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Good Ambient Water Quality

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Definition

Water quality is the suitability of water to sustain various uses or processes (Meybeck et al. 1996), and *ambient* is "relating to the immediate surroundings of something" (ambient, 2018). *Ambient water quality* refers to natural, untreated water in rivers, lakes, and groundwaters. *Good ambient water quality* is the positive conclusion of a water quality assessment of these waters affected by a combination of natural influences such as climate and geology and also anthropogenic activities, such as wastewater outflows and agricultural runoff. Ambient water quality is defined as "good" if the assessment concludes the water is not harmful to either the aquatic ecosystem or human health.

Recognizing that ambient water quality is not linked to any single *use* of water and that it refers to the quality of water in the natural environment which supports healthy ecosystems and serves as the source for all possible uses is critical for the management of water quality. It should be recognized that not all *natural* water bodies that are free from anthropogenic influence are necessarily classed as *good ambient water quality*. Some waters naturally contain high concentrations of compounds known to be harmful to human health, for example, arsenic in certain groundwaters of Bangladesh (Chakraborti et al. 2010) and fluoride in water supplies of Kenya (Gevera et al. 2018). Natural events can also result in water quality failing to meet quality requirements for certain uses on a temporary or long-term basis, such as torrential rainfall or hurricanes.

Being able to reliably define ambient water quality as "good," requires a thorough understanding of the natural and anthropogenic influences of water quality. This requires the robust and systematic collection of water quality data that in turn requires the capacity to assess the quality of ambient waters. The aim should be to achieve as high a proportion as possible that meet good ambient water quality status. Implementing management practices and policy measures to achieve this target at national or regional scales reduces efforts (and costs) to treat water for any

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intended single use, such as for drinking water or irrigation water supply, and assures that the quality of water is not harmful to aquatic ecosystem function.

Introduction

With freshwaters under threat globally, there is a critical need for information on the quality and suitability of water to meet the targets of the sustainable development goals. Pollution of freshwaters is a risk to human health, food security, and ecosystem services (Millennium Ecosystem Assessment 2005), but in many parts of the world, the magnitude of freshwater quality degradation is largely unknown (UN Water 2016; UNEP 2016). This freshwater pollution is being driven by socioeconomic development and population growth – with increasing levels of wastewater being generated from expansion of agriculture and industry with a high proportion discharged to water bodies without any form of treatment (WWAP 2017). This can result in degradation of water quality in both freshwaters and coastal zones (WWAP 2015). Economic development is entirely reliant upon the same freshwater resources it pollutes, and the ambitious targets of Agenda 2030 will not be met without good ambient water quality in our rivers, lakes, and groundwaters. Water of a certain quality is critical in terms of providing basic services and enabling activities such as water for drinking, irrigation, fisheries, industry, power generation, and functioning healthy ecosystems. It is critical that decision-makers have information on the quality status of freshwater in our environment, to inform decisions on the most appropriate use of the available freshwater and also to limit further impact on freshwater ecosystems.

Ambient Water Quality Influences

Ambient water quality is governed by hydrological, physical, chemical, and biological processes. These interacting processes are controlled by geological, climatic, biological, geographical, topographical, and anthropogenic factors resulting in waters with diverse characteristics. This diversity in nature and quality of water is expressed over spatial scales, within and between water bodies, and also temporal scales, ranging from hours to millennia in response to changing influence from the various controlling factors. The water contained in any water body originates from multiple sources that follow disparate flow paths. A specific flow path of water on its route to a water body significantly influences its characteristics. For example, the water in a stream may have fallen directly as precipitation onto the stream surface, or it may have entered through overland, shallow subsurface, or groundwater flows. Each flow path will bring water with a particular signature determined by the interactions of the water molecules with the wider environment. The quality status of a water body is the sum total of all these influences combined, weighted by the proportion of water derived from the different flow paths (Lintern et al. 2017).

Water bodies are often considered as discrete units for management purposes, but water continuously flows from one to another as part of the global hydrological cycle, and the significance of this connectivity between surface and groundwaters is often overlooked (Winter et al. 1998; IAH 2017).

Differences in velocity and discharge can drive changes in ambient water quality at a particular location over timescales ranging from hours for streams to millennia for groundwaters. The speed at which water flows through a water body can affect its ability to assimilate and transport compounds. For example, the amount of material held in the water column is directly proportional to its velocity. The residence time or the time that water remains in a water body is dependent on numerous interacting factors and can range by several orders of magnitude. Flowing waters such as streams and rivers have the shortest; standing water bodies such as lakes and reservoirs have intermediate length; and groundwaters have the longest residence times. This period dictates the length of time that the water can be influenced by the immediate surroundings of the water body which is especially relevant for groundwaters, but it also can be used to estimate the length of time that a pollutant entering a water body will remain (Meybeck and Helmer 1996).

Natural Influences on Ambient Water Quality

Ambient water quality in bodies of water that are free from significant human influence arises solely from natural processes in the water body. This quality of ambient water can be influenced by:

- Geology: the structure and lithology of rock matrix underlying the catchment area
- Climate: the long-term trends of precipitation, temperature, wind, and humidity of an area
- Biology: the ecosystems within the catchment area and the biological interactions within the water body itself
- Location: the geographic location of a water body, including the latitude/longitude, elevation, depth below ground (for groundwaters), and proximity to coast
- Topography: the arrangement and shape of the physical landscape

These influences govern ambient water quality by hydrological, physical, chemical, and biological processes. Understanding the influence of these natural processes on ambient water quality is key in the assessment process in determining whether the quality of water contained in a water body is good or not.

Geology

The lithology type and the geological structures underlying a catchment have a significant influence on water quality. The predominant influence that geology has on water quality is through weathering: weathering is the process by which water, ice, acids, salts, temperature, and biology act upon the rock. The rate of weathering differs depending on the characteristics of the rock and its structure. Weathering can be either physical, which is the break down as a direct result of atmospheric conditions, or chemical, driven by the reaction of atmospheric or biologically produced chemicals. The products of weathering are transported to the surface and groundwater bodies.

Chemical weathering of surficial rocks is a primary driver of characteristics of surface waters (Meybeck 1987). Interaction between the rock and carbonic acid, derived from the combination of carbon dioxide and water, leads to the formation of the major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and of dissolved silica and bicarbonates (HCO_3^{-}) (Meybeck et al. 1996). The varying solubility of different rock types and the contact time between rock and water will determine the solutes concentrations. Some of the most soluble rock types include limestones, rock salts, and gypsum. Groundwaters have a longer period for water-rock interaction, and it is groundwaters which generally have higher concentrations of solutes although this is entirely dependent on the lithology (Chilton 1996).

The products of weathering and the control of flow paths to water bodies by geology can significantly affect the quality of freshwaters. For example, fluoride is present in almost all freshwaters (Hem 1985; Brunt et al. 2004; Ozsvath 2009), but in extreme cases natural concentrations can exceed 1000 mg/L (Jones et al. 1977), which is far in excess of the World Health Organization's limit for fluoride in drinking water of 1.5 mg/L (WHO 2017). The deleterious effects on human health of drinking water with high fluoride concentration have been known since the early nineteenth century (Smith et al. 1931).

Climate

Precipitation, temperature, wind, and humidity can each influence ambient water quality. Precipitation drives the hydrological regime for a region by defining the amount and pattern of rainfall (Kalkhoff et al. 2016; Rostami et al. 2018). The average and range in temperature governs chemical and biochemical activity (Allan and Castillo 2007) as well as affecting evaporation and transpiration rates. Wind can directly affect certain water quality parameters by influencing the amount of mixing at surface of lakes and reservoirs (Morace 2007) and can assert influence over the distribution of atmospherically deposited compounds.

Regions where climate is characterized by alternating wet and dry seasons lead to seasonal differences in the chemical composition of streams and rivers. The climate can accelerate weathering chemical and biochemical reactions during warmer seasons, leading to large quantities of soluble organic and inorganic matter. In the wet season, streams have large variations in discharge and show a wide range in chemical composition as a result of the increased runoff and dilution. Cold weather climates inhibit weathering reaction rates because of low temperatures. As a result, runoff is mostly low in solute concentration.

Temperature plays an important role in determining the quality of ambient waters. Temperature plays a role in physical, chemical, and biological processes that can directly affect the nature of water quality. For example, the solubility of gases decreases with increasing temperature – this is especially relevant for dissolved oxygen which is required by aquatic animals and plants for respiration. Also, the toxicity of ammonia which is present in most freshwaters rises with increasing temperature. This is caused by the ammonia/ammonium equilibrium (NH_3/NH_4^+) moving toward the more toxic ammonia side in higher temperature. Increased evaporation rates with higher temperatures can lead to the concentration of solutes in water in arid and semiarid regions.

The quantity and intensity of precipitation falling on a catchment area of a water body will dictate the composition of water in a stream from different sources. For example, during a dry period, the flow in a stream may be dominated by groundwater discharge, but following a significant rainfall event, the proportion of overland and subsurface flow will increase, and these sources are likely to be considerably different from groundwater source in terms of chemical characteristics. Overland flow can often carry high concentrations of suspended particulate matter, whereas shallow subsurface flows can be high in dissolved organic carbon (DOC) and nutrients. During a relatively large rainfall event following a dry period, areas of the catchment which previously were hydrologically isolated from a river network may suddenly become connected (Dunne and Black 1970; Gburek 1990; Pionke et al. 2000) and serve as an untapped source and may transport large quantities of dissolved and particulate matter to the stream.

Biology

Biological processes within the aquatic environment can alter the physical and chemical composition of water. Terrestrial and aquatic vegetation can supply organic carbon and nitrogenous compounds and influence the soil type of the catchment. For example, wetlands can release large quantities of DOC, which is of great importance in the ecology of the aquatic ecosystem downstream. Aquatic flora and algae can directly affect water quality by uptake of nutrients from the water, and, also, through respiration and photosynthesis, they can alter the concentration of dissolved oxygen diurnally.

Microbiological activity in groundwater can speed up chemical oxidation rates. For example, under optimum conditions, the contribution of sulfate concentration by oxidation of sulfides can be more significant than physical or chemical factors (Chilton 1996). Also microbiological activity controls processes such as denitrification (conversion of nitrate (NO_{3-}) to nitrous oxide or free nitrogen which is released back to the atmosphere), organic matter burial in sediments, sediment sorption, and plant, and microbial uptake can also remove nitrogen from surface waters; this then reduces the amount carried by rivers into the sea (Laursen and Seitzinger 2002).

Location

The geographic location of a water body can be defined by latitude and longitude, altitude (depth below surface for groundwaters), and proximity to coast. Latitude is important because of its role in defining seasonality with stark differences observed between tropical and temperate surface waters. The proximity to the coast is especially important for surface waters which are subject to increasing atmospheric deposition of marine salt by wind. This is often more significant in determining the concentration of the major ions sodium, chloride, magnesium, potassium, and sulfate than contributions from chemical weathering for the first 100 km from coastlines where rainfall is an important contributor to surface water. These constituents are present not only in rainfall but in oceanic aerosols that accumulate on vegetation and land surfaces and are washed off by the rainfall (Meybeck 1983). Freshwaters that are closer to the coast are more influenced by high tides that drive salt water upstream. Also, coastal groundwaters are more subject to salt water intrusion.

Topography

For surface waters the topography of a water body catchment can have a significant influence on ambient water quality. For example, the gradient and length of slope can play an important role in determining velocity of river flow, soil wetness, and the distribution of wetlands. This can play an important role in the control of DOC, dissolved organic nitrogen, and nitrate in stream waters (Ogawa et al. 2006) and set the possible range for range DOC concentrations in lakes (Sobek et al. 2007). Higher-velocity water also has higher concentrations of dissolved oxygen, due to turbulence at the surface.

Anthropogenic Influences on Ambient Water Quality

Surface freshwater ecosystems are some of the most impacted by human activities globally (Carpenter et al. 2011). Very few, if any freshwaters are totally free from human influence (Meybeck and Helmer 1989; Meybeck 2003; Kelly et al. 2017), with anthropogenic compounds distributed globally (Luo et al. 2014), identified in arctic ice (AMAP 2017), as well as in remote mountain lakes (Fernández et al. 2005). Human activities can influence ambient water quality in a number of direct and indirect ways, but one of the most straightforward activities to conceptualize is the discharge of untreated wastewater directly to rivers or lakes. The resulting impact may affect the health of the ecosystem and alter the quality of water so that it may no longer be useful for agricultural, industrial, and recreational uses. Human activities can also indirectly impact ambient water quality through climate change-driven modification of weather patterns, but the degree of current impact and the potential of future impact are largely unknown (Whitehead et al. 2009).

The sources and pathways of pollutants entering freshwaters can be classified into point, diffuse, and atmospheric sources. Point sources by definition are associated with a single discharge location which contributes flow directly to a water body – an estimated 80% of wastewater globally are discharged without any form of treatment, and by this route (WWAP 2017). Diffuse source pollution cannot be attributed to a single point but generally refers to pollution that enters freshwaters from a large area such as agricultural runoff carrying fertilizer and pesticides that enter freshwaters. Atmospheric pollution can be in the form of solutes in rain or in particulate form (Meybeck and Helmer 1996) and can enter water bodies directly or by runoff from land.

Anthropogenic Activities

Many anthropogenic activities impact ambient water quality. Industry is globally responsible for discharging tonnes of heavy metals, solvents, and other wastes directly to water bodies (WWAP 2017). Rapid urbanization in many of the least developed countries, where population growth far exceeds the construction of wastewater treatment facilities with sufficient capacity, is resulting in untreated municipal and industrial wastewater reaching water bodies in large quantities (Van Leeuwen et al. 2016).

Agricultural practices can have varied and far reaching impacts on ambient water quality. Widespread use of fertilizers has resulted in nitrate now being the most common chemical contaminant in the world's groundwater aquifers (Haygarth and Jarvis 2002; Food and Agriculture Organisation of the United Nations 2017). Pesticides that are mobile and persistent and do not readily breakdown, such as atrazine, can readily enter groundwaters (Graymore et al. 2001) and pose a threat to human and ecosystem health.

In addition to expansion of agriculture, other land use changes can affect ambient water quality (Foley et al. 2005). Deforestation, for example, increases storm runoff and soil erosion and decreases infiltration to groundwater. Mello et al. (2018) found that the reduction in forested areas negatively affected the general water quality of low-order streams in southeastern Brazil. Forest cover in a watershed helps reduce sediment and nutrient loads entering streams. This is due to higher interception and soil infiltration of precipitation, thus reducing the sediment discharge, nutrients, and pollutant loading into the river during heavy rainfall periods.

Extractive industries can cause serious and widespread environmental pollution (Dudka and Adriano 1997). The recent collapse of the Samarco dam directly affected the Doce River, Brazil (Garcia et al. 2016). This event catastrophically released the contents of the tailings pond resulting in the deaths of 20 people and affecting biodiversity and environmental quality across hundreds of kilometers of river and riparian vegetation. Also, artisanal and small-scale gold mining was estimated to contribute 37% of new anthropogenic worldwide mercury emissions in 2010 (UNEP 2013).

Impacts Resulting from Anthropogenic Activities

The impacts of anthropogenic activities on ambient water quality are geographically widespread with regional and local differences. One of the greatest impacts in terms of human cost is the number of water-related diseases caused by insufficient safe water supplies. It is estimated that 3.4 million deaths a year, mostly among children, can be attributed to pathogen exposure from water (UNICEF 2008). For example, contamination of water supplies with *Vibrio cholerae* which is endemic in many countries; researchers estimate that there are annually 2.9 million cases of cholera leading to 95,000 deaths in 69 endemic countries (Ali et al. 2015).

Suspended solids (SS) and fine particulate matter are natural components of surface waters, but anthropogenic activities have modified natural fluxes and have caused serious and sometimes irreversible changes in the way that river systems function (Owens et al. 2005). Impacts of SS on water quality include reduction in dissolved oxygen, high turbidity, fish and invertebrate kills, and loss of aesthetic value (Ryan 1991).

Cultural eutrophication is the acceleration of natural eutrophication by human activities (Dodds and Smith 2016). Eutrophication is caused by the addition of excess nutrient inputs into a water body. It enables the natural productivity of a water body to be enhanced by blooms of phytoplankton including toxic blue-green algae, resulting in increases in organic matter, reduction in dissolved oxygen with microbial degradation of the organic matter, and the possibility of contaminant release from sediments when oxygen is depleted. Aesthetically the water body may also become unacceptable to the public.

Salinization is the increase in mineral salts above natural levels. Sources of these salts include mining wastewaters, industrial wastewaters, increased evaporation due to dam construction, and also evaporation of irrigation water resulting in salinized land; the salts are then transported to rivers during runoff when it rains.

In addition, atmospheric deposition and domestic wastewater inputs can increase mineral salt content. These factors can affect water quality by altering natural pH and electrical conductivity levels of the receiving water bodies (Meybeck et al. 1996).

Heavy metals are persistent in the environment (Foster and Charlesworth 1996) and have known health and environmental impacts. For example, in the USA the concentration of methylmercury in fish exceeds the US Environmental Protection Agency criterion for the protection of human health in 25% of streams. The predominant source of this mercury in fish was identified as the deposition of atmospheric inorganic mercury produced by coal combustion (Wentz et al. 2014). Globally the main source of mercury reaching surface waters is from artisanal and small-scale mining (UNEP 2013).

The reduction of pH in freshwaters (acidification) can be caused by human activities, such as direct inputs of acidic wastewaters from mining and certain industries. Additionally, sulfur dioxide from combustion emissions can react with hydrogen atoms in the atmosphere and precipitate as sulfuric acid rain. This acidified rain infiltrates soil and flows overland and can cause damage to acidsensitive ecosystems (Schindler 1988). Areas that are most likely to suffer from acidification have unreactive geology like granite, sandstone, and a base-poor soil. The buffering capacity of these river basins is very low due to the lack of carbonate rocks.

There are estimated 150,000 substances that have been registered for use in Europe or the USA over the last 30 years, of which less than 1000 are routinely monitored in the environment (AMAP 2017). The impacts of these compounds acting alone or synergistically are largely unknown, and therefore the impacts are difficult to gauge.

The effect of climate change on quantity and quality of water resources is still uncertain (Whitehead et al. 2009), but it is expected that water quality could be affected in areas experiencing increases in rainfall. Also freshwater resources along the coasts face risks from sea level rise. Increase in storm intensity may cause sewer systems to become overwhelmed resulting in the release of untreated sewage into water courses, and drought conditions may cause freshwater resources to become more saline as freshwater supplies from rivers are reduced. Reductions in rainfall particularly in agricultural areas could result in increases in salt both on land and in the water, as well as less dilution of contaminants.

Monitoring and Assessment of Ambient Water Quality

The definition of good ambient water quality relies on assessment of the data generated from a sound and robust monitoring program that accounts for the natural fluctuations of target variables. It is not practically possible to measure the tens of thousands of known chemicals entering our freshwaters. Of those which are monitored, doing so at the temporal and spatial resolution required to guarantee that there is no risk to human or ecosystem health is not possible. Monitoring programs is a compromise of what is required and what can be achieved using the available resources.

Common variables used in monitoring of ambient water quality are included in Table 1 below (from Chapman and Kimstach 1996). Not all programs will monitor all these variables; this will be determined by the local pressures to water quality and the resources and technical capacity available.

Many biological approaches to monitoring ambient water quality have been developed to assess quality of the aquatic environment. Biological approaches have advantages over physicochemical approaches because they integrate the effects of all human influences on the organism or community of organisms that exist in the aquatic environment over the period of their lifetime. Most physicochemical approaches rely on grab samples that are representative of a specific moment in time or a defined interval. The presence or absence, and relative abundance, of taxonomic groups or specific species can be used to provide a qualitative measure of water quality.

Some countries combine biological with physicochemical measurements to obtain an overall judgment of water quality. No single method has been tried and tested at a global level, but there are some general approaches that can be used to develop indices that are useful for spatial or temporal evaluation of water quality (Chapman and Jackson 1996).

In addition to the collection of data on concentrations of variable listed in Table 1, information on the hydrological condition at the time of sample collection is critical for the interpretation of results.

Effective management of freshwater resources is underpinned by a thorough understanding of a water body's natural condition that includes the natural variation and the pressures that the water body is subject to. By understanding the natural condition of a water body, a suitable reference condition can be set – this reference condition can be used to assess ambient water quality (Hawkins et al. 2010; McDowell et al. 2013).

Ambient Water Quality in the SDGs

Establishing the targets and indicators of Agenda 2030 recognized the coupled nature of water quality and sustainable development (United Nations 2018). SDG indicator 6.3.2 is the only indicator

Good Ambient Water Quality, Table 1 Common variables monitored in ambient water quality monitoring programs

Variable Group	Variable
General	Temperature, pH, color, odor, electrical conductivity, turbidity, transparency, total suspended solids, acidity, alkalinity, redox potential, hardness, dissolved oxygen, chlorophyll
Nutrients	Nitrogen compounds: ammonia, nitrate, nitrite, organic nitrogen Phosphorus compounds
Organic matter	Total organic carbon, chemical oxygen demand, biochemical oxygen demand, humic and fulvic acids
Major ions	Sodium, potassium, calcium, magnesium, carbonates, bicarbonates, chloride, sulfate
Other inorganic variable	Sulfide, silica, fluoride, boron, cyanide
Metals	Common metals: Fe (iron), Mn (manganese), Al (aluminum), Ni (nickel) Potentially toxic metals: Cd (cadmium), Zn (zinc), Cu (copper), Co (cobalt), Pb (lead), Hg (mercury) Semimetals: As (arsenic), Sb (antimony), B (boron)
Organic contaminants	Mineral oil and petroleum products, phenols, pesticides, surfactants,
Microbiological indicators	*Escherichia coli*, fecal coliforms, fecal streptococci
Biological monitoring	Biological index, biomonitors

that refers directly to "ambient water quality" and requires countries to monitor their freshwaters and report the proportion that meet good status: *proportion of bodies of water with good ambient water quality.*

Indicator 6.3.2 is directly linked to indicator 6.3.1 on wastewater treatment because inadequate wastewater treatment leads to degradation in the quality of the waters receiving the wastewater effluents. Indicator 6.3.2 is strongly linked to target 6.1 (access to safe drinking water) and target 6.6 on water-related ecosystems. Indicator 6.6.1 directly incorporates the output of indicator 6.3.2 as a sub-indicator. Also, within Goal 6, the relevance of water quality and its relationship with water quantity is significant in transboundary disputes (indicator 6.5.2). Many other SDGs rely on good ambient water quality, whether directly or indirectly. The information from indicator 6.3.2 can inform decisions relating to ending hunger by helping to ensure food security (SDG 2), improving public health by helping to identify safe water supplies (SDG 3), improving gender equality by limiting the distance women may have to travel to collect safe water (SDG 5) increasing access to energy (SDG 7), promoting sustainable tourism and industrialization (SDGs 8 and 9), reducing marine pollution (SDG 14), and safeguarding terrestrial biodiversity (SDG 15).

Ambient water quality in the SDG framework refers only to freshwaters in rivers, lakes, and groundwaters. It does not refer directly to transitional (estuarine), coastal waters, or water contained in wetlands, although these water bodies are inextricably linked and the boundaries between them are not always easily delineated. It should be kept in mind that some jurisdictions do encompass these water bodies in their definitions of ambient water quality. Table 2 lists the variables (parameters) that are used to assess ambient water quality in SDG indicator 6.3.2. The main elements of the methodology are summarized below.

- Reporting on indicator 6.3.2 requires a water quality monitoring program that collects in situ water quality samples from freshwater bodies, including rivers, lakes, and groundwaters.
- Samples are analyzed, the data must be well managed and stored, and the data needs to be assessed and then made available for reporting.
- The methodology uses a water quality index to assess water quality.
- The water quality index incorporates measurements for pH, dissolved oxygen, electrical

Good Ambient Water Quality, Table 2 The recommended monitoring variables for SDG indicator 6.3.2 for ambient water quality (from UN Water 2018)

Parameter group	Parameter	River	Lake	Groundwater
Oxygen	Dissolved oxygen	x	x	
	Biological oxygen demand, chemical oxygen demand	x		
Salinity	Electrical conductivity *Salinity, total dissolved solids*	x	x	x
Nitrogen[a]	Total oxidized nitrogen *Total nitrogen, nitrite, ammoniacal nitrogen*	x	x	
	Nitrate[b]			x
Phosphorous[a]	Orthophosphate *Total phosphorous*	x	x	
Acidification	pH	x	x	x

[a]Countries should include the fractions of N and P which are most relevant in the national context
[b]Nitrate is suggested for groundwater due to associated human health risks

conductivity, nitrogen, and phosphorus (pH, conductivity/salinity and nitrate for groundwaters) (Table 2).

- Measured values are compared with target values that represent water quality that will not be harmful to either human or ecosystem health.
- *Good ambient water quality* means that the target values have been met at least 80% of the time during the assessment period.
- *Bodies of water* may refer to sections of a river or a small river sub-basin, a lake, or an aquifer.
- Indicator 6.3.2 is reported at the national level but also at the subnational level based on river basins.

Cross-References

▶ Drinking and Wastewater Treatment
▶ Drinking Water
▶ Ecological Risk
▶ Eutrofication/Eutrophication
▶ Groundwater Pollution
▶ Monitoring and Assessment Methods
▶ Performance Indicators (Of Water Resource Management)
▶ Safe Water
▶ Sustainable Water Resource Management
▶ Wastewater Treatment
▶ Water Contamination and Biodiversity
▶ Water Contamination and Biodiversity
▶ Water Contamination, Guidelines, Risk and Hazard Alert Levels
▶ Water Contamination, Primary Productivity and Fisheries
▶ Water Contamination, Water Protection, Legislation and Law Enforcement
▶ Water Monitoring
▶ Water Quality and Protection at Source
▶ Water Quality, Public Information, Awareness and Safety
▶ Water Quality
▶ Water Sustainability, Water Sustainability Indicators
▶ Water Treatment
▶ Water-Related Ecosystems

References

Ali M et al (2015) Updated global burden of cholera in endemic countries. PLoS Negl Trop Dis 9(6). https://doi.org/10.1371/journal.pntd.0003832. Public Library of Science

Allan JD, Castillo MM (2007) Stream ecology. Springer Netherlands, Dordrecht. https://doi.org/10.1007/978-1-4020-5583-6

AMAP (2017) AMAP assessment 2016: chemicals of emerging Arctic concern. Arctic Monitoring and Assessment Programme (AMAP), Oslo

Brunt R, Vasak L, Griffioen J (2004) Fluoride in groundwater: Probability of occurence of excessive concentration on global scale. Fluoride. https://doi.org/10.1016/j.apgeochem.2003.09.004

Carpenter SR, Stanley EH, Vander Zanden MJ (2011) State of the world's freshwater ecosystems: physical, chemical, and biological changes. Annu Rev Environ Resour 36(1):75–99. https://doi.org/10.1146/annurev-environ-021810-094524. Annual Reviews

Chakraborti D et al (2010) Status of groundwater arsenic contamination in Bangladesh: a 14-year study report. Water Res 44(19):5789–5802. https://doi.org/10.1016/J.WATRES.2010.06.051. Pergamon

Chapman D, Jackson J (1996) Biological Monitoring. In: Bartram J, Ballance R. Water Quality Monitoring: A practical guide to the design and implementation of the freshwater quality studies and monitoring programmes. E & FN Spon, London, 263–302

Chapman D, Kimstach V (1996) Selection of water quality variables. In: Chapman D (ed) Water quality assessments: a guide to the use of biota, sediments and water in environmental monitoring, 2nd edn. Chapman and Hall, London

Chilton J (1996) Groundwater. In: Chapman D (ed) Water quality assessments: a guide to the use of biota, sediments and water in environmental monitoring, 2nd edn. Chapman and Hall, London, pp 413–510

de Mello K et al (2018) Impacts of tropical forest cover on water quality in agricultural watersheds in southeastern Brazil. Ecol Indic 93:1293–1301. https://doi.org/10.1016/j.ecolind.2018.06.030

Dodds WK, Smith VH (2016) Nitrogen, phosphorus, and eutrophication in streams. Inland Waters 6(2):155–164. https://doi.org/10.5268/IW-6.2.909. Taylor & Francis

Dudka S, Adriano DC (1997) Environmental impacts of metal ore mining and processing: a review. J Environ Qual 26:590–602. https://doi.org/10.2134/jeq1997.00472425002600030003x. Madison: American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America

Dunne T, Black RD (1970) Partial area contributions to storm runoff in a small New England watershed. Water Resour Res 6(5):1296–1311. https://doi.org/10.1029/WR006i005p01296. Wiley

Fernández P, Carrera G, Grimalt JO (2005) Persistent organic pollutants in remote freshwater ecosystems. Aquat Sci 67(3):263–273. https://doi.org/10.1007/s00027-005-0747-8

Foley JA et al (2005) Global consequences of land use. Science 309(5734):570–574. Available at: http://science.sciencemag.org/content/309/5734/570.abstract

Food and Agriculture Organisation of the United Nations (2017) Water pollution from agriculture: a global review executive summary, p 35. Available at: http://www.fao.org/3/a-i7754e.pdf

Foster IDL, Charlesworth SM (1996) Heavy metals in the hydrological cycle: trends and explanation. Hydrol Process 10(2):227–261. https://doi.org/10.1002/(SICI)1099-1085(199602)10:2<227::AID-HYP357>3.0.CO;2-X. Wiley-Blackwell

Garcia LC et al (2016) Brazil's worst mining disaster: corporations must be compelled to pay the actual environmental costs. Ecol Appl 27(1):5–9. https://doi.org/10.1002/eap.1461

Gburek WJ (1990) Initial contributing area of a small watershed. J Hydrol 118(1–4):387–403. https://doi.org/10.1016/0022-1694(90)90270-8. Elsevier

Gevera P, Mouri H, Maronga G (2018) Occurrence of fluorosis in a population living in a high-fluoride groundwater area: Nakuru area in the Central Kenyan Rift Valley. Environ Geochem Health. https://doi.org/10.1007/s10653-018-0180-2

Graymore M, Stagnitti F, Allinson G (2001) Impacts of atrazine in aquatic ecosystems. Environ Int 26(7–8):483–495. https://doi.org/10.1016/S0160-4120(01)00031-9. Pergamon

Hawkins CP, Olson JR, Hill RA (2010) The reference condition: predicting benchmarks for ecological and water-quality assessments. J N Am Benthol Soc 29(1):312–343. https://doi.org/10.1899/09-092.1

Haygarth PM, Jarvis SC (eds) (2002) Agriculture, hydrology and water quality. CABI Publishing, Wallingford. https://doi.org/10.1079/9780851995458.0000

Hem J (1985) Study and interpretation of chemical characteristics of natural water. U.S Geological Survey Water-Supply paper 2254. U.S. Geological Survey Alexandria, Virginia. Available at: https://pubs.usgs.gov/wsp/wsp2254/pdf/wsp2254a.pdf

IAH (2017) The UN-SDGs for 2030: Essential Indicators for Groundwater (Foster S, Carter R, Tyson G, Alley W, Furey S, Klingbeil R, Shivakoti B-R, Kabede S & Hirata R), International Association of Hydrogeologists www.iah.org. Available at: https://pub.iges.or.jp/pub/un-sdgs-2030-essential-indicators-groundwater

Jones BF, Eugster HP, Rettig SL (1977) Hydrochemistry of the Lake Magadi basin, Kenya. Geochim Cosmochim Acta 41(1):53–72. https://doi.org/10.1016/0016-7037(77)90186-7. Pergamon

Kalkhoff SJ et al (2016) Effect of variable annual precipitation and nutrient input on nitrogen and phosphorus transport from two Midwestern agricultural watersheds. Sci Total Environ 559:53–62. https://doi.org/10.1016/J.SCITOTENV.2016.03.127. Elsevier

Kelly JM et al (2017) Rivers of the Anthropocene. University of California Press, Oakland. https://doi.org/10.1525/luminos.43.SE.-.242.

Laursen AE, Seitzinger SP (2002) Measurement of denitrification in rivers: an integrated, whole reach approach. Hydrobiologia 485(1/3):67–81. https://doi.org/10.1023/A:1021398431995. Kluwer Academic Publishers

Lintern A et al (2017) Key factors influencing differences in stream water quality across space. Wiley Interdiscip Rev Water 5:e1260. https://doi.org/10.1002/wat2.1260

Luo Y et al (2014) A review on the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment. Sci Total Environ 473–474:619–641. https://doi.org/10.1016/J.SCITOTENV.2013.12.065. Elsevier

McDowell RW, Snelder TH, Cox N (2013) Establishment of reference conditions and trigger values for chemical, physical and micro-biological indicators in New

Zealand streams and rivers. Minsitry of Environment, New Zealand. Available at: https://www.mfe.govt.nz/sites/default/files/media/Fresh%20water/Establishment-of-reference-conditions-and-trigger-values-for-chem-phys-micro-biol-indicators-in-NZ-rivers-2013.pdf
Meybeck M (1983) Atmospheric inputs and river transport of dissolved substances. 1AHS Publ. Available at: https://iahs.info/uploads/dms/iahs_141_0173.pdf. Accessed 19 Nov 2018
Meybeck M (1987) Global chemical weathering of surficial rocks estimated from river dissolved loads. Am J Sci 287 (5):401–428. https://doi.org/10.2475/ajs.287.5.401
Meybeck M (2003) Global analysis of river systems: from earth system controls to Anthropocene syndromes. Philos Trans R Soc Lond B Biol Sci 358(1440): 1935–1955. Available at: http://rstb.royalsocietypublishing.org/content/358/1440/1935.abstract
Meybeck M, Helmer R (1989) The quality of rivers: from pristine stage to global pollution. Glob Planet Chang 1 (4):283–309. https://doi.org/10.1016/0921-8181(89)90007-6. Elsevier
Meybeck M, Helmer R (1996) An introduction to water quality. In: Chapman D (ed) Water quality assessments: a guide to the use of biota, sediments and water in environmental monitoring, 2nd edn. Chapman & Hall, London. 648 pp. Chapman and Hall
Meybeck M, Kuusisto E, Mäkelä A, Mälkki E (1996) Biological Monitoring. In: Bartram J, Ballance R. Water Quality Monitoring: A practical guide to the design and implementation of the freshwater quality studies and monitoring programmes. E & FN Spon, London, 3–30
Morace JL (2007) Relation between selected water-quality variables, climatic factors, and lake levels in Upper Klamath and Agency Lakes. Scientific investigations report 2007-5117. Scientific investigations report 2007–5117. Available at: https://pubs.usgs.gov/sir/2007/5117/pdf/sir20075117.pdf. Accessed 19 Nov 2018
Ogawa A et al (2006) Relationship of topography to surface water chemistry with particular focus on nitrogen and organic carbon solutes within a forested watershed in Hokkaido, Japan. Hydrol Process 20(2):251–265. https://doi.org/10.1002/hyp.5901. Wiley
Owens PN et al (2005) Fine-grained sediment in river systems: environmental significance and management issues. River Res Appl 21(7):693–717. https://doi.org/10.1002/rra.878. Wiley-Blackwell
Ozsvath DL (2009) Fluoride and environmental health: a review. Rev Environ Sci Biotechnol 8(1):59–79. https://doi.org/10.1007/s11157-008-9136-9
Pionke HB, Gburek WJ, Sharpley AN (2000) Critical source area controls on water quality in an agricultural watershed located in the Chesapeake Basin. Ecol Eng 14(4):325–335. https://doi.org/10.1016/S0925-8574(99)00059-2. Elsevier
Rostami S, He J, Hassan Q (2018) Riverine water quality response to precipitation and its change. Environment 5 (1):8. https://doi.org/10.3390/environments5010008
Ryan PA (1991) Environmental effects of sediment on New Zealand streams: a review. N Z J Mar Freshw Res 25(2):207–221. https://doi.org/10.1080/00288330.1991.9516472. Taylor & Francis Group
Schindler DW (1988) Effects of acid rain on freshwater ecosystems. Science 239(4836):149–157. Available at: http://science.sciencemag.org/content/239/4836/149.abstract
Smith M, Lanze E, Smith H (1931) The cause of mottled enamel. Science 74:244
Sobek S et al (2007) Patterns and regulation of dissolved organic carbon: an analysis of 7,500 widely distributed lakes. Limnol Oceanogr 52(3):1208–1219. https://doi.org/10.4319/lo.2007.52.3.1208. Wiley-Blackwell
UN Water (2016) Towards a worldwide assessment of freshwater quality: a UN-water analytical brief, pp 1–36. https://doi.org/10.1177/0891988715606233.
UNEP (2013) Global Mercury Assessment 2013: Sources, emissions, releases, and environmental transport. UNEP. Available at: http://wedocs.unep.org/handle/20.500.11822/7984. Accessed 19 Nov 2018
UNEP (2016) A snapshot of the world ' s water quality: towards a global assessment. Nairobi. Available at: https://uneplive.unep.org/media/docs/assessments/unep_wwqa_report_web.pdf
UNESCO – WWAP (2015) Water for a Sustainable World. Available at: http://unesdoc.unesco.org/images/0023/002318/231823E.pdf. Accessed 25 Oct 2017
UNICEF (2008) UNICEF handbook on water quality. New York. Available at: http://www.unicef.org/wes. Accessed 19 Nov 2018
United Nations (2018) Sustainable development goal 6 synthesis report on water and sanitation. New York. Available at: http://www.unwater.org/publication_categories/sdg-6-synthesis-report-2018-on-water-and-sanitation/
Van Leeuwen CJ, Koop SHA, Sjerps RMA (2016) City blueprints: baseline assessments of water management and climate change in 45 cities. Environ Dev Sustain 18 (4):1113–1128. https://doi.org/10.1007/s10668-015-9691-5. Springer Netherlands
Wentz DA et al (2014) Mercury in the Nation's streams – levels, trends, and implications. U.S. Geological Survey circular 1395. Reston. Available at: https://pubs.usgs.gov/circ/1395/
Whitehead PG et al (2009) A review of the potential impacts of climate change on surface water quality. Hydrol Sci J 54(1):101–123. https://doi.org/10.1623/hysj.54.1.101
WHO (2017) Guidelines for drinking-water quality: fourth edition incorporating the first addendum, 4th edn. World Health Organization, Geneva. https://doi.org/10.1016/S1462-0758(00)00006-6
Winter TC et al (1998) Ground water and surface water a single resource. U.S. Geological Survey, Denver. https://doi.org/10.3389/fpsyg.2012.00044
WWAP (2017) The United Nations world water development report 2017: wastewater; the untapped resource. UNESCO, Paris