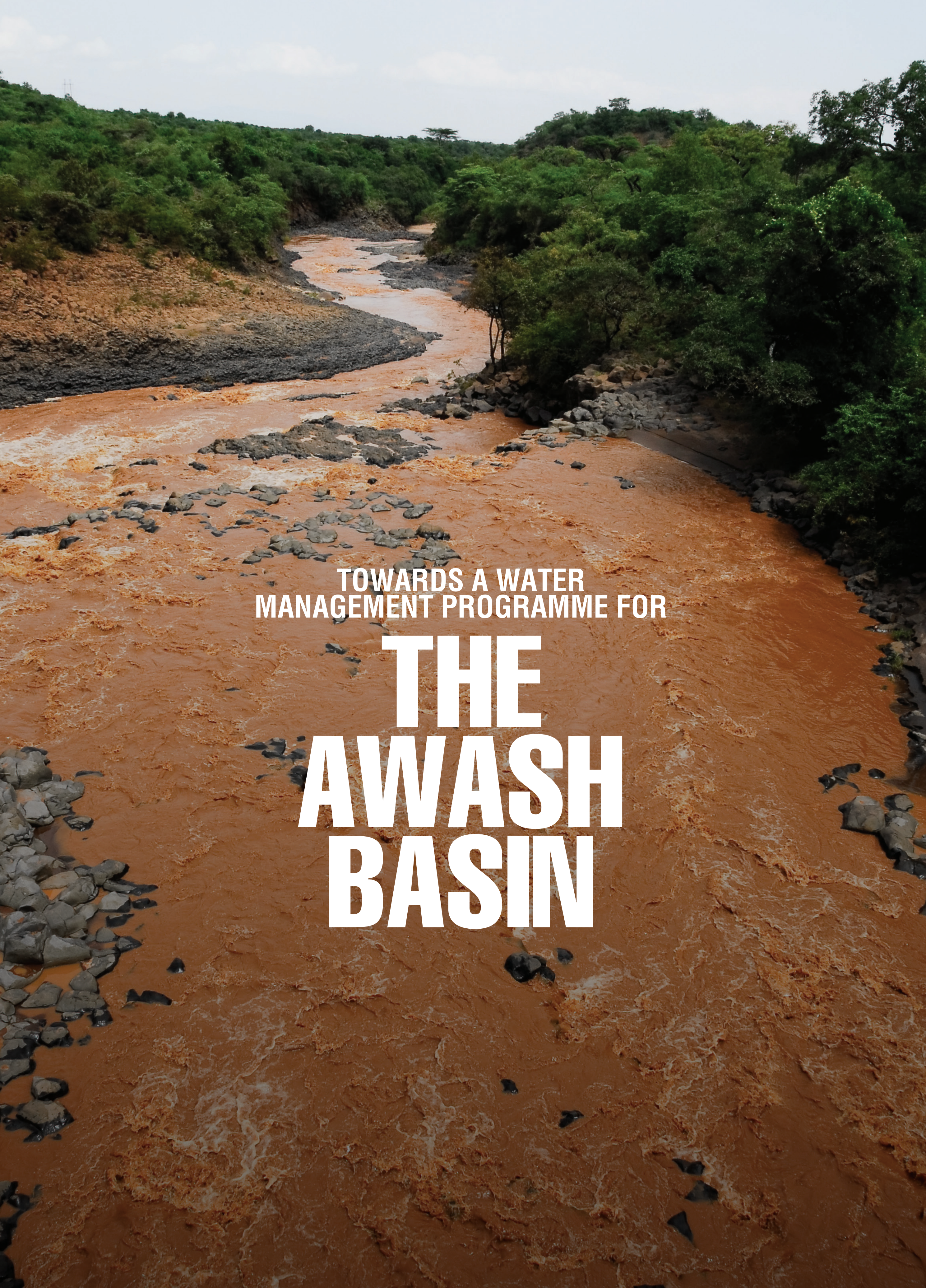

TOWARDS A WATER MANAGEMENT PROGRAMME FOR

THE AWASH BASIN

The **Ministry of Environment, Forest and Climate Change**, Ethiopia would like to acknowledge **Centre for Science and Environment** (CSE) for their support in the preparation of this strategy document for the Awash River basin.

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Ethiopia Environment and Forest Research Institute
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Ethiopian Standards Agency
Central Statistical Agency
and
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Material from this publication can be used, but with acknowledgement.

Maps in this report are indicative and not to scale.

TOWARDS A WATER MANAGEMENT PROGRAMME FOR

THE AWASH BASIN

Contents

LIST OF BOXES

LIST OF FIGURES

LIST OF FORMS

LIST OF MAPS

LIST OF TABLES

Foreword

The Federal Democratic Republic of Ethiopia is transitioning from an agricultural to an industrial national economy, but industrial development and urban expansion have caused serious environmental pollution in the country. Water is an engine of socio-economic development, so it is only natural that the country's rivers are feeling the pressure of pollution as waste disposal into them increases manifold.

Article 44 of Ethiopia's Constitution (1995) states that all persons have the right to a clean and healthy environment. Accordingly, the Ministry of Environment, Forest and Climate Change (MEFCC) has formulated practicable standards, based on scientific and environmental principles, for the discharge of industrial effluents into water bodies and sewage systems.

This document is largely intended as a strategy document for developing a water quality monitoring system for Awash river basin and has been developed by MEFCC jointly with Center for Science and Environment, India. It is hoped that the document will be a useful tool for effective monitoring of Awash river basin leading to improvement of the water quality.

Mehari Wondmagegn
Director General, Compliance Monitoring and Control Directorate
Ministry of Environment, Forest and Climate Change

Preface

Over the past two decades, Ethiopia's dependence on its river basins has increased. This comes as no surprise, since these decades have also witnessed unprecedented economic growth in the country.

Of the many river basins in Ethiopia, Awash is one of the most important one and of great cultural value to its people. Spanning over approximately 1,200 km, River Awash is located in the most densely populated region of the country. In recent years, rainfall has become erratic, increasing the dependence on the river and its tributaries to meet water requirements of irrigation, domestic and household uses, and of manufacturing and service sectors. This increasing dependence has resulted in deterioration of the basin's water quality and loss of its riverine ecosystem. Besides the environmental degradation, the basin is also adversely affected by annual floods, improper utilization and contamination of adjoining land resources, and poor agricultural practices.

For a developing country like Ethiopia, management of water resources is an imperative and key for ensuring sustainable economic growth. In order to prevent further deterioration of the river basin, a sound water resource management plan or a basin management plan is essential. An effective monitoring strategy—to monitor the quality and quantity of water resources—is the core of a sound water resource management plan.

The current basin management plan, although well-designed, has not been very effective in preventing and mitigating the degradation of the Awash basin. Lack of adequate and scientifically validated practices and procedures has come out as a major reason for weak implementation of the basin management plan.

Considering the importance of rive quality monitoring, Centre for Science and Environment (CSE), India in collaboration with Ministry of Environment Forest and Climate Change (MEFCC), Ethiopia and Awash Basin Authority (AWAB), Ethiopia has prepared this strategy document for a comprehensive water quality monitoring plan for the Awash Basin.

The main objective of this document is to highlight the importance of water quality monitoring in the overall management of Awash river basin and the ways in which an effective water quality monitoring programme can be developed and implemented. This strategy document also intends to address the existing gaps in the current basin management plan of Awash by strengthening the existing monitoring network, and by sharing and encouraging the adoption of alternative and affordable modes of monitoring that can prove beneficial to the monitoring agencies in the long run.

I would also take this opportunity to express my gratitude and appreciation to our colleagues from the MEFCC and the AWAB for their valuable contribution and support in the preparation of this document. It is my sincere hope that this strategy document sets a precedent for other basin authorities in Ethiopia to develop and strengthen their respective basin management plans.

Chandra Bhushan
Deputy Director General
Centre for Science and Environment

PART 1

A Guide for Water Quality Monitoring Programme

1. Introduction

Water resources of a country contribute both directly and indirectly towards its development. Water resources have economic, cultural and social impacts. In case of developing nations, the interaction of water resources with the lives of the lower income group in particular is complex in character and operates in multiple dimensions—providing water for safe drinking and other livelihood needs (livelihood security), reducing health risks and vulnerability, promoting pro-poor economic growth and alleviating poverty. Therefore, investing in water infrastructure and management has major ramifications on the socio-economic progress of a developing nation.

In this context, monitoring of water resources becomes crucial. It involves checking the health of water bodies, their usability and the seasonal variation in their characteristics, and identifying the sources that might be impacting their quality. Monitoring is a vital tool for designing and implementing, and renewing sound, robust and scientific policies and management plans for water resources.

In the Ethiopian scenario, monitoring is even more important due to the specific needs of the people of the country. The Ethiopian government has come to recognize the importance of its water resources as a major asset for the country's continuous economic development. Over 45 per cent of Ethiopia's Gross Domestic Product (GDP) depends on agriculture,[1] which in turn depends on the available of suitable water resources; almost 85 per cent of the Ethiopian population lives in the rural areas,[2] therefore, the dependence on water resources is significant. This underlines the importance of water resources in Ethiopia's economic and social development.

The onus of overseeing the management of Ethiopia's water resources falls on the Ministry of Environment Forest and Climate Change (MEFCC), Ethiopia and the River Basin Authorities. In case of the Awash River, the Awash Basin Authority (AwAB) is responsible for its management, including monitoring. However, it is to be noted here that the monitoring of the tributaries of the Awash River is under the MEFCC.

Currently, the monitoring in Awash Basin does not measure up. MEFCC and AwAB have laid down elaborate plans to upscale the monitoring activities. This document is part of these efforts and provides guidelines on developing an effective monitoring network along the Awash River.

1.1 MONITORING[3]

The International Organization for Standardization (ISO) defines water quality monitoring as "*the programmed process of sampling, measurement and subsequent recording or signalling, or both, of various water characteristics, often with the aim of assessing conformity to specified objectives*". This general definition can be differentiated into three types of monitoring activities that distinguish between continuous short-term and long-term monitoring programmes as follows:

- **Monitoring:** Long-term, standardized measurement and observation of the aquatic environment to define its status and trends.

- **Surveys:** Intensive programmes that are of finite duration, and targeted towards measuring and observing the quality of the aquatic environment for a specific purpose.
- **Surveillance:** Programmes that involve continuous, specific measurement and observation for water quality management and operational activities.

1.2 MONITORING PROGRAMME

Monitoring can be defined as a systematic observation made over a certain time-period (which can be predefined), to draw inferences (prediction) about an experiment or phenomena for which it is designed. Systematic observation, which can also be referred to as periodic observation with regular intervals, consists of three important sub-components:

- **When (how often) to observe:** This refers to the frequency of observation and, in science, to measurement
- **What to measure:** This refers to defining the parameters to be measured
- **Where to sample:** This refers to choosing the place best suited for sampling for reasons of data science as well as expediency

1.3 MONITORING STRATEGY

A good water quality monitoring programme aims at minimizing the cost of monitoring without sacrificing the quality and detail of the information sought from the monitoring programme. This 'information' in monitoring refers to the variability in spatial and temporal trends. Spatial variability is generally governed by factors like water withdrawn and wastewater discharged, whereas temporal variability is caused by seasonal and yearly variations. In general, hydraulic and hydrological factors are responsible for all variations; therefore, it is necessary to have background information of the river basin to be monitored.

Logistics is another factor determining the monitoring strategy. In a long river, the number of sampling point (stations) will naturally be higher and so will be the sampling and analysis costs. Further, if the number of parameters is higher, it will cause further increase in the total cost of analysis, since it will include addition to the laboratory infrastructure, including manpower. In addition to that, if the frequency of measurement is increased, it will also add to the cost of monitoring.

It is, thus, necessary to assess resources before commencing monitoring. Scoping and designing of a water quality monitoring programme must be based on a clear understanding of:

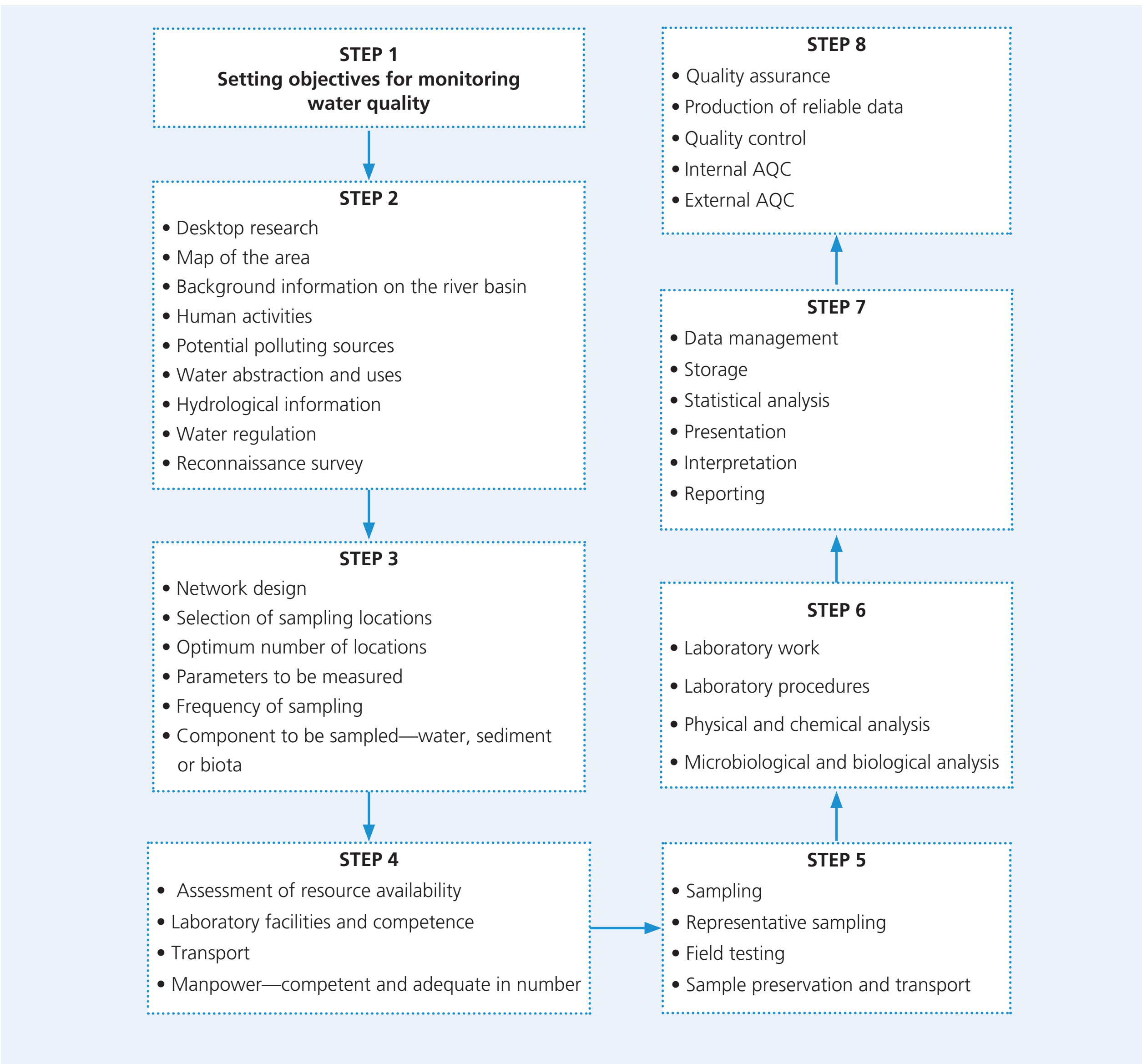
- Relevant background information of the riverine system
- Monitoring objective(s)
- Desired outcomes
- Methods appropriate to meet the monitoring objectives
- Dynamics and characteristics of the water system to be monitored

2. Eight steps of a good water quality monitoring programme

Within the background set in the previous section, the steps to monitor water quality are summarized are summarized in this section.

Overall, water quality monitoring programme involves eight steps which are illustrated in *Figure 1*.

Figure 1: Eight steps of a good water quality monitoring programme



Source: CSE

2.1 SETTING WATER QUALITY OBJECTIVES

Before formulating any water quality monitoring programme, it is very important to have a clear understanding on the objective(s) of the monitoring. A water quality monitoring programme can have various purposes summarized as follows:

- **Signal or alarm functions:** Whenever required, a monitoring system should be able to detect suddenly occurring (adverse) changes in the environment and track their causes on an immediate basis.
- **Control function**: A monitoring system should be able to assess the general quality of water in relation to adopted or stated water quality requirements or objectives, and for verification of the efficacy of pollution control strategies as well as a check on permitted effluent quality compliance.
- **Trend (recognition) function:** A monitoring system should be able to perform a time series analysis to enable prediction of future developments that are likely to occur based on a certain observed trend. This function is important to develop long-term policy and management plans.

Keeping these purposes in mind, the possible water quality monitoring objectives can be:

- Rational planning of pollution control strategies
- Identifying the nature and magnitude of the pollution control required
- Evaluating efficacy of the pollution control of effluent discharge
- Identifying status and trends in water quality, both in terms of concentration and effects
- Identifying mass flow of contaminants in surface waters and effluents

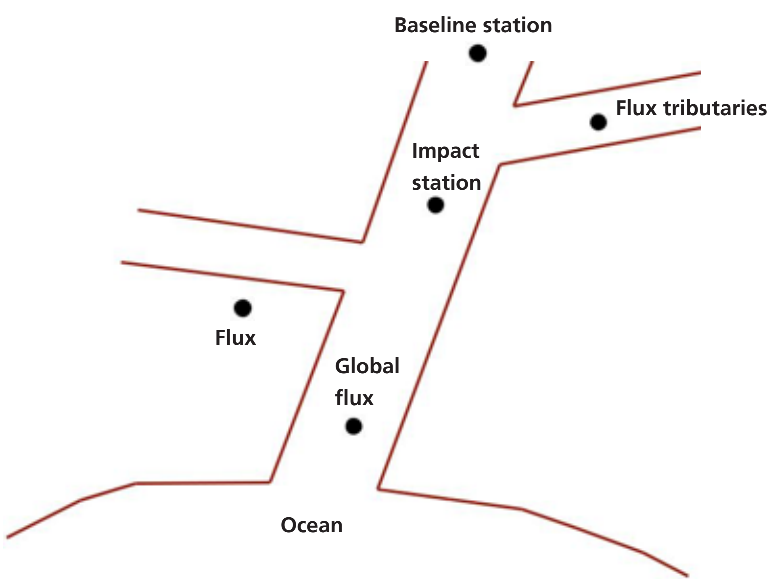
2.2 IDENTIFICATION OF MONITORING STATIONS

One of the most important aspects of water quality monitoring is the identification of location of sampling (monitoring stations). Monitoring stations can be of many types.

2.2.1 TYPES OF MONITORING STATIONS

- **Baseline station:** A monitoring location where no human activities affects the quality of the water body being considered, i.e., the water quality is pristine.
- **Flux station:** A monitoring location where the pollution load is discharged by tributaries, irrigation or storm-water drains etc. into the mainstream.

Figure 2: Types of monitoring stations



Source: CSE

- **Trend station:** A monitoring location designed to show how the parameters at a specific point on a water course vary over time due to the influence of human activity.
- **Impact station**: A station where a pollutant mixes with water of the mainstream.

The different types of monitoring stations are illustrated in *Figure 2*.

2.2.2 GENERAL CRITERIA FOR SELECTING SITES

The following steps list the general criteria for selecting appropriate sampling and monitoring sites:

1. Having a reference station upstream from all possible discharge points. The usual purpose of a monitoring exercise is to determine the degree of anthropogenic pollution and damage caused to aquatic ecosystems. Reference stations would be helpful in providing data on the original quality of the water and its biological aspects, which may vary locally and regionally.
2. Considering intake points of drinking water, bathing areas (including communal) and irrigation canal take-off points for monitoring.
3. Locating sampling stations upstream and downstream of significant pollution outfalls, such as city sewage drains and industrial effluent outfalls.
4. All samples must be representative, which means that the determinants in the sample must have the same value as the water body at the place and time of sampling. In order to achieve this, it is important to ensure that the sample is collected from a well-mixed zone. In order to identify a well-mixed zone, a homogeneity test must be performed.
5. Additional downstream stations are necessary to assess the extent of the influence of an outfall and locate the point of recovery of the water body.
6. In water bodies with poor and incomplete movement or flow, the effluent may tend to follow one bank. In such cases, stations on both sides are useful to make an estimate of the extent of the mixing by understanding its mixing profile.
7. In large rivers, a balance has to be found between the selection of a few stations giving poor coverage, and selection of more stations with different substrates and dissimilar fauna that cannot be compared spatially.
8. To enable comparisons among sampling stations, it is essential that all stations are sampled around the same time. The time difference between sampling the first and the last station should not be more than two weeks.
9. Sites for biological sampling stations should match sites for chemical sampling.
10. To estimate the oxygen exchange rate of a river, a measurement of the cross-section is required. Typically, every station should be aligned with the cross-section of the river.
11. Since the sampling team has to carry an appreciable burden of sampling gear and water samples in most cases, the distance they are able to walk is limited. Therefore, easily accessible sites should be selected. Sites should also be accessible under all weather conditions and river flows.
12. With respect to preservation, samples are taken to perform analysis on three types of parameter. For some parameters, such as heavy metals, the samples need not be preserved. For other parameters, samples can be reserved by cold storage or by addition of certain preventatives. However, the samples for analysis of parameters like biological oxygen demand (BOD) and bacterial counts cannot be preserved and need to reach the laboratory shortly after taking the sample. The need to transport the samples to the laboratory will govern the range of determinations which can be carried out for a particular sampling site. Travel time greater than 24 hours between the site and laboratory is not recommended.
13. Collection of samples should be avoided at locations where there is high turbulence or flow.

14. There are many disrupting influences in rivers, especially cattle wading, melon farming, fishing, sand recovery, etc. These can drastically influence chemical processes and the nature of the biological community. Dams and barrages provide a different kind of habitat. Such sampling sites should be avoided.
15. Availability of sampling facilities, such as bridges and boats, and possibilities for wading, is important in the selection of sampling sites.

2.3 APPROACH TO SELECT A MONITORING STATION

Four steps are involved in selecting a monitoring station, as follows:
- Basin characteristics
- Reconnaissance survey
- Mixing zone
- Depth
- Minimum distance

2.3.1 BASIN CHARACTERISTICS

Basin characteristics generally consists of natural system such as physiography, lithological classification, soil type, hydrology (rainfall and run-off), and human activities such as agriculture, livestock cultivation, urbanization and industrialization. All these factors are interrelated and reflect wide spatial variations that influence water quality. Basin characteristics vary from season to season. They also provide information about the water balance. Without such knowledge, water quality monitoring networks cannot be laid down and a meaningful water quality monitoring programme cannot be developed. Undertaking this research work is challenging, since it requires collection of data and collation of various databases developed by various departments. Stakeholder consultation with different stakeholders is one of the best ways to understand basin characteristics. The influence of various basin characteristics in developing a water quality monitoring programme is summarized in *Table 1*.

TABLE 1: Influence of various basin characteristics on, and their relation with, a water quality monitoring programme

PARAMETER	RELATION TO WATER QUALITY MONITORING PROGRAMME	
	LEVEL I	LEVEL II
Physiography and land use	Topographical zoning such as hilly region, valley and plains	Spatial distribution of water quality monitoring programme
Hydrology and climate	Variation due to flood, scarcity of water flow and zoning with respect to climate such as temperate, and whether arid, semiarid, etc.	Spatial and temporal variation with respect to water quality and water quantity
Irrigation, agriculture and livestock	Water withdrawn, flow regulation and application of agrochemicals (externalities)	Effects on water qualities like salinity, siltation (turbidity), and eutrophic elements (nitrate, phosphate or pesticide)
Soil and lithology	Infiltration into groundwater and run-off	Ground water quality and soil erosion to turbidity
Urbanization	Water withdrawn and wastewater generation	Impact on water quality with respect to organic load and nutrient load as well as bacteriological contamination
Industrialization	Toxic wastewater generation	Effects on water quality with respect to toxic chemicals

Source: CSE

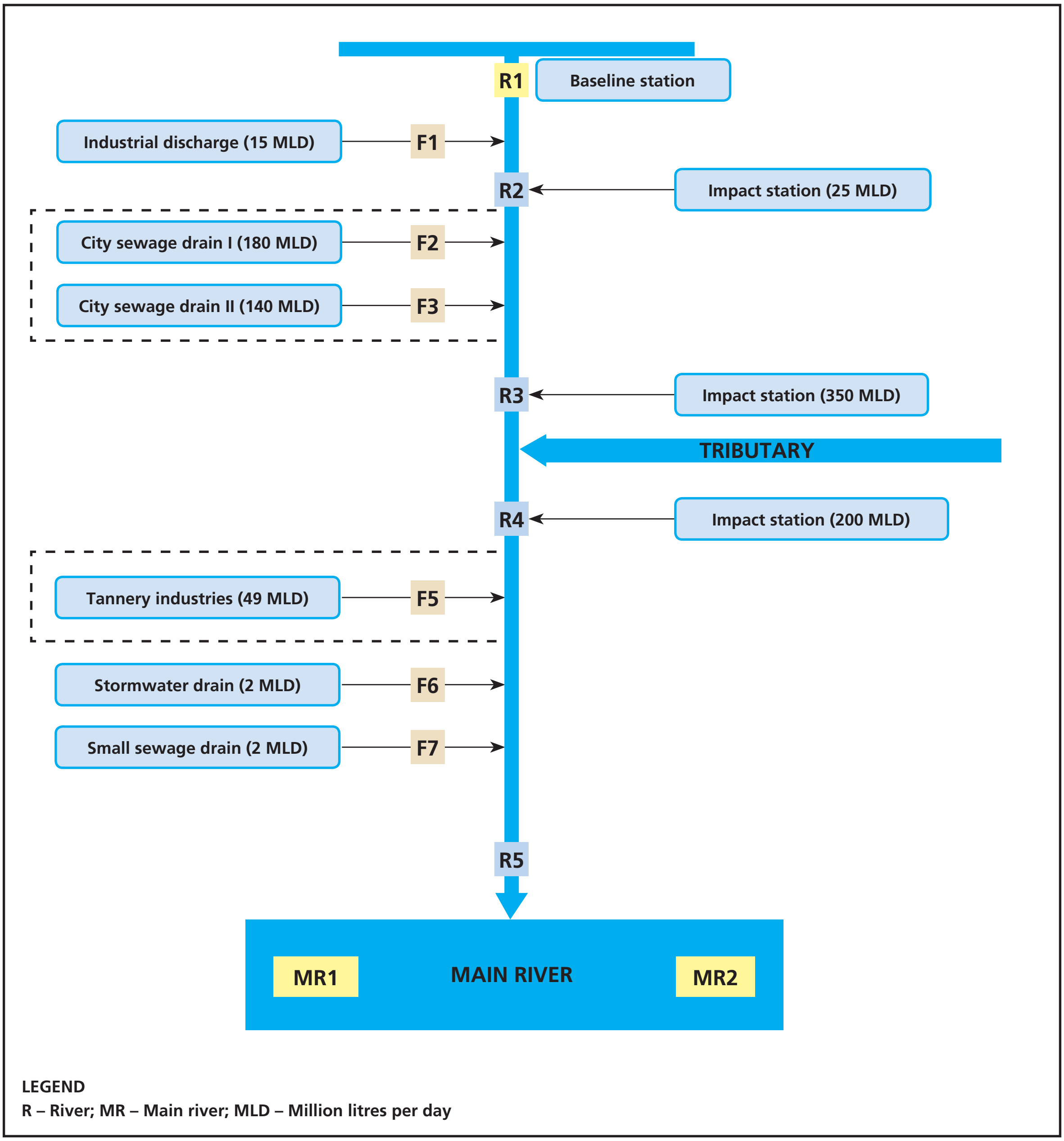
2.3.2 RECONNAISSANCE SURVEY

If basin characteristics are a result of desk research, then reconnaissance can be done by utilizing an on-spot survey for determining the exact location of the sampling points or stations. This survey will give an overview of the geographical location of the water body to be monitored and its susceptibility to human influences. This will be helpful in deciding appropriate locations and number of sampling points and stations.

The following information can be acquired during a survey:

- Location map
- Background information of the water body

Figure 3: Schematic diagram of reconnaissance survey of pollution load on a tributary or main river



Source: Central Pollution Control Board (CPCB), India

- Human activities around the water body, such as mass bathing, melon farming, cattle wading etc.
- Identification of potential polluting sources
- Water abstraction—quality and uses
- Water flow regulation—schedule, quality, etc.
- Usage pattern

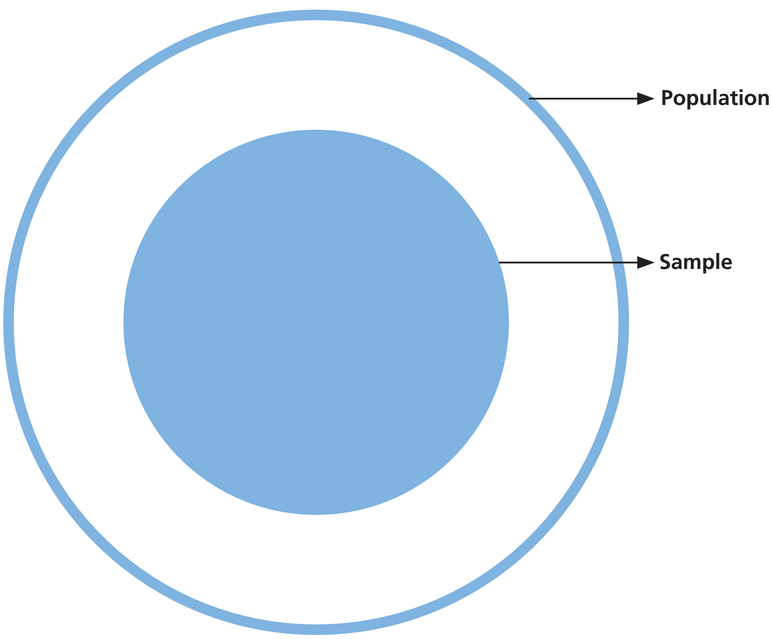
This information will help in designing a proper network as well in planning a monitoring schedule. A schematic diagram of identification of sampling points is given in *Figure 3*. All wastewater drains have been identified and the impact stations spotted on the river. There is one point where freshwater intake into the river is also identified, besides an impact station at the beginning of the baseline station.

2.3.3 MIXING ZONE OR DEPTH

This is one of the most important parameters for selecting the right point of sampling in a riverine system. After various point sources, such as tributaries, drainage from agriculture and urban systems and wastewater discharges from industries to the main stream of the water body are identified, water needs to be mixed well for sampling. Sampling, by definition, involves selection of elements from a collection in such a way that every element of the collection has the same chance of being selected. Thus, a sample with a specified number of items (objects or bits of information) is drawn from a population which is the larger body of collection of items or objects. Therefore, population can be defined as a larger body of collection of items or objects (see *Figure 4*).

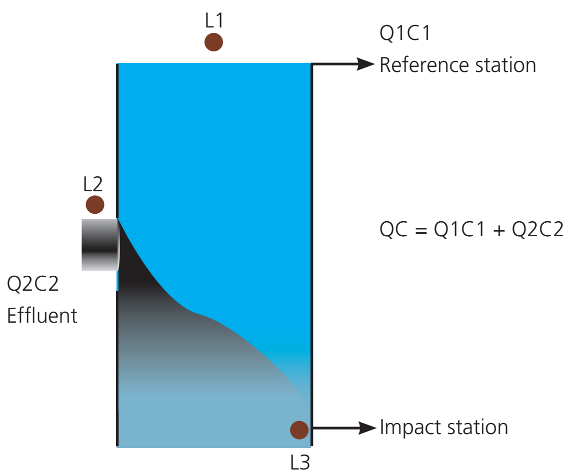
Representative samples are drawn at points where all the water bodies have mixed well, which would ensure that representatives of all the water bodies are evenly collected. Otherwise there is a greater chance of taking a sample of a dominant water body over the others that mix with it.

Figure 4: Sample and population



Source: CSE

Figure 5: Mixing zone



Note:

Q1 Quantity (volume) of the stream water;

Q2 Quantity (volume) of the drain effluent;

C1 Concentration (strength) of pollutants in the stream water;

C2 Concentration (strength) of pollutants in the effluent from the drain.

Q Total quantity (volume) of the stream after the mixing of the effluent from the drain

C Total concentration (strength) of pollutants in the stream water after the mixing of the effluent

L1 Reference station

L2 Flux station

L3 Impact station

Source: CSE

Table 2: Mixing zone and depth

Average width (m)	Mean depth (m)	Estimated distance for complete mixing (km)
5	1	0.08–0.7
	2	0.05–0.3
	3	0.03–0.2
10	1	0.3–2.7
	2	0.2–1.4
	3	0.1–0.9
	4	0.08–0.7
	5	0.07–0.5
20	1	1.3–11
	3	0.4–4
	5	0.3–2
	7	0.2–1.5
50	1	8–70
	3	3–20
	5	2–14
	10	0.8–7
	20	0.4–3

Source: *Water quality monitoring—A practical guide to the design and implementation of fresh water quality studies and monitoring programme*, UNEP/WHO

In order to identify the exact mixing zone, as experiment can be carried out, by gathering samples of a cross-section of the mainstream of the water bodies (see *Figure 5*), and the mixing zone with respect to the depth and width of a river (as summarized in *Table 2*).

In case of water quality monitoring in India, a depth of 1 meter and 1 km downstream of a point source as the depth and mixing zone respectively are generally considered. The minimum number of stations required for a river is generally decided based on the water discharge. United Nations Environment Programme (UNEP) and WHO guidelines also recommend the number of stations with respect to discharge (see *Table 3*).

Table 3: Minimum stations

Average discharge (cubic metre per second)	Type of stream or river	Number of sampling points	Number of sampling depths
< 5	Small stream	2	1
5–140	Stream	4	2
150–1,000	River	6	3
≥ 1,000	Large river	≥ 6	4

Source: *Water quality monitoring—A practical guide to the design and implementation of fresh water quality studies and monitoring programme*, UNEP/WHO

Through the Indian experience, it has also been observed that large rivers need one station for every 10 km. For example, the river Ganga, which is the biggest river in India, spanning a length of 2,525 km, needs around 250 stations. However, currently it has only about 60 monitoring stations, i.e., one station per 40 km.

3. Water quality parameters and sampling frequency

3.1 PARAMETERS OF WATER QUALITY

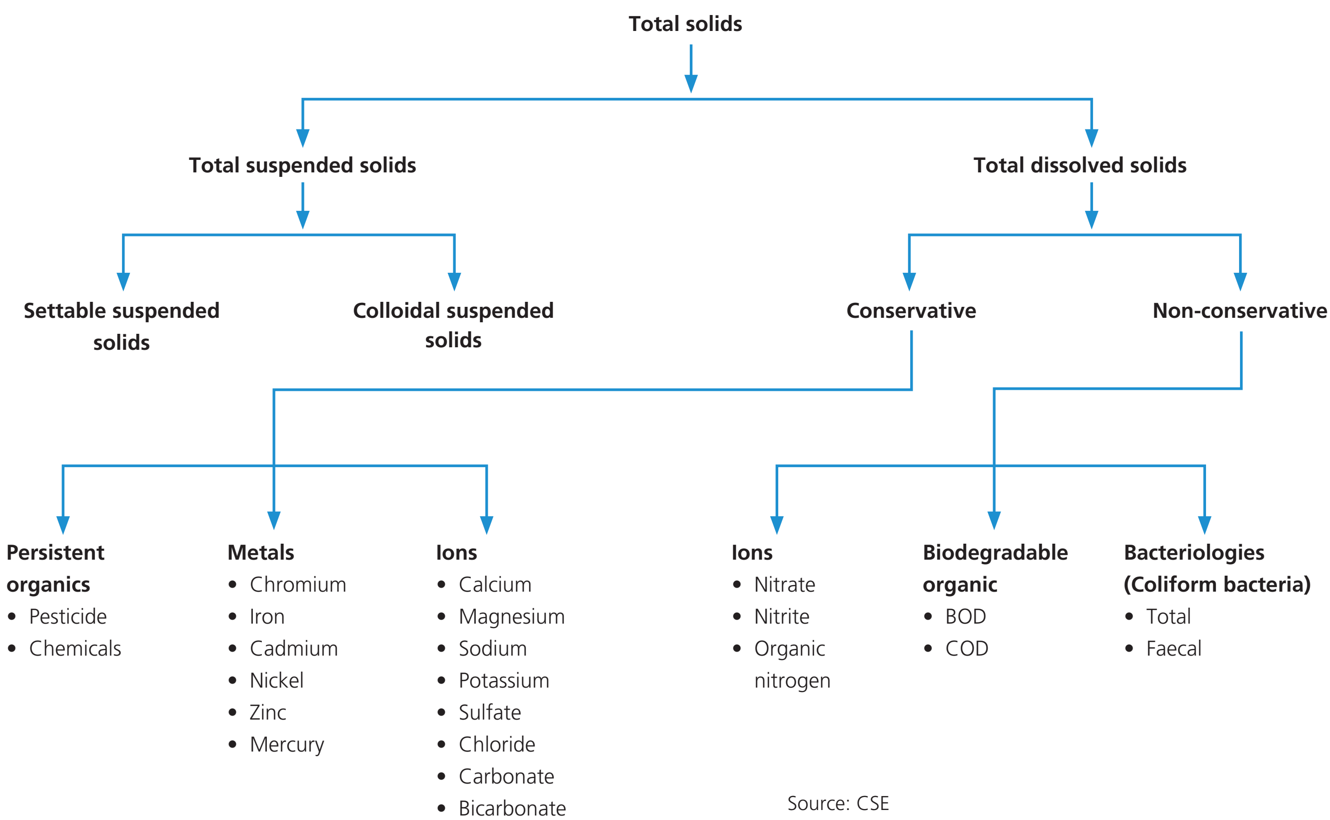
Water is a unique solvent. Besides common ions and biodegradable organics, it can also dissolve a range of other chemicals, including trace metals and other organics and a variety of microorganisms and planktons. This complex compendium of chemicals makes determination of the quality of water an intricate subject (see *Figure 6*).

Common ions, biodegradable organics and coliform bacteria are the dominant parameters of water quality, and these parameters vary seasonally. The monitoring authorities, therefore, enlist them as core or general parameters in all their monitoring programmes, including national water quality monitoring programmes (see *Table 4*). It is also pertinent to mention that such parameters are also an integral part of the Global Environment Monitoring Systems (GEMS) programme.

3.2 SAMPLING FREQUENCY

Sampling frequency is governed by the level of variations in the quality of water. If large variations occur in a short duration of time, sampling must be done on a more frequent basis. Variations in water quality could be of two types—random and cyclic or seasonal. Random variations are not predictable since they can happen due to many reasons or a combination

Figure 6: Solids affecting water quality



Source: CSE

Table 4: List of parameters monitored under a typical national programme for monitoring water quality

Observation	Core parameters (9)	General parameters (19)	Bio-monitoring (3)	Trace metals (µg/ml) (9)	Pesticides (30)
Weather	pH	Turbidity	Diversity index	Arsenic (µg/l)	Alpha BHC (µg/l)
Depth of main stream/depth of water table	Temperature	Phenolphthalein alkalinity, as ($CaCO_3$)	Saprobity index	Cadmium (µg/l)	Beta BHC (µg/l)
Colour and intensity	Conductivity (µmhos/cm)	Total alkalinity, as ($CaCO_3$)	P/R ratio	Copper (µg/l)	Gamma BHC (lindane) (µg/l)
Odour	Dissolved Oxygen (mg/l)	Chlorides (mg/l)		Lead (µg/l)	OP DDT (µg/l)
Visible effluent discharge	BOD (mg/l)	COD (mg/l)		Chromium (Total) (µg/l))	PP DDT (µg/l)
Station detail	Nitrate-N (mg/l)	Total Kjeldahl-N (Nmg/l)		Nickel (µg/l)	Alpha Endosulphan (µg/l)
Human activities	Nitrite-N (mg/l)	Ammonia-N (Nmg/l)		Zinc (µg/l)	Beta Endosulphan (µg/l)
	Faecal Coliform MPN/100 ml)	Hardness, as ($CaCO_3$)		Mercury (µg/l)	Aldrin (µg/l)
	Total Coliform (MPN/100 ml)	Calcium, as ($CaCO_3$)		Iron (total) (µg/l)	Dieldrin (µg/l)
		Sulphate (mg/l)			Carboryl (Carbamate) (µg/l)
		Sodium (mg/l)			2,4 D (µg/l)
		Total dissolved solids (mg/l)			Malathian (µg/l)
		Total fixed dissolved solids (mg/l)			Methyl Parathian (µg/l)
		Total suspended solid (mg/l)			Anilophos (µg/l)
		Phosphate (mg/l)			Chloropyriphos (µg/l)
		Boron (mg/l)			Corbamat (µg/l)
		Magnesium ($CaCO_3$)			Methyl Parathion (µg/l)
		Potassium (mg/l))			HCH Alpha Beta Delta (µg/l)
		Flouride (mg/l)			Isoprofuron (µg/l)
					Alachlor (µg/l)
					Atrazine (µg/l)
					Monochorotophos (µg/l)
					Ethion (µg/l)
					Phorate (µg/l)
					Butachlor (µg/l)
					Chlorandane (µg/l)
					Heptachlor (µg/l)
					Hexachlorobenzene (µg/l)
					Phosphamidon (µg/l)
					Diomethoate Diazinon (µg/l)

Source: Central Pollution Control Board (CPCB), India

of reasons, e.g., variations due to sudden rainfall in the catchment or unscheduled release of water from a dam. In such cases, increasing the frequency would not help much since it would not be possible to be cost effective in measuring such random variations. For water bodies that have frequent cyclic variations, sampling on a monthly basis is justified.

3.3 FREQUENCY OF REPORTING PARAMETERS

A combination of general parameters, nutrients, oxygen-consuming substances and major ions should be analyzed at all stations on a routine basis. Depending on the industrial activities and other anticipated activities upstream from the sampling station, more parameters such as micro-pollutants, pesticides and other site-specific variables may be investigated on a relatively less frequent basis.

A list of parameters to be considered for analysis and frequency of sampling is provided in the *Protocol for Water Quality Monitoring* notified by the government of India (see *Table 5*). But the following must be kept in consideration in this regard:

- The list does not restrict analysis of more parameters depending upon specific requirements of the analyzing agency and its available manpower.
- For lakes and reservoirs, monitoring of additional parameters, such as total Kjeldhal nitrogen, chlorophyll, total plankton count and productivity are to be included.
- The list of pesticides and toxic metals is flexible and should be decided case-by-case.

Table 5: Parameters for and frequency of monitoring surface water

Type of station	Frequency	Parameters
Baseline	Perennial rivers and lakes: Four times a year (seasonal) Seasonal rivers: Three to four times (at equal spacing) during flow period Lakes: Four times a year (seasonal)	PRE-MONSOON The following 25 parameters must be monitored once a year before the monsoon. • **GENERAL:** Colour, odour, temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), turbidity, Total Dissolved Solid (TDS) • **NUTRIENTS:** Ammoniacal nitrogen (NH_4-N), nitrite and nitrate nitrogen ($NO_2 + NO_3$) total phosphate (Total P) • **DEMAND PARAMETERS:** Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) • **MAJOR IONS:** Sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), carbonate (CO_3) bicarbonate (HCO_3), chloride (Cl), sulfate (SO_4) • **OTHER INORGANIC:** Fluoride (F), boron (B) and other location specific parameter, if any. Microbiological: Total coliform and faecal coliform For the rest of the year (after the pre-monsoon sampling) following 10 parameters—Colour, odour, temperature, pH, EC, DO, $NO_2 + NO_3$, BOD, total coliform and faecal coliform can be monitored at three-months intervals.
Trend or Flux or Impact	Once every month starting April-May (pre-monsoon) i.e. 12 times a year	During the pre-monsoon season,analyze 25 parameters as has been listed for baseline monitoring – • Other months: Analyse 15 parameters as listed below: • General: Colour, odour, temperature, pH, EC,DO and turbidity • Nutrients: NH_3 -N, $NO_2 + NO_3$, total P • Organic Matter: BOD, COD • Major ions: Cl • Microbiological: Total and faecal coliforms The analysis for micro pollutant must be done once a year, preferably during the pre-monsoon time. These would include – • PESTICIDES – Alpha benzenehexachloride (BHC), beta BHC, gama BHC (Lindane), OP-Dichlorodiphenyltrichloroethane (OP-DDT), PP-DDT, alpha endosulphan, beta endosulphan, aldrin, dieldrin, carbaryl (carbamate), malathion, methyl parathion, anilophos, chloropyriphos • TOXIC METALS – Arsenic (As), cadmium (Cd), mercury (Hg), zinc (Zn), chromium (Cr), lead (Pb), nickel (Ni), iron (Fe) (The parameters may be selected based on local need)

Source: Central Pollution Control Board (CPCB), India

4. Assessment of resources

Once the objectives of monitoring are known and its networks are established, it is important to look into the availability of resources for monitoring. Generally, a compromise is made between the quality and quantity of data required to fulfil the objectives within the available resources. Before planning a programme to monitor water quality, it is important to ensure that the following resources are available.

4.1. SAMPLING EQUIPMENT

The bare minimum items required to conduct a smooth on-the-spot sampling are summarized in *Table 6*.

Table 6: Checklist for field visits

Itinerary for the trip (including travel route, stations to be covered, start and return time)	Tissue paper boxes	First-aid kit	Submersible pump and accessories
Map of the area	Sample identification form(s)	Dump sampler to check well conditions	Gumboots/hip boots
Icebox filled with ice or icepacks	Field notebook	Personnel and sample transport arrangement	DO fixing and titration chemicals
BOD bottles	Hand sanitizer/ soap and towels	Sampling site location map	Other field measurement kit, as per requirement
Special sample containers for samples of bacteriological parameters, heavy metals, etc.	Spirit lamp	Weighed bottle sampler	Camera
Sample preservatives (e.g. acid solutions)	Drinking water	Rope	Stopwatch
Sample containers	Thermometer	Measuring tape	Gloves and eye protection
Labels for sample containers	Pen/pencil/marker	Match box	Knife
Torch	GPS	In-situ testing multimeters	Personal protective gear

Source: Protocol for Water Quality Monitoring, August 1999 (http://nhp.mowr.gov.in/docs/HP2/MANUALS/Water%20 Quality/5014/-download-manuals-WaterQuality-WQManuals-ProtocolforWaterQua.pdf

4.2. TRANSPORT FOR SAMPLING

Whenever a means of transport is hired or purchased for a water quality sampling survey, the space in the vehicle should be enough to accommodate seating for at least three people beside the driver. In addition, it should also have space for keeping sampling kits and the samples collected. The sampling van can be designed or build up to the following specifications:

- Seating for six passengers
- Length—6,065 mm
- Width—1,975 mm

- Height—2,550 mm
- Fully air conditioned with portable generators
- Deep freeze
- Space for sampling kits, one folding table and two chairs
- Multi-parameter boxes that can measure pH, DO, conductivity (can be placed in a table drawer with provision of keeping it in a fixed position)
- One rack to keep the sample bottles, reagent bottles, etc.

4.3. LABORATORY FACILITIES

A water laboratory set-up should have a space of at least 100 m^2, along with provisions for the following dedicated areas:

a. Analytical laboratory
b. Balance room
c. Instrument room
d. Microbiological laboratory
e. Space for sample receipt and storage room
f. Store room, and
g. Staff room with computer facilities

Besides these, there must be a dedicated space for distillation assembly and sample digestion or hood system. The laboratory set-up must have the facility of continuous power supply with a DG set as a backup arrangement. Continuous water supply is also an important requirement.

4.4. TRAINED MANPOWER

One of the most important factors in the production of reliable analytical result by a laboratory is the availability of adequate number of skilled and educated and laboratory analysts. The manpower should ideally be structured into a three-tier system as stated in *Table 7*.

Table 7: Manpower requirements

S. no.	Job description	Qualification
1	Supervisor	M.Sc. in chemistry, life or environmental science with at least five-year experience
2	Analysis and sampling	M.Sc. in chemistry, life or environmental science with at least three-year experience or B.Sc. with eight year experience
3	Lab or field attendant	Higher secondary with science

Source: LATS/9/2008-2009, Central Pollution Control Board, New Delhi

Adequacy in number is a function of the number of parameters and samples required (day or week or month).

4.5. CHEMICALS AND GLASSWARE

Selection of proper laboratory chemicals that are of appropriate quality is one of the most important factors in achieving results with desired accuracy and precision. The quality of chemicals or solvents used in the analytical laboratory may vary from laboratory grade to analytical or guaranteed grade (compiling to ANALAR or analytical reagent (AR) or general reagent GR). These reagents that are essential for analytical purposes and laboratory research work have very high purity and come with a certificate of guarantee, which gives the minimum assay and maximum limits of trace impurities.[4]

4.6. FUNDS FOR OPERATION AND MAINTENANCE OF LABORATORY AND SAMPLING PROGRAMMES

Generally, funds needed for the smooth functioning of laboratory are of two types—one is for laboratory infrastructure including purchase of equipment and instrument, or laboratory furniture or civil works. Other is the operation and maintenance cost accruing from day-to-day activities, including the salary of employed and contracted staff, cost for sampling, glassware and chemicals, annual maintenance charges for equipment and apparatus and other laboratory-based logistics.

5. Sampling programme and field activities

5.1 PLANNING FOR SAMPLING

When planning a sampling programme, an estimate of the number of sampling stations or wells that can be sampled in a day is required. For this, it is necessary to know the time required at each site. In addition to that, the programme also involves designing of a sampling scheme detailing out how and when the sampling has to be done, selecting the sample sizes, identification of parameters to be measured at the stations being monitored since each station can have some different parameters that are to be measured, and assigning roles and responsibilities to staff that will conduct the sampling work.

5.2 CHECKLIST FOR FIELD VISIT

At least one day before sampling, it should be ensured that all arrangements as listed in *Table 6* have been made. Location maps or GPS should be kept handy, to flag prominent landmarks near the sampling site(s). If there are any deviations from the fixed collection points, they must be recorded, and reasons must be cited for these deviations. If the laboratory conducting analysis is different from the one preparing the sample bottles, it must be ensured that the former should be informed about the programme and its objectives and should be ready to receive the samples, particularly those which need immediate attention.

5.3 GENERAL GUIDELINES FOR SAMPLING

The following points highlight the important rules to be followed during sampling:

- Rinse the sample container three times with the sample before it is filled with the sample.
- Leave a small air space in the sample container to allow for mixing of the sample at the time of analysis.
- Label the sample container properly, preferably by attaching an appropriately inscribed tag or label. The sample code and the sampling date should be clearly marked on the sample container or the tag.
- Sample identification forms should all be kept in a master file at the laboratory where the sample is analyzed.
- Complete the sample identification form for each sample. The sample identification form should be filled while carrying out sampling at each of the monitoring stations. In cases where more than one bottle is filled at a site, this is to be registered on the same form.

5.3.1 SURFACE-WATER SAMPLING

- Samples should be collected with a weighed bottle or DO sampler from a well-mixed section of the river 30 cm below the water surface.
- Samples from reservoir sites should be collected from the outgoing canal, power channel or water intake structure. When there is no discharge into the canal, samples should be collected at the exit point of the reservoir itself.
- DO content of a collected sample is determined in a bottle specialized for this purpose using a DO sampler. The DO in the sample must be fixed immediately after collection, using chemical reagents. DO concentration can be determined either in the field, or later, in a laboratory.

5.4 SAMPLE LABELLING

Sample containers should be labelled properly, preferably by attaching an appropriate inscription tag or label. Alternatively, the bottle can be labelled directly with a waterproof marker. Information on the sample container or the tag should include:

- Sample code number (identifying location)
- Date and time of sampling
- Source and type of sample
- Pre-treatment or preservation carried out on the sample
- Any special notes for the analyst
- Sampler's name

5.5 SAMPLE CONTAINER, PRESERVATION AND TRANSPORTATION

1. The type of containers and sample preservation to be adopted can be modelled on the guidelines mentioned in *Table 8*.
2. Samples must be transported to the concerned laboratory as soon as possible, preferably within 48 hours of collection.
3. Analysis for coliforms must be started within 24 hours of collection of samples. If the time is exceeded, it should be recorded with the result.
4. Samples containing μg/l level metal concentration should be stored at 4°C and analyzed as soon as possible. If the concentration is of mg/l level, it can be stored for up to six months, except mercury, for which the limit is five weeks.
5. Sample identification of the analysis for surface-water extracts should be done as mentioned in *Form I*.

Table 8: Container type and preservatives needed for sampling

ANALYSIS	CONTAINER	PRESERVATION
General	Glass, PE	4°C, dark
BOD	Glass, PE	4°C, dark
COD, NH_3, NH_2, NO_3	Glass, PE	H_2SO_4, pH<2
Coliform	Glass, PE, sterilized	4°C, dark
DO	BOD bottle	DO fixing chemicals
Fluoride	PE	None
P	Glass	None
Pesticides	Glass, Teflon	4°C, dark
Toxic metals	Glass, PE	HNO_3, pH<2

Source: Guidelines for Water Quality Monitoring (MINARS/27/2007-08), Central Pollution Control Board, New Delhi

5.6 TYPES OF SAMPLES

5.6.1 GRAB SAMPLES (ALSO CALLED SPOT OR CATCH SAMPLE)

One sample is taken at a given location and time. In the case of a flowing river, it is usually taken from the middle of the water and in the middle of the water column. When a source is known to vary with time, spot samples collected at suitable time intervals and analyzed separately can document the extent, frequency and duration of these variations. Sampling intervals are to be chosen on the basis of the expected frequency of the changes and may vary from continuous recording or sampling every five minutes, to several hours or more.

5.6.2 COMPOSITE SAMPLES

In most cases, these samples refer to a mixture of spot samples collected at the same sampling site at different times. This method of collection reduces the analytical effort, because

FORM I: Sample identification for surface-water samples analysis and record

Sample code		
Observer	Agency	Project
Date:	Station code	
Time:		

Parameter code	Container				Preservation				Treatment		
	Glass	PVC	PE	Teflon	None	COD	Acid	Other	None	Decant	Filter
1. General											
2. Bacteriology											
3. BOD											
4. COD, NH_3, NO_3											
5. Toxic Metals											
6. Trace Organics											

Source of sample			
Water	Point	Approach	Medium
o River o Drain o Canal o Lake, tank or pond	o Main current o Right bank o Left bank	o Bridge o Boat o Wading	o Water
Sample type	o Grab	o Time component o Flow component o Depth-integral o Width-integral	
Sample device	o Weighted bottle	o Depth sampler	

Field determination					
Temperature °C		pH	EC µMho/cm		DO mg/l
Odour code	1. Odour free 2. Rotten eggs 3. Burnt Sugar 4. Soapy 5. Fishy 6. Septic 7.Aromatic 8.Chlorinus 9.Alcoholic 10. Unpleasant		Colour code	1.Light brown 2.Brown 3.Dark brown 4.Light green 5.Green 6. Dark green 7. Clear 8.Other	
Remarks					
Weather	o Sunny o Cloudy o Rainy or Windy				
Water velocity (m/sec)	o High (> 0.5) o Medium (0.1–0.5) o Low (< 0.1) o Standing				

Source: Guidelines for Water Quality Monitoring (MINARS/27/2007-08), Central Pollution Control Board, New Delhi variations are averaged out in analysis. It is a useful technique when daily variations occur, and seasonal variations are the objective of the programme. If, however, the series of spot samples are not mixed but analyzed individually, information on the daily variability can also be obtained, and the averages can be computed later.

Sometimes the indication of 'time-composite' is used to distinguish it from 'location-composite' sampling. Time-composite sampling representing a 24-hour period is often used. For many determinations, the time interval between sampling events should be one–three hours. To evaluate the nature of special discharges (e.g. variable in volume or irregular in time), samples should be collected at time intervals representing the period during which such discharges occur. Especially in effluents, one may sample a volume that is proportional to the discharge (flow-based composite). This type of sampling is also required to measure the flux of pollution load discharged through a point source.

5.6.3 INTEGRATED SAMPLES

Sometimes, samples are collected at the same location but, because of horizontal or vertical variations in the composition of the river (or in the water flow) or lake, they come from different points in the cross-section and are accorded different relative importance. To evaluate the average composition, total load or mass balance, integrated samples are collected, often in proportion to the river flow of the areas of sample collection.

5.7 IN SITU MEASUREMENTS

Some determinants are more likely to be affected by sampling and sample storage than others. In several cases, the expected changes are so large that it is impossible to store the sampled material for a correct analysis later. If possible, these parameters should be analyzed on the sampling site or, even better, in situ. Most important parameters that should be analyzed in situ are pH, DO, temperature, conductivity, and, sometimes, turbidity. For several measurements, special portable measuring devices are available. The estimation on numbers and diversity of organisms is also to be considered as in situ analysis.

5.7.1 COLOUR

Determining the colour in the field is relatively easy. Pour an aliquot of approximately 10 ml of sample into a glass test-tube and judge the colour observed. Options can be listed as:

1. Light brown
2. Green
3. Brown
4. Dark green
5. Dark brown
6. Clear
7. Light green
8. Other (specify)

5.7.2 ODOUR

Odour should always be determined in the field after collecting a sample as soon as possible. After collection, fill a clean and odourless bottle to the halfway mark with the sample to be tested. Then cover the sample container with a stopper, shake vigorously for two–three seconds, open the stopper and quickly smell it. Alternatively, pour an aliquot of approximately 5 ml of sample into a glass test tube and judge the odour, considering one of the following options:

1. Odour-free
2. Septic
3. Rotten eggs
4. Aromatic

5. Burnt sugar
6. Chlorinous
7. Soapy
8. Alcoholic
9. Fishy
10. Unpleasant

5.7.3 TEMPERATURE

Water temperature should be measured in °C, using a mercury thermometer or a thermistor. Most electronic thermistors are built into larger devices which can also measure pH and electrical conductivity (EC) of the sample. Whenever possible, the temperature should be measured by directly dipping the thermometer in the natural body of water being studied. In case that is not possible, collect about 500 ml sample in a plastic or glass container, and measure temperature by immersing the thermometer in the sample. Read the temperature after calibration (no more change in the temperature reading). Report the temperature on the sample identification form in °C with one digit after the decimal point (e.g. 13.2°C).

5.7.4 pH

The most accurate method of measuring pH of a water sample in the field is by means of a portable purpose-designed pH meter. Such meters are normally capable of measuring pH to the nearest 0.05 of a pH unit using a 'glass' and a 'reference' electrode (these are often combined in a single probe). Before measuring pH, it is necessary to calibrate the meter. This should be done at least once per day, before the first pH measurement is attempted. The procedure for this is as follows:

- After removing their protective caps, the electrodes are rinsed in distilled water and carefully dried with soft absorbent paper.

Note: Care needs to be exercised here as the electrodes are very fragile.

- The electrodes are then placed in a fresh buffer solution and after suitable time for meter stabilization has passed, the pH reading of the meter is adjusted to the pH of the buffer solution (normally seven).
- The electrodes are then rinsed again with distilled water and dried.
- If the pH measurement is not to be taken immediately, the electrodes should be replaced in their protective caps. Normally, the glass electrode cap is filled with distilled water before replacement to prevent the electrodes from drying out.
- The pH should be reported on the sample identification form in pH units showing one digit after the decimal point, e.g. 7.6.

Once calibrated, the pH meter can be used to measure the pH directly by placing the electrodes in a water sample immediately after it is obtained. Care should be taken to ensure that the electrodes are rinsed with distilled water before and after each determination and that distilled water is placed in a glass electrode cap for transportation.

5.7.5 ELECTRICAL CONDUCTIVITY (EC)

EC can be measured in the field with a purpose-designed meter. Before measuring conductivity, it is necessary to calibrate the meter. This should be done at least once every day, before the first measurement is taken. Calibration is achieved by determining the conductivity of a known, fresh solution of potassium chloride and adjusting the meter accordingly. To ensure that the reading is accurate, it is necessary to adjust the conductivity reading to compensate for temperature changes. In most modern meters, this is done automatically. Once calibrated, the conductivity of the water can be measured by immersing the electrode in a sample of water as soon as it is taken. It is important to remember that conductivity meters often take some minutes to stabilize. The reading must, therefore, be taken after this stabilization has occurred. Report the EC at 25°C, preferably in μMho/cm with no figure after decimal point (e.g. 1,135 μMho/cm).

5.7.6 INSTRUMENTS FOR FIELD MEASUREMENT

There is a basic list of instruments and equipment which must be brought to the sampling sites. For example, temperature should always be measured in the field.

- For measurement of temperature, a (mercury) thermometer or thermistor is needed.
- For analysis of electrical conductivity, a conductivity meter is needed.
- For analysis of pH, a pH meter is needed.
- For analysis of redox potential, a pH meter (mV scale), reference electrode and oxidation–reduction indicator electrode are needed.

  (NOTE: It is possible that instead of separate meters for temperature, pH and conductivity, there is a single instrument with different probes which will measure all three parameters. These are called multi-parameters monitoring sensors.)

5.7.7 SAMPLE CONTAINERS

Sample containers needed for the campaign are prepared by the laboratory and given to the person collecting samples (see *Table 9*).

Table 9: Container types and volumes needed for sampling

Analysis	Container	Volume	Preservation
On-site analysis	PE bowl	±200	-
General (SS, TDS, major ions)	Glass, PE	1000	-
COD, NH_3, NH_2, NO_3	Glass, PE	500	$H2SO_4$, PH<2
o-PO_4	Glass	100	-
BOD	Glass, PE	1000	4°C, Dark
Coliform	Glass, PE, Sterilized	300	4°C, Dark
Heavy metals (Cd, Zn)	Glass, PE	500	HNO_3, pH<2
Mercury	Glass	1000	HNO_3, pH<2
Pesticides	Glass, Teflon	1000	4°C, Dark

Source: Guidelines for Water Quality Monitoring (MINARS/27/2007-08), Central Pollution Control Board, New Delhi

5.7.8 REAGENT SOLUTIONS

In some field analysis, reagent solutions are necessary. They must be prepared in the laboratory and brought to the field by a responsible sample collector. In all cases, sample preservatives and DO-fixing solutions, as applicable, must be brought to the field and added to the samples immediately after collection.

For analysis of pH, buffer solutions, for pH –4, 7 and 9, are necessary to standardize the pH meter. For analysis of EC, standard potassium chloride solution, KCl (0.01 M) is needed to standardize the conductivity meter. For preservation of certain samples, concentrated Sulphuric Acid, ZoBell's solution etc. are needed. A supply of distilled water is needed for rinsing equipment.

5.7.9 FIELD DATA PROTOCOL

The following list highlights the important checklist points that are part of the sample collection process:

a) Sampling team members
b) Date and time (24-hour method) of collection (time span; in case of composite sampling)
c) Nature of the sample: Spot, composite or integrated
d) Results of in situ or on-site analysis performed (water, temperature, DO, pH (field or

laboratory), EC (field or laboratory), turbidity, macro-fauna composition (bio-monitoring working party score), macro-fauna diversity (strategic bio-monitoring initiatives) and 24-hour oxygen production/ respiration ratio)

e) Exact sampling location (location along the river and distance from shore) and depth of collection
f) Definition of sampling intervals and volumes in case of composite sampling
g) Maximum depth of the river or lake, and current velocity in case of composite sampling
h) Weather conditions with respect to clouds, precipitation and wind (direction and force)
i) Consistency of sediment (sandy, silt-like, etc.)
j) Comments on smell, colour, discharge, etc.
k) Parameter(s) that will be analyzed
l) Sample bottle (number, type, material, volume, and an indication if a preservative is already present)
m) The method of preservation or storage

If a large number of different sample bottles have to be filled for various observations, it is convenient to have a space on the form to tick off when the sample has been collected. It makes it easy at the end of the sampling event to check if all samples have been collected in the correct number.

5.7.10 ANALYTICAL RESULT SHEETS

When offering the samples to the analytical laboratory, every series of replicate sample container has to be accompanied by a prefilled 'result sheet'. This sheet is marked with sample specifications identical to those marked on the bottle. The individual parameters to be measured in the sample are tabulated, together with the units they should be reported in. The sheet leaves space for the analytical lab to fill in the results of replicate analysis.

6. Laboratory work and analysis

6.1 WORK ASSIGNMENT AND PERSONNEL REGISTER

- The laboratory in-charge should maintain a detailed log of the work assignment.
- This register would link the laboratory and sample numbers to the analyst who makes specific analyses, such as pH, EC, BOD, etc.
- An estimate of time needed for performing the analyses may also be entered into the register.
- Each laboratory analyst should have a bound register or log book where all laboratory readings and calculations are to be entered.
- When analyses and calculation are completed, the results must be recorded in a register or computer containing data records sheets described in the next section.

6.2 LABORATORY ANALYSIS

It has been observed that many laboratories have developed their own procedures. They also use different units to present results and, sometimes, place several digits after the decimal. This creates problems in integrating results. To make the procedure and presentation methods uniform, a guideline has been prepared (see *Table 10*). It is important that all agencies monitoring water quality and entering data into websites must follow this procedure to achieve unity.

Table 10: Measurement methods, units and significant figures for different parameters used in monitoring water quality

Parameters	Unit	Measurement methods	Significant figures after decimal
Colour	-	Visual method	--
Odour	-	Manual	--
Temperature	°C	Thermometer	1
pH	-	pH meter	1
Electrical conductivity	µS/cm	Conductivity meter	0
Dissolved oxygen	mg/L	DO Meter or Winkler modified method	1
Turbidity	NTU	Nephelometer	1
Total dissolved solids	mg/L	Gravimetry	0
Ammonical nitrogen (NH_4-N)	mgN/L	Colorimetry	1
Nitrite + Nitrate-N	mgN/L	Colorimetry	1
Total phosphate	mg/L	Colorimetry	4
Orthophosphate	mg/L	Colorimetry	4
Biochemical oxygen demand (BOD)	mg/L	DO consumption in 3 days at 27 °C	1
Chemical oxygen demand (COD)	mg/L	Potassium dichromate method	1
Sodium	mg/L	Flame photometry	1

Potassium	Mg/L	Flame photometry	1
Calcium	mg$CaCO_3$/L	EDTA Titrimetric	1
Magnesium	mg $CaCO_3$/L	EDTA Titrimetric	1
Carbonate as $CaCO_3$	mg $CaCO_3$/L	Titrimetric	1
Bicarbonate, as $CaCO_3$	mg $CaCO_3$/L	Titrimetric	1
Chloride	mg/L	Argentometric titration	1
Sulphate	mg/L	Turbidimetry	1
Fluoride	mg/L	Ion meter, Colorimetry	2
Boron	mg/L	Ion meter, curcumin method	2
Total coliform	No./100mL	MPN or MF method	0
Fecal coliform	No/100mL	MPN or MF method	0
% Sodium	-	Calculation	2
SAR	-	Calculation	2
SPECIFIC PARAMETERS			
Arsenic	µg/L	Cold vapour AAS	1
Mercury	µg/L	Cold vapour AAS	1
All other heavy metals	µg/L	AAS	1
Pesticides and other organics	µg/L	GC, GCMS	1

Source: Guidelines for Water Quality Monitoring (MINARS/27/2007-08), Central Pollution Control Board, New Delhi

6.3. OUTLINE ON QUALITY ASSURANCE AND CONTROL

6.3.1. QUALITY ASSURANCE

Quality assurance programme for a laboratory or group of laboratories should contain a set of operating principles, written down and agreed upon by the organization, delineating specific functions and responsibilities for each person involved, and the chain of command. Following points describe various aspects of this type of programmes:

- **Sample control and documentation**
  Procedures regarding sample collection, labelling, preservation, transportation, preparation of derivatives, where required, and the chain of custody.
- **Standard analytical procedures**
  Procedures detailing methods for the analysis of each parameter giving results of acceptable accuracy.
- **Analytical qualification**
  Qualifications and the training requirements of the analysts must be specified. The number of repetitive analyses required to obtain results of acceptable accuracy also depends on the experience of the analyst.
- **Equipment maintenance**
  For each instrument, a strict preventive maintenance programme should be followed. This reduces instrument malfunctions, help maintains calibration and reduces downtime. Corrective actions to be taken in case of malfunction should also be specified.
- **Calibration procedures**
  In analyses where an instrument has to be calibrated, the procedure for preparing a standard curve must be specified, e.g., the minimum numbers of different dilutions of a standard to be used, method detection limit (MDL), range of calibration and verification of the standard curve during routine analyses.

- **Data reduction, validation and reporting**
  Data obtained from analytical procedures must be corrected, where required, for sample size, extraction efficiency, instrument efficiency and background value. The correction factors as well as validation procedures should be specified. Results should be reported in standard units. A prescribed method should be used for reporting results below MDL.

An important aspect of reporting results is the use of the correct number of significant figures. To decide on the number of significant digits, the uncertainty associated with the reading(s) in the procedure should be known. Knowledge of standard deviation will help in rounding off figures that are not significant. Procedures regarding rounding off must be followed.

6.3.2. ANALYTICAL QUALITY CONTROL (AQC)

AQC programmes consist of processes and procedures that help ensure acceptable levels of precision, accuracy and representativeness in the received samples. The programme helps ensure that for each analytical method, appropriate quality control parameters are established; and a suitable monitoring regime and performance criteria are defined and achieved.[5] Analytical quality control is obtained by including both intra-laboratory and inter-laboratory AQC.

In the intra-laboratory programme, studies may include recovery of known additions to evaluate the matrix effect and suitability of the analytical method, and analysis of reagent blanks to monitor purity of chemicals and reagent water; sample blanks to evaluate sample preservation, storage and transportation; duplicates, to asses method precision; and individual samples or sets of samples, to obtain mean values from the same control standards to check for random errors.

Inter-laboratory programmes are designed to evaluate laboratory bias. All the listed AQC actions may not be necessary for various determinants. Further, these are not one-time exercises but internal mechanisms for checking performance and protecting laboratory work from errors. These checks do not add to the workload of laboratories significantly.

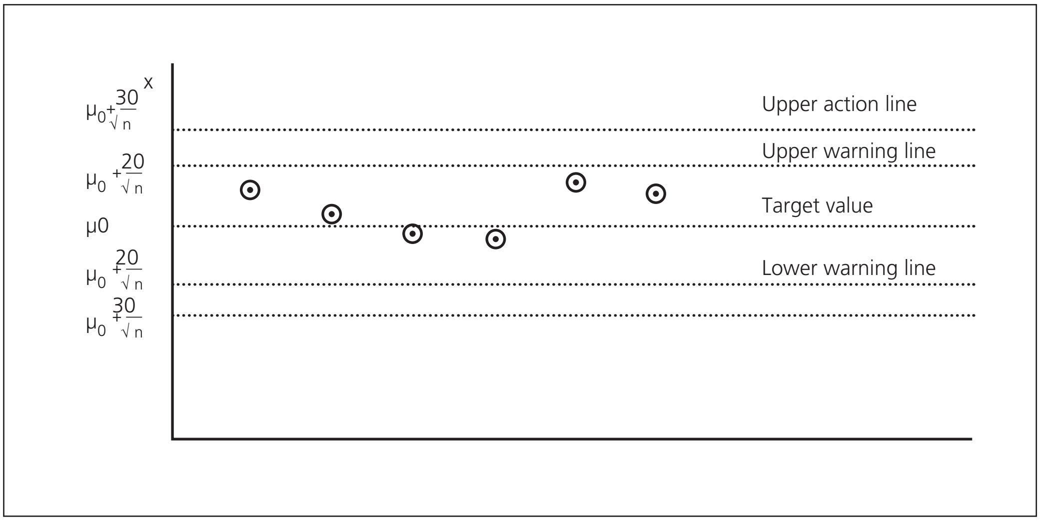
6.3.3 INTRA-LABORATORY EXERCISE (SHEWHART CONTROL CHART)

If a set of analytical results is obtained for a control sample under conditions of routine analysis, some variation of the observed values will be evident. The information is said to be statistically uniform and the analytical procedure is said to be statistically controlled if this variation arises solely from random variability. The function of a control chart is to identify any deviation from the state of statistical control.

Shewhart Control Charts (see *Figure 7*) are the most widely used form of control charts. In their simplest form, results of individual measurements made on a control sample are plotted on a chart in a time series. The control sample is analyzed in the same way as routine samples at fixed intervals, once or twice every week, after 20–50 routine samples.

Assuming the results for the control sample follow the normal frequency distribution, it would be expected that only 0.3 per cent of results would fall outside lines drawn at three standard deviations above and below the mean value, called upper and lower control limits (UCL and LCL) respectively. Individual results would be expected to fall outside these limits so seldom (three out of 1,000 results) that such an event would justify the assumption that the analytical procedure was no longer in statistical control, i.e., a real change in accuracy has occurred.

Figure 7: A typical Shewhart Control Chart



Source: *Statistics for Analytical Chemistry*, J. C. Miller

The chart is constructed from 20 or more results of replicate analysis of a control or standard sample. Two lines are inserted on the chart at two standard deviations above and below the mean value called upper and lower warning limits (UWL and LWL) respectively. If the method is under control, approximately 4.5 per cent of results may be expected to fall outside these lines.

A Shewhart Control Chart provides a check on both random and systematic errors gauged from the spread of results and their displacement respectively. The standard methods list's the following actions that may be taken based on the result of the analysis in comparison to the standard deviation.

CONTROL LIMIT: If one measurement exceeds the limits, repeat the analysis immediately. If the repeated analysis results are within the UCL and LCL, continue the analysis; if they exceed the action limits again, discontinue analysis and correct the problem.

WARNING LIMIT: If two out of three successive points exceed the limits, analyze another sample. If the next point is within the UWL and LWL, continue analysis; if the next point exceeds the warning limits, discontinue analysis and correct the problem (see *Figure 7*).

STANDARD DEVIATION: If four out of five successive points exceed one standard deviation or are in increasing or decreasing order, analyze another sample. If the next point is less than one standard deviation away from the mean or changes the order, continue analysis; otherwise discontinue analysis and correct the problem.

CENTRAL LINE: If six successive points are on one side of the mean line, analyze another sample. If the next point changes the side, continue the analysis; otherwise discontinue analysis and correct the problem.

PRECISION: The most important parameter to evaluate in the results is precision. The statistical term to evaluate precision is standard deviation. The numerical value of the standard deviation depends on the average concentration (standard deviation also has the unit of concentration). The ratio of variation of standard deviation and mean is the coefficient of variation and cancels the unit to become a dimensionless number. Numerical values of standard deviations of low concentration solutions are usually smaller than those of solutions with higher concentrations. Therefore, the coefficient of variation, defined earlier, should be used to evaluate precision. This is particularly useful when comparing results of analyses for samples with different concentrations. Before evaluating the results one should answer the question, 'What is the desired precision for analysis?' In fact, this question should be answered by the designated 'data users'. The use of data determines the required precision, e.g., detection of trends may require more precise results (in order to actually detect small changes with time) than checking water for use in, say, irrigation. Laboratory staff should always ask for the purpose for which they are performing the requested test. As a minimum goal, however, the precision that can be obtained by correctly and adequately following the method prescribed by the APHA (American Public Health Association) Standard Methods for the examination of water and wastewater may be adopted.

CALCULATING REVISED LIMITS WHEN CONTINUING THE EXERCISE: Warning and control limits should be recalculated periodically. Precision improves, especially when new techniques are introduced, when experience is gained with the technique. A good time for recalculating the control and warning limits is when the control chart is full and a new graph has to be created anyway. At this point, use the 20 most recent data points on the old chart for construction of LCL, LWL, average, UWL and UCL.

ERRORS THAT CANNOT BE DETECTED BY INTRA-LABORATORY AQC: The intra-laboratory AQC exercise focuses mainly on precision. A laboratory cannot detect many sources of its own bias. A good example to illustrate this is the total-hardness method. If the analytical balance in a laboratory always reads 10 per cent too much, all solutions prepared will have a 10 per cent higher concentration of the standard $CaCO_3$. This error can only be detected by analyzing a sample prepared by the laboratory with a correctly functioning balance. A laboratory without such bias will underestimate the concentration of such an inter-laboratory sample by 10 per cent. In some cases, a freshly introduced bias may be detected. For example, if the measurements consistently fall on one side of the previously calculated mean, it indicates a freshly introduced bias.

6.3.4. INTER-LABORATORY AQC

The objectives of an inter-laboratory AQC programme are:

1. To test for possible bias in measurements in a laboratory
2. To provide direct evidence of comparability of results among laboratories in a common programme to monitor water quality

Some related objectives and benefits are listed as follows:

- To assess the status of analytical facilities and capabilities of participating laboratories
- To identify the serious constraints (random and systematic) in the working environment of laboratories
- To provide necessary assistance to the concerned laboratories to overcome the shortcomings in the analytical capabilities
- To promote scientific and analytical competence of the concerned laboratories to the level of excellence for better output
- To enhance the internal and external quality control of the concerned laboratories

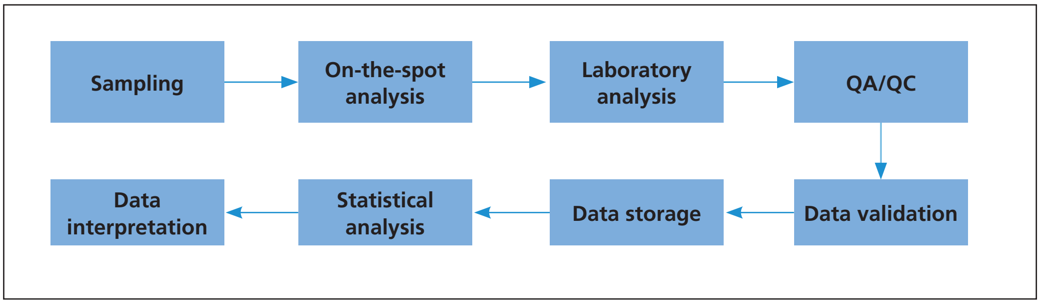
Inter-laboratory AQC should form a routine part of the monitoring programme. Such exercises will engender more confidence in results.

7. Data management

Data management has the following steps (see *Figure 8*):

- Data storage
- Data validation
- Statistical analysis
- Data interpretation

Figure 8: Data management flowchart



Source: CSE

7.1 DATA STORAGE

- A recommended format for recording data is given in pre-set formats in several softwares. It includes all parameters, except heavy metals and trace organics, which may be analyzed in the water-quality monitoring programme currently envisaged. Note that, ordinarily, a sample would not be analyzed for all the listed parameters in the environmental data bank (EDB).
- Record of analyses for heavy metals and trace organics, which would be performed on a limited number of samples, would be kept separately in a similar format.

7.2 DATA VALIDATION

Data validation employs the following steps:

- Absolute checking and data entry
- Checking if data is within the detection limits of a particular method
- Checking if the data is within the expected ranges for a parameter
- Checking if there are too many (or too few) significant digits reported
- Checking if data is physically or scientifically possible (general checks)
- Checking correlation of parameters (some conditional checks like BOD–COD relation, total coliform–faecal coliform relation)
- Checking the correlation between EC and TDS
- Checking cation–anion balance
- Total coliforms must be greater than faecal coliforms
- Total iron must be greater than dissolved iron
- Total phosphorus must be greater than dissolved (ortho-)phosphorus

7.3 DATA ANALYSIS AND PRESENTATION

It is often useful to subject data to simple statistical analysis. Analysis could, for example, be used to summarize the data, to transform it to aid understanding or compare it with a water-quality standard that is couched in statistical terms (annual mean, standard deviation, trend, seasonal changes or a percentile for certain parameters). The data can also be summarized in the form of an index. Statistical analyses such as parametric correlation, seasonal fluctuations and seasonal trends over a period of time are also common. After analysis, the data can be presented in different formats, for example, in a river, river profiles are commonly presented through:

1. Graphical representation
2. Time-series graphs
3. Histograms
4. Pie charts
5. Profile plots (river profiles)
6. Geographical plots (contours)

7.4 DATA INTERPRETATION

Data interpretation involves understanding water chemistry, biology and hydrology. Normally, data is analyzed and interpreted in terms of chemical quality, and quantity fluctuations and their possible effects on different uses and ecosystem. A comparison is made with predefined criteria or standards set for protection of different uses (like drinking, bathing and washing). Quality fluctuations are explained in view of possible sources of pollution, their fates in aquatic environment and their effects.

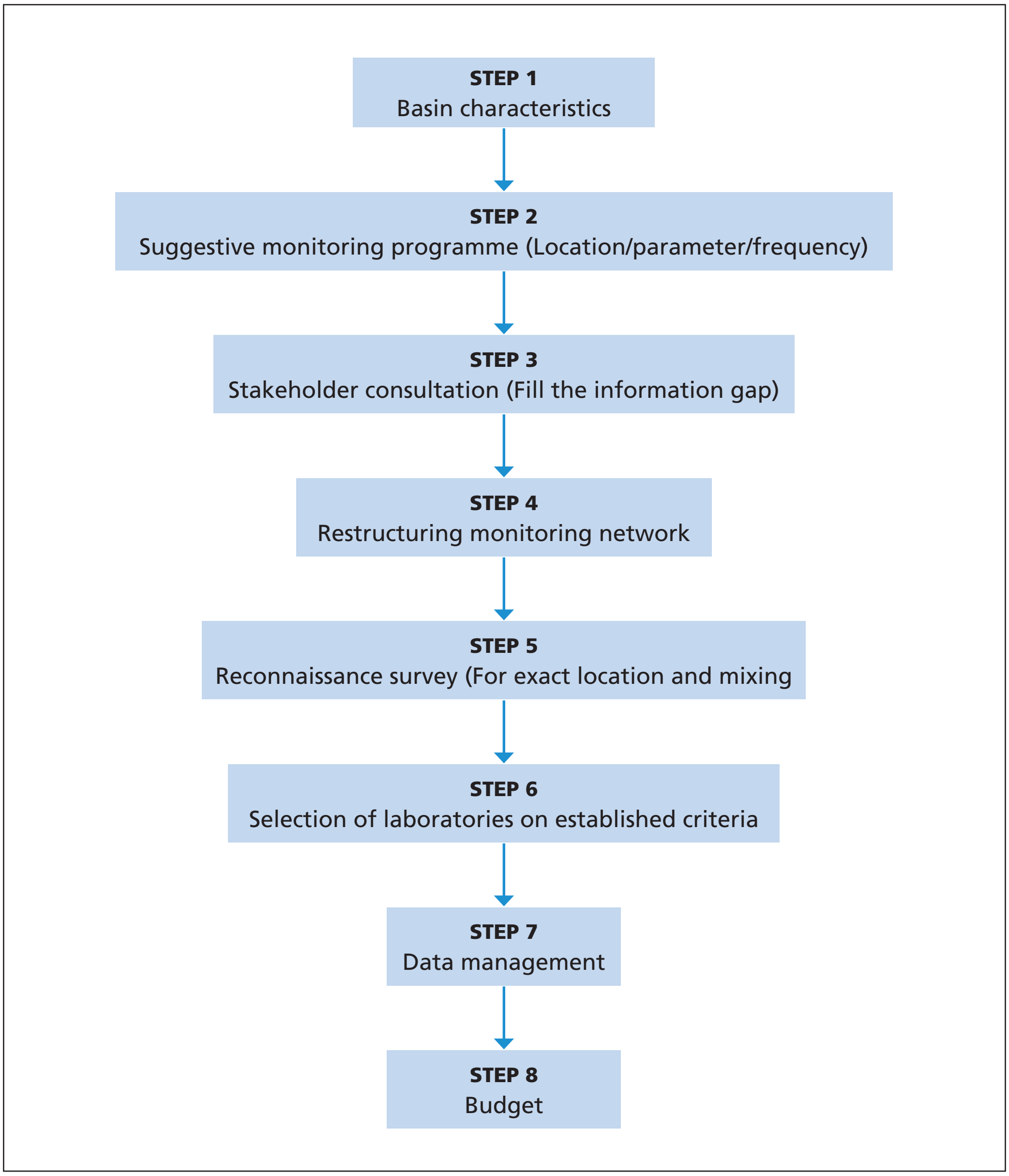
PART 2

Water Quality Monitoring Programme for Awash River Basin, Ethiopia

8. Steps for development of a water quality monitoring programme for Awash Basin

In order to develop an effective water quality monitoring programme, an understanding of the basin characteristics of a river is imperative. Basin characteristics include the important geographical, geological, hydrological and biological features of a definite catchment area. They also include the location, physiography, soils, climate, surfacewater and groundwater resources of the area under consideration, and the natural water quality. Basin characteristics not only influence water quality spatially but also temporarily. An examination of basin characteristic also addresses anthropogenic activities such as urbanization, industrialization, agriculture and livestock, and river flow regulation to support these activities. It leads to identification of the number and the location of monitoring sites, the parameters to be measured and the frequency of measuring the water quality of the water body. Since such an examination is multi-disciplinary, it needs multi-stakeholder consultations. The steps for development of water quality monitoring programme for Awash Basin includes understanding its basin characteristics, recommended monitoring programme as per learnings from Part A of this report, stakeholder consultation and reconnaissance (see *Figure 9*).

Figure 9: Steps for development of water quality monitoring programme for the Awash Basin



Source: CSE

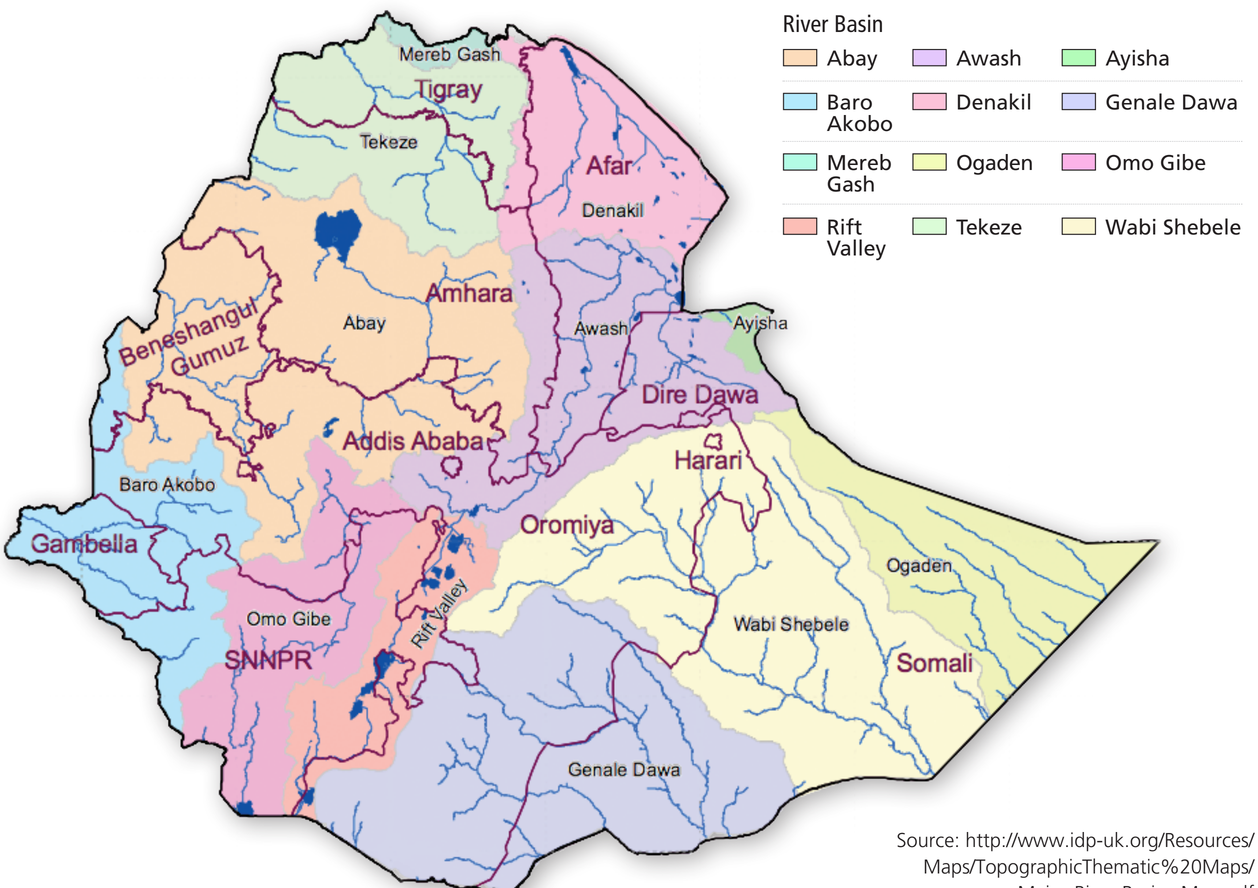
9. Understanding Awash Basin characteristics

9.1 RIVERINE SYSTEM IN ETHIOPIA

There are 12 major river basins in Ethiopia (see *Map 1*). With the exception of Awash Rift Valley Lakes and Omo-Ghibe, all the other rivers are transboundary and flow to the northwestern, western and southeastern areas of the country. The rivers are characterized by heavy sediment load and seasonality of water flows. For most rivers, 90 per cent of their annual run-off occurs from July to September. Consequently, development of water resources for irrigation and hydropower will be dependent mainly on large storage reservoirs. Most of the rivers are flowing in deeply incised gorges with waterfalls and cataracts and are not navigable except for the Baro-Akobo and some lakes.[6]

Wabi Shebelle (200,214 km^2), Genale Dawa (168,100 km^2), Abbay (199,812 km^2) and Awash River (112,000 km^2) basins are the four major river basins of the country, each of which caters to an area above 100,000 km^2 individually (see *Table 11*). The rest cover between 50,000 to 100,000 km^2 individually except for Aysha and Mereb Basin each of which covers an area of less than 5,000 km^2. The river basins can be divided into three cat-

Map 1: Major river basins in Ethiopia



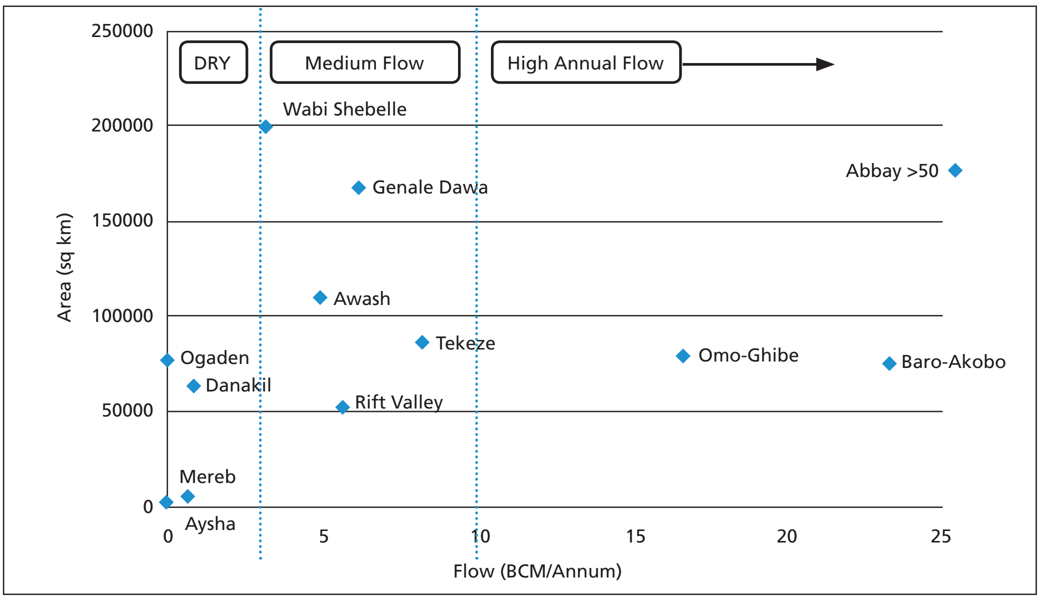
Source: http://www.idp-uk.org/Resources/Maps/TopographicThematic%20Maps/Major-River-Basins-Map.pdf

Table 11: Ethiopia's river basins

River basin	Area (km^2)	Annual flow (Billion cubic meter)
Abbay	199,812	52.62
Baro-akobo	76,000	23.24
Tekezee	86,510	8.20
Omo-ghibe	79,000	16.60
Rift valley	52,000	5.64
Awash	112,000	4.90
Wabi shebelle	200,214	3.16
Genale dawa	168,100	6.10
Ogaden	77,100	0
Danakil	64,380	0.86
Aysha	2,223	0
Mereb	5,893	0.65
Total	1,121,232	121.97

Source: The water of the Awash River Basin - A future challenge to Ethiopia (Girma Taddese, Kai Sonder & Don Peden)

Figure 10: Flow–area graph of river basins



Source: Centre for Science and Environment (CSE)

egories based upon the annual flow—high, medium and dry (see *Figure 10*). Abbay, Baro-Akobo and Omo-Ghibe basins can be classified as high-flow basins with an annual flow of more than 10 billion m^3. About 32 per cent of the total area covered by land basins in the country falls under these three basins. Five basins, namely Tekeze, Genale Dawa, Rift Valley, Awash, and Wabi Shebelle can be classified as medium-flow basins with an annual flow between 3–10 billion m^3. These five river basins, though being medium-flow, cater to an area that is more than 55 per cent out of the total 1,121,232 km^2 area covered by different water basins. Danakil, Mereb, Ogaden, and Aysha are dry basins with an annual flow of less than a billion m^3. These basins together cater to 149,596 km^2area, which 13 per cent of the total covered area.

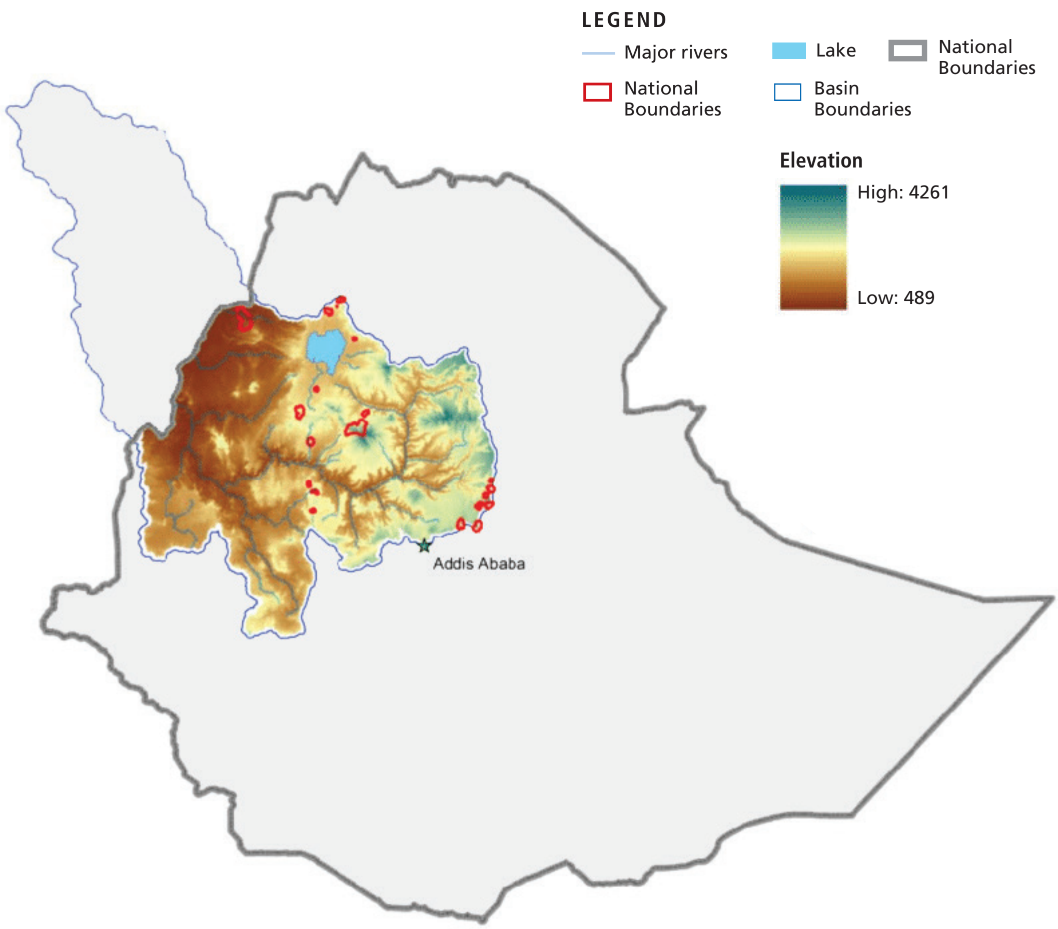
Abbay River basin is the most important river basin in terms of area and flow. It is pertinent to mention that Wabi Shebele is the major river with respect to area and Abbay River with respect to the highest flow. Awash River basin has a medium annual flow and caters to an area of more than 112,000 km^2. The northwest of Ethiopia is predominantly dry region.

9.2 BRIEF DESCRIPTION OF THE RIVER BASINS

9.2.1 ABBAY RIVER BASIN

Abbay River basin has a catchment area of 199,812 km^2, covering parts of Amhara, Oromia and Benishangul-Gumuz regional states. The major river in the basin is the Blue Nile (Abbay) River, which rises in Lake Tana and flows for about 1,450 km before merging with the White Nile to form the Nile Proper. The total mean annual flow from this river basin is estimated to be 54.8 billion m^3. Abbay is the most important river basin in Ethiopia. It accounts for 20 per cent of Ethiopia's land area; about 50 per cent of its total average annual runoff, which emanates from the Ethiopian highlands; and caters to 25 per cent of its population and over 40 per cent of its agricultural needs.

Map 2: Location of Abbay River basin, Ethiopia



Source: https://www.researchgate.net/figure/1-Upper-Blue-Nile-basin-also-called-Abbay-Basin-and-selected-ground-validation-sites_fig1_236682108

9.2.2 DENAKIL RIVER BASIN

Denakil River basin has an area of 74,002 km^2, and covers Tigray, Amhara and Afar regional states. The basin has no major river draining out of it. The basin also has the lowest elevation of -197 m at Denakil depression, the lowest altitude in the country, and the highest elevation of 3,962 m. The total mean annual flow from the river basins is estimated to be 0.86 billion m^3.

9.2.3 GENALE DAWA RIVER BASIN

Genale Dawa River basin has an area of 171,042 km^2, and covers parts of Oromia, SSNRP and Somali regions. It is the third largest river basin after Wabi Shebelle and Abbay River basins. The total mean annual flow from this river basin is estimated at about 5.8 billion m^3. The basin falls mainly in the arid and semi-arid zone of the country and is generally drought-prone with erratic rainfall.

9.2.4 WABI SHEBELE RIVER BASIN

Wabi Sheble River basin has an area of 202,697 km^2, covering parts of the regions of Oromia, Harari and Somali. The total mean annual flow from this river basin is estimated at about 3.16 billion m^3.

9.2.5 BARO AKOBO RIVER BASIN

Baro Akobo river basin has an area of 75,912 km^2, covering parts of the Benishangul-Gumz, Gambella, Oromia and SNNPR. The basin has a lowest elevation of 390 m and a highest elevation of 3,244 m. The total mean annual flow from this river basin is estimated to be 23.6 billion m^3. Twenty-two large-scale potential irrigation sites have been identified in this basin, with an estimated irrigable area of 1,019,523 hectares.

9.2.6 TEKEZE RIVER BASIN

Tekeze River basin has an area of 82,350 km^2, covering parts of the Amhara and Tigray regional states. There are two main tributaries (Angereb and Goang) that contribute to Tekeze River which rises in the central highlands of Ethiopia, and joins the Atbarah River, the lower course of which is a tributary of the Nile. This river basin has a lowest elevation of 536 m and a highest elevation of 4,517 m. The total mean annual flow from the river basins is estimated to be 8.2 billion m^3. The groundwater resources are not so promising except in a few areas. The quality of surfacewater is suitable for irrigation purposes.

9.2.7 OMO GHIBE RIVER BASIN

The Omo-Ghibe River basin has an area of 79,000 km^2, covering parts of the SNNPR and Oromia. The total mean annual flow from the river basin is estimated at about 16.6 billion m^3. Large-scale (57,900 hectare) and medium-scale (10,028 hectare) irrigation potential has been identified in the basin, with a total irrigable area of 67,928 hectares. The basin has the second highest hydropower potential, and most of the current hydropower development in Ethiopia is taking place in the basin. The basin is also endowed with a variety of wildlife; with Omo and Mago parks being located in the basin.

9.2.8 RIFT VALLEY BASIN

The Rift Valley basin has an area of 52,739 km^2, covering parts of the Oromia and SNNPR regions. The total mean annual flow from the river basins is estimated at about 5.6 billion m^3. Large-scale irrigation potential is estimated at 45,700 hectares with an estimated total irrigable area of 139,300 hectares. The basin is endowed with a number of lakes of varying sizes that are environmentally significant.

9.2.9 OTHER RIVER BASINS (MEREB, AYSHA AND OGADEN)

Aysha and Ogaden basins are considered relatively dry in most cases with seasonal river flows. Their potential in terms of irrigation development is considered less significant and, therefore, they are not included here. Mereb Basin is small in size, having a total mean annual flow of about 0.65 billion m^3.

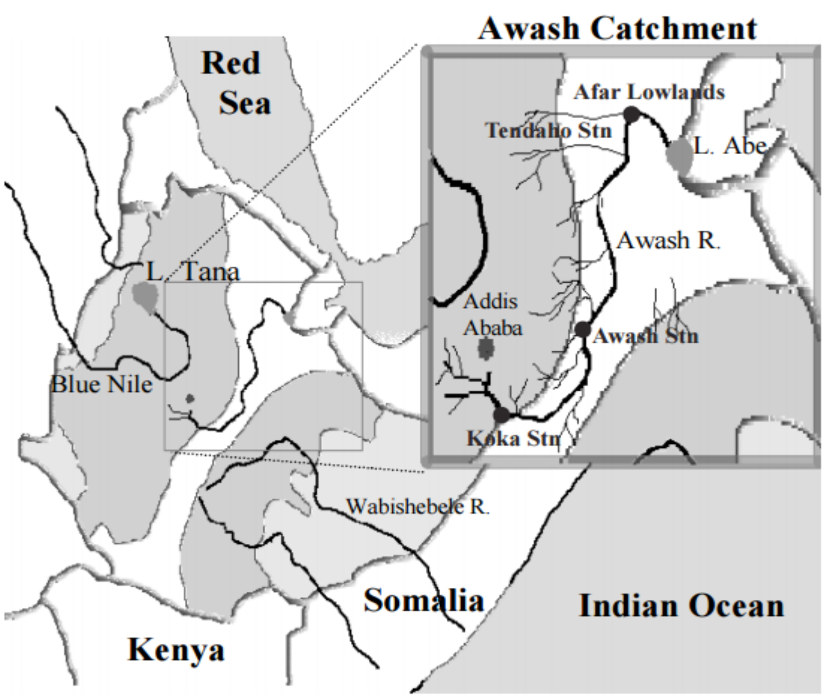
9.3 DESCRIPTION OF THE AWASH RIVER BASIN

Out of the twelve-river basins in Ethiopia, Awash basin is has a high utility value. It is relatively well-developed in terms of irrigation and hydroelectric plants, and it houses several towns, including the capital, Addis Ababa. In addition to this, several industrial enterprises lie within this basin. The basin covers a wide climatic zone from humid subtropical to arid and has a relatively long-running and dense meteorological and hydrological observation network.

Awash Basin covers parts of Afar, Amhara, Oromia, Somali Regional States, SNNP, Addis Ababa and Dire Dawa administrative councils. It is the fourth most populous basin in Ethiopia and ranks the third in terms of population density and fourth and seventh in terms of area and volume of water respectively. The overall population living within the Awash basin is estimated to be 14.9 million, with more than 65 per cent of this concentrated in the Upper Awash region. The Awash basin covers a total area of 112,000 km^2 and has an annual flow of 4.9 billion m^3.

The Awash River rises on the high plateau to the West of Addis Ababa, at an altitude of about 3,000 m and is fed by several major tributaries; including Kessem, Kebena, Awadi, Arso, Ataye, Borkena, Cheleka, Mile and Logiya rivers (see *Map 3*). After flowing to the southeast for about 250 km, the river enters the Great Rift Valley (see *Box: Rift Valley*) at an altitude of 1,500 m, and then follows through the valley for the rest of its course to Lake Abe on the border with the Djibouti Republic, which is at an altitude of about 250 m (see *Table 12*). The part of the catchment situated in the dry east of the river accounting for about 40 per cent of the total basin area does not contribute any significant surface runoff to the river. The total length of the Awash River is approximately 1,250 km.

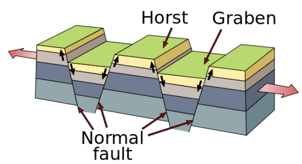
Map 3: Location of Awash River basin in Ethiopia



Box: Rift valley

A rift valley is a linear shaped lowland between several highlands or mountain regions created by the action of a geological rift or fault. A rift valley is formed on a divergent plate boundary, a crustal extension, a spreading apart of the surface, which is subsequently further dependent on the forces of erosion. When the tensional forces were strong enough to cause the plate to split apart, a center block dropped between the two blocks of its flanks, forming a graben (which, is a geology term, and refer to a depressed block of the earth's crust bordered by parallel faults). The drop of the center creates the nearly parallel steeply dipping walls of a rift valley when it is new. That feature is the beginning of the rift valley, but as the process continues, the valley widens until it becomes a large basin that fills with sediment from the rift walls and the surrounding area. One of the best known examples of this process in the East African rift.

(Above- The African Rift Valley)



(Above- Infrared enhanced satellite image of a graben in the Afar Triangle.)

Source: Awash Basin Authority, Ethiopia
https://www.int-res.com/articles/cr/12/c012p091.pdf

Table 12: Salient features of the Awash river basin

Place from where it originates in Ethiopia	Ginchi Town
Place where it terminates in Ethiopia	Lake Abbe
Regional states through which it flows	Oromiya, Afar, Amhara, Somali and SNNP
Administrative Councils through which it flows	Dire Dawa and Addis Ababa
Location	Rift Valley
Catchment area	112,000 km^2
Total length	1250 km
Annual flow	4.9 billion m^3
Average rainfall (mm)	557 mm
Serves as source of	Drinking water, hydropower, industrial consumption, irrigation, livestock watering, water for industry boilers and disposal of wastewater.
Dams on the Awash Basin	Koka (1960), Awash II (1966), Awash III (1971), Tendaho Irrigation Dam (2014) and Kassem Irrigation Dam (2015/16)
Hydropower plants	KOKA, AWASH II and AWASH III

Sources:
Ministry of Environment Forest and Climate Change (MEFCC), Ethiopia
Awash Basin Authority (AWAB)
https://en.wikipedia.org/wiki/Awash_River

9.4 PHYSIOGRAPHY AND CLIMATE

Based on physical and socio-economic factors, the Awash Basin can be divided into Upland (all lands above 1,500 m), Upper Valley, Middle (area between 1,500 m and 1000 m), Lower Valley (area between 1,000 m and 500 m) and Eastern Catchment (closed sub-basins are between 2,500 m and 1,000 m), and the Upper, Middle and Lower Valley are part of the Great Rift Valley systems. The lower Awash Valley comprises the deltaic alluvial plains in the Tendaho, Assaita, Dit Behri area and the terminal lakes area.

The climate of Awash River Basin varies from humid subtropical over central Ethiopia to arid over the Afar lowlands (see *Box: The Afar Triangle*). As mentioned earlier, Awash River basin also has a dense meteorological and hydrological observation network.

In general, plateaus over 2,500 m receive 1,400–1,800 mm of rainfall every year, mid-altitude regions (600–2,500 m) receive 1,000–1,400 mm per year, and lowlands get less than 200 mm per year. The rainfall distribution, especially in the highland areas, is bimodal, with a short rainy season in March and April and the main rains occurring from June to September. Some tributaries of Awash like Mojo, Akaki, Kassam, Kebene and Mile rivers carry water year round, while many lowland rivers only function during the rainy seasons.

Box: The Afar triangle

The Afar Triangle (also called the Afar Depression) is a geological depression caused by the Afar Triple Junction, which is part of the Great Rift Valley in East Africa. The Depression overlaps the borders of Eritrea, Djibouti and the entire Afar Region of Ethiopia, and it contains the lowest point in Africa, Lake Asal, at 155m (or 509 feet) below sea level.

The Awash River, flowing north-eastward through the southern part of the Afar region, provides a narrow green belt which enables life for the flora and fauna in the area and for the Afars, the nomadic people in the area.

There is no rain for most of the year. The yearly average rainfall ranges from 100 to 200 mm (4 to 7 inches). The climate varies from around 25°C (77 °F) during the very short rainy season (November–February) to 48°C (118°F) during the dry season (February–November).

Above: Perspective view of the Afar depression

Source: Awash Basin Authority, Ethiopia

In the lower valley, the mean annual evaporation loss potential is 2,348 mm, which is over ten times the average annual rainfall. This high evaporation loss increases the salinity in the river in the lower valley.

9.5 HYDROLOGY AND WATER AVAILABILITY IN THE AWASH BASIN

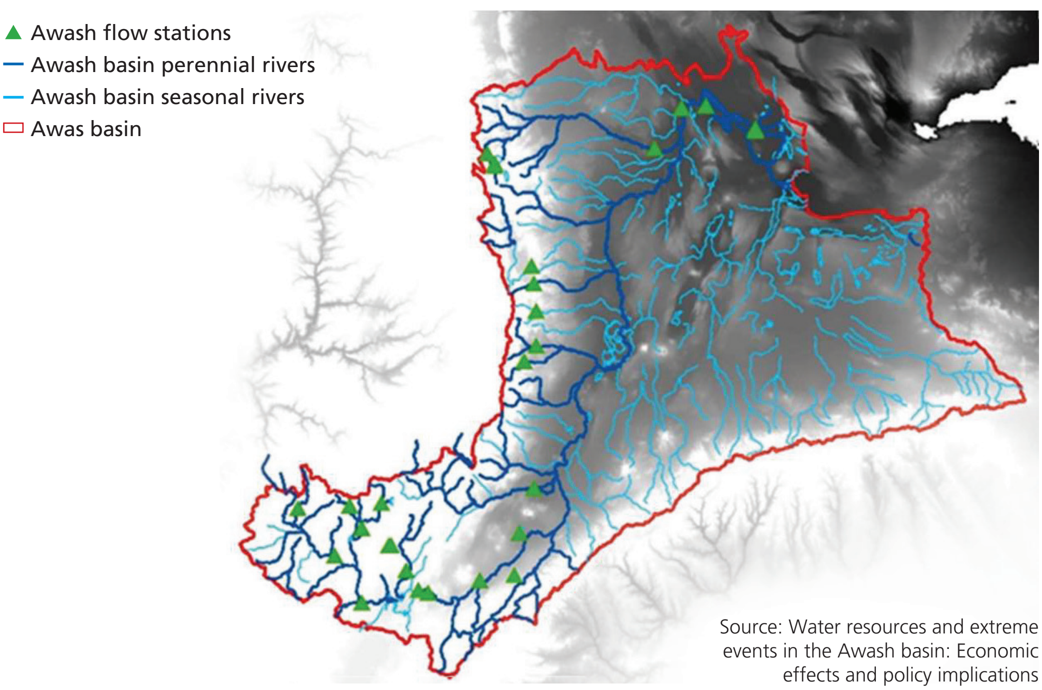
Awash River is fed by a large number of tributaries (see *Map 4*). Many of these tributaries are seasonal. It is interesting to note that most of the perennial rivers are on the west side of the Awash River while on the eastern part, most of the rivers are seasonal rivers. The basin covers a total land mass of 112,000 km^2 (of which about 64,000 km^2 is categorized as western basin and contributes almost the entire surface flow of the basin, and 46,000 km^2 area comes under the eastern part which does not contribute any surface flow to the Awash River) (see *Table 13*). A close examination of *Map 4* shows that there is a good network of hydrological stations for flow measurement.

Table 13: Vital population statistics of the Awash River basin

NAME OF REGION OR CITY ADMINISTRATION	PARTS OF THE REGION		POPULATION DENSITY			AREA KM^2
	Zone	Woreda	Male	Female	Total	
Oromiya Region	9	71	4,780,719	4,644,452	9,425,171	25,296
Amhara Region	5	35	1,843,515	1,836,529	3,680,044	14,573
Afar Region	4	20	550,495	444,759	995,254	28,104
Somalia Region	2	7	501,953	420,634	922,587	43,324
SNNP Region	1	1	78,087	78,561	156,648	93
Addis Ababa City Adm.	1	10	1,449,002	1,592,000	3,041,002	523
Dire Dawa City Adm.	1	1	194,000	193,000	387,000	1,554
Total	**23**	**145**	**9,397,771**	**9,209,935**	**18,607,708**	**113,467**

Source – AWBA Basin Master Plan Study Project Report and CSA 2009 Projection

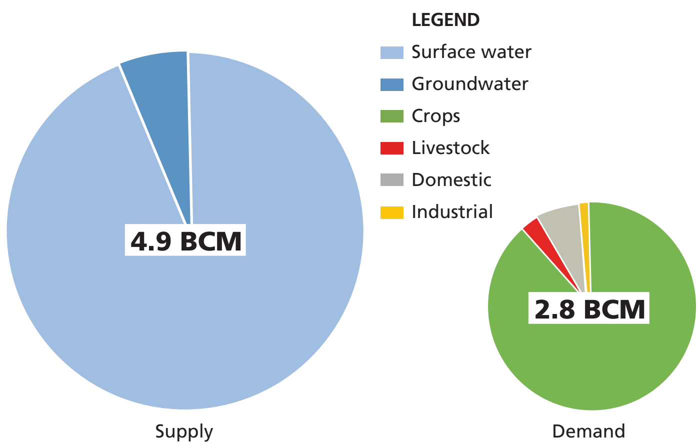
Map 4: Awash River and its tributaries



Source: Water resources and extreme events in the Awash basin: Economic effects and policy implications

Water resources in Awash basin are quite abundant. A total of 4.9 billion m^3 of water are available for use in a typical year, substantially more than consumptive extraction, which in 2013 was estimated at 2.8 billion m^3 as depicted in *Figure 11*. Renewable water supply mostly comprises surface water runoff, while irrigated crops account for 90 per cent of the demand.

Figure 11: Estimated consumptive water supply and demand by source and sector, 2014



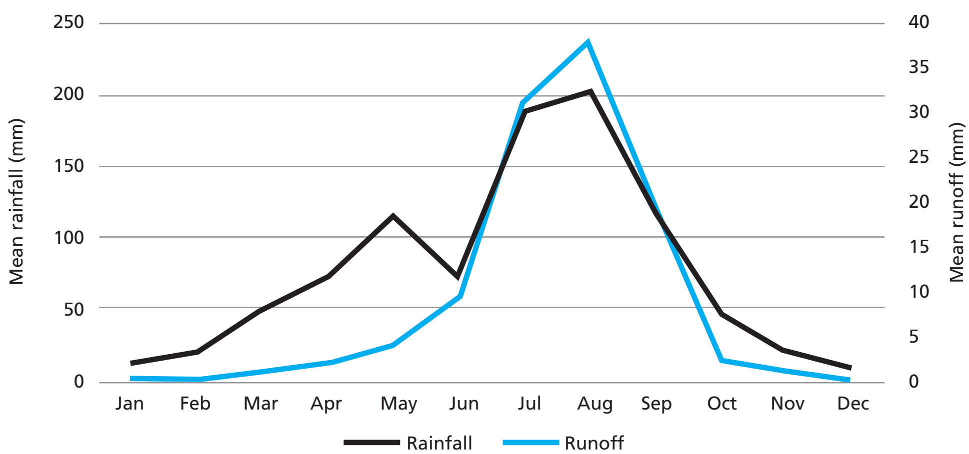
Source: Water resources and extreme events in the Awash basin: Economic effects and policy implications

9.5.1 SEASONAL AND GEOGRAPHIC DISTRIBUTION OF WATER

On an average, the peak rainfall occurring across the basin during August is greater than the rainfall in December by a factor of more than ten, which also translates into a heavy runoff during the month of August. With limited infrastructure installed along the river to smooth out this natural variation in water availability, dry season flows in the Awash River falls to an average of 28 per cent of their levels during rainy seasons (see *Figure 12*). The average rainfall in the basin from May to mid-September is 100 mm or above.

The hydrological character of Awash basin is significantly seasonal, and depends on the geographic and inter-annual variation in water availability. *Map 5* shows the inter-annual pattern of rainfall and runoff in the Awash basin.

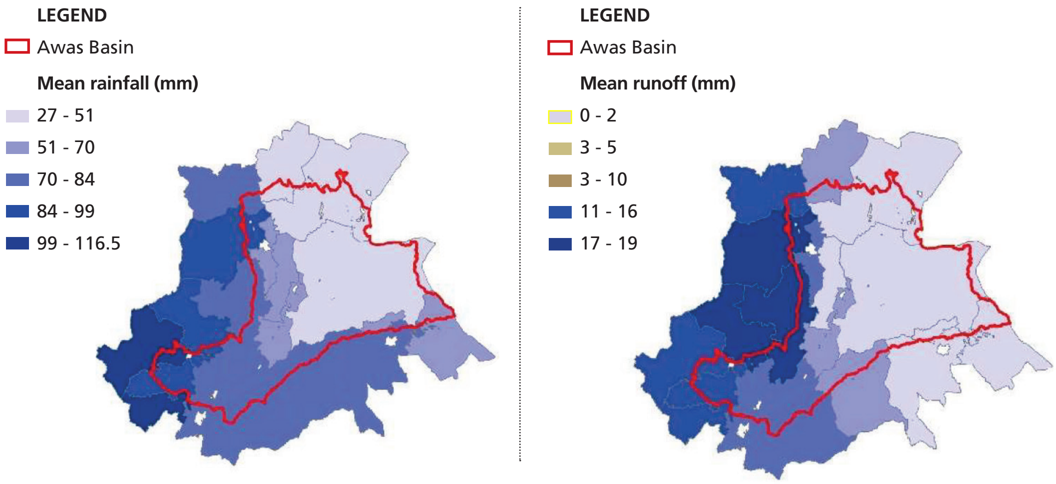
Figure 12: Mean rainfall and runoff



Source: Water resources and extreme events in the Awash basin: Economic effects and policy implications

The distribution of water availability is geographically uneven through the length of the basin (see *Figure 13*). It is indicated that downstream zones in the basin are much more arid than upstream zones, since in the lower Awash region rainfall is very meagre.

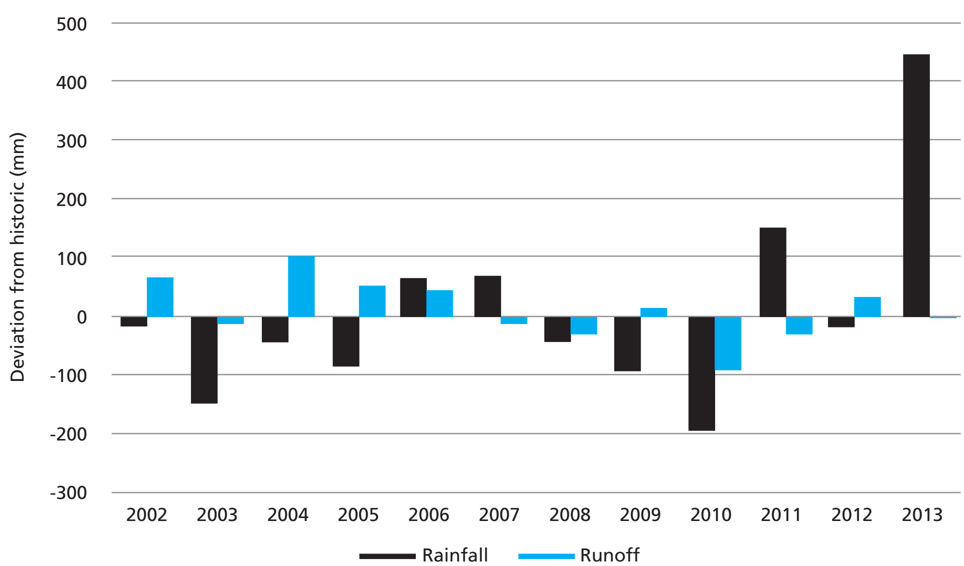
Map 5: Geographical distribution of rainfall and runoff



Source: Water resources and extreme events in the Awash basin: Economic effects and policy implications

There is uncertainty in the total annual water availability. As *Figure 13* shows, the maximum annual rainfall in the basin is almost double its minimum level over a ten year period. The mean runoff in the basin also shows a similar degree of variability. Uncertain rainfall in the basin region creates situations of flood and drought. The main reason for the transportation of heavy sediment load from the upper Awash regions can be attributed to flash floods.

Figure 13: Inter-annual variability of basin rainfall and runoff



Source: Water resources and extreme events in the Awash basin: Economic effects and policy implications

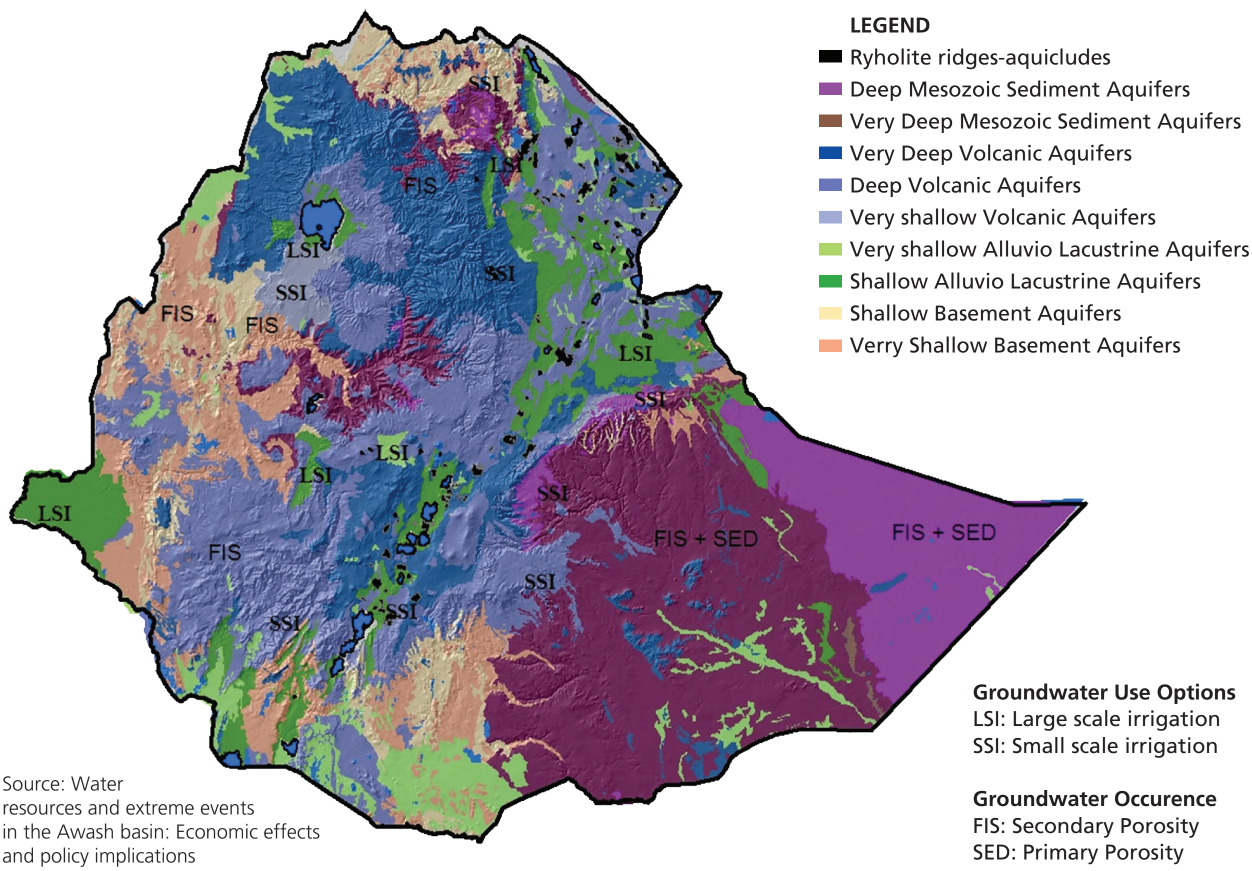
Major hydrological constraints to utilizing the abundant water resources are:

- Water scarcity at particular points in time and space due to seasonal and geographic patterns in water availability
- Introduction of uncertainty and risk throughout the basin due to doubts over water availability
- The basin faces a risk of extremes—events of flooding and drought during different months of the year. In the month of August, when there are heavy rains, it creates a flood-like situation due to heavy runoff. On the contrary, in the month of December, when the rainfall is really low, a drought-like situation is created.
- The impacts of agricultural and industrial development, which have notably contributed towards pollution and sedimentation, as well as reduction in water availability, thereby amplifying the region's vulnerability to extreme hydrological events. In addition to that, the growing population in urban areas has increased the demand for water and adversely affected the water availability in towns.

9.6 GROUNDWATER

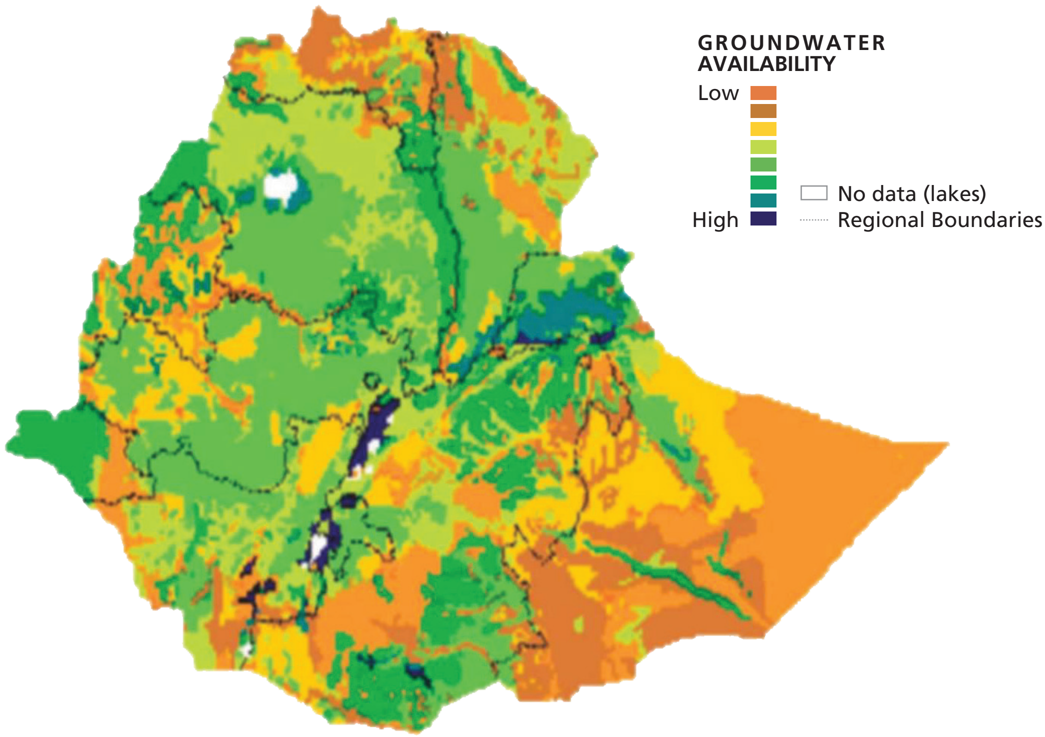
The total renewable groundwater exploitation is known only approximately while local groundwater availability, which depends on underground aquifer morphology, is poorly understood. *Map 6* illustrates what is broadly known about aquifer types. In the aquifers in Awash basin, it is observed that in the northwestern part, very deep volcanic aquifers exist. Where deep volcanic aquifers are present, small-scale irrigation is conducted. On the contrary, large-scale irrigation is carried out in places where shallow aquifers are present, and since considerable quantum of groundwater is utilized for irrigation in these parts, these irrigation activities generate return water to the basin with high TDS content.

Map 6: Ethiopia's aquifers



Source: Water resources and extreme events in the Awash basin: Economic effects and policy implications

Map 7: Ethiopia's estimated groundwater availability



Source: Water resources and extreme events in the Awash basin: Economic effects and policy implications

There are four expanding urban-industrial centres taking water from the Awash River, accelerating groundwater withdrawals. The city of Addis Ababa relies on two tributaries (Tilku Akaki and Tinish Akaki) of the Awash River for nearly 50 per cent of its water supply. Other major towns that extract water from Awash for domestic water supply are Adama, with a population of over 300,000; Awash, with a population 20,000; and Metahara, which has a population of around 10,000. Large water-intensive industries (including floriculture, horticulture and manufacturing) are abstracting water directly from the Awash River and its tributaries, or from the groundwater that is ultimately connected to the flow of the Awash. This raises concerns about pollution, for example, in the Akaki River. *Map 7* shows estimates of associated groundwater availability.

9.7 SOIL CHARACTERISTICS

Generally, three parameters determine soil characteristics, i.e. bulk density, soil available water capacity (AWC) and hydraulic conductivity. Bulk density is the weight of soil in a given volume, and soils with a bulk density higher than 1.6 gm/cm^3 tend to restrict root growth. Bulk density increases with compaction and tends to increase with depth. Sandy soils are more prone to high bulk density. (see *Table 14*)

Table 14: General relationship of soil bulk density to root growth

Soil texture	Ideal bulk densities for plant growth (gm/cm^3)	Bulk densities that restrict soil growth (gm/cm^3)
Sandy	>1.60	>1.80
Silty	<1.40	>1.65
Clayey	<1.00	>1.40

Source: Bulk Density-Soil Quality Indicators, USDA Natural Resources Conservation Service

Available water capacity or average water content (AWC) can be defined as the range of available water that can be stored in soil and be available for growing crops. Organic matter increases the available water capacity. Each per cent of organic matter adds about 1.5 per cent to the available water capacity. Bulk density plays a role through its control of pore space that retains available water. High bulk densities for a given soil tend to lower the available water capacity. So, there is a distinct relationship between soil texture and AWC, assuming intermediate bulk density and no rock fragments. The water holding characteristics of a soil also helps in reducing the chances of flash floods during heavy rains (see *Table 15*).

Table 15: Soil texture and its water holding capacity

TEXTURE CLASS	FRACTION AVAILABLE WATER (Per cent moisture)
Sand	7
Sandy loam	12
Loam	20
Silt loam	21
Clay loam	15
Silty clay	13
Clay	12

Source: Soil and Soil Water Relationships, Zachary M. Easton, Assistant Professor and Extension Specialist, Biological Systems Engineering, Virginia Tech

The third component is hydraulic conductivity and is represented as a property of vascular plants soils and rocks that describes the ease with which a fluid (usually water) can move through pore spaces or fractures.

Table 16: Soil texture classes and related saturated hydraulic conductivity classes

Texture	K stat class	K stat rate (µm/sec)
Coarse sand	Very rapid	>141.14
Sandy	Rapid	42.34-141.14
Sandy loam	Moderate rapid	14.11-42.34
Very fine sandy loam	Moderate	4.23-14.11
Clay loam	Moderate slow	1.41-4.23
Sandy clay	Slow	0.42-1.41
Clay	Very slow	0.00-0.42

Source: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/office/ssr10/tr/?cid=nrcs144p2_074846

Table 16 depicts that hydraulic conductivity of soils with sandy texture is rapid and it is slow in soils with clayey texture. Thus, AWC of the soil and its hydraulic conductivity are inversely proportional. Within this backdrop, soil characteristics of Awash Basin are summarized in *Table 17*.

Table 17: Physical characteristic of soil in the basin

Soil name	Hydraulic conductivity (mm/h)	Textural composition (per cent)			Soil BD (g/cc)	Soil AWC (cm/cm)	Area (sq km)	Watershed area (per cent)
		Sand	Silt	Clay				
Eutric C.	18	22	44	34	0.18	1.44	2792.9	4.41
Leptosols	0	40	10	50	0.12	1.34	304.0	0.12
Orthic S	38	30	45	25	0.11	1.45	3802.9	6.00
Haplic X.	20	44	41	15	0.15	1.43	1184.4	1.87
Calcaric F.	15	40	40	20	0.15	1.43	5480.7	8.65
Dystric N.	2	38	32	30	0.21	1.39	8280.4	13.00
Eutric R.	110	47	45	8	0.10	1.51	526.6	0.83
Vertic C.	6	55	30	15	0.11	1.47	14,704.5	23.2
Chromic L.	2	32	24	44	0.11	1.5	4.9	0.01
Eutric F.	29	70	13	17	0.08	1.5	65.3	0.10
Cambic A.	117	78	7	15	0.04	1.42	2660.5	4.20
Pellic. V	1	62	12	24	0.24	1.39	4878.6	7.70
Gypsic Y.	750	12	16	64	0.07	1.41	45.6	0.07
Eutric N.	72	22	14	64	0.08	1.45	381.6	0.6
Mollic A.	91	65	26	9	0.15	1.43	13,335.3	20.36
Luvic P.	307	34	55	11	0.15	1.31	231.5	0.37
Haplic C.	15	34	57	9	0.20	1.39	5320.3	8.39

Source: Assessment of water scarcity and its impacts on sustainable development in Awash basin, Ethiopia (Dereje Adeba, M. L. Kansal, Sumit Sen)

It is understood from the table that places where hydraulic conductivity is very low due to high clay, become suitable for growing cotton. In other places, where clay loam and sandy loam are present, the soil becomes conducive for growing cereals and sugarcane. There are also places where farming is not possible due to high hydraulic conductivity and sandy soil is dominant. Therefore, these places are good for pasture with range grasses.

9.8 LAND USE

Land use in Awash Basin comprises of agriculture, forestry, water bodies, residential areas, pasture and reserve land. Area- and percentage-wise land use patterns are given in *Table 18*.

Table 18: Land use in Awash Basin

Land use category	Area (km^2)	Watershed area
Agricultural land	33,059	51.65
Meadows brome grass	19,087	29.82
Range bush	5,190	8.11
Forest (mixed)	4,884	7.63
Water body	500	0.75
Residential	1,280	2

Source: Assessment of water scarcity and its impacts on sustainable development in Awash basin, Ethiopia (Dereje Adeba, M. L. Kansal, Sumit Sen)

Box: Important land use practices in Ethiopia

Meadows brome grass

Meadows brome grass is a hardy, long-lived, high-yielding, cool season perennial grass. It is an ideal pasture grass because of its high yields, rapid regrowth after grazing and excellent season-long forage quality. It has fibrous roots and short rhizomes which spread slowly.

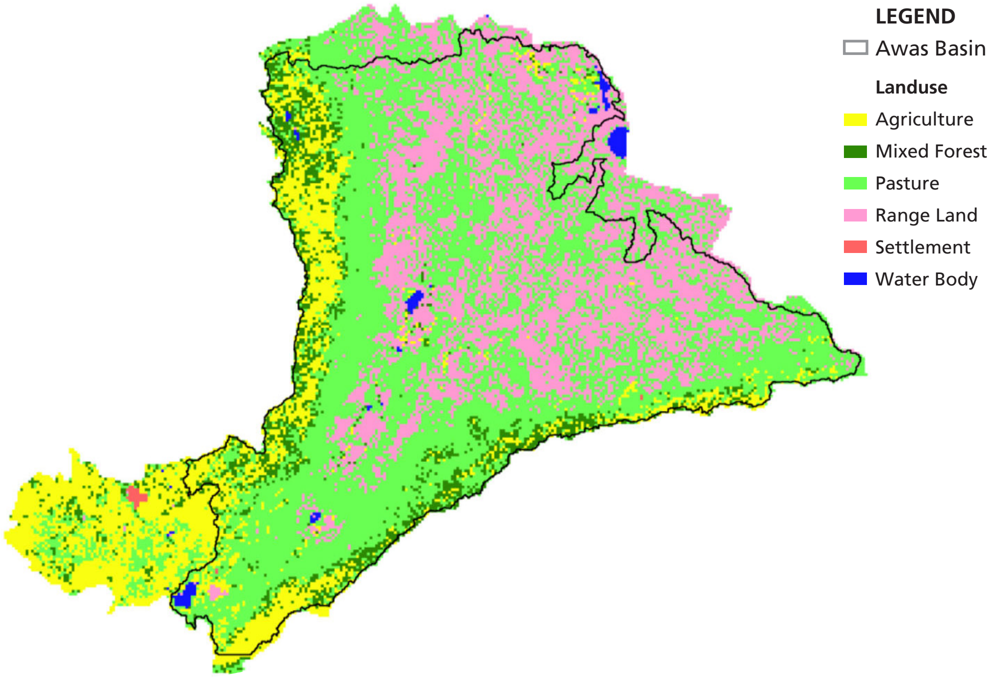
Range bush

Production of range grasses under irrigation has been widely adopted in the arid environments as a strategy to meet the seasonal forage supply gap. This information is needed for making sustainable management of irrigation water and also increased pasture productivity at the current intensification of the production systems.

Source: https://in.pinterest.com/pin/308778118173422935/

Land use patterns in the Awash Basin are given in *Map 8*. From the land use pattern information, it can be understood that agricultural land and pasture land are more dominant throughout the Awash basin.

Map 8: Land use map of the Awash Basin



Source: Assessment of water scarcity and its impacts on sustainable development in Awash basin, Ethiopia

9.9 DEMOGRAPHY

Ethiopia has nine regions and two city administrative areas. This, along with the population density, is summarized in *Table 19*. Area-wise, Oromia, Amhara and Southern Nations Nationalities and People (SNNPR) are the bigger regions, while Afar and Somali are placed in the moderate category. City administrations like Addis Ababa and Dire Dawa have smaller areas.

However, demographic distribution shows that city administration regions like Addis Ababa and Dire Dawa have high population density; regions like SNNPR, Amhara and Oromia have moderate population density, and regions like Afar and Somali have low population density.

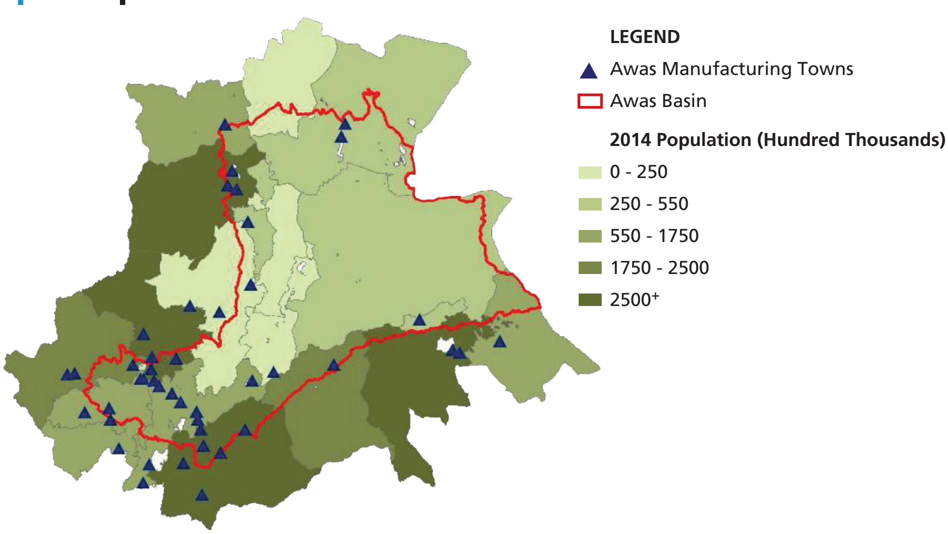
Table 19: Region-wise demography of Ethiopia

REGION	CAPITAL CITY	STATUS	AREA (KM^2)	POPULATION	POPULATION DENSITY (PERSON/ KM^2)
Addis Ababa	Addis Ababa	City	526.99	3,273,000	5198.49
Afar	Semmera	State	72,052.78	3,787,908[7]	19.58
Amhara	Bahir Dar	State	154,708.96	28,401,000	111.28
Dire Dawa	Dire Dawa	City	1,558.61	440,000	219.32
Oromia	Addis Ababa	State	284,537.84	39,692,000	95.45
Somali	Jijiga	State	279,252	6,518,000	15.90
Southern Nations Nationalities and People (SNNPR)	Awasa	State	105,476	18,276,000	142.06

Source: https://en.wikipedia.org/wiki/Regions_of_Ethiopia#cite_note-5

It is interesting to note that Awash River Basin comprises of regions that have higher population density such as Addis Ababa, Dire Dawa, SNNPR and Amhara as well as regions with low population density like Somali and Afar. This is depicted in *Map 9* (population and urban centre), which indicates that the downstream arid regions (Afar and Somali) have less population, with the exception of Dire Dawa, and more urbanization has taken place in Oromia, Addis Ababa, Amhara and SNNPR.

Map 9: Population and urban centres



Source: Water resources and extreme events in the Awash basin: Economic effects and policy implications

9.10 IRRIGATION

In 2002, the total area under irrigation was 197,000 hectares with coverage distribution of the nature of 38 per cent traditional, 20 per cent modern communal, 4 per cent modern private and 38 per cent schemes-related. The revised figure of the more recent years puts the total irrigated land area at about 250,000 hectares. This number gives a per capita irrigated area of about 30m^2, quite low compared to the global average of 450 m^2. There is also a revised targeted area of 45 m^2 per capita.

It is indicated from the integrated river basin master plan studies 1997–2007 (Ministry of Water Resources), that although 10 per cent of the cumulative area under basins in Ethiopia falls under the Awash Basin, the irrigation potential along with the surface runoff is low.

Table 20: Irrigation potential of the Awash Basin

	Area	Runoff (BCM)	Potential irrigated land (hectares)	Estimated ground water potential (BCM)
Total	1,135,494	124.25	3,798,782	2.36
Awash basin	112,696	4.9	83,368	0.20
Percentage	9.92	3.94	2.19	8.47

Source: Water Resources and Irrigation Development in Ethiopia, Working Paper 123

In this river basin, there are 37 potentially irrigable areas out of which five are small-scale, 18 are medium-scale and 14 are large-scale. Area-wise irrigation potential is estimated to be around 134,121 hectares, out of which, 30,556 hectares are for small-scale development, 24,500 hectares for medium-scale development, and 79,056 hectares for large-scale development.

There are five dams on the Awash River—Koka (1960), Awash II (1966), Awash III (1971) and Tendaho Irrigation Dam (2014) and Kassem Irrigation Dam (2015/16).

9.11 AGRICULTURE AND LIVESTOCK

9.11.1 AGRICULTURE

Agriculture is considered the base of Ethiopia's economy, contributing about 50 per cent to the country's GDP. Apart from this, it also contributes 85 per cent of the exports, and over 80 per cent of total employment of the labour force. Most of the country's large-scale irrigation schemes have been developed on the Awash River Basin. Thus, from the agricultural point of view, water quality in Awash River basin is of considerable significance.

In Ethiopia, agriculture and livestock development is generally governed by climate, soil characteristic, and land use patterns. Climactic elements such as precipitation, temperature, humidity, sunshine, and winds are affected by factors such as geographic location, altitude, precipitation and temperature. Factors like altitude and soil characteristics lead towards land suitability, and these factors in aggregate are responsible for the evolution of agro-climatic zone(s).

Traditionally, there are five agro-ecological zones (AEZS) in Ethiopia based on altitude and temperature—Bareha, Koba, Wendenga, Dega and Wurch. However, rainfall and its distribution are also important in classifying common agro-ecological zones. This is summarized in *Table 21*. All in all, the country has 18 major agro-ecological zones today.

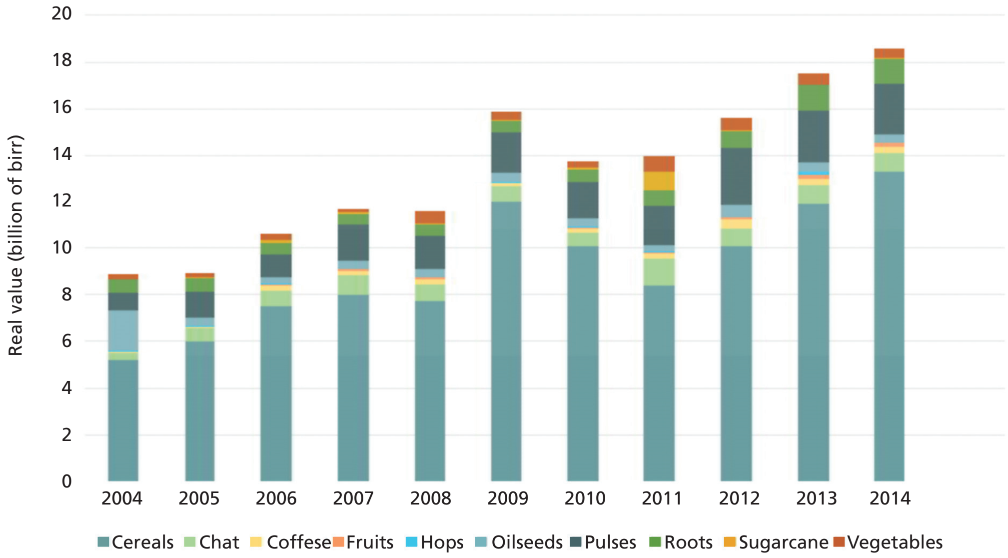
Table 21: General features of the agro-ecological zones

Traditional Zone	Altitude (m)	Rainfall (mm)	Soil type	Natural vegetation	Main plant vpecies	Crops	Livestock
High wurch (alpine)	> 3,700	> 1,400	Black, little disturbed	Afroalpine steppe meadow	Mountain grassland (Artemisia, Helichrysm, Lobelia)	None, Frost Limit	Sheep and cattle
Wet wurch (Sub-alpine)	3,700-3,200	> 1,400	Black, highly degraded	Subalpine	Erica, Hypericum	Barley (2 Crops/ Year)	Sheep and cattle donkeys
Moist wurch (sub-alpine)	3,700-3,200	1,400-900	Black, degraded	Subalpine	Erica, Hypericum	Barley (1 Crop/ Year)	Sheet, goats, cattle, poultry horses and bees
Wet dega (highland)	3,200-2,300	>1,400	Dark brown clay	Afromontane forest bamboo	Juniperus, Hagenia, Podocarpus, Arundinaria	Barley, Wheat, Neug, Pulses (2 Crops/Year)	Sheep, cattle, goats, horses, bees and poultry
Wet woyna dega (mid-altitude)	2,300-1,500	> 1,400	Widespread drainage		Acacia, Cordia, Ficus, Arundinaria	Tef, Maize, Enset (In West) Neug, Barley	Cattle, goats, sheep, horses, mules, donkeys, bees and poultry
Moist woyna dega (mid-altitude)	2,300-1,500	1,400-900	Red brown drainage		Acacia, Cordia, Ficus	Maize, Sorghum, Tef, Enset, (Rare) Wheat, Neug, Finger, Millet, Barley	Cattle, goats, sheep, horses, mules, donkeys, bees and poultry
Dry woyna dega (mid-altitude)	2,300-1,500	<900	Light brown to yellow	Savanna	Acacia	Wheat, Tef, Maize (Rare)	Cattle, goats, donkeys and bees
Wet kola (lowland)	1,500-500	>1,400	Red clay, oxidised		Millettia, Cyathea, Albizia	Mango, Taro, Sugar, Maize, Coffee, Orange	Cattle, goats, donkeys and bees
Moist kola (lowland)	1,500-500	1,400-900	Yellow silt		Acacia, Erythrina, Cordia, Ficus	Sorghum, Teff(Rare), Neug, Finger, Millet, Groundnuts	Cattle, goats, bees, donkeys and poultry
Dry kola (lowland)	1,500-500	<900	Yellow sand		Acacia spp.	Sorghum (Rare), Teff	Goats, cattle, camels, sheep, donkeys and poultry
Bereha (lowland deserts) Note: In the earlier table this unit is over 500 m!	<500	<900	Yellow sand	Acacia-Commiphora bush land	Acacia, Commiphora	Only With Irrigation	Camels and goats

Source: MoA /National Livestock Development Programme, 1998, Ethiopia, Working Paper 4 - National Resources and the Environment

The value of crop output was 18.6 billion Birr in 2014, and was led by cereals (13.3 billion), pulses (2.2 billion Birr) and roots (1.1 billion) respectively. It is to be noted that between 2004 and 2014, there has been a steady growth in the crop output from 9 billion Birr to 18 billion Birr (almost double). However, in 2010, the value of the crop output fell to a little less than 14 billion Birr but then the following year (2011), the value of the crop output again started an upward trend (see *Figure 14*).

Figure 14: Real value of crop output in the Awash Basin

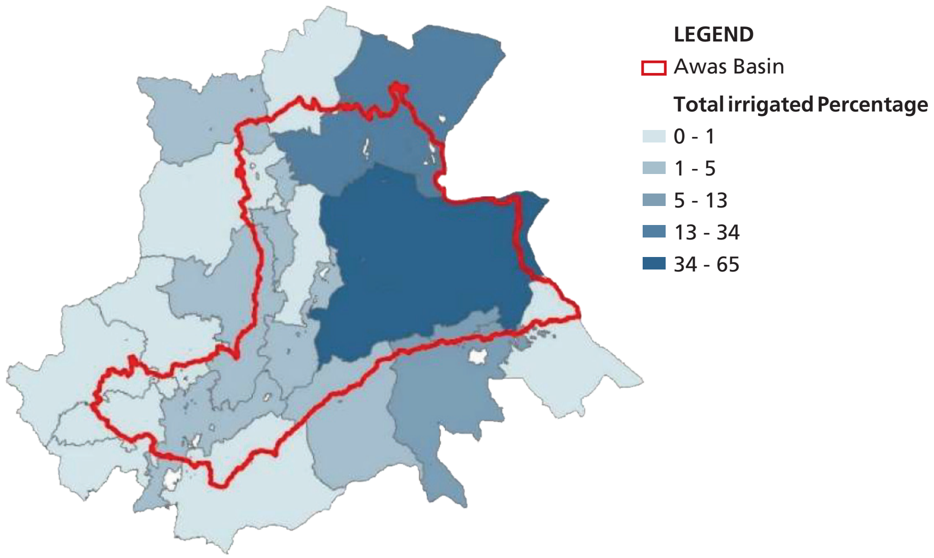


Source: Water resources and extreme events in the Awash basin: Economic effects and policy implications

The real value of crop output has grown very strongly at an annualized rate of 7.9 per cent from 2004 to 2014. The growth can be explained by a number of factors listed below:

- The area of the irrigated land has increased rapidly at a rate of 4.4 per cent per annum over the stated period (2004–14). However, total irrigated area of the basin remains less than 2 per cent of the total land under cultivation and is concentrated in the less productive lowlands (see *Map 10*).
- Changes to the production technologies, including greater and more effective use of fertilizers.
- The structure of production and investment in the sector. Commercial scale farming has grown to 5 per cent of output by value, with a greater role of state-owned enterprises.
- Stable and reliable rains over the last decades are encouraging.

Map 10: Percentage of cultivated land irrigated, 2012



Source: Water resources and extreme events in the Awash basin: Economic effects and policy implications

9.11.2 LIVESTOCK

It has been observed from land use patterns that pastoral land comprising meadow brome grass and range bush constitutes 37.93 per cent of the land, next only to agricultural land (51.65 per cent). It was also observed that livestock rearing takes place throughout the traditional agro-climatic zones. However, cattle variation is observed with changes in altitude and rainfall. For example, in the alpine zone, only sheep and cattle are the livestock; however, in the sub-alpine regions, donkeys, goat, and horses are added to sheep and cattle. In the mid-altitude zone, poultry and bee cultivation is carried out. This scenario is repeated in lowlands that are moist, wet and Kola). But in lowland desert region (Boreha) camels and goats are reared. Water requirement for livestock rearing is summarized in *Table 22*.

Table 22: Livestock population in the Basin

Type of animal in the basin	Livestock population (million)	Average water requirement (l/day/ head)	Water requirement (BCM/year)
Cattle	5.42	54	0.10683
Sheep or goat	10	7.14	0.02606
Equine	0.65	45.6	0.01082
Camel	0.90	55	0.01807
Poultry	1.89	450 l/1,000 birds/day	0.0031
Total			0.165

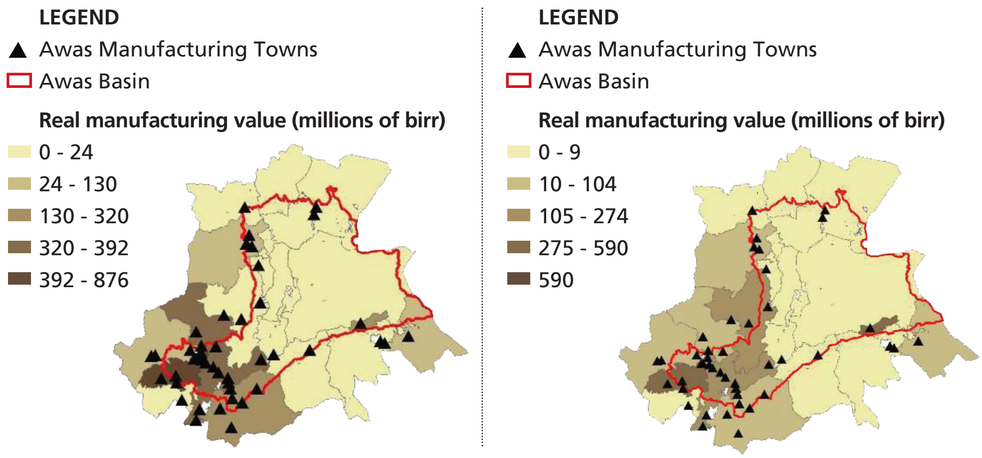
Source: Replacing Pastoralism with Irrigated Agriculture in the Awash Valley, North-Eastern Ethiopia: Counting the Costs

It can be inferred from the table that large animals like cattle, equine, camels, etc. require 45–55 litres per day per head. But a poultry unit with 1,000 birds needs only 450 litres per year. It is pertinent to mention that pastoralists and agro-pastoralist are more dominant in lowland regions, where livestock holdings are the primary source of wealth and a major component of income. However, these regions are more vulnerable to water scarcity than other parts of basin, which affects the total and per capita value of livestock in these regions.

9.12 MANUFACTURING AND INDUSTRIAL WATER REQUIREMENT IN THE AWASH BASIN

The geographical distribution of manufacturing in the basin is shown in *Map 11*, with the total and per capita value of output being greatest around the main urban centers of Addis Ababa and Adama in southwest and Dire Dawa in the east. Industries that produce metals, papers, pharmaceuticals, chemicals, liquor, textiles and others use water. It is difficult to estimate the water requirement of industries since they use water from groundwater source that they extract from within their premises instead of obtaining it through the municipality. However, an estimate is made in and around Addis Ababa and has been taken at 8 per cent of the total domestic water supply in the city. This is approximately 16,800 m^3 per day and 0.00613 BCM per year in and around Addis Ababa. For industries outside Addis Ababa but located in the basin, it is assumed that their water requirement is about 0.001 per cent of the basin yield, which is equivalent to 0.00464 BCM. Therefore, the total industrial water requirement in the basin is estimated at 0.01083 BCM.

Map 11: Distribution of manufacturing output by zone, 2012



Source: Water resources and extreme events in the Awash basin: Economic effects and policy implications

9.13 URBANIZATION: WATER DEMAND AND WASTEWATER GENERATION IN AWASH

There are three major cities in Awash basin—Addis Ababa, Adama (Nazareth) and Dire Dawa. Population, area and population density of these cities are summarized in *Table 23*.

Table 23: Population, area and population density

CITY	POPULATION	AREA (SQ KM)	POPULATION DENSITY (PERSON PER KM^2)
Addis Ababa	3,273,000	527	5,198
Adama	324,000	29.86	7,375
Dire Dawa	440,000	1,559	219

Source:
- https://en.wikipedia.org/wiki/Regions_of_Ethiopia
- https://en.wikipedia.org/wiki/Adama

With respect to water supply, all of Addis Ababa's surfacewater comes from three reservoirs (80 per cent) and one well system (20 per cent) with a total volume of 210,000 m^3 per day or 77 MCM per year and with an expected waste water generation of 168,000 m^3 per day. However, wastewater treatment capacity is around 7,600 m^3 per day. Therefore, huge untreated wastewater enters Awash River via the Akaki tributaries.

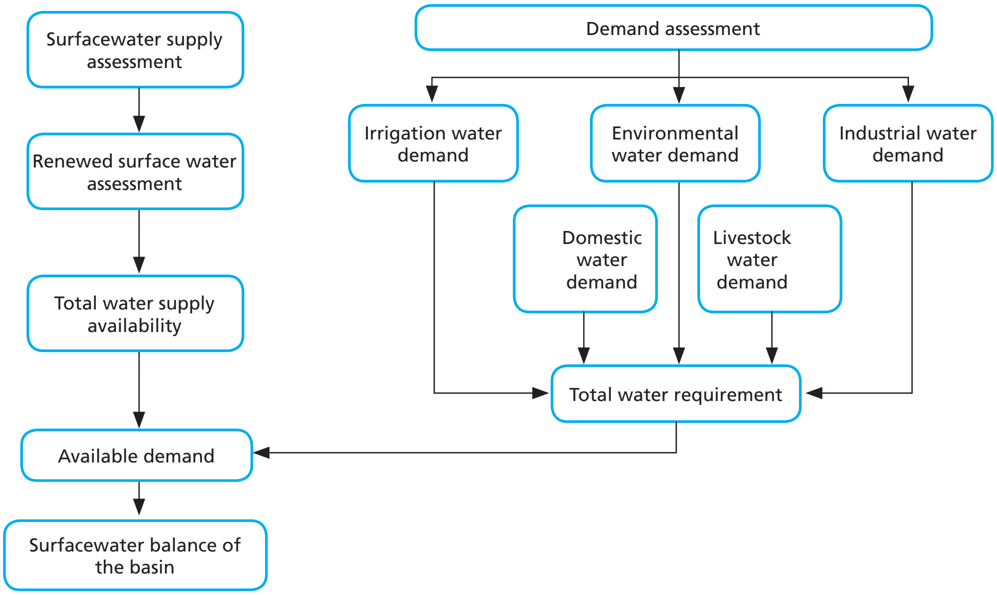
More than 65 per cent of the industrial units in the country are situated in the basin area and Addis Ababa alone is home to more than 2,000 units. Untreated solid and liquid wastes from these units are discharged directly into the river, in the absence of any kind of treatment facilities. The city of Nazareth (Adama) is situated downstream from Addis and, thus, the quality of water in Addis can adversely affect the health of its residents. It is interesting to note that per capita water supply is 20 litres per day in Ethiopian cities which is not sufficient. Human beings require fresh water for drinking, washing, food preparation and general hygiene. Therefore, it is very likely that substantial amount of groundwater is exploited to balance this shortage in demand. Considering a minimum per capita water availability of 145 litres per person per day for urban population and 45 liters per person per day for rural population, the total domestic water requirement of the basin comes to about 0.326 BCM/year.

9.14 WATER BALANCE

In order to develop a water balance estimation, the equation is:

INFLOW = OUTFLOW + CHANGE IN STORAGE

Figure 15: Flowchart for water balance evaluation



Source: Assessment of water scarcity and its impacts on sustainable development in Awash basin, Ethiopia (Dereje Adeba, M. L. Kansal, Sumit Sen)

Within this backdrop, the water balance is calculated in *Figure 24*.

Table 24: Annual water deficit in the Awash Basin

ANNUAL WATER AVAILABILITY (SURFACE YIELD) (in BCM)	ANNUAL WATER DEMAND (BCM PER YEAR)	
4.64	Domestic water demand	0.326
	Industrial	0.01084
	Livestock	0.165
	Irrigation	2.52
	Environmental flow	1.64
Total = 4.64	Total = 4.662	
Deficit: 4.662 – 4.64 = 0.022 BCM		

Source: Dereje Adeba Anon 2015. Assessment of water scarcity and its impacts on sustainable development in Awash basin, Ethiopia

However, it is important to understand the seasonal water deficit in the basin. A study was conducted during 2011 and 2012, in which it was noticed that from December to April, the basin shows a deficit of 1.27 BCM, while there is excess water of 1.67 BCM from May to September. In 2012, there is a deficit of 2.82 BCM between December and April, while there is a surplus of 3.16 BCM from June to October.[10]

9.15 EXISTING WATER QUALITY

The Awash Basin is growing economically, and demand for water is quickly increasing. Irrigation is expanding rapidly—both planned (e.g. for sugarcane) and unplanned. According to the agricultural water survey conducted in 2012 in the Awash Basin, current agricultural water demand for a physical area of 152,828 ha and a cropped area of 181,113 ha is 2,452 M m^3; current agricultural water withdrawals already amount to 2,285 M m^3, which means that the proportion of water withdrawals to water demand is 94.7 per cent. This leaves little space for the proposed irrigation expansion projects.

Hydropower generation is also an important priority. One large-scale hydropower plant (Koka) and two smaller-scale ones (the newly renovated Aba Samuel power plant and the Awash Melkassa plant) generate electricity from the flows of the Awash. With a reservoir of about 180 km^2, these dams risk losing up to 5 m^3 per second (or 197 M m^3 per year) of water owing to evaporation. In addition, operation rules for hydropower generation have a great impact on irrigation water availability and scheduling water availability for downstream regions. Therefore, existing water quality in the river basin can be understood and classified for three different segments, i.e., for Upper Awash region, Middle Awash region and Lower Awash region.

9.15.1 UPPER AWASH

The region is densely populated and almost 65 per cent of the population catered to by the basin reside in the Upper Awash region, which also includes the capital city, Addis Ababa. Urbanization, industrialization and soil erosion are some of the major factors contributing to the deteriorating water quality in the region.

Addis Ababa is home to more than 2,000 industrial units, about 65 per cent of all industrial units in the country. These units discharge their untreated effluents and other solid wastes directly into the river, since as much as 90 per cent of these units do not have any kind of treatment facilities. Akaki, the major river catering to Addis carries transports wastewater discharged from various sources in Addis (such as industries, domestic and municipal) to Awash at their confluence.

- Two perennial rivers, Akaki and Mojo, form the major part of the Upper Awash region
- Impact on downstream towns that extract water from Awash for domestic water supply and usage is significant
- These towns are Adama, with a population of over 300,000; Metahara, with a population 20,000; and, Awash, with a population around 10,000

Domestic and municipal discharge in River Akaki near Addis.

Source: https://www.researchgate.net/figure/People-discharge-toilet-and-domestic-waste-water-to-Little-Akaki-river_fig3_317572799

Untreated effluent discharge from industries in the river near Addis

Source:https://www.researchgate.net/figure/Akaki-river-pollution-Source-Alemayehu-et-al-3_fig5_317572799

- Loss of vegetation in the highlands is further accelerating the erosion rates in the Upper Awash and its tributaries and increasing the sedimentation problem

9.15.2 MIDDLE AWASH

The water coming to the region, already carries a burden of all types of raw effluent from Upper Awash region. The silt content in the river due to soil erosion gives a mud-like colour to the river, this can also be contributed to high turbidity in the river. The TDS value of the river is also on the higher side.

Soil in the region is mainly alluvial, deposited by erosion from the upper, fertile basin. Agriculture is the major activity conducted in the region and agricultural washout and runoff is the major concern as it tends to increase the salinity in the river basin. Several irrigation schemes have been developed for the region to promote banana, sugar and cotton production. However, drainage has remained a problem ever since irrigation became widely practiced in that region, with the rising concentration of salt and toxic elements in the drain water of irrigated lands being one of the major problems.

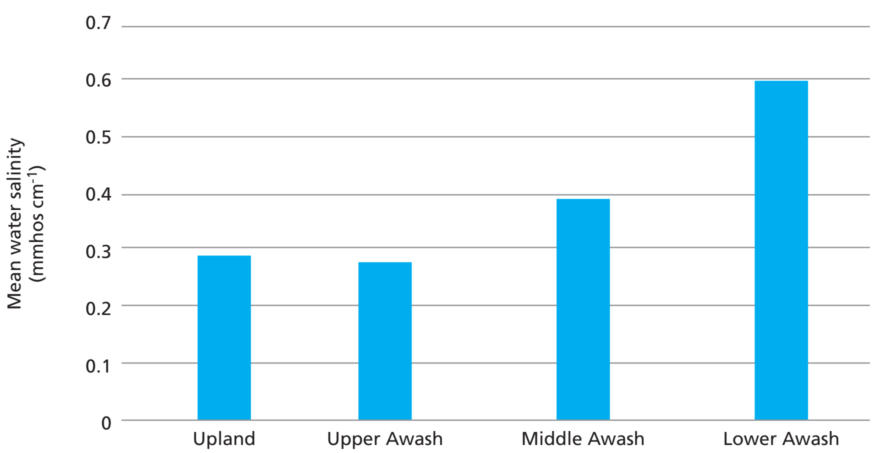
Evaporation and transpiration exceed mean annual rainfall, which leads to the accumulation of salts on the soil surface. Water in the region flows through limestone deposits, which results in increasing carbonate and bicarbonate content and high alkalinity. Fluoride concentration in the river water is also on the higher side. This may be due to the arid climate and being in the Rift Valley zone.

9.15.3 LOWER AWASH

The Lower Awash region starts from the lowlands and covers the Afar region before terminating at Lake Abbe. The region is typically arid and humid and the soil in the region is mainly sandy with high hydraulic conductivity which results in high evaporation losses. Agriculture and livestock raising are the major activities carried out in the region.

For irrigation purposes, the region must depend upon a large reservoir due to very less and uncertain rainfall. Tendaho irrigation dam serves as the reservoir for irrigation purpose. Concentration of pollutants in the already contaminated water which flows from the highlands of the Upper and Middle Awash region is increased further in the Lower Awash region in the absence of any significant rainfall and increased evaporation losses. *Figure 16* shows how the salinity of the river increases from Upper Awash to Lower Awash.

Figure 16: Mean salinity level of Awash River water (MMHOS/CM)



Source: The water of the Awash River Basin - A future challenge to Ethiopia (Girma Taddese, Kai Sonder & Don Peden)

The Awash River Basin and the Rift Valley lakes have special water quality problems to which attention needs to be paid. The Awash basin, as understood from the previous paragraphs indicates following facts:

- Due to deforestation in the Upper basin, there is a problem of sedimentation, i.e., silt in the river water.
- Water being discharged into the river, without efficient treatment of sewage of Addis Ababa city, causes serious pollution downstream. In fact, drinking water source of Adama (Nazareth) are vulnerable.
- Collected groundwater samples show the presence of fluorides.
- Some of the river samples have higher total dissolved solids and hardness due to wash out of limestone.
- Mean concentration of heavy metals (ppb) in Addis Ababa catchment is summarized in *Table 25*.

Table 25: Mean concentration of heavy metals

HEAVY METALS	STREAMS	SPRINGS part per billion (ppb)	BOREHOLES
pH	7.72	6.61	8.62
Mn	2187.44	29.88	5.14
Cr	4.24	1.84	1.30
Ni	9.03	0.32	0.51
As	1.2	8.44	0.44
Pb	0.00	4.64	16.58
Zn	0.00	3.05	35.25

Source: The water of the Awash River Basin - A future challenge to Ethiopia (Girma Taddese, Kai Sonder & Don Peden)

Even though measures are being taken against these issues, they are not backed by proper data since the monitoring exercise is carried out less frequently than what is required and mandated. Therefore, it becomes important to have a monitoring network in place that can help ensure accurate and precise measurement of all the seasonal trends and variation within the basin. This will not only allow for a better understanding of the water quality in each segment of the basin but will also help in the development of policies and practices that can be geared towards an overall well-informed basin management by the Awash Basin Authority.

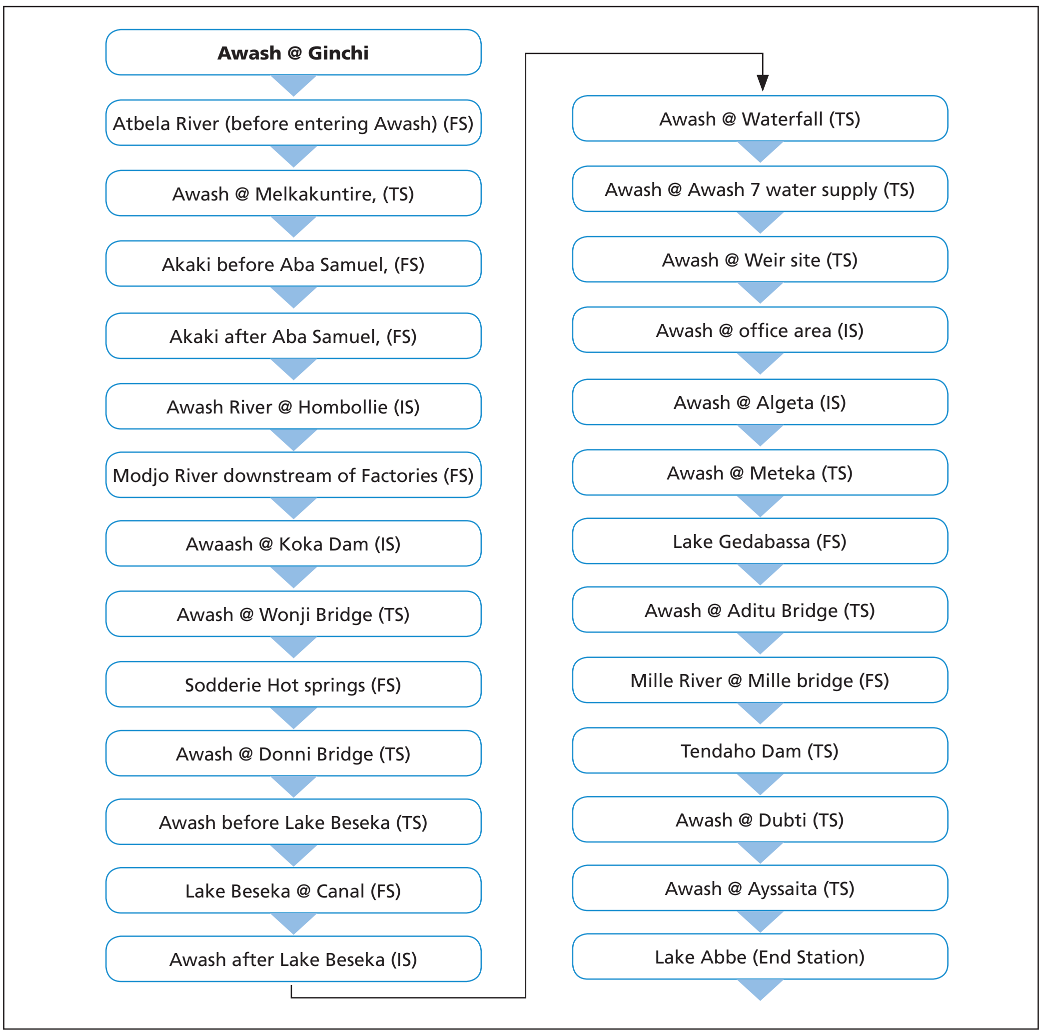
10. Suggestive monitoring network

10.1 SELECTION OF MONITORING LOCATIONS

Generally, stations can be classified as baseline stations (BS), impact stations (IS), trend stations (TS) and flux stations (FS) as discussed earlier. Baseline stations are those that are free from influence of any anthropogenic activities. Therefore, the proposed baseline station(s) will need to be near the Ginchi town (which is the place nearest to the origin of the Awash River).

Impact stations are those that are downstream of tributaries or drains carrying water or wastewater attaining mixing zones to understand the incoming pollution load. It has been stated that there are 11 major tributaries joining Awash River—Logiya, Mile, Borkana, Ataye River, Kabina River, Kassam (Germama River), Durkhema River, Keleta, Mojo, Akaki, Dochautu. Out of which Mile, Kabenna, Kassam, Mojo and Akaki are perennial tributaries.

Figure 17: Line diagram on suggestive water quality monitoring stations in Awash Basin



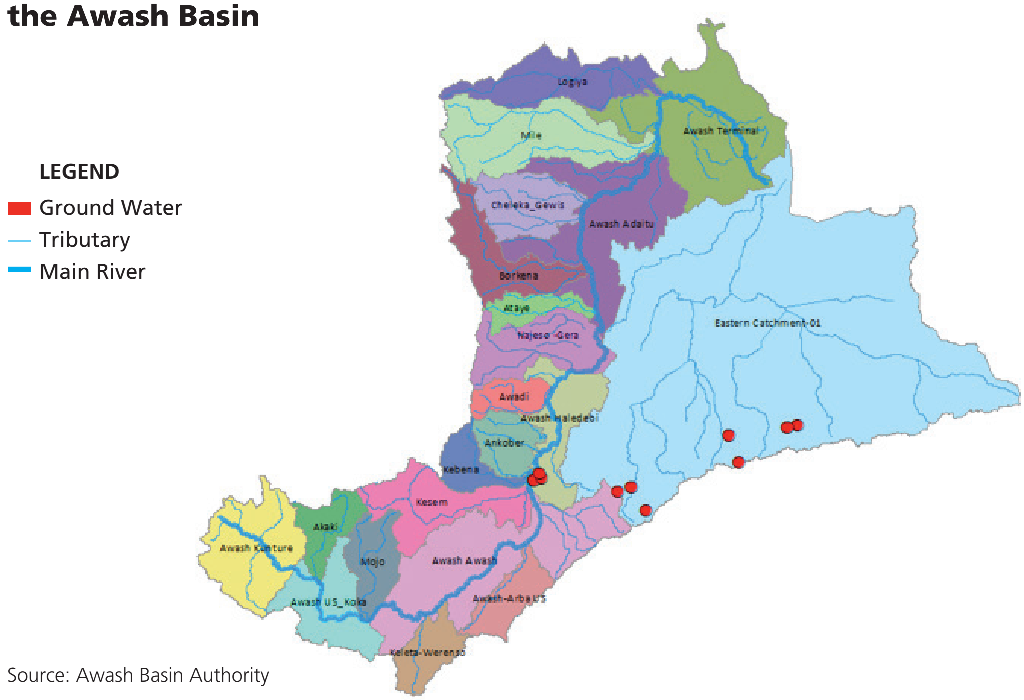
Source: CSE, MEFCC & AWAB

Akaki River is a tributary carrying wastewater from Addis Abba to the Awash River. The stations before the confluence of this tributary shall be the flux stations, for the calculation of load and mass flux. The impact station should be located downstream from the confluence of these tributaries with Awash. The stations upstream from the confluence on the tributaries of the Awash River shall be trend stations that will help in observing and understanding the changes taking place over time due to anthropogenic influences. However, only station(s) to be located in the Afar region should be categorized as trend station. There should be

Map 12: Surface-water quality sampling and monitoring stations in the Awash Basin

Source: Awash Basin Authority

Map 13: Groundwater quality sampling and monitoring stations in the Awash Basin



Source: Awash Basin Authority

flux stations at the end-point of Awash River, i.e. Lake Abbe. These have been traced in a line diagram given in *Figure 17* and are also summarized in *Tables 26–28* as per inputs and recommendations given by the Ministry of Environment, Forest and Climate Change (MEFCC), Ethiopia and the Awash Basin Authority (AwBA), Ethiopia.

The surface and groundwater monitoring and sampling stations in the Awash basin are represented in *Maps 12 and 13*. It should be noted that the eastern catchment has a majority of the groundwater monitoring and sampling stations, whereas surface water monitoring and sampling are carried out majorly along the river as well as along the western catchment of the basin.

It is also recommended that the authorities increase monitoring in the non-perennial tributaries such as Dechautu, Drukham River, Ataye River, Bokhara, Logiya, etc. especially

Table 26: The baseline station (one station)

Upstream	Station name	Water type	Landmark	Town name	Easting	Northing	Frequency
	Ginchi Bridge Station BS	River	Addis-Holeta-Ginchi @ Ginchi bridge	Ginchi	404136	997920	Two times per year

Source: Awash Basin Authority, AUGUST 2018

Table 27: Sampling stations resulting from ASTU'S recommendations and AWBA'S water quality (13 stations)

Sub-basin	Station›s name	Water type	Landmark	Town name	Easting	Northing	Frequency
	Akaki River FS	River	After Lake Aba Samuel	Akaki	467851	975027	Monthly
Upstream Koka sub-basin	Little Akaki @ Zenebework FS	River	Before Lake Aba Samuel	Akaki	474377	996337	Monthly
	Great Akaki River FS	River	Before Lake Aba Samuel	Akaki	473256	975027	Monthly
	Awash River @ Hombole IS	River	25 km far from Alemtena town	Hombole	475901	925811	Monthly
	Legedadi after Kera mix FS	River	After Kera mix	Legaddadi	491827	1003926	Monthly
	Modjo River after factories FS	River	After downstream of factories	Modjo	502812	931647	Monthly
Awash–Awash sub-basin	Before Lake Beseka TS	River	Around livestock's/ Lam Berret	Addis ketema	600365	978746	Monthly
	Lake Beseka @ Intake FS	Lake	Lake pumping site (old)	Addis ketema	598989	980653	Monthly
	Lake Beseka @ Canal FS	Lake	Between Metehara & Addis Ketma	Addis ketema	600908	982402	Monthly
	Awash after lake Beseka IS	River	South end of sugarcane plantation	Merti camp	609824	979426	Monthly
	Awash @ Awash water fall TS	River	Awash Park (11 km far from Road)	Awash Park	611281	977554	Monthly
Awash-Halidebi	Awash @ Weir site TS	River	Middle Awash main weir diversion	Melka sedi	629714	992849	Monthly
	Awash @ Office AreaTS	River	Awash back of Main office	Werrer	629088	1030185	Monthly

Source: Awash Basin Authority, AUGUST 2018

Table 28: Sampling station derived from the existing AWBA water quality sites, S2TAB & ASTU'S (17 stations)

Sub-basin	Station's name	Water type	Landmark	Town name	Easting	Northing	Frequency
	Atbela River before Awash mix	River	Before mixing Awash River	Melkakuntire	--	--	Quarterly
Upstream Koka	Awash @ Melkakuntire IS	River	At bridge	Melkakuntire	456726	961932	Quarterly
	Awash at Zeway road TS	Awash River	Near to Syngenta flower farm	Koka	509432	944969	Quarterly
	Modjo River before Modjo FS	Modjo River	Railroad trucks	Modjo	512621	951938	Quarterly
	Koka dam TS	Reservoir	At Koka dam	----------	517216	936157	Quarterly
Awash–Awash Sub-basin	Awash at Wonji TS	Awash River	At Wonji bridge	Wonji	525435	937268	Quarterly
	Awash after Soddire mix IS	Awash River	After mix of sodddre	Soddire	543082	929230	Quarterly
	Soddire hot springs FS	Hot springs	300m right before reaching Soddire	Soddire	543691	928283	Quarterly
	Awash @ Donni bridge TS	River	12km far from Sodere-Asella-Abadir	Donni	562189	940568	Quarterly
	Awash @ water supply TS	Awash River	Awash 7 water supply/pump	Awash 7	629912	995525	Quarterly
Awash-Halidebi Sub-basin	Awash @ Algeta IS	River	7km far from Algeta own	Algeta	643387	1053711	Quarterly
	Awash @ Meteka TS	Awash River	At bridge	Meteka	666527	1103137	Quarterly
	Lake Gedabassa FS	Lake/Swamp	33 km back from Gewanie town	Gewanie	691911	1261981	Quarterly
	Awash after Gedabassa IS	River	At the outlet of Gedabassa Lake	Gewanie	672843	1131198	Quarterly
Awash-Aditu	Mile River FS	River	Near to Mile town	Mile	691761	1261715	Quarterly
	Awash @ Aditu IS	Awash River	After Aditu town near to long bridge	Aditu	692441	1230592	Quarterly
After Tendaho	Awash @ Dubti TS	Awash River	Near to old office of lower Awash	Dubti	727336	1296950	Quarterly

Source: Awash Basin Authority, AUGUST 2018

Table 29: Sampling station resulting from reconnaissance survey (4 stations)

Between Awash–Awash and Awash–Tendaho sub-basin	Station's name	Water type	Landmark	Town name	Easting	Northing	Frequency
	Kassam Reservoir TS	Dam	Kassem dam out let	Saburie	604971	1011849	2 times per Year
	Dehho Hot springs FS	Hot spring	10 km far from Kessem	Deho small town	614781	1016702	2 times per Year
	Tendaho Reservoir TS	Dam	Ethio- Djibouti Road before Logiya	Logiya	713194	1293065	2 times per Year
	Awash @ Assayita TS	River	After Ayssita Town	After Afambo	775943	1275801	2 times per Year

Source: Awash Basin Authority, AUGUST 2018 as impact stations to assess the impact, largely that of the agricultural runoff during the rainy season. It is also pertinent to mention that the stations should be located closer to hydrology stations. This finalization has been achieved through stakeholder consultation and a reconnaissance survey. MEFCC, Ethiopia has also included some groundwater wells in the water quality network due to their importance, particularly as drinking water sources.

A total of 35 stations (that include both selected and proposed stations) are to be made functional on the Awash River in the coming months. There are six trends and seven flux stations at which monthly monitoring is carried out.

The first station is the baseline station that is located upstream from the Ginchi town, and details of this station are given in *Table 26*.

Based on the recommendations from the Adama Science and Technology University (ASTU), sampling stations identified and monitored on a regular basis are listed in *Table 27*.

Of the selected and proposed 35 sampling and monitoring stations, thirteen trends and three flux sites are to be monitored quarterly (four times per year) starting from July 2018 (see *Table 28*). The objective will be to observe and record the spatial and temporal variability at these stations.

Table 29 lists the details of the stations that have been identified after undertaking reconnaissance survey and have been found to be appropriately placed to be added to the existing monitoring network.

Out of the surveyed groundwater monitoring stations, 18 stations (listed in *Table 30*) have been proposed to monitor groundwater quality of the Eastern Catchment sub-basin. It has been proposed that these stations are monitored two times per year considering seasonal variability.

10.2 WATER QUALITY PARAMETERS

Global water quality monitoring system and subsequently National Water Quality Monitoring Programme can be classified as follows:[11]

- **Field observation**—colour, odour and dissolved oxygen
- **Physical parameters**—pH, temperature, turbidity and conductivity
- **Parameters to assess the organics**—BOD and COD
- **Parameters related to eutrophication**—total kjedahl nitrogen, nitrate–nitrite and total phosphorous
- **Common ions**—K^+, Na^+, Ca^{+2}, Mg^{+2}, CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-} and total dissolved solids
- **Pathogens**—total and fecal coliform
- **Special parameters**—fluoride, trace metals and pesticides

The combinations of field observation along with physical parameters are the core parameters which are to be analyzed in the field. It is, therefore, necessary to build a sampling van fitted with facilities to analyze these core parameters. Besides the above parameters, special parameters such as pesticides shall be finalized in consultation with agriculture department of Ethiopia. In case of trace metals, the Geological Survey of Ethiopia and other competent institutes may be consulted to provide information regarding the geological and lithological characteristic of the basin. It is pertinent to mention that sampling and testing must be carried out on periodic basis to identify arsenic, cadmium, copper, lead, chromium, nickel, mercury and iron in the groundwater. Fluoride in groundwater near Addis Ababa has already been reported.

Table 30: Sampling stations resulting from ASTU's recommendations

Sub-basin	Station's Name	Water Type	Land mark	Town Name	Easting	Northing	Frequency
Awash-Halidebi	Pizometer @ ASP 10/1	Pizo meter	Melka sedi farm b/n Sedi & 4th Camp	Werrer	625667	1024719	Once in a Year
	Drinking hole @ Bedula alie	Borehole	At Bedulalie Camp/ Melkasedi 2th	Melka sedi	630798	1026250	Once in a Year
	Werrer @ office area	Hot springs	Near to the primary school	Werrer	629074	1029873	Once in a Year
Eastern Catchment	Asebot Meisso	GW	At Asebot town after railroad	Asebot	684941	1016763	Once in a Year
	Meisso	GW	After Meisso town near to main road	Meisso	694129	1019860	Once in a Year
	Asebeteferi/Chiro	GW	At Chiro town before leaving the town	Chiro	704935	1003491	Once in a Year
	Hirna Tulo	GW/Springs	Near to River or TVT School	Hirna	730133	1019612	Once in a Year
	Tony Farm 1- Dire Dawa	GW	At the center of the city of Dire	Dire Dewa	811571	1063526	Once in a Year
	Melka Jebedu - Dire Dawa	GW	At the town of Melka Jebdu/Errer-3	Melka Jebdu	805030	1062547	Once in a Year
	Main Erer (Erer- 1)	GW	Near the edge of river/water supply	Erer 1	763120	1057112	Once in a Year
	Dewele/Ayesha	GW	Far from Aysha Dewele town/water sup.	Dewele	239104	1219699	Once in a Year
	Adele/Aysha	GW	Before reaching Adele/Hund dug well	Adele	240717	1199057	Once in a Year
	Aysha 2 (Mordale)	GW	1 km far from Aysah woreda town	Mordale	239685	1189505	Once in a Year
	Biyo Dile	GW	3 km from right side of Biyo Dile village	Biyo Dile	227733	1131358	Once in a Year
	Kerssa (Golachu)	GW	At the town of Kerssa	Kerssa	815319	1045880	Once in a Year
	Kulubi meta	GW	4 km far from right side of Kulibi town	Kulubi	793992	1040473	Once in a Year
	Chelenko meta	GW	At the town of Chelenko	Chelenko	786029	1036280	Once in a Year
	Kobo	GW	Near to the main road on Kobo town	Kobo	770266	1037623	Once in a Year

Source: Awash Basin Authority, AUGUST 2018

10.3 FREQUENCY

Statistically, more the sample size, more the information. More sample size also means that the frequency of sample collection would be higher, resulting in making it cost prohibitive in terms of logistics, infrastructure and manpower. Therefore, frequency must be optimized in such a fashion that no major loss of information is reported while ensuring that the monitoring programme is within the allocated budget.

In the beginning, it is will be more beneficial to monitor core parameters, while the general parameters can be analyzed once a month. Trace metals and pesticides can be monitored on a quarterly basis (pre-monsoon, post-monsoon and lean period). After observing the variations, the frequency can be charged as per the requirement of the area or station.

11. Stake holder consultation and sampling programme

11.1 STAKEHOLDER CONSULTATION

It is desirable to have stakeholder consultations before starting a sampling programme. Such consultations help the authorities to improve the existing database for defining basin characteristics in a better manner. They also help in guiding the authorities in better selection of water quality parameters, sampling locations and frequencies. Further, consultations also address the issue of selection of participatory laboratories and laboratory procedures.

Table 31:Important stakeholders and source of information

STAKEHOLDER	EXPECTED INFORMATION
Ministry of Water Irrigation and electricity	Hydrology, water abstraction and river flow measurement network
Awash Basin Authority	Hydrology, tributaries and its characteristics, water management policies and soil and lithology
Ministry of Mining and Industry	Lithology, geology, mining and industrial activities
Addis Ababa Water and Sewage Authority	Status of water supply, and wastewater generation, treatment and disposal in Addis Ababa
Adama Water and Sewage Authority	Status of water supply, and wastewater generation, treatment and disposal in Adama city
OEFCCA (Oromia Environment, Forest and Climate Change)	Information related to Oromia province
Environmental Protection Authority	Strategy of pollution control in Awash Basin
Ministry of Environment Forest and Climate Change	Overall water quality management programme policy

Source: CSE

11.2 SAMPLING PROGRAMME

Sampling programme consists of the following steps:

- Reconnaissance survey to identify sampling point(s)
- In situ observation and analysis
- Logistic and field kit

11.3 RECONNAISSANCE SURVEY

Reconnaissance survey, as indicated earlier, is to find out the exact sampling point(s), keeping in mind the mixing zone, depth and all weather access of these point(s). A reconnaissance survey will also help in the identification of drains discharging wastewater into the river or its tributaries. It will also help in making in situ observation related to the use of water in cattle bathing and washing. In addition, the sensitivity and characteristics to determine the quality of water being used for drinking and bathing will also be recorded. Any other notable and pertinent observation(s) shall be considered during the reconnaissance survey. This survey needs a team comprising of relevant stakeholder for meeting its primary objective(s).

11.4 IN-SITU FIELD OBSERVATION, ANALYSIS AND STORAGE

In situ field observations, analysis and storage begins with the observation of weather—whether it is sunny, cloudy, rainy or windy. Generally, in sunny and hot weather, the chances of bacteria dying are high.

In a pitter-patter or drizzle, there are chances of surface runoff carrying pollutants to water bodies without much dilution, which will add to the pollutant load. It is better to avoid sampling in moderate to heavy rain. Odour and colour are two essential parameters to be observed. Intensity of odour is dependent on temperature and weather. In hot and humid weather, decomposition is rapid and generates and unpleasant odour.

With respect to colour, the weather conditions directly affect the intensity of the colour of the water. Generally, water bodies flowing at a low velocity in fair weather generate some colour. However, it is to be noted that the colour fades away or disappears completely with rain. Apart from the weather, measurements of temperature, velocity of the river water, salinity and dissolved oxygen are necessary to be carried out in the field since they are all interrelated. These observations should be recorded. Besides the record of observations, containment, preservation and treatment of samples should be reported to the concerned laboratory. The type of sample, depth of the river, and depth of the sampling point are very vital pieces of information as well. Thus, there shall be a 'record card' of sample identification and a record shall be given. For the purpose of Awash monitoring programme, it shall be given in manner specified in *Form 1* provided earlier in this document.

11.5 LOGISTICS AND FIELD KIT

One of the most important aspects of the monitoring programme is conveyance. Conveyance must be such that it can accommodate three persons and has enough space to carry sampling kits and other accessories. Minimum requirement has already been stated in the first part of this manual in *Table 6***.**

12. Number of laboratories and evaluation of laboratories

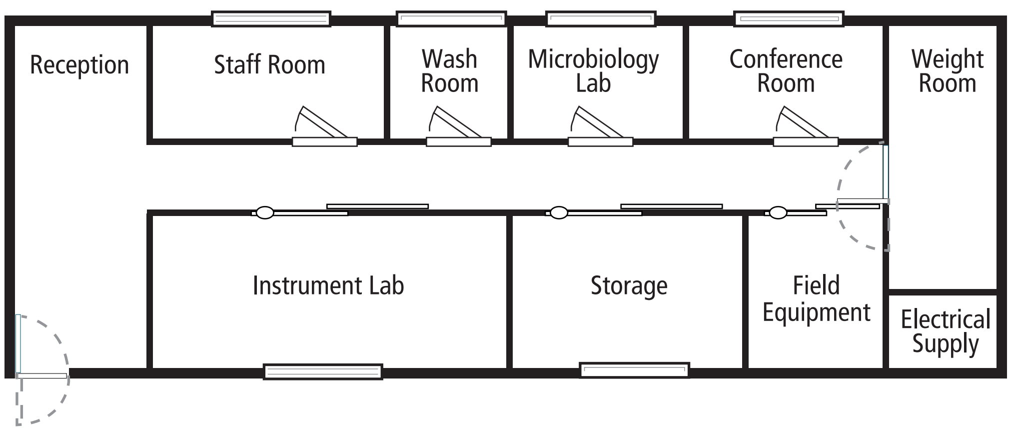
It is always desirable to complete a sampling exercise for an entire river as quickly as possible, preferably within 48 hours. For a long river like Awash (1,200 km), one single laboratory cannot perform the exercise, therefore, involvement of multiple laboratories is necessary. However, that might pose a challenge in the form of quality of data being at par among the different laboratories. Selection of laboratories considering their location relative to the sampling station and their individual capacities this becomes imperative. This process needs systematic evaluation, which should consist of the following things:
- Infrastructure
- Standard operating procedure of laboratory

12.1 INFRASTRUCTURE

12.1.1 LAYOUT PLAN
In general, the infrastructure of a laboratory is comprised of a minimum space with a layout plan, power supply, water supply including distillation assembly and laboratory furniture. Also, the laboratory space should have proper ventilation, good spacing, laboratory hoods, sinks, etc. Additionally, a good laboratory provides safety equipment like an eye wash fountain, safety showers, and firefighting arrangement, including a first-aid box.

In case of a layout plan, the minimum space requirement for a water laboratory shall be of 100-150 m^2. The entire space shall be divided into separate working areas such as analytical laboratory (wet laboratory), instrumental room with adequate provision of gas cylinder, balance room, microbial room, storage room for chemicals and glassware, field monitoring kits, and office room. An ideal model layout plan is given in *Figure 18*.

Figure 18: Model layout plan



Source: CSE

12.1.2 ELECTRICITY SUPPLY AND ELECTRIC SERVICES
Regular and stabilized electricity supply (220-230 V) is essential for smooth functioning of a laboratory and its instruments. Necessary and adequate provisions should be made for continuous supply, constant voltage, adequate load, proper electric fitting, etc. Because of the specialized nature of analytical work in a laboratory, the lighting system needs are

very specific. These include levels of illumination, brightness, glass and location of light sources. Proper lighting system facilitates help in making accurate readings of glassware graduations and balance.

Some sophisticated instruments require constant voltage to maintain stabilized and drift-free instrument operation. Regulating electric voltage, therefore, is of the outmost importance and can be achieved through use of voltage stabilizers and uninterrupted power supply (UPS) systems. Since the electric supply for a laboratory needs to be continuous, there must be additional provisions of diesel generator (DG) sets to ensure continuous supply of power to equipment like BOD incubators, oven, etc. in the absence of regular power supply.

12.1.3 WATER SUPPLY AND DISTILLED AND DE-IONIZED WATER

Water is an essential and basic need for laboratory operations such as washing, cleaning etc. Therefore, a laboratory should have provisions for continuous water supply. Dedicated water storage available exclusively for laboratory use is desirable. Cleaning of storage tanks at periodic intervals is also imperative.

Distilled water is one of the basic requirements of a laboratory and analytical errors can occur because of improper quality of distilled water. Generally, distilled water with electrical conductivity of 2.0 μSiemen/cm or less is considered reasonably ideal for routine work, the degree of purity of distilled water can be further classified as stated in *Table 32*.

Table 32: Degree of purity of distilled water

Purity	Maximum conductivity µSiemen/cm	Appropriate concentration of electrolyte (ms/l)
Pure	10	2.5
Very pure	1.0	0.2–0.5
Ultra-pure or nano-pure	0.1	0.01–0.02
Theoretically pure	0.05	0.00

Source – LABORATORY ANALYTICALTECHNICAL SERIES (LATS/9/2008-2009) CPCB

In a water laboratory, for the purpose of water quality monitoring of a river, pure and very pure quality of distilled water is the minimum requirement.

12.1.4 GLASSWARE

Generally, glassware of borosilicate glass, which is relatively inert, is used in analytical work. Plastic bottles of polythene (PE) or polypropylene (PP) are suitable for collecting and transporting water samples. Unless instructed otherwise, borosilicate glass bottles may be used for the storage of reagents and standard solutions. Standard solution of silica, boron, and alkali metals should be stored in polyethylene bottles. Whenever necessary, amber or dark coloured glass bottles must be used for storing photo-reactive chemical solutions.

12.1.5 QUALITY OF CHEMICALS/SOLVENTS

The poor quality of chemicals or solvents may become a cause of analytical error due to interference of impure material during determination. Thus, selection of chemicals or solvents of an appropriate quality is an all-important factor for achieving results of desired accuracy. Generally, chemicals used in a laboratory are of laboratory grade or analytical grade (AG) or guaranteed grade (GR). For the preparation of standard solutions, AR or GR chemicals are preferred. For calibration, reference material (RM) or certified reference material (CRM) is used.

12.1.6 SAMPLE DIGESTION SYSTEM AND HOOD SYSTEM

An efficient hood system is necessarily required in laboratories to remove various toxic and hazardous fumes from the workplace that are generated during use of organic solvents or during digestion.

12.1.7 LABORATORY FURNITURE

Laboratory furniture and work benches with ergonomic designs should be given more emphasis to provide suitable work environment. The top surfaces of the laboratory working benches are to be made up of acid- and alkali-resistant material. Steel or aluminum frames used for infrastructure or any fittings are to be non-corrosive type. Wherever stainless steel material is needed, the same is to be provided. Storage cupboards should be made up of clipboard covered with melamine sheets. All furniture is to be designed according to the requirements of the laboratory. Work desks are also to be laminated and coated with non-corrosive material.

12.1.8 CHECKLIST FOR ASSESSMENT OF LABORATORY INFRASTRUCTURE

A checklist for the development of laboratory infrastructure is provided in *Table 33*.

Table 33: Checklist for assessment of infrastructure of laboratories

ASSESSMENT	YES	NO	REMARKS
Is the laboratory space less than the minimum space required (100–150 m2)?			Acceptable, if not significantly low
Does the laboratory have proper layout plan with designated space for a wet lab, balance room, microbiology lab etc.			If no, examine whether it is possible to have such facilities in the future
Does the laboratory have arrangement of adequate power supply (220–230 Volts)?			
Is there a provision of a UPS system for designated instruments?			
Is there back-up power supply system (DG set)?			
Is there a system ensuring adequate water supply?			If no, ask them to provide
Is there distilled water making assembly?			If no, what is the present arrangement?
Does the laboratory have proper illumination and ventilation systems?			If no, is it possible to do so?
Is the laboratory's furniture up to expectations?			If no, is it possible to do so?
Is there a sample digestion system?			If no, is there space to do so?
Is the laboratory using AR/GR grade chemicals?			If no, what grade is being used?
Is the laboratory using Borosil glasswear?			If no, what are they using?
Is the laboratory's safety equipment adequate?			Ask for minimum requirement

Source: CSE

The assessor may utilize this checklist to assess the grading of the laboratory which can fall in any of the following categories: adequate, partially adequate, or not adequate. In case the laboratory is found to be partially adequate, there should be possibilities to make it adequate by providing some support.

12.2 DEVELOPMENT OF STANDARD OPERATING PROCEDURE OF A LABORATORY

Standard operating procedure of a laboratory shall be developed on the following steps:

- Sample acceptance requirement
- Sample storage condition and unused samples disposed
- Analytical procedure
- Quality assurance and quality control
- Date validation and management

12.2.1 SAMPLE ACCEPTANCE REQUIREMENT

The laboratory shall maintain written sample acceptance procedure that clearly outlines the circumstances under which samples will be accepted for analysis at the laboratory.

Sample acceptance procedure must necessarily include (but is not limited to) the following areas of concern:

- Proper and complete documentation to be accompanied with the samples for analysis, which shall include sample identification, the location, date and time of collection, collectors' name, preservation type, sample type and any special remarks concerning the sample.
- Proper sample labelling to include unique identification and labelling system for the samples with requirements concerning the durability of the labels (water resistant) and the use of indelible ink—adhesive cotton tape may be used for labelling.
- Use of appropriate sample containers
- Adherence to specified holding time for samples before analysis
- Adequate sample volume. Enough sample volume must be available to perform all the necessary tests.

12.2.2 SAMPLE STORAGE CONDITIONS

A laboratory shall maintain documented procedures and appropriate facilities to avoid deterioration, contamination, or damage to samples during storage, handling, preparation and testing. The samples must be stored or conditioned under specific environmental conditions; these conditions must be maintained, monitored and recorded.

A sample preservation protocol must be developed. This will contain a container, minimum sample size, preservation, and maximum storage recommendations. For example, for BOD, a minimum of 1,000 ml sample container must be used, which can be either polyethylene or glass bottle. The sample shall be kept in a refrigerator and stored for at least six hours. Similar protocols shall be developed for other parameters.

12.2.3 UNUSED SAMPLE DISPOSAL

The laboratory shall have a standard operating procedure for the disposal of samples, leftover digested samples, leachates and extracts or other sample predation products. The laboratory shall maintain appropriate documentation and records demonstrating that samples have been properly disposed of as per applicable rules, and ensure that no environmental hazard occurs due to disposal of sample leftovers.

12.2.4 ANALYTICAL PROCEDURE

In general, laboratories follow procedures laid down either in APHA (American Public Health Association) or BIS (Bureau of Indian Standard) or ASTM (American Society for testing and Materials). In India, a guiding manual has been developed by Central Pollution Control Board of India, titled *Water and Wastewater Analysis*. The standard methods manual does not offer much variation between water and wastewater analysis. The common acceptable parameter-wise analytical methods and equipment required are summarized in *Table 34*.

12.2.5 BASIC EQUIPMENT OR INSTRUMENTS FOR REQUIRED PARAMETERS

To analyze the core and general parameters using the analytical methods listed in *Table 34*, the list of basic and specific equipment required is provided in *Table 35*.

Advance laboratories that analyze metal and pesticides need atomic absorption spectrophotometer (AAS) and gas chromatograph. AAS shall have the required cathode lamp and gas chromatograph should also be equipped with the required detector.

Table 34: Parameter-wise analytical methods and associated equipment or instruments

S. no.	Parameter	Methods	Equipment or instrument
Physical methods			
1	pH	Electrometric method	pH meter
2	Turbidity	Nephelometry or turbidity meter	Nephelometer
3	Temperature (°C)	–	Thermometer
4	Conductivity (µMho/cm)	Instrumental methods	Conductivity meter
5	DO	Instrumental method	DO meter
Titrimetric methods			
6	DO (mg/l)	Winkler's method, isometric titration	Glass wear (pipette or burette)
7	Acidity or alkalinity (mg/l)	Acid-base titration	-DO-
8	COD (mg/l)	Oxidation–reduction titration	COD digestion assembly + glassware
9	Total hardness (mg/l)	Complexometric (EDTA) titration	Glassware
10	Calcium hardness (mg/l)	Complexometric (EDTA) titration	Glassware
11	Chloride (mg/l)	Argento-metric titration	Glassware
Colourimetric			
12	Nitrate/nitric (mg/l)	–	Spectro–photometer
13	Kjeldhl nitrogen (mg/l)	–	Khjeldahl assembly
14	Ammonia (NH_3) (mg/l)	Lesslerisation method	Spectro–photometer
15	Boron	Curcimine method	Spectro–photometer
16	Phosphate	Stannous chlorice/ ascorbic methods	Spectro–photometer
17	Sulfate	Turbidric method	Nephelometer or Spectro–photometer
18	Fluoride	Ion-selective methods SPAWD methods	Ion meter/ spectro–photometer
Gravimetry			
19	Total dissolved solids (mg/l)	Gravimetry (weight difference at 105°C)	Oven, analytical balance
20	Total fixed dissolved solids (mg/l)	Gravimetry (weight difference at 550°C)	Muffle furnace, analytical balance
21	Total suspended solids (mg/l)	Gravimetry	Oven analytical balance
Flame emission photometry			
22	Sodium (mg/l)	Flame emission measurement	Flame photometer
23	Potassium (mg/l)	-DO-	-DO-
Microbiological test			
24	Total Coliform (MPN/100ml)	• Multiple tube method • Membrane filler method	Special microbial lab
25	Faecal Coliform (MPN/100ml)	-DO-	-DO-

Note: BOD measurement, difference of DO measured at initial slop and after incubation for standard time and temperature.

Source: CSE

Table 35: Basic equipment required for core and general parameters

List of equipment	List of instruments
• Ice box (2) • Filtration assembly • Heating mantle • Hot air oven • Hot plate • Water bath • Thermometer • Autoclave • BOD incubator • Refrigerator (big size)	• pH meter • Conductivity meter • Spectrophotometer • Flame photometer • Ion selective electrode • DO meter • Analytical balance

Source: *CSE*

12.2.6 MANPOWER

Generally, an environmental laboratory (performing water, wastewater and air analysis) needs a minimum of nine full-time skilled workers. But for water samples with nine core and 19 general parameters, with an average of four samples being collected daily, five skilled workers have been found adequate. This is depicted in *Table 36***.**

Table 36: Manpower with qualification and job description

S. no.	Qualification	Nature of the job	No. of personnel
1.	High school or intermediate with science	Assistance in sampling and analysis	2
2.	Bachelor degree in science or equivalent master's degree in science	Sampling and analysis	3
3.	Master's degree in science	Sampling and analysis, Supervision of analysis	1

Source: *CSE*

12.2.7 DATA MANAGEMENT

Data management begins with handling of raw data, validation and entry of data, and safe storage of data. It will be discussed briefly in this section.

RAW DATA

Raw data refers to any laboratory worksheets, records, memoranda, notes or exact copies thereof that are the results of original observations and activities of a study. For raw data entries, it is recommended that laboratory notes be used for each study. This should be robust, bound and the pages numbered. All entries should be made in indelible ink.

DATA VALIDATION

The most important step of data validation is the checking of data from the raw data notebook. The supervisor must examine the calculations made by analysts, weighing of chemicals, filter value etc. as well as typing errors.

The supervisor shall also check the following things:

- Whether the data is within the detection limits of a well-defined established method
- Whether the data is within the expected ranges of a parameter
- Whether there are too many (or too few) significant digits reported
- Whether the data is physically or scientifically possible
- Ensure repeatability. At least three repetitions for each sample being analyzed must be performed, and the result shall be accepted on the two closest values to ensure precision

Besides generality, statistical investigation of parameters may also support the validation programme. Correlation of parameters with acceptable premises of chemistry may indicate consistency in data. Common correlation interrelated parameters are:

- COD vs BOD
- Total coliform vs faecal coliform
- TDS vs conductivity
- TDS vs FDS
- TDS vs common ions such as K^+, Na^+, Ca^{2+}, Mg^{2+}, CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2}

The third approach is the ionic balance in which the summation of cations shall be closely equal to summation of anions; for example, it will be something like the equation given below.

$\Sigma Na^+ + Ca^{2+} + Mg^{2+} \approx \Sigma CO_3^{2-}, HCO_3^- + Cl^- + SO_4^{2-}$

Ions shall be converted from the unit mg/litre to m equ/litre. Another visual aspect of checking is the greater or smaller values among the correlated parameters, such as given in *Table 37*.

Table 37: Correlation of various parameters

• COD > BOD • Total iron > Fe^{2+}, Fe^{3} • Total coliform > Fecal coliform • Total oxidized nitrogen ≥ nitrate+nitrite	• TS > TDS • TS > Total suspended solids • Total hardness = calcium hardness + magnesium hardness • EC ≥ TDS

Source: CSE

Identification of 'outlier' value is also an important technique for validation of data. Generally, the range of the data with respect to a parameter of a station based on the historical database is the criteria on identification of outlier.

DATA STORAGE AND TRANSMISSION

Once the data is validated, the participatory laboratories shall enter the data in a dedicated format onto a computer (dedicated hard disk) and transmit the data to dedicated server of the main laboratory. Besides the server, MEF&CC, Ethiopia shall also have an alternative arrangement, in case of any emergency. Participatory laboratories shall also maintain a physical file or register of date, for use in case the computer crashes.

13. Capacity building of a participatory laboratory

For capacity building of participatory laboratories, an assessment of infrastructure and procedures of a laboratory is necessary. To perform such an assessment, a checklist is an imperative tool.

13.1 CHECKLIST FOR LABORATORY PROCEDURE AND MANPOWER ASSESSMENT

The checklist for laboratory procedure from sampling to data management is summarized in *Table 38*.

Table 38: Checklist for assessment of laboratory procedure

ASSESSMENT	YES	NO	REMARKS
Is there any format for a reconnaissance survey and sampling programme?			If no, such format shall be developed as given in Table 6.
Is there a procedure to follow for sample storage?			If no, the condition shall be applied as per Tables 8 and 9.
Is there a format for sample acceptance requirements?			If yes, check its accuracy.
Does the laboratory follow an established analytical procedure?			If yes, identify the procedure such as BIS, APHA and ASTM.
Is the analytical procedure available to concerned analyst?			
Is the laboratory capable of analyzing all the core parameters?			If not, identify the parameter not analyzed
Is the laboratory capable of analyzing all the general parameters?			-DO-
Does the laboratory have adequate manpower?			If not, can it be strengthened?
Do the laboratory personnel have sufficient knowledge on water analysis?			
Does the laboratory have adequate equipment and instruments?			
Does the laboratory have a preventive maintenance protocol?			If yes, is it adequate?
Does the laboratory maintain a notebook or register?			
Does the supervisor have sufficient knowledge to validate data?			If yes, is it practiced?
If yes, is it practiced in routine work?			
Does the laboratory maintain computer-based data storage systems?			

Source: CSE

Once such an assessment, in terms of infrastructure, laboratory procedure and manpower is complete, the laboratory may be graded as adequate, partially adequate or inadequate. Inadequate laboratories may not be enlisted in the water quality monitoring programme. Adequate and partially adequate laboratories may be enlisted for the task with support in terms of infrastructure and knowledge.

The laboratory staff may also be trained to improve their skills and augment the manpower on the whole. A suggested training programme is given in *Table 39*.

Table 39: Suggested training programme

Training programme or workshop	Frequency	Target allowance	Duration (days)
LEVEL I—supervision			
A holistic approach to water quality monitoring programme	One	Supervisors and senior staff of each department	Three
Analytical procedure workshop on identification methods and uniform procedure	One	Supervisors and laboratory team	Two
Laboratory procedure worksheets, including maintenance schedule	One	Supervisors and laboratory team	Two
Statistical methods on water quality monitoring (data validation, quality control and interpretation of data)	Two	Senior officials	Five
Quality assurance and quality control	One	Supervisors	Three
LEVEL II—analysis			
Analytical methods (core and general parameters)	One	Supervisors and laboratory analysts	Five
Sampling programme, including field exercise	One	Laboratory analysts and field assistant	Five
Laboratory procedure	One	Laboratory team	Five
LEVEL III—general			
Laboratory activities including making of distilled water	One	Laboratory assistants	Two
Field activities (including field kit making)	One	Laboratory assistants	Two

Source: CSE

14. Quality assurance and quality control

Quality assurance is the definite programme and set of standards for laboratory operations that specifies the measures required to produce reliable data of known precision and accuracy.

14.1 CONCEPT OF ERROR

No quantitative result is of any value unless it is accompanied by an estimate of the error inherent in it. Error in science is not mistakes or blunders only, but it is also associated with uncertainty. There are three types of error:

1. Gross error is the error resulting from a human mistake. This usually happens when data is being entered (filter value, weighing value and pressure gauge)
2. Systematic error is measured as the difference between the mean of a series of subsequent standards and the true concentration of the standard sample. It is expressed as mean error.

   Where;
   X = Mean
   TV = True value
   Mean error = X – TV

   If the mean error is high, corrective measure must be taken. Incorrect weight or volumetric flask, pipette, incorrect calibration of instruments, even parallax (the apparent displacement of an observed object due to a change in the position of the observer) can be a source of systematic error.

3. Random error is an imprecise error and not repeatable. This happens due to drainage error in the volumetric glass wear, calibration in the glassware etc.

14.2 RELATIONSHIP OF ACCURACY AND PRECISION WITH SYSTEMATIC AND RANDOM ERROR

In the previous paragraph, the terms accuracy, precision, systematic and random error have been used. In this paragraph, the relationship among them shall be addressed.

- *Accurate value and accuracy:* By definition accurate value and accuracy are termed as true value or near true value
- *Precision:* Precision can be understood by understanding the spread of result in an experiment. If the spread is small, the result is called precise but if the spread is large the result is called imprecise.
- *Repeatability:* Within each run of an experiment (batch run), precision results from repeatability
- *Reproducibility:* Similarity between two experiments (batches) that are precise, results in reproducibility

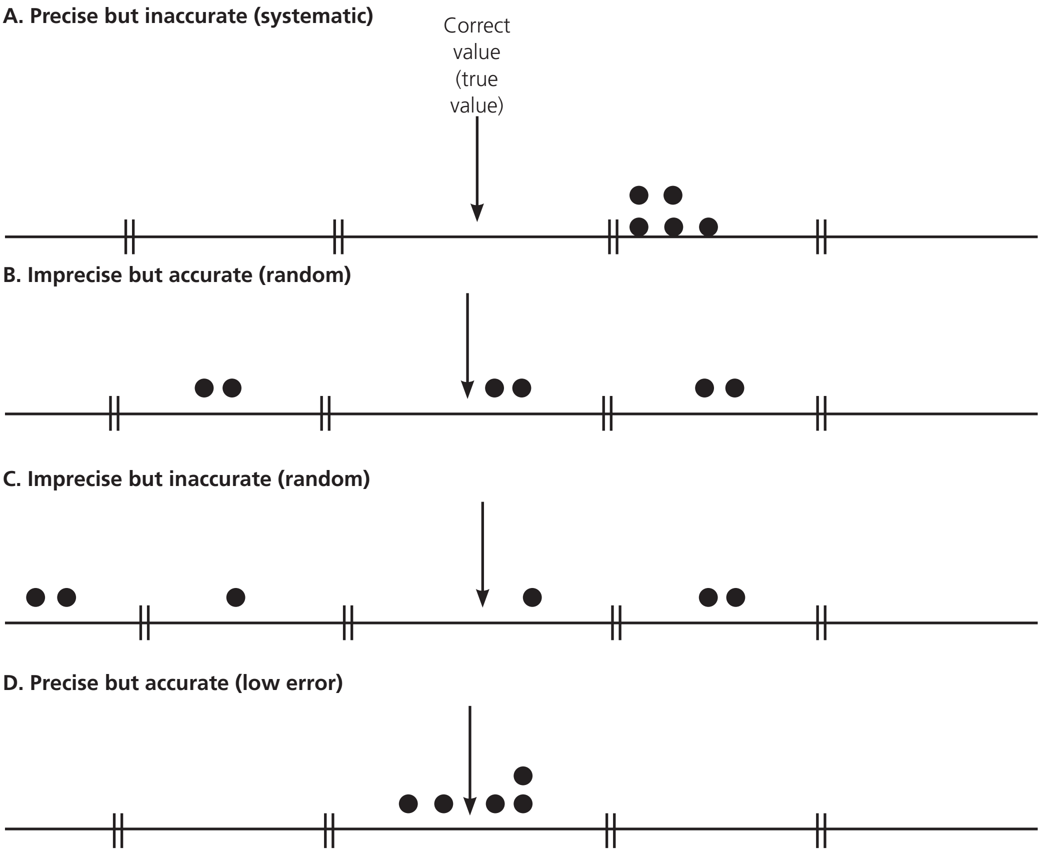
  The interrelationship is illustrated in *Figure 19*, in which four analysts A, B, C, and D produce results of five replicate titrations (titer values) of the same batch.

14.3 ANALYTICAL QUALITY CONTROL PROGRAMME

The objectives of an analytical quality control programme are:

- To assess the status of analytical facilities and capabilities of concerned laboratories

Figure 19: Interrelationship among accuracy, precision, repeatability and reproducibility



Source: J.C. Miller and J.N. Miller 1993. Statistics for analytical chemistry, Ellis Horwood PTR Prentice Hall, New York 1993

- To identify the serious constrains (random and systematic) in the working environment of laboratories
- To provide necessary assistance to the concerned laboratories in overcoming the shortcomings in the analytical capabilities
- To validate water quality monitoring data
- To promote the scientific or analytical competence of the concerned laboratories to a level of excellence for better output
- To enhance the internal and external quality control of laboratories in an organized manner

14.4 BASIC NEEDS OF QUALITY ASSURANCE

To assure good and reliable water laboratory results, the following are required:

- A well-designed sampling programme including sampling, in situ analysis, and sample preservation
- Suitable laboratory facilities
- Up-to-data laboratory instruments, sampling equipment glassware and reagents
- Well-maintained equipment and facilities
- Standardized analytical procedures covering the desired variables
- Well-trained laboratory staff
- Adequate filing and reporting system
- A systematic analytical quality control programme

14.5 QUALITY CONTROL CHARTS

Analytical quality can be violated by random and systematic errors during determination. Random errors are recognized to produce reduction in precision, while systematic errors give rise to reduction in accuracy. To check both types of errors, a quality control chart is based on the assumption that the experimental data has normally distributed errors. A quality control chat should be plotted from the results repeatedly obtained from standard samples of known concentration against time. To prepare a quality control chart, the mean and standard deviations are calculated based on initial calibration study (analysis of at least 20 replicate standards of realistic concentration). The control chart is then constructed with the calibration mean as its central line. Warning and rejection areas are added at ffl two lines and ffl two times the standard deviation from the mean (a) respectively. The analysis is performed each day for the same standard. If the analytical result of standard analysis falls outside the ffl 3 standard deviation line, the analysis is said to be out of control and an immediate check is required to know the cause for this gross analytical error. After corrective measures, the analysis should be repeated. The occurrence of an unduly high percentage of results exceeding the warning limits (two standard deviations) is an indication that laboratory precision may not be as good as expected or that the frequency distribution of the results is not normal. The control limit may be recalculated periodically as experience is gained with the technique. Preferably several standards that span a range of concentrations should be used to ascertain linearity and to avoid unintentional bias due to familiarity with fixed results. A typical control chart is given in *Figure 7*.

14.6 LEVELS OF ANALYTICAL QUALITY CONTROL (AQC) PROGRAMME

The AQC scheme is taken up at two levels:

14.6.1 INTERNAL AQC OR WITHIN-LABORATORY AQC

It is necessary to check the precision and accuracy of analytical results within the laboratory, that will help test the capability of the analytical functions of the laboratory. Various sequential stages involved for each parameter are:

- Choosing an analytical method suitably free from bias and ensuring the complete and unabridged description of that method
- Checking to obtain satisfactory precision with the method
- Establishing a control chart as a continuous check on precision and some source of bias
- Ensuring accuracy of standard solution

14.6.2 EXTERNAL AQC OR BETWEEN-LABORATORY AQC

A group of laboratories must achieve comparability in results by controlling the precision and accuracy of each laboratory. The reasons AQC tests between laboratories are necessary are as follows:

- To test for possible error caused by sources that have not been tested within a laboratory
- To provide direct evidence that the required compatibility of results between laboratories has been achieved
- Accuracy may deteriorate with time, hence subsequent testing on regular basis is required as a continuing check on laboratory bias
- The procedure to convert a method to standard status is done through running collaborative test (inter-laboratory studies)

14.7 DATA INTERPRETATION

Data interpretation and dissemination is the end-product of this programme. Data interpretation must be done with the help of the following statistical tools:

- Control tendencies of data—mean and median
- Spread of data-percentile value, at least 25.50, 90th value
- Temporal trends like non-parametric tests and time series analysis
- Spatial trends and interstation correlation and regression analysis

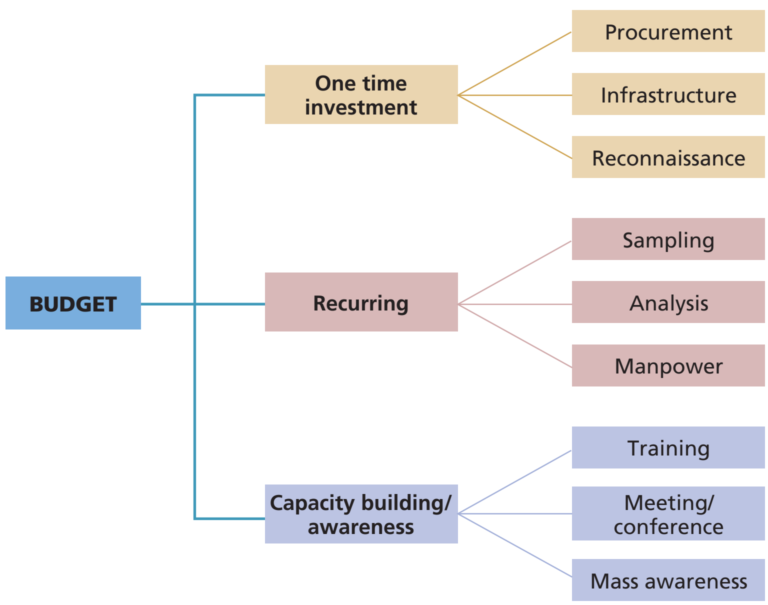
- Exceeding of limit—percentage of data with respect to each parameter
- Interrelation of parameters—correlation and regression

Data analysis helps identify the stretch as relatively good, critical or extremely critical with respect any important parameter. This outcome can also be drawn in some maps. A water quality index can be developed for such a purpose. Box-Wisker plots of a water quality index of every station in a map can also indicate spatial and temporal trends. A separate statistical manual can be brought out in due time for this purpose.

14.8 THINGS TO BE CONSIDERED WHILE PREPARING THE BUDGET

Budget calculations are comprised of two parts, the first is a one-time investment including procurement of equipment and instruments, and infrastructure development. The other is recurring costs that involve procurement of glassware, chemicals, cost of manpower and contingency for field investigation including sampling. In addition, there will be a cost for capacity building for meetings, conferences and costs of mass awareness programmes. The various components of the budget are given in *Figure 20*.

Figure 20: Components of the budget



Source: CSE

15. The way forward

The development of a water quality monitoring network is very crucial for the better management of the Awash River basin. The Ministry of Environment Forest and Climate Change, Ethiopia and the Awash Basin Authority will have to ensure the development of a sound monitoring network to facilitate better management of the basin. Although work in this direction has already been initiated, there are numerous challenges that have resulted in a slower-than-expected growth in the network. The main reasons for this are the high capital costs required for setting up the network stations, carrying out the sampling and analysis related work, hiring well-skilled man power and staff, and ensuring the fulfilment of other logistical and infrastructure requirements. Achieving all this is highly unlikely since the money allocated for monitoring on an annual basis is much lower than that required to support the necessary monitoring network.

This has also resulted in the authorities not having adequate representative and workable trend data that would have helped policy makers to undertake science-based decision making.

Under such circumstances, the use of SMART and Affordable technologies would be a viable alternative. SMART systems can be defined as systems that are based on self-monitoring, analyzing, and reporting technology and are very handy instruments that can be used in situ and give us instantaneous results, especially for non-conservative parameters, the values of which changes quickly after sampling. Equipment used by such systems can either be sensor-based or a field test kit-based and make use of established laboratory-based methods that have been miniaturized for them to be used in the field with ease. Parameters like dissolved oxygen, pH, total dissolved solids (TDS), alkalinity, turbidity, hardness, chloride, fluoride, nitrate, iron, ammonia, nitrite, phosphate and residual chlorine can be easily tested in situ. This will not only save a lot of time and resources but will also make the monitoring programme more efficient and that too without any significant increase in the budgetary allocations to the department.

More importantly, this technology can help address the current challenges in water quality monitoring in Awash River basin while providing an opportunity to the authorities to be able to build a denser water quality monitoring network that would result in the generation of more data for each season or month.

If quality control and assurance are carried out properly, data generated will be reliable and its analysis will result in drawing better observations by field scientists. This will prove to be crucial for the decision makers in making a sound management plan for the basin in the years to come. Therefore, the use of SMART and affordable devices, in conjunction with the traditional regulatory practices, is highly recommended for establishing and strengthening the current water quality monitoring network in the Awash River basin.

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