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Parameters and methods used for assessment of water quality

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Abstract
The quality of water is measured in terms of its physical, chemical and biological characteristics. Water quality assessment is done by experts from different fields to monitor the trend, provide information to water resource management authorities, policy makers and to make recommendations. The quality of water is influenced by several factors such as rainfall, climate, soil type, vegetation, geology and human activities. The rapid increase in population, urbanization and increased industrial and agricultural activities have affected water quality all across the globe. There are several methods adopted to assess the quality of water such as use of remote sensing GIS (Geographic information system), and Water Quality Indices (WQI). In this review, the various parameters of quality assessment of river water are discussed along with some of the recent advances in tools used for study of water quality.

Keywords: water quality; water quality index (WQI); physico-chemical parameters; biological parameters

Introduction
Water, a non-renewable resource, is one of the most important components of the ecosystem which support all living things including human beings on earth. Clean water is required for various purposes for healthy living and it is soon becoming a scarce commodity in many parts of the world [1]. Quality of water resources depend on many factors such as rainfall, climate, soil type, vegetation, geology and human activities. The quality of water is typically described by its physical, chemical and biological characteristics. These characteristics determine suitability of water for domestic, industrial or agricultural purposes. The main parameters which depict the water quality are pH, temperature, turbidity, minerals, dissolved oxygen, biological oxygen demand, chemical oxygen demand and microbial pathogens. Permissible limits for drinking water quality are set according to standards set by American Public Health Association (APHA), World Health Organization (WHO), Indian Standard Institution (ISI), Central Pollution Control Board (CPCB) and Indian Council of Medical Research (ICMR) [2].
Poor quality of water has hazardous impact on human health, flora and fauna. Contaminated water used for human consumption is linked to infant mortality and transmission of diseases such as cholera, diarrhoea, dysentery, and polio in developing countries [3].
At the present time, there is need for comprehensive water quality monitoring programs to safeguard public health and to protect the valuable and vulnerable water resources [4]. The data will enable planners, policy makers, water monitoring and water management agencies both at national and international levels to formulate strategies and suggest remedial measures. In this review the physico-chemical and the biological parameters of water is discussed along with the tools and recent advances in water quality assessment.

Physico-chemical parameters
Colour
Pure water is colourless; therefore, appearance of any type of colour in water sample indicates contamination by a foreign substance.
It can be suspended or dissolved organic and inorganic materials which contribute to the colour of water. There are different methods for measurement of water samples from different sources. Colour of water sample is measured by platinum-cobalt (Pt-Co) using Hazen scale or Cr-Co scale and spectrophotometric methods depending upon the source of sample water [5, 6].
In the platinum-cobalt method, visual comparison of sample water is done with standards prepared from diluted solutions of potassium chloroplatinate and cobaltous chloride. One colour unit is equivalent to the colour produced by a 1 mg/L solution of platinum (potassium chloroplatinate (K_2PtCl_6). Colour is graded on scale of 0 (clear) to 70 colour units and pure water is equivalent to 0 colour units. The maximum acceptable level for colour of drinking water is 15 TCU (True colour unit) [7].

Turbidity
Turbidity is cloudiness in water due to suspended and dissolved materials like organic, inorganic materials, particulate matter, soil particles, algae, plankton or microorganisms [8]. In aquatic ecosystems turbidity reduces the infiltration of light below water surface and in turn affects the aquatic flora and aquatic microbiota. Suspended particulate matter provide attachment for other pollutants such as heavy metals and microorganisms, thereby making turbidity readings an indicator of potential pollution in river waters. Turbidity is measured in Nephelometric-Turbidity Units (NTU), Formazin attenuation units (FAU), Jackson turbidity unit (JTU) or Turbidity unit (TU). The electronic turbidity meter called nephelometers which

measures NTU are devices which use optical scatter-detection techniques for detection of turbidity in water samples. It is expressed in NTU or TU where a TU is equivalent to 1 mg/L of silica in suspension [9]. Drinking water should have turbidity less than 5 NTU as per BIS and WHO standards [10]. Nephelometry is limited to lower turbidity readings below 40 NTU. Another method is use of turbidity sensor, a sensor which can be dipped directly into water source for reading the turbidity. They are called submersible turbidimeters and these sensors are ideal for monitoring water turbidity in in-situ conditions in streams, rivers, lakes and oceans instantaneously [11]. They are useful for relatively continuous surface water monitoring when left submerged in water. Turbidity promotes regrowth of pathogens in water and can lead to outbreaks of water borne diseases. Although it is not an indicator of health risk, there is strong relationship between turbidity and presence of protozoa, microorganisms and heavy metals in water [12].

Temperature

Temperature of water is a key factor which affects the water chemistry. It regulates the dissolved oxygen levels of water, sedimentation, the type of aquatic life, photosynthesis rate, parasites and microorganisms in water [13]. It also affects solubility, odour and viscosity and biosorption process of the dissolved heavy metals in water [14]. Temperature is measured in degrees Fahrenheit or Celsius (Centigrade) using mercury thermometer. The desirable temperature for tap water is 25°C and drinking water is 19°C as per standard prescribed by WHO [15].

Taste and odour

The taste and odour of water samples are mostly due to presence of inorganic salts, dissolved gases, organic matter and organic matter derived from algae blooms [16]. Nutrient poor water bodies do not exhibit detectable odours. When there is influx of nutrient from agricultural or urban discharge, there is detection of mild fishy or musty odour due to increase in algal biomass. Algae from class Cyanophyceae are responsible for most of the undesirable taste and odour. Several genera of microalgae, cyanobacteria, actinomycetes and diatoms release volatile metabolites like geosmin and 2-methylisoborneol which impart earthy, musty, muddy off-flavour and camphor-like taste and odour [17]. Chemicals even when present in only trace amounts also influence the taste and odour of water. They impart medicinal or metallic taste to water. A metallic taste of water can be due to presence of iron, manganese, copper or zinc in trace amounts; iron at levels over 0.004 mg/l, manganese at > 0.1 mg/L, copper between 2-5 mg/l and zinc between 4-9 mg/l. High iron or copper content in water sample also causes bitter and astringent taste [18]. The taste and odour of water sample is expressed in terms of Threshold number (T/O TN). The taste/odour threshold number (T/O TN) of a sample is that dilution of the sample with blank (reference) water where no taste or odour is detected. The value of odour or taste is determined quantitatively by measuring a volume of sample and diluting it with a volume of an odour-free distilled water so that the odour of the resulting mixture is just detectable at a total mixture volume of 200 ml [7].

Foam

Foam in water result from detergents, soaps, phosphates from fertilizer and from naturally occurring surfactants originating from algae and plants including humic and fulvic acid substances [19]. The purity of water can be estimated from the time of persistence of bubbles when the water sample is shaken in a closed container. If the persistence time is even 1 second it indicates presence of impurities. The foaming factor and the foam potential are used to estimate the capability of an effluent to cause foam in the receiving river [20]. The foaming factor is derived by shaking 250 ml of effluent in Erlenmeyer flasks with baffles on a laboratory shaker for 3 min at a speed of 300 rpm. Foam is undesirable in water bodies as it leads to anaerobic condition in aquatic ecosystem.

Conductivity

The electrical conductivity (EC) of water is a measure of its ability to conduct electrical current [21]. Electrical conductivity of water is due to presence of dissolved ions and ionic strength. Pure water has very low electrical conductance of 0.05 µS/cm. It is usually expressed as microsiemens or millisiemens per centimeter (uS/cm or mS/cm). The conductive ions are contributed by dissolved salts, the cations and anions like chlorides, sulphides and carbonates, potassium, sodium, nitrate, sulphate, magnesium, calcium, etc. Electrical conductivity of water is measured using a conductivity meter. The permissible limit of EC values as per BIS is 3000 µS/cm [10].

Total dissolved solid

Total dissolved solids (TDS) of water is the sum of all ion particles dissolved in it that are smaller than 2 microns in size [22]. The dissolved solids may be derived from organic or inorganic compunds and these influence the taste, odour and hardness of the water sample. The value of TDS is expressed in mg/L. It can be measured using a conductivity meter and by dividing the conductivity value (in mS/cm) by a factor of 1.56 or it can be determined by gravimetric method by drying water samples at 180 °C using an evaporating dish [23]. The latter method is time-consuming and cannot be used for in-situ measurements. Unexpected increase or decrease in TDS may indicate pollution or addition of ions such as potassium, magnesium, sodium, calcium, carbonate, bicarbonate, chlorides, fluorides, phosphates, sulphates or nitrate ions which may be traced to natural sources, sewage, agricultural runoffs or municipal leakages. In rivers and streams, the TDS is also contributed by the soil in the form of humic or fulvic acids. The standard TDS range prescribed by ICMR, WHO and BIS lies between 500–1500 mg/L [2]. pH

Water is acidic if it contains extra hydrogen ions (H^+) and basic if it contains extra hydroxyl (OH^-) ions. A pH value less than 7 indicates acidity and greater than 7 indicates basicity. High pH accounts for bitter taste in water. A pure water sample at 25°C has pH value very close to 7. The safe pH value for water lies Between 6.5 to 8.5 as per different standards of WHO, ICMR, CPCB and BIS [2]. pH of water affects the solubility of many toxic chemicals. Lower pH allows heavy metals such as chromium, lead and cadmium to dissolve easily in it, thereby increasing toxicity. On the other hand, a very alkaline pH becomes poisonous for living organisms in the aquatic environment. The pH of water sample is determined using either electrometric or colorimetric methods.

Acidity and alkalinity

Acidity of a water sample is the capacity to neutralize a strong base to a selected pH level. The acidity in natural water sources is due to atmospheric carbon dioxide gas which serves as a source of carbonic acid. Acidity in water affects the chemical reactions and biological activities in aquatic environments. Acidity of a water sample is determined by titration of the sample against a standard sodium hydroxide solution using phenolphthalein indicator.

Alkalinity of a water sample is the capacity of the sample to neutralize an acid. It is sum total of all the titratable bases usually bicarbonate and carbonate present in it. Alkalinity is caused by the presence of either hydroxide ions (OH^-) or bicarbonate ions (HCO^{3-}) and carbonate ions ($CO3^{2-}$). Organic acid such as humic acid also contribute to alkalinity in water. Alkalinity encourages growth of aquatic plants which in turn affects the taste of water and makes it unpalatable [24]. The optimum alkalinity for aquatic life is between 50 and 150 mg/L [25]. It is measured by titration against a standard acid solution such as sulphuric acid using indicators methyl orange and phenolphthalein.

Chloride

Chloride is present naturally in water sources but concentrations higher than 250 mg/L is regarded as undesirable [26]. The main source of chloride in water are rocks, agricultural run offs or domestic and municipality discharge and industrial effluents. Even though, chloride is not harmful, high concentration of chloride in water especially as sodium chloride, imparts an unpleasant salty taste to water. Other salts such as magnesium or calcium chloride do not affect the taste of water until higher concentration levels of around 1000 mg/L. The maximum permissible limit prescribed by BIS, 2012 is 250 mg/l [27]. The chloride concentration in drinking water is determined by titration method using silver nitrate.

Sulphate

Sulphate ions in water sources arise from mineral sources like gypsum and leaching of deposits of sodium sulphate or magnesium sulphate. Although it is not harmful to human health, presence of sulphate ions cause undesirable taste in water and may cause various intestinal diseases [28]. The desirable limit of sulphate content of water were is 200 mg/l as per standard set by BIS [10].

Phosphate

The main source of phosphates in water is inorganic fertilizers used in agriculture, detergents, industrial and sewage discharges. Huge level of phosphate content causes eutrophication in water bodies. The permissible limit for phosphate is 0.1 mg/L [27].

Nitrate-Nitrite

Nitrogen occurs as organic nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen in water sources. Contamination of water bodies from domestic and municipal sewage add organic nitrogen and ammonia. High concentration of nitrate in water triggers growth of algae [29]. Agricultural run offs which contain residual inorganic fertilizers and animal manure add to the nitrate content in water. The level of nitrate-nitrogen prescribed by ICMR, WHO, BIS are 20, 50, 45 mg/L respectively [2, 30, 31]. A concentration of more than 10mg/L in water can affect human health severely. Especially in infants, nitrate ions cause blue baby or methemoglobinemia where nitrate ions react with haemoglobin of blood and decreases the oxygen binding capacity of blood.

Fluoride

Minerals which contain fluoride are topaz, cryolite, fluorite, amphiboles, mica and fluoroapatite [32]. Fluoride in trace amounts benefits dental health, however, higher concentration of fluoride cause fluorosis or discolouration of teeth. In potable water, permissible limit of fluoride is 1.4 -2.4 mg/L; ingestion of fluoride more than 1.5 mg/L is harmful for human health [33].

Iron and Manganese

Iron enters water bodies from geogenic sources, discharge of domestic wastes or industrial effluents such as iron and steel industries, mining and metal corrosion. The permissible limit for drinking water is 0.3 mg/L as per WHO standards [34]. Iron when present in high concentration imparts undesirable odour, metallic taste and red colour to water. It is detected in water in form of oxides, silicates, carbonates and sulphides. Manganese (Mn) when present in even very low concentrations as manganous (Mn^{2+}) ions cause bitter taste in water sample [35]. The permissible level of Mn^{2+} ions is in the range 0.04–0.1 mg/L. Iron and manganese level in water sample is determined by atomic absorption spectrometry, flame atomic absorption spectrometry, cold vapor atomic absorption spectrometry, electrothermal atomic absorption spectrometry, and inductively coupled plasma (ICP) [36].

Copper and Zinc

Copper is found in water systems in dissolved, colloidal and particulate forms. Copper and Zinc cause unpleasant taste in water even though they are non-toxic in trace concentrations. Zinc imparts turbidity when present in higher concentrations. Zinc enters water bodies from mining activity discharges, pesticides and pigment production industries. Acceptable concentration of copper in drinking water is 50 mg/L and that of zinc is 5 mg/L as per BIS (2012) [27]. Copper and zinc are detected by spectrophotometric methods.

Hardness

Hardness in water is due to dissolved minerals mainly calcium (Ca^{2+}) and magnesium (Mg^{2+}) and is referred to as calcium hardness and magnesium hardness. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions enter water sources from soil, rock and limestone deposits as bicarbonates, sulphates, chlorides and nitrates, sewage discharge and industrial effluents. The permissible limit of magnesium hardness is 100 mg/l as prescribed by BIS, 2012[27]. Carbonates and bicarbonates cause temporary hardness which can be removed by boiling while sulphates and chlorides cause permanent hardness. Hard water contains 300 mg/L of hardness and soft water contain a level of around 75 mg/L. The maximum permissible limit for total hardness is 600mg/L as per BIS [14]. Hardness of water is estimated by titration against ethylene diamine tetra acidic acid or (EDTA) with Eriochrome Black and Blue indicators [37]. It is generally expressed in terms of mg/L of $CaCO_3$.

Dissolved oxygen and Biochemical oxygen demand (BOD)

The discharge of untreated or inadequately treated sewage or industrial effluents rich in organic matter lead to depletion of dissolved oxygen. Solubility of oxygen in water depends upon the temperature, pressure and salinity of water. The saturation concentration of oxygen at 20°C is around 9 mg/L and at 0°C is

14.6 mg/L. A DO range between 4 to 6mg/L is suitable for survival of aquatic life as per standards of CPCB and BIS [2, 38]. Dissolved oxygen is estimated by colorimetric method, Winkler titration or electrometric method.

Biochemical oxygen demand (BOD) is the measure of the amount of oxygen that bacteria will consume while decomposing organic matter in a water sample under aerobic conditions. An incubation of 5 days at 20°C, followed by titration is done to estimate the BOD of water sample. Increase in BOD is caused by high content of organic matter from inadequately treated sewage and also from high nitrate content in water bodies. Microorganisms like bacteria metabolize organic matter into simpler compounds to release energy and by products CO_2 and H_2O are formed, consuming DO in the process. The desirable limit for BOD is 4.0 mg/l and the permissible limit is 6.0 mg/l [39, 40]. Chemical oxygen demand (COD) is a measure of the total quantity of oxygen required to oxidize all organic material into carbon dioxide and water. COD measures all of the biodegradable organic natter as well as non-biodegradable substances present in water. High COD level is attributed to increased addition of both organic and inorganic contaminants. The maximum limit of COD in drinking water as per quality standards of WHO is 20 mg/l [1]. COD is estimated using strong oxidizing agent potassium dichromate and sulphuric acid and result can be obtained in around 2 hrs.

Heavy metals and other toxic inorganic substances

Different types of toxic inorganic substances enter water sources from untreated industrial effluents and other sources of hazardous wastes. They are present in water in form of metallic or non-metallic compounds. Metallic compound includes heavy metals such as cadmium, chromium, lead, mercury, silver, arsenic, barium, thallium and selenium [41]. These heavy metals are bio-accumulative and can enter the food chain from irrigation water. Presence of heavy metals in water samples can be determined by atomic absorption photometers, spectrophotometer, or inductively coupled plasma (ICP) for very low concentration. The non-metallic toxic compounds include nitrates (NO^{3-}) and cyanides. The maximum permissible limit of nitrate content in groundwater is 100 mg/l as per BIS, while concentration above 50 mg/l is harmful for health. It causes methaemoglobinaemia or blue baby syndrome in infants. The range of nitrate-nitrogen prescribed by ICMR, WHO, BIS are 20, 45, 45 mg/l respectively [42]. Cyanide is a highly toxic pollutant which enters the water system from industrial and mining activities. The permissible limit of cyanide in drinking water as per BIS is 0.05 mg/L [43].

Biological Parameters

Water bodies get contaminated with pathogenic microorganisms from discharge of untreated or inadequately treated domestic raw sewage, municipality sewage, industrial effluents, discharge from recreational waters, animal husbandary run-offs, wild animal wastes and urban run-offs. There are several waterborne diseases which arise from contaminated water such as typhoid and paratyphoid fever, leptospirosis, gastroenteritis, shigellosis, and cholera. As it is not feasible to detect, isolate and identify all types of pathogenic microorganisms in water bodies, faecal indicator bacteria and coliforms are used as microbiological water quality parameters. It involves selective culturing, confirmation of species by standard biological and serological methods like standard plate count (pour and spread plate methods), most probable number (MPN), defined substrate technology (DST) and membrane filtration [44]. Faecal indicator bacteria (FIB) are total coliforms, *Escherichia coli*, or *Enterococci* and *Streptococcus fecalis*. These are detected and enumerated with culture based methods. Even though the culture based methods give accurate results, it takes more than 48 hrs to get results. Moreover, there are several pathogenic strains which are viable but not culturable (VBNC). In order to overcome these limitations, culture-independent molecular methods are now adopted wherein DNA extracted from water sample is used for direct detection and quantification of target indicator strains. The maximum permissible limit of total coliforms in drinking water is 1 per 100ml (ICMR, 1975) and 10 per 100ml (WHO, 1993) [45, 46]. Other alternative methods include flow cytometry, fluorescence spectroscopy of dissolved organic matter (DOM); quantitative PCR (qPCR) methods; next-generation sequencing (NGS) technologies [47].

The advances in biological parameter assessment include biomonitoring and bioanalytics wherein plants, animals, algae, fungi, cyanobacteria, larval invertebrates, macroinvertebrates are used as bioindicators [48]. Bacteria, viruses and their derivatives such as enzymes and antibodies are used as biosensors for bioanalytics. These biosensors help in detection of presence of pollutants and level of pollution of water bodies [49].

Methods of assessment of water quality

The traditional method of water quality assessment is based on determination of water quality parameters and comparing them with standard limits. Even though the estimation of parameters is accurate, it is expensive and time consuming. Moreover, the information thus derived does not provide the spatial and temporal trends of the overall quality. An alternative method is the use of water quality indices (WQIs), wherein different physical, chemical and biological parameters are incorporated into various mathematical equations to determine the quality of water [50].

WQI is a concise and comprehensive method to evaluate water quality status by surveying a selected group of parameters and reducing the information onto a single dimensionless number [51]. The first WQI was suggested in Germany by Horton (1965) [52] and Brown *et al*. (1970) [53] using arithmetic aggregation function of parameters *viz*., dissolved oxygen (DO), pH, coliforms, specific conductance, alkalinity, and chloride. There are more than 20 different WQIs developed since the 1970s which are followed for assessment of water bodies all over the world. Each physico-chemical parameter selected is assigned a unit weight and weighted arithmetic index is used to calculate the WQI, thereby transforming the concerned parameters to a common scale [54]. The different water quality indices used worldwide are US National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), British Columbia Water Quality Index (BCWQI), Oregon Water Quality Index (OWQI), Weighted Arithmetic Water Quality Index (WAWQI) [55]. In India, the pioneer work on WQI was done by Bhargava (1983), [56, 57, 58] where the water quality is expressed as a number (ranging from 0 for highly/extremely polluted to 100 for absolutely unpolluted water) representing the integrated effect of the parameters amplifying the pollution load. The use of WQI makes the assessment cost effective with selection of only few critical parameters.

The assessment of water quality is mostly based on sampling and laboratory analyses or in situ monitoring. Though these conventional methods are accurate, they are costly, labour intensive, time consuming and one cannot derive water quality in spatial or temporal terms. For the water bodies which are not accessible for frequent manual sampling or monitoring, satellite remote sensing is a means to monitor them frequently. The use of remote sensing techniques for assessment and monitoring of water quality began in early 1970s [59]. Remote sensing measures the spectral and thermal differences in energy emitted from water surfaces. It can help monitor turbidity, temperature, pollutants, presence of pigments like chlorophyll or carotenoids, coloured dissolved organic matters, Secchi disk depth, total suspended sediments, total phosphorus, sea surface salinity, dissolved oxygen, biochemical oxygen demand and chemical oxygen demand (COD) of water bodies [60]. Appropriate satellite sensors are available for mapping water quality parameters. Some of the commonly used sensors are spaceborne sensors carried by sattelites or spacecrafts and airborne sensors mounted on aircrafts, balloon or boats. Oceanographic sensors include the microwave radiometers (MWR) and synthetic aperture radar (SAR) [61]. Thus the advances in water quality assessment applies the integrated approach of use of GIS, GPS and remotely sensed data. These databases generated will serve as baseline for water quality monitoring and pollution control.

Conclusion

The study of water quality is a multidisciplinary work which include assessment and monitoring of physico-chemical and biological parameters. This review aims to provide information on the parameters and methodology used for the assessment of water quality along with some recent advances in the established methods.

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