SDG Indicator 6.3.2 Technical Guidance Document No. 1:

Monitoring Programme Design

This document provides guidance on monitoring programme design for rivers and lakes for the five core parameter groups of Level 1 within the framework of SDG indicator 6.3.2. There is a separate technical document that addresses challenges faced when reporting groundwater quality.

This document is a companion to the Step-by-Step Methodology and forms part of a series of documents that provide detailed technical guidance on specific aspects of the indicator methodology. These technical documents were created in response to feedback received following the baseline data drive of 2017. These and other resources are available on the Indicator 6.3.2 Knowledge Platform (link).

This document is aimed at practitioners seeking further information on how to implement the methodology in their own country:

1. It expands upon the monitoring programme design guidance provided in the step-by-step methodology.
2. It describes the key phases of the monitoring programme design cycle.

Introduction

Efforts to collect monitoring data for indicator 6.3.2 should provide sufficient information on the current ambient water quality status at the national scale, and enable long-term trends to be identified. In order to identify the trends, data for the five core parameter groups are required from sites across the country, and the measurements should be taken in a standardised and consistent manner. From the experience of the first global data drive in 2017, it was clear that many countries were unable to report at the full country spatial scale, and that long-term records were incomplete in many countries. This document provides guidance for countries that could not meet the reporting requirements; it focusses on how to design a monitoring programme that makes best use of the available resources.

According to Meybeck *et al*. (1996), monitoring programmes (as opposed to surveys) are usually long-term and use standardised measurements and observations to determine trends. It is this type of programme that is needed for indicator 6.3.2 reporting.

Good monitoring programme design involves more than simply defining where samples are to be collected from. It should also define:

- the general monitoring **location**;
- the specific monitoring **station**;
- the **frequency** of sample collection;
- the **parameters** that will be measured *in situ*, and the samples that will be collected and transported to a laboratory for specific analysis;
- the quality assurance (**QA**) and quality control (**QC**) procedures to be applied;

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- guidance on the **field** operations and health and safety (**H&S**)
- **data management** procedures and how the data will be stored and reported.

MONITORING PROGRAMME DESIGN WITHIN THE CONTEXT OF THE METHODOLOGY

There are five main steps of the indicator methodology:

1. define reporting basin districts (RBDs);
2. define water bodies;
3. define monitoring locations;
4. collect water quality data; and,
5. assess water quality.

Defining RBDs and water bodies is a prerequisite and should be undertaken independently of monitoring programme design. Countries that operate an existing monitoring programme should preferably select monitoring locations from those that are currently active, and that best represent the defined water bodies. The alternative approach is to define water bodies based on the position of existing monitoring locations. This is most relevant for river water bodies and, if adopted, may lead to unequally sized water bodies that may be heterogenous in nature.

Reporting Basin Districts (RBDs) within the indicator methodology are based on river basins. They are the sub-national reporting units that apply to rivers, lakes and groundwaters. The RBD is the area of land, made up of one or more neighbouring river basins, or the national portion of transboundary river basins, together with their associated groundwater bodies. In terms of management of water resources, especially for transboundary waters, the RBD concept provides a more practical unit to assess water quality and provides the basis to apply management strategies. Many countries have river basin-based hydrological units already defined. These are often used for national reporting on many aspects of water and sanitation management. Countries are encouraged to apply these same units as RBDs for indicator 6.3.2 reporting to ensure that linkages between activities that both affect, and are reliant upon, good water quality are linked. Examples include wastewater generation, sewage treatment rates, and supply of drinking water.

In the absence of defined RBDs, countries can choose to request GEMS/Water to provide boundaries for RBDs. These hydrological units, provided in geographical information systems (GIS) format, will be derived from the HydroBASINS global dataset (Lehner and Grill, 2013) and the transboundary river basins of the UNEP-GEF Transboundary Waters Assessment Programme (TWAP) data portal (UNEP-DHI and UNEP, 2016).

Each RBD is subdivided into **water bodies** that are grouped by type: river, lake or groundwater. It is these smaller discrete units that are classified as either “good” or “not good” quality in SDG indicator 6.3.2. A water body can be a section or a tributary of a river, a lake, or an aquifer. Ideally, water bodies should be defined to ensure they are homogenous in terms of water quality – the smaller a water body, the more likely it will be homogeneous. A homogeneous water body can be classified reliably using fewer monitoring stations than one which is more heterogeneous. The disadvantage in defining many smaller water bodies, compared with fewer large ones, is that the monitoring effort will be greater, because a minimum of at least one monitoring station per water body is needed.

The capacity to monitor water quality at the national scale may be beyond that of many countries and a pragmatic approach to design may be needed. One option is to categorise monitoring stations as those that can be monitored using existing resources (human, equipment and data management), and to define those that could be included in the future if resources become available. For example, some countries may focus on collecting data from key RBDs that are of national significance but may go further and design the monitoring programme at the national level.

MONITORING PROGRAMME DESIGN PROCESS

The monitoring programme design process can be summarised in the steps shown in Figure 1. This flow chart shows the three main phases: phase 1 - **design**; phase 2 - **implementation**; and phase 3 - **assessment, reporting and management**. This approach is useful for designing any type of water quality monitoring programme and can be used when both initiating a new monitoring programme, or when reviewing an existing one (Meybeck *et al*., 1996a; Chapman *et al*., 2005).

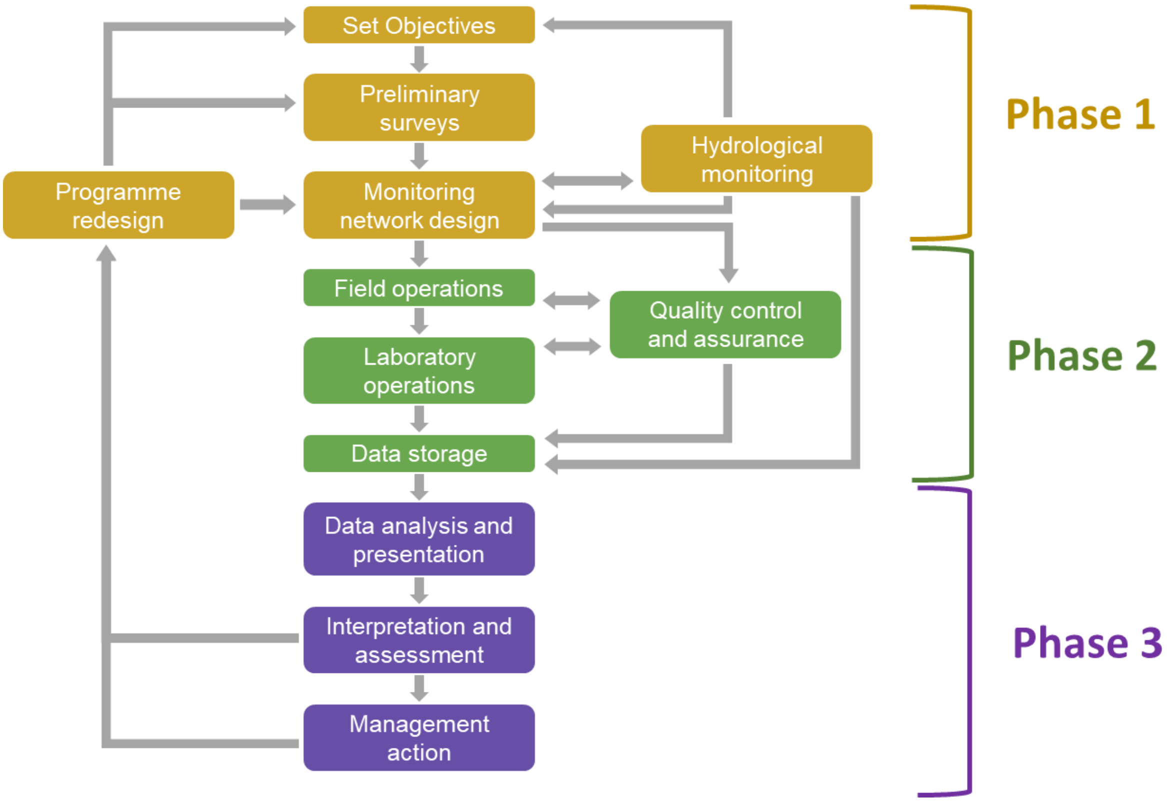

Figure 1 : The water quality monitoring programme design flowchart. Modified from Chapman et al. (2005)

For indicator 6.3.2 reporting, the aims of the monitoring programme are clear, i.e., to provide the most extensive and reliable data possible for the classification of ambient water quality. The objectives are to provide long-term trend monitoring data, for the five core parameter groups, in as many water bodies as possible.

Preliminary surveys provide background information that can greatly assist in designing the monitoring programme. All available information from other studies and monitoring programmes in the same, or similar geographical areas, or using similar monitoring techniques, may be useful. These could include historical water quality measurements, hydrological records, biological data and information on geology and land-use. A preliminary survey may also include site investigations such as sampling to assess the homogeneity of potential monitoring locations or to confirm easy and safe access to water bodies and suggested monitoring stations. This information once gathered will help in developing a monitoring network that efficiently uses resources to generate high quality, reliable data (Meybeck *et al*., 1996a}.

Good monitoring network design makes efficient use of resources while still producing high quality data that allow the objectives of the monitoring programme to be met. There are three main activities involved in the monitoring network design:

- Selecting the appropriate monitoring media (water, biota, particulate matter) and the sampling and analysis methods to be used.
- Selecting monitoring locations.
- Choosing the frequency of sampling.

SDG indicator 6.3.2 Level 1 monitoring is only concerned with the physical and chemical properties of the water. Level 2 reporting may use the other two media, i.e., the biota and particulate matter. The parameter groups to fulfil Level 1 one reporting are prescribed by the methodology: oxygen, salinity, nitrogen, phosphorus and acidification. Within each of these parameter groups, the country can decide which specific parameter to use for reporting. The parameters for the different water body types can be found in **Error! Not a valid bookmark self-reference.** below.

Table 1: Level 1 parameter groups, suggested parameters for the different water body types and the justification for their inclusion in the indicator (adapted from UN Environment (2018)).

Parameter group	Parameter	River	Lake	Groundwater	Reason for Inclusion / Pressure
Oxygen	**Dissolved oxygen**	•	•		Measure of oxygen depletion
	Biological oxygen demand, Chemical oxygen demand	•			Measure of organic pollution
Salinity	**Electrical conductivity** *Salinity, Total dissolved solids*	•	•	•	Measure of salinisation and helps to characterises the water body
Nitrogen*	**Total oxidised nitrogen** *Total nitrogen, Nitrite, Ammoniacal nitrogen*	•	•		Measure of nutrient pollution
	Nitrate**			•	Health concern for human consumption
Phosphorus*	**Orthophosphate** *Total phosphorus*	•	•		Measure of nutrient pollution
Acidification	**pH**	•	•	•	Measure of acidification and helps to characterises the water body
* Countries should include the fractions of N and P which are most relevant in the national context					
** Nitrate is suggested for groundwater due to associated human health risks					

Phase 2 of monitoring programme design, the implementation phase, involves all field activities, laboratory operations, data recording and storage and an effective quality control and assurance programme. Field activities refer to the recording of conditions at the time of sampling, *in situ* measurements, sample collection, and sample preparation for transport to the laboratory. The data recording and storage aspect of the monitoring programme design flowchart describes how the integrity of the data is maintained throughout the programme. This should provide the laboratory and management personnel with information on how to check and store the data coming from the field and laboratory operations.

Phase 3 includes assessment, reporting and management action. This phase makes use of the data generated from the implementation phase. Water quality assessments involve the synthesis of water quality data with other relevant information to meet the monitoring programme objectives. Indicator 6.3.2 has a standardised reporting process to help calculate and present the indicator score for each water body and then to aggregate these to produce an overall country score. This information can then be used by the country to develop management activities to improve ambient water quality.

Finally, the monitoring programme should be periodically reviewed to make sure the objectives are being met or to accommodate new monitoring developments or requirements.

Monitoring Location and Frequency of Analysis

This section provides information to help countries choose sample locations and to determine the frequency of sample collection.

Monitoring locations are less specific than monitoring stations. A **monitoring location** refers to the general location of where a sample is taken, such as a section of a river, whereas a **monitoring station** includes specific detail (e.g. geographic position an depth) on exactly where samples are to be collected or analyses are to be performed. For example, a monitoring location for a lake may be defined by geographical coordinates but, at this single location, there may be several monitoring stations at different depths.

Rivers

As a general rule, the larger or more heterogeneous a water body, the more monitoring stations are needed for reliable classification. If more than one station is needed, they should be located at both impacted and unimpacted locations. If data are not collected from representative locations, the water body may be portrayed as either less or more polluted than the reality. Where resources restrict monitoring to a single location for each water body, the optimum location is the most downstream point where the river drains into the next designated water body, which may be, for example, another river section or a lake. This location will integrate all the influences on water quality arising from the catchment upstream of that location

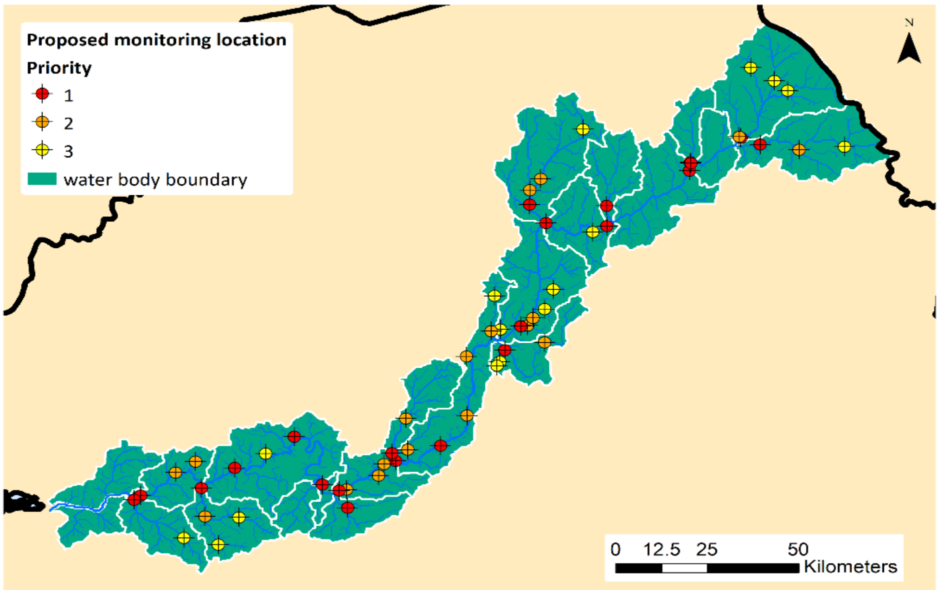

Figure 2 shows a proposed river monitoring network for the Rokel River basin, Sierra Leone. In this example, the agency responsible for monitoring decided to focus efforts on this river basin because of its national significance. Within this basin, the criteria for identifying monitoring locations included:

- at last one monitoring location per water body;
- they are situated at an intersection between a river and a road;
- safe access;
- the same location as existing hydrological stations if present;
- not being close to a known point sources of pollution;
- representative of impacted and unimpacted catchment areas.

The water bodies were determined in this example using the HydroBASINS Level 9 dataset (Lehner and Grill, 2013). The size and number of units produced by selecting this level (size) resulted in water bodies that were suitably homogeneous in terms of land use, geology, climate and human impact. Consequently, fewer monitoring locations per water body needed to be defined. Additionally, the resources available for monitoring were deemed sufficient to collect, analyse and manage the data produced for this number of monitoring locations for the foreseeable future.

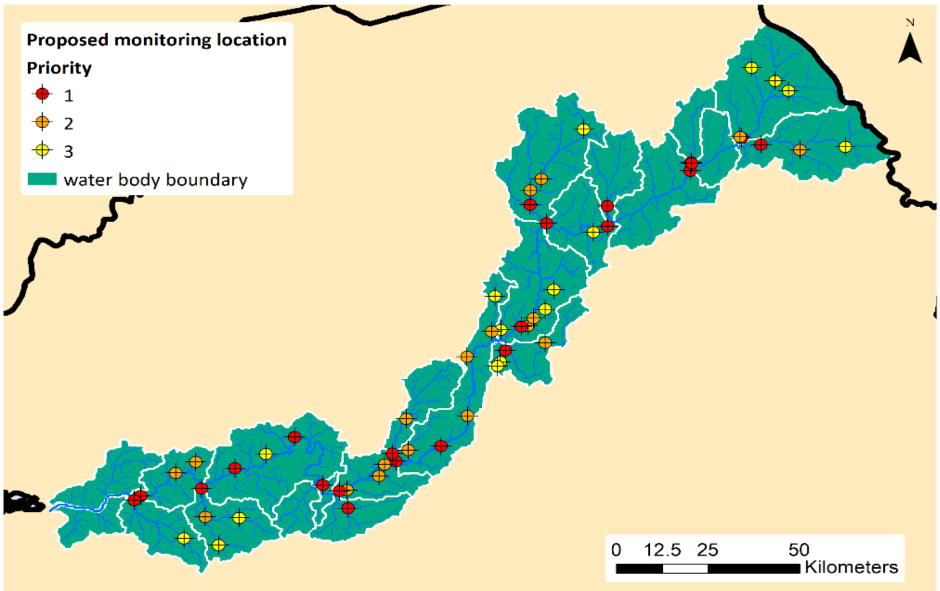

Figure 2: Map showing the Rokel River Basin, Sierra Leone, and a proposed monitoring network

Monitoring locations should be selected away from known effluent sources, and downstream of mixing zones. Bridges are often used because they are relatively easy to access, they are readily identifiable, and allow a mid-stream sample to be taken.

Ideally, monitoring stations should be established where the water is sufficiently mixed to allow a single sample to be taken that is representative of that section of the river. Water quality can vary across a river cross-section at a monitoring location. For example, when there is a point source of a contaminant entering a river, or where a tributary of differing water quality enters a main river channel, smooth lateral flow may inhibit water mixing for some distance downstream (Meybeck *et al.*, 1996b). Therefore, sampling stations should be a minimum distance downstream (for example one kilometre) from river confluences and from known point sources of contaminants. A bend in a river can induce mixing and therefore a sampling station after a bend may be relatively homogeneous in quality. Homogeneity should be tested at a monitoring location prior to establishing the monitoring station. This can be carried out by taking several samples across the width and depth of a river. If there is no significant variation between the samples then a monitoring station can be set up mid-stream or at the most convenient point of the river cross-section (Meybeck *et al.*, 1996b).

Trend monitoring requires a long-term record of relatively consistent data for the same places, and at the same frequencies, for a number of years. Ideally, samples should not be collected during extreme events, such as during flood events when discharge is very high, unless this is a regular seasonal occurrence. The samples should be taken during comparable conditions at the same times and locations over consecutive years. Simultaneous river discharge measurements can assist in the interpretation of water quality data where the reasons for fluctuations in concentrations may be unclear.

The frequency of data collection can range widely, from continuous measurement using an automated instrument situated at the sampling location, to annual grab samples. Sampling frequency should be higher at locations where water quality varies greatly than at stations where the water quality is relatively constant. This may be determined during the preliminary surveys or from an analysis of historical data. The decision about how frequently to sample should also take into consideration seasonal variations in water quality and the influence of the river hydrology on the variables being monitored. The recommended frequency is at least one sample per season. If resources allow, it is recommended to sample once a month but, preferably, no less than four times each year. Sampling at these intervals every year will provide information for long-term trend monitoring applicable for SDG indicator 6.3.2.

Lakes

The number and locations of monitoring stations in lakes depend on the lake size and morphology. If a lake is small and well-mixed, one sampling location near the centre or at the deepest part of the lake may be adequate. . However, if a lake has multiple basins, as shown in Figure 3, a monitoring location may be required within each basin. Figure 3 depicts lakes of different size and morphology, and the possible position of monitoring locations within these types of lakes. For the large, single-basin lake, four monitoring locations, one in each homogeneous sector, may be adequate. The large multi-basin lake has a monitoring location in each of the distinct basins and the small lakes along a river course have a monitoring location in each lake (Thomas *et al*., 1996).

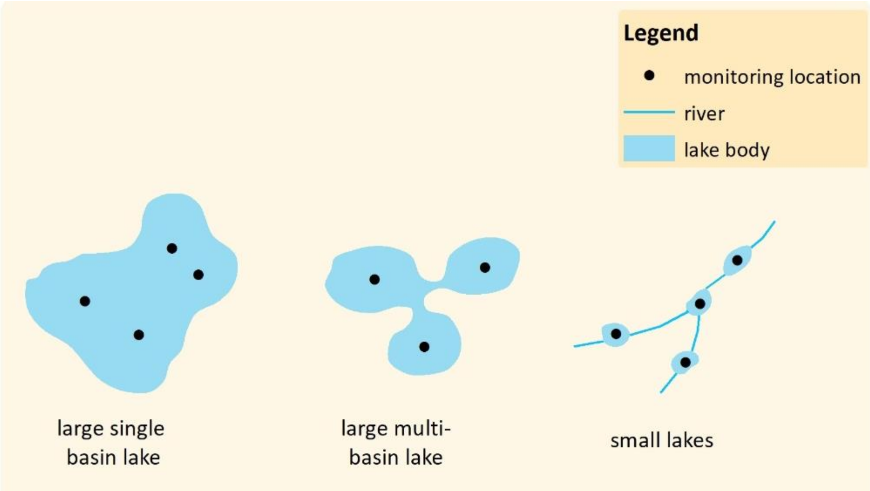

Figure 3: Lakes of different size and morphology and the associated minimum requirements for monitoring locations (Modified from Thomas et al., 1996).

For the purposes of SDG indicator 6.3.2, lake monitoring locations should be away from direct inputs of pollution. The depth from which samples are collected should be informed by whether the lake undergoes thermal stratification. This information should be collected during the preliminary survey. Thermal stratification occurs due to changes in water density caused by solar radiation. The thermocline is the zone where water temperature changes most dramatically. The type and extent of thermal stratification varies based on lake morphology, climate, latitude and altitude. For example, shallow lakes that are exposed to constant wind, or lakes in tropical regions where temperatures are constant may not stratify, or may show weak stratification for short periods of time (Thomas *et al*., 1996).

For the purpose of data collection for SDG indicator 6.3.2, samples from lakes that stratify seasonally should always be taken at a fixed depth below the surface. This depth should above the thermocline. Alternatively, an integrated depth sample can be collected. This kind of sample can be achieved by taking discrete depth samples and mixing them together or by using a hosepipe sampler (flexible plastic pipe or tube) which takes a sample through different depths of the water column (Thomas *et al*., 1996).

Information on the variability of lake quality should be used to inform the choice of sampling frequency. Locations where water quality varies should be sampled more frequently than locations where water quality is relatively constant. The frequency of sampling should also take into consideration seasonal variations, whether the lake stratifies and the residence time of the water in the lake. At least annual sampling is necessary, but one sample per season is preferable if resources allow.

Field and Hydrological measurements

Field operations comprise a significant component of the overall water quality monitoring programme budget and therefore careful planning should precede each field sampling campaign. Fieldwork and data collection should follow a Standard Operating Procedure (SOP) to ensure consistency and reliability. Field technicians must follow field quality assurance protocols and avoid disturbance of the monitoring station during sampling and contamination of samples, e.g. with dust, soil or residues from a previous sampling location.

Field observations made during each sampling campaign may prove useful to help interpret the resultant data and thereby increase data value. Field notes should include the date and time of sample collection, weather conditions, sample identity or code, notes on any field measurements taken, the methods used, and the results obtained. Additional observations might include, notes on the aquatic flora, unexpected colours or smells of the water, or the presence of potential sources of contamination such as a broken pipe or evidence of livestock entering the water body.

Health and safety should be of the utmost importance for any fieldwork. The sampling locations should be safe to access and free from hazards. The appropriate personal protective equipment (PPE) should be brought and worn during sampling, for example gloves, goggles, a life jacket and high visibility clothing. A first aid kit should also be brought on any field campaign. Efforts to avoid working alone should be taken but when unavoidable, strict call-in times and response plans should be put in place.

Hydrological measurements should accompany water quality data collection activities. These may include water level, flow and velocity measurements. The concentrations measured for some water quality parameters can be influenced by the hydrological conditions of a water body. These conditions change over time depending on weather events, seasons, and natural or anthropogenic alterations to the water body. Therefore, hydrological measurements made at the same time, and at the same location from which water quality samples are taken, can assist in interpreting the water quality data.

Quality Assurance and Quality Control

Quality assurance (QA) is the management system used to maintain a desired level of quality in a service, especially by means of attention to every stage of the process of delivery. Figure 1 above shows that QA feeds into the design process multiple times including the field operations, laboratory operations, as well as data storage steps.

A water quality monitoring programme with adequate QA produces credible and defensible data that can be relied upon to assess water quality and plan management actions. Obtaining credible data can be done by using recognised or standard methods such as those from the International Organisation for Standardisation (ISO) (www.iso.org) and by following good laboratory practice as prescribed in ISO 17025 (ISO 2017). Within a QA plan for a monitoring programme, there should be SOPs for all sampling, calibration processes, analytical processes and audits.

Quality control (QC) consists of a series of technical activities that aim to evaluate and improve the quality of data produced. It helps to reduce the possibility of introducing error into results. This is relevant for all aspects of the implementation phase of a monitoring programme including collection, preservation, transportation, storage, analysis, data handling and reporting.

Data Management

Investing time and effort into managing data appropriately, adds value for the future and ensures the data will remain valid beyond the planned lifetime of a monitoring programme. Water quality data often go through many processes and are manipulated by many people, resulting in several opportunities for errors to be introduced. Incorrect measurement units or conversions, limits of detection, significant figures or other anomalies, should be detected before the data are stored or reported. All records prior to input into the database, and during input, should use consistent naming conventions to group data (for example parameter names, locations and water body types). Following data entry, data checks should be carried out to look for impossible values and to check the validity of outliers.

A centralised storage system should be backed up regularly. The central data repository should keep all relevant metadata associated with the water quality measurements, including geographical co-ordinates for each monitoring location, type of water body and other recorded notes. The storage system used should allow the relevant data to be extracted for analysis and classification of water bodies for indicator 6.3.2 reporting easily. For example, if stored correctly, is should be straightforward to extract data for a particular time period or RBD.

Summary

This technical document provides information for ambient water quality monitoring programme design, particularly in the context of the implementation of SDG indicator 6.3.2. Reporting Basin Districts and water bodies should be delineated and defined before a monitoring programme can be designed. The monitoring programme design flowchart summarises the essential steps into three phases: **design**; **implementation**; and a**ssessment, reporting and management**. These three phases help to produce and maintain a successful water quality monitoring programme. Consistent quality assurance and periodic re-evaluation of the monitoring programme help to ensure the programme is capable of supplying sufficient and reliable data for indicator reporting.

Further Resources

Further information in relation to the indicator 6.3.2 available on our knowledge Indicator 6.3.2 Support/Knowledge Platform (https://communities.unep.org/display/sdg632).

Detailed information on water quality monitoring and assessment beyond the scope of this document can be found here: https://www.who.int/water_sanitation_health/publications/wqa/en/

HydroBASINS and HydroATLAS are available here: https://www.hydrosheds.org/

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