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Food and Agriculture
Organization of the
United Nations

IWMI

International Water
Management Institute

WATER QUALITY IN AGRICULTURE: Risks and risk mitigation



Required citation:

Drechsel, P., Marjani Zadeh, S. & Pedrero, F. (eds). 2023. *Water quality in agriculture: Risks and risk mitigation*. Rome, FAO & IWMI. <https://doi.org/10.4060/cc7340en>

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ISBN 978-92-5-138072-7

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Sara Marjani Zadeh, Pay Drechsel and Francisco Pedrero Salcedo

Pollution is the highest environmental cause of disease and premature death in the world today. According to the 2017 Lancet Commission on Pollution and Health, diseases caused by pollution were responsible for an estimated 9 million premature deaths in 2015 (i.e., 16 percent of all deaths worldwide) – three times more than deaths from AIDS, tuberculosis and malaria combined, and 15 times more than from all wars and other forms of violence. In the most severely affected countries, pollution-related disease is responsible for more than one death in four, and affects disproportionately the poor and the vulnerable. Health costs stemming from pollution-related disease are also responsible for up to 7 percent of health spending in middle-income countries which are heavily polluted and undergoing rapid development. Overall welfare losses due to pollution are estimated to amount to USD 4.6 trillion per year (Landrigan *et al.*, 2017).

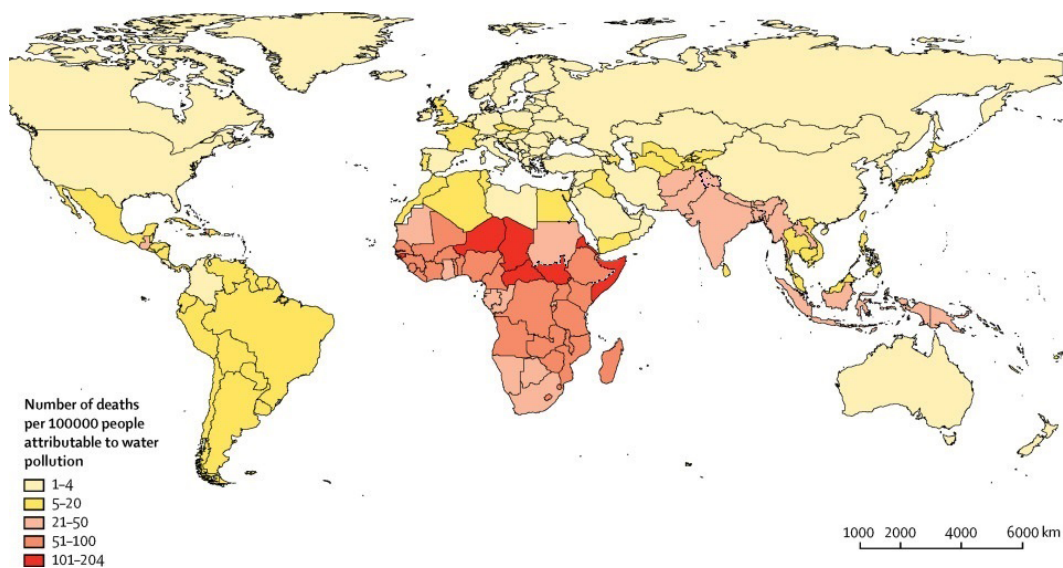
Only surpassed by air pollution, water pollution presents the second highest risk, which resulted in an estimated 1.8 million deaths in 2015. Of these, 1.3 million are attributed to polluted water sources including drinking water, followed by unsafe sanitation (Landrigan *et al.*, 2017). The principal diseases linked to water pollution are acute and chronic gastrointestinal diseases, the most significant of which are diarrhoeal diseases (70 percent of deaths attributed to water pollution), typhoid fever (8 percent), paratyphoid fever (20 percent) and lower respiratory tract infections (2 percent) (GBD, 2015).

However, these estimates do not integrate illnesses and deaths from chemical contamination of water, including by pesticides, due to lack of data from most low-income and middle-income countries. Some of the most severe examples of biological and chemical pollution of drinking water are observed in rapidly urbanizing and industrializing lower-middle-income countries, where local waterways and groundwater are heavily polluted and no alternative water sources exist (Schwarzenbach *et al.*, 2010).

Population-based estimates of the number of deaths from water pollution are highest in sub-Saharan Africa (Figure 2.1). Large numbers of deaths have also been attributed to water pollution in some southeast Asian countries, although China has greatly reduced mortality from waterborne infectious diseases over the past two decades (GBD, 2015).



Figure 2.1. Number of deaths per 100 000 people due to water pollution, 2015



Source: Reproduced with permission from Landrigan, P.J., Fuller, R., Acosta, N.J.R., *et al.*, 2017. The Lancet Commission on pollution and health. *The Lancet*, 391 (10119): 462–512; modified to United Nations map geodata, version April 2023.

Notes: Final boundary between the Sudan and South Sudan has not yet been determined. Final status of the Abyei area is not yet determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Water pollution also has effects on planetary health that extend beyond its impacts on human health. The pollution of rivers, lakes and oceans from agriculture, manufacturing and extractive industries can have catastrophic effects on freshwater and marine ecosystems that result in the collapse of fisheries and diminished livelihoods of local populations and others who rely upon fish as a major food source (WHO & CBD, 2015).

2.1 Agriculture as a cause and victim of water pollution

Over the past 100 years, increased population growth and shifts in anthropogenic activities have intensified agricultural production and expanded the industrial and urban sectors. These shifts have placed profound stress on ecosystems and natural resources, resulting in many regions in physical or economic water scarcity and water quality degradation. As the largest user of water resources, agriculture is both a cause and victim of water pollution.

2.1.1 Agricultural water pollution

Agricultural practices intensified at the start of the twentieth century, resulting in increased pollution due to heavy use of fertilizers and pesticides. Pesticide and fertilizer pollution are now among the most significant challenges to achieving safe water quality. According to FAO statistics, on average nearly 4 million tonnes of pesticides are used globally per year with China and the United States accounting for the highest levels of pesticide use at 1.4 million and 0.5 million tonnes per year, respectively. Globally, modelling has shown that agricultural insecticides may be entering surface waters in over 40 percent of land area (Ippolito *et al.*, 2015). In the United States, 90 percent of all water and fish sampled from streams across the country contained trace evidence of at least one chemical pesticide (Cassou, 2018). Pesticides are problematic in water because many of the chemicals used (aldrin, DDT, endosulfans and organochlorine insecticides) are persistent organic pollutants (POPs). In other words, they do not break down easily or rapidly but rather bioaccumulate in ecosystems.

Chemical fertilizer can be problematic when application exceeds plant need. Heavy fertilizer applications in China, and North and South America, for example, have produced adverse environmental consequences with increased nutrient loads in regional bodies of water, notably nitrogen and phosphorus, which are of particular concern. In the United States alone, the damage from eutrophication is estimated to cost almost USD 2.2 billion per year (Dodds *et al.*, 2009). A cross-country analysis showed that every additional milligram per litre of nitrate that enters the water increases stunting of children younger than 5 years by 11–19 percent and decreases adult earnings by 1–2 percent. This suggests that the marginal loss of health and productivity could outweigh the marginal gain in yields associated with an additional unit of fertilizer application (Damania *et al.*, 2019).

In addition to pesticide and fertilizer pollution, other agriculturally borne water quality challenges derive from animal husbandry and fishery effluent. These sources are responsible for depositing different assortments of antibiotics, pharmaceuticals, pathogens and nearly 700 other types of pollutants into the environment, contaminating groundwater, rivers, and surface and coastal waters (Mateo-Sagasta, Marjani Zadeh & Turral, 2017). Many of these pollutants are classified as emerging pollutants, which UNESCO describes as “any synthetic or naturally occurring chemical or any microorganism that is not commonly monitored or regulated in the environment with potentially known or suspected adverse ecological and human health effects” (UNESCO, n.d.). Scientists suspect that many of these pollutants are chronically and acutely toxic and carcinogenic, and disrupt endocrine function. The overuse of antibiotics is particularly problematic as this can lead to the emergence of antibiotic resistant microorganisms (Miranda, Godoy & Lee, 2018; Schar *et al.*, 2021).

2.1.2 Non-agricultural water pollution

Globally, between 50 percent and 80 percent of collected domestic and industrial wastewater is released without any prior treatment (Jones *et al.*, 2021; United Nations, 2017). An estimated 129 countries are currently not on track to achieving safe management of wastewater resources by 2030 (UN-Water, 2021), an issue that affects 35.9 million hectares of agricultural land that are directly and indirectly irrigated with wastewater (Thebo *et al.*, 2017). Municipal and industrial wastewaters contain similar pollutants as are found in agricultural run-off, but boast higher levels of pathogens aside from heavy, often toxic metals such as arsenic, lead or mercury. Pollution from industry and agriculture is also one of the most important ecosystem degraders, and in 2017 contributed to economic losses of over USD 579 million in China from damage to marine ecosystems alone (Song, Pan & Pan, 2020).

2.2 Water quality challenges and the Sustainable Development Goals

The 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDG) have concentrated global efforts to foster international collaboration. Global reporting mechanisms have been developed and are being implemented to monitor progress, also in view of water access and water quality.



The mission of SDG 6 is to ensure availability and sustainable management of water and sanitation for all. The specific targets for Goal 6 are listed below with sections referencing water quality in bold:

- 6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all;
- 6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations;
- 6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally;
- 6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity;
- 6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate;
- 6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.

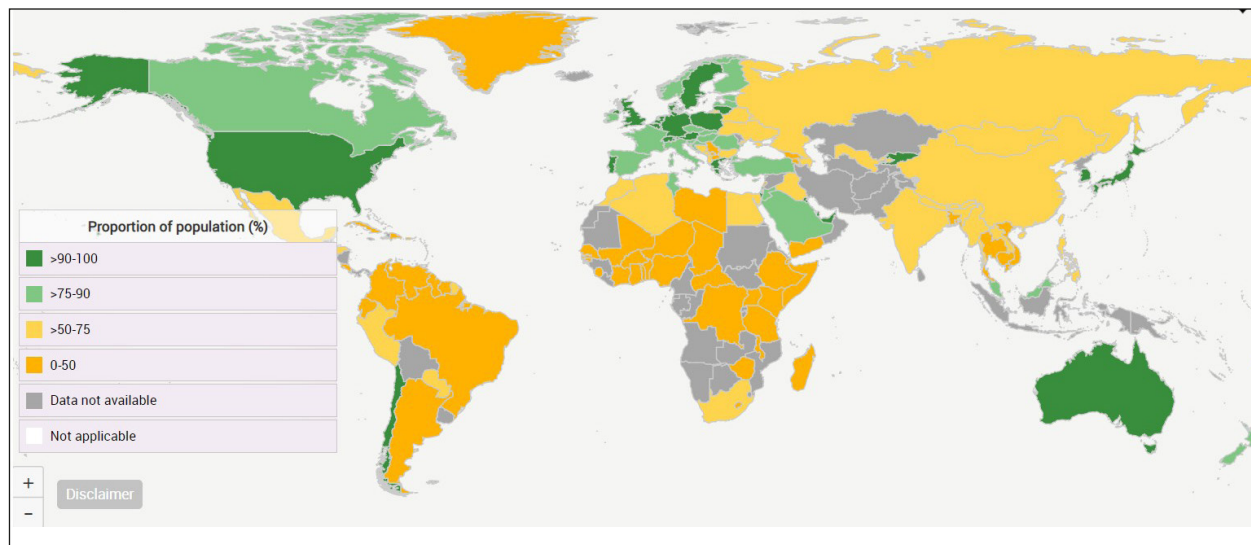
Several SDG 6 indicators are closely linked to water quality, with 6.3.1 and 6.3.2 having the greatest visibility:

- 6.2.1 Proportion of population using (a) safely managed sanitation services and (b) a hand-washing facility with soap and water;
- 6.3.1 Proportion of domestic and industrial wastewater flows safely treated ;
- 6.3.2 Proportion of bodies of water with good ambient water quality;
- 6.6.1 Proportion of water basins experiencing high surface water extent changes.

Safely managed sanitation (indicator 6.2.1a) is essential to protecting the health of individuals, communities and the environment. Open defecation, leaking latrines and raw wastewater can spread disease, provide a breeding ground for mosquitoes, and pollute groundwater and surface water that may serve as potential sources of drinking water (Damanian *et al.*, 2019). Therefore, SDG 6.2 aims to achieve the universal provision of adequate sanitation and an end to open defecation. However, between 1990 and 2015, sanitation improvements accounted for just under 10 percent of the decline in child mortality (Headey and Palloni, 2019), and while some progress has been made, achieving this ambitious goal remains a fundamental challenge in many parts of the developing world (Figure 2.2).

SDG indicator 6.3.1 is an indirect water quality indicator monitoring the proportion of total, industrial and domestic wastewater flows safely treated in compliance with national or local standards (Figure 2.3). Wastewater collection and treatment help protect freshwater systems, the oceans and also human health, by preventing detrimental pathogens, nutrients and other types of pollution from entering the environment.

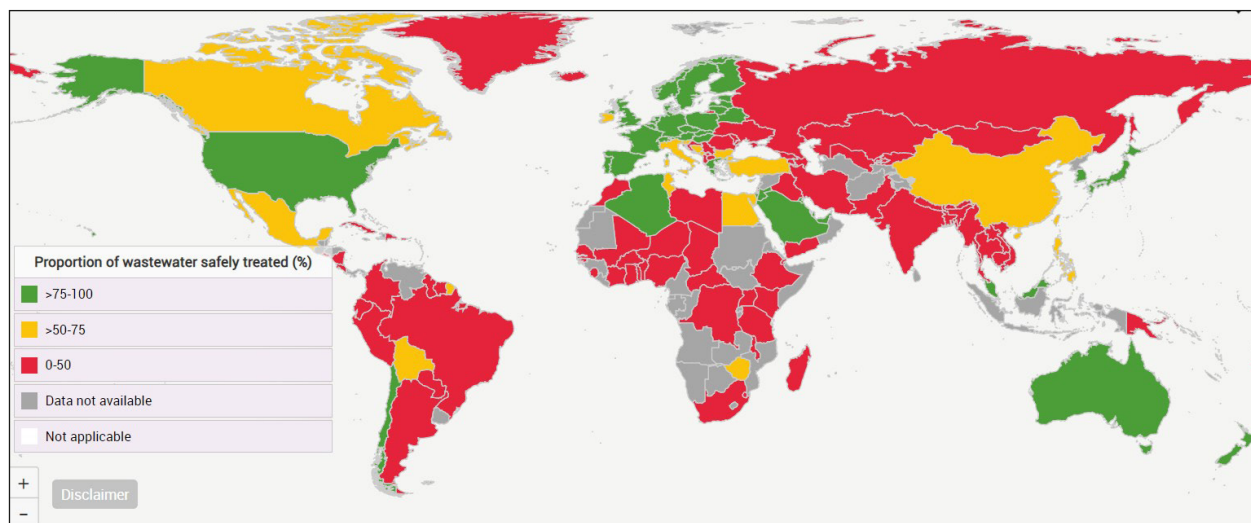
Figure 2.2. Proportion of population using safely managed sanitation services (indicator 6.2.1a), 2016-2022



Source: WHO, UNICEF. 2022. Progress on Sanitation (SDG target 6.2) Accessed 12 August 2023. <https://sdg6data.org/indicator/6.2.1a>.

Notes: Final boundary between the Sudan and South Sudan has not yet been determined. Final status of the Abyei area is not yet determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Figure 2.3. Proportion of domestic wastewater flow (safely) treated (indicator 6.3.1), 2020-2022



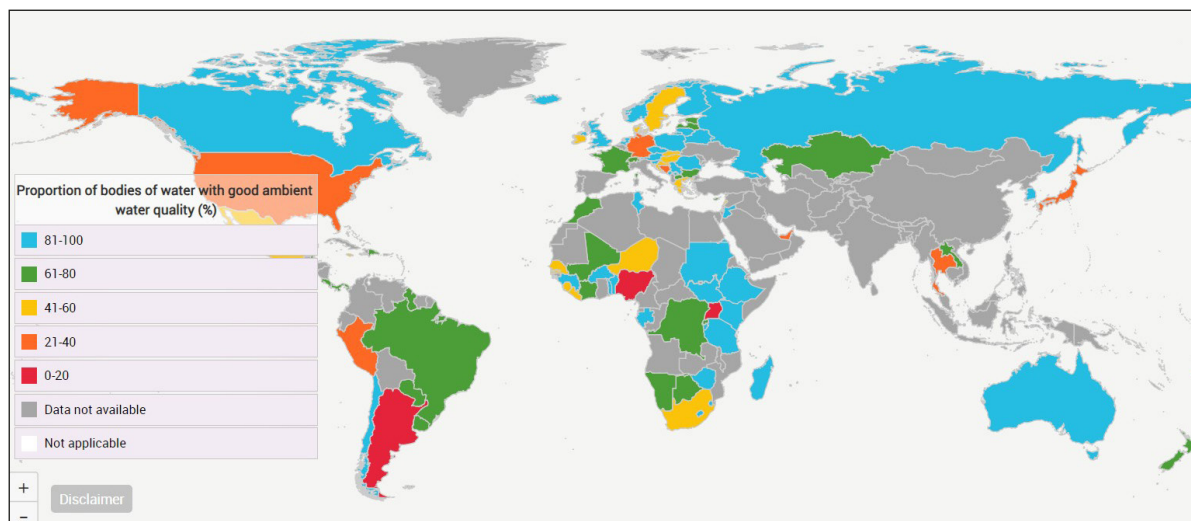
Source: WHO 2022. Progress on Wastewater Treatment (SDG target 6.3) Accessed 12 August 2023. <https://sdg6data.org/indicator/6.3.1>.

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The second indicator directly related to water quality is 6.3.2. This refers to the percentage of monitored water bodies in a country classified as having good ambient water quality (Figure 2.4). The methodology uses a water quality index to classify water quality, which incorporates measurements of five core parameter groups: acidification, oxygen, nitrogen, phosphorus and salinity for surface water (rivers and lakes), and acidification, salinity and nitrogen for groundwater.



Figure 2.4. Level 1 proportion of bodies of water with good ambient water quality (indicator 6.3.2), 2017-2020



Source: UNEP 2020. Progress on Ambient Water Quality (SDG target 6.3). Accessed 12 August 2023. <https://sdg6data.org/indicator/6.3.2>,

Notes: Final boundary between the Sudan and South Sudan has not yet been determined. Final status of the Abyei area is not yet determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

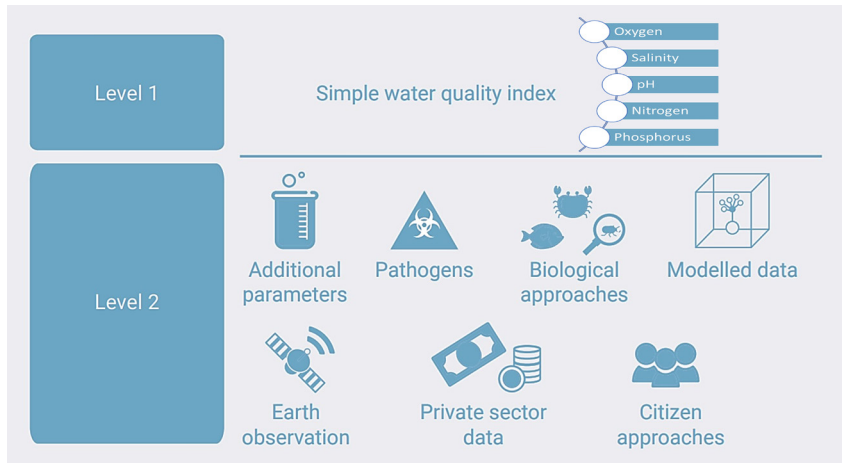
The methodology is based on samples collected or analyses performed in situ. Measured values are compared to target values that represent “good ambient water quality”. These targets are set by countries at either the national, reporting basin district or water body level.

A threshold value of 80 percent compliance has been established to classify water bodies as of “good” quality. Therefore, a water body is classified as “good” if the measurements from the water body meet their targets at least 80 percent of the time, or “not good” if the targets are met less than 80 percent of the time. The overall national indicator score is based on water body type (river, lake or groundwater), and reporting basin district, which will consist of either a single large river basin or several smaller river basins (<https://gemstat.org>).

Indicator 6.3.2 differs from most other SDG 6 indicators due to its requirement for actual water sampling and (at a minimum) field laboratories. At its most basic (level 1 monitoring), the indicator uses methods that focus on the physicochemical characteristics of water that change in response to pressures of global relevance. These are nutrient enrichment, oxygen depletion, salinization and acidification. Indicator 6.3.2 thus complements 6.3.1, which describes the impact of poor wastewater treatment and the risk of pathogenic and chemical pollution.

There are many other water quality parameters which are routinely measured, like heavy metals or pesticides, as well as alternative monitoring approaches such as those that examine species that live in the water, and Earth observation techniques which rely on satellite imagery. These additional parameters and approaches are captured under Level 2 monitoring (Figure 2.5) which provides additional flexibility for countries to include further information that may be of national concern or relevance.

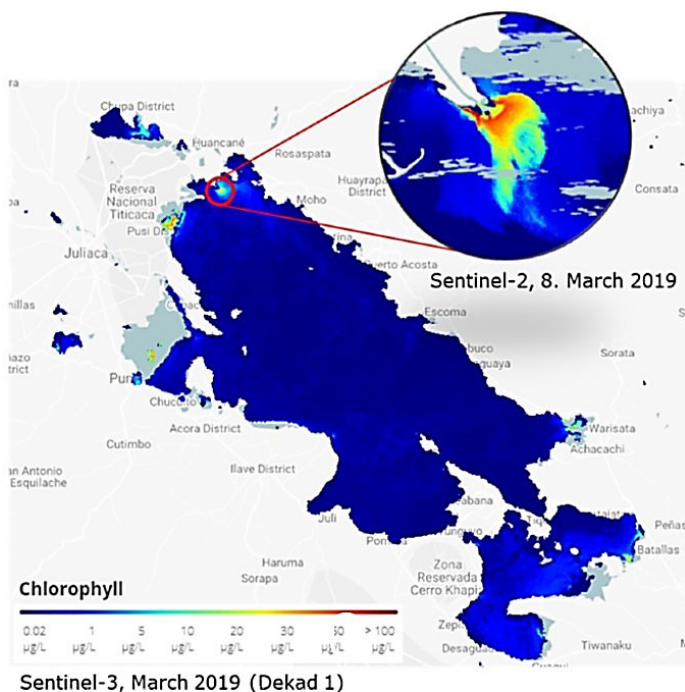
Figure 2.5. Examples of level 1 and 2 data sources for SDG 6.3.2. monitoring



Source: UNEP. 2021. Progress on ambient water quality. Tracking SDG 6 series: Global indicator 6.3.2 updates and acceleration needs. Nairobi, UNEP.

Advances in analysing satellite imagery have also enabled the creation of global datasets, for example on lake water quality, without need for local sampling (IOCCG, 2018). Although indicator 6.6.1 focuses on tracking spatial area changes over time in water-related ecosystems, the monitoring process also captures wherever possible water quality changes based on satellite data by measuring remotely two water parameters: turbidity and trophic state (UNEP, 2021b). Turbidity is a key indicator of water clarity and is influenced by the amount of suspended solids. The Trophic State Index shows the degree to which organic biomass accumulates in a water body and is most commonly used in relation to monitoring eutrophication. Remote sensing can assess water turbidity as well as chlorophyll-a concentrations in plants as a proxy for the trophic state, but cannot directly detect, for example, nutrient concentrations such as phosphorus and nitrogen. The potential for application is evident e.g. in the case of Lake Titicaca, where sewage water from nearby cities, industries and mines flows largely untreated into the lake (Figure 2.6). The nutrients in the wastewater support phytoplankton bloom events which the satellite can detect.

Figure 2.6. Elevated chlorophyll concentrations around the northern inlet of Lake Titicaca

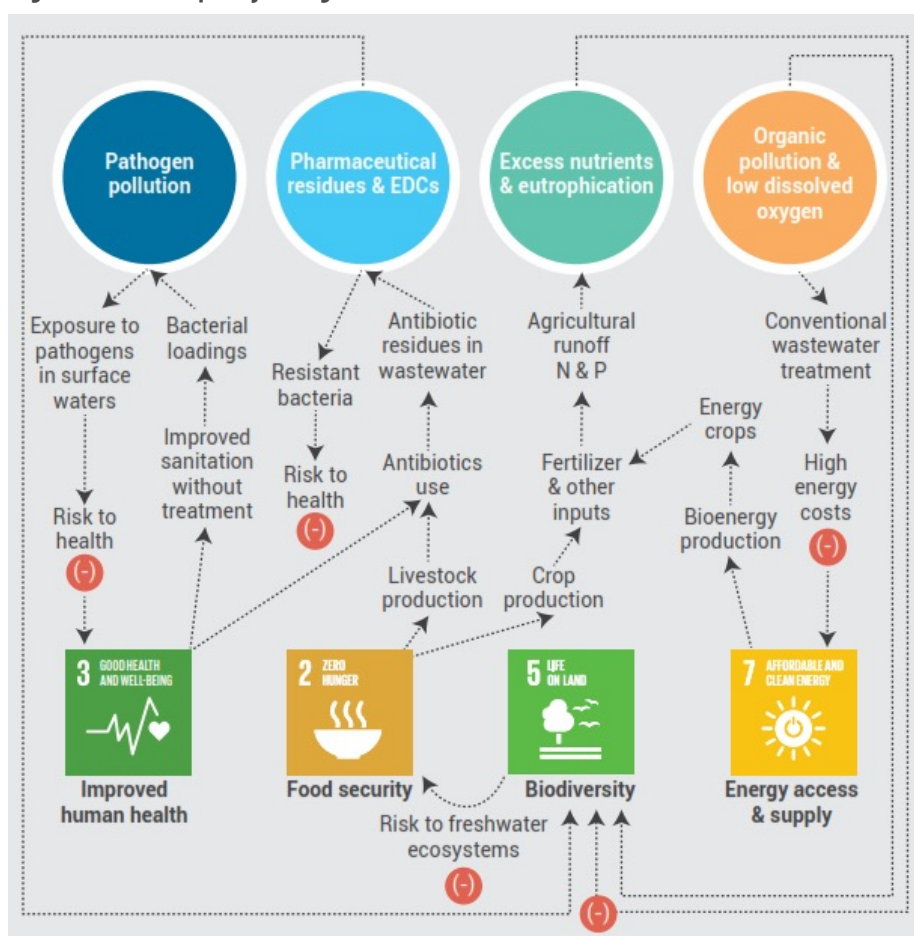


Source: UNEP 2021. Freshwater Ecosystems Analysis and Case Stories. Accessed 12 August 2023. <https://stories.sdg661.app/#/story/1/0>.

Globally, the highest shares of impacted lakes are found in sub-Saharan Africa, Latin America and the Caribbean, Europe and Northern America, and Oceania, where more than 40 percent of lakes show signs of water quality deterioration relative to the 2006–2010 baseline (UNEP, 2016).

In addition to the specific SDG 6 targets, water quality will also have a profound influence on other SDGs. A recent UN-Water publication, *Water and Sanitation Interlinkages across the 2030 Agenda for Sustainable Development*, documents the pattern of reinforcing interlinkages between SDG 6 (including water quality target 6.3) and the other SDGs (UN-Water, 2016). For water quality, these include connections to targets related to increasing access to public services (SDG 1 and SDG 11), ending hunger (SDG 2), improving health (SDG 3), increasing access to energy (SDG 7), promoting sustainable tourism and industrialization (SDG 8 and SDG 9), and reducing marine pollution (SDG 14). Figure 2.7 illustrates some of these connections.

Figure 2.7. Water quality linkages with SDGs other than SDG 6



Source: UN-Water. 2016. *Water and sanitation interlinkages across the 2030 Agenda for Sustainable Development*. Geneva, UN-Water

2.3 Water quality monitoring

A significant challenge for establishing a global water quality database is limited monitoring and reporting capacity, especially in developing countries where the required financial resources, institutional capacities or analytical infrastructure are often lacking. The UN estimates that the absence of routine water quality data collection places over 3 billion people at risk, due to lack of information regarding the health of their freshwater ecosystems and, consequently, a lack of action to adequately address quality issues (UN-Water, 2021).

Through the UN-Water Integrated Monitoring Initiative for SDG 6 (IMI-SDG 6), the United Nations seeks to support countries in monitoring water- and sanitation-related issues within the framework of the 2030 Agenda for Sustainable Development, and in compiling country data to report on global progress towards SDG 6 (UN-Water, n.d.).

IMI-SDG 6 brings together UN organizations that are formally mandated to compile country data on the SDG 6 global indicators, and builds on ongoing efforts such as UNEP's Global Environment Monitoring System for Water (GEMS/Water), FAO's Global Information System on Water and Agriculture (AQUASTAT), the UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS), and the WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP). There are currently four main approaches been employed to gather water quality data across countries (Damania *et al.*, 2019; UNEP, 2016):

- Efforts to grow the vast GEMStat database have proven vital for researchers and policymakers. The main limitation of the database, however, is that data are self-reported, and as a result, both the parameters employed and the frequency of collection are sporadic across and within countries. Coverage is particularly sparse in Africa, Central Asia, the Middle East, China, and southern and western South America.
- Remote sensing of water quality from satellite imagery or drones is a relatively new technique that is becoming more widespread and increasing in accuracy. Medium- to high-resolution and high-frequency satellites such as Envisat MERIS or Sentinel allow for Earth observations and data collection. Remotely sensed water quality data are limited, however, to certain parameters which demonstrate distinguishable changes in the spectrums observed by satellites (chlorophyll, total suspended solids, turbidity, floating vegetation, colourized dissolved organic matter and temperature). An important benefit is that the automatic capture of large water bodies by satellites eliminates the need for river or lake monitoring stations.
- When data from in situ observations or satellites are not available in the desired locations or at the required times, simulated data from hydrological models can be used. The factors that determine water quality are well known, and models that estimate risks of poor water quality at a global scale are gaining traction in the scientific and international community to fill existing gaps in available data (e.g. from GEMStat). Gaps can also be addressed through machine learning algorithms that can find patterns that would otherwise go undetected.
- Finally, citizen science and other crowdsourcing approaches may provide opportunities to simultaneously gather data and educate, engage and encourage public environmental compliance at different scales (Mistry, Borden & Lawson, 2016; UNEP, 2016). With the increasing availability of mobile phones and internet access in developing countries, citizen scientists can make a significant contribution to future water quality data collection, although recent evidence from a World Bank-supported project in Punjab, India, suggests that there are limits to this approach (World Bank, 2016, 2020).



According to UN-Water, current support mechanisms provided by the IMI-SDG 6 to engage countries and build their capacities are as follows:

- Written methodologies and guidelines for monitoring global indicators for use at the country level;
- Help desks, webinars and online tutorials;
- In-country technical assistance and training workshops for national, regional and global levels;
- Assistance with developing collaboration for cross-country learning and identification of good practices.

These mechanisms are helping countries to increase their access to existing water data, but require further efforts to generate new information. A wide array of technologies and methodologies are available for countries and communities to capture water quality data. Furthermore, modern chemistry methods and state-of-the-art monitoring technologies enable thousands of chemicals to be detected in water, even at extremely low concentrations (Zulkifli, Rahim & Lau, 2018). Fortunately, not everything needs to be tested for. While many parameters require state-of-the-art lab facilities, a much smaller and more practical set of tests can provide a good sense of chemical or microbial water quality for monitoring purposes. Low-tech versions of tests are also available for situations where budgets are limited and/or citizen science approaches are targeted (Lawson & Mistry, 2017; Mistry & Lawson, 2018). This is important as not all countries have the analytical facilities or budgets for more specific and/or large-scale testing.

Choosing which technologies to install will thus depend on the selected parameters, the costs of sampling and analysis, the biophysical site conditions and infrastructure, and ease of use, among other factors. Although customizing and implementing more site-specific water quality monitoring is crucial, it is also imperative that the captured data are accurate, capture spatial and temporal variation, and are comparable between different data providers to enhance the reliability of the overarching database.

For the interpretation of data, organizations such as the World Health Organization (WHO), the European Commission and the US Environmental Protection Agency (EPA) have established “safe” concentration levels for common pollutants. However, there remains uncertainty about many “safe” values, largely due to the lack of well-established and locally valid dose-response functions that describe how these pollutants actually affect ecosystems, including human and animal health (Damania *et al.*, 2019).

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