control of sewage from drain no.8 in Haryana
Hindon from Ghaziabad to confluence with Yamuna	BPI, BSI, PRI, NPI, OPI, PPI	Sewage and industrial wastes	control of sewage and industrial wastes from Ghaziabad
Wazirabad Barrage to Okhla Barrage	BPI,NPI,OPI, PRI,BSI and BDI	Sewage and industrial wastes.	Control of sewage and industrial waste of Delhi
Okhla Barrage to Chambal Confluence	BPI, NPI, OPI, PRI, BSI, AND BDI	Sewage and Industrial wastes	Control of Shahadara Drain and Mathura-agra drains
In the city limits of Mathura, Agra and downstream of Delhi (20-30 km stretches)	BPI, NPI, PRI, OPI, BSI, BDI	Sewage and industrial wastes	Control of Shahadara and Mathura Agra sewage inflows

This yardstick so developed is proposed to be validated in other river systems of India during the year 1992-93.If found suitable the yardstick is proposed to be introduced in the legislative framework of pollution control in India.

Data Validation

Validation of water quality data involves checking and assessment of the data to see if there have been any errors made during sampling or analysis of the water quality sample. Water quality data validation consists of a series of checks to see if errors have been made in water sampling, sample analysis or data entry.

Standard checks should be applied to test the data. These usually involve the application of check readings for errors in time and magnitude. While many of the data validation checks can be made by hand, the checks are also built into the database software. The advantage of computer validation techniques are that they are objective and uniform. Data from all sources are subjected to the same scrutiny. The computer also allows the use of checking algorithms which can be tedious to apply manually.

One another important organizational aspect of validation is the possibility of splitting data validation tasks between field centres equipped with data entry microcomputers and the central data processing computer. Since most microcomputers have standard data entry software packages that incorporate data validation options, no software development effort is required. Fields validation checks could include absolute checks for dates and variable codes, and relative checks for range and rate of change. Tables and plots of input data could also be made for manual checking. Such a system would reduce considerably the error rate of data arriving at the centre where more elaborate validation, e.g., inter-station consistency checks, could be performed.

General Procedure for WQ Data Validation

Water quality data validation should be conducted in part by the chemist at a water quality laboratory, and in part by the water quality experts at the regional or district data centers. The laboratory chemist will enter analytical results and field observations into the computer database. Most of the validation checks will be made by the database software. Once the data has been checked, any signalled errors should be corrected if possible. This may require new analysis of some samples. The validated data will be sent by diskette from the laboratories to the regional data centre, where they will be added to the water quality data base. Further validation of data will take place at the data centre, where the latest data entries can be checked compared to the historical data.

Specific Data Validation Tests

A series of data checks should be carried out to identify any problems in the data. A number of tests is described below including:
A series of data checks should be carried out to identify any problems in the data. A number of tests is described below including:

- Absolute checking/Data entry
- Checking if data is within the detection limits of a particular method
- Checking if the data is within the expected ranges for a parameter
- Checking if there are too many (or too few) significant digits reported
- Checking if data are physically or scientifically possible (general checks)
- Checking correlation of parameters (Some conditional checks)
- Checking the correlation between EC and TDS

- Checking the cation-anion balance

Absolute checking/Data entry

Absolute checking implies that data or code values have a value range that has zero probability of being exceeded. Thus, geographical coordinates of a station must lie within the country boundary, the day number in a date must lie in the range 1-31, and in a numeric-coding system the value 43A cannot exist.

The limits used may take one of the following forms:
- A single absolute value or range;
- A set of ranges applicable in different areas and/or at different times
- Ranges applicable to many stations or ranges which are applicable only to individual stations.

Data failing these tests must be incorrect. It is usually a simple task to identify and remedy the error. The database software should be programmed to catch these types of errors during data entry.

Detection Limits

The water quality results reported cannot be less than the detection limit of the analytical procedure being used to measure the concentration. Thus all data should be checked compared to the expected detection limit. The detection limits of all analytical procedures must be known. If there are different procedures possible for making an analysis, the procedure that is used must also be known.

Checking WQ data against expected ranges

Water quality data can also be checked against expected ranges.

Significant Digits

The number of significant digits to be reported for a water quality result depends on:
- the precision of the analytical procedure used
- the absolute value of the result compared to the range of expected results

General Checks

General checks are made to see if the water quality results are physically or scientifically possible.
A simple general check is that the totals of any variable must be greater than the component parts as in the following examples:
- Total coliforms must be greater than faecal coliforms
- Total iron must be greater than dissolved iron
- Total phosphorus must be greater than dissolved (ortho-)phosphorus
- Total iron must be greater than dissolved iron

General checks:

Total solids	≥ Total dissolved solids
Total solids	≥ Total settleable solids
COD	> BOD
Total Coli	≥ Faecal Coli

Total Iron	≥ Fe^{+2}, Fe^{+3}
Total P	≥ $PO4^{-3}$
EC (μS/cm)	≥ TDS (mg/l)
Total oxidized nitrogen	≥ Nitrate, nitrite
Total oxidized nitrogen	= Nitrate + nitrite
Total hardness	= Ca hardness + Mg hardness

Some conditional checks: correlation of parameters

When there are known correlations between one or more water quality parameters these can be used to

Some of the more well known correlations between parameters are:

- Total dissolved solids and specific conductance
- pH and carbonate species
- pH and free metal concentrations
- Dissolved oxygen and nitrate

Conditional checks

If pH > 6	then Al^{+3} < detection limit
If pH > 6	then Mn^{+2} < detection limit
If pH < 8.3	then CO_3^{-2} =0
If DO (mg/l) = 0	then NO_3^- =0
If DO (mg/l) > 0	then NO_3^- >0
If DO (mg/l) > 7	then Fe^{+2} =0
If NO_2^- (mg/l) > 0	then Fe^{+2} =0
If Fe^{+2} (mg/l) > 0	then NO_2^- =0

Correlation between EC and TDS

The numerical value of Electrical Conductivity (EC) in μS/cm should be higher than that of Total Dissolved Solids (TDS) in mg/l. It is recommended that conductivity be plotted against TDS and values lying away from the main group of data be checked for errors. The relationship between the two parameters is often described by a constant (commonly between 0.55 and 0.7 for freshwaters).

Thus: TDS (mg/l) ~ 0.6 x EC (μS/cm)

Ion Balance

When a water quality sample has been analysed for the major ionic species, one of the most important validation tests can be conducted: the cation-anion balance.

The principle of electroneutrality require that the sum of the positive ions (cations) must equal the sum of the negative ions (anions).

Data Analysis

Before the collected and stored data can be effectively used, they often need to undergo some form of analysis. Such analysis may be simple, for example, the calculation of elementary statistics or the production of graphical output, or may be more complex involving advanced statistics or mathematical modelling.

It is now possible to carry out many of the techniques described below on a computer running a proprietary statistical software package. However, it should be borne in mind that such an approach carries with it dangers for the inexperienced. With a computer package it is possible to generate any number of statistics from a set of data with no regard to their appropriateness. Care should be exercised if this method is contemplated, therefore.

Basic Statistics

It is often useful to subject data to some simple statistical analysis. It may be, for example, that such an analysis could be used to summarise the data; to transform them to aid understanding or to compare them with a water quality standard that is couched in statistical terms (some discharge licences are often quoted as an annual mean or a percentile for certain parameters, for example).

Minimum

This is the lowest value occurring in the data set (x_{min}).

Maximum

This is the highest value occurring in the data set (x_{max}).

The Range

The range is a measure of the spread of the data. It is simply the arithmetical difference between the highest (x_{max}) and the lowest value (x_{min}) in the data set.

The Median

The median (M) provides an indication of the central tendency of the data set, and is that value which has an equal number of data points on each side of it. It is also referred to as the 50^{th} percentile. That is, if there are for example, twenty-five values in a data set, then the thirteenth (i.e., the central) data point in numerical order is defined as the median.

Percentiles

Any given percentile is the value below which lies a given percentage of the observations in the data set. For example, the 25^{th} percentile is the data point at which 25% of the data values are less than its value and 75% of samples are more than its value. The median (see above) is also the 50^{th} percentile - that is, half of the data set have greater values, and half have lower values, than the median.

- The Mean
- The Standard Deviation
- The Variance
- The Coefficient of Variation
- Percent Standard Error about the Mean
- Kurtosis
- The Weighted-Arithmetic Mean ($\overline{X}_w$)

Frequency Distributions

A first step in data (statistical) analysis is often a study of the distribution of the measured characteristics. Different graphical presentations can be made to help with this analysis:

- histogram
- probability density functions

- cumulative distribution functions

The final goal of a monitoring programme is the transfer of information gathered from the programme to those who will use the information (e.g. resource managers, policy makers, scientists, etc.) for decision making. This is the *Reporting* stage of the monitoring programme, and is the final stage of the monitoring cycle. It makes the link between the processes of gathering information and using information. It is very closely linked with the process of data analysis and data interpretation.

Data Reporting

A good report is one that is relevant to its subject and is read and understood by its intended audience. It is possible to state a number of principles which, if adhered to, will increase the chances of producing a good report:

- the report should reflect the objectives or terms of reference of the study
- the report should be as concise as possible without compromising on necessary detail - reports which are too lengthy tend not to be read
- in order to increase the chances of the report's main findings and conclusions being read by its target audience, it is a good idea for the report to contain a summary in which all the important messages are contained
- if it is necessary to include base data in the report they should be placed in an appendix where they can be referred to if required

The frequency of report preparation, the level of detail in reports and the distribution of reports, depend on the use of the information.

It is recommended to provide at least annual reports of the routine monitoring programme, documenting the monitoring activities that have been conducted, and an overview of the results. Further level of detail can be included as required.

Issues in Data Reporting and Presentation

Reporting of water quality information can require a number of different types of reports addressing a hierarchy of information needs: the public, policy makers, administrators and technical staff. The frequency of reporting will vary as technical staff need more frequent numbers. There should be a designed method for converting the raw data into the desired information for each audience.

Data reports can provide simply lists of data. Other reports should be less technical as one moves from the regular (frequent) technical reports to the (less frequent) public reports.

In reporting water quality information, the following items can be considered:

- audience definition: The intended audience of a report will influence the format and level of detail to be included in the report.
- monitoring objective definition
- format definition

The audience group for whom the information report is targeted should be a consideration before the preparation of the report. Several audience categories are identified, and the reporting should be tailored to the expected reader audience.

Different audiences can be identified:
- Interested public/concerned citizen: These are people who have both a general interest in water resources quality and a specific interest in the quality of a certain water system (usually related to the location of their home, or their use of a water system for a specific work purpose).
- Media/general public: Media may represent organizations of mass communication such as newspapers, general interest magazines, radio statios, and television stations, and the people who receive these reports. These people have a general interest in water quality, though not as much as the concerned citizen.
- Policy makers: These people set national or regional goals and establish programmes for attaining them (e.g. elected officials, lawmakers, top level managers)
- Resource Managers: These people are responsible for implementing programmes to protect or improve water resource quality.
- Scientists: These individuals are engaged in technical observation identification, description, experimental investigations and theoretical explanation of natural phenomena. They will have more interest in a higher level of detail than some of the other audiences.

The monitoring objective should be presented as part of the reported information. Too often, report information is presented in a self-standing manner, and the connection with the original objectives is not given. As a result, the value of the information is diminished, and the use of the information in resonse to the original objectives is less likely.

The format of the reported information is also important for the efficient transfer of information from the monitoring programme to the intended users. Formatting decisions should be based on the type of audience the document is trying to reach, and the format should assist the audience in the understanding and using of the information in the document.

Graphical methods for reporting

There are a number of advantages associated with the data analysis using graphical techniques as follows:

- trends in the data are often easier to spot
- outlying data points are normally obvious
- many people find visually presented data more acceptable and more readily understandable

It is important when presenting data graphically that:
- all graphs are easy to read and understand - in particular the temptation to put too many data sets onto one graph should be avoided; it is better to present this information using more than one graph if necessary
- the scale of the axes used is such that the data cover a large percentage of the graph
- all graphs are clearly titled and each axis, and if appropriate each data set, is clearly labelled

There are a number of types of graph which can be effective in presenting water quality data as detailed below. The choice of graph will depend upon a number of factors including the information required from the plot, the intended audience and clarity and ease of use considerations. It is often the case that the choice of graph can only be finally decided by actually plotting a number of different types of graph and assessing them for effectiveness.

Time Series Graphs

A graph in which water quality data (on the 'y' axis) are plotted against time (on the 'x' axis) in units which will depend on the frequency of sampling. This type of plot helps to identify trends or cyclic patterns in the data and is also a good way of identifying outlying data points.

Time series graphs are also useful for spotting connections between two or more water quality variables. If it is suspected, for example, that the biochemical oxygen demand in a river reach increases when the suspended solids load increases, an effective way of checking this can be to plot both of these variables on a time series graph. Visual inspection can then be used to see if peaks and troughs for the two variables coincide.

Histograms

Histograms or bar charts are effective at displaying the relative differences in data. That is, it is easy to show that a sampling point has twice the pollutant concentration of its neighbour by means of a histogram.

Histograms are also useful for displaying data for a non-technical audience as they are easily understood by the majority of people.

Pie Charts

Pie charts, which are circular diagrams divided into a number of segments, are less frequently used for water quality data. They are used when it is necessary to present information about the relative proportions of a particular parameter, however. For example, the relative proportions of a pesticide which were dissolved in water, bound to suspended solid particles or present in the bottom sediments of a river could be represented using a pie chart.

Profile Plots

A plot of water quality data down the length of a river (longitudinal profile) can be useful for observing changes which occur as the river flows downstream. Often such plots are annotated with the positions of major discharges and river tributaries so that the effect of these inputs is clearly visible on the graph.

If samples have been collected at various depths, a vertical profile of the data can be plotted. Such plots are often used to analyse how lake water or groundwater varies with increasing depth.

Geographical Plots

It is often useful to plot water quality data on a map base to show local and regional variations in water quality. Such a technique can be used to attempt to pinpoint a pollution source from groundwater data or merely to show how one river or catchment compares to another in terms of its water quality or pollution load.

Data interpretation

The water quality data collected are the basis of the information that can be provided. However, the data themselves are not 'information'. If data are not in a form which can be used or understood by its intended recipients then they cannot be considered to be information. The process of data interpretation involves abstracting, transforming, summarising and commenting on the data so that they will be useful to those to whom they are ultimately transmitted.

In order to make a conversion of data to information, the data need to undergo some form of analysis. Such analysis may be simple, for example, the calculation of elementary statistics or the production of graphical output, or may be more complex involving advanced statistics or mathematical modelling.

The specific analyses to be conducted depend on the water quality information desired, or the specific questions about water quality being asked. Water quality concerns are wide and varied, but probably the most commonly asked questions are:

1. What is the water quality at any specific location or area?
2. What are the water quality trends in the region: is the quality improving or getting worse?
3. How do certain water quality parameters relate with one another at given sites
4. For surface water (rivers): how do certain water quality parameters relate to stream discharge?
5. What are the total mass loadings of materials moving in and out of water systems, and from what sources and in what quantities do these originate?
6. Are sampling frequencies adequate and are sampling stations suitably located to represent water quality conditions in an area?

It is now possible to carry out many of the techniques described below on a computer running a proprietary statistical software package. However, it should be borne in mind that such an approach carries with it dangers for the inexperienced. With a computer package it is possible to generate any number of statistics from a set of data with no regard to their appropriateness. Care should be exercised if this method is contemplated, therefore.

Types of Data Interpretation

It is often the case that those who receive, and may need to act upon, water quality data are non-technical people. Often managers, politicians or members of the public need to comment or make decisions based upon water quality data. Unless such people are technically qualified, data alone will not of any use to them; they need to know what the data means.

There are a number of ways that water quality data can be made more meaningful to a non-technical audience including the following:

- comparing the data with national water quality standards - this gives an insight into the scale of a particular data set (e.g., if the data show that a particular groundwater sample contains a higher concentration of pollutant than is allowed by a national drinking water standard, most people would assume that it may not be safe to drink this water)
- comparing the data to international standards - it may be useful to compare the data to standards used by other countries (e.g., the United States) or international organisations (e.g., the World Health Organisation or the European Union) particularly if standards for a particular pollutant have not been defined nationally
- calculating water quality indices, such as S.A.R. and **???**
- determining the water quality classification and comparing to desired classification

- comparing the data derived from one area to data from another similar area - for example, it is easy to see how two similar rivers compare in terms of their pollution load when their water quality data are presented together
- calculation of trends showing how water quality has changed at one or more sampling points either over time or due to a particular event (e.g., the construction of a power station on a river reach)
- calculating how much mass of a substance has travelled down a river (i.e. mass fluxes).

Calculation of Indices

In India, several water quality indices can be calculated which indicate the suitability of water for different uses:

- Water classification index for surface waters
- Sodium Absorption Ration (SAR) for irrigation suitability
- Percent Sodium for irrigation suitability
- Residual Sodium Carbonate – for irrigation suitability
- Chloride – bicarbonate ratio
- Wilcox
- Pipers Tri-linear plotting

Water Classification Index for surface waters

In India, a water classification index with 5 categories is used to indicate water quality required for different uses.

The Central Pollution Control Board has classified the inland surface waters into 5 categories - A to E on the basis of the best possible use of the water as shown in Table 1. The classification has been made in such a manner that the water quality requirement becomes progressively lower from class A to class E.

A water body may be subjected to more than one organised use. The use demanding the highest quality is the designated best use. A water body or stretch of river whose existing water quality does not meet the designated best use criteria requires action to mitigate the situation. Based on such analysis river action plans are formulated.

The results from the water quality monitoring should be used to calculate the water quality index, and to check with the designated use of that water body.

Sodium Adsorption Ratio

Sodium concentration is important in classifying an irrigation water because sodium reacts with soil to reduce its permeability. When high sodium water is applied to soil, the number of sodium ions combined with the soil increases, while an equivalent quantity of calcium or other ions is displaced. These reactions change the soil characteristics, causing deflocculation and reduction of permeability. The ion exchange occurs in the opposite direction when calcium is added. Thus, adding gypsum ($CaSO_4$) to a soil creates a flocculated and more permeable soil, improving soil texture and drainability.

Soils containing a large proportion of sodium, with carbonate as the predominant anion are termed alkali soils. Soils with chloride or sulphate as the predominant anion are termed saline soils. Ordinarily, either type of sodium-saturated soil will support little or no plant growth.

The Sodium Adsorption Ratio (SAR) is one common water quality index indicating sodium content and the suitability of water for irrigation.
The SAR is calculated from the major ions in water:

$$SAR = \frac{Na^{+}}{\sqrt{\left(Ca^{2+} + Mg^{2+}\right)/2}}$$

Where: all concentrations are in milliequivalents per liter.

The suitability of the water for irrigation decreases with increasing SAR value. Specifically, the sodium reacts with the soil, reducing its permeability. In international standards, the following classification scale is used:

- SAR < 3: suitable for irrigation
- SAR = 3 – 9: use may be restricted
- SAR > 9 : unsuitable for irrigation

In India, higher values of SAR are tolerated, in part because the annual flushing from monsoon rains prevents sodium accumulation in the soils. The following classifications are used:

- SAR < 10: Excellent
- SAR = 10 – 18: Good
- SAR = 18-26: Fair
- SAR > 26 Poor

Percent Sodium

Sodium can also be calculated as Percent Sodium (%Na) to indicate the suitability of water for irrigation:

$$\% Na = \frac{(Na^{+} + K^{+}) \times 100}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}}$$

Where: all concentrations are in milliequivalents per liter.

The following classifications are used:

- %Na < 20 Excellent
- %Na = 20 - 40: Good
- %Na = 40 - 60: Permissible
- %Na = 60 - 80: Doubtful
- %Na > 80 Unstuitable

Residual Sodium Carbonate (RSC)

The sodium hazard to soils is also increased if the water contains a high concentrations of bicarbonate ions. The bicarbonate values are conveniently expressed in terms of ‘Residual Sodium Carbonate’ (RSC).

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$$

Where: all concentrations are in milliequivalents per liter.

The following classification scale is used:

- RSC < 1.25 meq/l: suitable for irrigation
- RSC = 1.25 – 2.5 meq/l: marginal
- RSC > 2.5 meq/l : unsuitable for irrigation

Chloride – bicarbonate ratio of groundwater

The chloride –bicarbonate ratio is used to indicate sea water intrusion into groundwater. Chloride is the dominant ion of ocean water and normally occurs in only small amounts in groundwater. Additionally, bicarbonate is usually the most abundant negative ion in groundwater and occurs only in minor amounts in sea water. Often an increase in the chloride bicarbonate ratio, as well as total salinity can be seen near the coast.

$$Sodium - Bicarbonate\ Ratio = \frac{Cl^{-}}{CO_3^{2-} + HCO_3^{-}}$$

Where: all concentrations are in milliequivalents per liter.

Table1 *Primary water quality criteria for various uses of fresh water*

Designated best use	Class	Criteria
Drinking water source without conventional treatment but after disinfection	**A**	1. Total coliform organisms MPN/100mL shall be 50 or less. 2. pH between 6.5 and 8.5 3. Dissolved oxygen 6 mg/L or more 4. Biochemical oxygen demand 2 mg/L or less
Outdoor bathing (organised)	**B**	1. Total coliform organisms MPN/100mL shall be 500 or less 2. pH between 6.5 and 8.5 3. Dissolved oxygen 5 mg/L or more 4. Biochemical oxygen demand 3 mg/L or less
Drinking water source with conventional treatment followed by disinfection	**C**	1. Total coliform organisms MPN/ 100mL shall be 5000 or less 2. pH between 6 and 9 3. Dissolved oxygen 4 mg/L or more 4. Biochemical oxygen demand 3 mg/L or less
Propagation of wild life, fisheries	**D**	1. pH between 6.5 and 8.5 2. Dissolved oxygen 4 mg/L or more 3. Free ammonia (as N) 1.2 mg/L or less

Irrigation, industrial cooling, controlled waste disposal	**E**	1. pH between 6.0 and 8.5 2. Electrical conductivity less than 2250 micro mhos/cm 3. Sodium absorption ratio less than 26 4. Boron less than 2mg/L 5. Percent Sodium less than 60

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