Module 1: Introduction to the Course on Water Quality Assessment
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1.1. UNESCO-IHE Institute for Water Education (see: www.unesco-ihe.org)

The UNESCO-IHE Institute for Water Education was established in 2003. It carries out research, education and capacity building activities in the fields of water, environment and infrastructure. UNESCO-IHE continues the work that began in 1957 when IHE first offered a postgraduate diploma course in hydraulic engineering to practising professionals from developing countries.

The Institute is based in Delft, the Netherlands, and is owned by all UNESCO member states. It is established as a UNESCO ‘category I’ institute jointly by UNESCO and the Government of the Netherlands.

The Institute is the largest water education facility in the world, and the only institution in the UN system authorised to confer accredited MSc degrees. UNESCO-IHE is instrumental in strengthening the efforts of other universities and research centres to increase the knowledge and skills of professionals working in the water sector.

Vision and mission
UNESCO-IHE envisages a world in which people manage their water and environmental resources in a sustainable manner, and in which all sectors of society, particularly the poor, can enjoy the benefits of basic services.

The mandate given by UNESCO to IHE is to:
- strengthen and mobilise the global educational and knowledge base for integrated water resources management; and
- contribute to meeting the water-related capacity building needs of developing countries and countries in transition.

Within this mandate, the mission of the Institute is to:
- contribute to the education and training of professionals and to build the capacity of sector organisations, knowledge centres and other institutions active in the fields of water, the environment and infrastructure in developing countries and countries in transition.

The functions of the Institute include:
- Serving as an international standard-setting body for postgraduate water education programmes and continuing professional training;
- Building human and institutional capacities through education, training and research;
- Setting up and managing networks of educational and water sector institutions and organisations worldwide;
- Functioning as a ‘policy forum’ for UNESCO member states and other stakeholders; and
- Providing advice on water education to partner organisations and other members of the UN water family.
Beneficiaries and clients
UNESCO-IHE provides a wide range of services to a variety of target groups in developing countries and countries in transition:

- Education, training and research – for water sector professionals, engineers, scientists, consultants and decision-makers working in the water, environment and infrastructure sectors.
- Water sector capacity building – for water sector ministries and departments, municipalities, water boards and water utilities, universities, training and research institutes, industries, non-governmental and private sector organisations.
- Partnership building and networking – among knowledge centres, public and private sector organisations.
- Standard setting for education and training – for water-related institutions, universities and other education and training agencies in the water sector.
- Policy forum on water – for UNESCO member states and other stakeholders.

1.2. Course lecturers

Peter Kelderman - Senior Lecturer in Environmental Chemistry
Dr. Peter Kelderman has been attached to UNESCO-IHE since 1983. His academic teaching subjects include: Water Quality and Monitoring, General and Environmental Chemistry; Laboratory Chemistry; Water Quality Management and Modelling, and Aquatic sediments. He has also been teaching these subjects in many countries world-wide.

Before 1983, he was attached to the Netherlands Institute for Ecological Research (NIOO-CEMO), where he carried out a PhD study on sediment-water interaction of nutrients in a shallow, saline lake. For this, multidisciplinary research was undertaken in the field of sediment dynamics, pore water qualities, experiments on sediment water interaction under different environmental conditions.

Peter has supervised some 75 MSc and 8 PhD participants, mainly in the fields of water quality management and aquatic sediments, and has done much own research, mainly in the field of interactions between water and sediment, of nutrients and heavy metals. He has presented his work in many conferences and seminars and has published (by 2015) some 90 papers for peer reviewed journals and Conference Proceedings.

Gretchen Gettel - Senior Lecturer in Aquatic Biogeochemistry
Dr. Gretchen Gettel joined UNESCO-IHE in May 2010. Her research activities are focused on understanding the role of aquatic and wetland ecosystems in maintaining good water quality in the context of land use and climate change. Her research has focused mainly on nitrogen and carbon biogeochemistry.

Prior to arriving at UNESCO-IHE, Gretchen was employed at the University of New Hampshire as a post-doc and then as research scientist (2005 - 2010). There she studied the effects of rivers and wetlands in the processing of nitrogen and carbon at whole-basin scales. In 2006, Gretchen completed her Ph.D. from the Cornell University, USA, in the programme of Biogeochemistry and Environmental

Diederik Rousseau

Prof. dr. ir. Diederik Rousseau has been working at the Department of Environmental Resources at UNESCO-IHE Delft from 2005-2011. Currently he is working at the Ghent University (Belgium), in the field of environmental engineering. He holds both an MSc (1999) and PhD (2005) degree from the Ghent University, in Applied Biological Sciences - Environmental Technology.

With respect to Research, Diederik’s main expertise is natural systems for wastewater treatment, in particular constructed treatment wetlands and waste stabilization ponds. His own research as well as the results by numerous MSc and PhD fellows under his supervision has resulted in a large number of publications, among others (2015) some 40 peer-reviewed papers, 6 book chapters and 50 papers in proceedings of international conferences. He is a regular reviewer for various journals and is also actively involved in the WETPOL and IWA (Constructed) Wetland conferences.

Tamara Avellán

Dr. Tamara Avellán commenced her academic career in biology at the Ludwig Maximilian Universität, Germany, where she obtained her Vordiplom in 2002. Two years later, she graduated with a Master of Science in Biological Science from the Wayne State University, USA.

She was then invited to continue researching in the same institute where her focus lay on the ecotoxicological effects of heavy metals on the leaf morphology of submerged aquatic plants. In 2007, she returned to her home country, Uruguay, where she worked as an independent environmental consultant, performing e.g. environmental quality assessments. After receiving her PhD, Tamara now works as Research Fellow at the Water Resources Management Unit of the United Nations University, UNU-FLORES, in Dresden, Germany.

Mário Chilundo

Mário Chilundo is an Agriculture Engineer, lecturer at the Eduardo Mondlane University (EMU), Faculty of Agronomy and Forestry Engineering, Maputo, Mozambique. He has been involved in teaching subjects such as: Hydraulics; Irrigation Projects; Water in Agriculture; Irrigation and Drainage. He has also been involved as course facilitator on topics related to water management (e.g. tropical wetlands management; climate change impacts on water resources; integrated water resources management); and in setting up a water quality monitoring network for the Limpopo river basin.
Mário holds a BSc at EMU with honours in Agronomy (Rural Engineering) since 2002 and also a UNESCO-IHE MSc degree in Environmental Science-Water Quality Management. Currently, he is a PhD fellow at the Swedish University of Agricultural Sciences, and carries out research on Soil and water management in Agricultural systems. His activities have resulted into several scientific papers, reports as well as conference papers.

Fred Kruis

Fred Kruis is the Head of the Environmental Laboratory for Education and Research at UNESCO-IHE. He has experience in laboratory training and the establishment and management of environmental laboratories. Since 1991 his expertise is also used in teaching abroad where he was frequently involved in several capacity and/or consultancy projects. He has a BSc degree in Analytical Chemistry and his specialisation is in the field of Water Quality, groundwater as well as surface water and wastewater analysis.

Fred is also advising and guiding PhD and MSc students of UNESCO-IHE with their laboratory experiments. Since a few years he is involved in the design, construction and on site installation of pilot plants for the removal of pollutants in order to produce good-quality drinking water.

Extra information

- If you want more information on UNESCO-IHE, you can find a short introduction movie on YouTube: http://www.youtube.com/watch?v=A_rQ_hPyJsI. There are also other movies available, among others about the history of the institute. Simply type the keyword UNESCO-IHE in YouTube to access this information.

Unit 2 – General overview of the Course contents

2.1. Objectives of the Course

Over large parts of the world, rivers, lakes and ground water show increasing trends of water pollution. This holds especially for developing countries under economic expansion and increasing population sizes. Evaluation of the physical, chemical and biological water quality is essential for the abatement of freshwater pollution. For this, sound and sustainable water quality assessment programmes should be
aimed at integrating the different steps in the monitoring cycle, from the information needs, monitoring network design, field and laboratory procedures up to data collection and processing. The resulting water quality data can then be evaluated together with the natural water quality, human effects and water quality usages. Optimization of the water quality monitoring programmes, amongst others with respect to cost, should ensure that these programmes are sound and sustainable, also in future.

After successful completion of the Course, participants will be able to:
- Understand and apply concepts of water quality and pollution processes in rivers and lakes
- Understand and apply the different steps of the monitoring cycle in rivers and lakes
- Understand key concepts of groundwater quality monitoring
- Understand and apply common statistical techniques for water quality data evaluation
- Apply key concepts in the design of sustainable freshwater quality monitoring programmes.

2.2. Course contents

This Course consists of five Modules:
1. Introduction to the Water Quality Assessment Course
2. Water Quality and Pollution
3. Water Quality Monitoring and Assessment
4. Data handling and presentation
5. Design factors for a sustainable monitoring network for the Limpopo River Basin, Mozambique.

Module 1: Introduction
This Module will first introduce you to UNESCO-IHE and the teachers. After that we will review the contents of the Course. Finally we will introduce you to the world of Water and Water Quality, with some general information about “Water and Life” and “Sustainable Use of Water”.

Module 2: Water Quality
We will discuss the main water quality and pollution characteristics in rivers and lakes and the processes that affect these.

Module 3: Water Quality Monitoring and Assessment
In this module you will learn how to apply the different steps of the monitoring cycle in rivers and lakes. In less detail we will also consider some important factors in groundwater pollution and monitoring.

Module 4: Data handling and presentation
We will show you how to apply important statistical techniques in handling your monitoring data. Also we will review how to best present monitoring results.

Course 5: Design concepts
In this final Module, we will present some items that are essential in the design of a sustainable water quality monitoring programme; for this we use a specific region, viz. the Limpopo river basin in Mozambique.
2.3. Target group

The Course is designed for professionals actively involved in water quality monitoring and management. They may be working e.g. for environmental agencies, consultants, as environmental or water management officers in local, regional or national governments, as staff of NGOs, or as junior university lecturers, and may not have the time to undertake a course that lasts several weeks abroad.

2.4. How to study this Course and use the learning materials

Each unit consists of a number of learning materials. For most units, the basic materials consist of PowerPoint presentations with or without audio, lecture notes and supplementary materials such as YouTube videos. The PowerPoint presentations introduce the topic, whereas the lecture notes treat the topic more extensively. The supplementary materials are offered for further study. Some assignments will be used to let you check newly gained knowledge; these assignments are for self-evaluation. In contrast to UNESCO-IHE’s Online Courses (www.unesco-ihe.org), no contacts will take place with lecturers, internal and external experts, and with other Course participants.

Lecture notes. The lecture notes for each course, except #4, give additional information. They deal with the Module topics in-depth and contain references to scientific literature sources and background materials.

Manuals. In developing this Course, we have followed partly the book by D. Chapman (1996): Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring - Second Edition. Chapman & Hall, on behalf of UNESCO, WHO and UNEP. In the lecture notes and/or PowerPoints, we will refer to certain pages of this book whenever appropriate. Besides that, use will be made of more recent developments in water quality monitoring and assessment, via reports, books, websites, etc.

2.5. Study load

The following table indicates the estimated study load for each Module. This is the total time needed to view the presentations, read the lecture notes and carry out the assignments. The total study load of the WQA Course is about 110 hours divided, roughly, as follows:

<table>
<thead>
<tr>
<th>Module</th>
<th>Study load hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>14</td>
</tr>
<tr>
<td>Water Quality</td>
<td>24</td>
</tr>
<tr>
<td>Water Quality Monitoring and Assessment</td>
<td>40</td>
</tr>
<tr>
<td>Data handling and presentation</td>
<td>20</td>
</tr>
<tr>
<td>Design concepts</td>
<td>12</td>
</tr>
<tr>
<td>TOTAL</td>
<td>110</td>
</tr>
</tbody>
</table>
To-do-List for Unit 2

- Look at the PowerPoint presentation available as Lecture 1.1.: "General overview", which will give you some more details about the Course contents.
- Make sure you have downloaded and glanced through the book of Deborah Chapman, 1996, downloadable by: http://who.int/water_sanitation_health/resourcesquality/watqualassess.pdf?ua=1

Unit 3 – Water and Life
On the importance of water

This introduction to the topic Water Quality Assessment consists of a PowerPoint with audio comments. Four main items are discussed:

1. Water, an extraordinary molecule
2. Water, a multitude of appearances
3. Water, omnipresent but scarce
4. Water, a host of life

3.1. Water, an extra-ordinary molecule

What makes water so special and so essential? It is the fact that it occurs in liquid form at ambient temperatures (in fact between 0 – 100 °C). Most other molecules of similar composition and with similar small dimensions occur in the gas phase at these temperatures. This is entirely due to the structure of the water molecule and as a consequence its capacity to form bonds with other water molecules. The angle between both H atoms is not 90° but 104.5°. As a result, electrons (with negative charge) are “pushed” to the right hand side of the molecule (as depicted in Fig. 1) causing a negative load on the O side, and a positive charge at the H side. This makes water molecules strong dipoles, in fact they can be considered as tiny magnets. The negative side of one molecule will then attract the positive side on another molecule and a bond will form between both molecules (right hand picture below) which is called a “hydrogen bond”. These bonds make that individual water molecules cannot escape so easily to the gas phase; hence water remains liquid at ambient temperatures.

![Water molecule showing the dipole (left) and formation of hydrogen bridges between water molecules (right)](image_url)
What other consequences are there? For those that remember Chemistry classes, atoms/molecules "move" with a frequency/magnitude which is proportional to the temperature. At the absolute zero point (0 Kelvin = -273 ºC), molecules do not move at all; with rising temperatures movement increases. This is called Brownian motion (named after the Scottish botanist Robert Brown): the seemingly random movement of particles suspended in a liquid or gas. Therefore water molecules at 20 ºC move more than molecules at 10 ºC. As a consequence, the hydrogen bonds are stretched and molecules move a bit further away from each other. This means that fewer molecules will occur in the same volume or in other words this will have an effect on the density of water: the density of water decreases as the temperature increases.

At a temperature of 100 ºC, the movement of the individual molecules has become so strong that they can break the hydrogen bonds and escape to the atmosphere (they become water vapour = gas). This is called the boiling point.

At a temperature of 0 ºC, the movement has become so small that the hydrogen bonds are sort of "solidifying" and water starts forming crystals which are known as ice. Between the molecules there are large voids so water in this condition has a low density. That is why ice is floating on water (density of ice < density of liquid water).

The balance point between both processes is at 4 ºC, so at this temperature water has the highest density. A summary of all this is given in Fig. 2, showing the so-called "density anomaly" of water. This is extremely important for aquatic life because water with the highest density will always sink to the bottom, so the water temperature of the deepest water layers (in relatively deep water bodies) will never go below 4 ºC, which

![Fig. 2. Density of water at different temperatures](image-url)
is enough to allow survival of plants and animals. Imagine this would not be the case: if ice would sink, then as soon as it would be formed at the surface, it would sink down and crush all organisms below it.

This whole mechanism is also important in view of climate change! Higher temperatures will melt more ice, but since ice is floating on the oceans (e.g. icebergs); this will not change the water volume (or sea level). Of course this is not true for land ice (e.g. glaciers, the ice on Greenland). But higher temperatures also mean that water will heat up and so its density will decrease, meaning that the same mass of water will now occupy a larger volume. This could contribute to rising sea levels.

Different layers of water with different temperatures will have different densities. Let us take the example shown above: the deepest layer of a deep lake could have a temperature of 4 °C and the surface layer could have a temperature of 20 °C. The water with the highest density thus occurs in the bottom layer, the water with the lowest density occurs in the surface layer. Because “lighter” water will always stay on top, and “heavier” water always on the bottom, there will be little or no mixing between the different layers. This is called “stratification”. Stratification can be annulled when a change in air temperature changes the water temperature of the surface layer and hence its density. Then a new equilibrium will be established.

It is important to point out that density differences and hence stratification can also be caused by different concentrations of dissolved solids. The most common example is the effect of salt on density: a higher salt content means a higher density, thus sea water has a higher density than freshwater. An extreme case is the Dead Sea which has very high salt levels and thus also a high density. This makes it easier to float in the water, and you can easily find pictures of people floating in the water without any effort and reading for instance their newspaper. In an estuary, where freshwater from a river “meets” sea water, two distinct layers are formed, with freshwater on top and sea water in the deeper layers.

3.2. Water, a multitude of appearances

Water occurs in many different forms: lake water, river water, ocean water, ground water, water vapour in the air, clouds, ice, in the body of animals and plants. All these forms of water are connected via the so-called "Hydrological Cycle", see Fig. 3.

Precipitation: water vapour in the air can condensate and form clouds out of which precipitation can occur. Depending on the air temperature, this can occur in liquid (rain) or solid (snow, hail) form.

Runoff versus infiltration: precipitation that reaches ground level can penetrate in the soil when the soil characteristics (permeability) allow it – called infiltration -, or form runoff in case the soil is more or less impermeable. One of the main causes of flooding nowadays is the fact that in expanding cities more and more surface becomes impermeable (concrete, asphalt) so more runoff is formed which eventually exceeds the capacity of the drainage systems and results in flooding.

Groundwater and springs: water that infiltrates into the soil is called ground water. When because of local topography this ground water surfaces again, this is called a spring. Alternatively groundwater can reach rivers or oceans – ground water discharge – or remain in the soil for a long period of time – ground water storage -.
**Surface flow:** water always flows to the lowest point. When sufficient quantities come together, surface flow can occur; usually first as small brooks or rivulets, later as big rivers. The largest river on earth is the Amazon river in South-America, which is more than 6500 km long and has a final discharge of about 250,000 m³ per second; this equals the volume of some 80 Olympic swimming pools passing per second. Brooks and rivers usually discharge into: (1) another river, (2) a lake, (3) a sea or ocean. In exceptional cases there is no discharge, such as the Okavango River in Botswana. Evaporation (see below) is so high that 97% of all water is lost to the atmosphere so once the river has reached its delta (a large wetland area), it just stops flowing.

**Evapotranspiration:** this is the combined process of water loss to the atmosphere by evaporation (physical process) and by transpiration (by plants). Plants living in arid areas try to minimize their transpiration losses by reducing leaf areas (needles instead of leaves), having a wax-layer on the leaves etc.

**Condensation:** the conversion of water vapour into liquid water. When this happens on a large scale, clouds are formed.

**Surface water** is often divided into three categories depending on salt contents
- freshwater: < 0.5 ‰ dissolved salts (< 0.5 g per litre)
- brackish waters: 0.5 – 30 ‰ dissolved salts (0.5 – 30 g per litre)
- marine water: 30-50 ‰ dissolved salts (30-50 g per litre)

Approximately 71% of the Earths’ surface is covered by oceans and seas, the majority of which occurs in the southern hemisphere.
Most inland water is actually fresh water, such as lakes, rivers, pond, swamps etc. Also here three categories exist:

- Aboveground (river, lake, ...) versus below ground (ground water)
- Stagnant (lake, pond, ...) versus running (river, brook)
- Natural (river, swamp, ...) versus artificial (canal, hydropower reservoir, ...)

In particular for a lake or reservoir, it can be useful to draw up a water balance or water budget. This balance takes into account all inputs and outputs of water to calculate the change in storage volume of a lake. In case the area is known, this balance can also be used to calculate the change in water level. In most cases the balance will consist of the following components:

**INFLOWS**

- Inflow rate \(Q_i\) \(\text{m}^3/\text{day}\)
- Catchment runoff \(Q_c\) \(\text{m}^3/\text{day}\)
- Precipitation \(A \times P\) \(\text{m}^2 \times \text{m/day}\)
- Infiltration \(A \times I\) \(\text{m}^2 \times \text{m/day}\)

**OUTFLOWS**

- Outflow rate \(Q_o\) \(\text{m}^3/\text{day}\)
- Evapotranspiration \(A \times ET\) \(\text{m}^2 \times \text{m/day}\)
- Infiltration \(A \times I\) \(\text{m}^2 \times \text{m/day}\)

Infiltration can be positive or negative, depending on whether the groundwater is feeding the lake, or vice versa. \(A\) is the surface area of the lake \((\text{in m}^2)\).

**Change in stored volume over time**

\[
\Delta V = \frac{\Delta t}{t} = Q_i + Q_c + Q_{im} + (P \times A) - Q_o - (ET \times A) \pm (I \times A)
\]

For the theoretical case of a cubical lake with surface area \(A\) and depth \(d\), we can state that: \(V = A \times d\) and since \(A\) is constant, we can simplify to:

\[
\frac{\Delta d}{\Delta t} = \frac{(Q_i / A) + (Q_c / A) + (Q_{im} / A) + P - (Q_o / A) - ET \pm I}{\Delta t}
\]

3.3. Water, omnipresent but scarce

Despite the fact that almost three quarters of the Earth surface are covered with water, very few of that supply is actually directly consumable by humans as well as flora and fauna. We will focus on human use here.

Consider Table 1:

- 93.94% of all water on earth is salt water in oceans and seas, which is not fit for consumption (drinking, irrigation, ...) except when expensive and energy-demanding technologies such as membrane filtration or distillation are applied;
- 4.11% occurs as deep groundwater, which is hardly or not accessible
- 0.27% occurs as active groundwater, and could potentially be used for consumption
- 1.65% is locked in glaciers and permanent snow cover
- 0.02% of freshwater is contained in lakes
- <0.01% is present as soil moisture (bound to soil particles, not for consumption)
- <0.001% occurs as vapour in the atmosphere
- <0.0001% is present in rivers, brooklets etc.
The exact % might vary a little bit between various sources, but the main message is that only about 0.3% of all water on earth is potentially available for (almost) direct consumption! And we are polluting this water reserve at a very high pace; hence good water quality management is an absolute and urgent necessity.

### Table 1 — Distribution of water in the hydrosphere (from Llovich, 1979)

<table>
<thead>
<tr>
<th></th>
<th>Volume (km$^3 \times 10^3$)</th>
<th>Percentage of total vol.</th>
<th>Per cent of Replacement fresh water time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceans</td>
<td>1370323</td>
<td>93.94180</td>
<td>3000</td>
</tr>
<tr>
<td>Deep groundwater</td>
<td>60000</td>
<td>4.11320</td>
<td>5000</td>
</tr>
<tr>
<td>Active groundwater</td>
<td>4000</td>
<td>0.27400</td>
<td>14.094 330</td>
</tr>
<tr>
<td>Ice</td>
<td>24000</td>
<td>1.64500</td>
<td>84.566 8000</td>
</tr>
<tr>
<td>Lakes</td>
<td>280</td>
<td>0.01900</td>
<td>0.987 7</td>
</tr>
<tr>
<td>Soil moisture</td>
<td>85</td>
<td>0.00580</td>
<td>0.299 1</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>14</td>
<td>0.00096</td>
<td>0.049 0.027</td>
</tr>
<tr>
<td>Rivers</td>
<td>1.2</td>
<td>0.00008</td>
<td>0.004 0.031</td>
</tr>
<tr>
<td>Freshwater total</td>
<td>28380.2</td>
<td>1.92000</td>
<td></td>
</tr>
<tr>
<td>Water, Grand total</td>
<td>1458703</td>
<td>99.99984</td>
<td>99.999 2800</td>
</tr>
</tbody>
</table>

### 3.4. Water, a host of life

#### 3.4.1. Introduction

From now on, we will only consider fresh water. Management of oceans, seas and coastal zones is a discipline in itself and does not fall within the scope of this module.

It is important when talking about water quality assessment to know something more about the different zones in water bodies and the different communities that inhabit these zones. Intuitively you should already expect variations in water quality and
variations in community composition between for instance the deeper layers of lake and the surface layer, or between a small mountain spring river and the estuary of the Amazon River.

In very general terms, life in fresh water is governed by:

- high density of the medium
- lack of salt in the medium
- high solubility for inorganic and organic materials
- formation of vertical profiles

Salinity and density and density profiles (stratification) were discussed briefly before. Density stratification very often divides a deep lake into two parts: an upper part with a high water temperature which is called the epilimnion, and a deep part with a lower water temperature which is called the hypolimnion. In between there is often a narrow zone with a sharp temperature decline which is called the thermocline: see Fig. 4 for the indications.

Figure 4 shows the temperature profile and associated zonation in a lake.

Especially for plants however, there is another vertical profile which is extremely important, and that is the profile of light intensity. Light is an absolute requirement for photosynthesis, or "primary production" in which algae (phytoplankton) and plants can convert, in the light, CO$_2$ from the air, to new cell material and oxygen, O$_2$. The reverse process is called "respiration" and takes place all of the time. It will consume O$_2$ and produce CO$_2$. Later, we will come back to these very important processes.

At the water surface, light intensity is obviously at its highest value, and then decreases exponentially with depth. The euphotic zone is the zone where primary production can take place; the light intensity falls between 100 and about 1%. For pure water, the euphotic zone would extend to approximately 200 m below the water surface but in

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1 In fact, the in-between layer is called: metalimnion; the depth of highest temperature gradient is called thermocline.
reality it is often less than 50 m and in extreme cases even less than 1 m. This
decrease in light intensity with depth depends on some water characteristics: the more
particles there are (higher "turbidity; see later), the more quickly light will be absorbed.
The compensation plane or depth is the depth at which photosynthesis equals
respiration; above it is the euphotic zone.
Solubility of materials is another important factor. Nutrients (N, P, K), for instance,
dissolve easily in water and therefore also easily reach the plants in the water that
need nutrients for growth. Another crucial element is obviously oxygen. Although
concentrations in water are a lot lower than concentrations in the air, it can still dissolve
in sufficient quantities to be used by fish and other animals for respiration.

3.4.2. Subdivisions and communities in lakes (taken from www.lakeaccess.org)

A typical lake has distinct zones of biological communities linked to the physical
structure of the lake (Fig. 5). The littoral zone is the near shore area where sunlight
penetrates all the way to the sediment and allows aquatic plants (macrophytes) to grow.
The higher plants in the littoral zone - in addition to being a food source and a substrate
for algae and invertebrates to attach to - provide a habitat for fish and other organisms
that is very different from the open water environment.

![Fig. 5. Lake zonation (Source: www.lakeaccess.org)](https://www.lakeaccess.org)

The limnetic zone, also called pelagic zone is the open water area where light does
not generally penetrate all the way down to the bottom. The bottom sediment, known
as the benthic zone, has a surface layer abundant with organisms. This upper layer of
sediments may be mixed by the activity of the benthic organisms that live there, often
to a depth of 2-5 cm in organic-rich sediments. Most of the organisms in the benthic are
invertebrates, such as insect larvae (midges, mosquitoes, black flies, etc.). Higher plant
growth is typically sparse in sandy sediment, because the sand is unstable and nutrient
deficient. A rocky bottom has a high diversity of potential habitats offering protection
(refuge) from predators, substrate for attached algae (periphyton on rocks). A flat
mucky bottom offers abundant food for benthic organisms but is less protected and
may have a lower diversity of structural habitats, unless it is colonized by higher plants.
In each of these zones different communities of organisms occur. Table 2 summarizes them based on two criteria: (1) living in the water or on the bottom and (2) for those living in the water their ability to swim against currents.

**Table 2. Lake organisms.**

<table>
<thead>
<tr>
<th>THOSE THAT GO WHERE THEY CHOOSE = NEKTON</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FISH</strong></td>
</tr>
<tr>
<td>Fish</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THOSE THAT GO WHERE THE WATER TAKES THEM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LIVING THINGS = PLANKTON</strong></td>
</tr>
<tr>
<td>Animals - zooplankton</td>
</tr>
<tr>
<td>Algae - phytoplankton</td>
</tr>
<tr>
<td>Bacteria - bacterioplankton</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DEAD STUFF = DETRITUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal - produced within lake</td>
</tr>
<tr>
<td>External - washed in from watershed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THOSE THAT LIVE ON THE LAKE BOTTOM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BENTHOS = ANIMALS</strong></td>
</tr>
<tr>
<td>Aquatic insects</td>
</tr>
<tr>
<td>Molluscs - clams, snails</td>
</tr>
<tr>
<td>Other invertebrates - worms, crayfish</td>
</tr>
</tbody>
</table>

| **PLANTS** |
| Higher plants - macrophytes |
| Attached algae - periphyton |

| **BACTERIA & FUNGI** |
| Sewage sludge |
| Aufwuchs - mixture of algae, fungi and bacteria |

### 3.4.3. Subdivisions and communities in flowing waters

The main difference between rivers and lakes is that the water is flowing, fast or slow, but in any case such that the residence time of water is much lower in a river than in a lake. This has consequences for the colonization of rivers by organisms. Especially for fast-flowing rivers, it is easy to understand that weak organisms that do not have enough power to fight the currents (such as small planktonic organisms), will be dragged along by the water.

River plankton can only reach high concentrations when the residence time > generation time. For example when the doubling time of a particular species is one day and it takes the river several days before discharging in the ocean, then the algae have a chance to reproduce. In the opposite case (e.g. doubling time of 3 days, only one day before reaching the ocean), then the algae population has not enough time to grow.

Freshwater **benthic macroinvertebrates** are animals without backbones that are > 0.5 mm (and therefore visible with the unaided eye). These animals live on rocks, logs, sediment, debris and aquatic plants during some period in their life. The benthos include crustaceans such as crayfish, molluscs such as clams and snails, aquatic worms and the immature forms of aquatic insects such as stonefly and mayfly nymphs. They are an important part of the food chain, especially for fish (see later). Many invertebrates feed on algae and bacteria, which are on the lower end of the food chain.
Because of their abundance and position as “middlemen” in the aquatic food chain, 
benthos plays a critical role in the natural flow of energy and nutrients.

These organisms are very often used as indicators of the water quality, as we will see 
later in Module 3 – Water Quality Monitoring.

To-do- List for Unit 3

- Look and listen to the PowerPoint presentation available under 1.2.: "Water and 
life"
- Watch the YouTube illustrations given below

YouTube illustrations

- Properties of water
  http://www.youtube.com/watch?v=QH1yphfqlFI
- Illustration of the density differences between warm and cool water
  http://www.youtube.com/watch?v=_Ww6Bfy3nc0

Unit 4 – Sustainable Use of Water
On the uses and abuses of water

This topic on the Sustainable Use of Water consists of a PowerPoint with audio 
comments. Three main items are discussed:

1. Water, a matter of life and death
2. Use and abuse of water
3. United Nations GEMS/Water Programme

4.1. Water, a matter of life and death

The human body consists for on average 55-60% of water. Without food you can 
survive several weeks, without water just a few days (depending on ambient 
temperatures and activities). So water, after oxygen, is the most crucial substance for 
human beings. This water should also be of a minimum quality in order to be potable 
and not cause diseases among those people that drink it.

Yet, about 800 million people on the planet lack access to a steady supply of clean 
water²; and this is further exacerbated by the fact that about 2.5 billion people do not 
have proper sanitation, which results in further pollution and thus degradation of water 
resources. As a consequence, more than 350 million people suffer from water related

² See e.g. http://water.org/water-crisis/one-billion-affected/
diseases such as diarrhoea, schistosomiasis etc., resulting in a death toll of about 3.5 million each year!

Water resources are unequally distributed over the world. Compare for example the arid Middle-East with the humid tropics of the Amazon region. Climate change and population increase are likely to enhance this inequality. In 2003, about 40% of the world’s population was living in areas with moderate to high water stress; the projection for 2025 is that 66% of the population will live in such areas.

In reality though, most regions do have enough water to meet everyone’s need, but there are many problems in terms of:

- **Quantity**: unequal/unfair distribution over agricultural, industrial and domestic uses but also inefficient use (e.g. 60% of water used in agriculture is lost due to inefficient irrigation)
- **Quality**: pollution of water resources thus making them less useful

This unequal distribution of water can be the cause of conflicts between countries or regions in case of transboundary water resources. For example a dam on the upstream part of a river will reduce water availability for downstream users. Just type the keyword “water wars” in any internet search engine to get a wide range of examples.

In fact there are about 260 international basins that are being shared amongst 145 nations. In these international basins live ca. 40% of the world’s population and they contain some 60% of the global freshwater flow. Fortunately, real conflicts in these basins are rather rare because of increasing international cooperation. During the last 50 years there have been “only” about 40 acute disputes involving violence, whereas more than 150 treaties were signed to peacefully resolve conflicts.

Some examples of international management of river basins are:

- International Commission for the Protection of the Rhine (http://www.iksr.org/)
- Danube Commission (http://www.danubecom-intern.org/)
- Mekong River Commission (http://www.mrcmekong.org/)
- Amazon Cooperation Treaty Organisation (http://www.otca.org.br/en/)

To focus the attention on all these issues, and to search for sustainable solutions, among others the United Nations has triggered many initiatives:

- **UN Water Conference** held in Mar del Plata in 1977 agreed that all peoples have the right to have access to drinking water to meet their basic needs.

- The **1986 Declaration on the Right to Development**, adopted by the UN General Assembly, includes a commitment that States shall ensure equality of opportunity for all in their access to basic resources.

- The concept of meeting basic water needs was further strengthened during the **1992 Earth Summit** in Rio de Janeiro and expanded to include ecological needs.

- In Agenda 21, governments agreed that “in developing and using water resources, priority has to be given to the satisfaction of basic needs and the safeguarding of ecosystems. Beyond these requirements, however, water users should be charged appropriately.”

- **World Water Day** on 22 March of each year

- **2002 General Comment No. 15** on the implementation of Articles 11 and 12 of the 1966 International Covenant on Economic, Social and Cultural Rights: the
Committee noted that “the human right to water is indispensable for leading a life in human dignity. It is a prerequisite for the realization of other human rights.”

- **2003** was announced the International Year of Freshwater
- **E.g.,** for 2014, activities have included the **Stockholm World Water week** (an annual event), and various task force meetings in Geneva (Switzerland).
- Millennium Development Goal number 7: Ensure Environmental Sustainability
  - Target 1: Integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources
  - Target 2: Reduce biodiversity loss, achieving, by 2010, a significant reduction in the rate of loss
  - Target 3: Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation

Of course many other initiatives exist across continents, regions, countries and cities to protect freshwater resources and ensure equal and sufficient access to water resources for all.

### 4.2. Uses of water

The reason why the protection of our water resources is so important is among others that they have many functions, not only for man but also for ecosystems. A summary is given below, with some anecdotal information per topic.

**Source of drinking water for man and animals:** Water consumption varies considerable between countries, based on cultural habits but obviously also on water availability. In the Netherlands for example, the average consumption is in the order of 120 litres per person per day. Only 2.5% of that volume is really used for drinking and cooking, the rest is used for the shower, laundry machine, toilet flushing etc. When you think carefully about it, this is not very sustainable: a lot of money is invested to produce potable water of the highest quality, to transport it over large distances, after which it is used for ... toilet flushing etc. Therefore in many countries alternative water resources are increasingly being used for this, such as rainwater.

In economically weaker countries in arid regions, water consumption can be limited to just a few litres per day. Women have to walk sometimes several kilometres to encounter a spring or well or stand post and can only carry home a limited amount of water.

Water consumption can also be influenced by the season. Some countries (such as Australia) have sufficient water during winter time (or wet season), but lack water during summer time (dry season). Restrictions might be put in place, such as an interdiction use drinking water for washing your car, irrigating the lawn etc. Of course water is also important for animals. We all know the typical pictures of large herds of animals gathering around the water holes in the Serengeti or in Botswana’s Okavango Delta, as shown in Fig. 6. The most extreme example is of course the camel, which can survive for weeks without water, but can also drink 100-150 litres at a time when water is available.
**Bathing water**: use in bath tubs, showers, public baths etc. Public baths were already used by the ancient Greeks for example in the sixth century BC.

**Washing water**: water used for doing the laundry, washing your car, cleaning the house etc.

**Irrigation of arable land**: Archaeological investigation has identified evidence of irrigation in Mesopotamia and Egypt as far back as the 6th millennium BC, where barley was grown in areas where the natural rainfall was insufficient to support such a crop. Since then of course the practice has spread to practically every country around the globe. As an illustration, some country-specific information cited in Wikipedia is given below:

- **Australia**: Water consumption by the agriculture industry was 33 gigalitres (GL) in 2009-10, accounting for 52% of total water consumption in Australia during that period. Since 2005 climatic conditions and reduced allocations have caused the total water consumed to decline by 30% from 2004-2005 down to 8,521 GL in 2006-2007. The total gross value of irrigated agricultural production in 2004-05 was $AUD 9,076 million. Common crops produced using irrigation include rice, cotton, canola, sugar, various fruits and other tree crops and pasture, hay and grain for use in beef and dairy production.

- **Colombia**: Colombia has approximately 900,000 hectares of irrigated agriculture, which represents 16.3% of all agricultural land. Most of this is simple gravity irrigation.

**Fisheries and aquaculture**: According to the FAO, in 2012, the total world production of fisheries was 158 million tonnes of which aquaculture contributed 66.6 million tonnes or about 42% of the total world production. The growth rate of worldwide aquaculture has been sustained and rapid, averaging about 8 percent per annum for over thirty years, while the take from wild fisheries has been essentially flat for the last decade.
Industrial and municipal supplies: Water is obviously needed during various industrial production processes, directly for instance for the production of drinks, but also indirectly for instance for rinsing recycled glass bottles, rinsing machines etc.

Cooling water: a particular form of industrial use, used for cooling machinery but also used in power plants for cooling the generated steam etc.

Production of hydro-electricity: Hydropower is by definition power that is derived from the force or energy of moving water. Most commonly known are the hydropower dams that are widely used for electricity production. At present, the Three Gorges dam on the Yangtze river in China is the largest hydro-electric power station in the world, generating 22,500 MW. There are however also other forms of hydropower, such as water wheels and water mills which were used already centuries ago, tidal power plant that make use of the sea level difference at low and high tide, and wave power turbines harnessing power from ocean surface wave motion. Worldwide, hydroelectricity supplied an estimated 816 GW in 2005. This was approximately 20% of the world's electricity, and accounted for about 88% of electricity from renewable sources. The “champion” in this field is Norway, where more than 98% of all electricity is generated by hydropower.

Navigation and transport: transport of goods and people by ship

Fishing and body-contact recreation: use of water for recreational purposes, such as swimming, diving, fishing, surfing, ...

Municipal and industrial waste(water) disposal: Many water bodies have been and are still used for disposing of solid waste and wastewater. The impact of this will be an important topic of further study during this course.

Feeding of surface and ground water: As we have seen before (see Hydrological Cycle), precipitation can infiltrate into the soil and replenish the groundwater, and/or can gather to form small streams and rivers or lakes. Where precipitation is scarce, sometimes other sources are used for groundwater replenishment, such as treated domestic wastewater.

Carrier of ecosystems and biodiversity: Both freshwater and marine water support a vast range of fauna and flora. Here truly the credo “Water is Life” becomes true. Some of the most magnificent ecosystems on Earth can be found under water, i.e. the coral reefs. The largest one is the Great Barrier Reef off the coast of Queensland, Australia.

Aesthetic value: Many pieces of art are centred on water, including paintings, sculptures, music pieces, etc.

4.3. Abuses of water

As we have just discussed, water bodies have been and are still often used to dispose of solid and liquid waste products, causing pollution.

Pollution of the aquatic environment means the introduction by man, directly or indirectly, of substances or energy which result in such deleterious effects as:

• harm to living resources
• hazards to human health
• hindrance to aquatic activities including fishing
• impairment of water quality with respect to its use in agricultural, industrial and often economic activities
• reduction of amenities

Different substances result in different types of pollution. A short overview is given in the Table 3; details will be discussed later during the course. Obviously different types of pollutants can occur at the same time and interactions between different types of pollution are a real possibility.

<table>
<thead>
<tr>
<th>Type of pollutant</th>
<th>Type of pollution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutrients (N, P, K)</td>
<td>Eutrophication</td>
</tr>
<tr>
<td>Organic matter</td>
<td>Saprobiphication</td>
</tr>
<tr>
<td>Heavy metals</td>
<td>Toxicity</td>
</tr>
<tr>
<td>Pesticides, herbicides, ...</td>
<td>Toxicity</td>
</tr>
<tr>
<td>Pharmaceuticals</td>
<td>Toxicity</td>
</tr>
<tr>
<td>Microorganisms</td>
<td>Pathogenic diseases</td>
</tr>
<tr>
<td>Acid rain</td>
<td>Acidification</td>
</tr>
<tr>
<td>Salts</td>
<td>Salinization</td>
</tr>
<tr>
<td>Nuclear waste</td>
<td>Radioactivity</td>
</tr>
<tr>
<td>Inert substances</td>
<td>Turbidity</td>
</tr>
<tr>
<td>Heat</td>
<td>Heat pollution</td>
</tr>
</tbody>
</table>

We will discuss on the above items here, viz. pathogens. The other terms will be highlighted in Course 2.

4.4. Pathogens

Polluted waters have a large health risk by causing water-related diseases. Despite large advances in water and wastewater treatment, waterborne diseases still pose a major threat to public health. It has been reported that waterborne pathogens infect about 350 million people each year resulting in some 3.5 million deaths. Many of these infections occur in developing nations which have lower levels of sanitation, problems associated with low socio-economic conditions, and less public health awareness than in more developed nations. However, it has been documented that the incidence of waterborne disease in the US has actually increased in the past 20 years, with more waterborne outbreaks being recorded between 1971 and 1985 than in any previous 15 year interval since 1920.

Modern knowledge of the need for sanitation and treatment of polluted waters began with the frequently cited case of John Snow in 1855, in which he proved that a cholera outbreak in London was due to sewage contaminated water obtained from the Thames River.

Pathogens are organisms that cause disease. Viruses, bacteria and protozoa are the three types of organisms responsible for most waterborne/based/related diseases. The contamination of water with faecal matter from humans or other animals is the

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3 See the PowerPoint presentation; here also tables are outlined on occurrence of the organisms and their related diseases.
source of these diseases. In most cases, the intestinal tract is affected and symptoms include diarrhoea, vomiting, fever, chills and headaches. Some waterborne diseases can cause death.

**Viruses** are among the most important, and potentially most hazardous of the pathogens found in wastewater. Viral numbers have been detected in concentrations in excess of $10^3$-$10^4$ viral particles/litre of wastewater. Viruses are generally more resistant to treatment processes, are more infectious and require smaller doses to cause infection than most other pathogen types.

**Bacteria** are the most common of the microbial pathogens found in wastewater. Most of them are enteric in origin and cause gastro-intestinal infections; however, bacterial pathogens which cause non-enteric illnesses have also been detected in wastewaters. These include among others legionellosis (Legionnaire’s disease), a potentially fatal pneumonia caused by *Legionella* species. *E-coli* bacteria are commonly used to assess faecal contamination of the water.

**Protozoa** are microorganisms with several animal-like characteristics: they can eat other organisms (like bacteria) and they can move around. The protozoan life cycle often alternates between an active stage (which causes damage to the human body) and an encysted stage (which is the form that is passed along and causes infection). Cysts are resistant to the acids present in the digestive systems of animals and thus pass out of the body with faecal material. Protozoan diseases often lead to diarrhea and cramps. In the case of amoebic dysentery, the protozoans can destroy internal tissues, where bleeding accompanies diarrhea.

**Helminths** (nematodes and tape worms) are common intestinal parasites which, like the enteric protozoan pathogens, are usually transmitted by the faecal-oral route. They are a division of eukaryotic parasites that, unlike external parasites such as lice and fleas, live inside their host. They are worm-like organisms that live and feed off living hosts, receiving nourishment and protection while disrupting their hosts’ nutrient absorption, causing weakness and disease. Those that live inside the digestive tract are called intestinal parasites. They can live inside humans as well as other animals. Approximately 3 billion people globally are infected with helminths.

**Survival**

The survival of microbiological pathogens, once discharged into a water body, is highly variable depending on the quality of the receiving waters, particularly the turbidity, oxygen levels, nutrients and temperature. *Salmonella* bacilli have been reported in excess of 50 miles downstream of the point source, indicating an ability to survive, under the right conditions, for several days. In general, an exponential decay$^4$ takes place in the number of organisms, according to:

$$N_t = N_0 e^{-kt}$$

with $N_0$, $N_t$ number of organisms at time $t=0$, $t$, and $k =$ the decay rate constant (day$^{-1}$).

$^4$ For a mathematical description, see Unit 2.6. on "Water Quality Modelling"
**Question:** which percentage of the original number of organisms will have survived after 10 days, for $k = 0.3 \text{ day}^{-1}$; for $0.5 \text{ day}^{-1}$? How long time will it take to reach 99.99% reduction for $k = 0.3 \text{ day}^{-1}$? (Answers: 5%; 0.7%; 31 days)

Once in a water body, micro-organisms often become adsorbed onto sand, clay and sediment particles. The settling of these particles results in the accumulation of the organisms in river and lake sediments. The speed at which the settling occurs depends on the velocity and turbulence of the water body. Some removal of micro-organisms from the water column also occurs as a result of predation by filter feeding micro-zooplankton.

### 4.5. United Nations GEMS/Water Programme

The Global Environmental Monitoring System (GEMS) was initiated in 1974 as a means of promoting and coordinating the collection of environmental data nationally, regionally, and globally (see Fig. 7). 125 countries participated in 2012. While GEMS aims at assisting governments to develop monitoring systems for their own use, its other objectives are to improve the validity and comparability of environmental data globally and to provide for the collection and assessment of environmental data. Within GEMS, major programs were developed for climate-related monitoring, monitoring of natural resources, monitoring of the oceans, and health-related monitoring.

As part of the latter group of projects, the global water quality monitoring project, briefly GEMS/Water, was established in 1976 jointly by WHO, UNESCO, WMO and UNEP. The objectives of the project were:

- to collaborate with Member States in the establishment of new water monitoring systems and to strengthen existing ones;
- to improve the validity and comparability of water quality data within and between Member States, and
- to assess the incidence and long-term trends of water pollution by selected persistent and hazardous substances.

The global water quality monitoring project is based on the active participation of Member States which routinely monitor the quality of their water resources at selected locations and provide the data for global syntheses and dissemination. Wherever possible, the stations for the global network were selected from existing national or...
local networks. Where such stations did not exist, new ones were established. Priority was given to water bodies (rivers, lakes and groundwater aquifers) which are major sources of water supply for municipalities, irrigation, livestock, and selected industries. A number of stations were also included to monitor international rivers and lakes, rivers discharging into ocean and seas, and water bodies not yet affected by man's activities (baseline stations).

The target for the first stage of the project (1977-1981) was the establishment of a skeleton network of approximately 300 monitoring stations on rivers, lakes, and in groundwater aquifers. At that time it was estimated that a total of about 1200 stations might ultimately be required to achieve representative global coverage. Measurements of water quality variables at these stations include natural as well as anthropogenic constituents.

The years 1977 to 1979 were used as a preparatory phase during which time guidelines were prepared, specialists were trained in the different regions, and national, regional and global centres were established. National institutions were identified in agreement with the governments and designated as the focal points for GEMS/WATER activities within each country. In addition, laboratories were designated to conduct the routine sampling and analysis at the selected monitoring sites.

GEMS/Water is implemented by UNEP, Nairobi and WHO, Geneva, with the assistance of WHO Regional Offices. Technical support is provided by two WHO regional centres for environmental health. In addition, institutes have been designated as regional reference laboratories for implementing the analytical quality assurance component of the project. The Global Data Centre is located at the Canada Centre for Inland Waters, Burlington, Canada, which was designated both a WHO Collaborating Centre on Surface and Ground Water Quality and a UNEP GEMS Collaborating Centre for Freshwater Monitoring and Assessment. The Danish Institute for the Water Environment (VKI) in Horsholm, Denmark served as the global centre of analytical

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### Table 1. Stations and Values Participating in the GEMS Programme

<table>
<thead>
<tr>
<th>Region</th>
<th>Africa</th>
<th>North America</th>
<th>Latin-Caribbean</th>
<th>Europe</th>
<th>Asia-Pacific</th>
<th>West Asia</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Stations</td>
<td>368</td>
<td>733</td>
<td>1953</td>
<td>368</td>
<td>636</td>
<td>115</td>
</tr>
<tr>
<td># of Values</td>
<td>317884</td>
<td>1622923</td>
<td>362465</td>
<td>1086407</td>
<td>1401639</td>
<td>24973</td>
</tr>
</tbody>
</table>

**Fig. 7. Countries participating in the GEMS programme.** From: [http://www.unep.org/gemswater/FreshwaterAssessments/tabid/78231/Default.aspx](http://www.unep.org/gemswater/FreshwaterAssessments/tabid/78231/Default.aspx)
quality control. UNESCO participated in the field of training and measurement methodology. WMO has concentrated on network design criteria and hydrological monitoring methods.

**To-do- List for Unit 4**

- Look and listen to the PowerPoint presentation available under 1.3.: “Sustainable use of water”
- Have a look at the GEMS/Water website: [http://www.unep.org/gemswater](http://www.unep.org/gemswater)
- For those interested: go to the GEMS/Water Statistics website: [www.gemstat.org](http://www.gemstat.org)
  o Use the Search Data option in the left menu to find your own country (or a neighbouring one if your own country is not participating in GEMS)
  o Use “Search for Summary Data on Country Level”
  o Select one of the physico-chemical parameters (Temperature, Dissolved Oxygen, pH, ...) and make an overview for yourself (see also Module 4)
- Do the self-evaluation Quiz of Course 1 (true/false questions)