African Forest Forum

A platform for stakeholders in African forestry

Basic Science of Climate Change

A COMPENDIUM FOR TECHNICAL TRAINING IN AFRICAN FORESTRY 02

Basic Science of Climate Change

A COMPENDIUM FOR TECHNICAL TRAINING
IN AFRICAN FORESTRY

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Front cover photos: *Milicia excelsa* in a sacred forest at Toffo in Southern Benin (left), Zio riverbed at Alokoegbé-kpota in Southern Togo (middle), Private plantation of *Moringa oleifera* in southern Benin (right). Credit: Dèdéou A. Tchokponhoué

Back cover photo: Dense foliage of Milicia excelsa in a sacred forest at Toffo in Southern Benin. Credit: Dèdéou A. Tchokponhoué

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Abbreviations and Acronyms

CH4	Methane
CO2	Carbon dioxide
FAO	Food and Agriculture Organization of the United States
GHGs	Greenhouse gases
H2	Hydrogen
H2O	Water vapor
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter Tropical Convergence Zone
N2O	Nitrous oxide
NGOs	Non-Governmental Organizations
NH4+	Ammonia
O3	Ozone
WMO	World Meteorological Organization

Acknowledgements

This compendium has been developed through an organic process that initially led to the development of “Training modules on forest-based climate change adaptation, mitigation, carbon trading, and payment for other environmental services”. These were developed for professional and technical training, and for short courses in sub-Saharan African countries. The compendium provides the text required for effective delivery of the training envisaged in the training modules; in other words, it is structured based on the training modules. In this context many people and institutions, including those from government, civil society, academia, research, business, private sector, and other communities, have contributed in various ways in the process that culminated in the development of the compendium. We wish to collectively thank all these individuals and institutions for their invaluable contributions, given that it is difficult in such a short text to mention them individually.

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We are also grateful to the lead authors, the contributors mentioned in this compendium and the pedagogical expert, as well as reviewers of various drafts of the compendium.

We hope that the compendium will contribute to a more organized and systematic way of delivering training in this area, and eventually towards better management of African forests and trees outside forests.

Preface

African forests and trees support the key sectors of the economies of many African countries, including crop and livestock agriculture, energy, wildlife and tourism, water resources and livelihoods. They are central to maintaining the quality of the environment throughout the continent, while providing international public goods and services. Forests and trees provide the bulk of the energy used in Africa. Forests and trees are therefore at the centre of socio-economic development and environmental protection of the continent.

Forests and trees outside forests in Africa are in many ways impacted by climate change, and they in turn influence climate. Hence, African forests and trees are increasingly becoming very strategic in addressing climate change. The great diversity of forest types and conditions in Africa is at the same time the strength and the weakness of the continent in devising optimal forest-based responses to climate change. In this regard, given the role of forests and trees to socio-economic development and environmental protection, actions employed to address climate change in Africa must simultaneously enhance livelihoods of forest dependent populations and improve the quality of the environment. It is therefore necessary for Africa to understand how climate change affect the inter-relationships between food, agriculture, energy use and sources, natural resources (including forests and woodlands) and people in Africa, and in the context of the macro-economic policies and political systems that define the environment in which they all operate. Much as this is extremely complex, the understanding of how climate change affect these inter-relationships is paramount in influencing the process, pace, magnitude and direction of development necessary for enhancing people's welfare and the environment in which they live.

At the forestry sector level, climate affects forests but forests also affect climate. For example, carbon sequestration increases in growing forests, a process that positively influences the level of greenhouse gases in the atmosphere, which, in turn, may reduce global warming. In other words, the forests, by regulating the carbon cycle, play vital roles in climatic change and variability. For example, the Intergovernmental Panel on Climate Change (IPCC) special report of 2018 on the impacts of global warming of 1.5 ^{o}C above pre-industrial levels underscores the significance of afforestation and reforestation, land restoration and soil carbon sequestration in carbon dioxide removal. Specifically, in pathways limiting global warming to 1.5 ^{o}C, agriculture, forestry and land-use (AFOLU) are projected with medium confidence to remove 0-5, 1-11 and 1-5 $GtCO_2\ yr^{-1}$ in 2030, 2050 and 2100, respectively. There are also co-benefits associated with AFOLU-related carbon dioxide removal measures such as improved biodiversity, soil quality and local food security. Climate, on the other hand, affects the function and structure of forests. It is important to understand adequately the dynamics of this interaction to be able to design and implement appropriate mitigation and adaptation strategies for the forest sector.

In the period between 2009 and 2011, the African Forest Forum sought to understand these relationships by putting together the scientific information it could gather in the form of a book that addressed climate change in the context of African forests, trees, and wildlife resources. This work, which was financed by the Swedish International Development Cooperation Agency (Sida), unearthed considerable gaps on Africa's understanding of climate change in forestry, how to handle the challenges and opportunities presented by it and the capacity to do so.

The most glaring constraint for Africa to respond to climate change was identified as the lack of capacity to do so. AFF recognizes that establishment and operationalization of human capacities are essential for an effective approach to various issues related to climate change, as well as to improve the quality of knowledge transfer. For example, civil society organisations, extension agents and local communities are stakeholders in implementing adaptation and mitigation activities implicit in many climate change strategies. In addition, civil society organisations and extension agents are more likely to widely disseminate relevant research results to local communities, who are and will be affected by the adverse effects of climate change. It is therefore crucial that all levels of society are aware of mechanisms to reduce poverty through their contribution to solving environmental problems. Training and updating knowledge of civil society organisations, extension service agents and local communities is one of the logical approaches to this. Also professional and technical staff in forestry and related areas would require knowledge and skills in these relatively new areas of work.

It was on this basis that AFF organized a workshop on capacity building and skills development in forest-based climate change adaptation and mitigation in Nairobi, Kenya, in November 2012 that drew participants from selected academic, research and civil society institutions, as well as from the private sector. The workshop identified the training needs on climate change for forestry related educational and research institutions at professional and technical levels, as well as the training needs for civil society groups and extension agents that interact with local communities and also private sector on these issues. The training needs identified through the workshop focused on four main areas, namely: Science of Climate Change, Forests and Climate Change Adaptation, Forests and Climate Change Mitigation, and Carbon Markets and Trade. This formed the basis for the workshop participants to develop training modules for professional and technical training, and for short courses for extension agents and civil society groups. The development of the training modules involved 115 scientists from across Africa. The training modules provide guidance on how training could be organized but do not include the text for training; a need that was presented to AFF by the training institutions and relevant agents.

Between 2015 and 2018, AFF brought together 50 African scientists to develop the required text, in the form of compendiums, and in a pedagogical manner. This work was largely financed by the Swiss Agency for Development and Cooperation (SDC) and with some contribution from the Swedish International Development Cooperation Agency (Sida). In this period eight compendiums were developed, namely:

1. Basic science of climate change: a compendium for professional training in African forestry
2. Basic science of climate change: a compendium for technical training in African forestry
3. Basic science of climate change: a compendium for short courses in African forestry
4. Carbon markets and trade: a compendium for technical training in African forestry
5. Carbon markets and trade: a compendium for professional training in African forestry

6. Carbon markets and trade: a compendium for short courses in African forestry
7. International dialogues, processes and mechanisms on climate change: compendium for professional and technical training in African forestry
8. Climate modelling and scenario development: a compendium for professional training in African forestry

Another notable contribution during the period 2011-2018 was the use of the training module on "Carbon markets and trade" in building the capacity of 574 trainers from 16 African countries on rapid forest carbon assessment (RaCSA), development of a Project Idea Note (PIN) and a Project Design Document (PDD), exposure to trade and markets for forest carbon, and carbon financing, among others. The countries that benefited from the training are: Ethiopia (35), Zambia (21), Niger (34), Tanzania (29), Sudan (34), Zimbabwe (30), Kenya (54), Burkina Faso (35), Togo (33), Nigeria (52), Madagascar (42), Swaziland (30), Guinea Conakry (40), Côte d'Ivoire (31), Sierra Leone (35) and Liberia (39). In addition, the same module has been used to equip African forest-based small-medium enterprises (SMEs) with skills and knowledge on how to develop and engage on forest carbon business. In this regard, 63 trainers of trainers were trained on RaCSA from the following African countries: South Africa, Lesotho, Swaziland, Malawi, Angola, Zambia, Zimbabwe, Mozambique, Tanzania, Uganda, Kenya, Ethiopia, Sudan, Ghana, Liberia, Niger, Nigeria, Gambia, Madagascar, Democratic Republic of Congo, Cameroon, Côte d'Ivoire, Burkina Faso, Gabon, Republic of Congo, Tchad, Guinea Conakry, Senegal, Mali, Mauritania, Togo and Benin .

An evaluation undertaken by AFF has confirmed that many trainees on RaCSA are already making good use of the knowledge and skills gained in various ways, including in developing bankable forest carbon projects. Also many stakeholders have already made use of the training modules and the compendiums to improve the curricula at their institutions and the way climate change education and training is delivered.

The development of the compendiums is therefore an evolutionary process that has seen the gradual building of the capacity of many African scientists in developing teaching and training materials for their institutions and the public at large. In a way this has cultivated interest within the African forestry fraternity to gradually build the capacity to develop such texts and eventually books in areas of interest to the continent, as a way of supplementing information otherwise available from various sources, with the ultimate objective of improving the understanding of such issues as well as to better prepare present and future generations in addressing the same.

We therefore encourage the wide use of these compendiums, not only for educational and training purposes but also to increase the understanding of climate change aspects in African forestry by the general public.

Macarthy Oyebo
Chair, Governing Council of AFF

Godwin Kowero
Executive Secretary-AFF

Executive summary

Overview

Increasing of green house gases (GHG) emissions in the atmosphere is raising global concern. This is because these emissions have led to a shift of temperatures, unpredictable weather patterns and sporadic rainfall that has caused heavy floods, among other adverse impacts. As a result, many countries are pursuing various policies and strategies to help mitigate and adapt to climate change. This will require an understanding of the processes that contribute to it. This compendium will therefore introduce learners to the basic science of climate change by focusing on an understanding of global change, concept of climate change, causes of climate change, vulnerability to, and impact of climate change, generation of climate change data, and international dialogues, processes and mechanisms on climate change.

Aim

To build the learners' understanding of the basic science of climate change and its application in forestry and related sectors.

Objectives

At the end of this module, the learners will be able to:

- describe the elements of global change, components of climate systems and concepts of climate change;
- explain the causes and become familiar with evidence on climate change;
- generate relevant data and monitor climate change;
- relate concepts of vulnerability and response to climate change; and,
- explain the impact of climate change in forestry and related sectors.

Chapter 1: Introduction to Climate Change

Chapter overview

Climate change and the commensurate impacts are among the critical issues of our time. It is increasingly regarded not only as an environmental or intergenerational sustainability issue but also as a development concern. It is now more certain than ever, based on many lines of evidence, that humans are changing Earth's climate. The atmosphere and oceans have warmed, accompanied by sea-level rise, a strong decline in Arctic sea ice, and other climate-related changes. The evidence is clear. However, due to the nature of science, not every single detail is ever totally settled or completely certain. Nor has every pertinent question yet been answered. Scientific evidence continues to be gathered around the world, and assumptions and findings about climate change are continually analysed and tested. Some areas of active debate and on-going research include the link between ocean heat content and the rate of warming, estimates of how much warming to expect in the future, and the connections between climate change and extreme weather events. This chapter therefore introduces the concept of climate change and terminologies used. It also explores the basics of climate science, weather systems, hydrological cycles, elements of global change, definition and elements of climate, in addition to opportunities and challenges associated with climate change.

Goal

To eqiup learners with knowledge and skills enabling them to cope with the effects of climate change and of global change.

Learning outcomes

At the end of this chapter the learner will be able to:

- define global change and climate change; and
- explain elements of global change and the implications on climate change; and,
- explain the cycle of atmospheric elements.

1.0 Understanding terminologies in global climate change

1.0.1 Introduction

This training session introduces the basic aspects of the science of climate change. It defines the concepts of global change and climate change. It helps to explain the various terminologies in global and climate change.

Objectives

By the end of this session, the learner will be able to:

a) define global change and climate change; and,

b) explain various terminologies used in global and climate change.

Activity 1 (Brainstorming) (20 minutes)

What do we mean by the concept of climate change

1.0.2 Definitions of climate change and related terminologies

Climate

Climate is usually defined as the "average weather", or more rigorously, as the statistical description of the weather in terms of the mean and variability of relevant quantities over periods of several decades (typically three decades as defined by WMO). These quantities are most often surface variables such as temperature, precipitation, and wind, but, in a wider sense, the "climate" is the description of the state of the climate system.

Climate change

Climate change refers to any significant change in measures of climate (e.g. temperature, precipitation or wind) lasting for an extended period (decades or longer). Climate change may result from:

- natural factors, such as changes in the sun's intensity or slow changes in the Earth's orbit around the sun;
- natural processes within the climate system (e.g. changes in ocean circulation); and,
- human activities that change the atmosphere's composition (e.g. through burning fossil fuels) and the land surface (e.g. deforestation, reforestation, urbanization, desertification, etc.).

Climate variability

Climate variability refers to variations in the mean state and other statistics (e.g. standard deviations, occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations un-natural or anthropogenic external forcing (external variability).

Deforestation

Deforestation is the natural or anthropogenic process that converts forest land to non-forest, i.e.. those practices or processes that result in the conversion of forested lands for non-forest uses is termed as deforestation. This is often cited as one of the major causes of the enhanced greenhouse effect for two reasons:

- the burning or decomposition of the wood releases CO_2; and,
- trees that once removed CO_2 from the atmosphere in the process of photosynthesis are no longer present.

Desertification

It refers to land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities. The United Nations Convention to Combat Desertification (UNCCD) defines land degradation as a reduction or loss, in arid, semi-arid, and dry sub-humid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including those arising from human activities and habitation patterns, e.g. soil erosion caused by wind and/or water, deterioration of the physical, chemical and biological or economic properties of soil and long-term loss of natural vegetation.

Emissions

It is the release of a substance (usually a gas when referring to the subject of climate change) into the atmosphere.

In Text Question(s) (10 minutes)

1) Identify and define commonly used terminologies in the field of climate change?
2) Differentiate between climate change and global warming?

Global warming

Global warming is the average increase in the temperature of the atmosphere near the Earth's surface and in the troposphere, which can contribute to changes in global climate patterns. Global warming can occur from a variety of causes, both natural and human induced. In common usage, "global warming" often refers to the warming that can occur as a result of increased emissions of greenhouse gases from human activities.

Greenhouse effect

Greenhouse gases effectively absorb infrared radiation, emitted by the Earth's surface, by the atmosphere itself due to the gases and by clouds. Atmospheric radiation is emitted to all sides, including downward to the Earth's surface. Thus, greenhouse gases trap heat within the surface troposphere system. This is called the greenhouse effect.

Greenhouse gases (GHGs)

Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. Greenhouse gases include, but are not limited to, water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), ozone (O_3), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6).

Activity 2: (Group Discussion) (20 minutes)

1) Why would climate changes of a few degrees a cause of concern?
2) How will climate change in future?

Greenhouse gas reduction potential

Possible reductions in emissions of greenhouse gases (quantified in terms of absolute reductions or in percentages of baseline emissions) that can be achieved through the use of technologies and measures is termed as greenhouse gas reduction potential.

Hydrological cycle

The cycle in which water evaporates from the oceans and the land surface, is carried over Earth in atmospheric circulation as water vapour condensates to form clouds, precipitates again as rain or snow, is intercepted by trees and vegetation, provides runoff on the land surface, infiltrates into soils, recharges groundwater, discharges into streams, and ultimately, flows out into the oceans, from which it will eventually evaporate again. The various systems involved in the cycle are usually referred to as hydrological systems.

Ozone layer

The stratosphere contains a layer in which the concentration of ozone is greatest, the so-called ozone layer. The layer extends from about 12 to 40 km. The ozone concentration reaches a maximum between about 20 and 25 km. This layer is being depleted by human emissions of chlorine and bromine compounds. Every year, during the Southern Hemisphere spring, a very strong depletion of the ozone layer takes place over the Antarctic region, also caused by human-made chlorine and bromine.

Ozone depleting substance (ODS)

A family of man-made compounds that includes, but are not limited to, chlorofluorocarbons (CFCs), bromofluorocarbons (halons), methyl chloroform, carbon tetrachloride, methyl bromide, and hydrochlorofluorocarbons (HCFCs). These compounds have been shown to deplete stratospheric ozone, and therefore are typically referred to as ODSs.

Sequestration

It is the process of increasing the carbon content of a carbon pool other than the atmosphere, i.e. carbon storage in terrestrial or marine reservoirs. Biological sequestration includes direct removal of CO_2 from the atmosphere through land-use change, afforestation, reforestation, carbon storage in landfills and practices that enhance soil carbon in agriculture.

Sinks

It is any process, activity or mechanism that removes a greenhouse gas or aerosol, or a precursor of a greenhouse gas or aerosol, from the atmosphere.

Weather

Atmospheric condition at any given time or place. It is measured in terms of such things as wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation. In most places, weather can change from hour-to-hour, day-to-day and season-to-season. Climate in a narrow sense is usually defined as the “average weather”, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization (WMO). These quantities are most often surface variables such as temperature, precipitation and wind.

Climate in a wider sense is the state, including a statistical description, of the climate system. A simple way of remembering the difference is that climate is what you expect (e.g. cold winters) and ‘weather’ is what you get (e.g. a blizzard).

Adaptation

Initiatives and measures to reduce the vulnerability of natural and human systems against climate change effects. Various types of adaptation are, e.g. anticipatory and reactive, private and public, and autonomous and planned. Examples are raising river or coastal dikes, the substitution of more temperature shock resistant plants for sensitive ones, etc.

Source: http://nimbuseco.com/2013/01/deforestation-and-pollution-facts/

Study figure above carefully and carry out the following activities:

- describe the activity carried out in the photograph; and
- explain the relationship between climate change and the activity shown in the photograph.

Summary

In this session we discussed the terms and terminologies associated with climate change. In the next session, we shall talk about the basic of climate science and biogeochemical cycle.

1.1 Basics of climate science and biogeochemical cycles

1.1.1 Introduction

This training session introduces the basic of climate science biogeochemical cycles. In it, we shall discuss in more detail the basics of climate science and biogeochemical cycles.

Objectives

By the end of this session, the learner will be able to:

a) describe the basics of climate science;

b) explain the climate of the earth components of the climate system; and,

c) explain the composition and layered structure of the atmosphere.

Activity 1: Brainstorming (20 minutes)

Why is climate change happening?

1.1.2 Definition of climatology

Climatology is the scientific study of climate. The climate of a place can be defined as the average weather conditions obtained through the synthesis of weather elements prevailing there for over a period of 30-35 years. The weather, on the other hand, is defined by the atmospheric condition of a place or a given location at a particular time.

The weather elements at a particular place and time are sunshine, temperature, pressure, precipitation, humidity, evaporation, wind conditions, etc. Thus, climatologists seek the understanding of how the world's climate system works, how it varies from time to time and space to space, and any use that can be made of resources provided by climate.

Weather and climate are explained by the same element in combination but weather and climate are not the same. The climate pertains to an area over a long period of time while weather pertains to a place and at a particular time. In other words weather is an instantaneous condition of the atmosphere and it keeps changing all the time but the climate of an area is fairly constant over a period of time.

1.1.3 The earth´s climate

The Earth has different climates: tropical or hot, temperate and cold.

Tropical or hot climates

- Equatorial climate: high temperatures (over 23ºC) and abundant precipitation.
- Humid tropical climate: high temperatures (over 20ºC) and abundant precipitation. There´s a dry season in winter and a wet season in summer.
- Dry tropical climate: mild temperatures in winter and hot in summer (over 18ºC) Precipitation is scarce.
- Hot desert climate: high temperatures (over 20ºC). Precipitation is very rare.

Temperate climates

- Mediterranean climate: mild temperatures in winter and hot in summer. Precipitation varies. The summer is very dry.
- Humid sub-tropical climate: similar temperatures to the Mediterranean climate. Abundant precipitation, especially in summer.
- Maritime climate: mild temperatures in winter and cool in summer. High precipitation throughout the year.
- Continental climate: temperatures are very cold in winter and hot in summer. It rains mainly in summer.

Cold climates

- Polar climate: very low temperature (not over 0ºC). Precipitation is very rare.
- Alpine climate: temperatures fall with altitude. Winters are cold and summers cool. Precipitation increases with altitude.

In Text Questions (30 minutes)

1) Define the concept of climate and climatology.
2) Differentiate between weather and climate.

1.1.4 Biogeochemical cycles

In ecology, a biogeochemical cycle is a circuit or pathway by which a chemical element or molecule moves through both biotic and abiotic compartments of an ecosystem. In effect, the element is recycled, although in some such cycles there may be places where the element is accumulated for a long period of time. All chemical elements occurring in organisms are part of biogeochemical cycles. Biogeochemical cycles involve the fluxes of chemical elements among different parts of the Earth: from living to non-living, from atmosphere to land to sea, and from soils to plants. They are called “cycles” because matter is always conserved and because elements move to and from major pools via a variety of two-way fluxes, although some elements are stored in locations or in forms that are differentially accessible to living things. Human activities have mobilized Earth elements and accelerated their cycles – for example, more than doubling the amount of reactive nitrogen that has been added to the biosphere since pre-industrial times.

Reactive nitrogen is any nitrogen compound that is biologically, chemically or radioactively active, like nitrous oxide and ammonia, but not nitrogen gas (N_2). Global-scale alterations of biogeochemical cycles are occurring from human activities, with impacts and implications now and in the future. Global CO_2 emissions are the most significant driver of human-caused climate change. But human-accelerated cycles of other elements, e.g. nitrogen, phosphorus and sulfur, also influence climate. They can affect climate directly or act as indirect factors that alter the carbon cycle, amplifying or reducing impacts of climate change.

Climate change is having, and will continue to have, impacts on biogeochemical cycles, which will alter future impacts on climate and affect our capacity to cope with coupled changes in climate, biogeochemistry and other factors.

Biogeochemical cycles always involve equilibrium states: A balance in the cycling of the element between compartments. However, overall balance may involve compartments distributed on a global scale.

Biogeochemical cycles of particular interest in ecology are the: nitrogen, oxygen, carbon, phosphorus, sulphur, water and hydrogen cycles.

?

In Text Questions (30 minutes)

Write brief notes about the following:

1) Hydrogen cycle;
2) Carbon cycle;
3) Nitrogen cycle; and,
4) Phosphorus cycle.

1.1.5 The atmosphere

The term atmosphere refers to the gaseous envelope surrounding the earth. It is believed to have developed some millions of years ago and it is still maintaining its present form and composition as a result of chemical and photochemical processes combined with differential escape rates from the earth's gravitational field.

Composed of a mixture of various gases, water vapour and aerosols, the atmosphere is held to the earth by the gravitational force of the earth and it is densest at sea level and thins rapidly upwards. Generally, the atmosphere is highly oxidized and contains very little hydrogen. The most important constituents of the air in the earth's atmosphere are nitrogen and oxygen. The atmosphere helps to shield and protect all life forms from the harmful radiation from the sun and its gaseous content sustains plants and animals.

Composition of the atmosphere

Although some of the gases, like water vapour and ozone, are highly variable, the atmosphere is well mixed and is constant in composition in the lower layer referred to as the homosphere. At higher levels, the Heterosphere, there is little mixing and diffusive separation tends to take place up to about 100 km. Generally, the composition of the atmosphere changes with height above the sea level. Water vapour is limited to 10-12 km while at higher levels oxygen and minor constituents, such as CO_2 are dissociated by solar ultraviolet radiation. The non-gaseous constituents are concentrated in the lower layer of the atmosphere. The non-gaseous constituents are aerosols such as particles of dust, smoke, organic matter, sea salt and by-products of fire and industry, e.g. carbon, sulphur dioxide, carbon monoxide and lead. The aerosols are so light that even minor movements in air can sustain them. Dust, salt, carbon, sulphur, lead and aluminium compounds are the most abundant in the aerosols.

Table 1. The composition of the Atmosphere

Constituents	Chemical formula	Volume (%) dry air
Nitrogen	N_2	78.08
Oxygen	O_2	20.95
Argon	Ar	0.93
Carbon dioxide	CO_2	0.036
Water vapour	H_2O	0-4
Ozone	O_3	0.000004
Neon	Ne	0.0018
Helium	He	0.0005
Hydrogen	H_2	0.00005
Methane	CH_4	0.00017
Nitrous oxide	N_2O	0.00003

Source: Pidwirny (2006)

Activity 2: (Group Discussion) (20 minutes)

What do changes in the vertical structure of the atmospheric temperature- from the surface up to the stratosphere- tells us about the causes of recent climate change?

The layered structure of the Atmosphere

In general, the atmosphere can be divided into a total of four layers. They are the Troposphere, Stratosphere, Mesosphere, and the Thermosphere, that can be further subdivided into ionosphere and exosphere. Three of these are relatively warm layers (the layers near the surface between 50 and 60 km, and one above at 120 km) and the remaining two that separate the warmer layers are relatively cold (between 10 and 30 km, and around 80 km). Figure 1 shows the arrangement of these layers in the atmosphere.

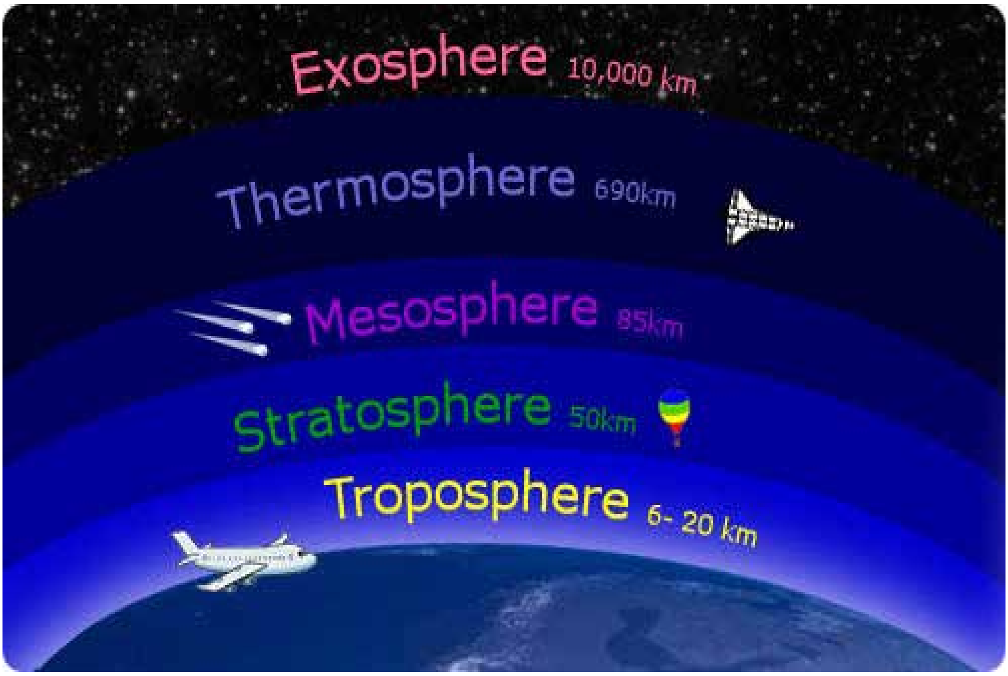


Figure 1. Layers of the atmosphere
Source: http://reedsclassblog.blogspot.com/2014/10/layers-of-atmosphere.html

Troposphere is up to 20 km altitude. It is where rain, snow and other weather phenomena occur.

Stratosphere is at an altitude of 10-50 km. It contains the ozone layer, which prevents harmful ultraviolet radiation from the Sun from reaching the Earth´s surface.

Mesosphere is at an altitude of 50-80 km.

Thermosphere is 80-500 km altitude. In this layer, temperatures can rise to 1,000°C.

Exercise questions (30 minutes)

1) To what extent are scientists confident that the earth will warm further over the 21st century?
2) What are the weather elements?
3) Which atmospheric constituent are of greatest concern and why?

Summary

In this session, we discussed the earth's climate and the atmosphere and its composition and layered structure. In the next session, we shall talk about the weather systems.

1.2 Weather systems

1.2.1 Introduction

This training session introduces the various weather systems. In it, we shall discuss in more detail the weather systems.

Objective

By the end of this session, the learner should be able to explain the various weather systems.

Activity 1: Brainstorming (20 minutes)

How will climate change in future?

1.2.2 Inter-tropical Convergence Zone (ITCZ)

The Inter-tropical Convergence Zone, known by sailors as the doldrums, is the area encircling the earth near the equator where the northeast and southeast trade winds come together. It appears as a band of clouds, usually thunderstorms. In the Northern Hemi-sphere, the trade winds move in a southwestern direction from the northeast, while in the Southern Hemisphere, they move northwestward from the southeast. When the ITCZ is positioned north or south of the equator, these directions change according to the Coriolis Effect imparted by the rotation of the earth. For instance, whenever the ITCZ is situated north of the equator, the southeast trade wind changes to a southwest wind as it crosses the equator. The ITCZ is formed by vertical motion largely appearing as convective activity of thunderstorms driven by solar heating, which effectively draw air in, which is called the trade winds. The location of the ITCZ varies over time.

Variation in the location of the ITCZ drastically affects rainfall in many equatorial nations, resulting in the wet and dry seasons of the tropics rather than the cold and warm seasons of higher latitudes. Longer term changes in the ITCZ can result in severe droughts or flooding in nearby areas.

In Text Questions (30 minutes)

1) What is the climate like at the equator, and why?
2) Describe the characteristics of what:
   a) cold air does?
   b) warm air does?

1.2.3 Sea Surface Temperature (SST)

Sea surface temperature is the water temperature close to the ocean's surface. Localized areas of heavy snow can form in bands downwind of warm water bodies within an otherwise cold air mass. Warm sea surface temperatures are known to be a cause of tropical cyclo-genesis over the Earth's oceans. There is less SST variation on breezy days than on calm days. In addition, ocean currents such as the Atlantic Multi-decadal Oscillation (AMO), can affect SST's on multi-decadal time scales, a major impact results from the global thermo-halide circulation, which affects average SST significantly throughout most of the world's oceans. Coastal SSTs can cause offshore winds generating upwelling, which can cool or warm nearby landmasses. Sea surface temperature affects the behavior of Earth's atmosphere above. While sea surface temperature is important for tropical cyclo-genesis, it is also important in determining the formation of sea fog and sea breezes. Heat from underlying warmer waters can significantly modify an air mass over distances as short as 35 km to 40 km.

1.2.4 Monsoons

Monsoons are large-scale sea breezes that occur when the temperature on land is significantly warmer or cooler than the temperature of the ocean. These imbalances happen because oceans and land absorb heat in different ways. Monsoons are used to describe seasonal changes in atmospheric circulation and precipitation associated with asymmetric heating of land and sea. Usually, the term monsoon is used to refer to the rainy phase of a seasonally changing pattern, although technically there is also a dry phase. The major monsoon systems of the world consist of the West African and Asia-Australian monsoons. The impact of monsoon on the local weather is different from place to place. In some places there is just a likelihood of having a little more or less rain. In other places, quasi semi-deserts are turned into vivid green grasslands where plants and crops can flourish.

The Indian Monsoon turns large parts of India from a kind of semi-desert into green lands. In places like this it is crucial for farmers to have the right timing for putting the seeds on the fields, as it is essential to use all the rain that is available for growing crops.

1.2.5 Tropical easterly jet

The Tropical Easterly Jet is the meteorological term referring to an upper level easterly wind that starts in late June and continues until early September. The strongest development of the jet is at about 15 km above the Earth's surface with wind speeds of up to 40 m/s over the Indian Ocean. The easterly jet is a region of the lower troposphere over West Africa where the seasonal mean wind speed is maximum and easterly. The jet marches northward from its southern location in January, reaching its most northerly latitude in August, and its strongest winds in September while shifting back towards the equator. Within the easterly jet, tropical waves form. The low-level easterly African jet stream is considered to play a crucial role in the southwest monsoon of Africa, and helps form the tropical waves which march across the tropical Atlantic and eastern Pacific oceans during the warm season.

Activity 2: (Group Discussion) (20 minutes)

Evaluate the relationship between weather and natural disasters?

1.2.6 Tropical cyclone

A tropical cyclone is a storm system characterized by a large low-pressure centre and numerous thunderstorms that produce strong winds and heavy rainfall. Tropical cyclones feed on the heat released when moist air rises, resulting in condensation of water vapour contained in the moist air. They are fuelled by a different heat mechanism than other cyclonic windstorms, e.g. European windstorms and polar lows, leading to their classification as 'warm core' storm systems. Tropical cyclones originate in the doldrums near the Equator, c. 10° away. The term 'tropical' refers to both the geographic origin of these systems, which form almost exclusively in tropical regions, and their formation in maritime tropical air masses. The term 'cyclone' refers to such storms' cyclonic nature, with anticlockwise rotation in the Northern Hemisphere and clockwise rotation in the Southern Hemisphere. Depending on its location and intensity, a tropical cyclone can be referred to by names such as 'hurricane', 'typhoon', 'tropical storm', 'cyclonic storm', 'tropical depression', or simply 'cyclone'.

Exercise Questions (30 minutes)

For each question below, select the correct answer.

1) Wind strength is dependent upon:
   A. vertical movement of air;
   B. air pressure differences;
   C. horizontal movement of air; or,
   D. amount of gravitation attraction.

2) Lines on a surface map which show areas of equal temperature are called:
   A. isobars;
   B. thermobars;
   C. thermtherms; or,
   D. isotherms

3) The instrument used to measure air pressure is called a(n):
   A. barometer;
   B. thermometer;
   C. anemometer; or,
   D. weather vane.

4) The global winds which most influence the weather in the United States are the:
   A. Trade Winds;
   B. Polar Easterlies;
   C. Westerlies; or,
   D. Doldrums.

5) Sea breezes occur during the --?-- and produce winds moving --?--.
A. night / out over the water;
B. night / in over the land;
C. day / out over the water; or,
D. day / in over the land.

6) Upward and downward currents of air which result from the uneven heating of the air are called:
A. conduction currents;
B. convection currents;
C. radiation currents; or,
D. winds.

7) The shift in global winds (to the right in the Northern Hemisphere) as a result of the Earth's rotation is called the:
A. Bernouli Principle;
B. Jetstream;
C. El Nino; or,
D. Coriolis Effect.

8) Winds are named according to:
A. the direction they are blowing towards;
B. the direction they are blowing from;
C. their speed; or,
D. their origin.

9) What is the movement of air around the center of a HIGH air pressure system ?
A. downward, outward and clockwise;
B. downward, inward and counterclockwise;
C. upward, outward and clockwise; or,
D. upward, inward and counterclockwise.

Summary

In this session, we talked about the types of weather systems: how they manifest themselves and their effect on the environment. In the next session, we shall talk about the hydrological cycle.

1.3 Hydrological cycle

This training session introduces the hydrological cycle of the earth system. In it, we will cover the steps of the hydrological cycle and then examine the differences that may be encountered within the water cycle on different types of islands.

Objective

By the end of this session, the learner should be able to explain the various stages of the hydrological cycle.

Activity 1: Brainstorming (20 minutes)

How will the climate affect the hydrologic cycle in future?

Water is the most precious thing on our planet. It allows life to exist. And water itself may seem to be alive: it is always on the move. Year after year, water rains down, runs into rivers, and flows into the ocean.The rain and rivers never run out. The ocean never gets bigger. Why? This is becausethe water in nature is continually recycled. This is called the hydrological cycle or simply, the water cycle.

The hydrologic cycle is the continuous circulation of water within the Earth's hydrosphere, and is driven by solar radiation. The hydrosphere includes the atmosphere, land, surface water and groundwater. As water moves through the cycle, it changes state between liquid, solid, and gas phases. Water moves through different reservoirs, including oceans, atmosphere, groundwater, rivers and glaciers, by the physical processes of evaporation (including plant transpiration), sublimation, precipitation, infiltration, runoff and subsurface flow. The total amount, or mass, of water in the water cycle remains essentially constant, as does the amount of water in each reservoir of the water cycle. This means that the rate of water added to one reservoir must equal, on average and over time, the rate of water leaving the same reservoir. The largest reservoir is the oceans, accounting for 97 % of the Earth's water. The next largest quantity (2 %) is stored in solid form in ice caps and glaciers. The water contained within all living organisms represents the smallest reservoir. The volumes of water in the freshwater reservoirs, particularly those that are available for human use, are important water resources.

In Text Questions (30 minutes)

1) What turns water on the earth into vapour in the hydrologic cycle?
2) In the water cycle, what is it called when water goes up through a plant and is turned into a vapour?
3) Water that soaks into the ground is called.
4) Studying the water cycle, where is the purest water on earth?

The residence time of a water molecule in a particular reservoir varies greatly from the order of seconds to hours and days (as in evaporation of precipitation) to much longer time scales of thousands of years. Groundwater can spend over 10,000 years underground before leaving, and ocean water can be on the order of a thousand years old. The hydrologic cycle begins with the evaporation of water from the surface of the ocean. As moist air is lifted, it cools and water vapor condenses to form clouds. Moisture is transported around the globe until it returns to the surface as precipitation. Once the water reaches the ground, one of two processes may occur:

- some of the water may evaporate back into the atmosphere; or,
- the water may penetrate the surface and become groundwater.

Groundwater either seeps its way to into the oceans, rivers and streams, or is released back into the atmosphere through transpiration. The balance of water that remains on the earth's surface is runoff, which empties into lakes, rivers and streams and is carried back to the oceans, where the cycle begins again.

Activity 2: (Group Discussion) (20 minutes)

Discuss the changes a drop of water goes through as it passes through the hydrologic cycle.

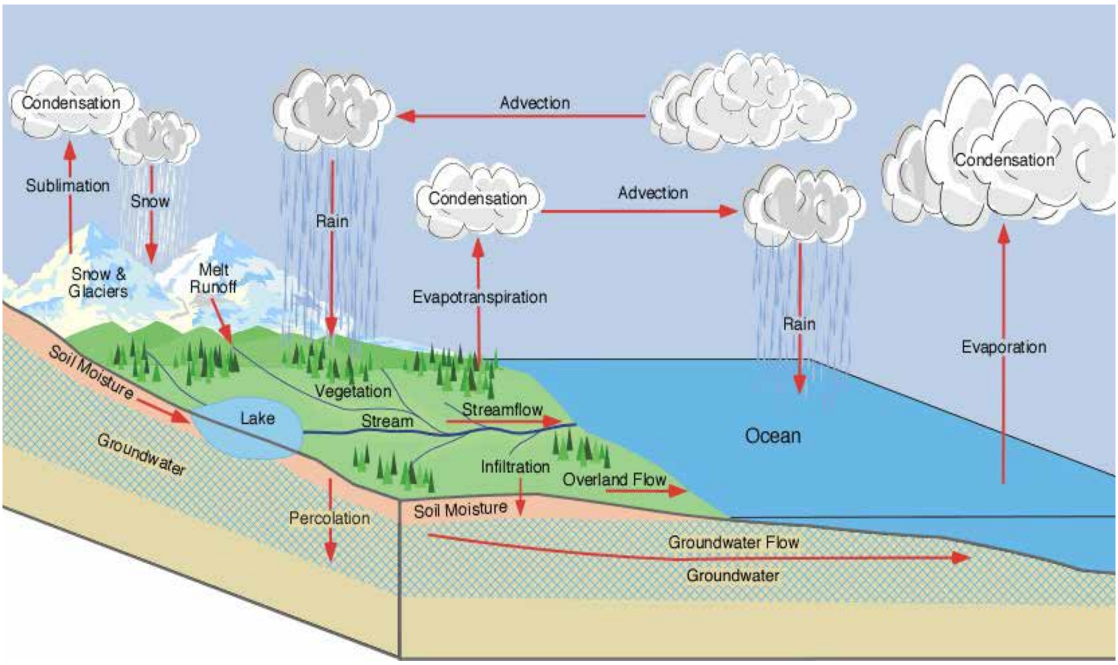


Figure 2. The hydrologic cycle. Source: Pidwirny (2006)

Evaporation of warm surface water increases the amount of moisture in the colder, drier air flowing immediately above a lake surface. With continued evaporation, water vapor in the cold air condenses to form ice-crystal clouds, which are transported toward shore. By the time these clouds reach the shoreline, they are filled with snowflakes too large to remain suspended in the air and consequently, they fall along the shoreline as precipitation. The intensity of lake effect snowfall can be enhanced by additional lifting due to the topographical features (hills) along the shoreline. Once the snow begins to melt, the water is either absorbed by the ground and becomes groundwater, or goes returns back to the lake as runoff.

Exercise Questions (30 minutes)

1) Where does the energy that powers the water cycle come from?
2) From where does most water evaporate?
3) What are the four stages of water cycle?
4) What is the name given to rain, snow and sleet?

Summary

In this chapter, we covered the hydrological cycle of the earth's system. Participants were taught about water, including how it moves through the water cycle. In the next chapter, we shall talk about the elements of global change.

1.4 Elements of global change

1.4.1 Introduction

This training session introduces the elements of global change and defines the concepts and elements of global change.

Objective

By the end of this session, the learner should be able to analyse the various elements of global change.

Activity 1: Brainstorming (20 minutes)

Provide a critical analysis of the concept of climate change.

1.4.2 Industrialization

Industrialization is the period of social and economic change that transforms a human group from an agrarian society into an industrial one, involving the extensive re-organization of an economy for the purpose of manufacturing.

- It may lead to the depletion of natural resources.
- It leads to air pollution, water pollution and soil pollution.
- Global warming, climatic changes are the major consequences of industrialization.
- It causes acid rain.
- It leads to the degradation of land quality.
- It leads to the generation of hazardous waste whose safe disposal becomes a big problem.
- Industries are often responsible adverse diseases and ill effects, like silicosis and pneumoconiosis, tuberculosis, skin diseases and deafness.
- Metallic contaminants like Cd, Zn, Hg, etc., destroy bacteria and beneficial micro-organisms in the soil.
- Industrial wastes, including toxins, may enter the food chain and cause a number of undesirable effects to living beings and animals.
- Industrial effluent damages the natural biological purification mechanism of sewage treatment causing several soil and water borne diseases.
- Radioactive industrial pollutant cause undesirable disease when food containing radio-nuclides is taken by man.

Activity 2: (Group Discussion) (20 minutes)

What role does human activity play in the current global warming trend?

1.4.3 Technological advancement

The applications of technology often result in unavoidable environmental impacts. Such impacts are often perceived as unavoidable for several reasons. First, the purpose of many technologies is to exploit, control, or otherwise "improve" nature for the benefit of humanity. Att the same time, the myriad of processes in nature have been optimized and are continually adjusted by evolution, and disturbance of these natural processes by technology is likely to result in environmental consequences, often negative. Second, the conservation of mass principle and the first law of thermodynamics (i.e., conservation of energy) dictate that whenever material resources or energy are moved around or manipulated by technology, environmental consequences are inescapable. Third, according to the second law of thermodynamics, order can be increased within a system (such as the human economy) only by increasing disorder or entropy outside the system (i.e., the environment).

Thus, technologies can create "order" in the human economy (i.e., order as manifested in buildings, factories, transportation networks, communication systems, employment and incomes, etc.) only at the expense of increasing "disorder" in the environment. According to many studies, increased entropy is often correlated to negative environmental impacts.

Summary

In this session, we analysed the elements of global change. In the next session, we shall talk about the elements of climate change.

Exercise Questions (30 minutes)

Source: The Royal Society

Study figure above carefully and carry out the following activities:

1) describe the activity carried out in the photograph; and,
2) explain the relationship between technological advancement and the activity shown in the photograph.

1.5 Definition and elements of climate

1.5.1 Introduction

This training session introduces the elements of climate.

Objective

By the end of this session, the learner should be able to describe the various elements of climate.

Activity 1: Brainstorming (20 minutes)

Differentiate between climate change and global warming?

1.5.2 Temperature

Temperature is the amount of heat in the air, object or organism. We measure it with a thermometer. It varies across the planet depending on altitude, latitude, proximity to the sea and ocean currents:

- *Altitude*: for every 1 000 m of altitude the temperature drops by 6 ^{0}C.
- *Latitude*: temperatures decrease from the Equator towards the poles.
- *Proximity to the sea*: the sea heats up and cools down more slowly than land.
- *Ocean currents*: warm ocean currents produce higher temperatures in nearby coastal regions. Cool ocean currents have the opposite effect.

Our planet is divided into different climate zones:

- *Tropical zone* situated between the two tropics where the insolation is maximum;
- *Temperate zones*, one in each hemisphere, located between the tropics and the polar circles;
- *Cold zones*, one in each hemisphere, located beyond the polar circles.

Activity 2: (Group Discussion) (20 minutes)

In which way(s) do temperature greatly influences the climate of an area?

1.5.3 Precipitation

Precipitation is water from the atmosphere that falls onto the Earth´s surface in the form of rain, snow, sleet (a mixture of water and snow) or hail. The atmosphere contains water vapour. The amount of water vapour in the air is called humidity. When humid air rises, it cools and produces condensation, forming small droplets of water, which form clouds. When the droplets become bigger and heavier, they fall onto the earth´s surface.

1.5.4 Pressure

Air has weight. Atmospheric pressure is the pressure that the atmosphere´s weight exerts on the Earth´s surface. Pressure is measured with a barometer in millibars (mbar). It is shown on maps using lines called isobars. Normal pressure at sea level is 1 013 mbar. High pressure areas or anti-cyclones are areas where pressure is more than 1013mbar. Anti-cyclones produce stable weather conditions. The air is also dry, so there is no precipitation. Low pressure areas or depressions are areas where pressure is below 1013 mbar. Depressions produce unstable weather conditions, with a lot of cloud and precipitation.

In Text Questions (30 minutes)

1) The temperature, precipitation and wind in a place on a given day is called?
2) The terms tropical, dry, mid- latitude, high latitude and highlands: identify?
3) A small area with the climate different from the surrounding area is called?
4) What is the opposite of a polar climate?

1.5.5 Wind

Wind is air that moves from areas of high pressure to areas of low pressure to balance differences in atmospheric pressure across the planet.

Exercise Questions (30 minutes)

1) Describe how wind is measured as well as the development and importance of local winds.
2) Describe the movements of air and features associated with the two types of pressure centers.
3) Discuss the atmospheric conditions and consequences of El Nino/El Nina and the global distribution of precipitation.

Summary

In this session, we learnt about the various elements that affect the climate of an area. In the next session, we shall talk about the challenges and opportunities associated with climate change.

1.6 Opportunities and challenges associated with climate change

1.6.1 Introduction

This training session introduces opportunities and challenges associated with climate change.

Objectivs

By the end of this session, the learner should be able to:

a) Describe the various opportunities associated with climate change; and,

b) Explain the challenges associated with climate change.

Activity 1: Brainstorming (20 minutes)

What can we do to manage climate change?

1.6.2 Opportunities associated with climate change

Climate change is a global threat that will impact the entire globe especially the African continent. In addition, the continent's low economic development, extreme poverty and dependence on primary sectors, means that it has a limited capacity to adapt and protect itself from these impacts. While climate change has made new challenges emerge for African countries, it has also provided new opportunities for both public and private investments, which, if embraced, can create new development opportunities and drive economic growth.

Substantial political efforts will be required in order to promote increased and improved climate change investments especially as increasing investment to mitigate climate change and co-benefit the ongoing adaptation effort can also provide an opportunity for African countries to sustain national efforts aiming at achieving Millennium Development Goals (MDGs) and poverty Reduction strategies. The resources necessary to help Africa's adaptation and mitigation efforts, including managing disaster risk and following a low carbon development, are limited and scattered among many national priorities and competing agendas, such as poverty reduction, and conflict resolution.

This chapter will present the role of national, regional and international policies and institutional frameworks in enabling African countries to access climate change financing and the role of institutions in providing supportive frameworks for governments when making decisions on climate change priorities and fully integrating climate change issues into national policies.

1.6.3 Climate change related national, regional and international policies

Some policy frameworks relevant to enabling climate change mitigation and adaptation are:

- national policies;
- integrated planning and policies;
- financial incentives (e.g., eco-taxes, environmental friendly subsidies);
- research and development policy;
- standards and regulations that incorporate climate change considerations;
- integrated land use planning; and,
- linkages across policy sectors and to “sustainable development”.

One of the indicators for African countries´ engagement in the global frameworks for climate change mitigation and adaptation is the submission of Initial National Communication (INC) and National Adaptation Programme of Action (NAPA) to the UNFCCC. Without a Climate Change Policy framework, or at least elements of it in place, host countries cannot approve CDM projects and are limited in their access to adaptation funding, which poses an additional investment risk to potential project developers or hinders the funding of adaptation projects or programs. More specifically, activities that focus on reforestation and improved forest management, improved agricultural land management, installation of solar voltaic panels and improved cooking stoves, and improved grazing land management have all been proposed. However, the lack of clarity observed in some of these key documents raises concerns as to the degree that mitigation and adaptation priorities have been identified and incorporated into national policies. While the region has received little in the way of financing for on-the-ground mitigation or adaptation activities, the sheer number of initiatives, particularly in relation to REDD, are an encouraging sign that this region will take a more prominent role within the carbon markets in the future.

In Text Questions (30 minutes)

1) In what capacity has financial research assessed climate risk?
2) What types of initiatives are investors pursuing on the issue of climate change risk?
3) How has businesses been affected by climate change over the last decade?
4) What are the biggest obstacles to transforming to a low carbon economy?

6.4 Benefits of engagement

Some of the significant benefits for African countries to participate in the global initiatives of mitigating and facilitating adaptation from climate change impacts include the access of funding opportunities coming through the UNFCCC. Under the UNFCCC, industrialized countries recognize the responsibility to assist developing countries' adaptation efforts, primarily through the provision of financing for adaptation measures. These funds represent the most concerted efforts to date by the international community to finance activities and projects aimed at improving the adaptive capacities of communities in developing countries. Some of the global fund sources for mitigation and adaptation to climate change include:

- **Global Environment Facility;**
- **Strategic Priority for Adaptation Fund** - financing concrete adaptation projects in the areas of biological diversity, climate change, international waters and land degradation;
- **Least Developed Country Fund** – focusing on supporting the implementation of LDC NAPAs and their most urgent adaptation needs; Special Climate Change Funds –focusing on projects in Non-Annex 1 countries to support adaptation, transfer of technologies, energy, transport, industry, agriculture, forestry and waste management, and activities to assist developing countries whose economies are highly dependent on income generated from the production, processing, and export or on consumption of fossil fuels and associated energy-intensive products in diversifying their economies;
- **Adaptation Fund** - established under the Kyoto Protocol for concrete adaptation projects and programmes in developing countries that are particularly vulnerable to the adverse effects of climate change; and,
- **Clean Development Mechanism (CDM)** - promotes investment in GHG abatement technologies in forestry and agriculture, energy generation/ usage, waste management, and transportation sectors by providing an incentive for emission reductions in the form of tradable credits. In parallel to the Kyoto markets – fundamentally compliance markets shaped by governmental regulation – voluntary carbon markets have stimulated a growing number of project developers implementing projects, many in developing countries, to create offset credits for voluntary markets.

Despite initiatives in place to balance future climate conditions, there are indicators showing that determining the future of the climate regime is a complex process influenced by the need to balance the diverse interests and national circumstances of developed and developing countries, to enable continued economic development in all countries, and to promote significant energy development in developing nations.

Activity 2: (Group Discussion) (20 minutes)

What is the role of the state in helping rural communities respond to climate change?

1.6.5 Challenges associated with climate change

Global warming refers to increases in global temperatures as a result of an accumulation of GHGs in the atmosphere. For the past 150 years, the average temperature of the Earth's atmosphere and oceans has been rising, and the pace of this change in our climate appears to be accelerating. For example, the 10 hottest years on record have all occurred since 1990. After decades of research and hundreds of studies, an overwhelming majority of scientists have come to believe that human activities, especially the burning of fossil fuels (coal, oil and gas) are a major cause of this trend. The kinds of consequences that scientists and leaders have been increasingly worried about include coastal flooding, extreme weather; droughts; and, economic downturn.

Coastal flooding

Global warming is already creating higher sea levels as glaciers melt and the warming oceans expand. A growing concern is that the large ice sheets of Greenland and West Antarctica will likely melt more quickly in the future, accelerating the rise in sea levels and threatening many coastal communities. The Dutch, much of whose land is already below sea level, are so concerned they have begun to experiment with floating houses.

Extreme weather

Many scientists believe that the increase in heat waves, episodes of extreme rainfall, and the intensity of hurricanes may be related to climate changes caused by global warming, and that we can expect harsher weather if the warming trend is allowed to continue.

Droughts

Rising temperatures may increase the number of droughts, which will in turn affect food crops and water availability across the globe. Many scientists are warning that we may already be seeing agricultural problems as a result of global climate change.

Economic downturn

Recent economic studies also warn of the economic consequences of climate change. One warns that they could be as bad, or worse, than the Great Depression of the 1930s.

Exercise Questions (30 minutes)

Source: http://fabiusmaximus.files.wordpress.com/2014/03/drought.jpg/

Study Figure above carefully and carry out the following activities:

1) describe the activity carried out in the photograph.

2) explain the relationship between climate change and the activity shown in the photograph.

Summary

In this session, we have learnt about climate change, its causes and effects on forests in Africa. The session has also explained the trends in climate change over time. In the next session, we shall look at the various causes of climate change and the risks associated with greenhouse gas emissions.

1.7 Atmospheric physics and chemistry

1.7.1 Composition of atmospheric gas

Goal

Equip the learner with knowledge and skills about the constituents of the atmosphere and their properties.

General introduction

The Earth's atmosphere is a mixture of gases present in different concentrations and various particles[1]. This mixture is retained around the Earth thanks to its gravitational field. The nature of the gases composing the atmosphere and their relative importance give it its unique character in the solar system, its leading role in the appearance and maintenance of life on Earth.

The atmosphere is a protective layer for the Earth, especially against the incidence of dangerous ultraviolet solar radiation. By its composition it attenuates the climatic variations at the global level by the displacement of the masses of air and participates in the thermal equilibrium of the Earth by the greenhouse effect. The Earth's atmosphere brings the gaseous elements necessary for life. Finally, it participates in the exchange of matter and energy between different terrestrial environments (lithosphere, biosphere, oceans, surface runoff).

Chemical composition of the atmosphere

The main chemical components of the atmosphere are nitrogen (78%), oxygen (21%), rare gases (Argon, Neon, Helium), water vapor and CO_2. The following table shows the chemical composition of the atmosphere.

1 http://www.mrcc.uqam.ca/effet_serre/serre/composition.html

Table 2. Chemical composition of the atmosphere

Atmospheric gas	Volumes (%)	Molar mass (O = 16.000)
Nitrogen (N_2)	78.09	28.016
Oxygen (O_2)	20.95	32.000
Argon (A)	0.93	39.944
Carbon dioxide (CO_2)	0.035	44.010
Neon (Ne)	$1.8\ 10^{-3}$	20.183
Helium (He)	$5.24\ 10^{-4}$	4.003
Krypton (Kr)	$1.0\ 10^{-4}$	83.07
Hydrogen (H_2)	$5.0\ 10^{-5}$	2.016
Xenon (Xe)	$8.0\ 10^{-6}$	131.3
Ozone (Rn)	$1.0\ 10^{-6}$	48.000
Radon (Rn)	$6.0\ 10^{-18}$	222.00

Source : http://eduscol.education.fr/obter/applied/circula/theme/atmos22.htm

The constituents of atmospheric air can be classified into two categories:

- constituents such as nitrogen, rare gases, whose concentration is constant, at least in the lower layers of the atmosphere; and,
- constituents whose content varies in the atmosphere, such as CO_2 and especially water vapour.

All the gases, whose proportions remain constant, forms the dry air considered as a perfect gas. The composition of the dry air and its molar mass were, for the purposes of meteorology, adopted internationally at the values indicated in the table above. Atmospheric air is considered to be a mixture of two gases, dry air and water vapor, from a thermodynamic point of view. Greenhouse gases are water vapor, CO_2, methane, nitrogen oxide and ozone. The essential gases for life are water vapor, the ozone layer (O_3), which filters out dangerous ultraviolet rays. CO_2, which in limited quantity retains solar energy and regulates temperatures.

Educational activities (exercise and case studies)

On the basis of the basic information presented in the course and other literature, prepare and present a technical sheet on the chemical composition of the atmosphere.

1.8 Main layers of the atmosphere

Objective

By the end of the session, the learner will be able to:

Describe the main layers of the atmosphere and their characteristics.

General introduction

The atmosphere participates in the mechanism of retention of the heat emitted by the Earth, the phenomenon of greenhouse effect, and the process of planetary distribution of heat and humidity. The Troposphere is where meteorological phenomena and horizontal and vertical atmospheric movements (thermal convection, winds) take place. The Stratosphere is home to much of the ozone layer that protects life on Earth from UV radiation. The Mesosphere is the transition zone between Earth and space. The Thermosphere is the zone where the ionization of gaseous molecules occurs and the formation of the majority of the particles at very high altitude (predominant helium and hydrogen).

Main layers of the atmosphere

The gases in the atmosphere are distributed in a non-uniform manner in the four main layers of the atmosphere (the troposphere, the stratosphere, the mesosphere and the thermosphere (Figure 1). These layers are characterized by several physical properties, including pressure, temperature, density and the presence of various gases.

The main layers of the atmosphere are described below:

- **Troposphere:** temperature decreases with altitude (from the surface of the globe to 8-15 km altitude); thickness ranging between 13 and 16 km at the equator and between 7 and 8 km at the poles; contains 80 to 90% of the total mass of the air and substantially all of the water vapor; meteorological phenomena and horizontal and vertical atmospheric movements (thermal convection, winds);
- **Stratosphere:** temperature increases with altitude up to 0°C (8-15 to 50 km altitude); it is home to much of the ozone layer;
- **Mesosphere:** temperature decreases with altitude (from 50 to 80 km of altitude) up to -80°C; Transition zone between Earth and space;
- **Thermosphere or ionosphere:** temperature increases with altitude (from 80 to 800 km) and can reach more than 1000°C; Ionization of gaseous molecules and formation of the majority of particles at very high altitudes; Helium and hydrogen; and,
- **Exosphere:** from 350-800 km of altitude to 50 000 km of altitude.

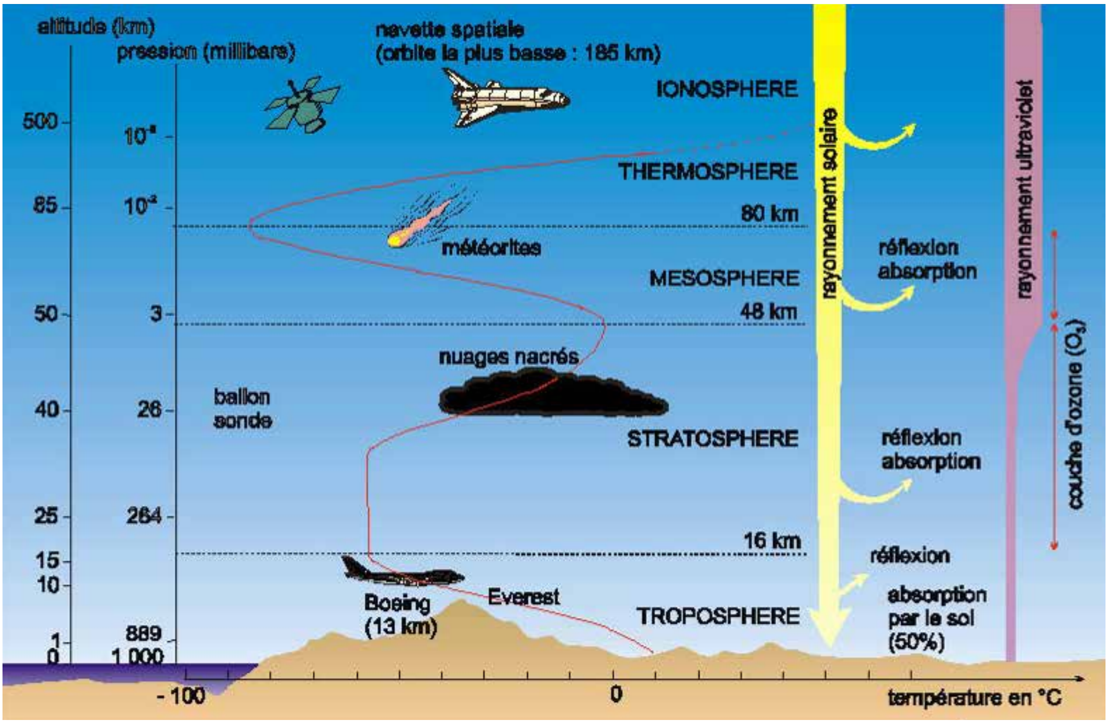


Figure 3. Variation of altitude, temperature and pressure as a function of atmospheric layers.
Source: http://www.mrcc.uqam.ca/effet_serre/serre/composition.html#couchesamospheriques

Educational activities (exercise and case studies)

Using the basic information presented in the course and other literature, prepare and present a technical sheet on the role of different layers of the atmosphere.

1.9 Atmospheric pollution

Objectives

By the end of the session, the learner will be able to:

- Describe sources and concentrations of atmospheric pollutants;
- Demonstratethe cycle of pollutants; and.
- Explain the impacts of atmospheric pollutants on ecosystems.

General introduction

The decline in forests attributed to air pollution is a major concern. For a long time, it has been known that the combustion of gases as well as the emissions from certain industrial installations can damage forests[2]. Air pollution has proven to be a complex process, the result of the interaction of many physical, chemical, natural and anthropogenic factors. Capacity-building to understand this process and reduce the burden of air pollution should reduce their impact on forest ecosystems.

Sources of atmospheric pollution

Air pollution may result either from a quantitative change, by raising the concentration in air of some of its normal constituents (e.g. CO_2, nitrogen peroxide, ozone) or a qualitative change due to introduction of external compounds (e.g. radionuclides, synthetic organic substances), or a combination of these two phenomena (Ramade, 1995).

Some pollutants in the atmosphere can result from the reaction between many substances to give new highly toxic compounds. Thus, the oxidation of SO2 in air to SO_3 reacts with water vapor to give sulfuric acid. The reaction of nitrogen oxides with unburned hydrocarbons, released to the atmosphere by burning fossil fuels, produces much more harmful peroxyacyl nitrates (PANs) than the original pollutants from which they originate.

Concentration of atmospheric pollutants

Emissions of pollutants corresponding to the quantities of pollutants directly released into the atmosphere by human activities (factories or dwellings, exhaust pipes, agriculture, etc.) or by natural sources (volcanoes or compounds emitted by vegetation and soils) expressed in kilograms or tonnes per year or per hour, for example, should not be confused with concentrations of pollutants that characterize the quality of the air being breathed and which are most often expressed in micrograms per cubic meter ($\mu g/m^3$)[3].

2 http://www.europarl.europa.eu/workingpapers/agri/s5-11-1_fr.htm
3 http://www.airparif.asso.fr/pollution/emissions-ou-concentrations

Nature of pollutant		Source of emission
Gas	Carbon dioxide	Volcanism Respiration of living things Fossil fuels
	Carbon monoxide	Volcanism Combustion engines
	Hydrocarbons	Plants Bacteria Combustion engines
	Organic compounds	Chemical industries Incineration of refuse Various combustions
	Anhydride sulfureux et autres dérivés soufrés	Volcanism Sea spray Bacteria Fossil fuels
	Dérivés nitrés	Bacteria Combustion
	Radionucléides	Atomic power stations Nuclear explosions
Particles	Heavy metals Inorganic compounds	Volcanism-meteorites Wind-spray erosion Various industries Combustion engines
	Organic compounds Natural or synthetic	Forest fire Chemical industries Various combustion Incineration of refuse Agriculture (pesticides)
	Radionuclide	Nuclear explosions

Table 3. Source and nature of atmospheric pollutants.
Source: Ramade (1995).

Air quality depends on emissions even if there is no simple and direct link between the two. It results from a complex equilibrium between the amount of pollutants discharged into the air and a series of phenomena to which these pollutants are subjected once in the atmosphere under the influence of meteorology: transport, dispersion by wind and rain, chemical deposition or reactions of pollutants between themselves or under the action of sunlight.

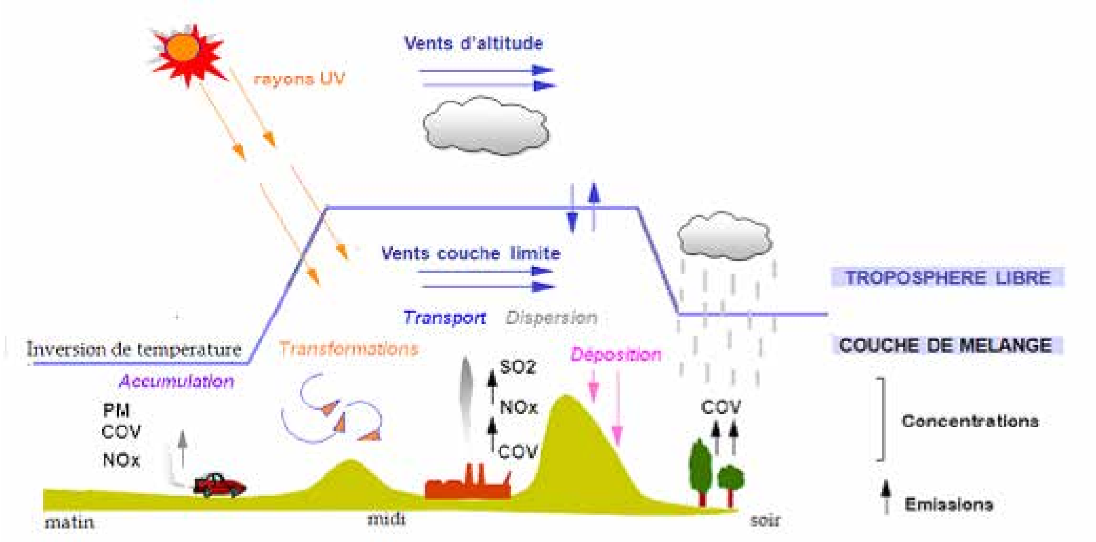


Figure 4. Dispersion of pollutants into the atmosphere.
Source: http://www.airparif.asso.fr/pollution/emissions-ou-concentrations

Box 1. Overview of the circulation of pollutants in the athmosphere

Distribution of pollutants by atmospheric movements, passage into air of solids in the form of fine particles and liquid pollutants by evaporation, dispersion of polluting substances in altitude and latitude by rising currents and winds, process of contamination of the atmosphere through mechanisms linked to the various parameters that control the phenomena.

Cycle of pollutants

All pollutants emitted in the environment undergo more or less rapid changes depending on their nature, weather conditions or other factors. As shown in the figure below, the "primary pollutants" emitted into the ambient air will be dispersed by atmospheric currents and undergo chemical transformations under the action of the sun, but also of moisture and suspended particles, to form "secondary pollutants". Depending on weather conditions, certain chemical reactions and physical phenomena, such as dispersion, accumulation or absorption may occur in the atmosphere.

Emission and immission are two distinct concepts[4]. Emissions consist of pollutants released to the environment through facilities, vehicles or products. They are measured at the source of their release when the pollutants are not yet diluted in the atmosphere. Immissions represent pollutants suspended in the atmosphere where it affects man, animals, plants, soil.

4 http://ge.ch/air/qualite-de-lair/polluants-de-lair/cycle-de-pollution

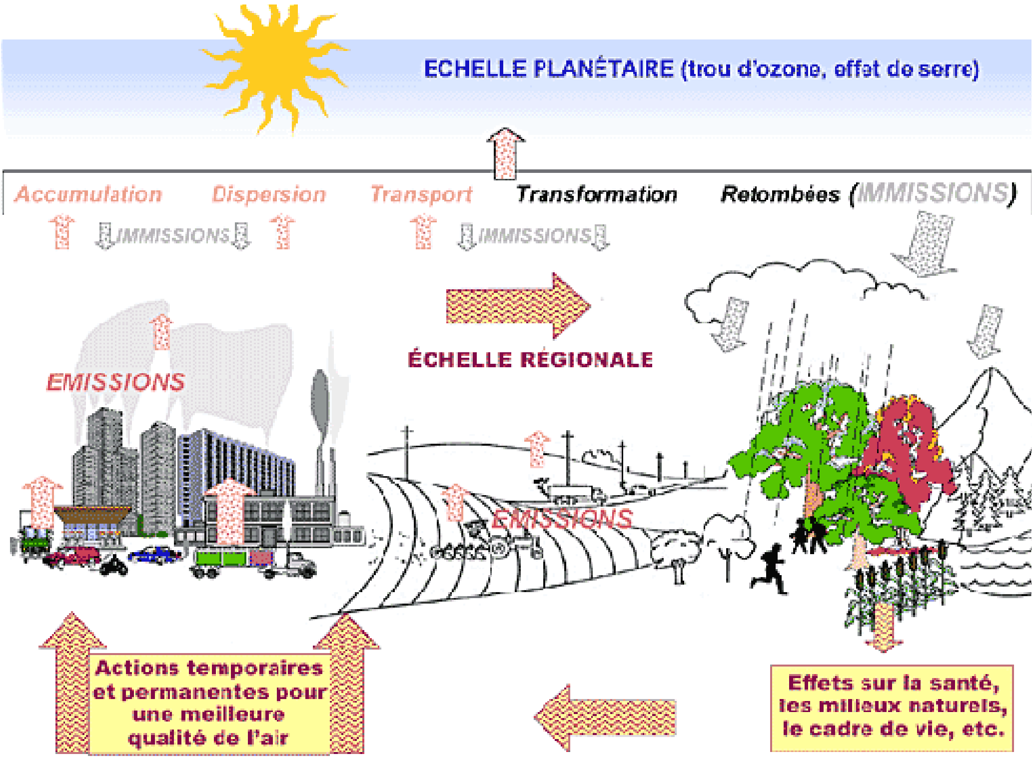


Figure 5. Cycle of pollutants in the atmosphere
Source: http://ge.ch/air/qualite-de-lair/polluants-de-lair/cycle-de-pollution

Impact of atmospheric pollution

Air pollution has effects on health and the environment. The effects of air pollution on the environment can be felt at different geographical scales, and they can reach sensitive aquatic or terrestrial ecosystems in the form of dry or wet deposits. Sulfur and nitrogen inputs are responsible for acidification and over-fertilization of sensitive ecosystems (e.g. forests, meadows, rivers and lakes). Ozone has acute chronic effects on vegetation.

High concentrations of some pollutants can lead to necrosis on plants. Air pollution can also cause a reduction in plant growth, even without visible damage (e.g. ozone may cause a drop in production of cereals) or reduced plant resistance to certain infectious agents[5].

5 http://www.airparif.asso.fr/pollution/effets-de-la-pollution-generalites

Box 2. Example of effects of air pollutants

Effects of air pollution on plant species and phytocoenoses

Sensitivity of plants including cultivated plants to atmospheric pollution: lichens and conifers as biological indicators of pollution; adverse effects (toxicity) of sulfur dioxide on plants.

Effects of air pollution on animals and humans

Penetration and accumulation of fluoride in plants through their stomata; poisoning of cattle and sheep through the contamination of trophic chains with fluoride; depletion of the entomofauna by fluorine and its mineral derivatives acting as a powerful insecticide; ingestion of lead by domestic animals; effect of the consumption of contaminated animals on human health.

Accumulation of pollutants in biomass

Incorporation of substances contaminating natural environments by living beings through multiple metabolic processes; penetration of pollutants into ecosystem food webs; integration into the cycle of matter in biocoenoses; harmful actions on innumerable plant species.

Box 3. Effects of air pollution on biogeochemical cycles

- Disturbing influence of air pollution on the main biogeochemical cycles.
- Comparison of the quantities of major pollutants released into the air by different technological sources with those generated by natural processes; changes in the rate of circulation of gaseous carbon, sulfur and nitrogen derivatives in the biosphere.
- Increasing perturbation of the biogeochemical cycle of carbon by the injection of a large mass of CO_2 into the atmosphere resulting from the combustion of various forms of fossil carbon.
- Disruption of the biogeochemical cycle of sulfur by the introduction of sulfur in the form of sulfur dioxide resulting from the use of fossil fuels.
- Disturbance of the nitrogen cycle by the release of nitrogen oxide from traffic and industries.

Educational activities (exercise and case studies)

- On the basis of the information presented in the course and other literature, perform an analytical summary in groups of 4-5 on emission sources and the cycle of atmospheric pollutants.
- Prepare and present a case study analyzing the effects of air pollutants on a forest ecosystem.

1.10 Atmospheric physics and solar radiation

Objectives

By the end of the session, the learner should be able to:

1. Describe the physical principles to understand the interactions of radiation with matter, as well as the radiative balance of the earth.

General introduction

The radiative balance of a given area is the difference per unit time between the gain of the radiation energy provided by the absorption of all or part of the incident radiation and the loss of this same energy caused by the emission of radiation (Aboudi, 2015). The interaction of radiation with matter has a slowing effect on the particles and physical and radio biological effects on the environment.

The Earth can be seen as an open ecological system, whose only external source of energy is the Sun. The study and understanding of the Earth's energy balance makes it possible to understand the physical processes that determine the environmental conditions in which organisms live and the physical interactions of these organisms and their environment (Delpierre, 2015). Forests have a positive effect on our climate. Forests draw CO_2 from the atmosphere for growth and thus reduce global warming.

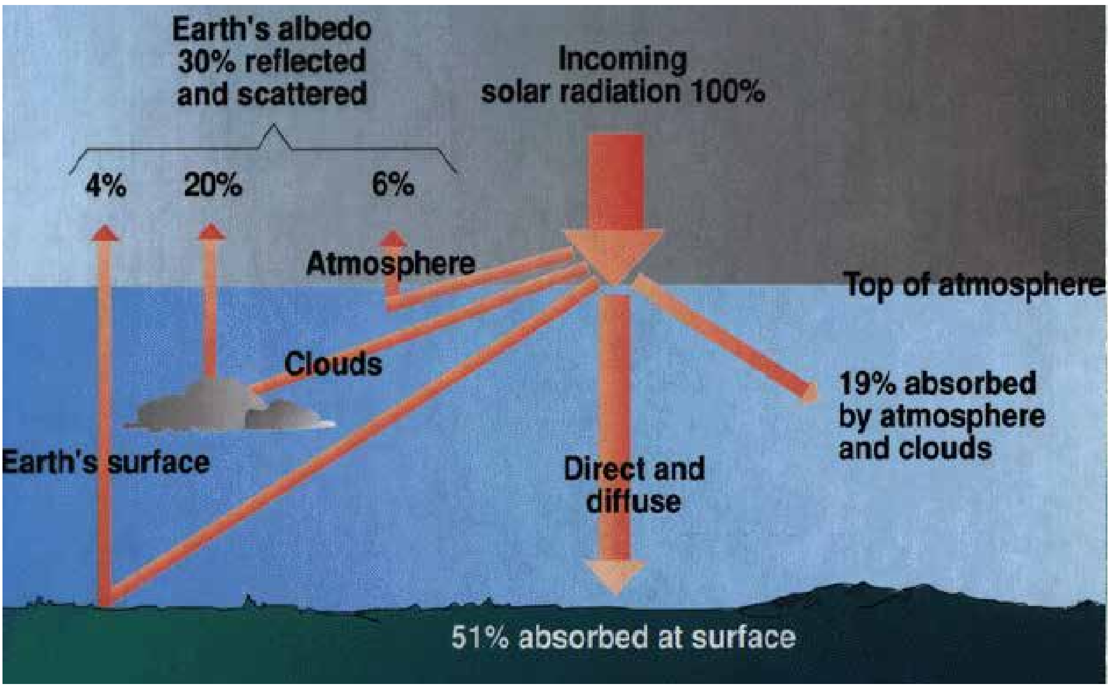


Figure 6. Radiation components.
Source: Delpierre (2015)

Interactions of radiation with matter

The particles and gases in the atmosphere can deflect or block the incident radiation. These effects are caused by the mechanisms of diffusion and absorption.

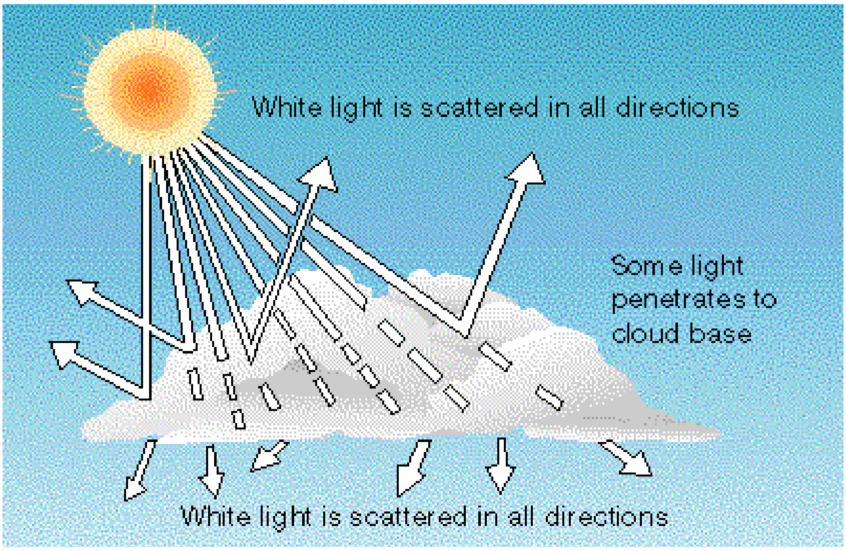


Figure 7. Lorenz-mie scattering for large particles (droplets).
Source: Wadsworth Publ. Comp. cited by Legras (2012).

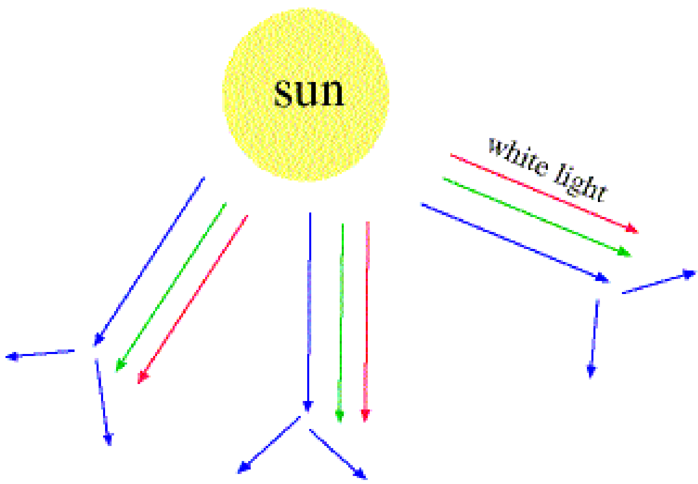


Figure 8. Rayleigh scattering for small particles (gas molecules).
Source: Legras (2012)

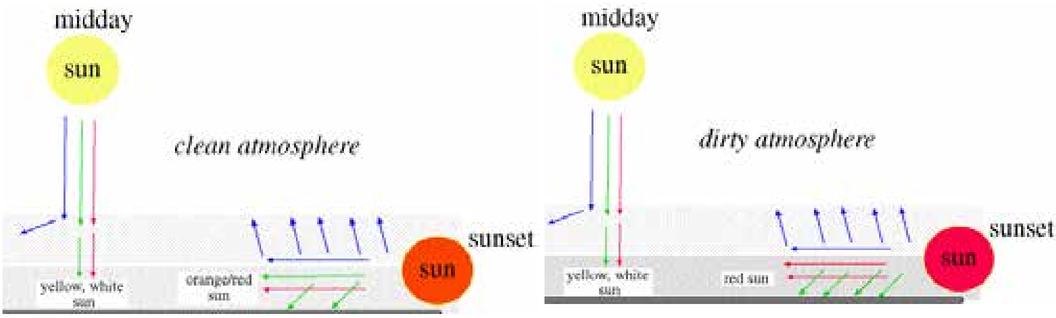


Figure 9. Effects of solar light diffusion.
Source: Legras (2012)

Radiative balance of the Earth

The radiative balance of the Earth is the difference between the radiation of short incoming wavelengths and the radiation of long wavelengths leaving the Earth. Every second, the earth receives 100 units of energy from the sun in the form of light and heat. It is a radiation of short wavelengths. Of these 100 units, 25 are immediately reflected in space by the albedo effect of the atmosphere. They are 104 units of energy in the form of long wavelength radiation (or infrared radiation) supplemented by 29 units consecutive to the evaporation of water and the direct calorific transmission between the Earth's surface and the atmosphere.

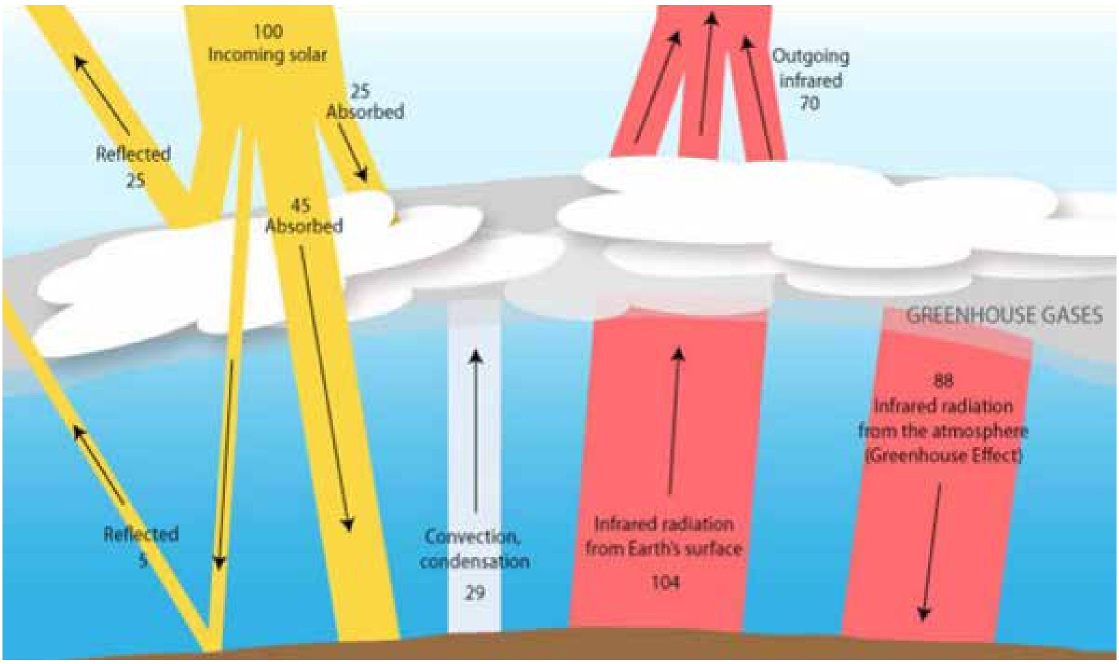


Figure 10. Radiative balance of the earth.
Source: http://www.climatechallenge.be/fr/des-infos-en-mots-et-en-images/le-changement-climatique/leffet-de-serre/leffet-de-serre-naturel/le-bilan-radiatif-de-la-terre.aspx

In the atmosphere, there is also an equilibrium: the surface of the Earth receives 45+88 units of energy and returns 29+104. This equilibrium illustrates once again the natural greenhouse effect. Indeed, the surface of the Earth emits more radiation (104) than it receives (45). In other words, the earth's surface loses more radiation of long wavelengths than it absorbs short-wave radiation. This lack is, however, compensated by the atmosphere, which returns part of the terrestrial radiation (88). The temperature at the surface of the Earth is thus determined by 45 units of energy from the sun, supplemented by 88 units of heat reflected by the atmosphere.

If only one component of the system changes, the radiative balance will be disrupted. As a result, the average temperature at the Earth's surface will change and, after a certain time, a new equilibrium in the radiative balance will be established. The change in temperature causes a change of climate on Earth.

Educational activities (exercise and case studies)

- On the basis of the basic information presented in the course and other literature, perform an analytical summary in groups of 4-5 on the inter-actions of radiation with matter and radiative balance.
- What are the physical principles and laws of radiation balance?
- What are the effects of radiative balance on plant ecology?

1.11 Water physico-chemistry

1.11.1 Water reservoirs and properties

Objective

By the end of the session , the learner will be able to:

Describe the constituents of water, as well as its physico-chemical and biological properties.

General Introduction

Surface and underground water throughout their constituents and properties interact with plants and are the source of nutrients and micronutrients that are essential to photo-synthetic organisms. Water is a continuous body, without rigidity, which flows easily, fills all the interstices, and then spreads out on the surface. It possesses a strong wetting power which confers it important capillary properties, enabling us to understand its behavior in soils. Moreover, its viscosity which greatly varies according to its chemical composition or its temperature is at the origin of remarkable miscibility characteristics[6].

Physico-chemistry of water

The mineral constituents of water are the result of the water-air, water-sediment and metabolism exchanges of the constituents of the aquatic biomass (Radoux, 1999). They includes the dissolved gases and mineral electrolytes.

The dissolved gases (O_2, CO_2, N_2). Biological activity and water-air transfers determine dissolved gas concentrations. The solubility of these gases is a function of temperature, pressure and air coefficient of solubility. The concentration of dissolved oxygen in surface waters results from the balance between inputs and losses. Contributions are made through the photosynthesis of upper plants and phytoplankton (up to 5-6 m deep) and through atmo-sphere-water transfer. Losses occur through respiration of aerobic bacteria (decomposition and mineralization of organic matter) of phytoplankton, plants, zooplankton, macro-invertebrates, batrachians, fishes, and through exchanges with atmosphere. This implies diurnal and nocturnal variations in dissolved O_2 concentrations and conversely in CO_2.

The nocturnal respiration of photosynthetic organisms causes changes in CO_2 concentration which strongly alters the water's pH. During the day, the CO_2 concentration decreases, the pH increases and vice versa during the night. CO_2 plays an important role in the calcocarbon system, which is crucial to the physicochemical equilibrium of waters.

The dissolved atmospheric nitrogen in the water is fixed by certain bacteria and certain algae (cyanophyceae or blue algae) and is released during the anaerobic process of denitrification. Only a few bacteria of the type *Azotobacter chroococcum* and *A. agilis*, photo-trophic bacteria and cyanobacteria can fix nitrogen. This fixation affects the nitrogen contents at the water-sediment interface.

6 L'eau: propriétés physiques et chimiques: http://www.ecosociosystemes.fr/eau_proprietes_physicochimiques.html

The following table shows the concentrations of dissolved gas in equilibrium with the atmosphere.

Table 4. Concentration of dissolved gases

Temperature (°C)	0	10	15	20	25	30
O_2	13.9	10.8	9.7	8.1	8.1	7.4
N_2	23.5	18.6	16.8	15.4	14.3	13.4
CO_2	1.06	0.70	0.59	20.53	-	-

Mineral electrolytes. The mineral composition of surface waters is a function of the chemical nature of the lands they traversed. There are basic and characteristic elements. There are six fundamental elements (H_2CO_3, HCO_3^-, Ca^{2+}, OH^-, H^+) which represent the calcocarbon system, resulting from the dissolution of CO_2 in water and $CaCO_3$ solubilizing under the effect of carbon acidity (Acid-Base balance in water). The characteristic elements are other mineral ions (Fe^{2+}, Mn^{2+}, Mg^{2+}, Al^{3+}, NO_3^-, SO_4^{2-}, PO_4^{3-}) resulting in particular from the dissolving action of carbonic acid. They give water its peculiarity (fresh water if the total concentration is less than 2-3 g/l, brackish water if the total concentration is greater than 2-3 g/l).

Organic constituents of water are a complex mixture of decomposing plant and animal products, synthetic products, microorganisms and their metabolites. Non-humid and humid substances are distinguished. Non-humid substances (amino acids, proteins, sugars, lipids) degrade rapidly whereas wet substances are essential organic constituents elaborated by microorganisms. The latter resist bacterial decomposition and form amorphous complexes of colloidal, brown, acidic and high molecular weight (Radoux, 1999).

Main physicochemical cycles. Carbon is present in water in both inorganic (CO_3^{2-}, CO_2, HCO_3^-) and organic forms. Organic carbon sources are diverse and independent of the type of ecosystem considered. The allochthonous organic matter (terrestrial or plant origin) is the major source of carbon in running water. Stagnant water contains a significant amount of indigenous carbon. The assimilation of CO_2 and its transformation into organic matter is ensured on one hand by the photosynthetic activity of plants, phytoplankton and phototrophic bacteria (Cyanobacterium) and on the other by various *chemolithoautotrophic* bacteria involved in the nitrification and methanogenesis processes (Radoux, 1999).

The nitrogen cycle follows to a large extent that of the carbon with which it is associated in all proteinaceous substances. In aquatic ecosystems, the nitrogen cycle is assured by many microorganisms. Depending to their characteristic metabolites, these microorganisms are located in the open waters or in the rhizosphere. The balance between various nitrogenous compounds, in addition to internal transformation in water, will depend on the amount of inputs and losses. Inputs depends on exogenous (runoff and sewage) and endogenous (biological fixation) inputs. Losses depend on exports by current, fishing, plant elimination, denitrification and volatilization of ammonium.

Molecular nitrogen can be reduced into NH_3 or NH_4^+ prior to incorporation as protein. This fixation is a property reserved to bacteria and cyanobacteria (blue algae). The nitrogen, present in organic form can be converted to ammonium (ammonification). The latter is the most reduced form of mineral nitrogen. It is oxidizable to nitrites and nitrates through the process of nitrification. Under these three mineral forms, but especially in the ammonium and nitrate forms, nitrogen can be assimilated by microorganisms (bacteria and fungi) and plants.

The future of phosphorus present in sediments rich in organic matter is intimately related to that of iron. In aerobic form, phosphorus is absorbed by sedimentable particles or precipitate in the form of ferric phosphates ($FePO_4$). The phosphorus solubilisation can result from the action of microbial H_2S on the insoluble ferric phosphates with the production of iron sulphide and the release of phosphate.

$2FePO_4 + 3H_2S \rightarrow 2FeS+2H_3PO_4+S$

Organic matters and dead biological mass (amino acids) are more often reused in biosynthesis by saprophytic bacteria (anaerobic bio-reducers) without prior mineralization. In anaerobic conditions, the degradation of sulfur compounds by putrefying bacteria takes place with the release of sulfur in the form of H_2S, CH_3SH, $(CH_3)_2S$. H_2S will either be released into the atmosphere or oxidized by sulfo-oxidizing bacteria in aerobic environments or by photosynthetic bacteria in anaerobic environments.

Fe^{3+} is insoluble in water. Only the Fe^{2+} form is soluble under reducing conditions, and mainly as $Fe(HCO_3)_2$. Fe^{2+} remains in solution under the following conditions: oxygen saturation less than 50%, presence of degradable organic matter, pH<7.5, high CO_2 concentration. These conditions are met in groundwater and in the hypolimnion of a lake. If $Fe(HCO_3)_2$ is contacted with oxygen, iron precipitates as $Fe(OH)_3$ and FeO(OH). Many bacteria are involved in these redox processes.

Box 4. Acid-Base balance

Acid-Base balances are influenced by all elements disolved in water. Main mineral elements play an important function in this balance that is highly pertubated in case of pollution (Radoux, 1999).

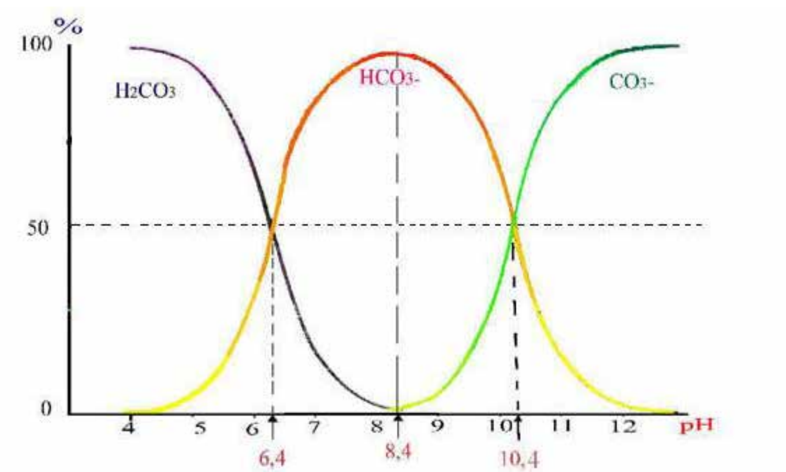


Figure 11. Trend in mineral carbon change in water follwing ph values.
Source: http://forums.futura-sciences.com/chimie/587433-pka-acide-fort.html

Suspended matters and sediments. There are great qualitative and quantitative diversities in suspended matter and sediments. Clays are a dominant component to which are added insoluble carbonates, metal hydroxides, quartz and organic particles. Important water-solid interfaces result from the presence of these elements. Suspended matters can be the source of significant material input and cause clogging of bottoms, altering water transfers between surface and underground waters. Suspended matters develop important adsorption effects which concentrate certain products dissolved as trace at their surface. They also fix micro-organisms, bacteria and viruses. Sediments (accumulation of suspended matter) represent a system where the solid phase is dominant although retaining the characteristics of a dispersed system. They cumulate pollutants and serve as a good indicator of present and previous pollution. Sediments are rich in microorganisms involved in physico-chemical and biological transformations in anaerobiosis (Radoux, 1999).

Biology of natural waters

Bacterial flora. Aquatic bacteria are extremely diverse and varied. Together with protozoa and fungi, they form the group of decomposers. Bacteria assume almost all degradation of organic matter by aerobic and anaerobic routes in surface waters. They are mainly heterotrophic for carbon and less phototrophic or chemo-autotrophic. Bacteria practice internal digestion by diffusing various enzymes in the medium which hydrolyze organic molecules that they absorb all over their surface. The composition of the bacterial flora of water depends on organic and inorganic fillers, pH, turbidity and temperature. Groundwater and spring water are poor in bacteria due to the filtering effect of the soil. Surface water bacteria are related to soil bacteria (Radoux, 1999).

Main roles of phytoplankton in aquatic ecosystems. Phytoplankton (plankton are micro-organisms in water, from 20 micrometers to a few mm, divided into zoo- and phyto-plankton) ensures the medium oxygenation (maximum at noon solar). Gas exchange due to photosynthesis are superior to those of respiration. It assimilates certain nitrogenous and phosphorus-based compounds and contributes to pH variation though photosynthesis and respiration mechanisms. It is a nutrient source for first-class consumers. Its proliferation indicates an eutrophic environment and can asphyxiate or poison an aquatic environment (Radoux, 1999).

Role of aquatic vegetation. The vegetation plays a physico-chemical, biological and mechanical role in aquatic ecosystems (Radoux, 1999).

Physico-chemical role. Daytime photosynthetic activity provides oxygen and consumes CO_2. Maximum concentra-tion of dissolved oxygen is reached at the end of the day and minimum at night. The screen constituted by the leaf water table of aquatic plants limits the penetration of solar radiation into the water and attenuates the day/night thermal deviations. Moreover, the development of phytoplankton is limited. Nitrogenous (NO_3^-, NH_4^+) and phosphorus-based (PO_4^{3-}) plant nutrition is carried out by the absorption of the nutrients present in the water and sediments. There is a release in water of organic substances throughout a continuous process (excretion of organic matter dissolved by leaves) and a process linked to the decomposition of organic matter of vegetable tissues. The evapotranspiration of a surface covered with plants is generally greater than the evaporation of an open water surface.

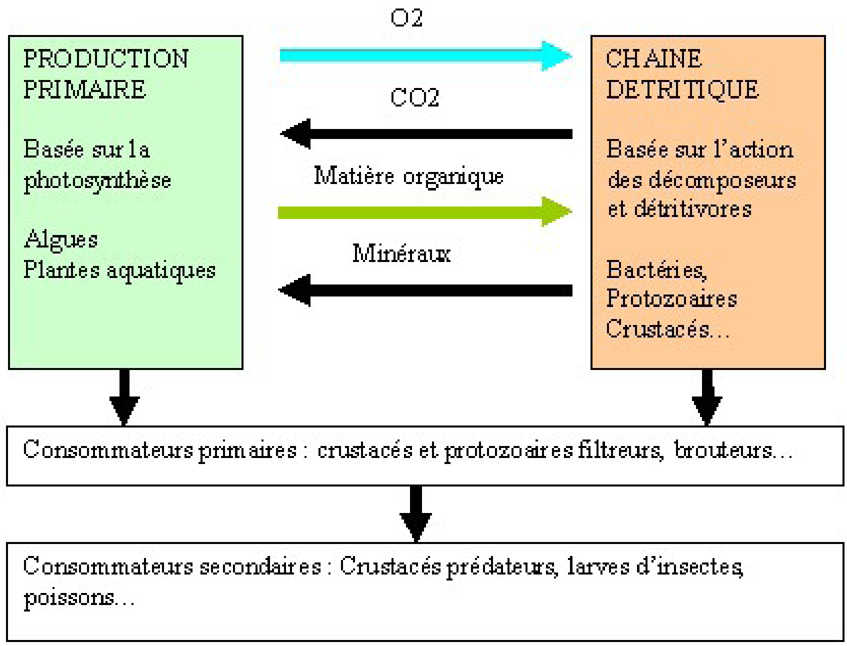


Figure 12. Matter Cycle and food pyramid. Source: haliosphere.over-blog.com

Biological role. The net annual production of plants immersed in fertile lakes varies from 4 to 7 t/ha and from 1 to 2.5 t/ha in poor lakes. This production depends on sediment and nutrient concentrations in the waters. Helophytes are the most productive plants in the world and are the most efficient natural transformers of light energy. The productivity of running water is lower, nutrients being trapped and decomposed at the bottom of the watercourse. Aquatic plants are an ideal spawning ground for fishes and invertebrates. Plants are consumed directly by phytophagous organisms and indirectly by second and third-order consumers. Some fishes (carps for example) are herbivorous (Figure 12 above).

Mechanical Role. The volume occupied by aquatic plants results in a decrease in the water flow velocity (of the order of 0.3 to 0.1 m/s) and an increase in water heights (of the order of 0.2 to 0.4 m). Plants also help to stabilize banks and consolidate elements (Figure 13 and 14).

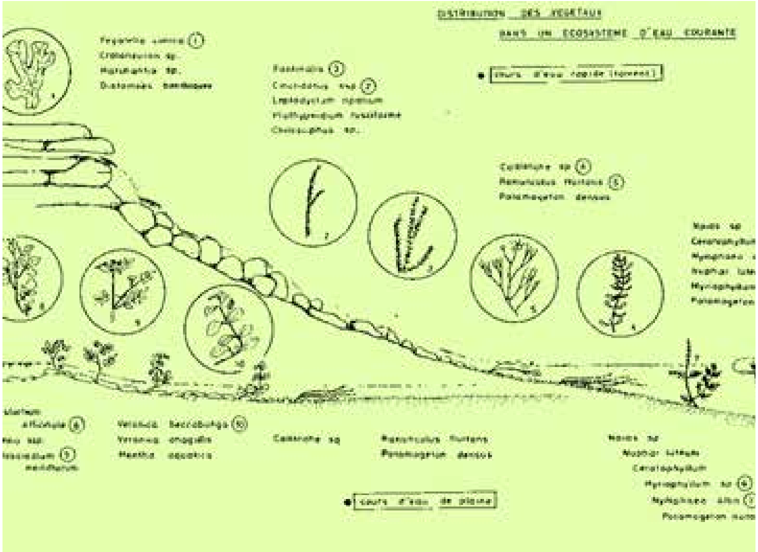


Figure 13. Plants in a running water ecosystem. Source: Radoux (1999)

Educational activities (exercise and case studies)

On the basis of the basic information presented in the course and others from literature, prepare in group of 4-5, a technical sheet on the properties of inland waters and a technical sheet on ocean waters.

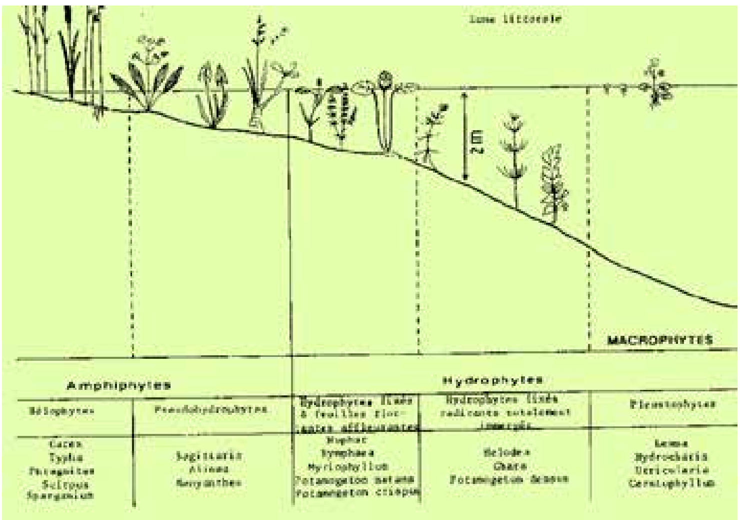


Figure 14. Distribution of plants in a stagnant water system. Source: Radoux (1999)

1.12 Pollution/water quality

Objective

By the end of the session , the learner will be able to:

Describe types of pollution and parameters for water quality characterization.

General introduction

Physical, chemical and biological parameters characterize surface waters by providing information on their qualitative status. The determination of the degree of pollution of watercourses enables us to assess their capacity for self-purification. Water pollution acts in a similar way on biotic and abiotic factors in both running water and in lakes and marshes, but the effects of pollution differ in the two types of limnic ecosystems. Pollution accelerates the process of eutrophication in both running and still water (Ramade 1995; Radoux, 1999).

The primary consequence of releases of pollutants into an aquatic ecosystem is the development of the water self-purification process. It is characterized by a multiplication of the purifying microorganisms, aerobic bacteria in a first time and in a second time by an increase in the consumption of dissolved oxygen (rapid decrease of the contents of dissolved oxygen). Populations of algae, protozoa and fish will be modified in composition, number and density.

A natural aquatic system is in equilibrium and its overall evolution is governed by a set of processes (redox equilibrium, basic acid balance, complexation). Aquatic biomass plays an important role and is considered as the main stability factor of the ecosystem. If biomass affects the steady state of an aquatic system reciprocally, any changes from external input will have a direct impact on biomass (Radoux, 1999). Thus the analysis of biomass allows evaluating the quality and the evolution of an aquatic system.

Chemical pollution of water

Mineral chemical pollution is all the more serious because its effects are incidious. Eutrophic compounds and metals are the two types of mineral pollutants (Stanitski et al., 2003; Ramade, 1995 and Radoux, 1999).

Eutrophic compounds are the mineral derivatives of nitrogen and phosphorus (nitrate, nitrite, ammonium, phosphates and other salts used in agriculture and industry). The transfer of nitrogen from a terrestrial to an aquatic environment plays a fundamental role in the nitrogen cycle at a planetary and regional scale. The oceans are deficient in nitrogen (low fixation and loss by denitrification). A widespread continuum of interdependent ecosystems ranging from aquifers to hydrographic networks, lakes, estuaries and coastal marine areas is the interface between the continents and oceans. The flow of concentrated nitrogen exchanges from continents to oceans is the result of numerous chemical and biological processes that determine the level of fertilizer input into the ocean environment.

Land use, the type of agriculture (intensive, extensive, monoculture, polyculture or mixed) and the tertiary purification yields of the water purification networks determine the quality of the groundwater and the nitrogen flow carried by the hydrographic network. The pollution sources of the water table by nitrates are punctual: domestic rejections by lost well, industrial discharges, percolation through landfills and runoff water and leaching of agricultural soils. Groundwater pollution by nitrates and pesticides has three main characteristics (slow process, stable process, local phenomenon). The process is slow due to the fact that the rate of infiltration is more or less low depending on the type of soil profile that the pollutant must pass through. The stable process is explained by the fact that the aquifer remains polluted because of slowness of groundwater flow. The phenomenon is localized because of the slow migration of pollution.

Box 5. Protection of aquifers and catchments

Methods for protecting groundwater against contamination should be developed on the basis of fundamental concepts of the assessment of the risks of pollution and vulnerability of the aquifers.

Natural aquatic environments are overall very poor in phosphorus to the extent that this element plays an essential role as a limiting factor. Artificial phosphorus inputs are of diffuse origin (soil erosion, leaching of agricultural land) and point source (discharge of domestic, agricultural and industrial wastewater, detergents used in industry). The eutrophication process is explained in the following box.

Box 6. Watercourse eutrophication

Excessive nitrates and phosphates concentrations induce the phenomenon of eutrophication (choking of aquatic life). These substances are normally generated by the mineralization of organic matter. However, present in excessive amounts due to untimely releases, they favor the proliferation of algae and photosynthetic microorganisms which reduce the penetration of light in the layers of deep water. If these photosynthetic algae and microorganisms produce oxygen during the day, they consume them at night and these variations in oxygen concentration can be fatal to fish. Moreover, the decomposition of dead algae also induces an oxygen consumption. When water is not heavily oxygenated, the anaerobic conditions may also result in an accumulation of ammonia compounds and nitrites that can poison flora and fauna.

Source : Institut Bruxellois pour la Gestion de l'Environnement/Observatoire des Données de l'Environnement, 2005
http://document.environnement.brussels/opac_css/doc_num.php?explnum_id=5378

Heavy metals. Water pollution by heavy metals is created by the chemical industry, the metallurgy, the thermal power plants, the agriculture and the household products (batteries, etc.). The doses released into the environment accumulate in the trophic chains to reach thresholds of lethal toxicity. By way of example, heavy metal are concentrated to a thousand times by molluscs and thus constrains their use for food purposes. Heavy metals contained in urban and industrial effluents act in an inhibiting or detrimental manner on micro-organisms which purify water.

Box 7. Example of concentrations in mg/liter considered as nitrification inhibitor

Elements	Concentration (mg/l)
Cu	0.1 – 0.4
Cr	0.25 – 0.9
Pb	0.5 - 1
Zn	10

Source: Edeline (1980)

Heavy metals mainly act in a harmful way in the dissolved state. Their solubility is also pH-dependent. The future of heavy metals in water is conditioned by the complex formation. All metals are hydrated in water solution. Metal hydroxides are numerous. For each metal, a *log(C) = f(pH)* diagram can be established.

Organic chemical pollution can be characterized by the loading of water in two categories of carbon molecules: i) synthetic organic compounds from chemical industries and other; ii) organic compounds derived from human, animal and vegetable metabolisms (fecal matter, urine, organic residues of cultures, lipids, protein, polysaccharides, etc.).

Synthetic organic compounds originate from human activities causing discharges of chemicals into the aquatic, terrestrial or marine environment. There are about 4 million chemical compounds of which 50 to 60 thousand are used for technical purposes. We mainly distinguish pesticides, products for domestic and industrial use used in open circuit, products for industrial use used in closed circuit. These organic contaminants are, depending on the case, remanant or more or less easily biodegraded. They impact aquatic ecosystems and human health. It is necessary to monitor their concentrations and effects, as well as to establish quality criteria and limiting standards.

Pesticides used in agricultural environments can reach surface waters through rainfall and by artificial or natural drainage. Their transfer depends on a set of biogeochemical phenomena that influence their persistence and mobility: degradation, volatilization percolation, and adsorption in soils. The persistence of agricultural products mainly depends on their suitability for biological and chemical degradation. The durations of persistence expressed in time necessary for a degradation of 70 to 100% are very variable according to the chemical category of the pesticide and even from one product to another. Urban and wastewater contain large amounts of detergents. Synthetic detergents are complex mixtures which contain an active material with surface-active properties, a polyphosphate filler.

Organic compounds are derived from animal and plant human metabolisms, e.g. organic fecal matter, various organic cooking and culture wastes, etc. These materials are readily biodegradable. However, the volume of the pollutant and its local concentrations can increase rapidly.

Box 8. Effect of chemical pollution of water

- Eutrophication of the aquatic environment.
- Contamination of water tables by nitrates.
- Lethal and sub-lethal toxicity of organic pollutants (short-term).
- Chronic toxicity of organic pollutants (long term).
- Mutagenic, teratogenic, and carcinogen risks associated to organic compounds.
- Water reoxygenation limited by detergents.
- Obstruction of the purifying action of bacteria by certain detergents.
- Poisoning of freshwater animals.
- Interference with the self-purifying role of the receptor medium by organic compounds derived from human, animal and plant metabolisms.

Physical pollution of water

Mechanical pollution results from the presence in water of particles and solid waste. They are essentially insoluble minerals, silt and clay. This pollution originates in the extractive industries (mines, quarries), wood defibration plants, tanneries, agri-food industries, but also domestic activities and run-off water, whether natural, agricultural or other (Radoux, 1999). The measurement unit of mechanical pollution is the suspended solids content (MES) expressed in mg of insoluble dry matter solids per liter.

Box 9. Effect of physiscal pollution

- Watercourse clogging.
- Recovery of water plans by plants.
- Destruction of spawning grounds.
- Fish gill obstruction.
- Inhibition of aquatic life.

Box 10. Effect of thermal pollution

- Enhancement of dissolved oxygen depletion.
- Necessity of more intense branchial circulation for freshwater animals to compensate the reduction in dissolved oxygen concentration.
- Risk of concentration of toxic substances by freshwater animals.
- Development of organic matter degradation in anaerobiosis.
- Bacteria Proliferation.
- Development of diatoms below 20°C; replacement by green algae from 25°C; succession by blue algae.
- Difficult mixtures of cold and hot water and stratification of the watercourse.
- Changes in the water regime causing changes in fish communities
- Development of pathogens for humans (eg Naegleria-amoeba).
- Decrease in the aquatic fauna and flora diversity, exacerbation of organic pollution, eutrophication of lakes and rivers.

Thermal pollution is not generally visible. Although well known, its consequences are not easily correlated with the phenomenon that gave rise to it. Thermal pollution results from the presence of a growing number of nuclear power stations and industries that generally use water from a watercourse as a refrigerant (Radoux, 1999; Ramade, 1995). This pollution essentially results in the reduction of water.

Radioactive pollution is serious in its short, medium and long-term consequences and is due to accidents in power stations or transport of radioactive products (Radoux, 1999).

Biological water pollution

Biological pollution results from the discharge into the continental and littoral waters of a wide variety of fermentable organic substances. These can be of various origins: urban or industrial effluents containing household wastes, fecal matters, sweets, stationery, etc. Biological pollution of water results in high bacteriological contamination (Ramade, 1995). It includes viral bacterial and zoo-parasitic pollution. The origin is specifically human and animal. Fecal matters contaminate urban, agricultural and industrial (agri-food) domestic wastewater through massive inputs. It represents a serious health risk for humans and animals and requires the implementation of purification processes (Radoux, 1999).

Pollution by bacteria. The total bacterial concentration of domestic wastewater is in the order of 10^8-10^{10} germs/100 ml. The bacteria responsible for the most frequent waterborne infectious diseases are gram-negative, aerobic and facultative anaerobic bacteria. In several African cities, the near-total absence of wastewater collection networks and sewage treatment stations accentuates the importance of water contamination.

Pollution by viruses. Organic waste, especially excrements, contains viruses (entero-viruses, adenoviruses, rotaviruses) that are also sources of pollution of surface and under-ground waters.

Pollution by zooparasites. Freshwater parasitology concerns, on the one hand, parasitic fauna present naturally and, on the other hand, others introduced by anthropogenic activities. The presence of a parasite in the water will usually indicate fecal contamination. In general, there are no standards or legislation concerning the presence and control of these zoo parasites in the aquatic environment.

Box 11. Effects of biological pollution of water

- Recurrence of affection (colibacillosis, or viral hepatitis).
- Epidemic of chlolera.
- Serious pathogens (typhoid, dysentery).
- Multiplication of pathogenic germs.

Water quality

The quality of water and the nature of the pollutants at a given time can be determined by measuring the physico-chemical and bacteriological parameters. However, the quality of water fluctuates with time, seasons, flows, pollutant charges and their origins. Therefore, the sole measure of these parameters gives an incomplete assessment of the qualitative state of water. To assess the actual state of pollution, analysis of biomass constituents is essential because it integrates the qualitative history of surface waters and seasonal variations.

Measurement of physical parameters and primary pollution

Four parameters are to be measured.

The temperature of water plays an important role, e.g. with regard to the solubility of salts and gases, including the oxygen necessary for the balance of aquatic life. Furthermore, the temperature increases the rates of chemical and biochemical reactions by a factor of 2 to 3 for a temperature increase of 10°C. The metabolic activity of aquatic organisms is therefore also accelerated as the temperature of water increases. The value of this parameter is influenced by the ambient temperature but also by possible discharges of hot wastewater. Sudden temperature changes of more than 3°C often prove detrimental to aquatic life.

The electrical conductivity (EC) is a numerical expression of the ability of a solution to conduct electric current. Most mineral salts in solution are good conductors. On the other hand, organic compounds are bad conductors. Standard electrical conductivity is usually expressed in millisiemens per meter (mS/m) at 20°C. The conductivity of natural water is between 50 and 1500 µS/cm. Estimation of the total amount of dissolved matter can be obtained by multiplying the conductivity value by an empirical factor depending on the nature of the dissolved salts and the temperature of the water. Knowledge of the content of dissolved salts is important in so far that each aquatic organism has its own requirements with regard to this parameter. Aquatic species generally do not survive significant variations in dissolved salts, which can be observed, for example, in the case of wastewater discharges.

The measurement of the conductivity enables to determine the overall quantity of dissolved salts in the waters. The amount of dissolved salt present in natural water is a function of the slow dissolution of certain rocks in the watershed. Conductivity expresses the ease with which a water conducts an electric current.

pH is the measure of water acidity. The pH scale extends in practice from 0 (very acid) to 14 (very alkaline); The median value 7 corresponds to a neutral solution at 25°C. Low pH (acid water) increases the risk of the presence of metals in a more toxic ionic form. High pH increases ammonia concentrations, toxic to fish.

Suspended matters are expressed in mg/l of insoluble dry matter. Their determination is essential to assess the distribution between dissolved pollution and sedimentable pollution (TSS>10 µm) (Radoux, 1999). Suspended materials include all mineral or organic materials that do not solubilize in water. They include clays, sands, silts, small organic and mineral materials, plankton and other microorganisms in water. The quantity of suspended matters varies, in particular, according to the seasons and the flow regime. These materials affect the transparency of water and reduce the penetration of light and, consequently, photosynthesis. They can also interfere with the respiration of fish. In addition, suspended solids can accumulate high amounts of toxic materials (metals, pesticides, mineral oils, polycyclic aromatic hydrocarbons, etc.).

Measurement of organic chemical parameters and secondary pollution

Chemical oxygen demand (COD) and biochemical oxygen demand (BOD5). Wastewater is characterized by a wide variety of organic substances polluting the surface waters. In the context of organic pollution, chemical oxygen demand (COD) and biochemical oxygen demand (BOD5) are the evaluation parameters (Radoux, 1999).

The measurement of these two parameters is based on the difference between the initial dissolved oxygen content and the final dissolved oxygen content after oxidation of the organic matter present in a water sample. Biochemical Oxygen Demand (BOD) is the amount of oxygen used by bacteria to partially decompose or oxidize biochemicals in water that constitute their source of carbon (fats, carbohydrates, surfactants, etc.). This removal of oxygen is to the detriment of other living organisms of the aquatic environment.

As far as domestic water is concerned, about 70% of the organic compounds are generally degraded after 5 days and degradation is practically complete after 20 days. The indicator used is generally the BOD5 which corresponds to the amount of oxygen (expressed in mg/l) required by the decomposing microorganisms to degrade and mineralize within 5 days the organic matter present in a liter of polluted water. The higher the BOD5, the higher the amount of organic matter present in the sample.

The chemical oxygen demand (COD) is the amount of oxygen required for the chemical degradation of the organic compounds in the water using a powerful oxidizer. It enables measuring the content of total organic matter (except some compounds that are not degraded), including those that are not degradable by bacteria. It is therefore an important parameter to characterize the global pollution of a water by organic compounds. The difference between COD and BOD is due to substances that cannot be biologically decomposed.

The ratio of BOD to COD is an indicative measure of the biochemical "degradability" of the compounds present in the water. The COD/BOD ratio ranges from about 2.5 (waste water recently spilled) to 10-20 after total decomposition (Lisec, 2004). In the latter case, water is well mineralized. However, when toxic compounds are present, the biological activity is slowed down and, as a result, the amount of oxygen consumed after 5 days is less. This also results in a high COD/BOD ratio. BOD and COD are measured in mg of O_2 per liter.

Dissolved Oxygen (OD) concentrations are, along with pH, one of the most important water quality parameters for aquatic life. Oxygen dissolved in surface waters mainly comes from the atmosphere and photosynthetic activity of algae and aquatic plants. The concentration varies daily and seasonally as it depends on many factors such as atmospheric oxygen partial pressure, water temperature, salinity, light penetration, water agitation and nutrient availability. This concentration of dissolved oxygen is also a function of the rate of oxygen depletion in the medium due to the activity of aquatic organisms and the processes of oxidation and decomposition of the organic matter present in the water. Overall, the closer the dissolved oxygen (DO) concentration is to saturation, the greater a river's ability to absorb pollution:

- a value less than 1 mg of O_2 per liter indicates a near anaerobic state; this condition occurs when the oxidation processes of mineral waste, organic matter and nutrients consume more oxygen than is available; a low dissolved oxygen content causes an increase in the solubility of toxic elements that are released from sediment;
- a value of 1 to 2 mg of O_2 per liter indicates a highly polluted but reversible river;
- a value of 4 to 6 mg of O_2 per liter characterizes good quality water; and,
- levels higher than the natural content of oxygen saturation indicate eutrophication of the medium resulting in intense photosynthetic activity; sensitive fish species may be disturbed by an oxygen content of less than 4 mg/l; the concentration of dissolved oxygen may also be expressed as %oxygen saturation; at a temperature around 15°C, the quality objective of 50% oxygen saturation corresponds to a concentration of 5 mg of O_2/liter.

Measurement of mineral chemical parameters and tertiary pollution

The main mineral chemical parameters are nitrogen and phosphorus content. Both elements are important nutrients for plants. The compounds containing them, such as phosphates and nitrates, are therefore crucial for plants.

Concentrations of nitrites (NO_2^-), nitrates (NO_3^-), ammonia (NH_3) and ammonium (NH_4^+), phosphates (PO_3^-), nitrogen (N) and phosphorus (P) are therefore important parameters for monitoring the quality of surface water. Nitrogen "Kjeldahl" represents organic nitrogen (e.g. amino acids, urea) and ammoniacal nitrogen. As for "total" nitrogen, it corresponds to the sum of organic nitrogen, ammoniacal nitrogen, nitrites and nitrates.

Educational activities (exercise and case studies)

On the basis of the basic information presented in the course and from other literatures, prepare as a group of 4-5, an analytical summary on the types of surface water pollution.

1.13 Water treatment

Objective

By the end of the session, the learner will be able to:

Explain the different techniques of intensive and biological treatment of wastewater.

General introduction

Intensive wastewater treatment processes are designed to respond to serious pollution problems of industrial and domestic origin. Industrial discharges are often highly polluting and toxic. Urban domestic waste is normally less chemically toxic, but contaminating by its volume and the pathogenic risks involved. The number of techniques and devices that can be implemented in a conventional station is considerable. Their choice depends on the characteristics of the water to be treated, the degree of purification desired and the financial resources available.

The rustic treatment plants (without electromechanical equipment and without artificial energy support) are very diverse and of varied design. These are so-called extensive techniques because they involve large areas of land, integrating purification processes into more or less developed natural ecosystems or artificial copies of ecosystems. Knowledge on intensive and biological treatment methods of wastewater by forestry technicians is necessary to undertake actions to reduce the effects of water pollution on forest resources.

Intensive wastewater treatment

Pretreatments include screening, plastering, equalization basins, decanting and flotation:

Screening is used for the removal of large suspended solids before any other treatment processes. In the treatment of domestic wastewater, bar screens are usually installed at the head of the station to retain coarse materials. Simple bar screens generally consist of metal screens, with bar spacing of 4 to 7 cm which can be cleaned mechanically or manually (Radoux, 1999).

Plastering: sand and heavy materials whose sedimentation is related to granulated particles must be quickly eliminated in the treatment line in order to avoid abrasion of bodies, pumps and mechanical equipment. A correct sizing should avoid the simultaneous deposition of organic matter which would complicate the subsequent pouring of the sand. The choice of a type of sand trap will depend on the sand concentration in the water, the size of the station and its cost (Radoux, 1999).

Equalization basins have the goal to reduce variations in the characteristics of the waste water in order to be located under the optimum conditions for subsequent treatments. The type and the capacity of the basin are related to the volume of water discharged and the degree of fluctuation of the wastewater characteristics.

Decanting. Decanters can be either rectangular or circular. In most cases, rectangular decanters are equipped with a bottom scraper moving counter-current at a speed of 0.3m/min.

Flotation is a clarification and thickening technique, like gravitational sedimentation, except that materials to be retained are gathered on the surface, from which they are scraped. Dissolved air flotation is generally used for the treatment of wastewater, the elimination of suspended solids, oils and greases, fibers and other materials of low density, or for the thickening of activated sludge or flocculated chemical sludge.

Secondary treatments include bacterial beds, activated sludge, organic discs and anaerobic fermentation.

Bacterial bed, made up of a layer of material called lining covered with a biofilm on which the wastewater runs. During the percolation of water through the bed, the organic matter is removed by the biofilm: the substrate and the oxygen diffuse through the biofilm where metabolism occurs. Metabolites and CO_2 diffuse in the direction of the liquid. During penetration into the biofilm, oxygen is consumed due to microbial respiration, thus defining an aerobically active zone; beyond that bacterial activity is anaerobic.

Activated sludge. An activated sludge tank is a continuous biomass reactor in which the biomass is stirred and aerated together with the waste water. The biomass is then separated in a secondary decanter, a part of the thickened sludge being recycled to the aerator. The activated sludge process can provide an effluent whose soluble BOD will vary from 10 to 30 mg/l; the residual COD may be as high as 500 mg/l, depending on the inert organic matter content of the waste water. It is necessary to first remove the water from a number of pollutants, such as oils and fats.

Organic discs. The reactor consists of a high diameter plastic disk set on a horizontal axis. The half-submerged drum (about 40%) rotates around this axis. A biofilm whose thickness varies from 1 to 4 mm develops on the discs. The rotation of the disks ensures both oxygenation and contact with the waste water. The excess biomass breaks off in the same way as in the bacterial beds and is separated in a secondary decanter. The efficiency of the processes essentially depends on:

- the speed of rotation of the discs;
- the length of stay;
- the number of floors; and
- the temperature

Anaerobic fermentation of organic compounds is a very complex process. It results from a high number of reactions. In a conventional heavy load digester, all of the reactions take place simultaneously in the same reactor. When the digester is in dynamic equilibrium, there is no accumulation of intermediate metabolites. Although a large number of factors (composition and concentration of medium, pH, temperature, mixing) influence the reaction speed, it is assumed that the overall speed is controlled by the conversion speed of fatty acids into methane and CO_2. If this balance is not respected, digestion is restrained or stopped; this leads to an accumulation of volatile fatty acids. Anaerobic fermentation is used for the treatment of highly charged industrial wastewater. Two types of implementation are used : the anaerobic contact method and the anaerobic bacterial bed.

Tertiary treatment include elimination of ammonia, phosphorus removal, coagulation and precipitation, filtration, adsorption on activated carbon and ion exchange (Radoux, 1999).

Elimination of ammonia. In water containing ammoniacal nitrogen, the ammonium ions and the ammonia are in equilibria:

$$\mathbf{NH_3 + H_2O \underset{pH}{\leftrightarrow} NH_4^+ + OH^-}$$

At pH 7, only ammonium (NH_4^+) ions exist in solution, while at pH 12 the solution contains only dissolved ammonia (NH_3). The air stripping of ammonia consists of bringing the pH of the waste water to 10.5 - 11.5 and creating an intimate contact between the water and the air to lead the ammonia gas out of the solution (stripping). Conventional cooling towers are generally used to carry out this operation. Caustic soda and lime can be used for adjusting the pH of wastewater.

Phosphorus removal. Phosphorus in its different chemical combinations causes serious problems in rivers and dormant waters that receive them, by stimulating the growth of algae (eutrophication). Phosphorus removal can be successfully accomplished by physico-chemical and biological processes.

Coagulation and precipitation. Colloidal materials, both organic and inorganic, can be removed by coagulation that consists of the addition of chemical agents to a dispersion of colloids in order to destabilize them so as to collect them in the form of flocs. Coagulation therefore involves, on the one hand, the reduction of surface electrical charges and, on the other hand, the formation of complex hydroxides in the form of flakes. Precipitation consists of forming an insoluble compound of the pollutant whose elimination is desired. Coagulation is applied, for example, for the removal of turbidity or the coloring of waste water and precipitation, for the removal of phosphates.

Filtration is used to remove suspended solids, and serves as a pretreatment in the case of poorly charged water or as a finishing treatment downstream of a physico-chemical and biological process. In the latter two cases, it is referred to tertiary purification.

The suspended solids are removed on the surface of the filter by sieving and within the filter by sieving and adsorption. The suspended matter encountered in wastewater is essentially variable in terms of both dimensions and loads. Some of them will therefore escape the filtration treatment.

Adsorption on activated carbon. The adsorption processes are used for the removal of refractory organic materials (COD) in tertiary treatments or for the removal of biodegradable or non-biodegradable organic materials in physico-chemical processing chains.

Ion exchange relies on the exchange of ions which can take place between ions in solution and those linked to certain chemical functions in the exchanger. This technique is used for the removal or replacement of certain ions contained in water such as calcium and magnesium ions (hardness of water) or certain metal ions (Cr^{6+}, Zn^{2+}, etc.).

Disinfection is the process by which pathogenic germs are destroyed through the action of chemical agents or by other means. It can be accomplished by the direct action of ultraviolet radiation or temperature. It is also possible to use chemical agents which, when reacting on the cell, induce toxic compounds or disruptive structural modifications leading to the death of pathogenic germs.

Sludge treatment. Most of treatment processes normally used in controlling water pollution produce sludge from a solid-liquid separation process (decanting, flotation) or resulting from a chemical reaction (coagulation or biological). These materials will undergo a treatment process including thickening, dehydration and final evacuation. Organic sludge may also undergo treatments to reduce the organic fraction or volatile matter before final disposal.

Biological treatment of wastewater

Lagoons. Biological purification processes of extensive types such as lagoons (or stabilization ponds) are increasingly commonly used in situations where conventional wastewater treatment systems and individual sanitation reach their operating limits (Radoux, 1999). The various communities in a lagoon are: algae or microphytes, bacteria, microfauna and fish (Radoux, 1999).

The pathogenic germs contained in domestic effluents come mainly from the intestinal microbial flora. The most well-known pathogenic organisms are: *salmonella* responsible for typhoid fever and paratyphoid fever, *shigella* responsible for dysentery, and *vibrio* responsible for cholera. Natural lagooning can lead to a very significant reduction of germs for the following reasons:

- the germs scattered in a large environment where they are left for a long time hardly find an adapted substrate in sufficient quantity and evolve under temperatures to which they are not adapted;
- they are subject to vital competition with better-adapted organisms and predators of bacteria; antibiosis phenomena highlighted in natural environments also play an important role in lagoons;
- germs fixed on suspended matter sediment to the bottom of the lagoon are thus removed from the liquid medium;
- the direct action of plants producing inhibitory or bactericidal substances has been demonstrated on some macrophytes; and,
- the germicidal role of ultraviolet radiation is well known; it essentially affects the superficial layer of lagoons which is constantly renewed by the convection currents.

Meadows with floating or free hydrophytes. Ponds are shallow and rapidly colonized by plants and environment is stable and homogeneous. The vegetation cover prevents any excessive growth of algae and keeps temperatures stable. Suspended matter moves vertically and is sedimented, with roots limiting horizontal movement. Oxygen is supplied to the medium via plants (leaves, stems and aquatic roots). Vegetation is colonized by a complex community of microorganisms (zooplankton and microfauna). The significant improvement in water quality mainly concerns suspended matter and organic load. Retention time is short, the assimilation is fast. The system is compatible with the treatment of effluent from a natural lagoon; the financial cost is interesting.

Educational activities (exercise and case studies)

Based on the background information presented in the course and other from literature, prepare as a group of 4-5 an analytical summary of the most relevant wastewater treatment methods in forestry.

1.14 Physico-chemistry of soils

1.14.1 Soil pollution and remedy

Objectives

By the end of the session, the learner will be able to:

1. Analyse sources of soil pollution, pollutant diffusion mechanisms,
2. Describe the different methods of mechanical and biological decontamination of soils.

General introduction

Industrial activities and modern agriculture are sources of soil pollution. Others are inadequate waste management practices (uncontrolled landfills, embankments of mining or industrial wastes), or accidental pollution (dumping dangerous products, leakage of tanks).

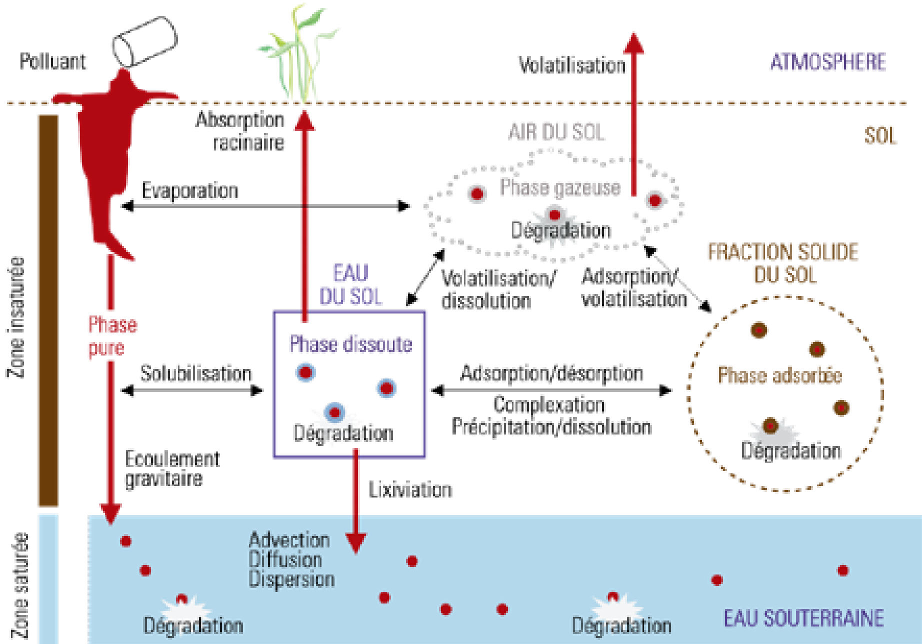
The management of polluted soils is necessary because they are harmful to the environment (soil, surface water, groundwater, vegetation, air), pose a risk to health, or degrade the living environment.

Knowledge of the main techniques of treatment of a polluted site by forestry technicians is necessary to advise intervention actions in case of soil pollution in forest areas.

Sources of soil pollution

Soil pollution by modern agriculture. Soils can be polluted by mineral substances and synthetic organic compounds. The toxic sulfur and ammoniacal compounds resulting from anaerobic fermentation of solid waste of agricultural origin increasingly contaminate the soil. Chemical fertilizers and pesticides can irreversibly pollute cultivated soils. There is often a systematic dispersion of increased amounts of pesticides in rural agricultural space.

Pollution from industrial contaminants. Soil pollution may originate from the transfer of contaminants to the soil from the use of fossil fuels, mining, metallurgical and chemical industries. There are also sources of point pollution by industrial waste (hazardous chemical waste).



Source: SITEREM cited by Schadeck, 2007

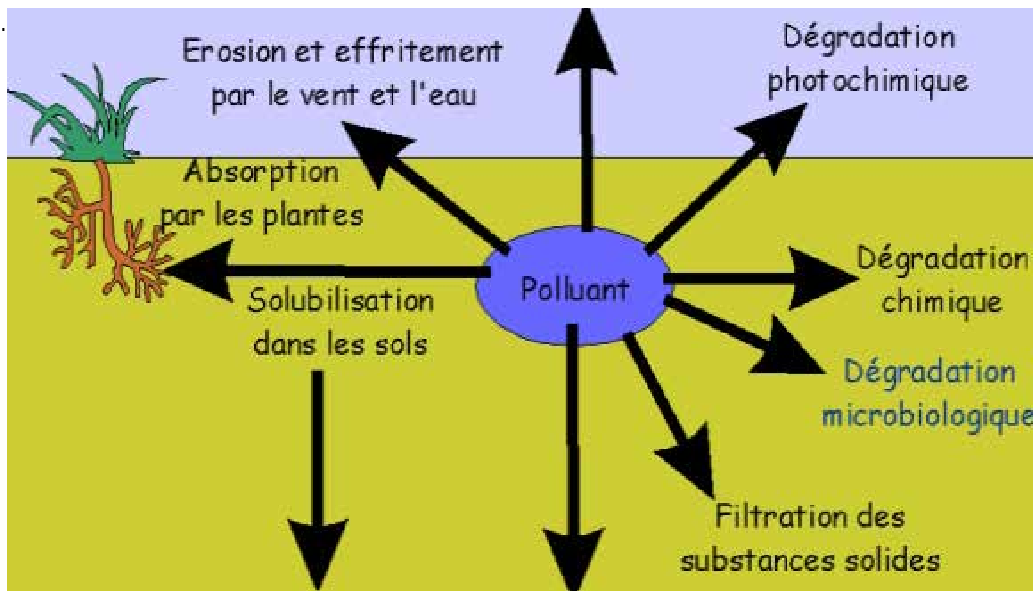


Figure 15 a + b. Fate of pollutants in soil.
Source: http://www.ecosociosystemes.fr/pollution_diffuse_sols.html

Mechanisms of diffusion of pollutants

Figure 15 (a + b) above shows the processes that influence the behavior and migration of contaminants in soils. They are essentially (Schadeck, 2007):

- exchange reactions (volatilization, adsorption-desorption, complexation, dissolution-precipitation) between the solid (mineral and organic constituents of the soil), liquid (interstitial water) and gaseous (porosity not filled with water) phases;
- degradation reactions: photolysis, chemical hydrolysis, biodegradation; and,
- phenomena of transfer of pollutants and their degradation products: to the atmosphere by volatilization, to surface water by runoff, to groundwater by leaching or gravity flow (liquid water immiscible pollutants), to plants by root absorption.

For a given pollutant, the result of these processes depends on:

- intrinsic properties (solubility, volatility, hydrophobicity, stability, density, viscosity);
- soil characteristics (clay mineral content, organic matter content, pH, porosity, biological activity, etc.);
- hydrogeology (depth of water table, hydraulic conductivity, direction of flows); and,
- local conditions (rainfall, topography, vegetation cover).

The outcome of diffusion processes determines the fate of pollutants in the soil: persistence, bioavailability, preferential accumulation in certain soil horizons, biomass immobilization, migration speed in the profile, ability to reach groundwater (Schadeck, 2007).

Box 12. Effects of soil pollution

Alteration of the nitrogen cycle through the use of fertilizers; increase of the nitrogen flux due to human activity and not denitrification of all the quantities of nitrates introduced; breakdown of the balance between nitrification and denitrification in the biosphere; accumulation of excess nitrate in the hydrosphere as a result of leaching and surface runoff from fertilized soils; increase of the natural rate of phosphate circulating between the lithosphere, soil and the hydrosphere; immobilization of the majority of phosphorus used as chemical fertilizer in soils due to their richness in calcium, aluminum and iron that bind phosphorus; induction of the phenomena of eutrophication in inland waters by part of the surplus phosphorus drained in these waters; extensive toxicity for animal and plant species; persistence of pollutants in the various compartments of the environment; contamination of aerial parts of plants and soils by residues from pesticide treatments; biocoenotic changes due to the elimination of a dominant species in a community; disastrous pollution of underground aquifers by infiltration; risk to human health.

Different methods of mechanical and biological decontamination

Mechanical methods of depollution in situ

Evacuation of pollution by ventilation of the unsaturated zone is a proven technique, widely commercialized and applied for many years, notably for the rehabilitation of oil or petrochemical sites. It makes it possible to extract volatile pollutants by depressurizing the unsaturated zone. The volatile compounds poured into the soil will evaporate to saturation of the pores. The depressurization of each extraction point, induces air circulation and causes a renewal of the polluted air in the pores of the ground. This air renewal has the consequence of modifying the chemical equilibria between the different phases present (air, water, soil). Thus, during its passage through the contaminated zone, the air becomes "loaded" with contaminants. The equilibrium displacement of the phases makes it possible to depollute the solid and gaseous phases of the unsaturated zone. The vapors are recovered via the extraction points and then treated on the surface (Khan et al., 2004).

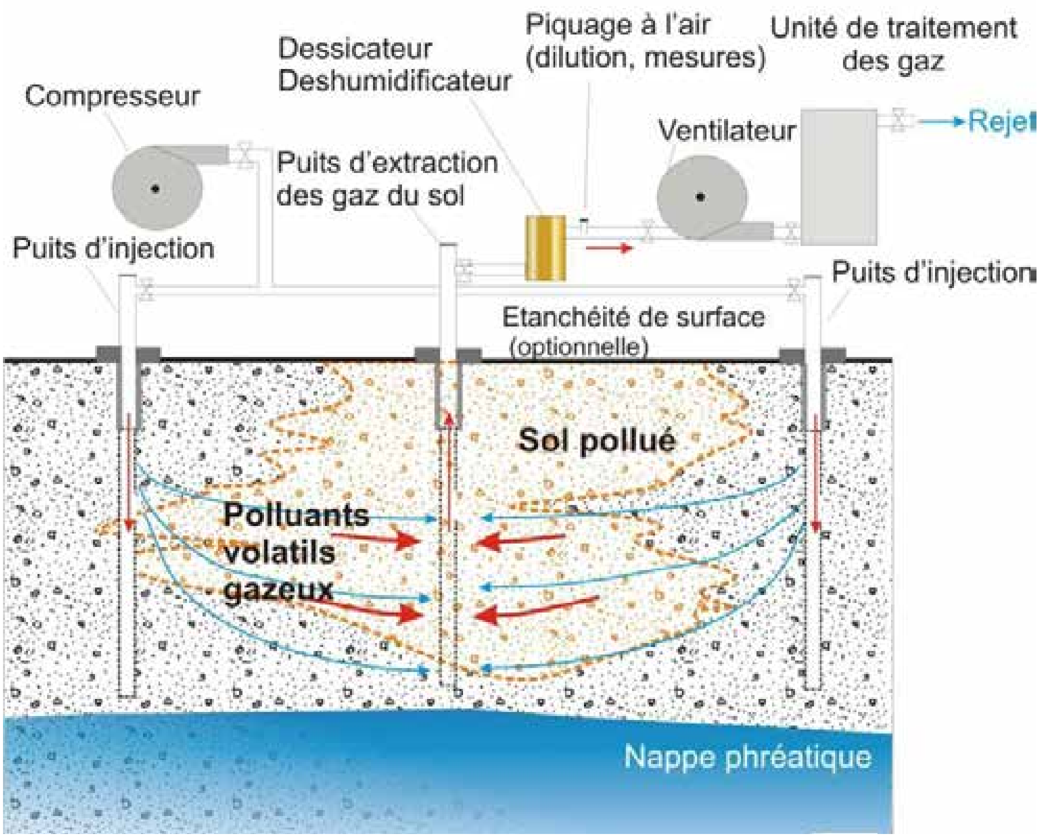


Figure 16. Schematic diagram of ventilation.
Source: BRGM, 2010.

Evacuation of pollution by dual phase extraction consists of exerting a significant depression in the unsaturated zone, at the level of the capillary fringe and at the level of the upper part of the saturated zone, in order to extract soil gases, the supernatant (in the case of floating products) and the dissolved phase. The extracted liquids and gases are separated and processed (BRGM, 2010).

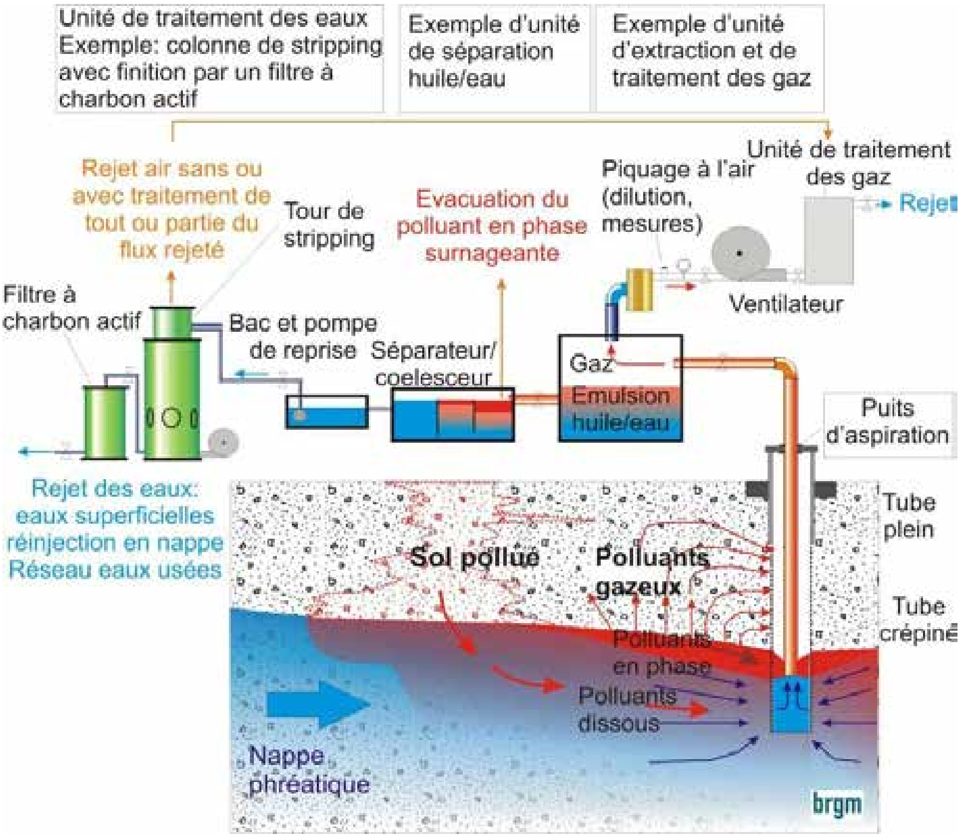


Figure 17. Dual phase extraction principle diagram.
Source: BRGM, 2010

Evacuation of pollution by bubbling involves injecting air into the groundwater to encourage the volatilization of pollutants that will be extracted from the vadose zone and treated on site (Khan et al., 2004). This air, flowing through the saturated zone and rising towards the surface, creates air channels which come into contact with the dissolved or adsorbed pollutants, which allows their volatilization. The air then becomes charged with pollutants and is evacuated via extraction wells positioned alternately with the injection wells towards the gas treatment system.

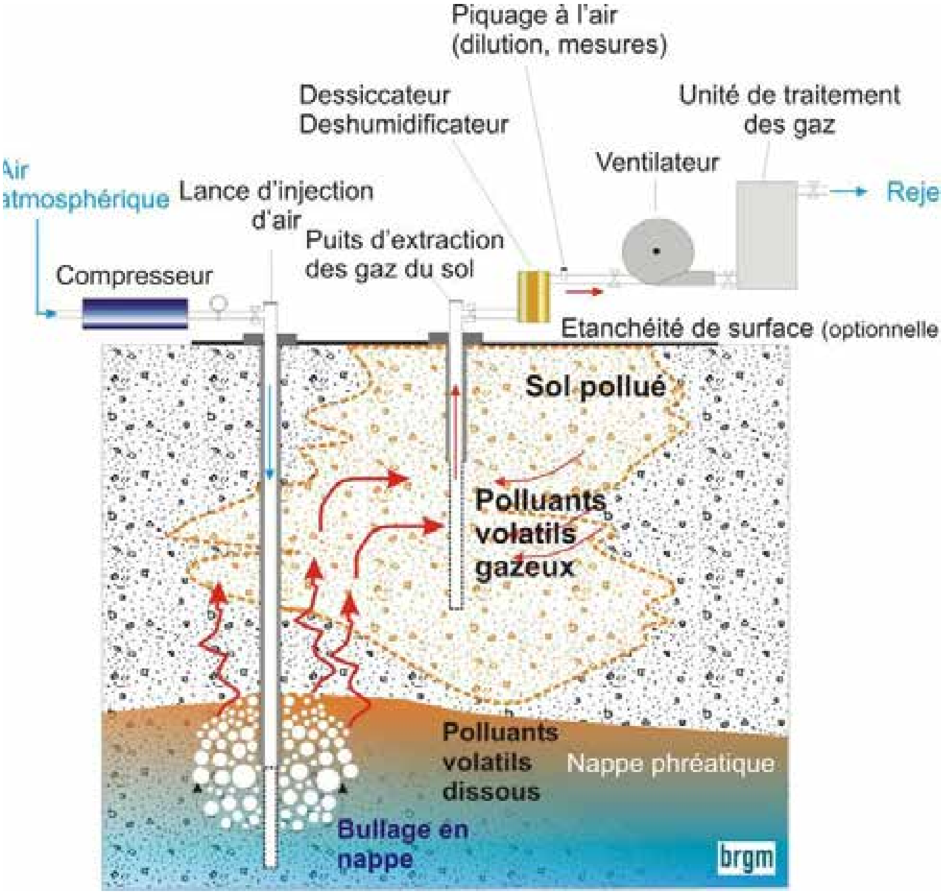


Figure 18. Schematic diagram of the bubbling coupled with the ventilation.
Source: BRGM, 2010

Evacuation of pollution by pumping and treatment makes it possible to extract organic or inorganic pollutants in dissolved phase in the saturated zone and the capillary fringe and to direct them towards extraction points for their treatment. A folding at one or more points of the sheet is then created (increase of the hydraulic gradient). This technique treats the plume rather than the source of pollution. It is therefore advisable to treat, if possible, the source of pollution beforehand. The circulation of water induced by the pumping makes it possible to renew the water in the pores of the saturated zone. The phase equilibria are then moved. Water passing through a polluted zone will become pollutant and the concentrations of pollutants adsorbed on the solid matrix (in the capillary and saturated zones) and present in gaseous form (vadose zone) will decrease slightly (BRGM , 2010).

Prior to the installation of the treatment, it will be necessary to find an outlet for the pumped water. The choice of the point of discharge is paramount. Depending on the environmental context, pumped flows and administrative authorizations, discharges may be carried out at certain concentrations in wastewater networks, stormwater systems, surface water, groundwater (re-injection), in some cases In approved disposal facilities (BRGM, 2010).

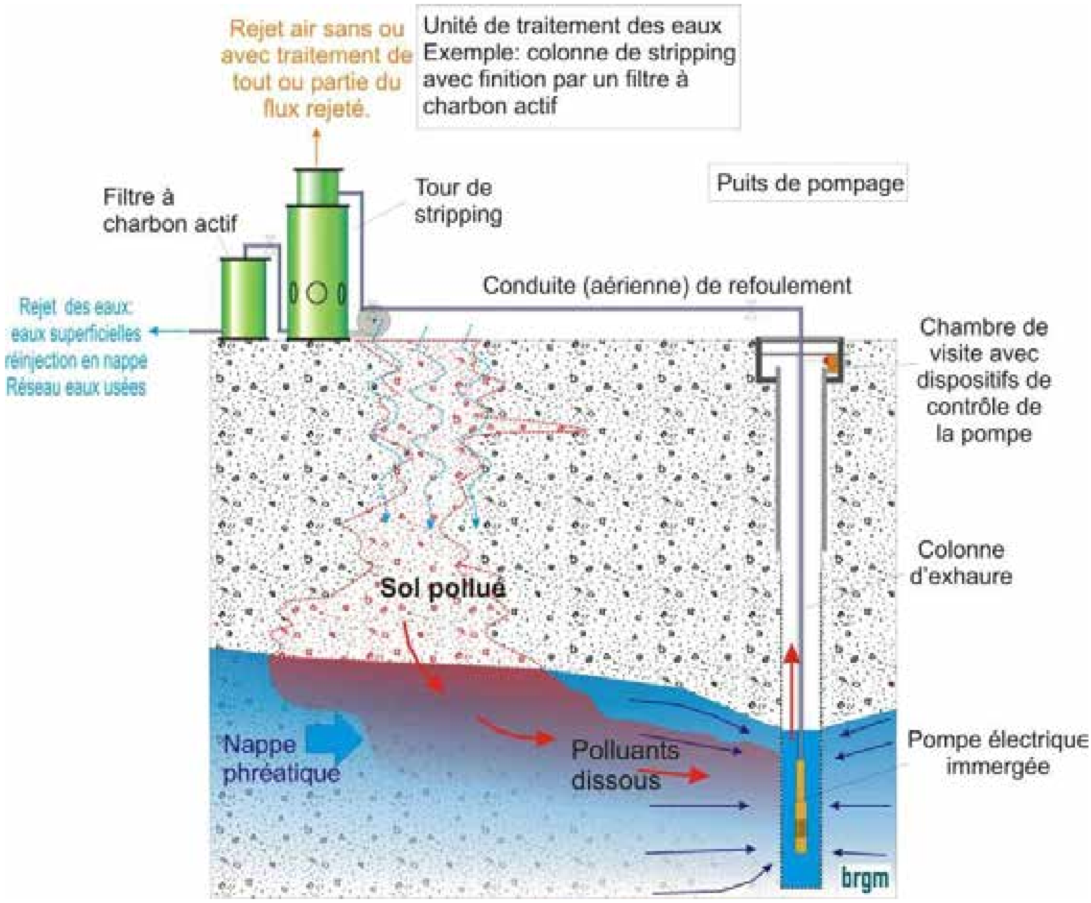


Figure 19. Pumping principle and treatment diagram.
Source: BRGM (2010)

Evacuation of pollution by pumping skimming. In the presence of supernatant, the groundwater is pumped, which generates a taper cone. The products in pure phase accumulate gravity in the center of this cone facilitating their recovery on the surface (BRGM, 2010).

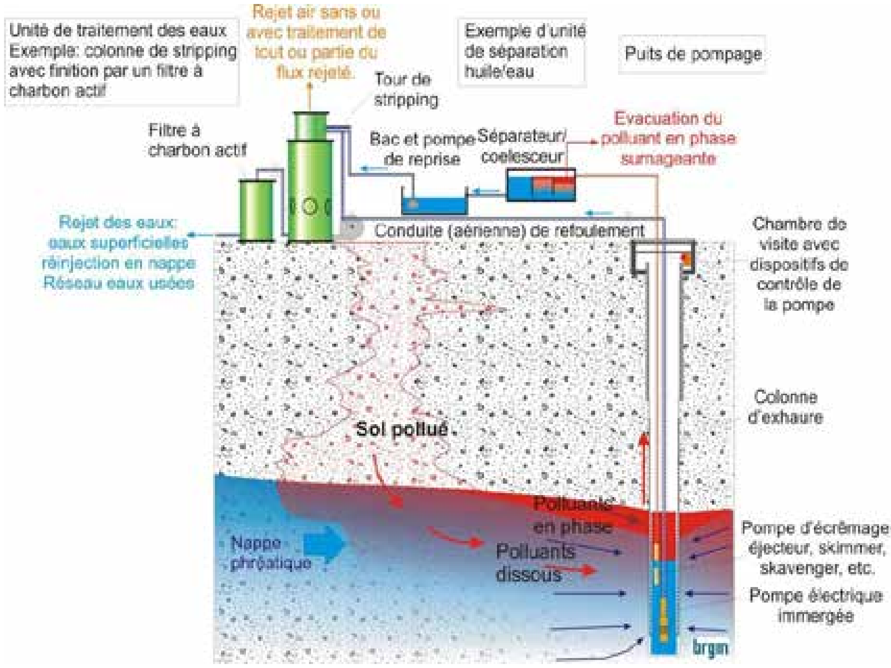


Figure 20. Schematic diagram of pumping skimming.
Source: BGRM (2010)

Trapping of pollution by containment and sealing is intended to prevent the flow of groundwater from the contaminated site. This technique consists in isolating the contaminants so as to prevent their propagation in a perennial manner. The choice of measures to be implemented depends on the particular conditions of each case (nature and extent of contamination, geological, hydrogeological and hydrological characteristics of the terrain). These containment measures must be sustainable over time and must be adapted to the site's uses (BGRM, 2010).

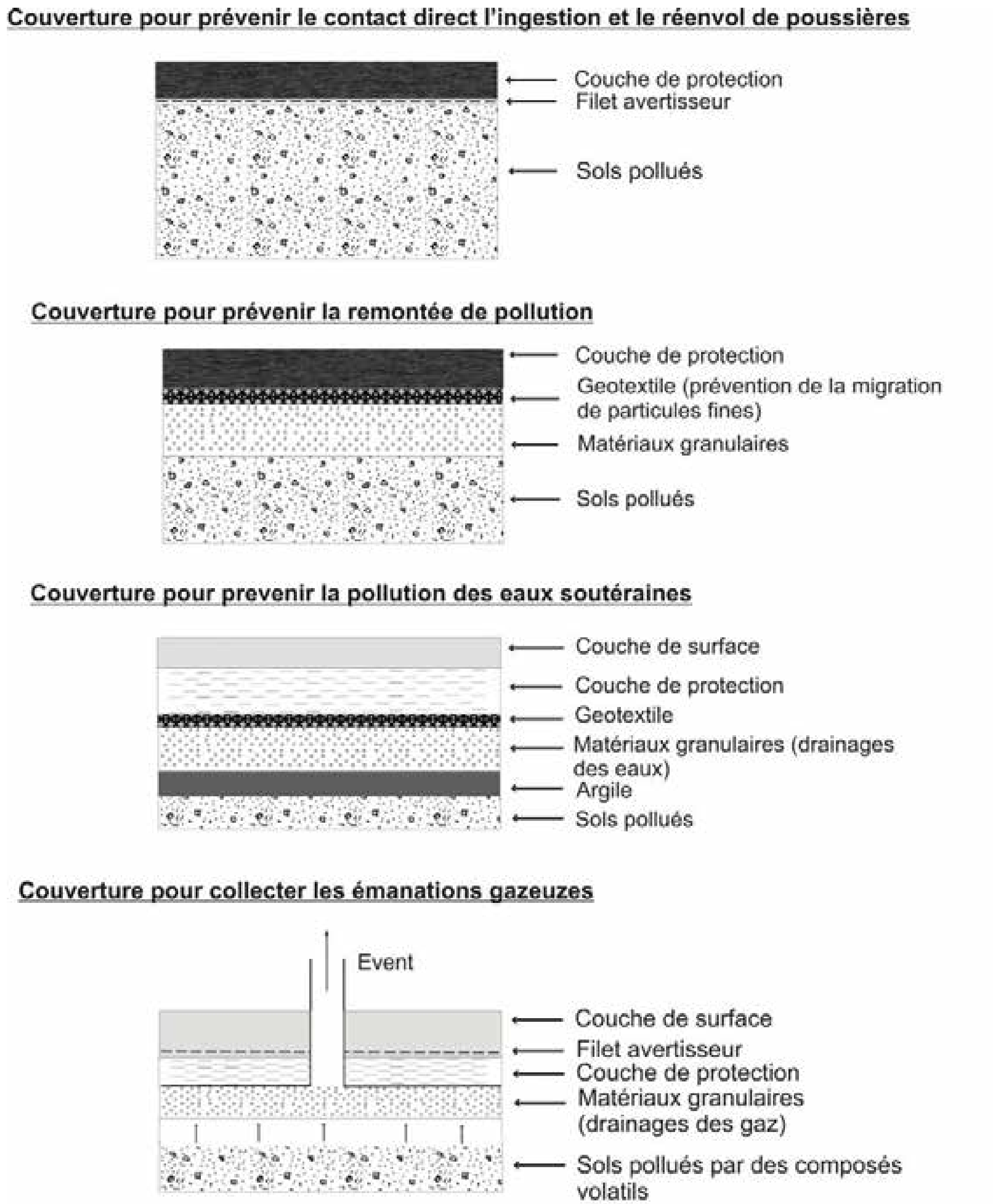


Figure 21. Example of different types of polluted site overlap.
Source: BGRM (2010)

Trapping pollution by vertical confinement consists of isolating the contaminants so as to prevent their propagation in a perennial way by implanting the confinement at the periphery, downstream or upstream of the source of pollution. The aim pursued is multiple:

- the establishment of a barrier between the source of pollution and groundwater and surface water;
- strengthening the mechanical stability of pollutant storage.

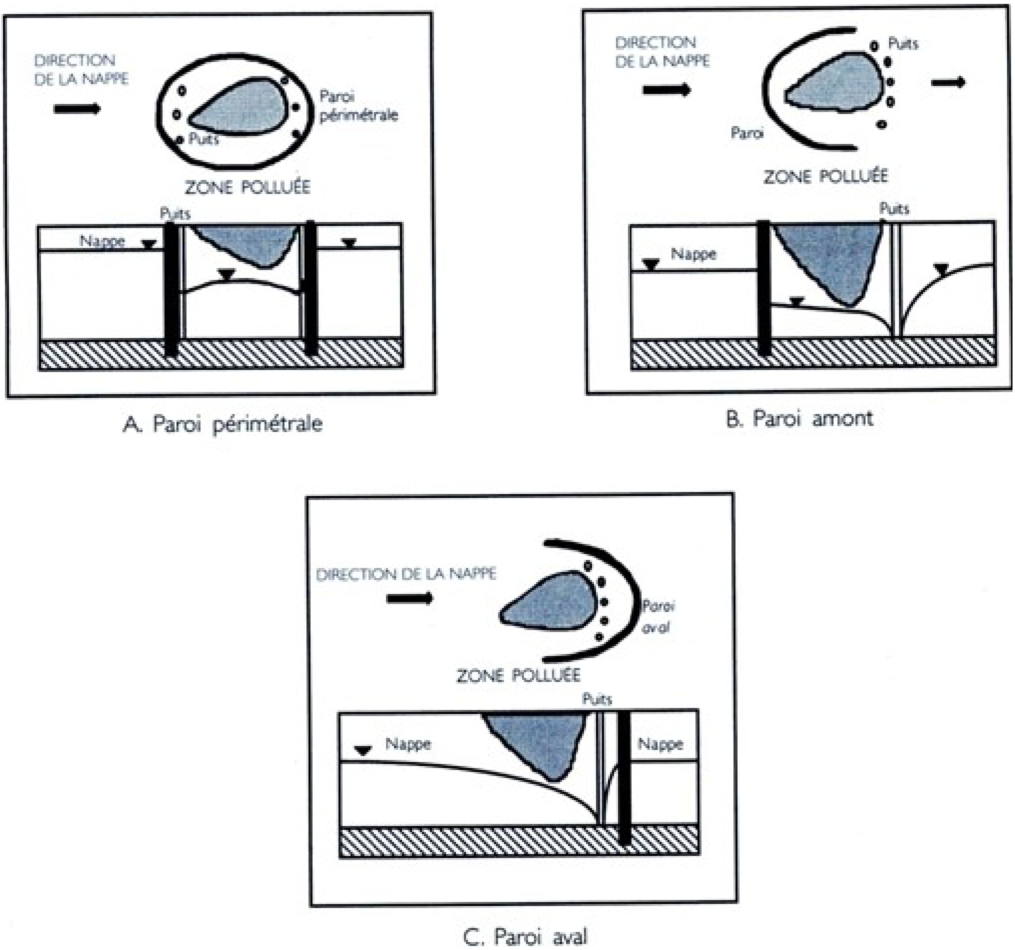


Figure 22. Example of vertical containment associated with pumping
Source: ADEME (1999) cited by BGRM (2010)

Hydraulic Containment of Pollution consists only in maintaining the polluted groundwater in a predefined space so as not to generate pollution downstream. This confinement can be carried out actively (by pumping) or passively (via drainage trenches) (BGRM, 2010).

Pumping makes it possible to extract groundwater as well as organic or mineral pollutants in dissolved phase in the saturated zone and the capillary fringe and direct them to extraction points for treatment. A folding at one or more points of the sheet is then created (increase of the hydraulic gradient).

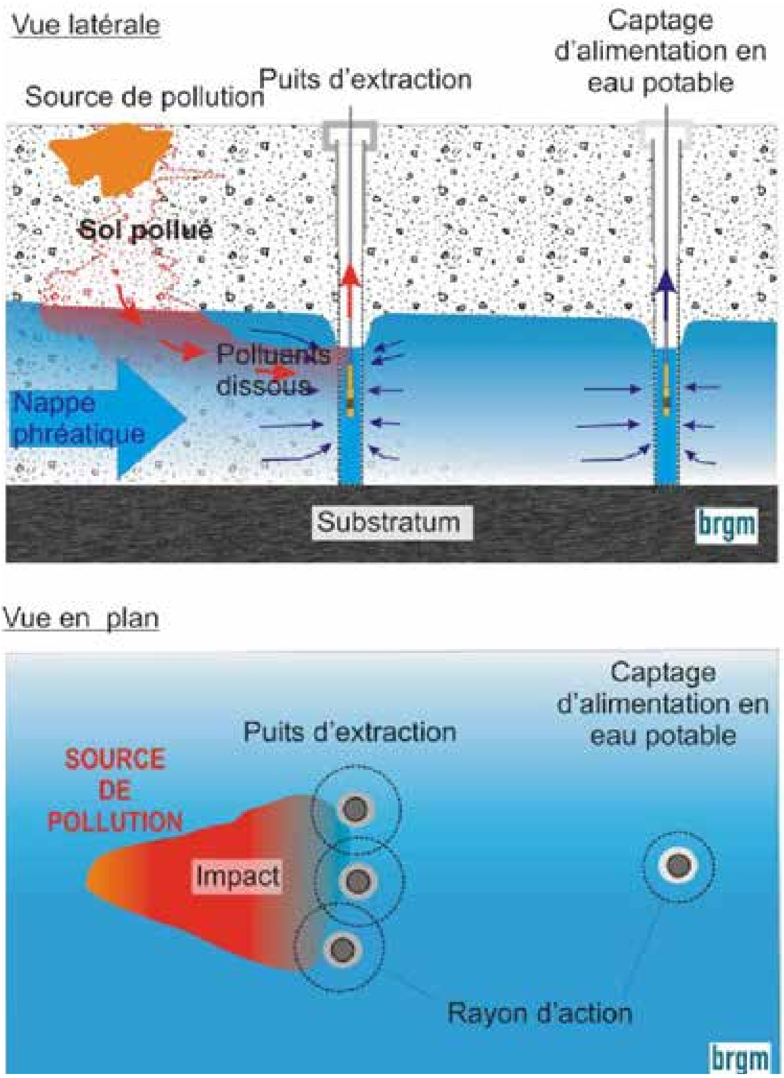


Figure 23. Example of active hydraulic trapping (pumping).
Source: BRGM (2010)

Solidification/stabilization pollution control. The purpose of this technique is to trap pollutants in order to reduce their mobility. Pollutants are either physically bound and included in a stabilized matrix, or chemically bonded.

The addition of the adjuvants necessary for solidification and in situ stabilization can be applied in two different ways:

- mechanical mixing in situ (pressurized and rotating) ; and,
- forced injection of a fluid with high kinetic energy to destruct land and mix it with cement for stabilization (BGRM, 2010).

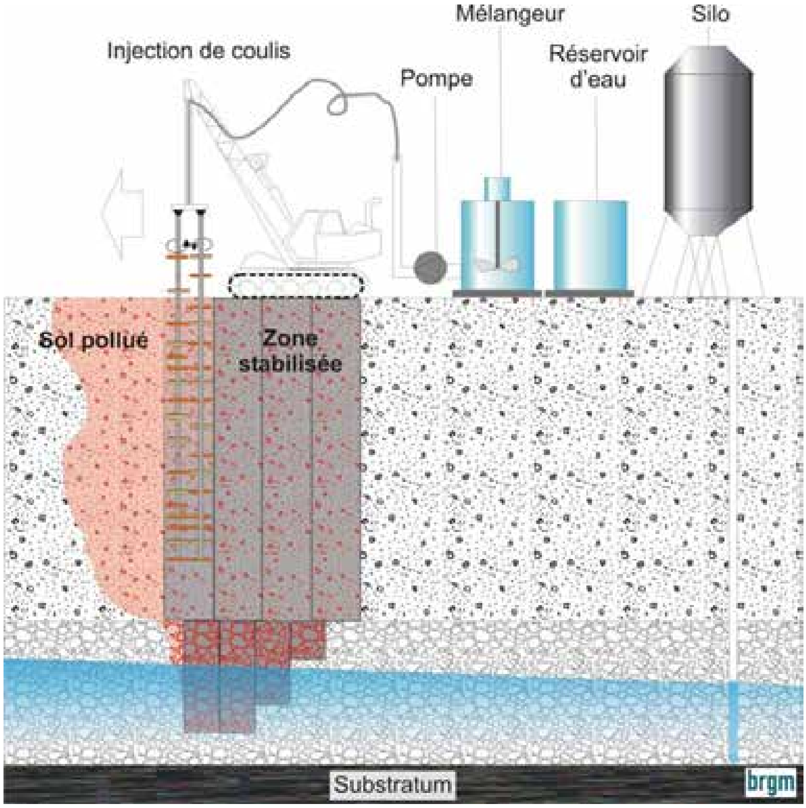


Figure 24. Schematic of the principle of mechanical mixing.
Source: BRGM (2010)

Biological in situ decontamination methods. The majority of biological treatments in situ involve microorganisms, mainly bacteria, in order to completely or partially degrade pollutants (BRGM, 2010).

Dynamic biodegradation requires the addition of specific compounds in soils or groundwater to create favorable conditions for the activity of the microorganisms responsible for the biodegradation of contaminants. In order to do this, the microorganisms are maintained under the optimum conditions (oxygen, pH, temperature, oxidation-reduction potential) and nutrients are added essentially in liquid form. Compounds which can be added in an unsaturated or saturated zone are shown in the following table.

Table 5. Compounds used in bioremediation

Actions	Example	Mechanism involved
Biaugmentation	Insemination with non-endogenous bacteria	• Aerobic oxidation (direct or cometabolism) • Anaerobic reduction (direct or cometabolic)
Nutrient addition	Addition of nitrogen, phosphates or other growth factors that may be deficient in the medium	• Aerobic oxidation (direct or cometabolism) • Anaerobic reduction (direct or cometabolic)
Addition of electron donors	Addition of substrate such as toluene, propane, methane	Aerobic oxidation (cometabolism)
	Addition of hydrogen, a source of hydrogen, or a Hydrogen Release Compound (HRC)	Anaerobic reduction (direct or cometabolism)
Addition of electron acceptors	Addition of oxygen by bioventing, biosparging or an oxygen source such as Oxygen Release Compound	Aerobic oxidation (direct)
	Addition of nitrates	Anaerobic reduction (cometabolism)

Sources: ITRC (1998); Leeson (1999); Sewell (1998); U.S. Air Force (1998)

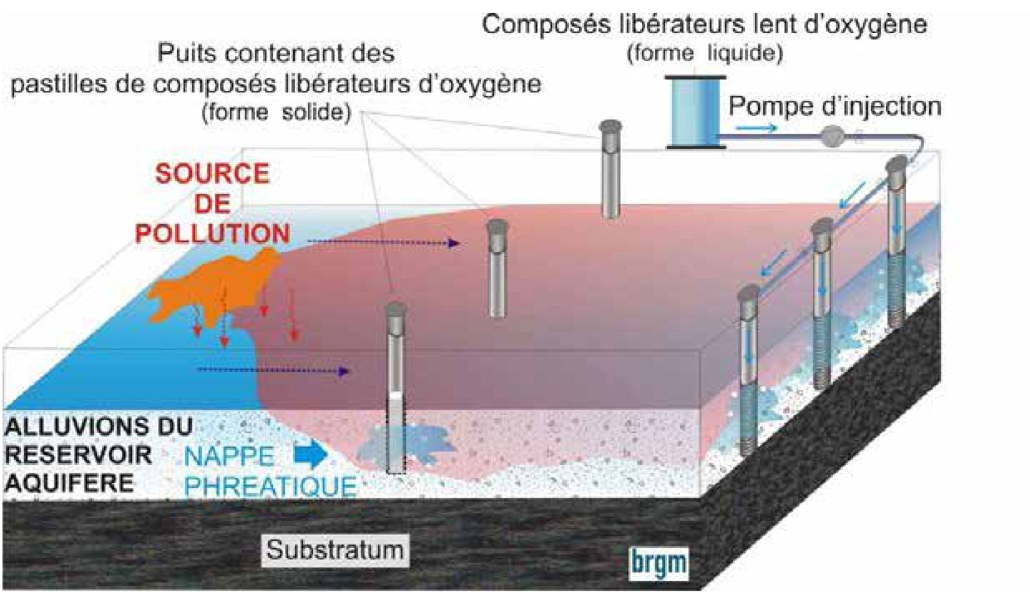


Figure 25. Schematic diagram of dynamic in situ biodegradation.
Source: BRGM (2010)

Bioventing is an aerobic biological treatment that involves stimulating the biodegradation of pollutants in the unsaturated zone by supplying oxygen by injecting air through injection wells (Figure 26).

Biosparging is an aerobic biological treatment that stimulates biodegradation in the saturated zone and the capillary zone by supplying oxygen (Figure 27). It is often coupled with bioventing.

Controlled natural attenuation is a naturally occurring process in soils and groundwater without human intervention to reduce the mass, toxicity, mobility, volume or concentration of contaminants in these environments. The processes considered are: dispersion, dilution, volatilization, adsorption, mechanisms of stabilization or destruction of pollutants, whether physical, chemical or biological (US EPA, 1997) (Figure 28). The technique includes at least one of the following: a destructive process and/or a sequestration process (e.g. adsorption).

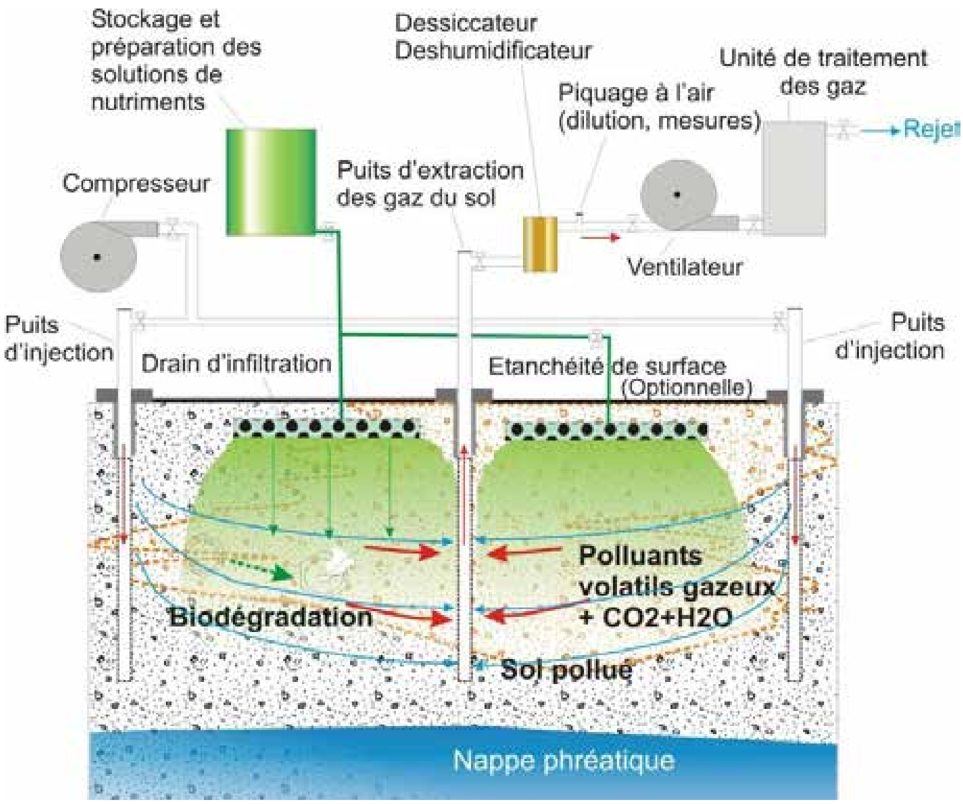


Figure 26. Diagram of the principle of bioventing.
Source: BRGM (2010)

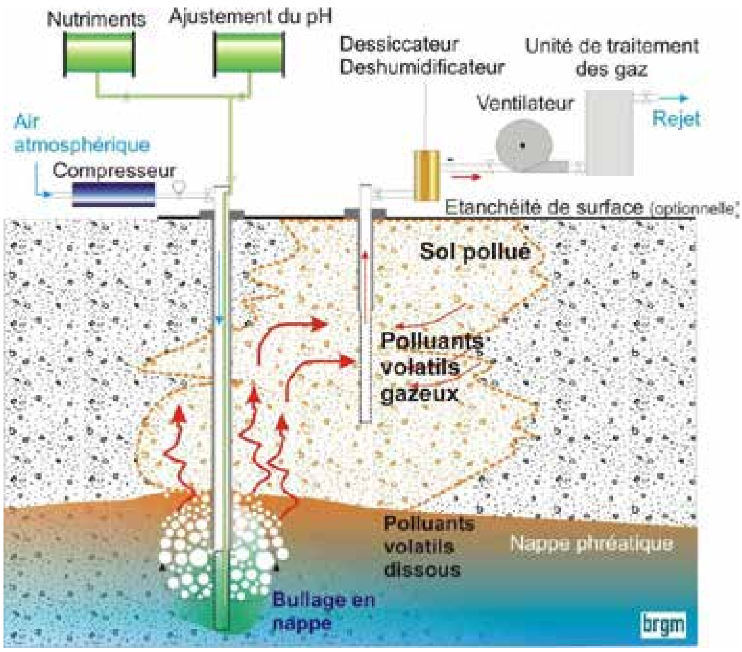


Figure 27. Schematic diagram of biosparging.
Source : BRGM (2010)

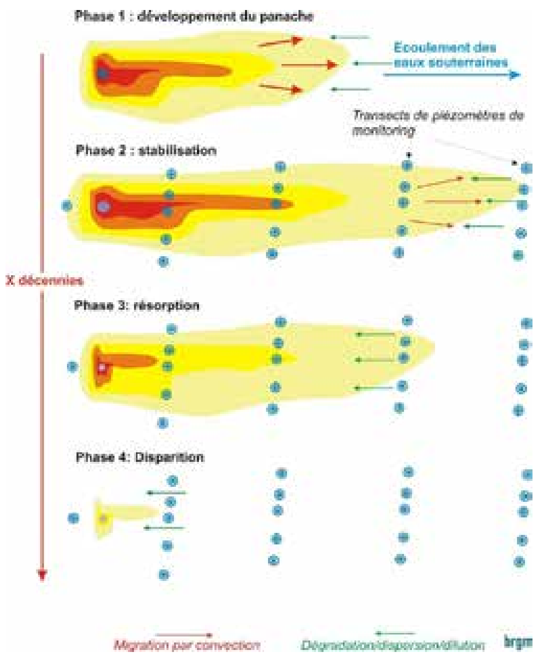


Figure 28. Life cycle of a plume subjected to natural attenuation.
Source: Adapted from Sinke and Le Hécho (1999) by BRGM (2010)

Phytoremediation involves using plants to treat subsurface soils by degradation, transformation, volatilization or stabilization. In general, the inorganic compounds are immobilized or extracted while organic compounds are degraded (BRGM, 2010) (Figure 29).

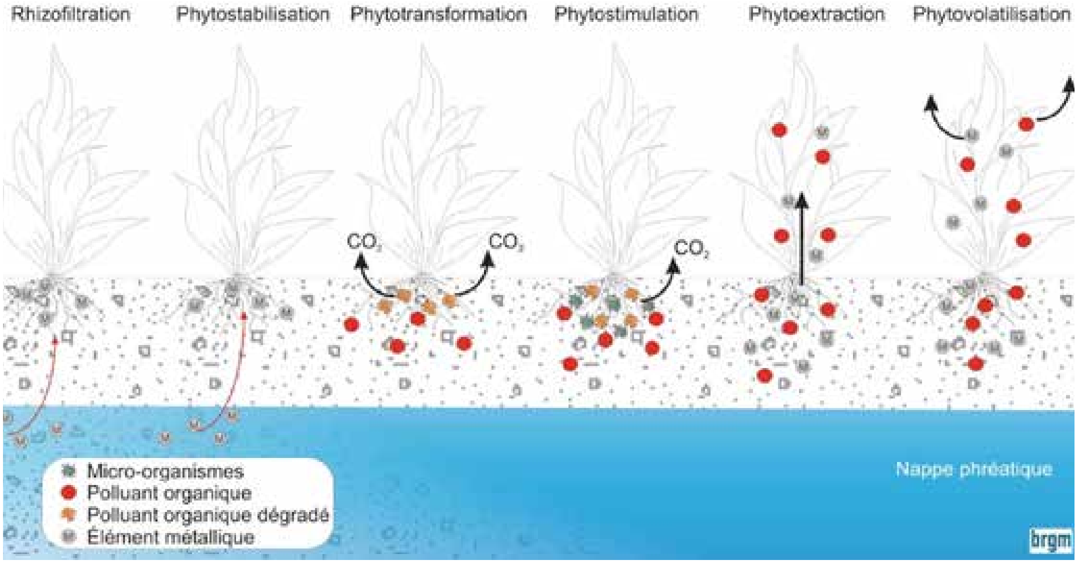


Figure 29. Examples of different types of phytoremediation.
Source: BRGM (2010)

Mechanical methods of ex situ pollution control

Evacuation of pollution by excavation of soils. The excavation process is generally carried out once the source of pollution is delimited via field investigations and analyzes. This is the simplest, most radical and fastest way to remove a source of pollution. Contaminated soil excavated should be treated/confinement on or off site (Figure 30).

Pollution removal by granulometric sorting. This technique makes it possible to separate the different fractions from the soils. The fine fractions which represent the most polluted fractions are thus isolated before treatment (Figure 31).

Evacuation of pollution by washing with water is a process commonly used after particle size sorting. The contaminants adsorbed onto the fine particles, previously separated from the coarse particles, are transferred to the aqueous phase (or extractant solution). This polluted solution is subsequently treated. In order to increase the transfer of pollutants from fine particles to water, chelating agents, pH adjustments, surfactant additions (known as chemical extraction) are commonly used (BRGM, 2010) (Figure 32).

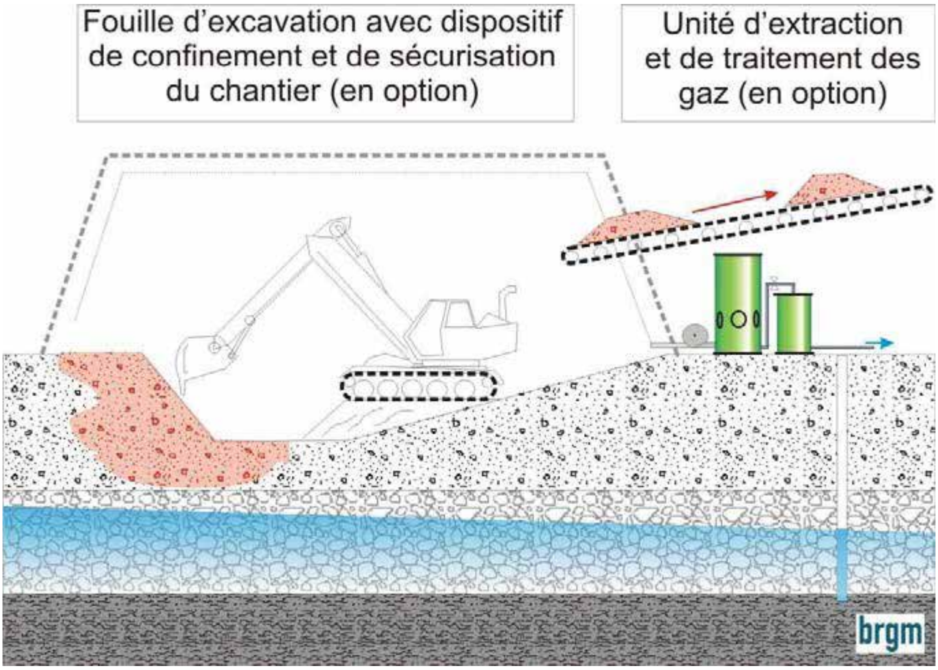


Figure 30. Excavation principle diagram.
Source: BRGM (2010)

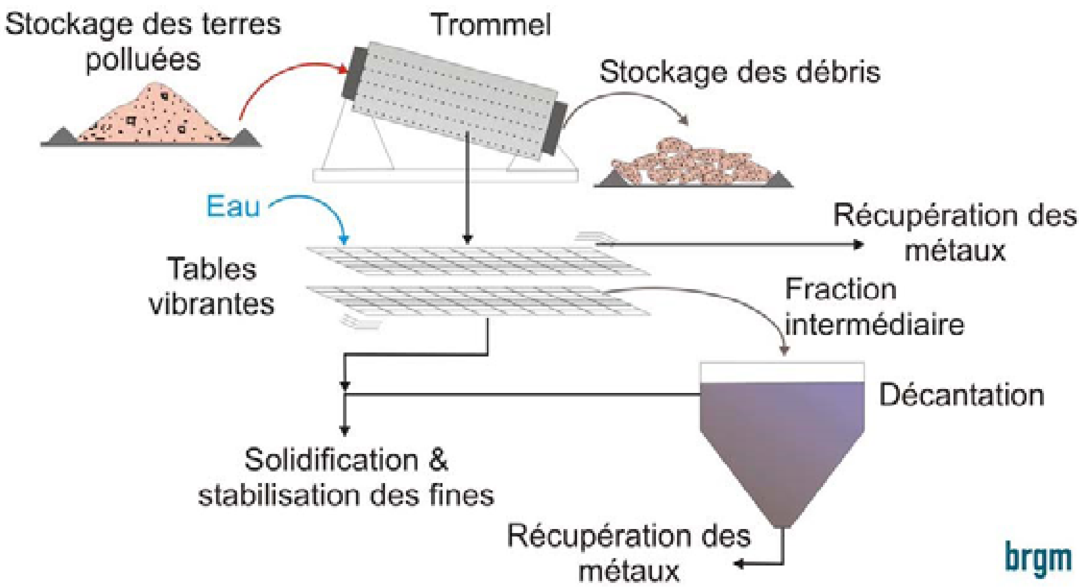


Figure 31. Schematic diagram of granulometric sorting.
Source : BRGM (2010)

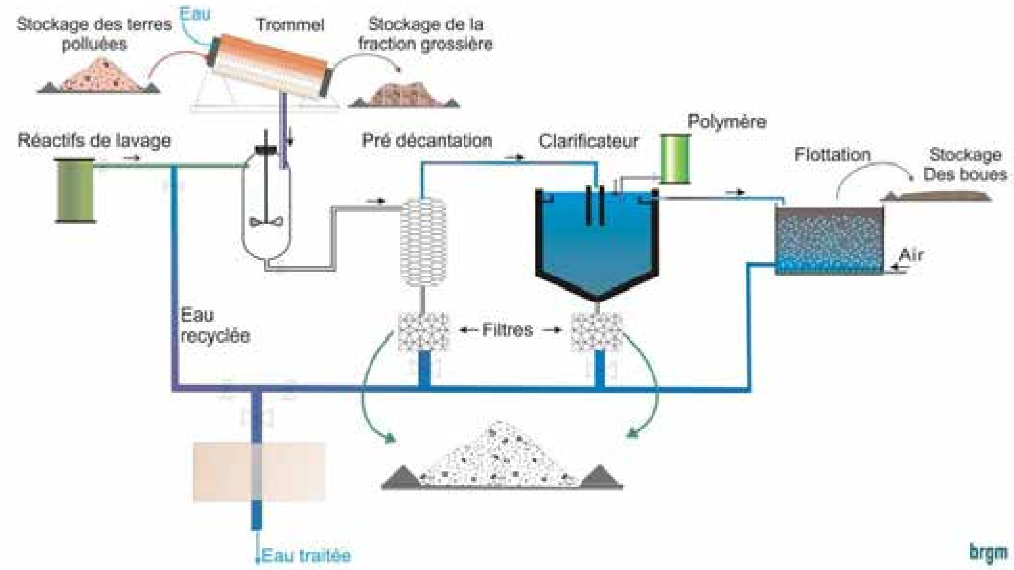


Figure 32. Schematic diagram of ex situ washing.
Source: BRGM (2010)

Biological methods of ex situ pollution control

Bioreactor. This technique consists of mixing polluted soils with water and various additives in order to put the soil particles in suspension in the water and to form a muddy mixture. This therefore allows a better contact pollutants / microorganisms and also facilitates the enzymatic operation. Then, the sludge is treated biologically in bioreactors and then dehydrated (BRGM, 2010) (Figure 33).

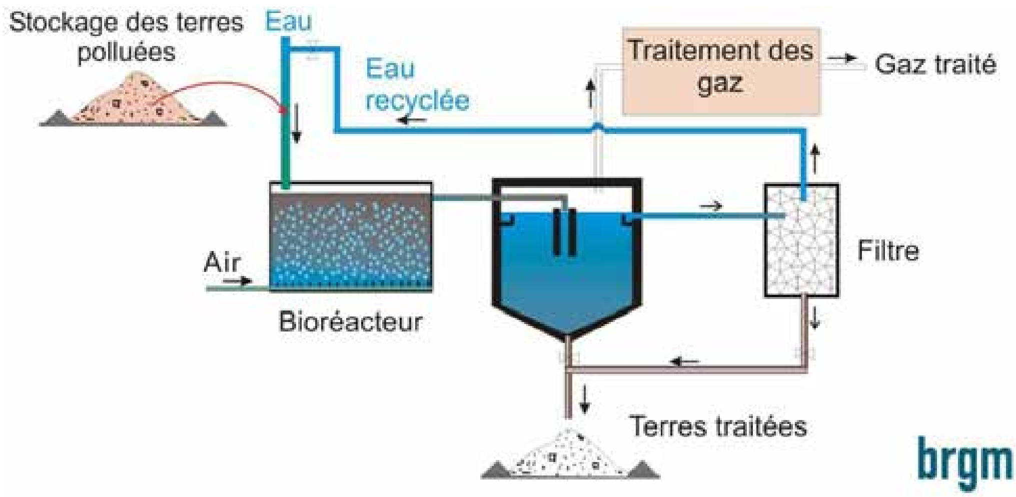


Figure 33. Schematic diagram of a bioreactor.
Source: BRGM (2010)

Biopile. It involves putting polluted soils into heaps for biological treatment. The process requires prior excavation. Contaminated soils are mixed with an amendment (structuring agent) and are then directed to a treatment area containing, at a minimum, a leachate collection system and ventilation units (extraction or insufflation of air) in order to optimize the transfer of oxygen and the stimulation of biodegradation (BRGM, 2010) (Figure 34).

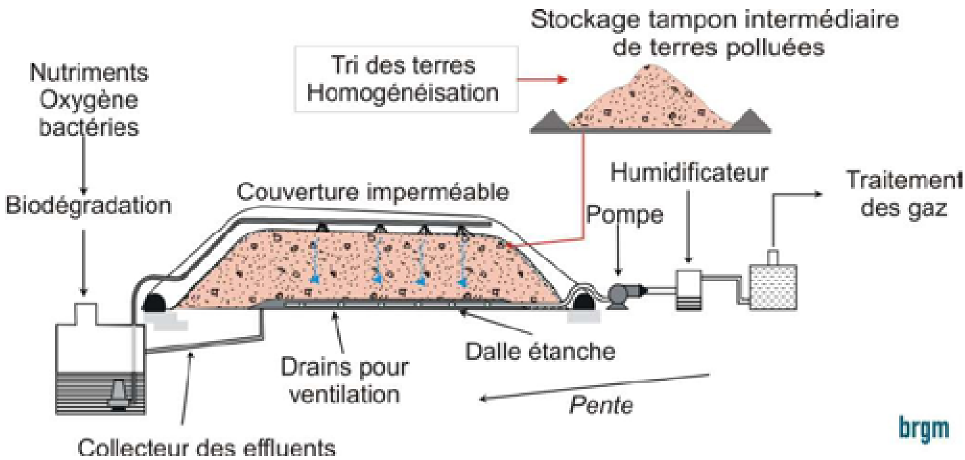


Figure 34. Schematic diagram of the biopile.
Source: BRGM (2010)

Composting. This technique consists of mixing excavated soil with organic amendments (called compost) and disposing them in trapezoidal piles (swaths) regularly spaced to promote biodegradation (Figure 35).

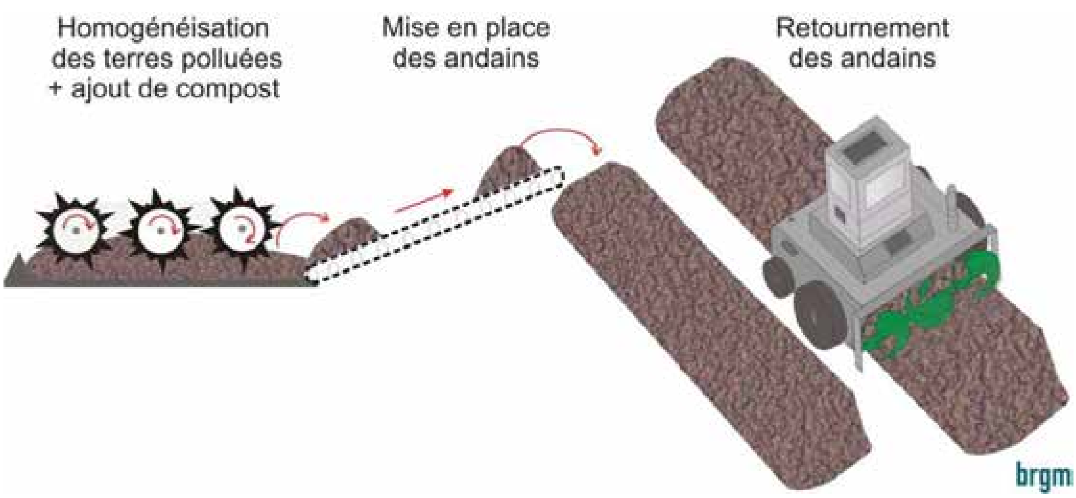


Figure 35. Schematic diagram of composting.
Source: BRGM (2010)

Landfarming. The method consists in spreading a polluted soil over a thin layer on an impermeable support and promoting, through conventional agricultural techniques, their aerobic biodegradation (Figure 36).

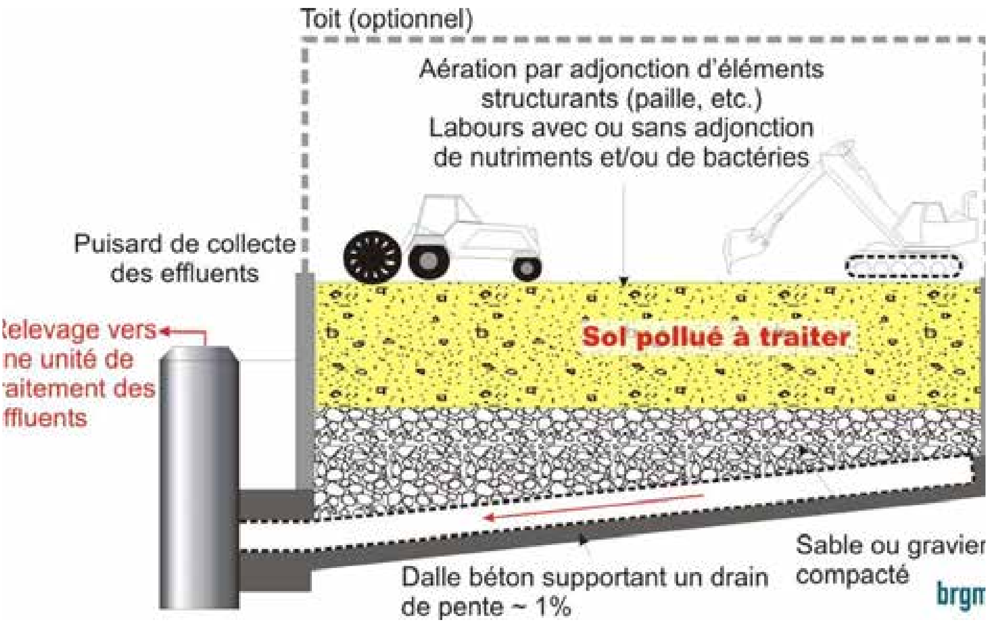


Figure 36. Schematic diagram of landfarming.
Source: BRGM (2010)

Educational activities (exercise and case studies)

- On the basis of the information presented in the course and other from literature, prepare in groups of 4-5 a technical sheet on the different mechanical and biological treatment methods of polluted soils.
- Describe the techniques used and explain their principles of operation

1.15 Degradation and rehabilitation of degraded lands

Objective

By the end of the session , the learner will be able to:

Analyse the concept of land degradation mechanisms and restoration measures.

General introduction

Land degradation and desertification[7] processes are the result of both human activities and climate variability (UNEP, 2008). Half of the arable land in the world is degraded by erosion by water, wind or chemical damage (acidification, salinization) and agricultural practices. About 25% of the world's arable land is threatened by desertification.

In African countries, it would be important to train qualified actors capable of identifying, developing and promoting crop practices that reduce agricultural emissions and sequester carbon while helping to increase yields and improve farmers' livelihoods. It would also allow opportunities to capture carbon credits under the mechanisms that have emerged since the Kyoto Protocol.

Wind and water erosion

Water erosion is a natural mechanism that drives soil particles from high altitude to lower areas where they will sediment depending on the rate of water flow and density (Villeneuse, 1998). The extent of water erosion depends on the intensity of rainfall and runoff, soil erodibility, slope and length, crops and vegetation, and cultural practices (Ritter, 2015).

Wind erosion can cause considerable land losses. There are three modes of displacement of soil particles: *suspension* (elevation of fine soil particles in height and transport over long distances), *saltation* (particle lift from medium to fine over short distances and displacement by small successive bounds) and *rolling* (rolling of large particles on the surface of the ground). The mode varies according to particle size and wind power (Ritter, 2015).

The consequences of erosion do not all have the same importance nor the same duration over time. A large erosion rate on a very thick soil does not have the same temporal impacts as the same erosion rate on thinner soil. In the former case, the soil can remain fertile and productive for decades, while in the second the effects of erosion can be felt very rapidly in only a few years. Soil erosion is responsible for a loss of production of some 20 million tons of cereals. The arable land is limited. In Egypt, for example, it accounts for only 3% of the country's surface area.

Loss of soil fertility

Land degradation refers to the reduction of an earth's ability to produce food or other natural materials. It is estimated that 65% of Africa's agricultural land is degraded due to erosion and/or

7 Planète terre, Pertes de terres agricoles rendues incultivables du fait de l'érosion: http://www.planetoscope.com/cereales/13-pertes-de-terres-agricoles-rendues-incultivables-du-fait-de-l-erosion.html

chemical and physical damage. 31 % of Africa's pastures and 19 % of forests and woodlands are also considered degraded (FAO, 2005).

Changes in land productivity can be positive (through irrigation or soil fertilization) or negative (through pollution or erosion). With land conversion, changes in productivity can be natural or induced by human activity. Concerns arising from the changing environment in Africa also reflect negative changes in land productivity due to land degradation and desertification (UNEP, 2008).

Decline in soil fertility (also described as a decline in soil productivity) is a deterioration of the chemical, physical and biological properties of the soil (FAO, 2003). The main processes involved, apart from soil erosion, are:

- reduction of organic matter content and soil biological activity;
- degradation of soil structure and loss of other soil physical qualities;
- reduced availability of key nutrients (N, P, K) and trace elements; and,
- increased toxicity due to acidification or pollution.

Mechanical and biological restoration of land

Reversing the degradation of biological, soil and water resources and improving agricultural and livestock production through appropriate land use and management practices are key elements in ensuring food security and sustainable livelihoods. Efforts to restore the productivity of degraded soils must be coupled with other measures that affect land-use practices, particularly *conservation agriculture*, *good agricultural practices*, and *integrated plant nutrient management*.

Conservation agriculture (CA) aims to achieve sustainable and profitable agriculture and thus aims to improve farmers' livelihoods through the application of the three principles of conservation agriculture: minimal disturbance of soil, permanent soil cover and crop rotation. CA has great potential for all types of farms and agro-ecological environments.

Good agricultural practices (codes, standards and regulations) have been developed by the food industry and producer organizations, but also by governments and NGOs to codify farming practices at the farm level for a range of products. Their objective varies from the response to governmental and commercial regulatory requirements (particularly food safety and quality), to more specific requirements in specialized or niche markets.

Integrated plant nutrient management integrates soil, nutrients, water, crops and vegetation management practices. It is adapted to a particular system of crop and agricultural production and is implemented with the aim of improving and maintaining soil fertility, land productivity and reducing environmental degradation. The aim of Integrated Plant Nutrient Management is to optimize the soil, its physical, chemical, biological and hydrological properties to improve agricultural productivity. Mechanical and biological measures for the restoration of degraded lands are presented below.

Mechanical restoration

Gabions are metal cages filled with stones. The purpose of this technique is to combat water erosion by allowing water to pass through these structures while retaining the materials contained in the soil. It is a semi-permeable barrier which, placed downstream of a gully, prevents water erosion. Their flexibility allows them to avoid breaks (FAO, 2012).

Figure 37. Gabions in North Africa

Fixation of sand dunes with palm leaves constitutes barriers in sheets of palm leaves or corrugated iron sheets (or any inert material available) installed perpendicular to the dominant direction of the winds if they are unidirectional or gridded for multidirectional winds (FAO, 2012).

Figure 38. Fixation of sand dunes with palm leaves

Biological restauration

Biological fixation of mobile dunes can be performed when mechanical stabilization is complete. It involves planting biological barriers for a definitive fixation of sand dunes.

Figure 39. Example of biological dune fixation in North Africa

Pastoral improvement through resting: these techniques are generally the most advisable if degradation has not yet becomeirreversible, because of the ease of their application and relatively low cost. Among restoration operations, resting is the technique most commonly used to ensure spontaneous biological upward movement of degraded vegetation. The results of resting in several arid places where the dynamics of the vegetation have been blocked, testify to the effectiveness of this technique. This efficiency result in resettlement and regeneration of species of high pastoral value that have disappeared (FAO, 2012).

Figure 40. Example of exclosure of degraded land

Agroforestry is a form of land use that involves the deliberate conservation, introduction and management of trees and shrubs into agricultural systems that provide ecological, economic or social benefits through interaction between agriculture and/or livestock and arboriculture. Planting crops or raising animals in areas planted with trees to conserve soils and increase yields (FAO, 2012).

Live-root hedges are rows of trees, shrubs or shrubs of one or more species planted on one or more rows around an agricultural perimeter so as to protect and restore the soil (FAO, 2012).

Educational activities (exercise and case studies)

Using the basic information presented in the course and other literature, prepare in a group of 4-5 an analytical summary of mechanical and biological measures for the restoration of degraded lands in a given agro-ecological zone.

1.16 Water-earth-atmosphere interactions

1.16.1 Earth-Atmosphere: Greenhouse effect

Objectives

By the end of the session , the learner will be able to:

1. Describe the natural greenhouse effect,
2. Explain the equilibrium of the atmosphere-earth radiative balance, and;
3. Analyse the role of forests in mitigating the greenhouse effect.

General introduction

The greenhouse effect is a natural process that allows life on earth at an average temperature of 15°C instead of -18°C, in the absence of the earth's atmosphere. Over the past two centuries, the increase in greenhouse gas emissions due to human activities has changed the equilibrium of the radiative atmosphere-earth balance. For several decades, industrial development has led to an increase in greenhouse gases, notably CO_2. The increase in CO_2 has a major impact on eco-systems, since it is directly responsible for warming our planet. Forests can play an important role in the regulation of these emissions and therefore contribute to the fight against climate change. Through photosynthesis, trees absorb atmospheric CO_2 and transform it into wood, thus acting as a carbon sink.

Greenhouse effect

The greenhouse effect is a natural phenomenon whereby the atmosphere traps some of the heat radiation emitted by the earth under the effect of sunlight. In the absence of this greenhouse effect, the average temperature on earth would be -18°C.

Climate on Earth is a complex system, the driving force of which is provided by solar radiation. The Earth receives the energy of the sun in the form of light and heat. Approximately half of this short wavelength radiation is reflected by the atmosphere and the earth's surface. This is the albedo effect. The other half is absorbed by the earth's surface and warms the Earth. This heat is then returned in the form of ascending radiation of long wavelengths. Some of the heat flows into space, some is absorbed into the atmosphere by greenhouse gases and sent back to Earth.

There is thus a continuous exchange of rays of high wavelengths between the earth and the atmosphere. This causes a warming. The atmosphere behaves like a thermal insulation: this phenomenon is called the natural greenhouse effect. The main natural greenhouse gases are CO_2, methane (CH_4), nitrous oxide (N_2O), water vapour and ozone (O_3). These gases are present in the atmosphere, but they can also be generated by human activities and thus disrupt the radiative balance of the Earth. This disturbance causes climate change.

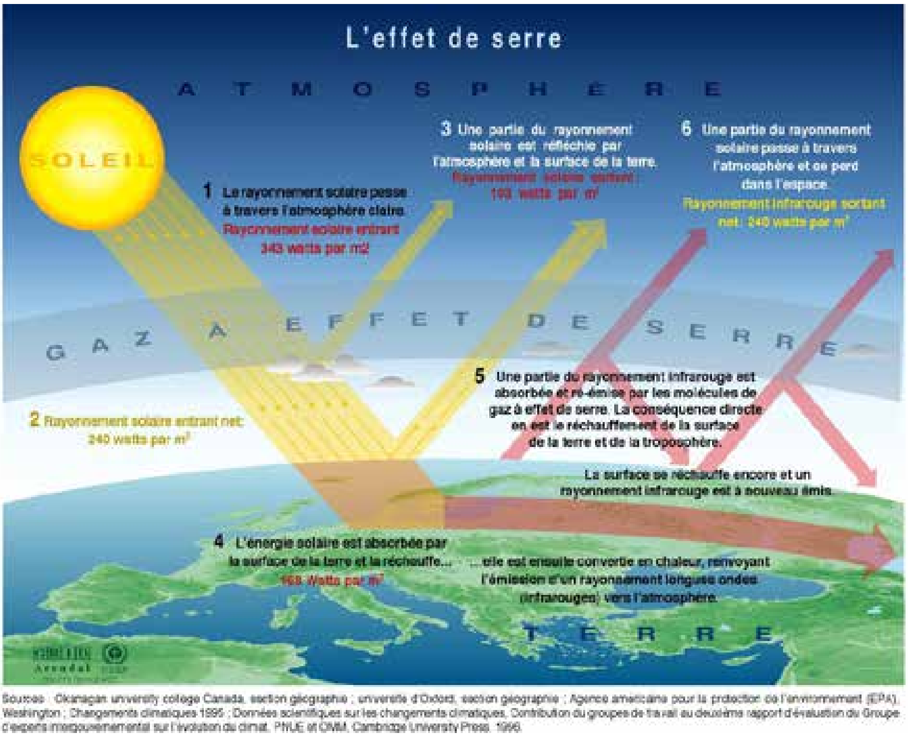


Figure 41. Greenhouse effect

Figure 42. Forest of the Congo basin

Forests and greenhouse effect

Forests play a role in mitigating the greenhouse effect. When they grow, trees absorb CO_2 from the atmosphere at the rate of about one tonne per cubic meter of new wood. They fix the carbon and release the oxygen we breathe. This process of photosynthesis traps carbon during the life of the tree. Conversely, when wood decomposes or the forest burns, carbon is released into the atmosphere. Forest and wood have three main positive roles against the greenhouse effect: 1) absorption of CO_2 through photosynthesis, 2) storage of CO_2; ans, as 3) alternative to fossil fuels.

Educational activities (exercise and case studies)

Based on the background information presented in the course and other literature, prepare as a group of 4-5 an executive summary on the role of forests in mitigating the greenhouse effect.

1.17 Atmosphere-water-vegetation

Objectives

By the end of the session, the learner will be able to:

1. Describe evaporation, evapotranspiration
2. Expain the role of variation in leaf incidence in the water balance.

General introduction

Evapotranspiration is a complex process consisting of physical evaporation (free water surface, bare soil water) and physiological evaporation (transpiration). Given the difficulty of distinguishing these two types of processes in the situation of a soil covered by vegetation and the fact that they occur simultaneously, they are generally grouped under the generic term of evapotranspiration (Musy 2005).

In order for the evaporation process to occur, it is necessary on the one hand that the system has the capacity to evaporate water (limiting factor) and, on the other hand, that the ambient air exerts an evaporative demand (the air must not be saturated). Evaporation therefore depends on meteorological conditions but also on the availability of water. In addition to these two factors, the physical and physiological properties of the vegetation cover are considered in the case of evapotranspiration (Figure 43).

Forests play an important role in regional water balances in Africa. The understanding of evapotranspiration in forest formations is useful for establishing their water balances.

Evaporation

Evaporation begins with the movement of water molecules. Inside a mass of liquid water, the molecules vibrate and circulate in a disordered way related to the temperature: the higher it is, the more the movement is amplified and the more the associated energy is sufficient to allow certain molecules to escape and enter the atmosphere (Musy, 2005).

Meteorological factors. Evaporation depends essentially on two factors: i) the amount of heat available and ii) the capacity of the air to store water.

Heat available. The amount of water that can be evaporated from a surface depends on the amount of heat from the sun. This varies depending on the geographic conditions (latitudinal gradient) and on the elevation of the liquid surface relative to the sea level (altimetric gradient). The heat exchanges between the atmosphere, the surface of the soil and the surface of lakes and oceans, which are the agents of evaporation, are carried out by convection and conduction. The exchanged energy is compensated at all points by a transfer of water which evaporates at one place to condense at another and falls back in the form of precipitation. These heat exchanges maintain the water cycle.

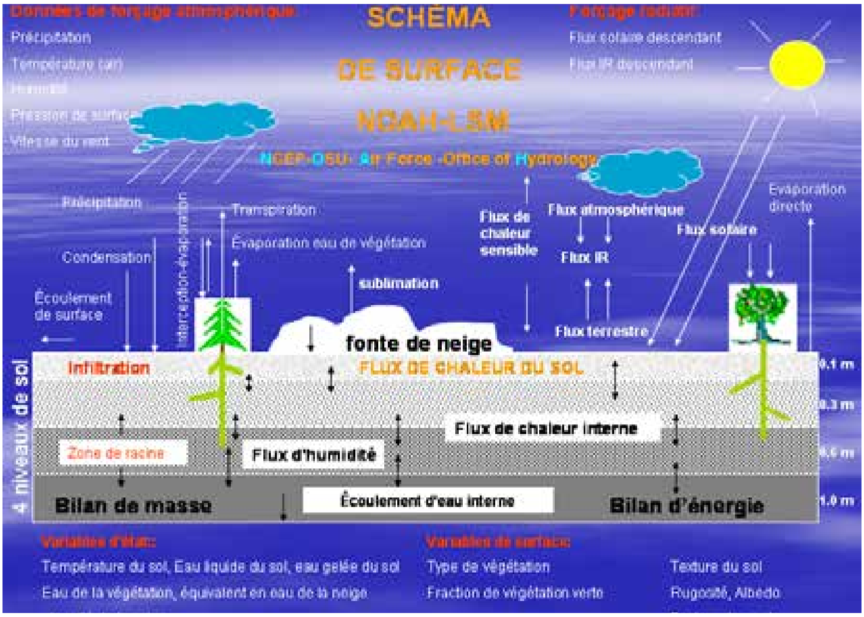


Figure 43. Overview of the climatic, physical and physiological characteristics of the environment.
Source: Bokoye et al. (2004)

Horizontal and vertical movements in the atmosphere involve exchanges and trans-formations of energy. One of the fundamental causes of this agitation is the distribution of temperatures on the Earth's surface as well as within the atmosphere itself. Evaporation is therefore a function of the energy relationships between the atmosphere and the evaporating water body. The action of solar radiation on the atmosphere, the hydrosphere and the lithosphere is illustrated in the following figure.

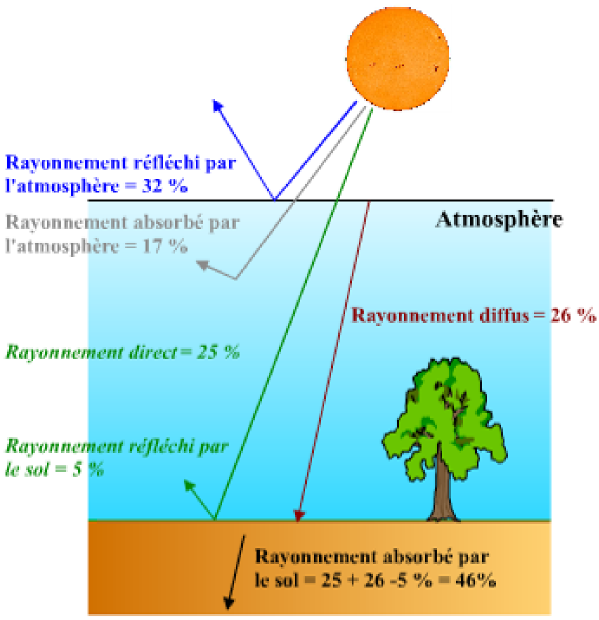


Figure 44. Action of solar radiation on the atmosphere, hydrosphere and lithosphere

The global radiation is partially reflected by the surface of the ground, depending on the nature, colour, inclination or roughness of the latter. Albedo is defined as the percentage of sunlight reflected from the Earth's surface for an irradiated area.

Table 6. Albedo value for different surfaces

Soil surfaces	Albedo
Water Surface	0.03 – 0.1
Forest	0.05 – 0.2
Cultivated soil	0.07 – 0.14
Stones and rocks	0.15 – 0.25
Fields and meadows	0.1 – 0.3
Bare floor	0.15 – 0.4
Old Snow	0.5 - 0.7
Fresh snow	0.8 – 0.95

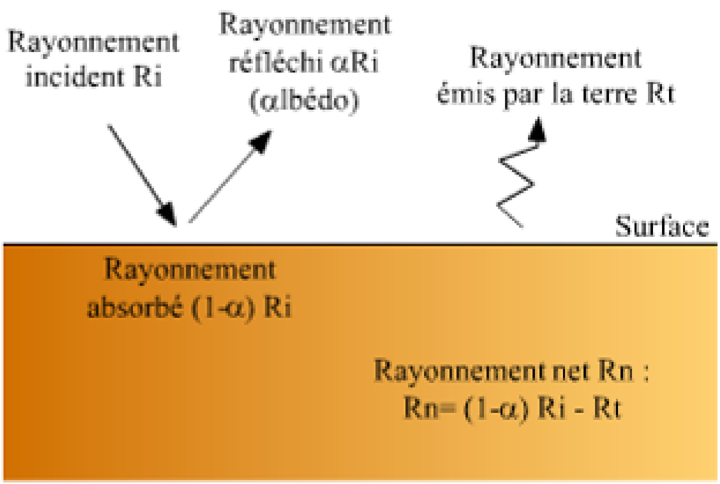


Figure 45. Balance of raditive exchange at the soil surface.
Source: Musy (2005)

Air capacity to store water. Evaporation is a function of the temperature of the evaporating surface. The rate of evaporation is, in particular, an increasing function of the temperature of the water. Since the temperature of the water varies in the same direction as the air temperature, it is easier to measure the temperature. The temperature of the air rather than that of the water is thus used in the formulas for calculating the evaporation.

The relationships between vapour pressure, temperature and relative humidity are shown in the following figure.

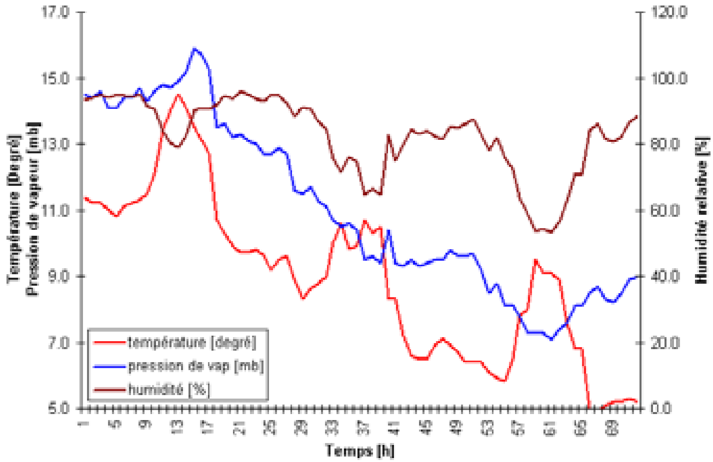


Figure 46. Evolution of temperature, vapour pressure and relative humidity.
Source: Musy (2005)

Physical factors of the area

Evaporation from open water surfaces depends not only on the physical and geometric properties of this surface (depth, extent) but also on the physical properties of water (temperature, salinity).

Evaporation from bare soil is conditioned by the same meteorological factors as those involved in the evaporation of a surface of open water. However, the amount of water available is a limiting factor. The evaporation from bare soil is thus influenced on the one hand by evaporative demand but also by the capacity of the soil to meet this demand and its capacity to transmit water to the surface. It depends on various characteristics: soil water content, capillarity, soil color and albedo.

Estimated evaporation of open water

Evaporation rates can be evaluated directly (evaporating tanks) and indirect (energy and water balance or mass transfer). Empirical and pseudo-empirical formulations for evaluating evaporation rates are not taking into account the effects due to the presence of vegetation.

Evapotranspiration

The concept of evapotranspiration encompasses the processes of direct evaporation of soil water and transpiration by plants. On land with even vegetation cover, transpiration exchanges are quantitatively larger than direct evaporation exchanges (Musy, 2005).

Transpiration can be defined as the emission or exhalation of water vapour by living plants. Plants take water from the soil through roots with epidermal cells. The development of the root system is related to the amount of water available in the soil. Roots can reach very variable depths, from about ten centimeters to several meters. Water absorption is achieved by osmosis or imbibition. Water flows through the channels of the vascular system of the plant to reach the leaves. The seat of the evaporation then lies essentially at the level of the internal walls of the stomata. Some evaporation can occur directly through leaf cuticles.

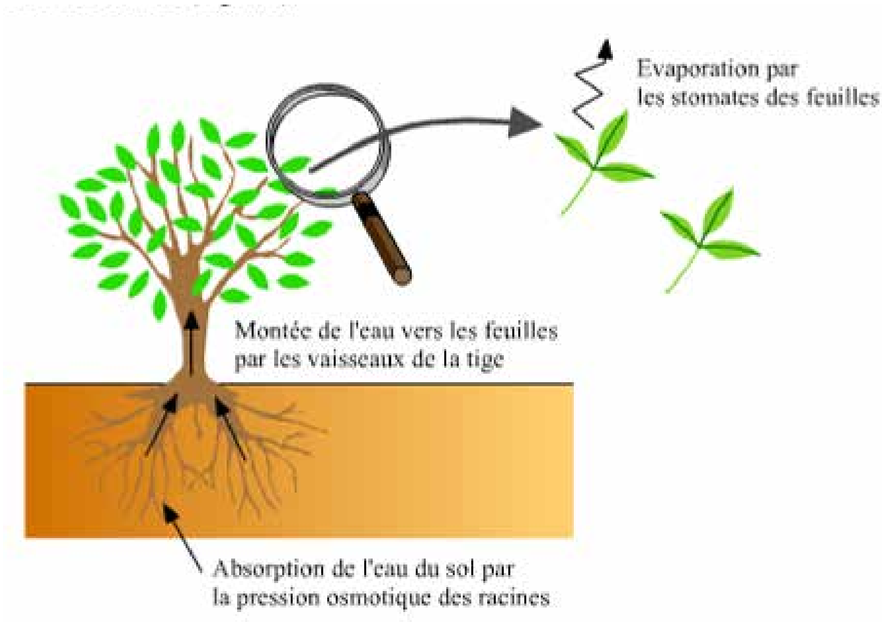


Figure 47. Water flow in plants.
Source: Musy (2005)

In addition to its participation in the hydrological cycle as a source of water vapour in the atmosphere, transpiration has many other functions, such as nutrient carrier in the plant or as a cooling system for leaves.

The amount of water transpired by vegetation depends on meteorological factors, soil moisture in the root zone, age and species of the plant, and the development of its foliage and depth of roots.

Box 13. Concepts of evapotranspiration

Reference evapotranspiration (ET_0) or potential evapotranspiration is defined as the set of water losses by evaporation and transpiration of a turf surface of uniform height, completely covering the ground, in full growth period, covering the whole soil and abundantly provided with water.

Maximum evapotranspiration (ETM) of a given crop is defined at different stages of vegetative development, when the water is sufficient and the agronomic conditions are optimal (fertile soil, good sanitary condition, etc.).

The actual evapotranspiration (ETR) is the sum of the amounts of water vapor evaporated by the soil and by the plants when the soil is at its current specific moisture and plants at a stage of actual physiological and sanitary development.

For the reference crop, in this case turf, we have: $ETR \leq ETM \leq ET_0$.

For all other plants, only the $ETR \leq ETM$ relationship is still valid throughout the year.

Evaluation of evapotranspiration

The evapotranspiration of a soil covered by vegetation is difficult to estimate. Crop water requirements, equivalent to the ETM, are determined by correcting the potential evapotranspiration (ET_0) of a reference crop (lawn) by the crop coefficient (kc) using the following formula:

$$ETM(crop) = kc\ ET_0$$

The time scale on which plant water requirements are calculated may be hour, day, decade, month or phase of growth, depending on the objective and availability of data. The value of the coefficient kc is largely affected by the nature of the crop, its height, cycle time and growth rate, but also by the frequency of rainfall or irrigation at the beginning of the crop cycle. Kc is always established experimentally at the beginning for a given region and crop and then confined to tables for later use in the same or similar region. The values of the coefficient kc are theoretically between 0 and 1, depending on the stage of the culture.

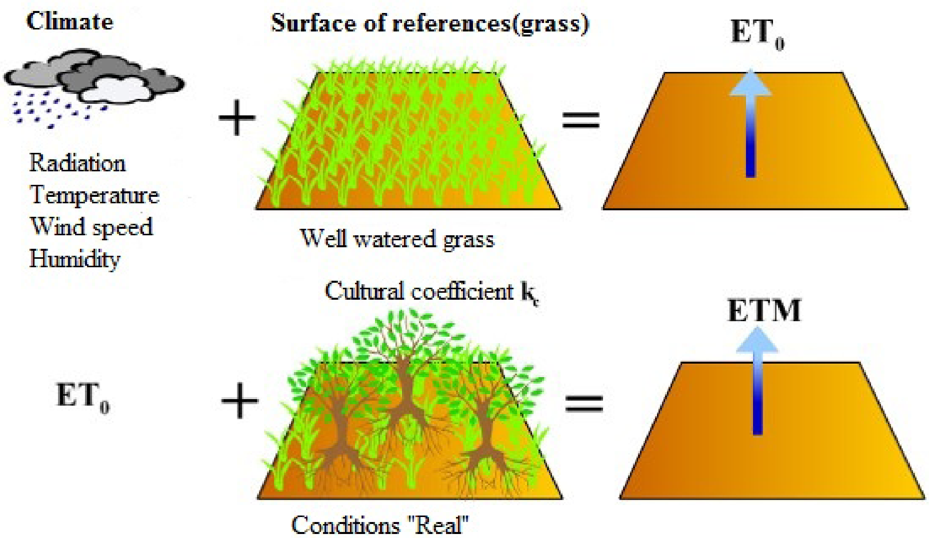


Figure 48. Crop water requirement (CTE) and reference evapotranspiration (ET0).
Source: FAO (1998) cited by Musy (2005).

The determination of ET_0 can be made either directly using lysimeters, or indirectly by means of empirical and theoretical (or physical) formulas that combine climatic variables.

Educational activities (exercise and case studies)

- On the basis of the basic information presented in the course and other literature, prepare in groups of 4-5 a technical sheet on evaporation and evapotranspiration estimation methods adapted to the African context.
- Give examples of application of these methods.

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Chapter 2: Evidence and Causes of Climate Change

Chapter overview

The causes of climate change are an integral part of the science of climatology. These causes have mainly been associated with human (anthropogenic) activities. This chapter will introduce learners to anthropogenic causes of change that result in GHG emissions, e.g. land use changes including deforestation, urbanization and transportation. It will also describe the risks associated with GHGs emissions and review trends in climate change.

Goal and learning outcomes

To equip learners with knowledge and skills on causes and evidence on climate change.

At the end of this chapter, the learners will be able to:

- explain the causes of climate change;
- describe the risks associated with climate change; and
- assess and interpret trends in climate change and their impacts.

2.0 Causes of GHGs and climate change related effects

2.0.1 Introduction

This training session introduces the various causes of greenhouse gases.

Objectives

At the end of this session, the learner will be able to:

a) describe what greenhouse gases are

b) determine the various sources of greenhouse gases

c) determine the risk associated with greenhouse gases.

Activity 1: Brainstorming (20 minutes)

Share your views on the concept of climate change

2.0.2 Greenhouse gases

A greenhouse gas (GHG) is any gas in the atmosphere which absorbs and re-emits heat, and thereby keeps the planet's atmosphere warmer than it otherwise would be. The main GHGs in the Earth's atmosphere are water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). GHGs occur naturally in the Earth's atmosphere, but human activities, such as the burning of fossil fuels, are increasing the levels, causing global warming and climate change. The Kyoto Protocol is an international treaty for controlling the release of GHGs from human activities.

It's worth noting that different GHGs last in the atmosphere for different lengths of time, and they also absorb different amounts of heat. The "global warming potential" (GWP) of a GHG indicates the amount of warming a gas causes over a given period of time (normally 100 years). GWP is an index, with CO_2 having the index value of 1 and the GWP for all other GHGs is the number of times more warming they cause compared to CO_2. For example, 1kg of methane causes 25 times more warming over a 100 years period compared to 1kg of CO_2, and so methane has a GWP of 25.

In Text Questions (30 minutes)

1) What is greenhouse effect, and how does it affect the climate?
2) What are the most visible signs of climate change?

2.0.3 Carbon dioxide

Carbon dioxide (CO_2) is the most common GHG emitted by human activities, in terms of the quantity released and the total impact on global warming. As a result, "CO_2" is sometimes used as a shorthand expression for all greenhouse gases. However, this can cause confusion, and a more accurate way of referring to a number of GHGs collectively is to use the term "CO_2 equivalent" or "CO_2e". Because CO_2 is considered the most important greenhouse gas some GHG assessments or reports only include CO_2, and don't consider other GHGs, and this can lead to an understatement of total global warming impact. GHG inventories are more complete if they include all GHGs and not just CO_2.

Activity 2: (Group Discussion) (20 minutes)

CO_2 is already in the atmosphere naturally, so why are emissions from human activity significant?

2.0.4 Sources of greenhouse gases

Deforestation is the removal of a forest or stand of trees where land is converted to a non- forest use. Examples of deforestation include conversion of forest land to farms, ranches or urban use. The most concentrated deforestation occurs in tropical rain forest areas. Deforestation is a contributor to global warming and is often cited as one of the major causes of the enhanced greenhouse effect. Deforestation is responsible for c. 20% of world GHG emissions. According to IPCC, deforestation, mainly in tropical areas, could account for up to one third of total anthropogenic CO_2 emissions. Deforestation causes CO_2 to linger in the atmosphere. As CO_2 accrues, it produces a layer in the atmosphere that traps radiation from the sun. The radiation converts to heat which cause global warming, which is better known as the greenhouse effect.

Forest degradation is the long-term reduction in the overall capacity of a forest to produce or provide benefits such as carbon storage, biodiversity, wood and other products due to environmental and anthropogenic alterations. It results in a decrease in the number of species in the forest and tree cover or the alteration of the forest structure. Forest degradation is different from deforestation. Forest degradation creates great ecological problems in all parts of the world, the most significant impact of which is the loss of habitat of many species or loss of biodiversity. It also leads to the disruption of water cycles and river ecosystems, soil erosion, injcreased intensity and frequency of droughts, and escalates mean and peak temperatures. Extreme weather conditions considerably decrease tree cover and dry out bodies of water that run through the forest.

Urbanization is a population shift from rural to urban areas, and the ways in which each society adapts to the change. It is predominantly the process by which towns and cities are formed and become larger as more people begin living and working in them. The existence of urban heat islands has become a growing concern over the years. An urban heat island is formed when industrial and urban areas produce and retain heat. Much of the solar radiation that reaches rural areas is consumed by evaporation of water from vegetation and soil. In cities, where there is less vegetation and exposed soil, most of the sun's energy is instead absorbed by buildings and asphalts, leading to a higher surface temperature. Vehicles, factories and industrial and domestic heating and cooling units release even more heat. Impacts also include reducing soil moisture and a reduction in reabsorption of CO_2 emissions which leads to global warming.

Transportation is the movement of people, animals and goods from one location to another. Modes of transport include; air, rail, road, water, cable, pipeline and space. It can be divided into infrastructure, vehicles and operations. Transport is important because it enables trade between persons, which is essential for the development of civilizations. Transport infrastructure consists of fixed installations including roads, railways, airways, waterways, canals and pipelines, and terminals like airports, railway stations, warehouses, trucking and refuelling terminals (fuelling docks and fuel stations) and seaports. Transport is a major use of energy and burns most of the world's petroleum. This creates air pollution; including nitrous oxides and particles and is a significant contributor to global warming through emission of CO_2, for which transport is the fastest- growing emission sector.

Activity 3: (Group Discussion) (20 minutes)

What climatic changes would we witness if greenhouse gases were stopped?

2.0.5 Risks associated with climate change

Food insecurity refers to the social and economic problem of lack of food due to resource or other constraints, non-voluntary fasting or dieting, illness, or other reasons. This definition means that food insecurity is experienced when there is:

- uncertainty about future food availability and access;
- insufficiency in the amount and kind of food required for a healthy lifestyle; or,
- the need to use socially unacceptable ways to acquire food.

Although lack of economic resources is the most common constraint, food insecurity can also be experienced when food is available and accessible but cannot be used because of physical or other constraints, such as limited physical functioning by elderly people or those with disabilities. Some closely linked consequences of uncertainty, insufficiency and social unacceptability are assumed to be part of the experience of food insecurity. Worry and anxiety typically result from uncertainty. Feelings of alienation and deprivation, distress, and adverse changes in family and social interactions also occur.

Food insecurity is measured as a household-level concept that refers to uncertain, insufficient, or unacceptable availability, access, or utilization of food. It is experienced along with some closely linked consequences of it. There is a strong rationale for measuring food insecurity at the household level. It is possible for individuals to be food secure in a food-insecure household, just as it is possible for individuals to not be poor in a poor household, depending on the intra household allocation of resources. It means that we can measure and report the number of people who are in food-insecure households (with not all of them necessarily food insecure themselves). When a household contains one or more food-insecure persons, the household is considered food insecure.

Although food is a fundamental need in that each individual must have access to necessary nutrients to survive and to participate actively in society, food is only one of the needs that people must consider. Households often make trade-offs among needs to ensure their long-term viability as units. They manage the stocks and flows of assets and cash to meet basic needs, offset risk, ease shocks, and meet contingencies.

Pollution is the introduction of contaminants into the natural environment that causes adverse change. Pollution can take the form of chemical substances or energy, such as noise, heat or light. Pollutants, the components of pollution, can be either foreign substances/energies or naturally occurring contaminants. Pollution is often classed as point source or non- point source pollution.

Adverse air quality can kill many organisms including humans. Ozone pollution can cause respiratory and cardiovascular diseases, throat inflammation, chest pain and congestion. Water pollution causes c. 14,000 deaths per day, mostly due to contamination of drinking water by untreated sewage in developing countries. An estimated 500 million Indians have no access to a proper toilet, Over ten million people in India fell ill with waterborne illnesses in 2013, and more than 1,500 died, most of them children.

- CO_2 emissions cause ocean acidification, the ongoing decrease in the pH of the Earth's oceans as CO_2 becomes dissolved.

- Emission of GHGs leads to global warming which affects ecosystems in many ways.
- Invasive species can compete with native species and reduce biodiversity. Invasive plants can contribute debris and biomolecules that can alter soil and chemical compositions of an environment, often reducing native species competitiveness.
- Nitrogen oxides are removed from the air by rain and fertilize land which can change the species composition of ecosystems.
- Smog and haze can reduce the amount of sunlight received by plants to carry out photosynthesis and leads to the production of tropospheric ozone which damages plants.
- Soil can become infertile and unsuitable for plants. This will affect other organisms in the food web.
- Sulfur dioxide and nitrogen oxides can cause acid rain which lowers the pH value of soil.

Disease incidences. Warming temperatures, alternating periods of drought and deluges, and ecosystem disruption have contributed to more widespread outbreaks of infections like malaria, dengue fever, tick-borne encephalitis and diarrheal illnesses. People living in poverty will be hardest hit by the surge in infectious diseases. Disease-carrying mosquitoes are spreading as the climate allows them to survive in formerly inhospitable areas. Mosquitoes that can carry dengue fever viruses were previously limited to elevations of 3,300 feet but recently appeared at 7,200 feet in the Andes in Colombia. Malaria has been detected in new high-elevation areas in Indonesia and Africa, posing new risks to millions of impoverished people whose health is already challenged.

Heavy rainfall events can wash pathogens from contaminated soils, farms, and streets into drinking water supplies. An outbreak of diarrheal illness in Milwaukee in 1993 which affected 403,000 people was caused by the parasite *Cryptosporidium*, which washed into the city's drinking water supply after heavy rains. Higher outdoor temperatures can cause increased outbreaks of foodborne illnesses, such as salmonella, which reproduces more rapidly as temperatures increase. Another foodborne bacteria, *Vibrio parahaemolyticus*, once native to subtropical regions, has expanded its range as far north as Alaska, where in 2004 it sickened unlucky cruise ship passengers when they ate raw local oysters.

Exercise Questions (30 minutes)

1) How does climate change affect the strength and frequency of
   (i) floods;
   (ii) droughts;
   (iii) hurricanes; or
   (iv) tornadoes?
2) What is ocean acidification and why does it matter?

Summary

In this session, we discussed the causes of climate change, sources of greenhouse gases and risks associated with greenhouse gas. In the next session, we shall examine the trends in global climate change.

2.1 National, regional and global climate change trends and scenarios

2.1.1 Introduction

This training session introduces National, Regional and Global climate change trends and scenarios. It summarizes how climate is changing, why it is changing, and what is projected for the future.

Objective

By the end of this session, the learner should be able to explain the trends and scenarios in global climate change.

Activity 1: Brainstorming (20 minutes)

Share your views on the concept of climate change.

The Earth's climate system includes the land surface, atmosphere, oceans, and ice. Many aspects of the global climate are changing rapidly, and the primary drivers of that change are human in origin. Evidence for changes abounds, from the top of the atmosphere to the depths of the oceans. Scientists and engineers from around the world have compiled this evidence using satellites, weather balloons, thermometers at surface stations, and many other types of observing systems that monitor the Earth's weather and climate. The sum of this evidence tells an unambiguous story: the planet is warming.

In Text Questions (10 minutes)

1) How do scientists know that recent climate change is largely caused by human activities?
2) What instruments help scientist in compiling evidences of climate change?

2.1.2 The modern temperature trend

Tracking the world's average temperature from the late 19th century, it was realized in the 1930s there had been a pronounced warming trend. During the 1960s, weather experts found that over the past couple of decades the trend had shifted to cooling. With a new awareness in the early 1970s that climate could change in serious ways, some scientists predicted a continued gradual cooling, perhaps a phase of a long natural cycle or caused by human pollution of the atmosphere with smog and dust. Others insisted that the effects of such pollution were temporary, and humanity's emission of GHGs would bring warming in the long run. All agreed that knowledge was primitive and any prediction was guesswork. But understanding the climate system was advancing swiftly. The view that warming must dominate won in the late 1970s as it became clear that the cooling spell (mainly a Northern Hemisphere effect) had indeed been a temporary distraction. When the rise continued into the 21st century, penetrating even into the ocean depths, scientists recognized that it signaled a profound change in the climate system. Nothing like it had been seen for centuries, and probably not for millennia. The specific pattern of changes, revealed in objects ranging from ship logs to ice caps to tree rings, closely matched the predicted effects of GHG emissions.

The 2015 annual average U.S. temperature was 12.5°C, 1.3°C above the 20th century average, the second warmest year on record. Only 2012 was warmer for the U.S. with an average temperature of 12.9°C. This is the 19th consecutive year the annual average temperature exceeded the 20th century average. The first part of the year was marked by extreme warmth in the West and cold in the East, but by the end of 2015, record warmth spanned the East with near-average temperatures across the West. This temperature pattern resulted in every state having an above-average annual temperature.

The average contiguous U.S. precipitation was 876 mm, 115 mm above average, and ranked as the third wettest year in the 121-year period of record. Only 1973 and 1983 were wetter. The central and southeastern U.S. was much wetter than average, while parts of the West and Northeast were drier than average. The national drought footprint shrank about 10 percent during the course of the year.

In 2015, there were 10 weather and climate disaster events, each with losses exceeding $1 billion. They included a drought, two floods, five severe storms, a wildfire and a winter storm. The evehts resulted in the death of 155 people and had significant economic effects.

Activity 2: (Group Discussion) (20 minutes)

Why is it a problem if the earth's average temperature gets a little warmer?

2.1.3 Sea level rise

The oceans are absorbing over 90% of the increased atmospheric heat associated with emissions from human activity. Like mercury in a thermometer, water expands as it warms causing sea levels to rise. Melting of glaciers and ice sheets is also contributing to sea level rise at increasing rates.

Activity 3: (Group Discussion) (20 minutes)

How fast is sea level rising?

Since the late 1800s, tide gauges throughout the world have shown that global sea level has risen by about 20 cm. The rate of global sea level rise measured by satellites has been roughly twice the rate observed over the last century, providing evidence of additional acceleration. Projecting future rates of sea level rise is challenging. Even the most sophisticated climate models, which explicitly represent Earth's physical processes, cannot simulate rapid changes in ice sheet dynamics, and thus are likely to underestimate future sea level rise. In recent years, "semi-empirical" methods have been developed to project future rates of sea level rise based on a simple statistical relationship between past rates of globally averaged temperature change and sea level rise. These models suggest a range of additional sea level rise from about 0.6 m to as much as 1.8 m by 2100, depending on emissions scenarios. Regardless of the amount of change by 2100, however, sea level rise is expected to continue well beyond this century as a result of both past and future emissions from human activities.

Scientists are working to narrow the range of sea level rise projections for this century. Recent projections show that for even the lowest emissions scenarios, thermal expansion of ocean waters and the melting of small mountain glaciers will result in 0.28 m of sea level rise by 2100, even without any contribution from the ice sheets in Greenland and Antarctica. This suggests that about 0.3 m of global sea level rise by 2100 is probably a realistic low end. In particular, the high end of these scenarios may be useful for decision makers with a low tolerance for risk. Although scientists cannot yet assign likelihood to any particular scenario, higher emission scenarios that lead to more warming would be expected to lead to higher sea level rise. Nearly 5 million people in the U.S. live within 1.2 m of the local high-tide level. In the next several decades, storm surges and high tides could combine with sea level rise and land subsidence to further increase flooding in many of these regions. Sea level rise will not stop in 2100 because the oceans take a very long time to respond to warmer conditions at the Earth's surface. Ocean waters will therefore continue to warm and sea level will continue to rise for many centuries at rates equal to or higher than that of the current century. In fact, recent research has suggested that even present day CO_2 levels are sufficient to cause Greenland to melt completely over the next several thousand years.

Exercise Questions (30 minutes)

1) What are the causes of current global sea level rise?
2) How much is global sea level projected to increase by 2100?
3) Is there any evidence that global sea level has been rising in the 20th century and currently is rising?

Summary

In this session, we covered National, Regional and Global climate change trend and scenarios. That is how the climate is changing, why it is changing, and what is projected for the future.

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Chapter 3: Monitoring Climate Change

Chapter overview

Access to high quality and timely data and other related relevant information is central to managing the challenges of climate change. Such information includes climate data (temperature, humidity, wind direction, wind speed, sunshine, rainfall and frequency of extreme events), as well as non-climatic data (e.g. with respect to the current situation on the ground for different sectors including water resources, agriculture and food security, human health, terrestrial ecosystems and biodiversity, and coastal zones).

The forms of climate data are very useful in modeling climate change and also building strategies for its mitigation from past climate trends. Defining uniform data collection standards is very important in producing reliable and truly global baseline meteorological information. Reliable baseline data on climate change will depend on the source of your data, collection methods, instruments used and how the management, analysis and inter-pretation are done. This chapter will introduce learners to different sources of climate and non-climatic data, data collection methods, tools and instrumentation, data management, analysis and interpretation.

Goal

Generate relevant data and monitor climate change

Learning outcomes

At the end of this chapter, the learners will be able to:

- distinguish climatic and non-climatic data and sources;
- apply appropriate methods for collecting climate data;
- clean, analyse and interpret climate data; and,
- translate climate data into meaningful information for decision-making in forestry and its related sectors.

3.0 Data types and sources

"Without data you are just like another person with an opinion"

3.0.1 Introduction

This training session introduces the various types of data on climate change. It further enlightens us on the various sources of data on climate change.

Objectives

By the end of this session, the learner will be able to:

a) identify the various types of data on climate change; and

b) Analyse the various sources of data on climate change.

3.0.2 Types of data

Quantitative or numerical data arise when the observations are counts or measurements. The data are said to be discrete if the measurements are integers (e.g. number of people in a household, number of cigarettes smoked per day) and continuous if the measurements can take on any value, usually within some range (e.g. weight).

Qualitative data arise when the observations fall into separate distinct categories. E.g. colour of eyes (blue, green, brown etc.), exam result (pass or fail) and socio-economic status (low, middle or high). Data are classified as nominal if there is no natural order between the categories (e.g. eye colour), or ordinal if an ordering exists (e.g. exam results, socio-economic status).

In Text Questions (10 minutes)

1) Identify and define the major kinds of data

2) Under each type, give some examples of climate data that fall under them.

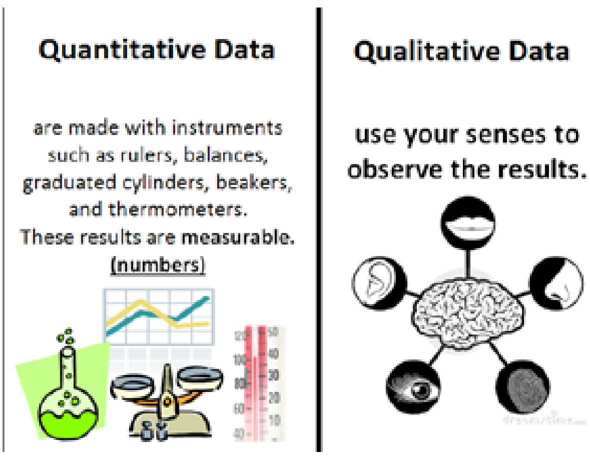

Figure 49. Quantitative data vs Qualitative data.
Source: Kenan (2015)

3.0.3 Sources of data

- Global Historical Climatology Network (GHCN)
- National Centers for Environmental Prediction (NCEP)
- Climate Research Unit (CRU) of the Univ. of East Anglia (UEA) and the International Water Management Institute (IWMI)
- Global Circulation Models (GCM)
- UNDP Climate profiles
- CI:GRASP
- International Partnership on Mitigation of MRV
- IRI Columbia
- CIAT climate models
- NOAA climate services
- SERVIR
- IPCC Data Distribution Center

Activity 2: (Group Discussion) (20 minutes)

Discuss the major sources of climate data in the world, the type of data they provide and how essential the data.

Summary

In this session, we have learnt about some key types of data and the various sources of data on climate change. In the next session, we will learn about the various data collection methods involved in collecting climate data.

3.1 Data collection methods

"You can have data without information, but you cannot have information without data"

3.1.1 Introduction

This training session introduces us to the various methods involved in the collection of data on climate change.

Objective

By the end of this session, the learner should be able to identify the various methods involved in the collection of climate data

Activity 1: Brainstorming (20 minutes)

Share your views on the various types of data collection methods you have used before in your home country.

3.1.2 Data collection methods

- Experiments
- Census
- Questionnaires
- Interviews
- Action research
- Case studies
- Registrations
- Observational study
- Focus groups

In Text Questions (10 minutes)

Explain how the data collection methods are used to collect climate data.

Activity 2: (Group Discussion) (20 minutes)

Discuss the flaws associated with each data collection method during the collection of climate data.

Exercise Questions (30 minutes)

Figure 50. Tools and instrumentation.
Source: Subterranean Ecology (2016)

Study the figure above carefully and carry out the following activities:

a) identify all the instruments;

b) identify what each of the instrument is used for in climate data collection;

c) identify the errors each instrument may incur during data collection; and,

d) identify the various way each instrument can be maintained.

Summary

In this session, we have learnt about the methods used to collect climate data. In the next session, we will learn about the various the tools and instruments used in collecting climate data.

3.2 Tools and instrumentation

"Anything that is measured and watched, improves"

3.2.1 Introduction

This training session introduces us to the various tools and instruments involved in the collection of climate date. It further enlightens us on what exactly they are used for.

Objectives

By the end of this session, the learner should be able to:

a) identify the various tools and instruments involved in climate data collection; and

b) identify functions of these tools and instruments.

Activity 1: Brainstorming (20 minutes)

Share your views on essence of gaining on understanding concerning tools and instrumentation in climate data collection.

3.2.2 Tools and instruments used to record climate data

Thermometer (fig. 51) is an instrument used to measure temperature in either Celcius or Fahrenheit. When temperature incraeses the mercury in the thermometer rises when it decreases the mercury falls.

Anemometer (fig. 52) is a type of weather instrument that measures wind speed. An anemometer and a wind vane are often combined into one instrument to gather information about moving air. The anemometer shown here is called a cup anemometer. As air moves and the cups turn data is collected mechanically to produce a rating of wind speed and force.

Figure 51. Thermometer.
Source: http://www.weatherwizkids.com/?page_id=82

Figure 52. Anemometer.
Source: http://www.weatherwizkids.com/?page_id=82

Wind vane/Weather vane/Weather cock (fig. 53) is an instrument used to determine the direction from which air is moving. For example, a westly wind is moving from west to east, not towards the west.

Figure 53. Wind vane.
Source: http://www.weatherwizkids.com/?page_id=82

Hygrometer (fig. 54) is an instrument used to measure relative humidity.

Figure 54. Hygrometer.
Source: Khara (2016)

Rain gauge/Udometer/Pluviometer/Fluviograph (fig. 55) is an instrument to measure the amount of liquid precipitation over a certain length of time. This can be mounted like the image on the top or they can be anchored into the ground like the image on the bottom.

Figure 55. Rain gauge.
Source: http://www.weatherwizkids.com/?page_id=82

Barometer (fig. 56) is used to measure atmospheric pressure. Meterologists can determine whether the air pressure is rising or falling using a barometer. This data can then be used to predict specific weather conditions. High pressure is an indication of good weather, while low pressure indicates stormy weather.

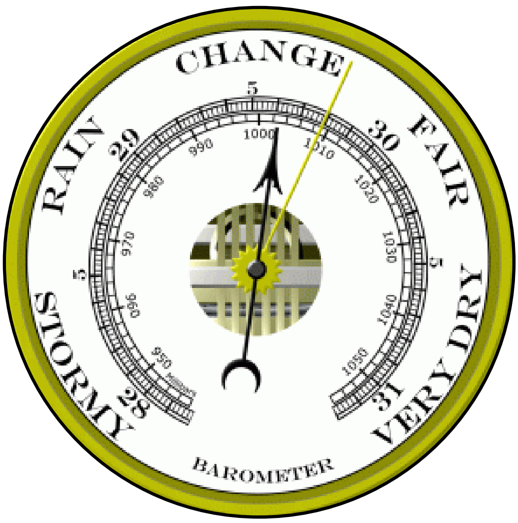

Figure 56. Barometer.
Source: http://www.weatherwizkids.com/?page_id=82

Seismograph (fig.57) is an instument used to measure ground movement caused by earth-quakes or explosions.

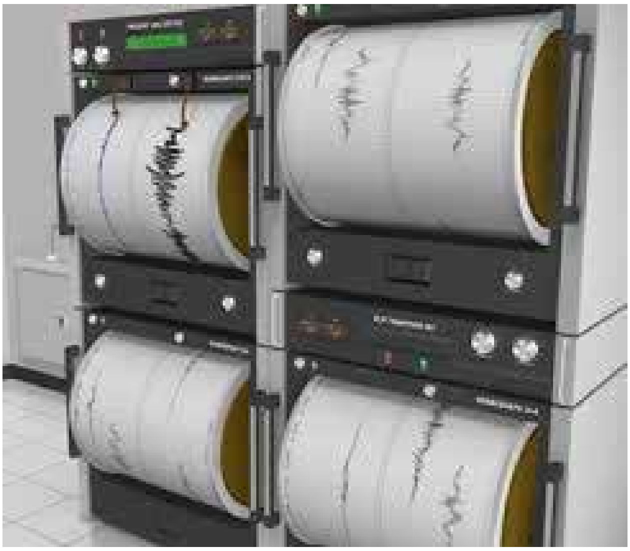

Figure 57. Seismograph
Source: http://www.weatherwizkids.com/?page_id=96

Hydrometer (fig. 58) is an instrument used to measure the relative density or the specific gravity of liquids.

Figure 58. Hydrometer.
Source: http://www.wilko.com/homebrew-accessories+equipment/ wilko-hydrometer-loose-wine-and-beer/invt/0022575

Snow gauge (fig. 59) is an instument used to measure solid precipitation.

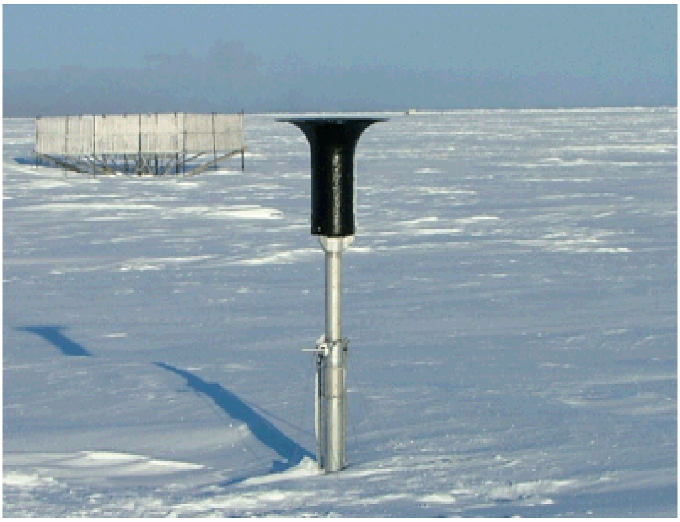

Figure 59. Snow gauge. Source:

http://www.globalspec.com/learnmore/sensors_transducers_detectors/weather_sensing/weather_instruments

Sunshine recorder (fig. 60) is an instrument that records the amount of sunshine at a given location.

Figure 60. Sunshine recorder.
Source: http://www.metcheck.co.uk/acatalog/ Sunshine_Recorder.html

Wind sock (fig. 61) is a conical textile tube which resembles a giant sock, designed to indicate wind direction and relative wind speed.

Figure 61. Wind sock.
Source: http://www.weatherwizkids.com/?page_id=82

Weather maps (fig. 62) indicate atmospheric conditions above a large portion of the earth's surface. Meteorologists use weather maps to forecast the weather.

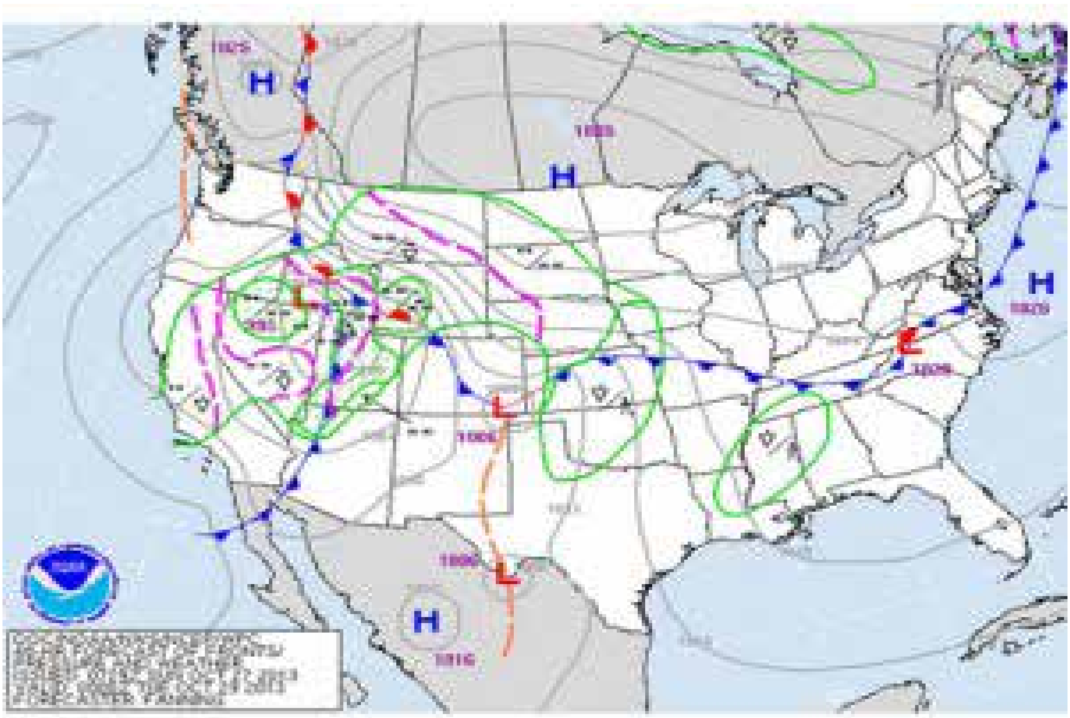

Figure 62. Weather maps.
Source: http://www.weatherwizkids.com/?page_id=82

Weather ballon (fig. 63) measures weather conditions higher up in the atmosphere.

Figure 63. Weather ballon.
Source: http://www.weatherwizkids.com/?page_id=82

Compass (fig. 64) is a navigational instrument for finding directions.

Figure 64. Compass.
Source: http://www.weatherwizkids.com/?page_id=82

Weather satellite (fig. 65) is used to photograpgh and track large scale air movements. Then metoerologists compile and analyze the data with the help of computers.

Figure 65. Weather satellite.
Source: http://www.weatherwizkids.com/?page_id=82

Your eye (fig. 66) is one of the best ways to help detect the weather. Always keep an eye at the sky and you will usually be on top of weather conditions.

Figure 66. Your eye.
Source: http://www.weatherwizkids.com/?page_id=82

In Text Questions (10 minutes)

1) Identify some commonly used instruments involved in climate data collection.
2) Identify what each instrument listed above is used for.

Activity 2: (Group Discussion) (20 minutes)

Discuss how the instruments can be maintained and how they can be used to minimize errors in the data collected.

Exercise Questions (30 minutes)

Figure 67.Tools and instrumentation.
Source: http://www.slideshare.net/atyler29/weather-instruments-33270034

Study the figure above carefully and carry out the following activities:

1) identify all the instruments;
2) identify what each of the instrument is used for in climate data collection;
3) identify the errors each instrument may incur during data collection; and,
4) identify the various way each instrument can be maintained.

Summary

In this session, we have learnt about some key instruments used in climate data collection and what they are used for. In the next session, we will learn about the management, analysis and interpretation of climate data.

3.3 Introductory data management, descriptive analyses and interpretation

"Data is a precious thing and will last longer than the systems themselves"

3.3.1 Introduction

This training session introduces us to how various climate data collected can be managed for both current and future use. It further enlightens us on the analysis and interpretation of climate data for scientific uses and decision making.

Objectives

By the end of this session, the learner will be able to:

a) demonstrate their ability to manage climate data;

b) Analyse and interpret climate data.

Activity 1: Brainstorming (20 minutes)

Share your views on your involvement in any data analysis and interpretation process.

3.3.2 Data management

- Data management is the process of controlling the information generated during a research project. Any research will require some level of data management.
- During the course of your research, you may accumulate a large amount of data, which will need to be carefully organized and managed for later analysis
- Climate data management deals with collecting, recording and achiving weather/climate data from the department's observational network.
- The basic goal of climate data management is to preserve, capture and provide access to climate data and products for use by planners, decision makers and researchers. Climate data is stored and managed in a climate data management system (CDMS).
- A CDMS is a set of tools and procedures that allows all data relevant to climate studies to be properly stored and managed.
- The primary goals of database management are to maintain the integrity of the database at all times, and to ensure that it contains all the data and metadata needed to meet the requirements for which it was established, both now and in the future.
- Database management systems have revolutionized climate data management by allowing efficient storage, access, conversion and updating for many types of data, and by enhancing data security.

- The main data processing operations have been automated, with the help of computers in all stages of processing.
- Data quality control is carried out through software adapted from WMO, CLICOM which is now being replaced by a later database, CLIMFOT
- In management planning, consideration also needs to be given to the long-term life of climate data, so it remains available as a resource for future users. Issues include succession planning and training of personnel, the replacement cycle for hardware, maintenance and upgrade costs, support and training for commercial software.

In Text Questions (10 minutes)

1) What is data management?
2) What is the relevance of data management with respect to climate data?

3.3.3 Data analysis and interpretation

- Data analysis and interpretation is the process by which sense and meaning are made of the data gathered in qualitative research, and by which the emergent knowledge is applied to clients' problems. This data often takes the form of records of group discussions and inter-views, but is not limited to this. Through processes of revisiting and immersion in the data, and through complex activities of structuring, re-framing or other-wise exploring it, the researcher looks for patterns and insights relevant to the research issues and uses these to address the client's dissertation.
- Raw data such as tables of number (dates and temperature), descriptions (cloud cover), location, etc., can be useful in and of itself. For example, if you wanted to know the air tem-perature in London on June 5th, 1801. But the data alone cannot tell you anything about how temperature has changed in Lodon over the past two hundred years, or how that information is related to global-scale climate change. In order to see patterns and trends in the data, they must be analysed and interpreted first.
- The analysed and interpreted data may then be used as evidence in scientific arguments, to support an hypothesis or a theory. Good data is a potential treasure trove - it can be mined by scientiss at any time and thus an important part of any scientific investigatin is accurate and consistent recording of data and the methods used to collect that data.
- Data processing and analysis are sometimes misinterpreted as manipulating data to achieve the desired results but, in reality, the goal of these methods is to make the data clearer, not to change it fundamentally.
- The analyzed data can then be interpreted and explained. In general, when scientists interpret data, they attempt to explain the patterns and trends encovered through analysis, bring all of their background knowledge, expeerience, and skills to bear on the question and relating their data to existing scientific ideas.

Activity 2: (Group Discussion) (20 minutes)

Discuss the processes involved in the management, analysis and interpretation of climate data.

Summary

In this session, we have learnt about the management, analysis and interpretation of climate data. This ends the chapter on generating a baseline data on climate change.

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Chapter 4: Vulnerability to and Impact of Climate Change

Overview

Over some years now climate change has become an issue of global concern. The world's average surface temperature has increased by around 0.6 degrees Celsius over last 100 years. The changing climate patterns have already had significant impact on our planet. Melting of polar ice caps, change in rainfall patterns, and increase in frequency of storms are some of the adverse effects. Saving our planet, lifting people out of poverty, advancing economic growth are all the same fight. We must connect the dots between climate change, water scarcity, energy shortages, global health, food security and women's empowerment. Solutions to one problem must be solutions for all. Vulnerability is a critical component of the basic science of climate change because it comprises a set of conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards or to get hurt by an external stress. Impacts demonstrate the effect of climate change on different sectors from both natural and human systems. These impacts have serious implications for societies by aggravating vulnerabilities. To contain such adverse effects will require the development of adaptation mechanisms to the changing climate. This chapter will introduce learners to concepts of vulnerability, biophysical vulnerability and impacts, socio-economic vulnerability and impacts, and disaster reduction, and risks associated with climate change.

Goal

Relate concepts of vulnerability and response to climate change.

Learning outcomes

At the end of this chapter the learner will be able to:

- classify key concepts involved in the vulnerability of systems to climate change impacts;
- describe the biophysical and socio-economic effects of climate change on ecosystems; and
- explain risks associated with climate change and how to undertake disaster risk reduction across various sectors.

4.0 The concept of vulnerability: definitions of terminologies

"*Knowledge is power*"

4.0.1 Introduction

This training session introduces us to the vulnerability of systems to the impacts of climate change. It enlightens us on the definition of certain key concepts of vulnerability, such as exposure, sensitivity, adaptive capacity/resilience, etc. It helps to explain the various concepts of vulnerability and their implications as far as climate change is concerned.

Objectives

By the end of this session, the learner should be able to:

a) define vulnerability; and,

b) explain certain key concepts of vulnerability.

Activity 1: Brainstorming (20 minutes)

Share your views on human vulnerability to to the impacts of climate change.

4.0.2 Definitions and terminologies in vulnerability to climate change

Vulnerability is the extent to which a natural or social system is susceptible to sustaining damage from climate change, and is a function of the magnitude of change, the sensitivity of the system to changes and the ability to adapt the system to such changes. Hence, a highly vulnerable system is one that is highly sensitive to modest changes in climate and one for which the ability to adapt is severely constrained.

In Text Questions (10 minutes)

1) Explain the term "vulnerability" in the context of climate change.

2) Identify some natural systems and how vulnerable they are to climate change.

3) Identify some social systems and how vulnerable they are to climate change.

Exposure is the degree of climate stress on a particular unit of analysis, represented as either long-term change in climate conditions, or by changes in climate viability, including the magnitude and frequency of extreme events.

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli.

Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Activity 2: (Group Discussion) (20 minutes)

Discuss how vulnerability relates to the impacts of climate change in Africa.

Exercise Questions (30 minutes)

Figure 68. Tools and instrumentation.
Source: VOA (2010)

Study the figure carefully and carry out the following activities:

1) identify what is happening on the scene;
2) establish the link between adaptive capacity, sensibility and exposure with respect to vulnerability; and,
3) identify ways in which such occurrences can be solved.

Summary

In this session, we have learnt about some key terms, such as vulnerability, exposure, sensitivity and adaptive capacity. In the next session, we will be looking at the vulnerability of biophysical systems to the impacts of climate change.

4.1 Vulnerability of biophysical systems and impacts

"When the last tree dies the last man dies"

4.1.1 Introduction

This training session introduces us to the various biophysical systems and how vulnerable they are to climate change. It enlightens us on the various ways in which certain elements of biodiversity, topography and edaphic factors are affected by climate change. It helps to explain the vulnerability of biophysical systems to the impacts of climate change.

Objectives

By the end of this session, the learner will be able to:

a) define a biophysical system;

b) identify key factors that contribute to the success of a biophysical system;

c) explain how the factors contribute to the success of the biophysical system; and,

d) explain the impacts of climate change on these biophysical systems.

Activity 1: Brainstorming (20 minutes)

Analyse the various systems in an environment and explain how each system is vulnerable to climate change.

4.1.2 Definitions and terminologies in vulnerability of biophysical systems to impacts of climate change

Biophysical system is a biological system that involves physical methods and theories.

Biodiversity is the term given to the variety of life on Earth. It is the variety within and between all species of plants, animals and micro-organisms and the ecosystems in which they live and interact.

Genes are segments of DNA located on chromosomes. They exist in alternative forms called alleles, which determine traits that can be passed on from parents to offspring.

Species is a group of closely related organisms that are very similar to each other and are usually capable of interbreeding and producing fertile offspring.

Ecosystems includes all living things (plants, animals and organisms) in a given area, interacting with each other, and also with their non-living environments (weather, earth, sun, soil, climate and atmosphere).

Edaphic factors are the ecological properties of the soil brought about by its physical and chemical characteristics.

In Text Questions (10 inutes)

Define the following terminologies with examples:

1) biophysical systems;
2) biodiversity;
3) genes;
4) species;
5) ecosystems; and,
6) edaphic factors.

4.1.3 Vulnerability of biodiversity to the impacts of climate change

- Climate change result in extinction of many plant and animal species and also cause the reduction in the diversity of terrestrial, freshwater and marine ecosystems. According to IPCC, 20-30% of plant and animal species are likely to be at increased risk of extinction, if increases in global average temperature exceed 1.5-2.5°C.
- Vulnerability of ecosystems and species is partly a function of the expected rapid rate of climate change relative to the resilience of such systems. 1 million species may face an increased threat of extinction as a result of climate change, according to the Millennium Ecosystem Assessment.
- Human development substantially reduces the resilience of ecosystems and makes many ecosystems and species more vulnerable to climate change through blocked migration routes, fragmented habitats, reduced populations, introduction of alien species and stresses related to pollution.
- Changes in species distributions, phenology and ecological interactions will have impacts, e.g. on pollination, invasions of agricultural systems by weed and locations of major marine fishing grounds.
- Climate change has already begun to affect the functioning, appearance, composition and structure of ecosystems (e.g. decreasing thickness of sea ice in the Arctic, wide-spread bleaching of corals, wetland salinization and salt-water intrusion). Changes in timing of natural events affect interactions between organisms, disrupting equilibriums and ecosystems.

4.1.4 Vulnerability of edaphic factors to the impacts of climate change

- The change in certain climate parameters such as temperature and rainfall patterns damage the physical structure of soils. Temperature and water have a large influence on processes that take place in soils. Organic matter in particular is being affected. This balance is crucial to the nutrient balance of the soil, its stability, the amount of water it can hold, and the population of soil organisms.

- In addition, changes are likely to leave some soils more vulnerable to erosion. Climate change affect soil properties such as moisture content, infiltration capacity, water holding capacity, temperature, nutrient content, organic matter content, etc.

Activity 1: (Group Discussion) (20 minutes)

Discuss the vulnerability of forest soils to the impacts of climate change in Africa.

Exercise Questions (30 minutes)

Figure 69. Vulnerability of biophysical systems to climate change
Source: Schuetze C. F (2013)

Study the figure carefully and carry out the following activities:

1) describe the activity carried out in the photograph;
2) list the biophysical systems present in the photograph; and
3) explain the various ways the activities in the photograph will affect the bio-physical systems involved.

Summary

In this session, we have learnt about what makes certain biophysical systems vulnerable to climate change and its impacts. The session has also highlighted various concepts involved in a system's vulnerability to climate change. In the next session we will learn about how socio-economic aspect and livelihood of people are vulnerable to the impacts of climate change.

4.2 Socio-economic and livelihood vulnerability and impacts

"Climate change is a terrible problem, and it absolutely needs to be solved. It deserves to be a huge priority"

4.2.1 Introduction

This training session introduces the vulnerability of socio-economic development and livelihood to climate change impacts. It enlightens us on how key areas of socio-economic development and livelihood, such as infrastructure and settlement of communities, are affected by the impacts of climate change. It further explains how various sectors like forest, health, agriculture and food security, water and coastal resources, and transportation are vulnerable to impacts of climate change.

Objectives

By the end of this session, the learner will be able to:

a) explain how infrastructure and settlements are vulnerable to climate change; and

b) explain the various sectors in the world are vulnerable to climate change.

Activity 1: Brainstorming (20 minutes)

Share your views on the various ways in which climate change has impacted on infrastructure and settlement in your home country.

4.2.2 Vulnerability of infrastructure and settlement to climate change impacts

- Climate change could affect the sustainability of human settlements either by directly affecting the quality of life (e.g. by changing the probability of floods or the effects of air-pollution), by modifying the effects of the settlements on their surrounding environments (e.g. by changing the demand for water or changing the assimilation capacity of wetlands), or by changing the economic underpinnings (e.g. by changing the productivity of croplands, forests, or fisheries on which the settlement depends).
- Most of the impacts on human settlements from climate change are likely to be experienced indirectly through effects on other sectors (e.g. changes in water supply, agricultural productivity, and human migration).
- Many of the expected impacts in the developing world will occur because climate change may, by reducing natural resource productivity in rural areas, accelerate rural-to-urban migration, exacerbating already crowded conditions in the cities and further depleting the labor force of the countryside.

- Global warming can be expected to affect the availability of water resources and biomass, both of which are major energy sources in many developing countries. Loss of water and biomass resources may jeopardize energy supply and materials essential for human habitation and energy production.
- In rural areas, particularly those in low-income countries, roads represent a lifeline for economic and agricultural livelihood, as well as a number of indirect benefits including access to healthcare, education, credit, political participation, and more.
- Roads may be sparse through geographic locations, making each road critical. Extreme events pose a costly hazard to roads in terms of degradation, necessary maintenance, and potential decrease in lifespan. Climate change poses costly impacts in terms of maintenance, repairs and lost connectivity.

Activity 2: (Group Presentation) (20 minutes)

Divide yourselves into four groups, each group representing one continent in the world. You will make group presentations on the vulnerability of the infrastructure and settlement of that continent to the impacts of climate change with practical examples.

4.2.3 Sectorial vulnerability to the impacts of climate change

Forest

- Forests are highly dependent on climate for their function (e.g. growth) and structure (e.g. species composition). Forest distribution is generally limited by either water availability or temperature.
- With respect to organisms and species, changes in temperature, rainfall, wind and humidity are likely to affect many processes, including growth, reproduction, pollination, seed dispersal, phenology, pest and disease resistance and competitive ability.
- Climate change effects on species are likely to alter ecosystem balance and composition in unpredictable ways. For example, climate change may both disrupt and improve plant defenses against pests and pathogens.
- Interactions among pests, pathogens and fire may cause either negative feedback loops or destabilizing positive feedback loops. Fires can lead to outbreaks of pests and pathogens, and these can increase the probability and severity of fires. Sometimes, fires can reduce pest outbreaks and fire suppression may increase the risk of epidemics.
- Habitat fragmentation and disturbance also create opportunities for invasive species and reduce the likelihood that native species will migrate within contiguous areas.
- The health and vitality of forests are threatened by stress factors such as uncontrolled logging, hunting and collection of NWFPs, fire, drought, invasive species and pests and diseases. These factors are likely to intensify in the future as the climate changes.

Agriculture and food security

- Agriculture is one of the most climate sensitive sectors. Climate change affects all four dimensions of food security: food availability, food accessibility, food utilization and food systems stability.
- Climate change affects the health and productivity of crops, livestock, fish and forests and dependent rural livelihoods. This leads to hunger and malnutrition in such areas.
- A drop in water levels, drought, desertification and saltwater intrusion leads to more hunger and impoverishment. Water and food insecurity are exacerbated.
- While some mid-latitude and high-latitude areas will initially benefit from higher agricultural production, for many others at lower latitudes, especially in seasonally dry and tropical regions, the increases in temperature and the frequency of droughts and floods are likely to affect crop production negatively, which could increase the number of people at risk from hunger and increased levels of displacement and migration.

Water and coastal resources

- Climate change affects water resources through its impacts on the quantity, variability, timing, form and intensity of precipitation.
- Increased evaporation rates, a higher proportion of precipitation received as rain, increased water temperatures and decreased water quality in both inland and coastal areas. These tend to reduce water supplies to both agricultural and municipal sectors.
- Drought-affected areas will likely become more widely distributed. Heavier precipitation events are very likely to increase in frequency leading to higher flood risks.
- By mid-century, water availability will likely decrease in mid-latitudes, in the dry tropics and in other regions supplied by melt water from mountain ranges. More than one sixth of the world's population is currently dependent on melt water from mountain ranges.
- The impacts of climate change on water and coastal resources affects ecosystems and communities, ranging from economic and social impacts to health and food insecurity, all of which threaten the continued existence of many regions in the world.

In Text Questions (10 minutes)

How are the following vulnerable to climate change impacts:

1) forests;
2) agriculture and food security; and,
3) water and coastal resources.

Health

- Changes in climate are likely to alter the health status of millions of people, including through increased deaths, disease and injury due to heat waves, rising sea-levels, floods, storms, intense hurricanes, degraded air quality, fires and droughts.

- Changes in precipitation are creating changes in the availability and quality of water, as well as resulting in extreme weather events such as intense hurricanes and flooding.
- Climate change can be a driver of disease migration, as well as exacerbate health effects resulting from the release of toxic air pollutants in vulnerable populations such as children, the elderly, and those with asthma or cardiovascular disease.
- Increased malnutrition, diarrheal disease and malaria in some areas will increase vulnerability to public health and development goals will be threatened by longer term damage to health systems from disasters.
- Extreme and unprecedented cold spells and prolonged wet environment result in health problems, such as hypothermia, bronchitis and pneumonia, especially among old people and young children.

Transportation

- Higher temperatures can cause pavement to soften and expand. This can create rutting and potholes, particularly in high-traffic areas and can place stress on bridge joints. Massive floods, hurricanes, cyclones, typhoons and storm surges lead to the destruction of houses, infrastructure (bridges, roads, electrical lines, dams, mine tailing ponds, etc.).
- Heat waves may limit construction activities, particularly in areas with high humidity. With these changes, it may become more costly to build and maintain roads. Heavy rains may result in flooding, which could disrupt traffic, delay construction activities and weaken or wash out the soil and culverts that support roads, tunnels and bridges.
- Exposure to flooding and extreme snow events also shortens the life expectancy of highways and roads. The stress of water and snow may cause damage, requiring more frequent maintenance, repair and rebuilding. Road infrastructure in coastal areas is particularly sensitive to more frequent and permanent flooding from sea level rise and storm surges.

Activity 3: (Group Discussion) (20 minutes)

Discuss how the various sectors are vulnerable to the impacts of climate change in a country of your choice in Africa and rank the sectors according to their vulnerability to climate change.

Exercise Questions (30 minutes)

Figure 70. Sectorial vulnerability to climate change

Study the figure above carefully and carry out the following activities:

1) describe the scene in the photograph;
2) explain the relationship between climate change and the scene;
3) identify the sector vulnerable to this effect of climate change; and,
4) outline the possible causes of the happening in the scene.

Summary

In this session, we have learnt about some key terms used in the vulnerability of various biophysical systems to climate change impacts. In the next session, we will learn about how climate change leads to disasters and the strategies for reducing such risks.

4.3 Climate change and disaster risk reduction

"We cannot stop natural disasters but we can arm ourselves with knowledge: so many lives wouldn't have to be lost if there was enough disaster preparedness"

4.3.1 Introduction

This training session introduces participants to how disaster risks associated with impacts of climate change can be reduced. It further enlightens us on the various weather factors that contribute to such disasters. It educates us on key strategies that can be adapted to help reduce disaster risks cause by climate change.

Objectives

By the end of this session, the learner will be able to:

a) define disaster risk reduction;

b) identify the weather factors that contribute to disasters and how it happens; and

c) outline strategies for reducing climate change disaster risks.

Activity 1: Brainstorming (20 minutes)

With practical examples share your views on the relationship between climate change and disasters risk reduction.

4.3.2 Definitions and terminologies in climate change and disaster risk reduction

Disaster risk reduction refers to actions taken to reduce risks of disasters and adverse impacts of natural hazards, through systematic efforts to analyze and manage the causes of disasters, including through avoidance of hazards, reduced social and economic vulnerability to hazards, and improved preparedness for adverse events.

In Text Questions (10 minutes)

1) Definethe concept of disaster risk reduction.

2) Identify five examples of disasters caused by climate change effects.

4.3.3 Weather factors that contribute to disasters

Disasters are mostly causes by certain weather conditions, such as temperature, cloud cover, wind, humidity and air pressure.

4.3.4 Strategies for reducing climate change disaster risks

- Ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation.
- Identify, assess and monitor disaster risks and enhance early warning.
- Use knowledge, innovation and education to build a culture of safety and resilience at all levels.
- Reduce the underlying risk factors.
- Strengthen disaster preparedness for effective response at all levels.

Activity 2: (Group Discussion) (20 minutes)

Discuss the impact of population growth and urbanization on climate change and commensurate effect on forestry in a country of your choice in Africa.

Exercise Questions (30 minutes)

Figure 71. Climate change and disaster risk reduction.
Source: Heidorn (2000)

Study the figure above carefully and carry out the following activities:

1) describe the scene in the photograph;
2) identify the various factors that might have contributed to what is happening in the photograph; and,
3) outline some strategies that can be employed to reduce such disaster risks.

Summary

In this session, we have learnt about how climate change leads to disasters and the strategies for reducing such risks. The ends the chapter on vulnerability to and impacts of climate change. In the next chapter, we will learn about generating baseline data on climate change.

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Chapter 5: Basic Knowledge on Organisms and Their Living Environment

Overview

Knowledge of the interactions between organisms and their environment is a prerequisite to understanding the science of climate change. This chapter recalls to the students/learners the main components of the living, terrestrial and atmospheric systems and their evolution.

The stability of ecosystems depends on their internal dynamics and interactions with external factors. Stability and sustainable forest management can help mitigate the adverse effects of climate change. This chapter also deals with the typology of terrestrial ecosystems, the monitoring mechanisms of these ecosystems and the concepts of sustainable management and conservation of ecosystems.

Goals

Provide students with basic knowledge on the interactions between organisms and their living environment as well as some assessment methods.

Provide technicians with basic knowledge on tools/approaches and methods for sustainable management of ecosystems.

Learning outcomes

At the end of this chapter, learners will be able to:

- explain the interactions between organisms and their environment
- explain the evolution of terrestrial ecosystems;
- explain how different terrestrial ecosystems work;
- Prepare ecosystem inventory and monitoring tools; and,
- Develop sustainable ecosystem management tools.

5.0 Understanding the basics on earth and life sciences

5.0.1 Botany

Objective

By the end of the session, the learner will be able to:

1. describe and recognize plants.

General introduction

Definition of botany: "science which aims at studying plants". Plant is defined as a "living organism characterized relatively to others (animals) by a lower mobility and sensitivity, a specific chemical composition (chlorophyll, cellulose) and nutrition from single elements" (Petit Robert dictionary). The term botany comes from the Greek word *botanê*, which means "plant", derived from the verb *boskein* meaning "feed". This etymology clearly shows the key role of plants in food chains due to their autotrophic and light-based metabolism.

Life characteristics: Living organisms have a specific mode of functioning made up of several activities. The first one called metabolism consists of taking up substances needed from their environment for their functioning and producing waste. The second mode is called reproduction which enables living organisms to multiply. Living organisms can also move, visible or not to the naked eyes, are in contact with the environment (communication) and remain in a relatively constant shape despite the changes occurring in their environment (Larousse.edu.fr).

From the points above, seven characteristics of living organisms can be observed: movement, nutrition, excretion, respiration, growth, sensitivity and reproduction[8].

Figure 72. Shoot of a spiral leaf.
Source: Life Features: http://www.larousse.fr/encyclopedie/divers/vie/101614

8 Source: Life Features: http://www.larousse.fr/encyclopedie/divers/vie/101614

Plant characteristics: Plants are characterized by the cell, tissue, photosynthesis, vegetative propagation, cell titopotence and their capacity to reproduce[9] themselves.

Plant cell: The plant cell is characterized by the plastids and absorbing pigments (chloro-phylls, carotenoids, and phycobilins), the wall and the vacuole[10] .

Tissue: cells differentiate, specialize and form various tissues. The combination of tissues give organs such as roots, stems, leaves and flowers[11] which have various functions.

Photosynthesis: Plants are autotrophic. They synthesize their organic material from mineral substances they draw from the soil (water and mineral salts) and in the air (carbon in the form of CO_2). The energy required for the synthesis, generated by the sun, is captured by absorbing pigments (chlorophylls) during the photosynthesis. The chemical equation for photosynthesis reaction can be summarized as follow[12]:

n $[CO_2+H_2O]$ + Light energy $[CH_2O]$ n + nO_2

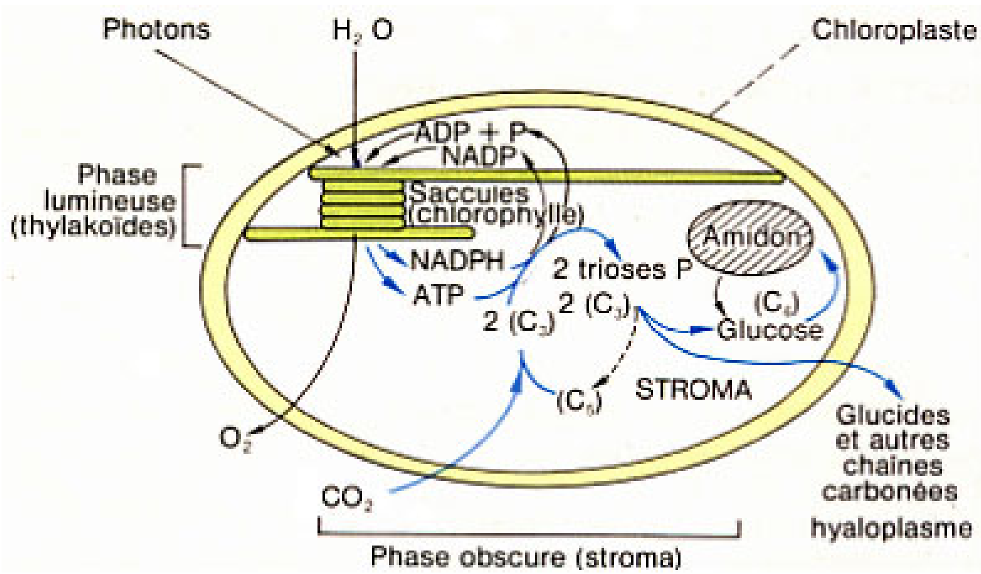


Figure 73. Photosynthesis process.
Source: Plant characteristics: Autotrophy and photosynthesis http://www.creaweb.fr/perso/bv/autotro.html

Plants are either photosynthetic or photoautotrophic. The autotrophy is essential since it is the precondition to the existence of plants[13].

Vegetative propagation and totipotentiality: Cell plant totipotency is the ability of any potential plant cell to differentiate itself in order to redifferentiate and generate a new organism.

Reproduction can be either sexual or asexual.

9 Plant characteristics: Vegetative multiplication and Totipotentiality: http://www.creaweb.fr/perso/bv/tissus.html
10 Plant characteristics: Plant cell: http://www.creaweb.fr/perso/bv/tissus.html
11 Plant characteristics: Tissues: http://www.creaweb.fr/perso/bv/tissus.html
12 Plant characteristics: Autotrophy and photosynthesis: http://www.creaweb.fr/perso/bv/tissus.html
13 Plant characteristics: Autotrophy and photosynthesis: http://www.creaweb.fr/perso/bv/tissus.html

Major plants groups: prokaryotes and eukaryotes

The first living organisms, appearing on earth about 3.5 billion years ago were bacteria devoid of a cell nucleus: these are prokaryotes. From these prokaryotes, more complex organisms appeared: eukaryotes. Their essential characteristic is a cell nucleus, which contains the DNA carrying the genetic information . All animals and plants are eukaryotes. The main differences between eukaryotes and prokaryotes are summarized in table 7:.

Table 7. Major plants groups4

Prokaryotes	Eukaryotes
No nucleus	Existence of a nucleus
Cell division by scissiparity	Cell division by mitosis and meiosis
No subcellular organelles	Many organelles (mitochondria, reticulum, dictyosomer, and plastids in plants)
Glycoprotein wall	Pectocellulosic wall in plants
No cytoskeleton	Cytoskeleton (actin, microtubules)

Source: Systematics of superior plants; Classification; definition of species http://ecologieenvironnement.blogspot.com/2015/01/systematique-des-plantes-superieures.html

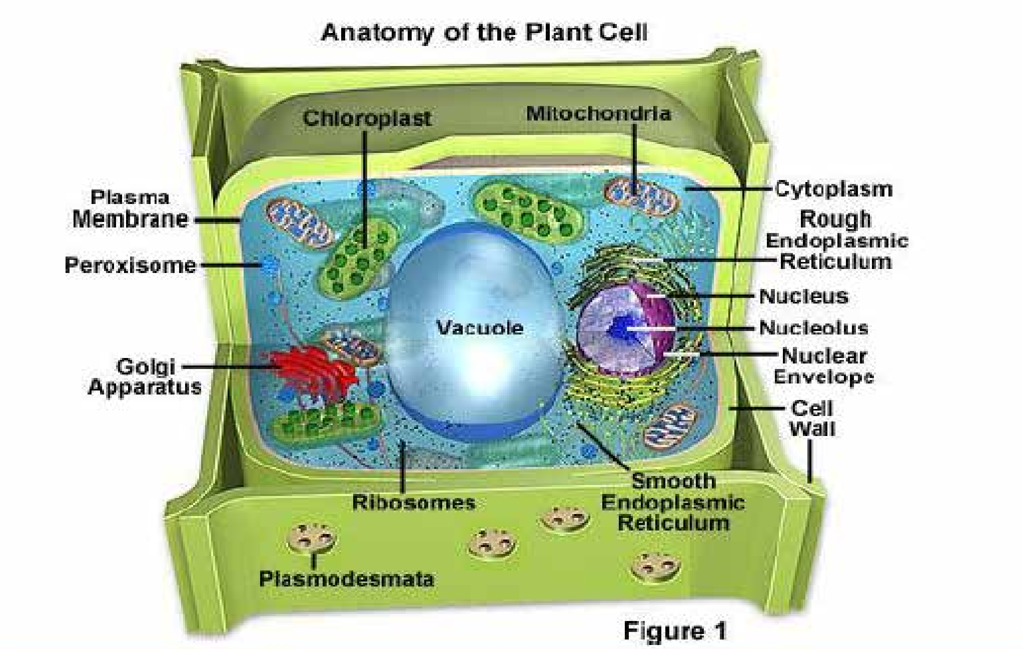


Figure 74. Eukaryotic plant cell content.
Source: Herbology: http://www.doc-developpement-durable.org/file/Agriculture-Lutte Biologique/ebook_cours_de_botanique_l_appareil_vegetatif_des_vegetaux_superieurs_jean_marie_savoie.pdf

Plant morphology

Plant morphology: part of botany which describes the shape and external structure of plants and their organs (Figure 75). The morphological diversity results from the expression of genotypes influenced by the environment. The main difference between plant species lies in their morphology. The morphology is determined by many factors among which are the genetic factors.

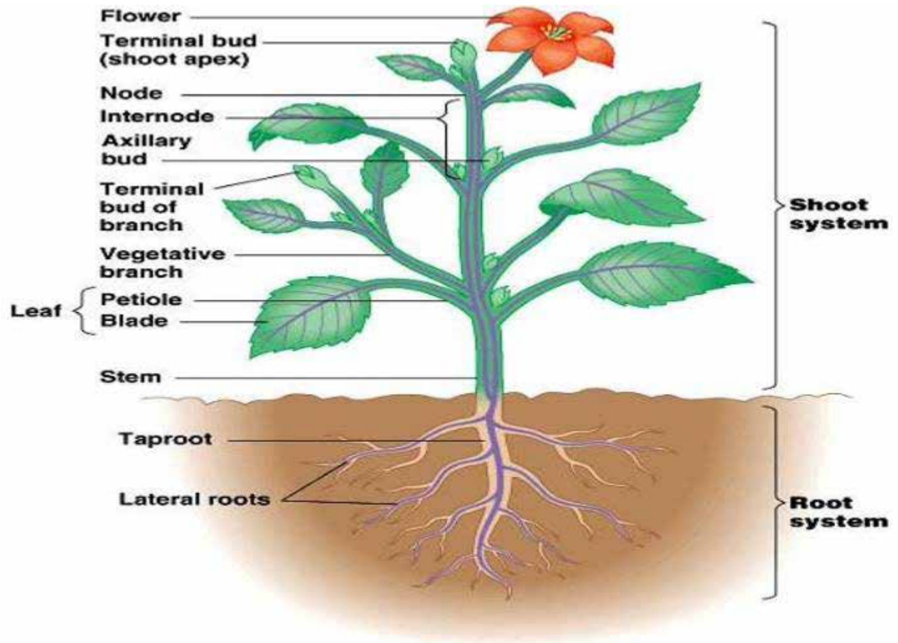


Figure 75. Plant morphology.
Source: http://image.slidesharecdn.com/plantmorphology-110809031433-phpapp01/95/plant-morphology-2-728.jpg?cb=1312859858

Systematics of higher plants

Systematics of higher plants refers to the study of biological diversity. The aim of its study is the reconstitution of plant phylogeny (study of kinship relations between living organisms). Systematics highlights the evolving relationships between various organisms. It includes taxonomy which is the science of describing living organisms and grouping them into entities called taxa in order to identify, name and classify them. Systematics organizes the classification of taxa and their relationships[14].

14 Systematics of higher plants: classification, definition of species http://ecologieenvironnement.blogspot.com/2015/01/systematique-des-plantes-superieures.html

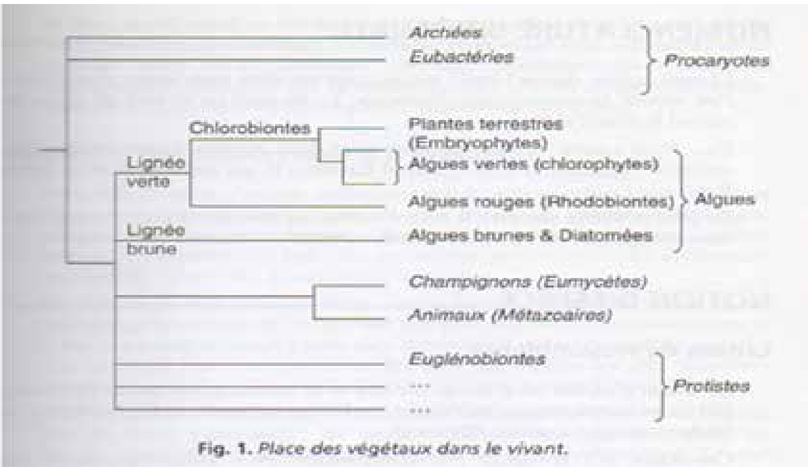


Figure 76. Systematic of higher plants, definition and classification of species.
Source: http://ecologieenvironnement.blogspot.com/2015/01/systematique-des-plantes-superieures.html

Prokaryotic organisms (Archaea and Eubacteria) are at the origin of two lineages:

- a green lineage characterized by the presence of chloroplasts that includes red algae or Rhodobiontes which chlorophyll is masked by phycoerythrin and Chlorobiontes (chlo. a and b) including green algae and terrestrial plants; and,
- a brown lineage of Ochrophytes (fucoxanthine) with brown algae or Diatoms.

Some Ochrophytes have secondarily lost their photosynthetic pigments and behave like mushrooms (a sibling group of Choanoflagellates and Sponges) and are therefore closer to animals than plants. Euglenobiontes = Protists (paramecium or amoeba).

Branch, Class, Order, Family, Genus, Species

Each of the major groups corresponds to different evolutionary lineages.

- Each of them is a clade of the Greek Klados = branch constituted by the common ancestor and its descendants.
- Some are monophyletic (from 1 lineage) e.g: Chlorobiontes common ancestor unknown.
- Some are polyphyletic e.g.: Algae, no direct common ancestor but +++.
- Some are paraphyletic e.g.: green algae, because they include only part of their descendants.

Classification of living organisms in hierarchical categories

High level divisions are called branch or phylum, which are subdivided into S-branch, classes, S-classes, Orders, Families. All these divisions are called taxa. The ending letters are used to figure out levels of classification e.g.: ales for orders, aceae for families. The species is the basic systematic unit in the botanical nomenclature.

Methods of phylogenetic systematics

Methods include: comparative morphology, comparative anatomy, palynology, phyto-paleontology, phytogeography, comparative biochemistry, chemo-taxonomy, nucleic acid sequencing, numerical and computer taxonomy, cladistics, and phylogenetic tree. The phylogenetic or cladistic classification is based on morphological, anatomical, cytological and molecular characters (RNA, DNA, proteins).

Box 14. Classification guidelines

The classification guideline includes:

- constitution of clades comprising the common ancestor and its descendants;
- formation of trees whose branches are separated by means of progressive innovations;
- comparison of amino acids and RNA to form clades or monophyletic taxa (having the same common ancestor); and
- demonstration of polyphyletic groups (derived from 2 or more ancestors).

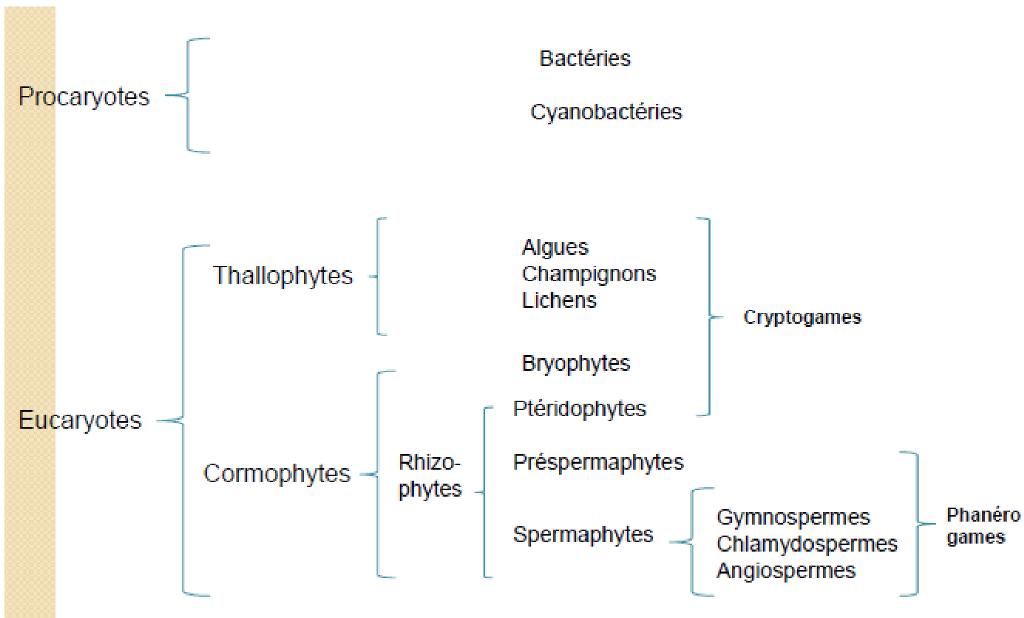


Figure 77. Classical representation of the plant kingdom (morphological and anatomical bases, then cytological and biological bases).
Source: Office de l'environnement de la Corse (2012)

Reproduction modes

Sexual reproduction involves two fundamental processes: meiosis and fertilization. During the fertilization, the union of two haploid gametes results in a diploid zygote (n $_{2}$ 2n) whose genetic heritage is the result of the random recombination of the two parental genomes originated from the gametes[15].

Conversely, during the meiosis process, the diploid chromosome stock is divided into two numerically equal parts (2n> n), but qualitatively different. Individuals from sexual reproduction are the result of a double genetic mixing. These are original individuals, genetically unique; some will be better adapted to a new environment than others. Sexual reproduction is thus the real engine of the evolution of living organisms and allows the creation of new species[16].

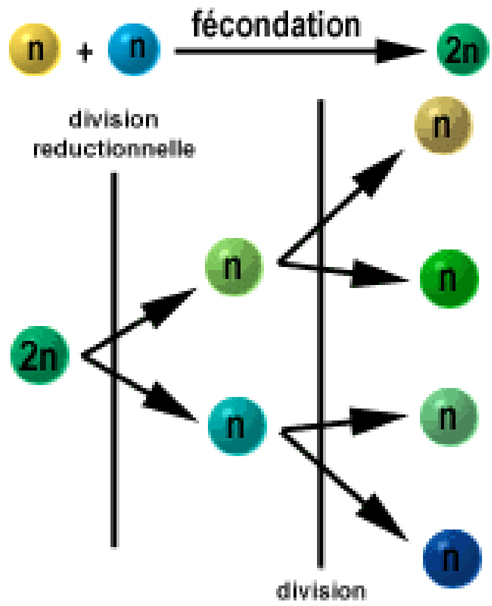


Figure 78. Fertilization.
Source: http://www.creaweb.fr/perso/bv/cellule.html

Box 15. Step of sexual reproduction cycle

The steps of sexual reproduction are:

- pollination (transport of pollen from the anther of the stamen to the stigma of the pistil);
- fecondatotion (union of a male cell and a female cell);
- fructification (formation of a fruit bearing seeds); and
- germination (development of the embryo within the seed and emergence of roots and stem).

15 Plant characteristics, the plant cell: http://www.creaweb.fr/perso/bv/cellule.html
16 Plant characteristics, the plant cell: http://www.creaweb.fr/perso/bv/cellule.html

In asexual reproduction, an individual derives from the development of a vegetative part of a parent plant (stem, root, leaf). These fragments give back identical individuals to the mother plant. Vegetative multiplication involves only one genome which is identical in all derived individus, and there is formation of a clone.

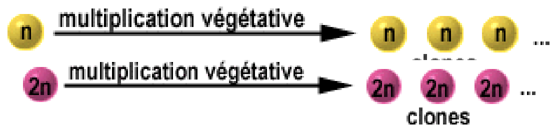


Figure 79. Formation of clones.
Source: http://www.creaweb.fr/perso/bv/cellule.html

Types of asexual reproduction: cell division (splitting of the cell in two), budding (development of a new individual from an outgrowth of a parent's body), layering (technics of increasing the density of certain shrubs, low branches near the ground reproduce roots thus forming new shrubs), cuttings (fragments of organisms produced naturally or artificially capable of producing a new complete individual).

Educational activities (exercise and case studies)

From the basic information presented in the course and others from the literature, make an executive summary based on the following questions:

- What are the major groups of plants and their characteristics?
- What is the morphological diversity of plants? Explain and summarize?
- What do you know about the systematics of higher plants? Analyze and summarize the different evolutionary lineages.
- What are the methods of phylogenetic systematics?
- What are the modes of reproduction of plants?

5.1 Zoology

Objective

By the end of the session, the learner will be able to:

1. Determine the diversity of animals and how they reproduce.

General introduction

Zoology is the branch of natural sciences dedicated to the study and classification of animals. Its fundamental purpose is to make an inventory of animal forms for a methodical classification and analyzis of their structure, development, and relations within themselves and with the surrounding environment.

Animals are very diverse. Their size can vary from 0.1mm to a few tens of meters. Their lifespan varies from a few days to a century. They are found in all habitats, ranging from mud to the peaks of the highest mountains. Despite these differences, they have several things in common: they probably come from the same ancestor, basically have the same needs and face the same environmental constraints. There are currently 1,500,000 known animal species, but it is estimated that there may be 5-30 times more because of those unrecorded. Three main habitats host them: the marine, freshwater and terrestrial environ-ments. Constraints related to their sruvival are related to these different environments.

Major groups of animals

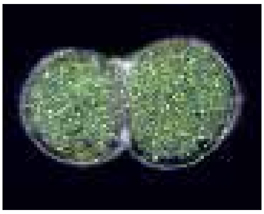
Systematics is the branch of biology that deals with the classification and scientific name of organisms. It is based on the grouping of species sharing certain anatomical similarities and coming from the same evolutionary lineage. The classification of animals by branch based on general characteristics is as follows.

Arthropoda (insects, spiders, crabs)

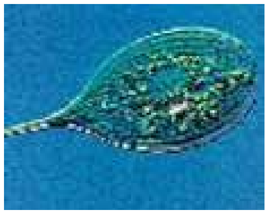
The arthropods, from the Greek arthron "articulation" and podos "foot", are a branch of invertebrate animals whose organizational line is characterized by a segmented body formed of heteronomous metamers each provided with a pair of "articulated" appendages and covered with a cuticle or a rigid carapace, which constitutes their exoskeleton, in most cases consisting of chitin. Moulting allows, by periodically changing their exoskeleton, to grow in size (growth molting) or acquire new organs or change shape (metamorphosis molting). They appeared 540 million years ago.

The branch of arthropods is by far the one with most species and most individuals in the whole animal kingdom (80 % of the known species). There are more than one and a half million living species of arthropods presenting the most varied lifestyles (ecological guilds), probably thanks to their stigmatization. Arthropods are a cosmopolitan group which has adapted to natural environments (deserts, forests, abysses, mountains, etc.) or anthropo-genic ones (housing, oil wells, etc.)

and are among the first animals to have colonized land. Microarthropods are the smallest of them. Although discreet, those of them that decompose play an essential role in trophic networks by ensuring the recycling of necromass, especially in the soil where together with fungi, they contribute to the production of humus[17].


Cyanobacterium


Giant crab

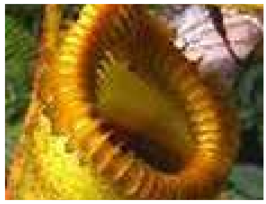

Protozoa


Lymphocytes

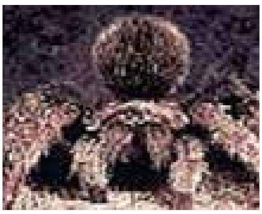

Starfish


Mite


Orca Keiko


Carnivorous flower


Lotte

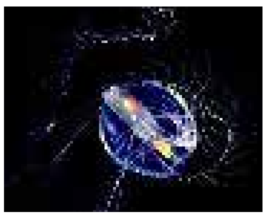

Tarantula

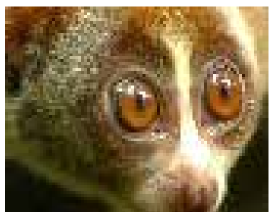

Toucan


Saw shark


Sea turtle


Emperor


Ctenophore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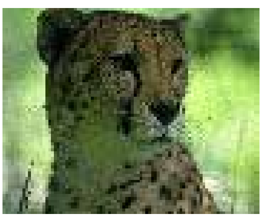
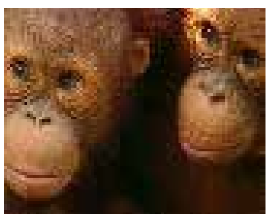

Cheetah


Jellyfish


Orang-Outang


H.s.sapiens

17 https://fr.wikipedia.org/wiki/Arthropode

Figure 80. Arthropods of different classes: a trilobite , an eurypteride, a scorpio, a crusta-cean, a myriapod and an insect.
Source: https://fr.wikipedia.org/wiki/Arthropode

Mollusca (snails, mussels, octopuses)

Molluscs (Mollusca) are a branch of lophozoan animals. They are non-segmented, with a bilateral symetry sometimes altered. The body usually consists of a head, a visceral mass, and a foot. The visceral mass is covered wholly or partly by a mantle, which secretes a calcareous shell. The nervous system comprises a double periosophageal collar. The general cavity is more or less reduced to the pericardium and the nephridia. The branch of molluscs (Mollusca) derives its name from Latin mollis, “soft”. The science devoted to the study of molluscs is malacology, from the Greek equivalent malakos, “soft.”

In phylogenetic classification, molluscs are coelomatic, triploblastic metazoans (the terms “coelomate”, “acœlomate” and “pseudo-coelomate” were recently removed from the classification), prototomic bilaterals; the main synapomorphies of this clade being the presence of a radula and a mantle. The mollusc’s branch contains more than 130 000 species, among which some are often consumed by humans. Some molluscs secrete pearls by covering with mother-of-pearl the irritating elements that enter into their shell. Molluscs or their shells (and their pearls in some cases) are used for different purposes, including food for human consumption since prehistoric period.

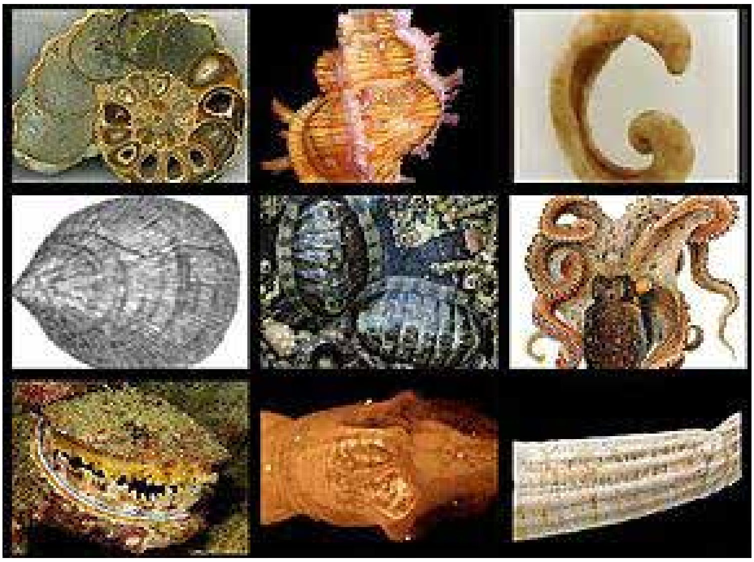


Figure 81. Examples of different classes of molluscs.
Source: https://fr.wikipedia.org/wiki/Mollusca

Nematoda (Ascaris)

Roundworms are a branch of non-segmented worms. Classified as ecdysozoans, they are covered with a thick cuticle. They live a type of "open life" (in soils, water, sediments, deadwood and other forms of necromass where they are detritivores or micro-predators). Many species have a parasitic life, within fungal organisms, plants or animals. In the latter case, they are most often gastrointestinal parasites, but some species colonize different types of tissues, including muscle). Among the parasitic forms, there are worms whose cycle does not require an intermediate host (monoxenous development), and others requiring two hosts (tenenes), in particular wires[18].

Figure 82. Ascaris (*Ascaris lombricoïdes*)- Chordata (Mammals, birds, fish, reptiles)

18 https://www.google.com/#q=Nematoda

Chordates are a branch of bilaterial deuterostomian animals. Thee are three sub-branches: Cephalochordata, Tunicata and Craniata containing Myxines and Vertebrates. The latter two groups are sometimes classified under the taxon Olfactores.

Figure 83. Chordata from different classes.
Source: https://www.google.com/#q=Nematoda

Platyhelminthes (Solitary Worm)

Platyhelminthes are flatworms containing many species which are parasites. This branch mainly consists of worms which are elongated animals without appendix. The best-known worms in the Turbellaria class (flat worms that are not exclusively parasitic) are planar, free worms, swimmers or creepers, whose body thickness can be less than one millimeter. They are bilaterally symmetrical and belong to the former category of aco-lomates (they do not possess a general cavity: neither coelom nor pseudo-coelom), it appears that the absence of coelom is due to regression of it. The only trace of it remaining visible is their mesen-chyme. The digestive tract has an opening (mouth). They also have complex genitalia and can reproduce in a sexual way (the planar ones are hermaphrodites, cross fertilization is the mode of reproduction) or by scissiparity. Their body is extremely fragile; they are able to regenerate their amputated parts, including the head, which contains an organized network of neurones. They are complex organisms, capable of memorizing. The elements in their memory remain unchanged after decapitation and regeneration of the head [19].

19 https://fr.wikipedia.org/wiki/Platyhelminthes

Figure 84. Pseudobiceros bedfordi, a turbellar flatworm.
Source: https://fr.wikipedia.org/wiki/Platyhelminthes

Annelida (Earthworms, leeches)

Annelids are vermiform metamerized protostomic animals, in other words “worms”. They live mainly in water (seawater like gravette or freshwater like leech) although some species like earth-worms live in the soil. The three major classes are:

- Polychaetes which have an indirect post-embryonic development with larva (trocho-phore) and metamorphosis, and whose body is covered with numerous bristle (e.g. arenicola);
- Oligochaeta, showing less abundant bristle (e.g. earthworm); and,
- Achaeans, devoided of bristles (e.g. leeches).

Oligochaetes and Achaeans can be grouped in the category of Clitellates which have a direct post-embryonic development. Some polychaete annelids (syllidians) are able to perform asexual reproduction by splitting in two and regenerating the missing parts. Many clitellate annelids are hermaphrodites (earthworms, leeches). Some annelids in the tidal swing area have a tube life: in limestone tubes (spirorbe, Pomatoceros) or membrans (spirograph, sabelle), sometimes covered with agglomerated sand grains (Lanice conchilega). Others like Arenicola marina whose hemoglo-bin could be used as human blood substitute, dig tunnels in the sand [20].

Figure 85. Earthworm *(Oligochaeta, Lumbricina)* (left) and leech *(Haemopis sanguisuga)*, from the Order Arhynchobdellida (right).
Source: https://fr.wikipedia.org/wiki/Annelida

20 https://fr.wikipedia.org/wiki/Annelida

Cnidaria (Jellyfish and polyps)

The cnidaria, or branch of the Cnidarians, are relatively simple animald, specific to the aquatic environment (marine 99%, fresh water 1%). The name comes from the ancient Greek κνίδη (knidē, “nettle, urticant”), referring to the urticating cells, characteristic of these animals (the cnidocytes or cnidoblasts), the vernacular name of “sea nettles” being given by Aristotle who groups together the Acalephes (jellyfish) and the Coralliaires. The term coelenterata (Coelenterata or Coelentera) once referred to this group but also includes the nearby branch of the ctenophores. Cnidarians are well represented in fossils: they are found even in the Cambrian and possibly even in the fauna of Ediacara. Cnidarians exist in two forms: fixed forms or polyps (coral, sea anemone) and free and mobile forms (jellyfish). There are over 10,000 known species[21].

Figure 86. *Chrysaora quinquecirrha* (left) and *Arachnanthus nocturnus* (cérianthe Penicilaria) (right).
Source: https://fr.wikipedia.org/wiki/Cnidaria

Echinodermata (sea urchins , starfish)

Echinoderms (Echinodermata) form a branch of benthic marine animals present at all oceanic depths, and whose first fossil traces date back to the Cambrian. They currently include five classes: starfish (Asterids), sea urchins (Echinidae), sea cucumbers (Holothurians), Crinoids and Ophiures (Figure 87). Several thousand species of extinct echinoderms have been recorded by paleontologists; their calcified skeleton generally allowed a good fossilization. The representatives of this group are original and possess a number of unique characteristics among animals. The main ones are a general symmetry pentaradied (central symmetry of order 5, although they remain bilaterian), the existence of a skeleton consisting of calcite plates pierced with numerous channels (stereomic structure) and the presence of an aquifer system. They are very close to the chordates group within the deuterostomists[22].

21 https://fr.wikipedia.org/wiki/Cnidaria
22 https://fr.wikipedia.org/wiki/Echinodermata

Figure 87. Different echinoderms: crinoids, starfish, rittle stars, Sea urchin, sea cucumbers.
Source: https://fr.wikipedia.org/wiki/Echinodermata

Porifera (sponges)

Sponges (Porifera) are animals forming the basal branch of metazoans. They are defined as sessile metazoans. Inhalant and exhalant pores connect to a chamber containing choanocytes, which are flagellate cells characteristic of sponges. Choanocytes are heterotrophic cells. The body of sponges is a non-living mass between two layers of cells: the pinacoderm that lies outside and the choanoderm inside. Their nervous system is very primitive and diffuse.

In the history of biology, they have been considered as a plant for a long time. The geographical distribution of the sponges is very wide, as they have colonized the marine waters, soft and brackish, from low depths to more than 5,000 m depth, in all climates. They have an important role in the filtration of water.

Sponges are exploited by man for their ability to absorb liquids. The skeleton of the demosponges is used as an object for the hygiene, in surgery, for the tanning of leathers and ceramics. They have recently been shown to hold exceptional diversity of microbial or microalgal endosymbiotes[23].

Figure 88. *Aplysina archeri.*
Source:https://www.google.com/#q=Porifera

23 https://www.google.com/#q=Porifera

Reproduction and conservation of wildlife and pastoralism

Natural reproduction of wildlife

Mating is the sexual relationship between a male and a female of the same species, allowing sexual reproduction. The term hermaphrodite refers to a living being that has both a male reproductive system and a female reproductive system. The characteristic stage of sexual reproduction is fertilization: the fusion of a male gamete, or spermatozoa, and a female gamete, or ovum, leading to a cell-egg = zygote. The union of the nucleus of the spermatozoa with the nucleus of the ovum brings together at random chromosomes of paternal and maternal origin.

The multiplication and organization of cells derived from the egg-cell (or zygote) is the embryonic development or embryogenesis. In sponges, cnidarians, caryans, and mesozoans, the animal remains at the two-layer stage. In most animals, the next stage of embryonic development is the formation of a third layer, the mesoderm or mesoblast. The three-layer animals are called triploblastic.

Viviparous are animals that give birth to living cubs. This is the case for most mammals, some reptiles and some cartilaginous fish. Oviparity is when an animal reproduces by laying eggs; the eggs hatches and gives new individuals. This is the case of many vertebrates: birds, most reptiles and fishes, and amphibians.

Assisted reproduction and wildlife conservation

Assisted reproduction techniques are a formidable means to genetically enhance a wild population. They are based on a good planning of remotely couplings; consanguinity should be avoided because it is source of biological regression. Encouraging reproduction is essential to support the conservation of endangered species. This original approach aims at providing concrete and valuable support to species conservation strategies.

The loss of genetic variability is now one of the main factors of animal species decline, especially when populations are shrinking and become fragmented due to the expansion of human activities. The consanguinity resulting from this genetic thinning out induces numerous deleterious effects: decrease in the adaptation to the environment, increased susceptibility to infectious diseases, decreased fertility and increase of congenital malformations. Due to this, IUCN mentions among the conservation strategies to be developed, assistance to reproduction, and in particular artificial insemination. The latter has a vital role to play when many species are highly fragmented. They are no longer made up of small sub-populations scattered with no chance of meeting for natural reproduction. The causes of this fragmentation are multiple but unfortunately often irreversible: decline of the species, downsizing, fragmentation of habitat, expansion of agricultural land, urbanization, setting up of fences preventing or limiting the search of sexual partners.

Consequently, assisted reproduction becomes very useful for restoring genetic exchanges between distant populations and reducing the risk of consanguineous depression. This technique makes it possible to maintain the gene pool of small populations, by inseminating females with seed of males that are genetically different to infuse new genes into weakened and declining populations. It is less dangerous, less expensive and more convenient to transport and use seed than to transport and introduce live animals (Cresam, 2007).

Pastoralism and wildlife

It is well-known in nature conservation that the coexistence of livestock with large wild fauna leads to a reduction in wildlife population. There is competition between the two that exploit similar ecological niches and exhibit the same pasture behavior. Domestic livestock may affect wildlife with contagious diseases and vice versa. In the relations between livestock and wildlife, wildlife sometimes constitutes a source of epidemiological risk. Wildebeest in Tanzania are suspected of being the source of tick-borne diseases, which become more dangerous in case of cohabitation with cattle herds (Homewood and Rodgers, 1984).

Based on the fact that the ecology of pastoralism and that of fauna are interwoven and historically compatible, development plans integrating wildlife conservation and socio-economic development of pastoralists have been implemented, for example in the wetlands of Amboseli (Western, 1982).

Educational activities (exercise and case studies)

- From information presented in the course and other sources from the literature, make an executive summary.
- Analyze and provide comments on the study of animals in terms of diversity, structure, behavior, reproduction, development, origin, distribu-tion and relationships of animals with their environment.
- Briefly describe the different disciplines that zoology calls for.
- How do you analyze the links between conservation and pastoralism?
- What are the positive and negative effects of cohabitation between livestock and wildlife?
- What are the effects of pastoralism on flora and fauna?
- Present a case study on livestock development around a protected area.
- Which strategies can be implemented to reconcile pastoralism and conservation?

5.2 Applied ecology

Objectives

By the end of the session, the learner will be able to:

1. Describe pollution-related problems and their ecological implications
2. Explain the mechanism of deforestation and soil erosion.

General Introduction

The destruction of forests, soil erosion, desertification, depletion of sea fisheries, scarcity of raw mineral materials, the energy crisis, and environmental pollution are all evidence that human civilization is having an increasingly strong and negative influence on the biosphere (Romade, 1995). Degradation of the biosphere not only threatens aesthetic wealth of the earth, rare flora and fauna elements, but also human survival.

In response to these challenges, an international awareness led to the creation of IUCN and the publication of the Brundtland report under the guidance of UN. This is dedicated to draw the attention of heads of states from around the world to the urgent needs of implementing an active policy for the conservation of nature and its resources (Cresam, 2007).

Pollution issues and ecological implications

Air pollution

Industry and traffic development is accompanied by the release into the atmosphere of increasing quantities of smoke, toxic gases and other pollutants. The increase in energy production, metallurgical industry, cement works, road traffic, garbage incineration, fermentation of organic matters are included in air pollution (Ramade, 1995).

Due to the relatively low rate of industrial development in Africa, air pollution is not as severe or widespread as in other parts of the world. However, in the most crowded cities of the continent, continuous exposure to polluted air through a congested road traffic represents a real health risk. In rural areas, the pollution resulting from the combustion of biomass release a large number of harmful particles into the atmosphere, contributing to the increase and the development of respiratory problems and allergies (UNEP, 2008).

Figure 89. Bush fire in Guinea

Figure 90. Air pollution in Cotonou

Box 16. Effect of air pollution on forest ecosystems

Nitrogen deposits in the form of nitrate or ammonium resulting from air pollution are harmful to forest ecosystems.

Excessive accumulation of nitrogen in soils and vegetation can have toxic effects, harmful to plants, soils, and microbial interactions. This "nitrogen saturation" can lead to loss of fertility, decline in primary production, and even death of trees (Aber et al., 1998).

Nitrogen inputs in the form of HNO_3 and NH_4^+ releases H^+ which causes soil acidification, removing nutrients such as calcium and magnesium, and mobilizing aluminum which is toxic. The same applies to H_2SO_4 the deposit.

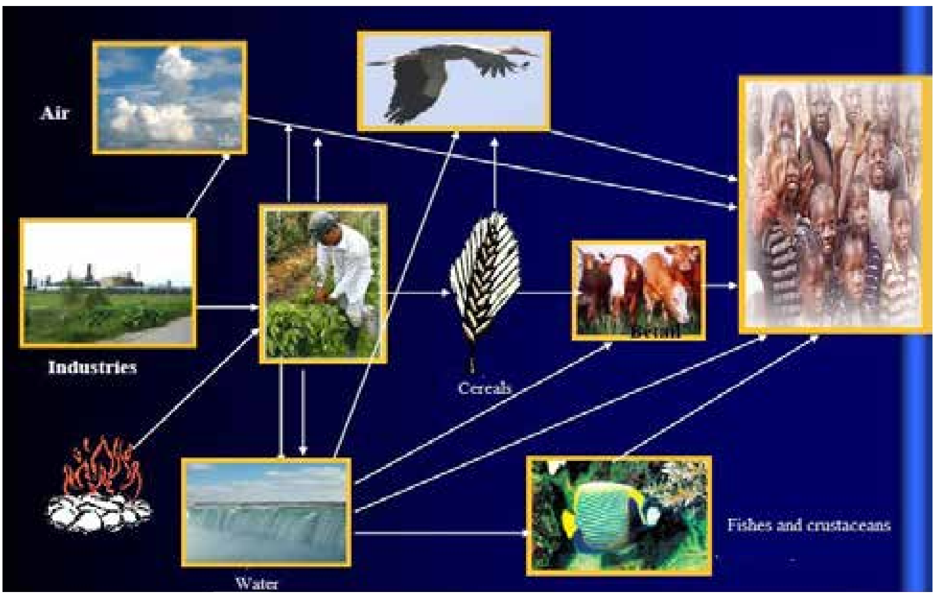


Figure 91. Air Pollution.
Source: http://slideplayer.com/slide/3810987/

Soil pollution

Intensification of agriculture and increasing use of artificial substances (chemical fertilizers, pesticides, etc.) are leading to contamination of cultivated soils. Chemical pollution accompanied by their local overload of excessively fermentable organic products ineluctably undermines the long-term soil fertility. The current practices of over-fertilization with mineral fertilizers, combined with the poor recycling of organic matter in cultivated soils pose a serious threat to soil fertility in the long term. This threat results not only from the continued accumulation of metals and toxic metalloids in the form of impurities in chemical fertilizers but also from changes in soils structure.

Box 17. Effects of soil pollution

The pollution of the terrestrial environment by pesticides will result in various ecological disturbances which derive from the contamination of aerial parts of plants and soil. These disturbances can be:

- biocoenotic upheavals or breakdown of biological equilibria;
- changes in ecosystems;
- changes in the vegetation cover of agroecosystems;
- some species mortalities; and
- the dimunitions of biotic potential.

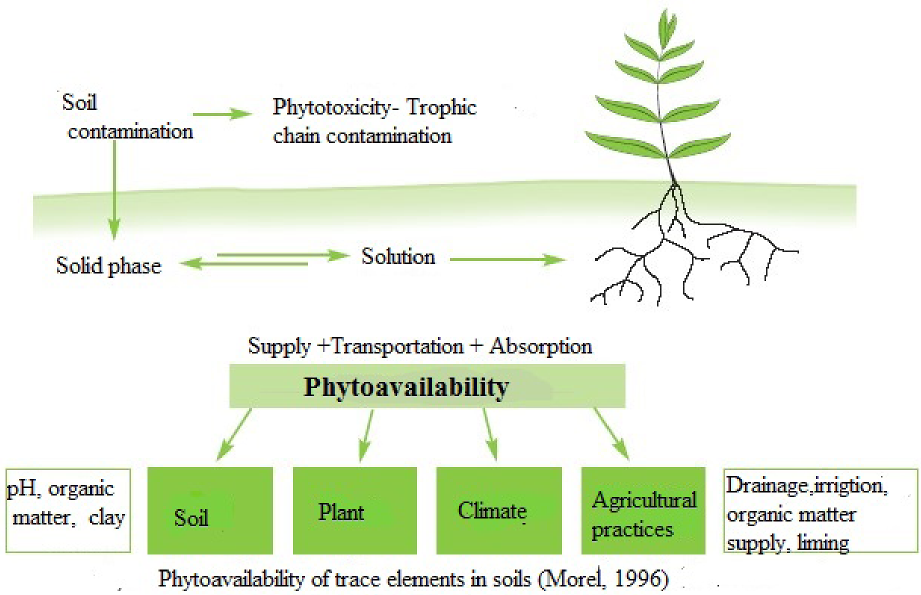


Figure 92. Soil pollution.
Source: https://basoooma.wordpress.com/design-for-social-change/soil-pollution-pictures/

Box 18. Effects of continental and oceanic waters pollution

The release of organic pollutants into watercourses causes a disturbance of the ecosystem, which results in the formation of a degradation zone (mixing water and the effluent), a decomposition zone (fungi and bacteria multiply to decompose the organic matter) and a septic zone (formation of reducing compounds after consumption of all the oxygen).

The eutrophication of lakes results from an increase in the fertility of the lake's waters by addition of nutrients, especially phosphate and nitrate, which promote the proliferation of phytoplankton and aquatic plants. Gradually, this process accelerates sedimentation: the lake becomes smaller and eventually disappears (Romade, 1995).

Phytoplankton and macrophytes are variously affected by water pollution depending on the contaminant. Many pesticides, in particular all herbicides, are highly toxic to phytoplankton.

Box 19. Pollutants

The major pollutants are gaseous (air pollutants, sulfur dioxide (acid rain), nitrogen oxides, CO_2, CO), solid (particles/aerosols, hydrocarbons, aldehydes, SH_2, lead, waste, heavy metals, nitrites, pesticides, organic materials), and liquid (domestic and industrial wastewater).

Major causes of pollution include energy production, industrial activities, traffic, agriculture, and population growth.

There are many types of pollution including physical pollution (mechanical, thermal, radioactive radiation, noise and low-frequency vibration); chemical pollution (gaseous derivatives of carbon and liquid hydrocarbons, detergents, plastics, pesticides and other synthetic organic compounds, sulfur derivatives, nitrogen derivatives, heavy metals, fluorides, solid particles, fermentable organic materials); biological pollution (bacteria, viruses, zooparasites, untimely introduction of animal or plant species); and aesthetic nuisances (wild urbanization, establishment of industry in biotopes).

Impacts of pollution of terrestrial and oceanic waters.

Biological water pollution results in high bacteriological contamination. The use of streams as a means of diluting urban effluents affects public health. Pollution by organic matter allows many species of pathogenic germs to multiply.Mineral water pollution results from the release into urban effluents of various compounds such as nitrates, phosphates and other salts used in agriculture, and various residues from industries. Water can also be polluted by synthetic organic substances. The production and use of chemical products in agriculture is a serious threat to the hydrosphere (Ramade, 1995). Plastics are a widespread contaminant in rivers and marine environment in Africa. See boxes 18 and 19 above.

Deforestation

Deforestation is the most obvious form of land conversion in Africa. Forests and woodlands provide many ecosystem goods and services (building materials, food, energy, drugs, river protection, soil protection, habitat, grazing, water quality, river flows regulation) contributing to economic and social development (UNEP, 2008). At an international level, African forests and woodlands are recognized for their role in climate regulation and biodiversity maintenance (UNEP, 2006c). Forest exploitation, land conversion to agriculture, over-grazing, forest fires, exploitation of firewood and coal, mining, urbanization, implementation of infrastructure projects and civil wars are the main causes of deforestation (UNEP, 2008).

In Africa, many factors contribute to the degradation of rich and diverse biomes. The practice of shifting cultivation is a major cause of deforestation in Africa. The reduction of fallow periods leads to soil depletion and accelerated erosion. Industrial crops (cotton, palm, rubber, coffee, cocoa) are devastating forest ecosystems. For example, in Ghana the cultivation of cocoa and other industrial plants reduced the forested area by 85 % in about fifty years (Ramade, 1995). In East Africa, the expansion of plantations of tea, coffee, pineapple and other export crops was done at the expense of old deciduous tropical forests.

The conversion of forests to agricultural land is needed for food production but the impacts of deforestation as practiced threaten ecosystems and result in the loss of natural habitats (UNEP, 2008). The global carbon cycle is also disrupted: when a tree is cut, the carbon is released into the atmosphere (by combustion or decomposition), enters the atmosphere as CO_2 and contributes to global warming (Willcocks 2002).

Box 20. Effect of deforestation

- Ecosystem changes and habitat loss.
- Disruption of the global carbon cycle.
- Agricultural land degradation and change in productivity.
- Climate chane
- Resurgence of diseases

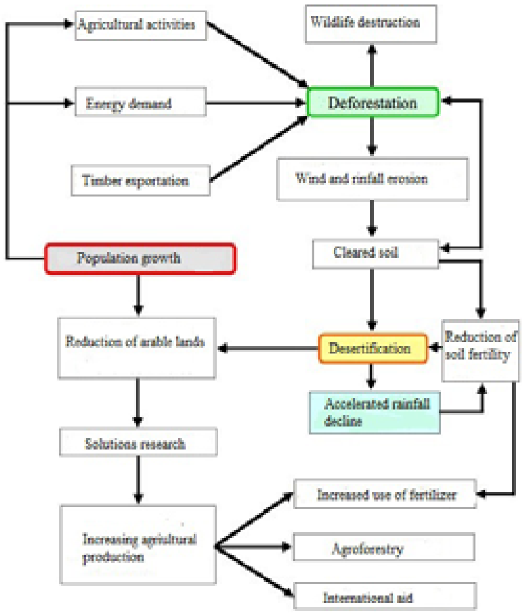


Figure 93. Diagram of the sources of deforestation

Soil erosion

Erosion is a natural phenomenon, caused by wind and water, and expressed on all land areas. Erosion leads to a redistribution of soil particles. All soils are subject to erosion which may have various origins. In agriculture, soil erosion refers to the thinning of the topsoil of a field under the effect of natural erosive forces of water and wind, or under the effect of agricultural activities, such as tillage (Ritter, 2015). Other causes that accelerate the phenomenon of erosion are soil compaction, depletion in organic matter, structure degradation, poor internal drainage, problems of salinization and acidification.

Water erosion is a natural mechanism that carries away soil particles from high altitude areas to lower areas where they will sediment depending on the speed of water flow and density (Villeneuse, 1998). Water erosion is caused by moving water. Its extent depends on the intensity of rain and runoff, soil erodibility, slope and its length, crops and vegetation as well as cultural practices.

The risk of erosion is higher as the duration of rainfall gets longer. The impact of raindrops on the soil surface can break up the aggregates and disperse the soil particles. The lightest particles, including very fine particles of sand, silt, clay and organic matter, are easily washed away by rainwater splashing and runoff (Ritter, 2015). The erodibility of a soil is an estimation based on its physical characteristics and of the soil's vulnerability to erosion. The erodibility is influenced by texture, structure, organic matter content and permeability. Water erosion increases with the length of the slope due to increased runoff. As the flow of water becomes faster, sediment transport increases, leading to increased risks of erosion.

The risk of erosion increases if the soil is not sufficiently covered by the vegetation and/or a layer of crop residues. Residues and vegetation protect the soil from the impact of raindrops and splashes of water. They also tend to reduce the water flow rate and promote infiltration into the soil.

Water erosion is influenced by cropping practices, including the depth of the tillage, its direction, the time of plowing, the type of agricultural materials used and how many times the soil is subject to farming operations.

Box 21. Forms of water erosion

Sheet erosion: usually occurs in an equal manner on a uniform slope and goes unnoticed until the topsoil has been removed.

Gutters erosion: occurs when runoff come together and form nets or gutters.

Gully erosion: advanced stage of erosion in gullies characterized by a deep indentation of the soil with the formation of a depression.

Bank erosion: wearing away of the banks of a stream or river.

Wind erosion. Under favorable conditions, wind erosion can cause considerable land and soil losses. There are three types of wind erosion: suspension (blowing of tiny particles into the air where they may be carried for long distances) saltation (repeated lifting and dropping of slightly larger particles) and creeping (movement of particles too large to lift along the ground). The type varies depending on particle size and wind power.

The speed and extent of wind erosion depends on soil erodibility, soil surface roughness, climate and vegetation cover. The erodibility of the soil is defined as the natural process by which wind, moving water, ice, and gravitational forces displace the solid and particulate materials of the land. Smooth surfaces have little resistance to wind in comparison with rough ground. The wind speed and the duration of the windy episode have a direct effect on the extent of soil erosion. Moisture levels are very low on the surface of excessively drained soils or during periods of drought, causing particles to be detached and blown away. In the absence of vegetation cover, preventing wind, the latter moves the soil particles over long distances, thereby increasing erosion.

Box 22. Erosion Effects

- Soil nutrient depletion
- Lower productivity of land and pollution of watercourses, wetlands and lakes
- Loss of topsoil and nuisance to its quality, structure, stability and texture
- Ensiling streams, silting of tanks, and damage to aquatic habitats
- Degradation of water quality
- Contamination and pollution of water sources
- Crop damage
- Decreased water retention capacity of the soil
- Degradation of human health
- Permanent loss of fertility and decline in soil biodiversity
- Landslide

Educational activities (exercise and case studies)

- From the basic information presented in the course and others from the literature, make an executive summary.
- What are the pollution problems and their environmental implications?
- Identify sources of pollution for different environments.
- Conduct a systemic analysis of air, water and soil pollution.
- Analyze and explain the mechanisms of deforestation and their effects on other ecosystems
- Prepare a case study on the state of forest resources in an African country
- Prepare a technical sheet on the phenomenon of erosion
- Analyze and explain the effects of different types of erosion on different ecosystems

5.3 Pedology

Objective

By the end of the session, the learner will be able to:

Describe soil genesis and evolution, soil fertility issues, and long-term fertility management.

General introduction

A soil is an alteration film covering a rock, composed of mineral and organic matter (humus). It originates from the rock and then evolves under influence of environmental factors, mainly climate and vegetation. Pedology is the study of soils (Beauchamp, 2008). The inventory of soils allows the generation of knowledge about them. It makes it possible to characterize soils from the point of view of their biological, physical and chemical properties, by showing their relative importance and their distribution over a territory.

In Africa, the diversity of parent rocks and contrasts in relief and climatic influences give relatively varied soils, divided into many subclasses according to their physical, chemical and biological properties. In Africa where soils are generally fertile, they are often degraded by human actions on the vegetation (bush fires, deforestation, shortening of the fallow period) and on soils (pollution, extractions), and under influence of erosive rainfall.

The preservation of soil resources in Africa depends first and foremost on improving knowledge of the state and evolution of soils, in particular the establishment of an inventory, a land resource planning atlas and the establishment of a harmonized database on soil physicochemical and biological parameters. Subsequently, capitalizing on this knowledge will enable better management of soil resources, rehabilitation of degraded lands, and restoration of soil fertility and management of agricultural land.

Pedogenesis

Structure and evolution of soils. In a temperate climate, when a rock is visible on a surface, it is gradually altered and colonized by vegetation: plants, herbaceous plants and then trees; the soil is formed. A humus horizon is first established on the altered rock (AC profile, young soil) and then a type B horizon (ABC profile). The depth increases and the soil profile evolves until reaching a state of equilibrium with climate and vegetation. The materials circulate in the soil in the downward direction, by infiltration of the solutions, and in ascending senses, by capillary upwelling and biological upwelling (earthworms, termites in tropical climate, roots) (Beauchamp, 2008). Soil texture is defined by the size of the particles that compose it, gravel, sand, silt, clay. The mineralogical composition of the particles is also related to their size (the coarse ones are mainly based on quartz, the fines based on philo silicates). Figure 94 shows the granulometric composition in three components, figure 95 shows the mineralogical nature and size of the soil particles., and figure 96 shows the trend rate of two soils type under atlantic climat.

Structure is the organization of the soil. The structure is made possible by colloids: clays, humic hydroxides substances. Clays promote soil fragmentation by producing shrinkage slits on desiccation. They can coat other particles and clog pores. They can also fetch organic compounds through absorption on their layers via the oxyhydroxides of Aluminium and Iron which form a film coating. These organomineral (or clay-humic) complexes are agglomerated into aggregates incorporating mycelial filaments and polysaccharide bacteria (Beauchamp, 2008). Figure 97 shows the fixation of the ions on the clay-humic complex.

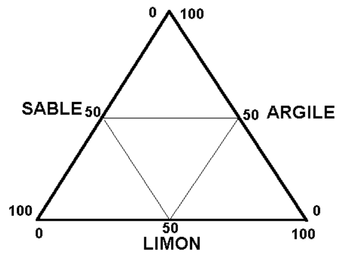


Figure 94. Granulometric composition.
Source: Beauchamp (2008)

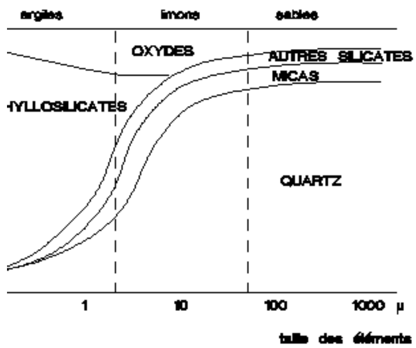


Figure 95. Mineralogical nature and size of the soil particles.
Source: Beauchamp (2008)

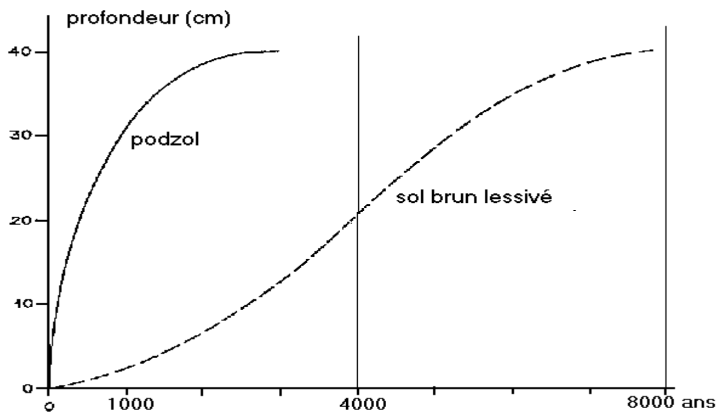


Figure 96. Trend rate of two soils type under atlantic climate.
Source: Duchaufour quoted by Beauchamp (2008)

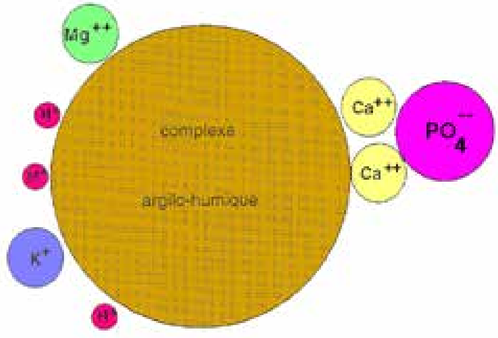


Figure 97. Fixing of ions on the clay-humic complex.
Source: Beauchamp (2008)

There are 3 main types of structures: *particulate* (very loose soil); *massive* (cement-bonded elements); and, *fragmentary*: in aggregate (mn), lumps (cm) or polyhedral, very favorable to crops.

The vegetation provides humus and ensures the ascending circulation of matter; it then protects the rock from erosion. The destruction of vegetation causes the destruction of well established soils or the regressive evolution of soils. Soils evolution-regression cycles take over at short (cataclysms, human action) or long (climate) time intervals. The determining role of climate in rock alteration and soil development has led to the formulation of Erhart's theory of bio-rhexistasis. In wet climates, conditions favor rock alteration, vegetation development and soil formation; the destruction of rocks is limited to chemical phenomena which essentially release soluble ions: this favorable period for life is biostasis. In the dry period, exposed rocks are subjected to mechanical disintegration which produces coarse detrital materials: it is rhexistasis (Beauchamp, 2008).

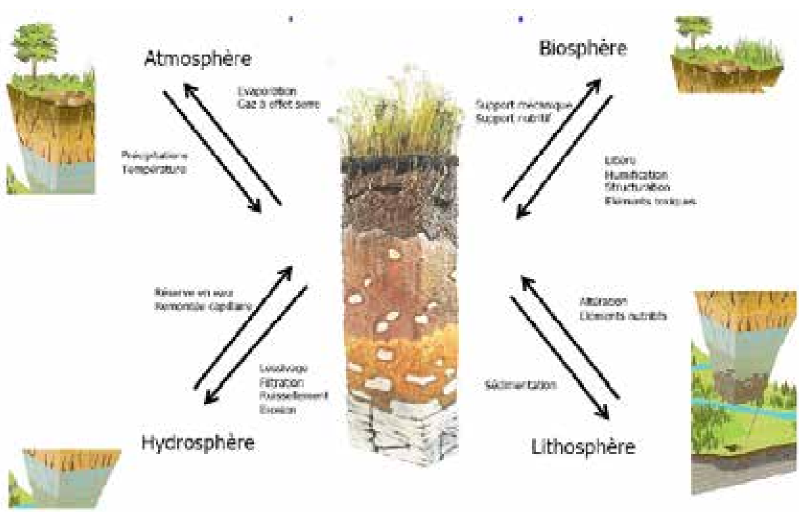


Figure 98. Soil formation processes.
Source: Duchaufour (2001)

Soil fertility

Management of soil fertility. Seven percent of Africa's farmland requires more careful management but has strong agricultural potential. The majority of these areas have one of the four major types of soils. Large concentrations of glossy chernozems occur in Côte d'Ivoire, southern Ghana and Tanzania. In the Democratic Republic of Congo and Nigeria, vast areas of humic andosols are found. Zambia is home to a wide Chernozeme calcium region, while northern Morocco has vast areas of andosol mollic (UNEP, 2008). Many traditional and modern practices can improve soil fertility and climate change adaptation. Improving soil fertility may be considered by agro-ecological zone (Table 8 below).

Some examples of soil fertility improvement approaches are presented below for some agro-ecological zones (FAO, 2003).

Wetlands. Good crop yields and sustainable systems can be achieved in wetlands while maintaining:

- a satisfactory level of organic matter in the soil to mitigate acidity problems, increase the activity of soil microorganisms and maintain appropriate soil structure;
- a sufficient level of nutrients in the soil to allow economic crop yields; and,
- a vegetal cover to avoid erosion.

Sub-humid highlands of East Africa. Here, maintenance and improvement of soil fertility will depend on:

- the use of mineral fertilizers and lime;
- the cultivation of green manure and cover crops; and,
- the use of agroforestry and integrated nutrient management through the collection of manure or other sources of organic matter.

Semi-Arid zone of eastern and southern Africa. The development of water harvesting techniques and soil and water conservation for maximum use of limited rainfall provides the only realistic option to increase the production of food crops in these areas.

Table 8. Characteristics of major agro-ecological zones in sub-Saharan Africa

Areas	Population Projections (millions)			Major climatic features		Major soil types	Dominant vegetation	Production systems
	2000	2010	2025	LGP*	Rain**			
Wet and subhumid regions								
West Africa	215.9	283.9		> 180	> 1000	Ferralsols and Luvisols	Tropical rainforest and forest-savannah mosaic	Itinerant and semi-permanent farming with low levels of inputs. Perennial shrub and tuber crops
Central Africa	64.8	83.2		> 270	> 1500	Ferralsols and Acrisols		Shifting cultivation
Subhumid mountain regions								
East Africa	149		281	180-270	900-1500	Nitisols, Ferralsols, Andosols	Mountain forest and meadow	Permanent and semi-permanent crops with mixed crops and livestock.
Subhumid and semi-arid South Africa								
Subhumid	99		199	120-270	700-1500	Ferralsols, Luvisols, Cambisols	Dry forest-savannah and meadow mosaic	Shifting cultivation, mixed semi-permanent crops.
Dry to Semi Dry	20		41	75-120	250-700	Luvisols and Arenosols	Dry forest-savanna mosaic	Shifting cultivation, mixed semi-permanent crops, pastoralism.
Sudano-Sahelian Africa								
Dry to Semi Dry	102.7***		127.8***	75-120	250-700	Arenosols	Annual sparrow and grass shrubs	Nomadism with complementary mixed production, pastoralism.
Semi arid to Wet				120-180	700-1300	Luvisols and Arenosols	Savannah with deciduous trees and perennial grasses	Partial nomadism, shifting cultivation and mixed semi-permanent production.

Source: FAO, 1986. African agriculture: the next 25 years (adaptation)

* Length of growth period; **Rainfall in millimeters per year; *** Not separated between wet and dry semi arid.

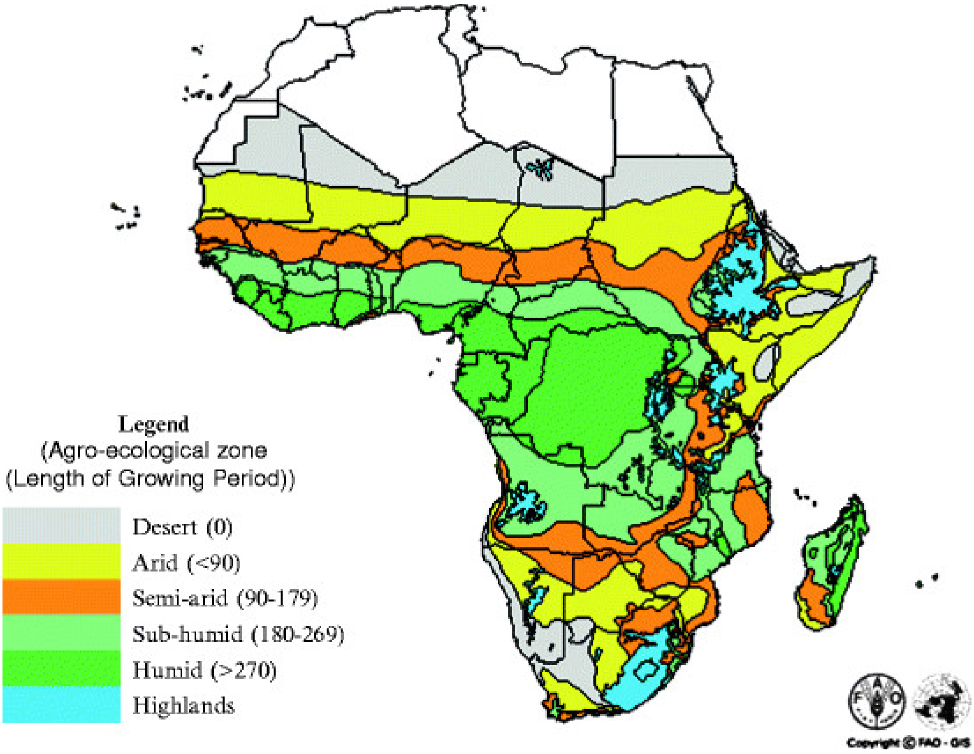


Figure 99. Main agro-ecological zones in sub-Saharan Africa.
Source : https://www.researchgate.net/figure/278687988_fig3_Figure-2-2-Major-agro-ecological-zones-based-on-the-length-of-the-growing-period

Educational activities (exercise and case studies)

- From the basic information presented in the course and others from the literature, write an executive summary in groups of 4-5 on soil fertility, soil horizons formation, soil formation and evolution in Africa.
- Prepare and present a case study on good soil fertility management practices in an African country.

5.4 Hydrology

Objectives

By the end of the session, the learner will be able to:

a) Describe the hydrological cycle and their relative importance.

b) Analyse major water reservoirs, characteristics, distribution use; and,

c) Calculate a water balance.

General introduction

In many parts of the world, water availability and quality are increasingly threatened by overexploitation, misuse and pollution leading to a growing awareness that both aspects are strongly influenced by forests (FAO, 2007). Moreover, climate change alters the role of forests in the regulation of water flows and their influence on water availability (Bergkamp et al., 2003). The relationship between forests and water is therefore critical and deserves close attention.

Forested watersheds provide a high proportion of water used for domestic, agricultural, industrial and ecological purposes in upstream and downstream areas (FAO, 2007). Land, forests and water resources managers have a big task to maximize the wide range of multi-sectoral benefits provided by forests without affecting water resources and ecosystem functions (FAO, 2007). To meet this challenge, it is urgent to improve the understanding of interactions between forests/trees and water, raise awareness and build capacity in forest hydrology, and to integrate such knowledge and research findings into policy (FAO, 2007).

Definition of the hydrologic cycle components

The hydrological cycle is a concept that encompasses the phenomena of movement and renewal of water on earth (Musy, 2005). The components of the hydrological cycle are: precipitations, evaporation, transpiration (of plants), interception, runoff, infiltration, percola-tion, storing and underground flows (Musy, 2005).

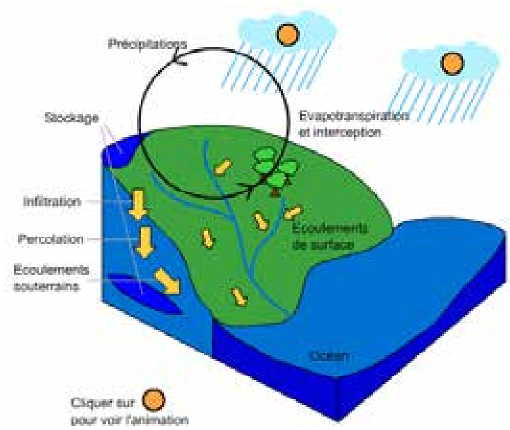


Figure 100. Water cycle.
Source: http://www.physicalgeography.net/fundamentals/8m.html

- **Precipitation** is all water that fall on the surface of the earth, both in liquid (drizzle, rain) and in solid (snow, sleet, hail) form and dropped off or occult precipitation (dew, white frost , frost).
- **Evaporation** is defined as the physical passage from the liquid to the vapor phase. Water bodies and vegetation cover are the main sources of water vapor. Sublimation is the direct passage of water in solid form (ice) into vapor. The main factor governing evaporation is solar radiation.
- **Evapotranspiration** encompasses the evaporation and transpiration of plants. The actual evapotranspiration is the sum of the amounts of water vapor evaporated by the soil and the plants when the soil is at a certain humidity and the plants at a stage of specific physiological and sanitary development. Reference (formerly potential) evapo-transpiration is the maximum amount of water that can be lost in the vapor phase, under a given climate; by a specified continuous vegetation cover (grass) well fed with water and for a healthy growing plant. It therefore includes the evaporation of soil water and the transpiration of the vegetation cover during the time considered for a given land.
- **Interception and storage in depressions.** Rain (or in some cases snow) can be retained by vegetation, then redistributed into one part that reaches the ground and another that evaporates. The part never reaching the ground forms the interception. Storage water is defined as the water retained in the soil hollows and depressions during and after a downpour.

Box 23. Water retention by vegetation cover

The amount of water that can be intercepted varies considerably. If the vegetation has a large basal or leaf area, therefore a significant degree of cover, water retention can reach up to 30% of the total precipitation for a mixed forest, 25% for grassland and 15% for crops (Musy, 2005).

The respective effect of interception and storage in depressions is highly variable and decreases during the downpour. It usually causes a delay in start-up and hydrologic response which can be perceived at the outlet of the basin (Musy, 2005).

- **Infiltration and percolation** refers to the movement of water penetrating the surface layers of the soil and the flow of that water in the soil and subsoil, under the action of gravity and pressure effects. Percolation represents deep infiltration into the soil towards the water table. The infiltration capacity or infiltrability is the maximum water amount that can permeate per unit time in the soil under given conditions. Infiltration is necessary to renew the soil water stock, supply groundwater and replenish aquifers. Moreover, by absorbing some of the rainwater, infiltration can reduce runoff flows.
- **Flows.** Fast flows are distinguished from slower underground flows. “Rapid” flows and, in contrast, underground flows referred to as “slow” represent the infiltrated part of the rainwater moving slowly through the aquifers to the outlets. Flows that quickly gain outlets in order to constitute floods are subdivided into surface flow (movement of water on the surface of the soil) and subsurface flow (movement of water in the first soil horizons). Underground flow refers to the movement of water in the soil.

Large water reservoirs: distribution and use

Surface water stocks. Surface retention includes all water accumulated on or above the ground (Musy, 2005). It includes water intercepted by vegetation cover, evaporation during precipitation and storage in soil depressions which is the volume of water stored in the small depressions of the soil up to their level of spill. It does not include surface retention which is the part of the rain that remains on the surface of the soil during precipitation and drips or seeps when the rain has stopped. All the water collected in the surface depressions, from the smallest, due to the roughness of the soil, to the largest flooded plains, lakes, marshes, ponds, etc., is designated as the surface water stock.

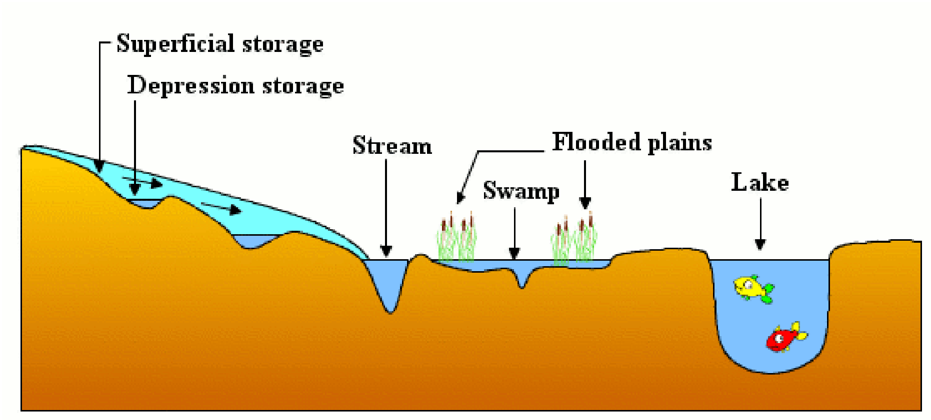


Figure 101. Surface water storage.
Source: Musy (2005)

Depending on the time (rainfall, season, year, etc.) and the spatial (type of depression) scale, it is possible to distinguish: small surface depressions that fill up as soon as the intensity of precipitation exceeds soil absorption capacity. During heavy downpours, these depressions are filled and the surplus goes in surface runoff. The total volume of water that can be retained in these surface depressions is called surface retention capacity. Flooded lakes, ponds or floodplains are natural or artificial surface water reservoirs of considerable volume and area. They directly intervene in the water balance by the exchanges of water with the soil (surface water-groundwater relationships) by promoting evaporation from their surface or by delaying river flow through rolling.

Groundwater stocks are related to water that penetrates the soil and stays for a short time or many years (Musy, 2005). The constraints to the circulation of water throughout the thickness of the soil and subsoil make it possible to distinguish soil water and water from underground tanks.

Soil water is assimilated to the water found in the unsaturated zone[24]. The evolution of quantity (volume) and quality (composition of water) results from a transfer dynamics related to water properties and soil characteristics. The zone of soil water is the site of plant roots and constitutes an important upper limit of the aquifers (food, evaporation). It is also the transit point of materials and

24 The non saturated zone, a three phase (solid, liquid, gaseous) system where only a small part of lacuna space is filled by water, the remaining being filled by air and soill (Musy, 2005).

substances. These processes are part of the soil-plant-atmosphere continuum.

Subsoil water. The water in the subsoil corresponds to the water in the groundwater. Infiltration renews the water in the subsoil and underground reservoirs and maintains, through its circuit in aquifers, the flow of underground flow (basic flow). It feeds springs and streams.

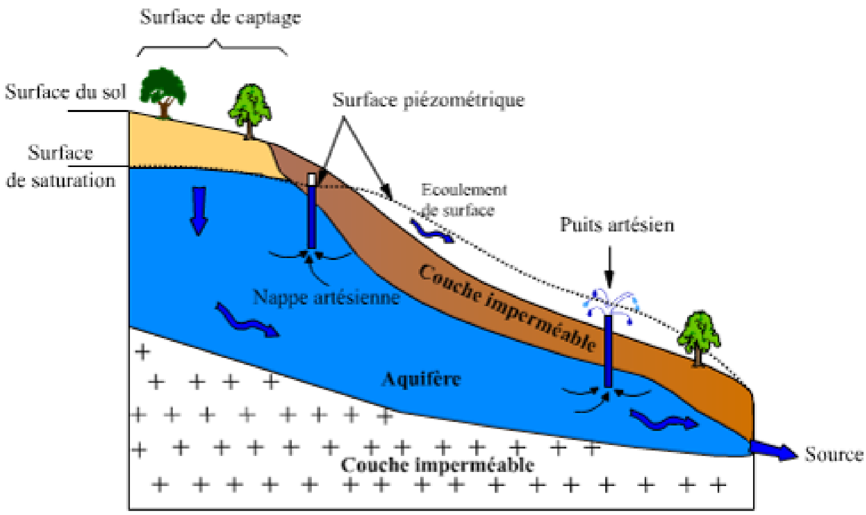


Figure 102. Groundwater.
Source: Champoux and Toutan, cited by Musy (2005).

The level of groundwater is influenced by the percolation regime of rain or irrigation water through the unsaturated zone.

Box 24. Calculation of groundwater stock

In order to evaluate the volume of the groundwater, an estimate of the impermeable level is made by an appropriate geological study, or by determining the coefficient of storage of the rock, or by measurements of the piezometric levels.

The *exploitable reserve* of groundwater of a free or captive aquifer is given by the difference of the current piezometric level with the level at which it is agreed to fold the groundwater, multiplied then by its average surface and its coefficient of storage.

Distribution/allocation and use of water supplies

Water distribution can be realised in: i) a quantitative and qualitative distribution of water on a global scale, and in relation to the various components of the hydrological cycle, ii) a spatial distribution of water balance on the continents.

On a global scale. The oceans occupy an area roughly equal to 70% of the surface of the globe and represent 97% of the total mass of water in the biosphere. Quantitative distribution of water on land shows that freshwater represent only about 3% of the total volume of the waters of the globe. They are 99% in the polar ice caps, glaciers and groundwater of great depths which represent hard-to-reach freshwater supplies. Table 9 presents some indicative quantities of water reserves (from Gleick, 1993).

Groundwater is the second largest freshwater resource in the world after glacial waters. It is far ahead of continental surface water. Its contribution to drinking water is very important so that in some parts of the world, people exclusively use groundwater through wells and boreholes, as is the case in the majority of semi-arid and arid zones in Africa. In other African countries, surface water is the source of drinking water, particularly in rural areas. However, continental surface waters (freshwater lakes, rivers, etc.) are increasingly being polluted by anthropogenic activities. The box 25 presents a process of reversing trends in land and water degradation in Africa.

Table 9. Indicative quantities of water reserves

Reservoir	Fraction of total reserves [%]	Fraction of fresh water reserves [%]
Ocean waters	96.5379	
Total groundwater	1.6883	
Freshwater tables	0.7597	30.0606
Soil water	0.0012	0.0471
Glaciers and permanent snow cover	1.7362	68.6972
Antarctic	1.5585	61.6628
Greenland	0.1688	6.6801
Arctic	0.0060	0.2384
Mountainous regions	0.0029	0.1159
Permafrost	0.0216	0.8564
Water reserves in lakes	0.0127	
Fresh	0.0066	0.2598
Salted	0.0062	
Swamp	0.0008	0.0327
Rivers	0.0002	0.0061
Biologic water	0.0001	0.0032
Atmospheric water	0.0009	0.0368
Total Reserves	100	
Freshwater reserves	2.53	100

Box 25. Example of tools for cross-border management of water resources in Africa

Transfrontier Diagnostic Analysis (TDA) process: identification and prioritization of trans-boundary problems, assessment of environmental impacts and socio-economic consequences, analysis of causal chains (immediate, sub-adjacent and deep causes), analysis of governance.

Formulation of the Strategic Action Program (SAP): formulation based on a long-term vision (ecosystem quality objectives), assessment of options in response to the problems identified in the TDA, system of partnerships and implementation of the actions of the selected option.

At the continental level, the main elements of water distribution are given in table 10. The percentage of runoff precipitation is higher in the Northern Hemisphere (~ 40%) than in the Southern Hemisphere (Australia: ~ 35%, Africa: ~ 20% and South America: ~ 10%).

Table 10. Main elements of global water distribution

Continents	Precipitation (mm)	Evaporation (mm)	Runoff (mm)
Europe	790	507	283
Africa	740	587	153
Asia	740	416	324
North America	756	418	339
South America	1600	910	685
Australia and Oceania	797	511	280
Antarctic	165	0	165
Average for all continents	800	485	315

Box 26. Example of water reserves in Africa

National and transboundary river basins (Nile basin, Niger, Senegal, The Gambia, Zambezi, Volta, Orange, Juba-Shibeli,); main lakes (Victoria, Chad, Tanganyika, and hydroelectric dam reservoirs); streams and wetlands (rivers,); transboundary aquifer systems (UNEP, 2008).

Water drainage system

The following figures illustrate the drainage system.

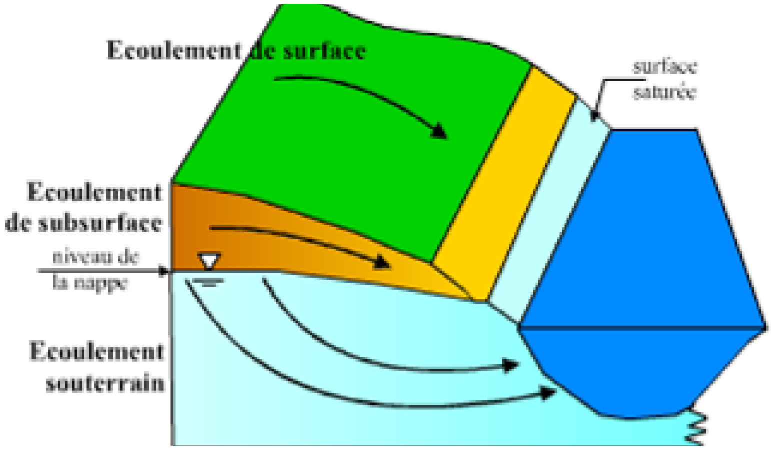


Figure 103. Different types of flow. Source: Musy (2005)

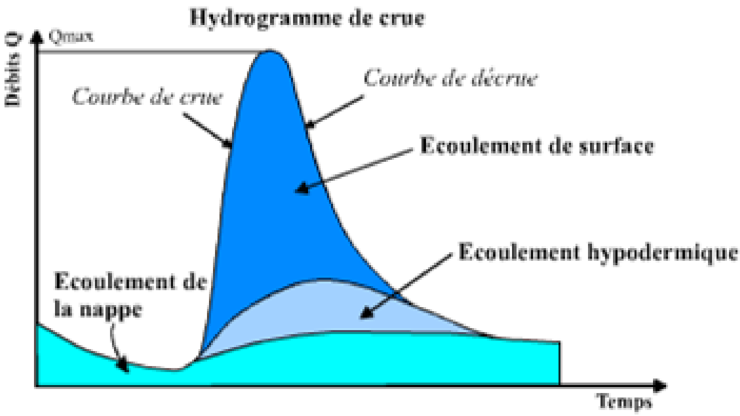


Figure 104. Breakdown of different phases of a flood hydrograph.Source: Musy (2005)

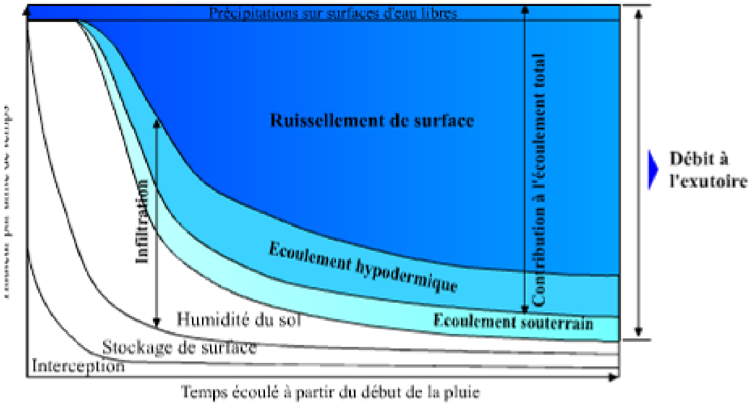


Figure 105. Repartition of precipitation height during a constant intensity showers. Source: Remanieras cited by Musy (2005)

Slow flows of water represent the infiltrated part of the rainwater which transit slowly through the water table towards the outlets. Flows that rapidly reach outlets to constitute floods are subdivided into surface flow and subsurface flow. The surface flow or runoff flow of water occurs when excess stormwater, meltwater, or other sources flows over the Earth's surface. Subsurface flow or hypodermic flow includes the contribution of partially or fully saturated surfaced horizons with water or the perched aquifers temporarily above the clay horizons. There is also the water flow due to the melting of the snow.

Educational activities (exercise and case studies)

- From the basic information presented in the course and other issues from the literature, write an analytical summary in groups of 4-5.
- On the functioning of the hydrological cycle, the different types of water stocks and their use.
- Analyze the impact of climate change on the hydrological cycle.
- What is the role of forests in regulating the hydrological cycle?
- Prepare and present a case study on the delimitation and description of morphological characteristics of a watershed in Africa.

5.5 Description of ecosystems

Objective

By the end of the session, the learner will be able to:

d) Describe terrestrial and aquatic ecosystems.

5.5.1 Terrestrial ecosystems

Terrestrial ecosystems include dense rainforest, savanna, steppe, dry dense forests, semi moist forests and gallery forests. Terrestrial ecosystems are formed by animal and plant species interacting with their physical and chemical environment. It is not easy to give definite outlines of these different units. Subdivisions are often made based on plant associations but also animal components (M'Bongo, 1996).

Rainforest. In Africa, for example, dense rainforest is an integral part of the Congo Basin, the most diversified in animal and plant species throughout Africa. This ecosystem is considered as one of the "hot spots" of global biodiversity.

Savannas. The main characteristic of this ecosystem is the presence of an herbaceous stratum. Due to its extent and the differences in its characteristics, in several regions of Africa, it encompasses a rich and varied fauna.

Steppes. This ecosystem corresponds to the Sudano-Sahelian area. The steppes are characterized essentially by the disappearance of the common savannas species. It is an area of predilection for large mammals, birds and reptiles.

Deciduous forests are found both in the medio-Sudanian domain and in the Sudano-Sahelian domain and are formed by several forest "flaps". This ecosystem contains the same animal species as the savannas.

Semi-deciduous forests and gallery forests. These two ecosystems have many similar characteristics. Semi-humid dense forests are common in Sudano-Guinean domains. The gallery forests are found mainly along rivers. The dense semi-humid forest constitutes the transition zone between dense rainforest and dense dry forest. This makes it possible to harbor a remarkable biological richness. Both forest and savannah species are found there.

5.5.2 Aquatic ecosystems

Aquatic ecosystems are composed of marine ecosystems (oceans, seas), lotic ecosystems (rivers, rivers) and lentic ecosystems (lakes, ponds).

Marine aquatic ecosystems. These ecosystems are very diverse. Like lakes, the exposure of the surface to solar radiation leads to a vertical zonation of the water mass. It can be distinguished up to 200 meters (clear water) in a photic zone (or phytal system) in which photosynthesis is possible, and an aphotic (or aphytal) zone. Similarly, a thermal stratifica-tion of the water column separating successively the superficial zone, the thermocline zone and the deep zone is observed[25].

Lotic ecosystems are characterized by flowing water, mostly permanent. They correspond to streams, torrents, rivers and streams. Within the same lotic system, three ecological zones are distinguished: the crenon or zone of the sources, the rhithron or upper river, nearest to the sources, and the potamon which includes middle and lower courses, part of the courses of low-level water.

Lentic ecosystems present stagnant water trapped in soil depressions. The lakes are generally permanent and therefore regularly renewed. Their depth goes from a few meters to more than 1500 m. More or less extensive or deep, their origin is diverse (lakes of collapse ditch, volcanic lakes, lakes of glacial origin, fluvial lakes).

Ponds are often superficial, surface layers of water with limited area and depth. The water balance of lentic systems depends on the size of the water body initially stored, external inputs (precipitation, runoff, groundwater), losses by evaporation and infiltration. Dam lakes and ponds are bodies of water of human origin whose depth and renewal are controlled.

Educational activities (exercise and case studies)

On the basis of the basic information presented in the course and other literature, prepare as a group of 4-5 an optional technical sheet on terrestrial or aquatic ecosystems.

25 Les écosystèmes aquatiques : http://www.eau-seine-normandie.fr/fileadmin/mediatheque/Enseignant/Outils_Pedagogiques/Professeurs/AESN10-prof.chap_13.pdf

5.6 The ecosystem organization

Objective

By the end of the session, the learner will be able to:

Describe the composition, structure and level of organization of an ecosystem.

General introduction

An ecosystem is a functional system that includes a community of living beings and their environment. It is a relatively stable and integrated unit that relies on photosynthetic organisms. An ecosystem is considered as a kind of collective entity, made up of transient individuals, some of which can live up to several thousand years (e.g. big trees), while some microorganisms can live only a few hours, or even a few minutes[26].

Composition

Biocenosis is the set of organisms that live together (zoocenosis, phytocenosis, microbiocenosis, myocenosis)[27]. Phytocenosis includes trees, herbaceous plants and zoocenosis composes of animals. Biocenosis is composed of three categories of living organisms: producers, consumers and decomposers.

Biotope (ecotope) is the fragment of the biosphere that provides biocenosis with the necessary abiotic environment. It is also defined as the set of abiotic ecological factors (substrate, soil, climate) that characterize the environment where a specific biocenosis lives. The biotope is defined by the characteristics and qualities of five essential elements to life: water, soil, air, light, temperature[28].

The biotope is characterized by a number of essentially abiotic factors (independent of living beings), among which physical and other chemical factors[29] are distinguished. Physical factors include climatic factors (precipitation, temperature, light, wind, relative humidity), geographical factors and edaphic factors whereas oxygen content, mineral content, and pH are the main chemical factors. Also, some of these factors are periodic (such as light, temperature, rainfall), others are not (such as thunderstorms, cyclones, fires, etc.).

26 Notion d'écosystème (cours) : http://www.uvt.rnu.tn/resources-uvt/cours/ecosystemes/lecon1/co/Contenu_04.html
27 Cours d'écologie générale de l'université Badji Mokhtar Annaba, plate forme Elerning: Site : http://elearning.univ-annaba.dz/course/view.php?id=330
28 Cours d'écologie générale de l'université Badji Mokhtar Annaba, plate forme Elerning : Site : http://elearning.univ-annaba.dz/course/view.php?id=330
29 Notion d'écosystème (cours) : http://www.uvt.rnu.tn/resources-uvt/cours/ecosystemes/lecon1/co/Contenu_04.html

Structure

The ecosystem is composed of two elements: a biotope and a biocenosis

Ecosystem sizes. Considering the size criterion, there are three types of ecosystems:

- a micro-ecosystem: e.g. a tree stump;
- a meso-ecosystem: e.g. a forest or a meadow; and
- a macro-ecosystem: ocean, savanna, desert, etc.

If we consider the biocenoses, we have:

- *synusia* corresponds to the micro-ecosystem: temporary and independent biocenosis;
- *community* corresponds to the meso-ecosystem: it is a sustainable and autonomous biocenosis; and,
- *biome* is the community of living beings specific to a macro-ecosystem.

The productivity is the amount of organic matter produced by the ecosystem, related to the flow of energy, water, mineral elements, CO_2, etc.

Extent. In nature, the limits of the ecosystem are difficult to identify because there is a gradient between two neighboring ecosystems, hence an edge or ecotone effect. Ecotones are particularly rich in fauna whose species do not mix.

Types of current ecosystems are not the original ecosystems because they have been modified by humans especially with regard to biocenosis:

- original biocenosis: very rare, e.g. virgin forests;
- potential biocenosis: a biocenosis becomes original or almost original, if all action of the human ceases, it would find a species of equilibrium or climax; and,
- real biocenosis: it is the one that exists in its present state.

Level of organization

The living world is structured according to organizational levels of increasing complexity (molecules, organelles, cells, tissues, organs, individuals, populations, communities)[30]. The levels involved in ecological studies are the individual, population and community.

Individual: this level encompasses all individual organisms from single-celled organisms to trees and large mammals. At this level, the studies are called autoecological, as opposed to those of the higher levels, called synecological.

Population is the set of individuals of the same species, living on a given surface. The development of a population and its evolution are controlled by the environment.

30 Notion d'écosystème (cours) : http://www.uvt.rnu.tn/resources-vt/cours/ecosystemes/lecon1/co/Contenu_04.html

Community is the group of populations gathered in the same space and who presents a certain homogeneity with regard to the criteria retained to distinguish it. The notion of community may mean:

- plant populations are a plant group or phytocenosis;
- animal populations or zoocenosis;
- soil micro-organisms or micro-biocenosis; and
- it may also refer to all organisms or biocenosis.

The environment in its broadest ecological sense is constituted at the world level by the biosphere, which is defined as the region of the planet that contains all living beings and in which life is permanently possible. Indeed, the whole surface of the earth globe is not equally favorable to organisms. There are some areas, such as the polar ice caps and the high mountains where life is almost impossible.

The biosphere can be subdivided into three compartments of different physical types:

- the lithosphere: limited to the most superficial layers of the Earth's crust. It is the solid medium constituted by all the emerged continents;
- the hydrosphere: or global ocean, a medium liquid that covers the 7/10 of the world area; and,
- the atmosphere: homogeneous gaseous layer which constitutes the most peripheral zone of our planet and envelops the two preceding environments.

Educational activities (exercise and case studies)

Based on the basic information presented in the course and other literature, prepare in group of 4-5 an analytical summary on the structure and organization of a forest ecosystem.

5.7 Ecosystem functioning

Objective

By the end of the session, the learner will be able to:

Analyse interactions, trophic chain, dynamics and resilience of forest ecosystems.

General introduction

An ecosystem is a landscape made up of a mosaic of stationary compartments that each have their own ecological characteristics made up of plant and animal communities with specific functioning. This landscape responds to a dynamic logic of a temporal order. These phenomena induce changes in the demographic dynamics of plant populations. They also cause the gradual transformation from one plant community to another, as well as changes in micro-climatic and edaphic conditions[31].

Understanding the typology and functioning of forest ecosystems is useful for forestry technicians in identifying the main types of ecosystems in a natural region, accuracy of fundamental functional data, and potential for exploitable species.

Food chain

An ecosystem is an integrated unit (with its various abiotic and biotic components) that works, despite the competition of large organisms for resources. All living beings, even the smallest ones (bacteria, fungi, etc.) constitutes a source of food for another living organism, which is called the food chain and consists of a transfer of matter and energy from one trophic level to another[32].

Solar energy is the essential source of matter on earth. About 30% of the solar energy is immediately reflected back into space as light and about 20% is absorbed by the earth's atmosphere. Most of the remaining 50% is absorbed by earth itself and transformed to heat.

Green plants and other photosynthetic organisms catch less than 1% of solar energy. They transform this energy into chemical, electrical and mechanical energy used by the same organisms (called autotrophs) and by all other living beings, known as heterotrophs, thus ensuring their nutrition and their survival and various activities. This flow of energy is the essence of life. The energy captured by green plants is thus transferred in a very organized way across the different levels of the food chain before dissipating. The distribution of energy at the level of producers and consumers can be schematized as well.

31 Dynamique des écosystèmes : http://www.ecosociosystemes.fr/dynamique.html
32 Notion d'écosystème (cours) : http://www.uvt.rnu.tn/resources-uvt/cours/ecosystemes/lecon1/co/Contenu_04.html

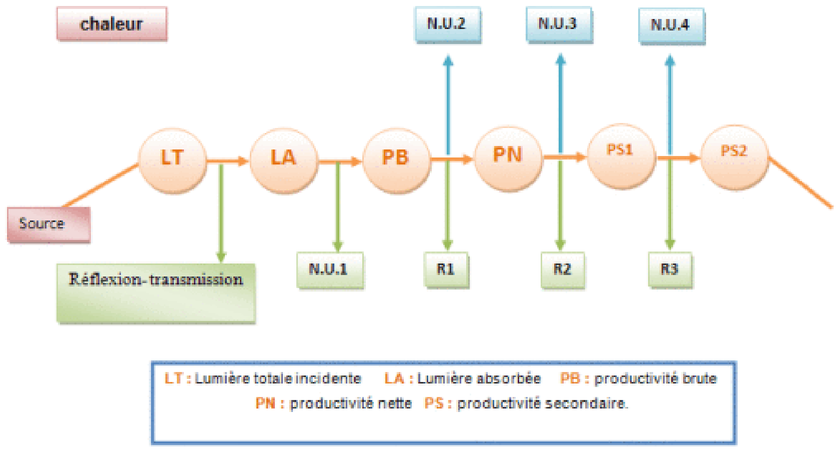


Figure 106. Distribution of energy at producer and consumer level.
Source: http://www.uvt.rnu.tn/resources-uvt/cours/écosystèmes/lecon1/co/Contenu_04.html

All unused energy is taken up by decomposition; the breathing energy (R1, R2, R3) will be lost. The amount of energy available decreases, therefore, all along the food chain. The plant absorbs only 1 to 5% of the energy received. Herbivores use on average 1% of the energy set by the food they have consumed: PS1/PB = 1%. For carnivores, the yield is higher: PS2/PS1 = 10%.

Producers is the set of chlorophyll plants that will fix the energy of the sunlight (photosynthesis). There is on average 1 to 5% of the solar energy captured by the plants.

Consumers are all plants and animals that consume organic matter from producers to obtain the energy necessary for their metabolism. This energy production takes place essentially from the oxidative degradation (respiration) of the organic matter (catabolism). Then there is edification of the own (organic) matter of these consumers (anabolism). There are several categories of consumers according to the diet:

- *herbivores*: these are the consumers of plants (e.g. cetaceans consume phytoplankton; algae are eaten by gastropods, sea turtles, etc.; lichens are the food of terrestrial gastropods and myriapods; etc); in the case of the higher plants, all organs may be consumed (grasses and leaves of trees by vertebrates and insects, fruits and seeds by birds and other vertebrates, etc.);
- *saprophagous*: consume dead plants and animals, their role is to recycle organic matter before being demineralized by decomposers; there are several types of saprophagous:
    - *detritivores*: consume plant and animal debris;
    - *coprophagous*: feed on excreta of various animals and are mainly insects;
    - *necrophagous*: feed on dead bodies and are birds and insects (scavengers); and,

- *carnivores:* feed on other animals from which they will digest organic matter; they are also called predators and compose of three categories:
  - *first order predators*: that eat herbivores: (jackal, lion, etc.);
  - *second order predators*: that eat first order predators (snakes, etc.); and
  - *third order predators*: (raptors that eat snakes, etc.).

There is therefore a transfer of energy from one trophic level to another:

Photosynthesis → plant organic matter → herbivorous organic matter → carnivorous organic matter I → carnivorous organic matter II → carnivorous organic matter III , etc.

The trophic chain will not extend indefinitely. In principle, it will stop at the level of the carnivore III because there is loss of energy from one level to another.

Decomposers are mainly bacteria and fungi. They feed on dead organic matter (dead bodies, bedding, etc.). Their role is to decompose organic matter or mineralize it (into CO_2, NH_3, H_2S, etc.). These mineral elements will be taken up by other bacteria: e.g. nitrifying bacteria → nitrates; sulfurizing bacteria → sulphates; etc.

Nitrates and sulphates are better assimilated by plants. The process of decomposition is as important as that of production in a given ecosystem. The amount of organic matter that returns to the soil in terrestrial ecosystems, in the form of leaves, roots or dead wood, can range from a few tons to a few tens of tons per ha each year. A large number of species act on this material for recycling, fractionation, transformation, decomposition and mineraliza-tion. It becomes available again to producers and use for the synthesis of new organic molecules. In conclusion, decomposers play an essential role in the biogeochemical cycle.

Ecosystem dynamics

The dynamics of forest ecosystems are characterized by cycles that can be grasped at very different temporal and spatial scales. Thus, an interglacial cycle spreads over several tens of thousands of years and concerns a continent; it is observed in the slow resettlement of the forest and then its disappearance in favor of a steppe, a tundra or glaciers. Changes in temperature and, more generally, in climate are the driving force behind these processes[33].

Silvigenetic cycles. A virgin forest (not exploited by human) presents so-called sylvigenetic cycles that characterize the internal dynamics of forest environments. At the scale of a forest, the set of sowing that develop is a unit of regeneration. The dynamics is related to the inter-individual competition (growth in diameter and height, elimination of some individuals, progressive establishment of the future statuses of trees: dominant and dominated).

At the scale of the living space of a tree, many changes are observed during its growth. Dynamic phenomena (variations of the humus, grass carpet) are related to the development of the architectural model of the species, thwarted by the effects of competition by neigh-boring individuals (multiple reiterations).

33 Dynamique des écosystèmes : http://www.ecosociosystemes.fr/dynamique.html

Regardless of scale studied, forest tree species have a number of invariants responsible of identical dynamic logics. Two of these invariants are related to: 1) adaptive strategies of species (and the resulting functional groups of species), and 2) seed potentials.

The dynamics of wild forests. In the case of a managed forest, the perenniality of the wooded state is ensured by the forester who operates the regeneration (natural or artificial by plantations)[34].

In order to study this cyclical dynamics, we have to look at natural forests (little modified by humans and thus keeping all primitive characters) or sub-natural (abandoned by man for a long time or little influenced by it).

Tropical or equatorial forests (primary forests that have not been destroyed as opposed to secondary forests, reconstituted after deforestation) are the site of a fundamental process: regeneration; any wooded surface is subjected to two phases which alternate in discontinuity in space and time:

- *phase of growth* with predominance of slow phenomena (growth, maturation, aging without significant changes in the ecosystem); and,
- *phase of short rejuvenation* that starts with a more or less brutal break, such as a windthrow or simply the death of a tree, therefore creating a gap.

Depending on the size of the gap, the pre-existing state, the species present (in the adult state, vegetative recruit, seed potential), the stand of the future will be reconstituted by healing with the trees near the gap, of the recruit (germination of the seeds present in the soil or brought).

An opening of the stand favors the penetration of solar radiation which contributes to the rejuvenation of the forest, to its regeneration by favoring the colonization by sowing.

During this phase of reorganization, the elements that settle slow down or select the arrival of new occupants by physical or biological inhibitions or facilitations. The vault closes, heals and a new cycle begins again.

The opening of the gap results in a temporary trauma; the evolution of the stand resulting from it depends on its size and the time of the disturbance. A small opening that corresponds to a dying tree and a windfall of a few hectares will not have the same effects. The results will be different depending on whether the gap occurs at a time of fruiting or is ahead or behind it. They cause sudden changes in ecological conditions, with marked differences depending on the stationary characteristics (modification of microclimate, humus, soil when trees are uprooted, herbaceous vegetation).

Resilience of ecosystems to climate change

Definition

In ecology, resilience is the ability of a dynamic system to redefine its structure and regain a new stability or equilibrium after being affected by an external shock (Gunderson, 2000). The resilience of forests thus represents their ability to recover from major disturbances. It is an emerging property of an ecosystem that results from biodiversity at multiple levels, ranging from genetic to

34 Dynamique des écosystèmes : http://www.ecosociosystemes.fr/dynamique.html

landscape diversity (Thompson et al., 2009). Resistance is related to the concept of resilience and represents the ability of a forest to withstand minor disturbances over time, e.g. the death of a few trees or a chronic level of herbivory from insects (Thompson, 2011). In most natural disturbances, forests maintain their resilience over time. To be able to provide the goods and services that humans derive from forests, forest ecosystems must be able to recover from disturbances and not degrade over time.

Forests may also be resistant to certain environmental changes, e.g. in weather patterns over time, due to redundancy within species with functional roles (redundancy means overlaying or duplicating functions ecologically assumed by a group of species) (Díaz et Cabido, 2001). Ecosystems can be highly resilient but not resistant to a given disturbance. In general, most natural forests, especially old-growth primary forests, are both resilient and resistant to various kinds of changes.

Resilience to climate change

The loss of forest resilience can be caused by the loss of functional groups resulting from environmental changes such as large-scale climate change, poor forest management, or a sufficiently large or continuous alteration of natural disturbance regimes (Folke et al., 2004).

Global climate change is the most important source of impact on forest ecosystems. Climate has a descriptive influence on the rhythms of forest respiration and production as well as on other processes, operating through temperature, atmospheric irradiative forcing and water regimes over medium and long terms[35]. Also climate and weather conditions influence in short-term processes in forests, such as fires, herbivory and species migration. Climate change will have an adverse effect on forest ecosystems because it may cause the physiological tolerance of certain species to be exceeded and many biophysical forest processes altered. Most scientific studies show that many tropical forests will not be resilient to climate change over the long term if the current and predicted trend of rainfall decreases and drought increase continues (Betts, Sanderson, Woodward 2008, Malhi et al., 2008).

The state of an ecosystem is defined by its dominant botanical composition and the expected stand structure. Forest state change results from a loss of resilience, resulting in a partial or complete transition to a different ecosystem type than would be expected in the area considered. This change in status leads to a reduction in the goods and services provided by a forest ecosystem. Consequently, the change of state of an ecosystem can be retained as an indicator of degradation. For example, if a forest is said to be mixed, but is dominated by a very small number of species, or if it is expected to see dense forest cover and face a covered forest or to a savanna, is that there has been a change of state. These state changes lead to the degradation of biodiversity and the level of production of services goods from forest ecosystems (Thompson, 2011).

35 Biodiversité, seuils de tolérance des écosystèmes résilience et dégradation des forêts. http://www.fao.org/3/a-i2560f/i2560f05.pdf

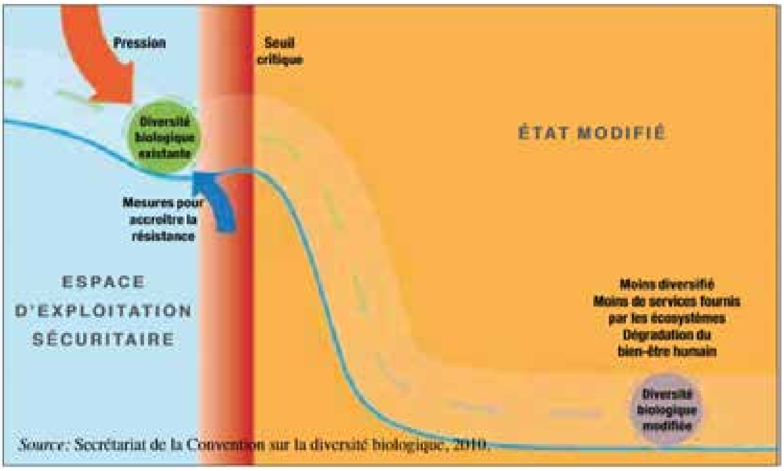


Figure 107. Illustration of tipping points, or thresholds, of ecosystems

Educational activities (exercise and case studies)

From the basic information presented in the course and other literature issues, prepare in group of 4-5 an analytical summary on the dynamics and resilience of forest ecosystems.

5.8 Humans and ecosystem

Objectives

By the end of the session, the learner will be able to:

1 Identify the goods and services offered by forest ecosystems, and;

2 Assess the threats to them and the opportunities to be seized to learners.

General introduction

In a stable state, the biodiversity of a tropical forest can produce a series of goods and services representing value for humans. Loss of biodiversity is likely to have significant negative impacts on forest productive capacity (Thompson et al., 2009; Bridgeland et al., 2010; Cardinale et al., 2011). Thus, to the extent that forest degradation can be defined as the loss of their ability to produce the expected goods and services (FAO, 2009), loss of biodiversity is a major criterion for measuring this degradation. Conservation of biodiversity is therefore a cornerstone of SFM (Montréal Process, 2009) and a key factor in maintaining the functioning of forest ecosystems (Thompson, 2011).

Mastering ecological principles and modes of conservation of biodiversity is essential for the sustainable management of forest ecosystems. Payment for environmental services (PES) is part of these new approaches that favor positive environmental externalities through the transfer of financial resources between service recipients and their suppliers. The use of PES systems for the conservation of river basins, biodiversity and landscape beauty and for carbon sequestration has been increasingly favored in recent years.

Understanding the various limitations and issues surrounding methods for assessing the value of goods and services is essential to design a PES system and to reduce human pressures on forest ecosystems. Natural changes in the environment can, in some cases, have a detrimental effect on ecosystems. In recent centuries, the human population has grown faster and faster; today, more than 7 billion people live on earth. By 2050, this is expected to reach 9 billion (UNEP, 2008). Throughout the world, the population explosion plays a major role in environmental change, in many aspects and on a scale that is difficult to define with precision (UNEP, 2008).

The human-related actions developed over millennia deeply mark their impacts on current landscapes and are thus responsible of the diversification of the dynamic trajectories observed (UNEP, 2008). Landscapes in many areas have been transformed. The implementation of PES systems can contribute to behavioral change in favor of sustainable use of natural resources.

Ecosystem services

Products. One of the challenges in designing of PES systems is to transform the services provided by ecosystems into "products" that can be sold to beneficiaries. This requires precise data on the nature of the market, the structure of demand and the value of services for beneficiaries (Unifera, 2004).

PES systems focus on environmental services that are already, or could be, the subject of an application under the right conditions. PES systems focus on services provided by forest conservation, reforestation and SFM, and some agroforestry or silvopastoral practices. Available services are divided into four categories: carbon sequestration, biodiversity conservation, landscape beauty and hydrographic services (Unifera, 2004).

Carbon sequestration services are included in multiple commercial transactions around the world and in several PES systems. Carbon sequestration occurs when trees or other plants absorb carbon from the atmosphere during their growth. Conversely, the destruction of forests results in the release of carbon into the atmosphere. Carbon sequestration can therefore involve two types of services: active absorption through reforestation or reduction of emissions through forest cover conservation (Unifera, 2004).

Biodioversity conservation. PES systems often involve services related to biodiversity. This can therefore be measured by ecosystems, species and genetic diversity. The biological services that can be provided under PES systems include the protection of ecosystems, natural habitats, species and genetic resources and their valorization. The protection of biodiversity is particularly aimed at ensuring its sustainable use for scientific and pharmaceutical purposes (Unisfera, 2004).

Beauty of the landscapes. Services related to the beauty of landscapes are mainly associated with the aesthetic or cultural value given to some natural sites. These include protection of natural heritage sites, coral reefs, cultural sanctuaries or even traditional livelihoods as part of a unified approach to protect cultural and environmental areas. However, few PES systems use these services because they are difficult to quantify and evaluate because of their cultural basis. Still, they are increasingly common in PES systems given the increase in cultural awareness and the development of the global tourism industry (Unisfera, 2004).

Hydrographic services. Many PES systems target hydrographic services that are:

- regulation of water flow, their maintenance in dry weather and regularization of floods;
- water quality management: regulation of solid, nutrient (eg, phosphorus and nitrogen) and chemical loads, and salinity;
- control of erosion and sedimentation;
- reduction of soil salinization and regulation of the ground water; and,
- management of aquatic habitats (eg, maintaining water temperature, shading rivers/ streams, ensuring sufficient woody debris in the water).

The services provided by forest ecosystems to catchment basins depend on a number of site-specific factors, including land, soil composition, tree species, vegetation, climate and existing management regimes. In addition, catchment basins are sometimes subject to seasonal, annual and multi-year fluctuations that make it virtually impossible to predict and quantify the delivery of specific levels of water-related services at any given time.

Economic value of ecosystem services

By definition, negative and positive environ-mental externalities are not included in the price of products and services sold on the market. Some markets therefore do not promote conservation or pollution prevention through price indications or other economic incentives. This usually results in a gradual destruction of natural capital or unacceptable levels of pollution. In the past, to address this issue, the mandatory method was the adoption of laws and regulations on environmental protection, pollutant emissions, human health and land use (Unisfera, 2004).

However, the evolution of environmental regimes has made it possible to advocate market-based economic instruments aimed at internalizing environmental externalities through price indications and incentive systems, which include subsidies, tax policies, the establishment of markets for polluting emissions and many other tools (Commission de coopération environnementale, 2003).

The PES systems are unique but have a common structure, which is illustrated in the following figure.

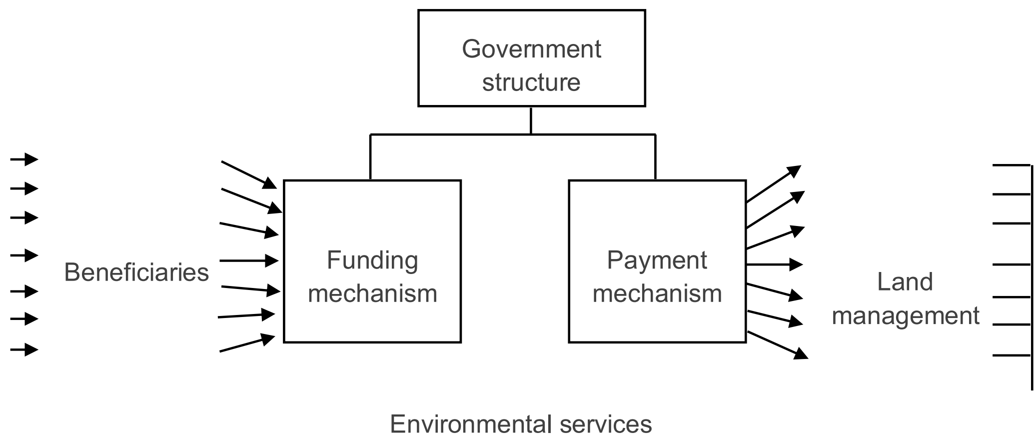


Figure 108. Structure of PES mechanisms.
Source: S. Pagiola, Banque Mondiale (2003) cited by Unisfera (2004)

The beneficiaries may be local (e.g. water users in the downstream catchment basin), national (public authorities, NGOs or trade associations) or international organizations. They may also include local, national and international beneficiaries. The nature, number and provenance of beneficiaries are directly related to the nature of the environmental services generated under the PES system. If beneficiaries are few and well organized, transaction costs will be reduced (Unisfera, 2004).

The methods for determining the economic value of ecosystem services are presented in the following figure:

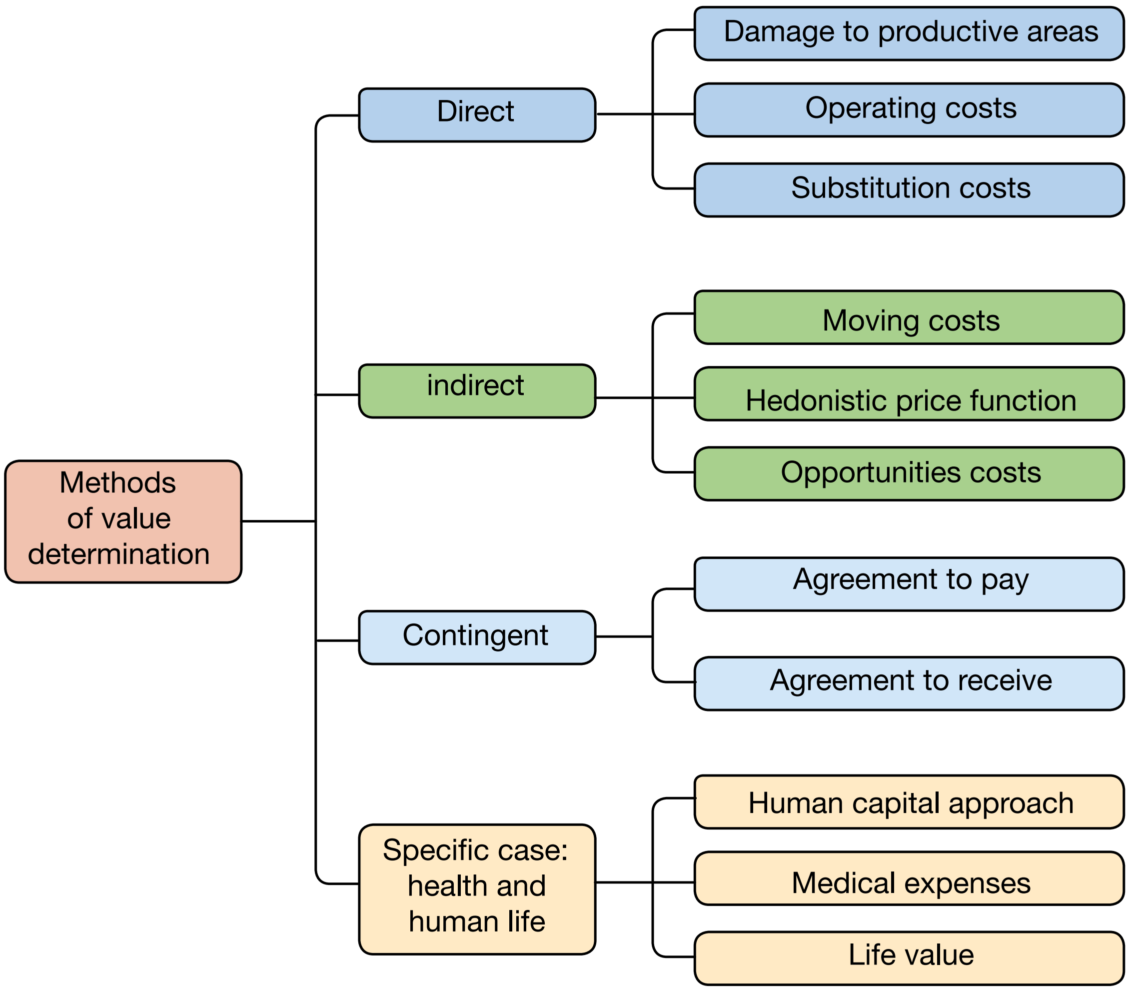


Figure 109. Economic methods of value determination

It is also necessary to design a compensation mechanism that distributes money to land users. In theory, such payments must cover the cost of conservation efforts and the cost of renouncing to some land uses. A balance must therefore be struck between the maximum payment that beneficiaries are willing to pay and the minimum payment that will ensure the delivery of services by land users (Unisfera, 2004).

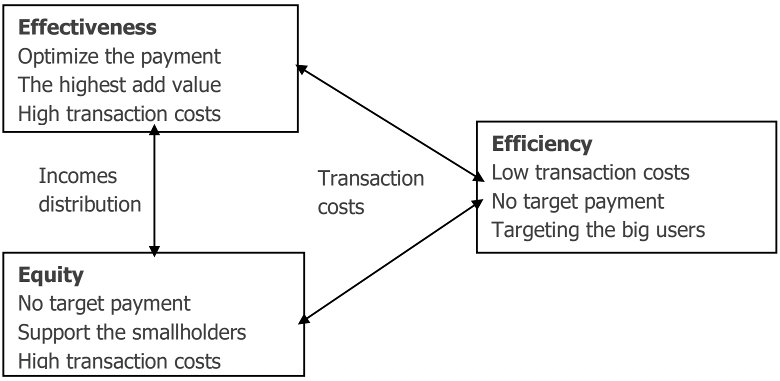


Figure 110. Relationships of interdependence in PES systems.
Source: Unisfera (2004)

Ecosystem value

Most goods and services provided by ecosystems are not traded in markets and their economic value is not reflected in market prices. The only way to attribute monetary values to them is by using non-market valuation methods. Without these estimates, these resources may be implicitly undervalued and decisions about their use may not accurately reflect their right value to society. Services can be classified into four categories (MS, 2005a): procurement services, regulatory services, cultural services and support services.

Procurement services. The general function of procurement services is to provide a supply of goods and products directly obtained from the ecosystem and for the benefit of humans. These services include, for example, the supply of fresh water, food and pharmaceuticals.

Regulatory services of an ecosystem have the general function of regulating the environment through regulatory cycles or agents (EM, 2005a). For instance, the regulation can occur at the climate level, the propagation of diseases or pollination (where bees are recognized as very good pollinators). As far as water regulation is concerned, it is recognized that a marsh, being wetland, has a very good water retention capacity, which regulates the water levels in the surrounding environment (Ducks Unlimited Canada, 2004). This storage significantly reduces the risk of flooding and erosion, particularly at the edge of a lake. As a corollary, this water retention capacity contributes to well-being by reducing the costs of damage to buildings caused by potential flooding. This service has a value not estimable monetary (Massicotte, 2012).

Cultural services. The general function of cultural services is to offer non-material benefits that satisfy the human mind (EM, 2005a). This type of service includes spiritual and religious values, the inspiration and aesthetic appreciation of a landscape, and cultural heritage. One service that illustrates this category is the cultural value associated with a particular ecosystem (e.g. the sacred forests of a community).

Support services. This category of services is the basis for the operation of all ecological goods and services. It encompasses the services generated by the first three categories (EM, 2005a). The following table provides examples of services associated with the ecosystem value of each category.

Table 11. Categories of ecosystem goods and services.
Source: Massicotte (2012)

Procurement services	Regulatory services	Cultural services	Support services
Food	Climate, water and erosion regulation	Environmental diversity and cultural heritage	Soil formation
Fresh water	Air and water purification	Educational and spiritual values	Water cycle
Woody fibre	Carbon sequestration	Aesthetic appreciation	Nutrients cycles
Fuels	Pests and diseases regulation	Sense of belonging	Raw materials
Genetic, biochemical and medical resources	Pollination	Recreotouristy	Photosynthesis

Human pressures

Sub-Saharan Africa is rapidly urbanizing and expected to have the highest urbanization rate in the world for many decades (UNFPA 2007).

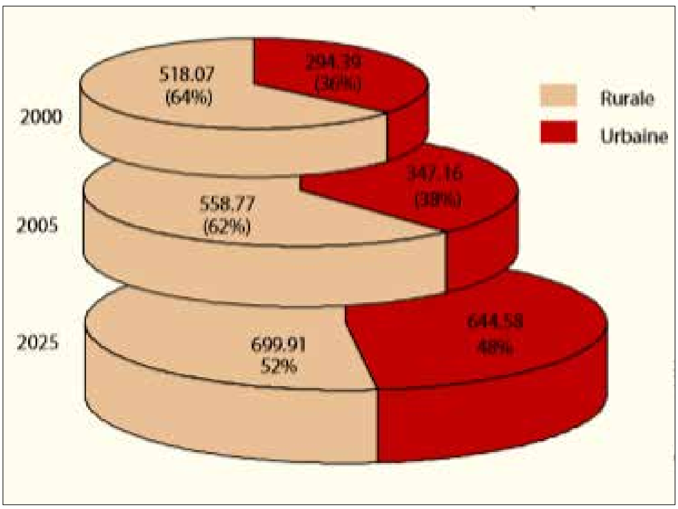


Figure 111. Trends in urbanization rates in Africa.
Source: UNEP (200 8)

The phenomenon of urban expansion will generate more and more needs, particularly in terms of agricultural land, to ensure food security. Satisfying food needs of urban populations will imply a decline in other types of land cover, and the reduction or elimination of natural habitats and resources (UNEP, 2008). In some cases, increasing human pressure on natural resources causes serious damage, e.g. the disappearance of West African rainforest and related goods and services has contributed to social unrest and poverty (Gibbs 2006). Illegal logging or poor logging practices are often at the root of the degradation of forests in Africa. However, forests may also be degraded for other reasons. Remote sensing is an effective tool for assessing state changes in a forest ecosystem.

Educational activities (exercise and case studies)

Using the basic information presented in the course and other literature, prepare in a group of 4-5 a case study on exploring indicators and methods to assess the quality of an forest ecosystem and its goods and services.

5.9 Tools and methods of characterization of ecosystems

Objectives

By the end of the session, the learner will be able to:

1 Describe phyto-sociological survey methods, inventory of forest biodiversity, and;

2 Determine the importance of remote sensing and GIS in spatialization

3 Analyse information on forest resource dynamics.

5.9.1 Remote sensing and Geographical Information Systems (GIS)

It is important to collect data from objectively selected areas in order to determine the spatial arrangement and dynamics of the components of the ecosystem. For quantitative (e.g. occupied areas and their evolution), qualitative (e.g. health status) or socio-economic indicators (e.g. exploited resources, infrastructure, type of land use), it is fundamental to spatialize information in such a way that it is possible to locate precisely the distribution of species, the fragmentation of environments, and the type of forest, by positioning them in the context of their physical and biological environment (Poso et al., 1995).

It is also essential that the available information on biodiversity be stored in geographically referenced databases if they are to be mobilized rapidly for mapping, analysis or modelling purposes. In order to be effectively used, this information should also be integrated with other data on environments, socio-economic conditions, types of natural resources and potential risks of degradation. Remote sensing and GIS are keys to integrating information at the desired resolution and spatial analysis scales (Jeffers, 1996).

5.9.2 Forest inventory

In general, two main types of forest inventories are distinguished: management inventories and national or regional inventories.

Management inventories

The sustainable management of biodiversity at the level of forest stands or landscape units (Olivier, 1992) or at the scale of forest management units (plots of a few ha to a few tens of ha) requires that a number of key elements be taken into account at regular intervals (Rondeux, 2002):

- coverage, diameters, heights and characteristics of all trees above a predetermined diameter to specify the stand structure;
- the stand fertility index in relation to the stationary conditions;
- topographic features;

- soils and the geological substratum of the stand, including the nature and depth of the humiferous horizons;
- ground vegetation with particular reference to any rare or unusual species (the presence of fungi, bryophytes, lichens, etc., is also timely to relate);
- the presence and importance of regeneration (seedlings or trees that have not yet reached a given diameter);
- the nature and quantity of any dead wood on the soil or standing and/or decaying within the stand;
- human influence and the history of settlement (culture, rights of use, thinning, cutting, hunting); and,
- remarkable ecotones and species particularly associated with the ecosystems in contact (forest-agriculture interface, forest-open field).

National/regional forest inventories

The purpose of national forest inventories is to provide the following data:

- areas occupied by the forest: distributed by owners, by types of stand, by age groups, by species;
- dendrometric characteristics of stands: numbers of stems, soil surfaces, volumes (according to different cuts, heights or qualities), productivity levels, stand compositions; and,
- qualities and forms of trees, classifications of market size, etc.

Most national forest inventories carried out on the basis of systematic and sometimes multiphase sampling (combining measurements and field observations with analysis of aerial photos and/or satellite images) and using permanent plots (Poso et al., 1995) are to provide information on the timber production and availability of forests; thus, they contain a priori little data on forest biodiversity (Rondeux, 2002).

Forest inventory missions should include information related to forest functions and not exclusively directed to wood production (Lund, 1986). If several environmental variables are already present in these types of inventory, some may be partially or totally deduced; others require a specific harvest, or even the use of adapted methodologies (Lund, 1993).

5.9.3 Biodiversity inventory

The inventory of biodiversity is a list of animal and plant species present on a given site. It makes it possible to have a knowledge of the natural heritage on a territory, to guide or refine local development projects. The objectives of a biodiversity inventory are to:

- carry out an inventory of the biodiversity (fauna, flora and environments) in order to identify the major issues related to the remarkable and ordinary biodiversity and to improve its knowledge;
- sensitize and mobilize elected representatives, technical agents and citizens to conserve or

restore the fauna and flora of the territory;

- initiate concrete actions to take account of biodiversity on the territory and enhance this biodiversity; and,
- support communities to integrate biodiversity issues into the management of their territories.

5.9.4 Phytosociological description

A phytosociological description contains varied information on the existing plant community and its context (Loic, 2015): floristic composition, vegetation structure, abundance of different taxa within the vegetation studied, physiognomy and perimeter of the survey, etc.

Concretely, it is produced by a list of taxa (quantified) and by a series of synthetic information making it possible to determine the conditions of realization of the statement. In order to be able to be compared with other surveys and thus contribute to the improvement of knowledge, the survey must include a minimum of information (surname and first names of the observers, date, location, name of the species).

Educational activities (exercise and case studies)

- Based on the basic information presented in the course and other literature issues, prepare a 4-5 case study of the importance of GIS in forest inventories.
- Participate in a phytosociological record on a given site.

5.10 Structural and spatial variability of ecosystems

Objective

By the end of the session, the learner will be able to:

Describe vertical and horizontal demographic structures of forest ecosystems.

5.10.1 Horizontal demographic structure

The arrangement and distribution of individuals along the horizontal plane (density of species, value of basal area and biovolume of individuals); method of census of the different individuals of the species and measurement of the dendrometric parameters.

5.10.2 Vertical demographic structure

Maximum level of leaf mass concentration (stratum), study of vertical structure (knowledge of different strata, determination of degree of degradation of plant formation).

Educational activities (exercise and case studies)

Using the basic information presented in the course and other literature issues, prepare in groups of 4-5 a technical sheet on demographic structures.

5.11 Phytogeography

Objective

By the end of the session, the learner will be able to:

Determine the phytogeographical areas and districts.

5.11.1 Phytogeographical domains

Guinean phytogeographical region

The Guinean forests are separated into two blocks by the advance of the savannas to the Atlantic coast in Togo and Benin: a fluvial 'Upper Guinea' (West Africa) and a 'Lower Guinea' (Central Africa around the Gulf of Guinea, White 1979).

Coastal evergreen forests along the African Atlantic coastline, from Sierra Leone to western Gabon, benefit from very wet climates, with annual rainfall that can exceed 2000 mm. These forests contain a very rich flora with a high endemism rate (Aubreville, 1958, 1962; Hall & Swaine, 1976, 1981; White, 1983; Letouzey, 1985; Hawthorne, 1995; Doumenge et al., 2003).

The Lower Guinean domain has in turn been subdivided into two phytogeographic sectors: the coastal sedimentary basin (coastal forest) sector and the Atlantic hills (bivouac forests) (Letouzey, 1968, 1985; Caballé, 1978; Doumenge et al., 2001). These Atlantic hills form an archipelago bordering the Atlantic coastline from Cameroon to DRC. The main summits do not exceed 1000 m above sea level and include: the Rumpi Mountains, the Ngovayang Mountains and the Campo-Ma'an region (Cameroon), the Monte Alèn and Monte Mitra regions (Equatorial Guinea), The Cristal mountains and the Doudou mountains (Gabon), the Chaillu massif (Gabon and Congo) and the Mayombe chain (from Gabon to DRC) (Gonmadje, 2010).

Sudanian phytogeographical region

This phytogeographic unit extends from the coast of Senegal to the foot of the high plateaus of Ethiopia in a relatively narrow long strip (500 to 700 km). The most characteristic natural and semi-natural vegetation is an open forest, which can be subdivided into several distinct types. Most Sudanian trees are characterized by a large ecological amplitude and a very wide geographical distribution both in longitude and in latitude (Devineau, 1997). This area corresponds to the Sudanian and sub-Sudanian climate zones. Vegetation is a savanna of all subtypes, from wooded savanna and open forest to grassy savanna.

Sahelian phytogeographical region

The formations are mainly steppe shrubs, for the most part dominated by thorns and subjected to strong pastoral pressure. The floristic analysis makes it possible to distinguish two phytogeographical sectors: the strict Sahelian sector and the sub-Sahelian sector. The strict Sahelian sector is located north of the 14th parallel in the Sahelian climate with a rainfall of less than 600 mm and is characterized by a lot of typical Saharan and Sahelian species which are very rarely found in the southern territories. The sub-Sahelian sector extends between the 13th and 14th parallels with a rainfall of between 600 and 750 mm. It is the area where many Sahelian and Sudanian species interact. The general appearance of the vegetation is dominated by the Sahelian and Saharan elements[36].

5.11.2 Phytogeographical districts

Phytogeographic districts include: tropical moist evergreen forests, savannas and tropical dry forests, hot deserts, sclerophyllous forests, lauriphyllous forests, subtropical moist deciduous forests, cold steppes and deserts, taiga, tundra. These forests occur in various agro-ecological zones in Africa.

Humid zones

The largest wetlands in sub-Saharan Africa are found in central and western Africa. Precipitation occurs for more than nine months, with totals exceeding 1 500 mm per year. The main soils are acidic with low levels of fertility. One of the key points in this area is the management of organic matter because most of the nutrients are associated with it and are thus concentrated in the upper horizon. Thus, when cultured, when organic matter is lost through oxidation or erosion, fertility declines rapidly (FAO, 2003).

Subhumid zone of West and Central Africa

In West Africa, near the coast, there is a transition from the humid tropical forest to the semi-deciduous forest and a mosaic of savanna and forest to the grasslands of the wooded savanna when the duration of the dry season increases and precipitation decreases. Shifting cultivation is common with devices similar to those practiced in wetlands. Fallows are generally inadequate to maintain soil fertility and crop yields decline, except when new, better-yielding and resistant crop varieties.

Upper subhumid lands of East Africa

Large upland areas are more than 1 000 m above sea level and several mountainous areas have elevations from 1 500 to over 4 000 m. Temperatures throughout this area are relatively low due to altitude. Fields above 1500 m can see crop yield limited by low temperatures. Rainfall is 900-1,500 mm per year and the length of the growing season is six to nine months. Soils (Nitisols, Andosols and some Ferralsols) have relatively good fertility: Ferralsols and Andosols have good structure and depth, Nitisols have a high base saturation, and lower temperatures slow down the decomposition of matter (FAO, 2003).

The subhumid and semi-arid zones of southern Africa

The vast areas from southern Rwanda to the Cape of Good Hope are mostly at altitudes between 500 and 1000 m, and receive lower rainfall than those received on the highlands. Part of this area is subhumid but most of it is semi-arid.

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36 Situation des ressources genetiques forestieres : http://www.fao.org/docrep/004/ab385f/ab385f03.htm#bm3.1

The natural vegetation of the subhumid zone ranges from miombo woodlnds via wooded savanna to grasslands, becoming dominant when the climate becomes drier. The dominant soils in the semi-arid areas are the Arenosols, with low natural fertility. When the climate becomes more humid, the Luvisols, Ferralsols and Cambisols dominate, with a slightly higher natural fertility but still weak. Degradation through erosion and nutrient depletion is common throughout the region (FAO, 2003).

The Sudano-Sahelian zone

The Sudanian savannah zone is generally considered to be semi-arid wet and the Sahelian zone as semi-arid dry. In these two areas, water availability tends to be the critical factor determining production systems. In the drier parts of the Sahel, extending to the arid zones, nomadism is still widespread. From drier to wetter areas, agricultural production plays an increasing role in the system. In the past, long fallows gave a chance to regenerate the sparse vegetation of trees and bushes, when the cattle were moved to graze elsewhere.

The arid zone of eastern and southern Africa

Despite very low and irregular precipitation, there is normally sufficient vegetation to allow livestock grazing. But as rainfall is uncertain, livestock must move where food is available and nomadism is therefore frequent (FAO, 2003).

Educational activities (exercise and case studies)

On the basis of the information presented in the course and other literature, prepare in a group of 4-5 a technical sheet on the phytogeographical domains

5.12 Monitoring objectives

Objective

1. Identify and analyse indicators for monitoring forest biodiversity.

Stating the problem of analyzing and monitoring biodiversity in forests implies not only fixing the limits of investigation (within the plant world, for example), but also of deciding precisely the scale of analysis and the frequency of observations to be made (Rondeux, 2002). Biodiversity is dynamic and evolving, its processes and composition are constantly changing due to natural and anthropogenic factors. With biodiversity, there are problems of spatial and temporal variation that are related to biospheric and geospheric processes.

Biotic successions and the development of soils relate to complex ecological phenomena which are integrations of several biological, chemical and physical processes requiring years, sometimes centuries, to express themselves (Jeffers, 1996).

The monitoring objectives are:

- carry out long-term observations of forest ecosystems, mainly for production purposes, in the context of climate change;
- generate knowledge on the causal relationships between external factors and observed trends for forecasting and predictive scenarios through modeling;
- develop partnerships and be part of the continuum of forest ecosystem measurement and observation devices allowing necessary extrapolation and generalization in connection with other relevant devices or experiments; and,
- help decision-makers and managers make sustainable management choices for forest ecosystems in a changing and uncertain context.

Educational activities (exercise and case studies)

On the basis of the information presented in the course and other literature issues, prepare in groups of 4-5 a case study on identifying issues and building indicators for monitoring forest biodiversity in a given territory.

5.13 Evaluation of the state and the dynamics of biodiversity

5.13.1 Biodiversity assessment and monitoring (Biomonitoring)

Objective

By the end of the session, the learner will be able to:

Describe indicators for monitoring and evaluation of biodiversity.

Learning outcomes

At the end of this session, learners will be able to assess future changes in the state of a forest ecosystem and its biodiversity.

General introduction

Assessments of intra-specific and interspecific diversity of forest ecosystems are essential to conserve and manage forest resources (Hunter, 1999). Such assessments are used to provide data needed to support decisions related to biodiversity at policy and forest mana-gement levels. Assessing biodiversity presents a number of challenges. First, because of its complexity, information must be gathered and expressed with simplified variables, normally in the form of indicators (Noss, 1990, 1999). Second, given that forest decisions are taken at different scales, biodiversity data and indicators will need to be grouped together with these scales for monitoring and reporting purposes (Noss, 1990; Turner, 1995).

Choice of indicators

The choice of indicators to be used in an assessment of forest biodiversity depends on the objectives pursued. Biodiversity indicators adapted to the level of a forest ecosystem can be subdivided into eight major groups[37]:

- forest area by type and stage of succession in relation to land area;
- forest protected area by type, stage of succession and protection category in relation to total forest area;
- degree of fragmentation of forest types;
- conversion rate of forest cover (by type) to other uses;
- area and percentage of forests affected by anthropogenic and natural disturbance;
- complexity and heterogeneity of the forest structure;
- number of species dependent on the forest; and,

37 FAO, Indicateurs de la biodiversité dans les inventaires forestiers nationaux http://www.fao.org/docrep/005/y4001f/Y4001F09.htm

- state of conservation of forest-dependent species.

Indicators of forest fragmentation require large-scale spatial data on forest cover and may include measurements of forest block size and connectivity, or indices that associate these attributes (Kapos, Lysenko and Lesslie, 2000).

Evaluation method

Traditional forest inventory methods combined with remote sensing and GIS techniques can be used to collect data on monitoring and evaluation indicators. The inventory of taxa not included in the forest inventory can be carried out by field surveys. Particular attention should be paid to sampling design and stratification and monitoring methods during both the forest inventory and complementary studies (Dallmeier and Comiskey, 1998a; Bachmann, Köhl and Païvinen, 1998; Boyle and Boontawee, 1995; Vanclay, 1998). Satellite imagery can be used as a basis for stratification of field samples as well as for mapping the distribution of species closely associated with distinct types of vegetation.

Educational activities (exercise and case studies)

Based on the background information presented in the course and other literature, prepare as a group of 4-5 an analytical summary on forest biodiversity indicators and assessment methods.

5.14 Biodiversity indices

Objective

By the end of the session, the learner will be able to:

Explain the methods used for estimating biological diversity.

General introduction

Biodiversity refers to the diversity of the living world in all its forms and at all scales: ecosystem diversity, species diversity and genetic diversity[38]. Knowledge of forest biodiversity is essential for its management and rational exploitation. Several methods are generally used to better understand the biodiversity of forest ecosystems. Biodiversity indices can be combined with other methods to estimate changes and generate knowledge on forest biodiversity.

Shannon index

To quantify simultaneously the taxonomic richness and distribution of taxa in a community, diversity indices are often used; the three main ones being Shannon-Weaver, Simpson's and Gleason's[39]. The Shannon index is an index for measuring specific diversity. It gives an idea of the specific diversity of an environment. That is, the number of species of this medium (specific richness) and the distribution of individuals within these species (specific equitability)[40]. The Shannon-Weaver Index is based on the proportions of species that 'we observe. It therefore combines taxonomic richness and equitability[41].

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

H': biodiversity index; *i*: a species; $p_i = n_i / N$ where n_i is the number of individuals of the species and N is the total number of individuals of all species combined[42].

In nature the value of H' is generally between 0.5 (very low diversity) and 4.5 (in the case of complex communities). The higher the value of the H' index, the greater the diversity. The Shannon-Weaver index is well suited to the comparative study of communities because it is relatively independent of the size of the surveys[43]. It is part of the information theory indices that assume that diversity in an ecosystem can be measured as the information contained in a message or code[44]. The Shannon-Weaver index is the simplest of these indices and is the most widely used (as an example, see table 12).

38 CNPF, 2012, Indice de biodiversité potentielle: http://crpf-paysdelaloire.fr/sites/default/files/fiches/lindice_de_biodiversite_potentielle.pdf
39 Nature ordinaire, Mesurer la biodiversité d'un site: http://natureordinaire.over-blog.com/article-mesurer-la-biodiver-site-d-un-site-57668977.html
40 Indice de Shannon : https://fr.wikipedia.org/wiki/Indice_de_Shannon
41 Mesures de la diversité biologique Roscoff (2005) : http://max2.ese.upsud.fr/epc/conservation/BEMA/Indices_biodiversite_070305.pdf
42 Indice de Shannon : https://fr.wikipedia.org/wiki/Indice_de_Shannon
43 Nature ordinaire, Mesurer la biodiversité d'un site: http://natureordinaire.over-blog.com/article-mesurer-la-biodiver-site-d-un-site-57668977.html
44 Observatoire du sahara et du sahel : http://www.oss-online.org/cd_envi/doc-new/02/06/02/05.pdf

Table 12. Method of calculation of the Shannon-Weaver index and its equitability for a permanent monitoring station

Station 1	Species Frequency	$p_i = n_i/N$	$log^2\ p_i$	$-\ p_i\ log^2\ p_i$
Astragalus armatus	4	0.1739	-2.5236	0.4389
Deverra tortuosa	2	0.0870	-3.5236	0.3064
Zygophyllum album	1	0.0435	-4.5236	0.1967
Cynodon dactylon	1	0.0435	-4.5236	0.1967
Diplotaxis harra	4	0.1739	-2.5236	0.4389
Astragalus corrugatus	1	0.0435	-4.5236	0.1967
Stipa capensis	10	0.4348	-1.2016	0.5224
N = 23				
S = 7				
Shannon index	H'= 2.2966			
Equitability E = H'/log2S = 0.8181				

Source: Jauffret (2001)

Simpson index

This index is part of the dominance indices that take into account the measured frequency of species. It is the most widely used. The Simpson index attaches more importance to, and is therefore more sensitive to, the more frequent species than to the total species richness (Magurran, 1988). The expression of the Simpson index (Simpson, 1949) is:

$$D=\sum_{i=1}^{S} p_i^2$$

The lower the Simpson index, the higher the specific diversity. The measure of equitability corresponding to the Simpson index is:

$$E=\frac{D}{1-\frac{1}{S}}$$

The inverse of Simpson makes it possible to vary the index in the same direction as the diversity: the more the specific diversity is higher the index is strong[45].

$$D=\frac{1}{\sum_{i=1}^{S} p_i^2}$$

45 Observatoire du sahara et du sahel : http://www.oss-online.org/cd_envi/doc-new/02/06/02/05.pdf

Equitability index

The relative abundance structures of species determine equitability or the dominance component of diversity. For example, given a phytocenosis consisting of S species, diversity is higher if all S species are well represented (high equitability, low dominance) than if a small number of species, called T, are very common and the remainder (S - T) are present but rare (low fairness, strong dominance). Equity assessment is useful for detecting changes in the structure of a community and has sometimes proved effective in detecting changes of anthropogenic origin. The equivalency measure for the Shannon-Weaver index is calculated using the following formula[46]:

$$E = \frac{H'}{\log_2 S}$$

Potential biodiversity index (PBI)

The PBI is a simple and fast tool that allows forest managers:

- to estimate species hosting capacity of their stands; and,
- to choose the improvements to be made in the day-to-day management of their forests.

It can be used before silvicultural intervention or in the preparation of management documents [47].

Educational activities (exercise and case studies)

From the basic information presented in the course and other literature issues, prepare in groups of 4-5 a fact sheet on biodiversity indices with examples of application.

46 Observatoire du sahara et du sahel : http://www.oss-online.org/cd_envi/doc-new/02/06/02/05.pdf
47 CNPF, 2012, Indice de biodiversité potentielle: http://crpf-paysdelaloire.fr/sites/default/files/fiches/lindice_de_biodiversite_potentielle.pdf

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