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Climate is indeed an important environmental influence on ecosystems. Changing climate affects ecosystems in a variety of ways. Climate and natural ecosystems are tightly coupled, and the stability of that coupled system is an important ecosystem service. Keeping this in view, in this block, soil ecosystem, ocean ecosystem, wetland and mountain ecosystem are discussed with the view that the functioning of many ecosystems can be restored, if appropriate action is taken in time.

Unit 5 “Soil Ecosystem” provides with an overview of soil interactions with environmental components. This unit also highlights soil as a source of greenhouse gases emissions, impact of climate change on evapotranspiration, soil salinization and soil carbon and nitrogen dynamics.

Unit 6 “Ocean Ecosystem” discusses the effects of climate change on the physical, chemical and biological properties of ocean; the vulnerability of marine organisms to climate change, and response of ocean ecosystem to climate change. This unit also deals with the migration pattern of marine organisms to climate change.

Unit 7 “Wetland Ecosystem” deals with the impacts of climate change on wetland productivity and sustainability. This unit delves on the inter-linkages between climate change and wetland and how wetland restoration and conservation play a crucial role for climate change resilience and sustainable development. The unit also covers the vulnerability and impact assessment of wetlands to climate change and wetland restoration for climate change resilience.

Unit 8 “Mountain and Hill Ecosystem” discusses the distinct features of mountain ecosystem, potential threats of climate change on glaciers’ melting, biodiversity, crop production, livelihood support system, and the vulnerability of traditional agricultural system. This unit also discusses soil erosion, sedimentation, bank cutting, floods, traditional agriculture and migration of people due to climate change.

**Objectives**

After studying this unit, you will be able to:

- Discuss the climate change impact on soil carbon and nitrogen dynamics;
- Discuss the greenhouse gases emissions from soil;
- Explain the effects of climate change on the physical, chemical and biological properties of ocean;
- Explain the response of ocean ecosystem to climate change;
- Explain the interactions between wetlands and climate change;
- Discuss the vulnerability and impact assessment of wetlands to climate change;
- Discuss the role of wetlands in climate change resilience; and
- Describe potential threats of climate change on glaciers’ melting, biodiversity, crop production, livelihood support system.

We hope that after studying this block, you will acquire an understanding of the effects of climate change on soil ecosystem, ocean ecosystem, and wetland and mountain ecosystem.

Wishing you success in this endeavour!
UNIT 5 SOIL ECOSYSTEM

Structure

5.1 Introduction
5.2 Objectives
5.3 Soil and its Interactions with the Environment
5.4 Climate Change Impacts on Soil Carbon and Nitrogen Dynamics
5.5 Greenhouse Gases Emission from Soil
5.6 Impacts of Climate Change on Soil Salinization
5.7 Impacts of Climate Change on Evapotranspiration
5.8 Let Us Sum Up
5.9 Keywords
5.10 Suggested Further Reading/References
5.11 Answers to Check Your Progress

5.1 INTRODUCTION

Since the industrial revolution, anthropogenic activities such as industrial, economic and land-use and population growth have contributed substantially to climate change by adding CO\textsubscript{2} and other heat-trapping gases to the atmosphere. CO\textsubscript{2} remained the major anthropogenic GHG accounting for 76\% (38±3.8 GtCO\textsubscript{2}eq/year) of total anthropogenic GHG emissions in 2010. 16\% (7.8±1.6 GtCO\textsubscript{2}eq/year) come from CH\textsubscript{4}, 6.2\% (3.1±1.9 GtCO\textsubscript{2}eq/year) from N\textsubscript{2}O, and 2.0\% (1.0±0.2 GtCO\textsubscript{2}eq/year) from fluorinated gases. The IPCC estimated that global mean surface temperature could rise over 6°C by 2100. The atmospheric concentration of CO\textsubscript{2} has increased by 42\% from 280 ppm in the preindustrial era to 400 ppm in 2014. Increase in the concentration of CO\textsubscript{2} and other GHGs (CH\textsubscript{4}, N\textsubscript{2}O) has increased the global mean temperature by 0.85°C (0.65±1.06°) over the twentieth century (IPCC 2014).

Continued emission of GHGs will cause further warming of the atmosphere; changes in entire components of the climate system; and severely affect the livelihood, and cause pervasive and irreversible impacts on people and ecosystems (terrestrial and aquatic ecosystem). Climate change will also amplify existing risks and create new risks for natural and human systems. Risks are unevenly distributed and are generally more significant for disadvantaged people and communities in countries at all levels of development. The appearance of abnormal precipitation and extremes will modify climate change impacts and creates adverse effects on soil, plants and human and animals. Climate change is also assumed to enhance the severity and frequency of floods, wildfire, glaciers melting, dry spell, spreading of new disease, crop shifting, famine and insect-pest attacks (Lal, 2011). This unit will give you an overview of soil interactions with environmental components; soil as a source of greenhouse gases emissions; climate change impacts on soil carbon and nitrogen dynamics; and also the impacts of climate change on evapotranspiration, and soil salinization.
5.2 OBJECTIVES

After studying this unit, you should be able to:

- identify the interactions between soil and components of environment;
- explain greenhouse gases emissions from soil;
- explain the climate change impacts on soil carbon and nitrogen dynamics; and
- explain the impacts of climate change on evapotranspiration, and soil salinization.

5.3 SOIL AND ITS INTERACTIONS WITH THE ENVIRONMENT

The soil is an integral part of the environment. The lithosphere, hydrosphere, atmosphere, and biosphere are environmental compartments that overlap and are intimately associated in the ecosystem. Therefore, what happens in soil should have a profound impact on not only soil quality but also ecosystem health. The soil is a dynamic system in which continuous interaction takes place between soil minerals, organic matter, and organisms. Each of these three major soil components influences the physicochemical and biological properties of terrestrial systems. Interactions between the mineral, organic and biological factors have an enormous impact on terrestrial processes critical to environmental quality and ecosystem health; they control the cycling and bioavailability of nutrients and xenobiotic substances in the environment through physical, chemical, biochemical and biological processes. Soil and its interactions with the environment components is presented in Fig. 5.1.

Fig. 5.1: Soil and its interactions with the environment components (Modified from Lal, 2011)
Changing climate is a growing consensus among the scientific as well as the farming community in the 21st century. As per the World Meteorological Organization (WMO), there are several natural and human-made mechanisms affecting the global energy balance and force changes in Earth’s climate. The radiatively active gases, viz. carbon dioxide (CO$_2$), methane (CH$_4$) and nitrous oxide (N$_2$O), popularly known as the ‘greenhouse gases’ (GHGs) are one such mechanism. GHGs absorb and emit some of the outgoing energy radiated from Earth’s surface, causing that heat to be retained in the lower atmosphere. Consequently, the average temperature of Earth’s surface atmosphere is increasing, a phenomenon which is commonly known as global warming.

The climate change and its variations are driven by both natural as well as anthropogenic factors and that are separately emphasized in definitions of climate change stated by Intergovernmental Panel on Climate Change (IPCC) and United Nations Framework Convention on Climate Change (UNFCCC). According to IPCC, climate change can be defined as a change in climate state that can be identified by changes in the mean and/or variability of its properties, that persists for an extended period typically decades or longer, whether due to natural variability or as a result of human activity. Moreover, UNFCC, defined as a change of climate that is attributed directly/indirectly to anthropogenic activity that alters the global atmospheric composition and that is in addition to natural climate variability observed over comparable periods (UNFCCC, 2011).

The global environmental consequences of climate change will pose severe effects on terrestrial ecosystems, especially for agriculture and forestry. The apparent connection between soil health and climate is moderated through sink and source of carbonaceous (CO$_2$, CH$_4$, soot), nitrogenous (N$_2$O, NO$_x$), and other organic and inorganic compounds. In agriculture, the soil is an essential component that supports crop production, a platform for biogeochemical processes, source or a sink for GHGs, buffer medium for chemical reactions, microbial diversity and life on the earth (Fig. 5.1). Soil organic matter (SOM) is an integral part of soil to sustain soil fertility and health and, also provide a resilient capacity to soil. The increasing SOM can halt the rising concentration of GHG mainly CO$_2$ in the atmosphere and improve soil structure, and reducing soil erosion and land degradation processes. A healthy soil improves plant yield, promotes plant, animal and human strength, maintains water and air quality, supports a diversity of soil microbes, and resists stresses of human impact and climatic perturbations, so resists environmental degradation. However, climate change can adversely affect the vital processes of soil like physical, chemical and biological functions as shown in Table 5.1 (Lal, 2011).

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Climatic variable</th>
<th>Effects</th>
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<tbody>
<tr>
<td>1.</td>
<td>Increasing temperature</td>
<td>Loss in SOC</td>
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<td></td>
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<td>Decrease in labile pool of SOM</td>
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<td>Decrease in moisture content</td>
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<td>Increase in mineralization rate</td>
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<td>Soil structure destruction</td>
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Table 5.1. Climate change effects on soil processes (Pareek, 2017).
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<th>2.</th>
<th>Increasing CO₂ level</th>
<th>Loss of SOM</th>
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<td></td>
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<td>Increase in WUE</td>
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<td>More availability of carbon to soil microbes</td>
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<td></td>
<td>Nutrient cycling acceleration</td>
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<td>Increase in soil respiration rate</td>
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<td>3.</td>
<td>Fluctuations in rainfall (Increase/decrease/scattered)</td>
<td>Increase in soil moisture content</td>
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<td>Surface runoff and erosion increased</td>
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<td></td>
<td></td>
<td>Nutrient leaching acceleration</td>
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<td>Increased reduction of Fe and nitrates</td>
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<td>Increased volatilization loss</td>
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<td>Increase in productivity in arid zones</td>
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<td></td>
<td></td>
<td>Reduction in SOM</td>
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<td></td>
<td></td>
<td>Soil salinization increased</td>
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<td>Reduction in nutrient availability</td>
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</table>

### 5.4 CLIMATE CHANGE IMPACTS ON SOIL CARBON AND NITROGEN DYNAMICS

Physical, chemical and biological properties of soil provide information associated with water, air, temperature, microbial activities, and soil reactions, as well as conditions influencing germination, root growth and erosion processes. Several soil physical properties form the basis of other chemical and biological processes, which may be further directed by climate, landscape position, and land use. The carbon and nitrogen dynamics of soil are highlighted as potential soil health factors, and critical soil indicators about climate change include mineralization, volatilization, microbial decomposition, salinization, evapotranspiration, enhanced greenhouse gases emissions, which are discussed below (Fig. 5.2).

The organic matter content in the soil is a sign of organic matter quality and soil health, acting as nutrient agent for microbes during the nutrient cycling process under climate change conditions (Gregorich et al. 1994). SOM drives the soil functions, and decreases in SOM can lead to a reduction in fertility and microbial biodiversity, as well as a loss of soil structure, followed by decreased WHC, increase in soil erosion (Weil and Magdoff 2004). At the farm level, land use change and management practices that lead to building up of organic matter in soil will help absorb CO₂ from the atmosphere, thus mitigating global warming and climate change abnormalities. By increasing soil moisture and water storage, organic matter can perform an essential role in the mitigation of flooding impacts following extreme rainfall events, while saving water in the event of droughts thus increasing soil resilience.
Microbial biomass, the living segment of SOM, is regarded as the common labile C pool in soils and a sensitive indicator of changes in soil quality, with links to soil nutrient and energy dynamics due to climate change (Haynes 2008; Saha and Mandal 2009). The recent investigations are showing that a significant decrease in the soil microbial biomass during long-term simulated climatic warming experiments (Rinnan et al. 2007). Soil organic carbon (SOC) decomposition is a microbial and enzymatic process, and the temperature dependence of SOC decomposition follows the Arrhenius equation, that is:

$$k = a \exp^{\frac{-E_a}{RT}}$$

Where $k$-reaction rate is constant, $a$-frequency factor, $E_a$-activation energy, $R$-gas constant (8.314 J K$^{-1}$ mol$^{-1}$) and $T$-temperature (K) (Arrhenius 1889).

The temperature dependence of SOC decomposition has also been described by $Q_{10}$ based functions, which is the factor by which the reaction rate increases with every 10 degrees rise in temperature (Table 5.2) (Davidson et al. 2006; Kirschbaum, 1995, 2000).

**Table 5.2.** Likely changes in soil organic carbon (C) stocks in major pools in a simulated upland soil and a permafrost soil in response to global warming by 2100 (modified from Dalal et al., 2011; Davidson and Janssens, 2006)
Deposition of atmospheric nitrogen ranges from 1 to >20 kg N ha$^{-1}$ year$^{-1}$ (Galloway et al. 2004; Phoenix et al. 2006), with primary deposition (>10 kg N ha$^{-1}$ year$^{-1}$) happening in populated regions of North America, Western Europe, South Asia and East Asia (Galloway et al. 2004). The extra nitrogen provided through atmospheric deposition can spur plant growth and hence increases C input as well as adds to soil N supply. The additional deposited N supply not only improves the result of elevated CO$_2$ concentration on SOC, it may also slow the rate of organic matter decomposition (Pepper et al. 2007).

Carbon stocks in the terrestrial ecosystem have been changed by growing atmospheric CO$_2$ concentration and N deposition, as well as by changing the land use pattern (Matson et al. 2002). In 2005, agriculture considered for an estimated emission of 5.1–6.1 Gt CO$_2$-eq year$^{-1}$, which is 10–12% of total global anthropogenic emissions of GHGs (Smith et al. 2007). The N-limited systems initially hold the deposited N by using it for plant and microbial growth as well as via accumulation in plant biomass and soil organic matter. Though, when inputs of N found to exceed the biotic needs within the ecosystem, the excess N can be possibly lost via leaching and gaseous emissions and triggers climate change (Matson et al. 2002). The induced N addition can have a deleterious impact on the soil through acidification and a consequential reduction in plant and microbial biodiversity (Galloway et al. 2003). During the acidification process, soils release base cations (Ca$^{2+}$ and Mg$^{2+}$), neutralizing the development in acidity. Though, over time and with sustained enhancement of N, the base cations can be consumed, at which time Al$^{3+}$ is released from soil minerals, often approaching towards toxic levels. Soil acidification influences to reduce microbial N immobilization (Venterea et al. 2004).

Check Your Progress 1

Note: a) Use the space given below for your answers.

b) Check your answers with those given at the end of the unit

1. What are the effects of increase in surface air temperature on soil?

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2. What are the potential impacts of increasing atmospheric carbon dioxide concentration on the soil environment?

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3. What are the significance of soil organic matter?

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5.5 GREENHOUSE GASES EMISSION FROM SOIL

Climate change is global phenomena and happening continuously since the earth came into existence. Climate change has become a significant scientific and political concern during the last decade. The soil appears to be more relevant for human societies than ever before to meet the global food requirements for the increasing population from limited soil resources. Climate change is predicted to have obvious consequences on agriculture through direct and indirect effects on crops, soils, livestock, and pests. Though climate change is a slow process including comparatively small changes in precipitation and temperature over a long time, these slow changes in climate influence the several soil processes. The impact of climate change on soils are expected mainly through a change in soil moisture content and fluctuations in soil temperature and CO$_2$ levels as a consequence of adverse climatic effects. The principal effect of climate change is expected through emission of GHGs especially CO$_2$, CH$_4$ and N$_2$O, and increase in temperature (Pareek, 2017).

Soil microbes have significant roles in climate change as well as in carbon and nitrogen dynamics in soil. The mitigation roles link to the capacity of microorganisms such as bacteria, algae, fungi, and archaea to create and utilize all the GHGs, i.e., N$_2$O, CH$_4$ and CO$_2$. The biogeochemical processes are cyclic, dynamic and adaptive and are regulated by several edaphic and climatic factors such as ambient and soil temperature, moisture content and management strategies (Fig. 5.3) (Mele, 2011). The soil microbes are likely to be influenced directly like physiological stress and adaptation responses and indirectly via habitat modification by global change scenarios. These climatic scenarios involve elevated temperature (1.4-5.8°C by 2100), elevated atmospheric CO$_2$ (540 and 970ppm by 2100), elevated atmospheric N (316ppb in 2000) and fluctuating CH$_4$ concentrations (700ppb in 1,750 to 1,775ppb in 2005), and precipitation changes by an average of 20% on current levels (Solomon et al. 2007).

Human-induced change of the biogeochemical cycles is the most significant environmental challenge, particularly for C and N cycling (Mele, 2011). These cycles are highly interdependent and involved explicitly in greenhouse gas emissions into the atmosphere. Nitrous oxide (N$_2$O) and nitric oxide (NO) both are major GHGs that are generated from the plant and organic nitrogen by microbes which are converted into nitrogen gases, N$_2$O and N$_2$, and intermediary NO. There are two highly linked, microbial processes that produce N$_2$O and NO are nitrification
and denitrification. Nitrous oxide is released from soil during the processes of nitrification and denitrification. Nitrification is the microbial oxidation of $\text{NH}_4^+$ to $\text{NO}_3^-$ in the soil. Although the nitrification process is a key measure in the conversion of ammonia nitrogen into its gaseous forms, this process is less connected to $\text{N}_2\text{O}$ emissions. Denitrification includes the reduction of $\text{NO}_3^-$ to $\text{NO}$, $\text{N}_2\text{O}$, and $\text{N}_2$ under anaerobic conditions of the soil (Green et al. 2010).

Globally, the SOC pool is expected to be $\sim 1,395 \times 10^{15}$ g (Post et al. 1982), and accumulation is regulated mainly by net primary productivity (NPP) while losses are mainly a function of the biological stability of the several chemical forms such as cellulose, tannins, lignin, starches, sugars and the gases ($\text{CO}_2$ and $\text{CH}_4$). The decomposition of organic carbon in soil and the generation of $\text{CO}_2$ during aerobic respiration are governed by the heterotrophic microbial community (Paul, 2007). The production of $\text{CH}_4$ in the comparatively more complicated microbial process governed by methanogens is also a respiration process that uses $\text{CO}_2$ and other forms of C instead of oxygen. $\text{CH}_4$ has 25 times more global warming potential than carbon dioxide (IPCC, 2007) and thus even at lower atmospheric concentrations provides about half the radiative climate forcing of $\text{CO}_2$ (Beerling et al. 2009). $\text{CH}_4$ is produced by methanogens and consumed by methanotrophs in the soil and ocean sediment at particular climatic conditions. $\text{CH}_4$ can be produced by both acetotrophic and hydrogenotrophic methanogens, and variations in environmental situations influence the structure of these communities (Demirel and Scherer 2008).

Climate is a principal factor in the growth and development of plant, and animals. The severe climate events and unsustainable land use and management, such as degradation of forest lands and intensive tillage operations in croplands, have been threatening soil fertility and the health of the surrounding environment. These outcomes, rather than turning soil into a sink of gases, make soil a source of GHG
emissions, thus deteriorating the physical, chemical and biological components of soil quality. Holistically, under the nexus of climate change scenario and agricultural systems, sustainable management practices play a significant role in resilience to climate change. Such as conservation agriculture practice, i.e., minimal soil disturbance, plant and soil microbe’s biodiversity, soil cover and careful integration of livestock into farming systems that build SOM and SOC could help improve soil resilience to climate change via fulfilling the soil health components.

5.6 IMPACTS OF CLIMATE CHANGE ON SOIL SALINIZATION

Salt is necessary for cooking and food preparation, but much quantity of salts in the soil can destroy the crops and render fields useless. Soil salinization in irrigated and rainfed areas is a degradation process that wrecks both soil fertility and crop productivity. The main foreseen consequences of climate change will be denoted by higher and more variable in temperatures, precipitation patterns and a higher frequency of extreme events (Ashour and Al-Najar, 2012). Diminishing water resources linked with salinity intrusion into surface and subsurface water will pose menace to water security. Therefore, sensing the linking of surface and subsurface water is crucial in managing sustainable water resource utilization. Water scarcity and soil salinization globally will have a significant impact on food security (Teh and Koh, 2016). The consequence of global warming and climate change are ubiquitous but essential for arid areas that are most prone to soil salinization. Salt accumulation is considerably accelerated in the soils of Central Asia. The climatic factor (mainly precipitation) defines the way of salt redistribution in the soil profile. The winter and spring rainfall ensures more rapid carryover of readily soluble salts.

The climatic variations will expand the regions of saline soils mainly due to following reasons: firstly, the increasing temperature and aridity have a direct effect on salt movement and the salt balance of soils, and secondly, the indirect effect on salt dynamics by altering the land use pattern (Szabolcs, 1990). When sea levels rise, low-lying coastal regions are frequently being inundated with saltwater, continually contaminating the nearby soil. These salts can be scattered by rainfall, but climate change is also increasing the incidence and severity of extreme weather situations, including droughts and heat waves. This leads to more exhaustive use of groundwater for drinking and irrigation, which further drains the water table and allows even more salt to leach into the soil. Climate change factors affect soil salinity by rising ocean temperatures and warming the water. Investigators currently predicted that global mean sea levels would rise by at least 0.25 to 0.5m by 2100, even with higher decreases in GHG emissions. Globally, soil salinity will cause increased food prices and more food deficits and several farmers are also getting lower yields, which indicates less income.

5.7 IMPACTS OF CLIMATE CHANGE ON EVAPOTRANSPIRATION

Evapotranspiration (ET), one of the principal elements of the hydrologic cycle, is influenced by climate change. The climatic factors are changing over extended periods, which is an indication of climate change (IPCC, 2014). A change in the patterns of climatic factors due to climate change intends a variation in evapotranspiration rates (Helfer et al., 2012). Potential evaporation ($ET_0$) can be
regarded as a measure of atmospheric evaporative demand and is a measure of
the integrated effect of several meteorological factors, i.e., solar radiation, wind
speed, ambient temperature, vapour pressure, and humidity (Dinpashoh et al.,
2018). Atmospheric temperature is probably considered to be the most broadly
used indicator of climatic change on both regional as well as global scales. As per
the IPCC report (2013), over the past 100 years (1913–2012), global temperature
has increased by 0.91 °C (Stocker et al. 2014) and it is expected to continue
rising throughout the twenty-first century, modifying the hydrological cycle by
altering both precipitation and evaporation (Huntington 2006). This could have
significant influences on water quantity, quality and availability particularly in poor
semiarid regions (Dastorani and Poormohammadi, 2012). Potential
evapotranspiration (ET₀) is broadly recognized as a critical hydrological variable
describing a substantial water loss from catchments. It is related to groundwater
recharge, runoff, and water movements in soil, some critical kinds of hydrological
processes (Zhang et al. 2011), and it can also be used to determine actual
evapotranspiration (ETa), scheduled irrigation, and other management practices in
the crop field (Xu and Li 2003). Drought situations will reasonably be increased
due to climate change by raising potential evapotranspiration and growing crop
water consumption in water-scarce regions (Thomas 2008). According to the
forecasts of climate change models, ET₀ is supposed to increase over the coming
years due to expected temperature acceleration (Liu et al., 2018; Goyal 2004).

Check Your Progress 2

Note:  a) Use the space given below for your answers.
       b) Check your answers with those given at the end of the unit

1. What are the influences of climate change on soil salinization?

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2. What is potential evapotranspiration? What are the impacts of climate
   change on evapotranspiration?

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5.8 LET US SUM UP

We have studied in this unit about the importance of soil in crop production. We
have discussed in detail the potential impact of changing climate on soil carbon
and nitrogen dynamics, and also on evapotranspiration and soil salinization.

5.9 KEYWORDS

Soil : Soil is natural body developed by natural forces
acting on natural materials. It is usually differentiated
Soil Ecosystem

into horizons from mineral and organic constituents of variable depth which differ from the parent material below in morphology, physical properties and constituents, chemical properties and composition and biological characteristics.

Soil Moisture : Water stored in or at the land surface and available for evapotranspiration.

Evapotranspiration : The combined process of evaporation from the Earth’s surface and transpiration from vegetation.

Drought : A period of abnormally dry weather long enough to cause a serious hydrological imbalance.

5.10 SUGGESTED FURTHER READING/REFERENCES


5.11 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress 1

1. The effects of increase in surface air temperature on soil include but not limited to increase in mineralization rate; decrease in lable pool of soil organic matter; loss in soil organic carbon; decrease in moisture content; and soil structure destruction.
2. The potential impacts of increasing atmospheric carbon dioxide concentration on the soil environment include acceleration of nutrient cycles; increase in soil respiration rate; and increased availability of carbon to soil microbes.

3. The organic matter content in the soil is a sign of organic matter quality and soil health, acting as nutrient agent for microbes during the nutrient cycling process under climate change conditions. By increasing soil moisture and water storage, organic matter can perform an essential role in the mitigation of flooding impacts following extreme rainfall events, while saving water in the event of droughts thus increasing soil resilience. At the farm level, land use change and management practices that aid in building up of organic matter in soil will help absorb CO₂ from the atmosphere, thus mitigating global warming and climate change abnormalities.

Check Your Progress 2

1. The climatic change and variability will expand the regions of saline soils due to following reasons: firstly, the increasing temperature and aridity have a direct effect on salt movement and the salt balance of soils, and secondly, the indirect effect on salt dynamics by altering the land use pattern. The rise in sea levels rise lead to inundation of low-lying coastal regions, and contamination of soil. Increasing temperature leads to more exhaustive use of groundwater for drinking and irrigation, which further drains the water table and allows even more salt to leach into the soil.

2. Potential evaporation (ET₀) can be regarded as a measure of atmospheric evaporative demand and is a measure of the integrated effect of several meteorological factors, i.e., solar radiation, wind speed, ambient temperature, vapour pressure, and humidity. Potential evapotranspiration (ET₀) is broadly recognized as a critical hydrological variable describing a substantial water loss from catchments. It is related to groundwater recharge, runoff, and water movements in soil, some critical kinds of hydrological processes. Drought situations will reasonably be increased due to climate change by raising potential evapotranspiration and growing crop water consumption in water-scarce regions.
UNIT 6 OCEAN ECOSYSTEM

Structure

6.1 Introduction
6.2 Objectives
6.3 Ocean Ecosystem Responses to Climate Change
6.4 Climate Change Effect on the Physical, Chemical and Biological Properties of Ocean
   6.4.1 Changes in Physical Properties
      6.4.1.1 Changes in Water Temperature
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   6.4.2 Changes in Chemical Properties
      6.4.2.1 Ocean Acidification
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   6.4.3 Changes in Biological Properties
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      6.4.3.3 Effect of Sea Level Rise on Biological Diversity
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6.11 Suggested Further Reading/References
6.12 Answers to Check Your Progress

6.1 INTRODUCTION

The oceans occupy about 70 percent of the Earth’s surface and have an inter-relationship with daily and long-term changes in weather or climate. Climatic changes influence many properties of the ocean, while changes in the ocean also play a central role in regulating weather on local to global scales. Aquatic ecosystems (ocean and coastal ecosystems) like salt marshes, mangroves, etc., render significant services with respect to “carbon storage and sequestration” as they deliver important ecosystem services viz. “carbon storage, oxygen generation, food, and income generation”. The carbon stored in coastal and marine ecosystems is called blue carbon and it is now known to sequester and store more carbon per unit area than terrestrial forests, hence playing a role in climate change.
The ocean has huge thermal inertia and dynamic capabilities. Being a huge reservoir of heat, the ocean plays as a moderator of climatic variations. It controls the formation of wind and rain. The ocean also traps and stores carbon dioxide (CO₂), thereby preventing an extreme greenhouse effect in the atmosphere. The ability of ocean to absorb atmospheric carbon dioxide released due to fossil fuels use, is being critically examined by scientific fraternity, as they can render significant role in mitigation of climate change. According to the Fifth Assessment Report (AR5) published by the Intergovernmental Panel on Climate Change (IPCC), “the ocean has thus far absorbed 93% of the extra energy from the enhanced greenhouse effect, with warming now being noted at depths up to 1,000 m” (https://www.iucn.org/resources/issues-briefs/ocean-and-climate-change). Consequently, increased ocean stratification, changes in ocean current regimes and increase in depleted oxygen zones are now being observed. Further, shifts in geographical ranges and behaviour of marine species, changes in growing seasons, diversity and abundance of species communities are observed of late (https://www.iucn.org/resources/issues-briefs/ocean-and-climate-change). In this unit, we would endeavour to discuss the response of ocean ecosystem to climate change; effects of climate change on the physical, chemical and biological properties of ocean; and the vulnerability of marine organisms to climate change.

6.2 OBJECTIVES

After studying this unit, you should be able to:

- explain the response of ocean ecosystem to climate change;
- explain the effects of climate change on the physical, chemical and biological properties of ocean; and
- explain the vulnerability and migration pattern of marine organisms to climate change.

6.3 OCEAN ECOSYSTEM RESPONSES TO CLIMATE CHANGE

By means of the natural carbon cycle, many billions of tons of carbon flow through the atmosphere, ocean, terrestrial biosphere, and lithosphere in various forms. A great number of biological, chemical and physical processes, known as carbon pumps form the foundation of this continuous transport and conversion. Climatic factors strongly influence these processes and changes in the atmospheric concentrations of greenhouse gases (GHGs) and aerosols, land cover and solar radiation alter the energy balance of the climate system and act as drivers for changes in climate. Natural drivers of climate change include changes in the sun’s energy output, earth’s orbital variations (known as Milankovitch cycles) and large volcanic eruptions. The more significant and fast drivers are the anthropogenic climate drivers including emission of greenhouse gases and alteration of land cover that make changes in the amount of sunlight reflecting back into space (the albedo).

The gases and solids released by volcanic eruptions which include carbon dioxide, water vapour, sulphur dioxide, hydrogen sulphide, hydrogen, and
carbon monoxide can influence the climate over a period of a few years, causing short-term climate changes. Studies have shown that volcanic gases and particles sprayed into the stratosphere cool the oceans and temporarily slow down the rate of global sea level rise caused by the greenhouse effect, followed by acceleration over periods of a decade or more. CSIRO in 2005 reported that, subsequent to a series of major eruptions occurring since 1960 (Mt. Agung in Indonesia in 1963, El Chichon in Mexico in 1982 and Mt. Pinatubo in the Philippines in 1991), there was temporary offset in rising of global sea level, which briefly masked the acceleration of sea level rise, that would otherwise have resulted from the effects of atmospheric GHGs. In addition to GHGs, volcanic eruptions inject sulphur bearing gases into the stratosphere which get oxidized to form sulphate aerosols, with a lifetime of about 2–3 years. They spread around the globe by the atmospheric circulation, producing a cooling effect on the ocean surface temperature by approximately 0.2-0.3 °C, which usually lasts for several years. However, in the subsurface ocean, the cooling signals may linger long and may have impacts on some decadal variability, such as the Atlantic Meridional Overturning Circulation (AMOC). Lava and ash, also act as a fertilizer providing iron and phosphorus, fuelling the algae growth which has been observed in the ocean near the eruption zone.

The ocean is being also disproportionately impacted by rising carbon dioxide and other GHGs resulting from anthropogenic activities. The marine environment is already registering the impacts of increased heating in the lower atmosphere or Earth’s surface resulting from the ‘greenhouse’ effect caused by increasing atmospheric CO₂, methane and other gases (at a value of about 3 Wm⁻²). The direct physical consequences include increasing wind velocity and storm frequency; changes in ocean circulation, vertical structure and nutrient loads, rise in mean global sea surface temperatures (by 0.13°C per decade since 1979), and ocean interior temperatures (by >0.1°C since 1961), as well as global sea level rise (by more than 15 cm in the last century and presently by a mean of about 3.3 mm per year). All these changes in the physical, chemical and biological properties of oceans have been discussed in detail through subsequent sections.

### 6.4 CLIMATE CHANGE EFFECT ON THE PHYSICAL, CHEMICAL AND BIOLOGICAL PROPERTIES OF OCEAN

Climate change is having enormous impacts on ocean ecosystems, but we are only beginning to understand the magnitude of these changes. Warming trend appears to be accelerating irrespective of ocean’s vast capacity to absorb heat and carbon dioxide. Oceans witnessed more than 90 percent of Earth’s warming since 1950. In effect, climate change has resulted in increased ocean stratification; changes in ocean current regimes; expansion of depleted oxygen zones; changes in the geographical ranges of marine species; and shifts in growing seasons, diversity and abundance of species communities. Melting of inland glaciers and ice, causing rising sea levels with significant impacts on shorelines (coastal erosion, saltwater intrusion, and habitat destruction) and coastal human settlements are happening due to atmospheric warming (https://www.iucn.org/resources/issues-briefs/ocean-and-climate-change). The IPCC has given an estimated global mean sea level rise of 0.40 (0.26–0.55) m for 2081–2100 compared with 1986–2005 in a low emission scenario, and 0.63 (0.45–0.82) m for a high emission
Changes in ocean physical properties include changes in water temperature, oceanic circulation, rising sea levels as well as increased storm intensity.

6.4.1 Changes in Water Temperature

The ocean has absorbed more than 80 percent of the heat added to the Earth’s system by climate change, but it is taking a toll on the ocean. Over the course of less than a century, the frequency of oceanic heat waves has increased by more than 50 percent. Marine heat waves are defined as ‘at least five days with temperatures far above average, caused by heat from blazing sunshine and by shifting warm currents’. As a global average, there were over 50 percent more marine heat wave days per year in the duration 1982–2016 compared to the earlier part.

In general, heat stress and heat waves cause harm to marine environments. Heat waves result in considerable ecological and economic effects, such as coral bleaching, mass mortality of marine species due to heat stress, loss of kelp forests, species migration, and associated reshaping of community structure. Some studies suggest that fish and mobile invertebrates seem to manage the heat waves by moving out to unoccupied habitats which in turn increases diversity. Birds and corals did poorly because of changes in prey availability and susceptibility to bleaching at high temperature, respectively. Corals and sea grasses, which tend to provide both habitats and resources for many other organisms to survive, are hardly hit making the adverse effects cascade across the ecosystem.

6.4.1.2 Melting of the Polar Ice

Increasing atmospheric warming is causing polar ice to melt and sea-ice in the Arctic has shown significant changes in coverage and thickness over the last 30 years. Studies show that, between 1980 and 2008, the extent of sea ice has declined by an average of 11%, with evidence of a recent acceleration and between 1980 and 2008 (28 years), the thickness of sea ice reduced by 50% to 1.75 m.

6.4.1.3 Rising Sea Levels

Sea level monitoring programmes and other data indicate increased sea levels currently compared to the past 2000 years. Sea expands when its water temperature increases. Likewise, melting of glaciers and polar ice leads to rise in sea level. Human activities like draining wetlands, groundwater withdrawal, dam construction, and land use change also contribute to sea level rise. Sea level rise is a serious concern as 41% of the world’s population lives within 100km of the coast. The current rate of increase in sea levels (3.1mm per year), is higher than that the values predicted by the IPCC for 2100. However, these rates are not similar globally and have spatial variability.

6.4.1.4 Changes to the Ocean’s Major Current Systems

Changes in ocean temperatures and wind patterns will affect and alter oceanic currents. As the ocean currents play a significant role in maintaining Earth’s
climate, changes in the ocean’s major current systems will have major repercussions for the global climate. Oceanographers have observed changes in the North Atlantic Ocean currents on account of increase in sea surface temperature and increase in melting of ice. The Atlantic plays a key role in managing global ocean currents. The sinking of large amounts of cooler water in this ocean creates currents in the Southern and Pacific oceans. Hence a slowing down of the currents in this region has global impacts. The entire Northern Hemisphere cools, Indian and Asian monsoon areas dry up, North Atlantic storms get amplified and less ocean mixing results in less plankton and other life in the sea. Also, it would lead to heating up of the southern hemisphere. The IPCC concluded that the circulation may reduce up to 54% by this century, if temperature increases by 4 degrees C and GHG emissions keep increasing.

### 6.4.2 Changes in Chemical Properties

The ocean acts as a carbon sink by absorbing large quantities of CO\textsubscript{2}. The CO\textsubscript{2} absorption capacity of the ocean is ten times than that of fresh water, as CO\textsubscript{2} is immediately reactive in sea water. This phenomenon causes changes in the chemical properties of the ocean.

#### 6.4.2.1 Ocean Acidification

It is reported that “the oceans absorb about 1/3\textsuperscript{rd} of the anthropogenic CO\textsubscript{2} emitted into the atmosphere”. As soon as CO\textsubscript{2} enters into the water from the atmosphere, it can form carbonic acid by reacting with water molecules, which causes a shift in the concentrations of the hydrogen carbonate (HCO\textsubscript{3}-) and carbonate (CO\textsubscript{3}\textsuperscript{2-}) ions. This has significantly slowed down global warming but made the ocean more acidic, threatening the survival of many marine species and ecosystems. The ocean acidification observed in the recent past is found to be 30 times greater than the natural variation. Further, the mean surface ocean pH has decreased by about 0.1 unit since the industrial revolution, which accounts to 25-percent increase in acidity, which is significant. If the carbon dioxide emissions continue, it is projected that ocean acidification levels would grow 144 percent by the year 2100.

Higher acidity greatly reduces the ability of marine organisms like corals to form their shells from calcium carbonate. Studies have shown that ocean acidification is disrupting calcium carbonate formation. Further, ocean acidification exacerbates existing “physiological stresses” and greatly reduces the growth and survival rates of few marine species, particularly in their early growth stages.

#### 6.4.2.2 Hypoxia

Increasing heat content in the ocean waters warms the water leading to lesser dissolved oxygen holding capacity. Changing global and regional climates and coastal eutrophication are observed to increase the prevalence of reduced oxygen levels (hypoxia) making marine ecosystems more vulnerable. Water where oxygen levels are less than 2ppm is known as hypoxic waters. In addition, if surface water is warmer, it doesn’t mix down as much into the ocean depths any longer. Reduction in mixing of lighter, warmer surface water with denser bottom water consequently hinders the supply of dissolved oxygen to deep-dwelling aquatic organisms. This can lead to areas called “oxygen minimum zones” where plants, fish, and other organisms would struggle to survive. Well-known examples of
such “dead zones” include the Gulf of Mexico, the Baltic Sea, the Adriatic Sea, the East China Sea, and the north-western shelf of the Black Sea. It is a swelling problem with severe consequences for marine life, including altering the habitat and behaviour of marine life, death, and catastrophic changes.

Check Your Progress 1

Note: 1) Use the space given below for your answers.
       2) Check your answers with those given at the end of this unit.

1. What is blue carbon?
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2. What is ocean acidification?
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6.4.3 Changes in Biological Properties

Biological changes include changes in the diversity and abundance of marine species. The ocean is an abode for millions of species, but our knowledge, especially for deep zones of oceans and its organisms are still only very partial making us significantly underestimate oceanic biodiversity. Climate change has a direct role in the loss of biological diversity; it alters abundance, diversity, and distribution of marine species. Their feeding, growth, development, and breeding, as well as the interactions between species are affected. Variations in water temperature, oxygen level, acidification, the severity of extreme climatic events and ocean biogeochemical properties affect marine life either directly or indirectly causing alterations on the metabolism of individuals, life cycles of species, predator-prey relationships and on changes in habitat.

6.4.3.1 Effect of Ocean Warming on Biological Diversity

- Warmer waters cause corals to expel the algae living in their tissues resulting in coral bleaching. Coral bleaching in turn adversely impacts the entire coral ecosystem and the species dependent on these coral ecosystems for growth.

- Forced migration of many species in order to reach the temperature requirements they need for feeding and breeding.

- Warmer waters can directly impact hatching, growth, development, the age of sexual maturity, the timing of spawning and survival of marine life such as cephalopods.

- Warmer waters decreases the upwelling causing lesser nutrients to reach the surface of ocean water. It is important to note here that many marine
Natural Ecosystems

ecosystems available prominently in the upwelling areas of ocean. Few prominent examples of such marine ecosystems thriving in the upwelling areas are found near Galapagos Islands and along the coast of California.

6.4.3.2 Effect of Melting of Polar Ice on Biological Diversity

- Algae play a significant role in the arctic food web, and support species such as Arctic cod. On the other hand, Arctic cod is found to support Arctic species like beluga whales, seals, polar bears, and narwhals. Nevertheless, melting of sea ice affects the algal production, resulting in the cascading effect in the arctic ecosystem.
- Decreasing extent of sea ice results in habitat loss for marine organisms such as minke whales, polar bears, seals, walruses, orcas, etc.
- Further, decreasing extent of sea ice affects the Antarctic krill, which perform a significant role in the Antarctic food chain. Antarctic krill is found to be an important food source for many seabirds and mammals (https://www.conservation.org/publications/Documents/CI_Five-Effects-of-Climate-Change-on-the-Ocean.pdf).

6.4.3.3 Effect of Sea Level Rise on Biological Diversity

- Species like coral reefs, mangroves, sea grasses, etc. depend on the shallower waters for their growth and development. Nevertheless, species that are slow growing are more vulnerable to sea level rise, as they are unlikely to keep pace with the rising sea level.
- Further, rising sea levels and change in ocean currents may affect the nesting beaches and migratory patterns of sea turtles.

6.4.3.4 Effect of Ocean Current Changes on Biological Diversity

- Ocean current changes may alter the migratory patterns of many marine animals.
- Also, species that are dependent on the ocean currents for growth and reproduction be affected. For example, many reef-building coral and reef fish species rely on dispersal of their larvae by currents (https://www.conservation.org/publications/Documents/CI_Five-Effects-of-Climate-Change-on-the-Ocean.pdf).

6.4.3.5 Effect of Increasing CO₂ on Biological Diversity

- Increase in carbon dioxide concentration in ocean and resulting ocean acidification has potential to affect marine organisms particularly those organisms which build shells of calcium carbonate. Examples are reef-building corals, molluscs, etc. Incidentally, these organisms play a significant role in maintaining the biological diversity of oceans.
- The growth of those species whose photosynthesis was limited by CO₂ will be increased in enhanced CO₂ situations. For example, a strong increase in photosynthesis rates was reported for cyanobacteria under higher CO₂ concentrations.

Rising ocean temperatures together with ocean acidification affect marine species and ecosystems. Fishes, seabirds, and mammals living in oceans, all are at great
threat from changing climate, including mass movements as species search for favourable environmental conditions, higher mortality rates and loss of breeding grounds. Physiochemical changes in characteristics of sea water also affect the metabolism of individuals, the life cycles of species, predator-prey relationships and alteration of habitats.

### 6.5 GEOGRAPHIC DISTRIBUTIONS

The current displacement rate of fishes towards the poles is 72.0±13.5 km/decade. Fisheries and food security in many southern countries will face a huge challenge as the geographic distribution of fish and the dynamics of ecosystems could undergo significant changes in the coming decades. The maintenance of healthy and productive marine ecosystems is a critical issue. The disturbances are now clearly established across a wide range of taxonomic groups ranging from plankton to top predators and in agreement with the theoretical approaches regarding the impact of climate change.

### 6.6 THE VULNERABILITY OF MARINE ORGANISMS

**Coral Bleaching**

Coral reefs are important group of marine organisms as they found to provide habitat to about one-third of the marine organisms. The growth and development of coral reefs are influenced by a suite of factors like temperature (optimum range lies between 22°C and 29°C), nutrients, currents, turbidity, light, pH, calcium carbonate content, etc. As regards the temperature condition, coral reefs are sensitive to rise in temperature. Under the condition of warm water (temperature more than the optimum for the coral growth), corals expel the algae (zooxanthellae) living symbiotically in their tissues, resulting in the bleached appearance of the corals. This is called as coral bleaching. Eventually, the coral bleaching results in the death of the corals. ([http://www.ocean-climate.org/wp-content/uploads/2017/03/coral-reefs_07-12.pdf](http://www.ocean-climate.org/wp-content/uploads/2017/03/coral-reefs_07-12.pdf)).

In addition, acidification adversely affects coral skeletons by reducing the calcification rates of corals, by impeding the thickening process causing low skeleton density and leaving them more susceptible to breaking. However, the acidification effects differ with the species, as it may be due to a differential ability of the organisms to control the pH of its calcification site ([http://www.ocean-climate.org/wp-content/uploads/2017/03/coral-reefs_07-12.pdf](http://www.ocean-climate.org/wp-content/uploads/2017/03/coral-reefs_07-12.pdf)).

- Rising sea levels also threaten the survival of many marine species. Species such as corals and sea grass meadows are also endangered since they require relatively shallow water for photosynthesis. Several marine species are also affected by rising sea levels. Example: Hawaiian Monk Seal. The monk seal population is reportedly declining at 4% annually.
- Declining phytoplankton population and krill may affect many marine organisms.
Check Your Progress 2

Note: 1) Use the space given below for your answers.

2) Check your answers with those given at the end of this unit.

1. What is coral bleaching?

2. What are the effects of sea level rise on biological diversity?

6.7 MIGRATION PATTERN

The distributions of many marine species including those we rely on for food are shifting because of their dependence on specific water temperatures and nutrient availability. Many marine species are moving toward the poles disrupting fisheries around the world. A recent study noted that more than 800 species of commercially important fish, including halibut, herring, tuna, and cod have migrated north. Many marine species such as whales and salmon time their migratory and reproductive cycles around prey. Whales migrate to the Arctic to prey on krill in the summer and salmon migrate to the oceans for seasonal nutrients. When these patterns are altered due to a changing climate, it results in a change of predator-prey relationships and increases mass strandings’, starvation, and poor reproductive success. For example, warmer sea surface temperatures along the US Northeast continental shelf are forcing a specific zooplankton species to shift to cooler waters. Atlantic cod that prey on them in the Gulf of Maine and Georges Bank are found to have lower reproductive success.

A recent study predicts that climate change will force hundreds of ocean fish northward. Northward shifts of warm water species by more than 10° latitude coinciding with a decrease in the number of cold-water species are related both to the rise in temperature in the Northern Hemisphere and to the North Atlantic Oscillation. A large number of biological events concerning maximal phytoplankton abundance as well as reproduction and migration of invertebrates, fish, and seabirds, all take place earlier in the year. Hence, in the past fifty years, the spring events have been shifting earlier for many species by an average of 4.4 ± 0.7 days per decade and the summer events by 4.4 ± 1.1 days per decade. Observations show that for all taxonomic groups, with great heterogeneity, the rate of displacement towards the poles reaches 72.0±13.5 kilometres per decade. Changes in the distribution of benthic, pelagic and demersal species can extend up to a thousand kilometres. These poleward migrations have led to an increase in the number of warm-water species in areas like the Bering Sea, the Barents Sea or the North Sea. The observed modifications in the distribution of benthic fish and
shellfish with latitude and depth can be mainly explained by changes in the temperature of the sea. The migration rates recorded in the marine environment appear to be faster than observed in the terrestrial environment.

### 6.8 SPECIES EMERGENCE AND EXTINCTION

About 252 million years ago, the largest extinction in Earth’s history marked the end of the Permian period, wherein 96% of marine species were lost. Studies reveal that this happened due to global warming. Rising temperatures led to the increased metabolic rate of marine animals. As the warm oceans were not capable of holding as much oxygen at higher temperatures, these species could not survive. Simulation and modelling studies showed that the most severe effects of oxygen deprivation are for species living near the poles. Several species are also at higher risk of extinction due to climate change effects. On the other side, some species might emerge in new areas due to range shifting caused by temperatures fluctuations. Species whose ranges might shift pole wards due to warmer water include lionfish, sea snakes, crown-of-thorns starfish and a number of different types of venomous jellies.

### 6.9 LET US SUM UP

Oceans play a key role in the mitigation of impacts of climate change, but this property of oceans is also slowly destroying and altering the marine ecosystem. Impact of climate change on oceans, noted in terms of rising ocean temperatures and its associated effects are modifying the distribution of fishes and the productivity of marine species, which has direct and indirect impacts on the livelihoods of people who depend on fisheries. Apart from the havoc on the marine species, the degradation of coastal and marine ecosystems such as coral reefs also threatens the sustainability of the tourism industry and economy. Hence it is imperative that we develop a proper understanding of the vast secrets of the ocean, and act fast so that this abundant climate change mitigation system which supports numerous people globally is able to retain its functions and services. We have studied in this unit about the response of ocean ecosystem to climate change, and effects of climate change on physical, chemical, and biological properties of ocean. Further, we have discussed the vulnerability including the migration behaviour of marine organisms to climate change.

### 6.10 KEYWORDS

**Coral Bleaching**: Loss of coral pigmentation through the loss of intracellular symbiotic algae (known as zooxanthellae) and/or loss of their pigments.

**Ocean Acidification**: Ocean acidification refers to a reduction in the pH of the ocean over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide from the atmosphere, but can also be caused by other chemical additions or subtractions from the ocean. Anthropogenic ocean acidification refers to
Natural Ecosystems

Upwelling Region: A region of an ocean where cold, typically nutrient-rich waters well up from the deep ocean.

Sea Level Change: Sea level can change, both globally and locally due to (1) changes in the shape of the ocean basins, (2) a change in ocean volume as a result of a change in the mass of water in the ocean, and (3) changes in ocean volume as a result of changes in ocean water density.

6.11 SUGGESTED FURTHER READING/REFERENCES


The carbon stored in coastal and marine ecosystems is called blue carbon. The carbon captured by the living organisms (ocean’s vegetated habitats)
in the marine and coastal ecosystems, is stored in the form of biomass and sediments. The ocean’s vegetated habitats include but not limited to mangroves, salt marshes, and sea grasses.

2. Ocean acidification occurs due to the uptake of \( \text{CO}_2 \) by the ocean mainly from the atmosphere. As \( \text{CO}_2 \) enters into the water, it forms carbonic acid by reacting with water molecules, which causes a shift in the concentrations of the hydrogen carbonate (\( \text{HCO}_3^- \)) and carbonate (\( \text{CO}_3^{2-} \)) ions. Since the Industrial revolution, the mean surface ocean pH has decreased by about 0.1 unit.

Check Your Progress 2

1. Coral reefs are important group of marine organisms as they found to provide habitat to about one-third of the marine organisms. The growth and development of coral reefs are influenced by factors like temperature (optimum range lies between 22° and 29°C), nutrients, currents, turbidity, light, pH, calcium carbonate content, etc. As regards the temperature condition, coral reefs are sensitive to rise in temperature. Warmer waters cause corals to expel the algae (zooxanthellae) living symbiotically in their tissues resulting in coral bleaching. Coral bleaching in turn adversely impacts the entire coral ecosystem and the species dependent on these coral ecosystems for growth.

2. Marine species like coral reefs, mangroves, sea grasses, etc. depend on the shallower waters for their growth and development. Further, species that are slow growing are more vulnerable to sea level rise, as they are unlikely to keep pace with the rising sea level. In the case of sea turtles, rising sea levels may affect the nesting beaches and migratory behaviour of sea turtles.
UNIT 7 WETLAND ECOSYSTEM

Structure
7.1 Introduction
7.2 Objectives
7.3 Wetlands
    7.3.1 Overview
    7.3.2 Significance
    7.3.3 Ecosystem Services
7.4 Wetlands and Climate Change Interactions
7.5 Vulnerability and Impact Assessment of Wetlands to Climate Change
7.6 Role of Wetlands in Climate Change Adaptation
    7.6.1 Priorities on Wetlands for Enhancing Climate Action
7.7 Wetland Restoration for Climate Change Resilience
7.8 Let Us Sum Up
7.9 Keywords
7.10 Suggested Further Reading/References
7.11 Answers to Check Your Progress

7.1 INTRODUCTION

Wetlands are one of the most productive ecosystems of the world. They are considered fundamental for human well-being and environmental sustainability. Wetlands are very rich in biodiversity as more than 40% of all the world’s species live and propagate in wetlands. As a result, the types of ecosystem services provided by wetlands are considered higher as compared to other ecosystems of the world. The various life sustaining services provided by the wetlands include maintenance of water quantity and quality, source and sink for greenhouse gases, retention of soils and sediments, livelihoods, food security and provide a wide range of ecological niches, supporting extensive biodiversity, etc. Despite these vital roles, wetlands are one of the most threatened ecosystems. Approximately 40% of wetlands have been lost over the last 40 years, 76% species are threatened and approximately 81% of populations of freshwater species have been decline globally. The rate of decline of wetland species is much sharper than any other terrestrial or marine biome. In fact, the significance of wetlands have been highlighted way back in 1971 through “The Ramsar Wetland Convention”. Further, it is one of the important ecosystems to attract the attention of the global community and hence a global environmental agreement on “the conservation, protection and sustainable use of wetlands”.

Anthropogenic climate change is one of the main drivers of wetland loss or decline. Climate change along with industrialization, urbanization, resource exploitation, and environmental pollution threaten the wetlands across the world. Consequently, the ecosystem services provided by the wetlands such as “water recharge and discharge”, “flood control”, “wildlife habitats”, and “nutrient storage...
functions and services” are severely affected. The potential impact of climate change on wetland ecosystem and species are recognised by the “Ramsar Convention (RC) on Wetlands”, the “Intergovernmental Panel on Climate Change (IPCC)” and the “United Nations Framework Convention on Climate Change (UNFCCC)”. Keeping in view the impacts of climate change on wetland productivity and sustainability, this unit delves into inter-linkages between climate change and wetland and how wetland restoration and conservation play a crucial role for climate change resilience and sustainable development.

7.2 OBJECTIVES

After studying this unit, you should be able to:

- explain the importance of wetlands;
- explain the interactions between wetlands and climate change;
- discuss the vulnerability and impact assessment of wetlands to climate change; and
- discuss the role of wetlands in climate change resilience.

7.3 WETLANDS

7.3.1 Overview

Wetlands are areas where water is the primary factor controlling the environment and the associated plant and animal life. They occur where the water table is at or near the surface of the land, or where the land is covered by water (https://www.ramsar.org/sites/default/files/documents/library/info2007-01-e.pdf). Article 1 of the Convention states that “wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six metres”. Ramsar Convention has adopted a Ramsar classification of wetland type which includes 42 types, grouped into three categories:

- “Marine and coastal wetlands;
- Inland wetlands; and
- Human-made wetlands”.

Five major wetland types that are generally recognized by the conventions are:

- “Marine wetlands viz. coastal lagoons, rocky shores, and coral reefs;
- Estuarine wetlands viz. deltas, tidal marshes, and mangrove swamps;
- Lacustrine wetlands viz. lakes;
- Riverine wetlands; and
- Palustrine wetlands viz. marshes, swamps and bogs”.

Further, the human-made wetlands include “fish and shrimp ponds”, “farm ponds”, “salt pans”, “reservoirs”, and “sewage farms”.

7.3.2 Significance
Wetlands are found at the intersection of the terrestrial habitats and aquatic habitats. It is construed as one of the biologically productive ecosystem on the Planet Earth. They are significant for their services rendered to mankind. They play a significant role in hydrological cycle by “receiving, storing, and releasing” water and immensely supporting the fauna and flora. Also wetlands play a vital role in pollution control and regulation of nutrients. In other words, wetlands role in biogeochemical cycling of nutrients cannot be overemphasized. They are storehouse of the majority of the global soil carbon. In addition to the water purification service, wetlands provide food security to billions as they provide fish and paddy. Wetlands along with the rivers and streams play a critical role in hydrology. Also, wetlands act as a “natural sponge” and hence aid in mitigating floods and droughts. The marshy wetlands and mangroves along the coastlines act as bulwark against extreme weather events. The significance of the wetlands can be summarized as:

- **Wetlands maintain the hydrological cycle**

  As stated earlier, wetlands play a critical role in hydrological cycle by “receiving, storing, and releasing” water and hence maintaining the “water flows” which are essential for the sustainability of life support system. The hydrological regime is a “measure of the levels, volume, timing and frequency of water flows into and out of wetlands”. The hydrological regime in a way decides the structure and function of wetlands. The structure and function of wetlands provide unique services such as pollution control, flood control, nutrient cycling, etc. It is important to note that the changes in the hydrological cycle would eventually influence the processes that are taking place in wetland ecosystem. Along with human intervention, climate change, precipitation and temperature regime influence the hydrological processes.

- **Wetlands are the world’s largest carbon stores**

  Not only wetland plays a major role in water cycling but they are the world’s largest carbon stores. The majority of the global soil carbon pool is held in wetlands. Carbon sequestration and storage are result of mainly the processes like primary production and taking in carbon dioxide for photosynthesis and producing organic matter and secondly respiration or decomposition which generate carbon dioxide or methane from organic matter. Wetland facilitates slow decomposition and when decomposition is less than plant productivity, carbon accumulates or stored. These processes get affected mainly by changing temperature and precipitation regimes. With rich biodiversity, wetlands are a vital means of storing carbon. Wetlands are also tremendously productive ecosystems that provide a myriad of services to society worldwide. As a result, change in climate can shift the balance of these processes, causing wetlands to become a potential carbon sources. For example, peatlands are powerful carbon sinks, holding the largest, long-term store of any ecosystem which makes peatlands one of the largest global reserves. Peatlands occupy only 3% of the land surface but they store twice as much carbon as the world’s forest. Same way, if we take the example of coastal and marine wetlands, including salt marshes, mangroves and seagrass beds, they are also important sites of carbon uptake and storage. Another example is mangrove forests
which are some of the most “carbon dense” ecosystems in the world. This “blue carbon” accumulates due to high primary production and sediment trapping, enabling carbon to accumulate over long time periods. In river deltas, these processes may allow wetlands to keep pace with sea level rise. When sediment inputs are cut off, sediment starvation and subsidence of delta wetlands can occur. Anthropogenic disturbances in coastal zones causes loss of carbon from wetland soils.

- **Wetlands are unique ecosystems**

Wetlands are unique ecosystems because they are in general sinks for carbon dioxide and sources of methane. Wetlands are the world’s largest carbon stores, but also release methane. Their climate footprint therefore depends on the inter-linkages of the land-atmosphere exchange of these two major greenhouse gases. The net climate impact of wetlands is strongly dependent on whether they are natural or managed. Freshwater wetlands are also the largest natural source of methane, a greenhouse gas, especially when not well managed. Tropical reservoirs also release methane, sometimes offsetting the reported low-carbon benefits of hydropower.

### 7.3.3 Ecosystem Services

Wetlands comprise approximately 6% of the Earth’s surface area and are essential for many ecosystem services such as water purification, flood attenuation, and climate change mitigation. The services rendered by the wetland ecosystem outweigh the services provided by terrestrial ecosystems. Wetland ecosystems as stated earlier provide nutritional and food security through provision of food such as rice, fish, etc. As regards the regulating services, wetlands provide ecosystem services such as climate regulation, and regulation of hydrological regimes. Further, the services provided by wetlands have both cultural and spiritual connotations. In addition to providing recreational services, the wetlands act as a repository of carbon, and hence playing a vital role in regulating global climate. Wetlands are particularly important provider of all water-related ecosystem services. They regulate water quality, groundwater recharge, and can contribute to regulating floods and the impacts of storms. Wetlands also help in erosion control and sediment transport, thereby contributing to land formation and increasing resilience to storms.

**Table 7.1: Ecosystem Services provided by Wetlands**

<table>
<thead>
<tr>
<th>Ecosystem Services</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Provisioning Services</strong></td>
<td></td>
</tr>
<tr>
<td>Food</td>
<td>Fish, wild game, grains</td>
</tr>
<tr>
<td>Fresh water</td>
<td>Storage and retention of water; supply of drinking water</td>
</tr>
<tr>
<td>Fibers and fuel</td>
<td>Production of logs, fuelwood, and fodder</td>
</tr>
<tr>
<td>Bio-chemicals</td>
<td>Medicines from flora and fauna</td>
</tr>
<tr>
<td><strong>Regulating Services</strong></td>
<td></td>
</tr>
<tr>
<td>Climate regulation</td>
<td>Source and sink for greenhouse gases; Regulation of local and regional climate.</td>
</tr>
<tr>
<td>Wetland Ecosystem</td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Water regulation and ecological flows</strong></td>
<td>Groundwater recharge and discharge</td>
</tr>
<tr>
<td><strong>Pollution control</strong></td>
<td>“Retention, recovery and removal” of excess nutrients, and pollutants</td>
</tr>
<tr>
<td><strong>Others: Erosion control</strong></td>
<td>Flood control; Retention of soil particles</td>
</tr>
</tbody>
</table>

**Cultural Services**

- **Spiritual services**
  - Spiritual and religious values associated to wetlands
- **Recreational services**
  - Wildlife tourism
- **Aesthetic services**
  - Aesthetic value of wetland ecosystems
- **Educational services**
  - Education and training

**Supporting Services**

- **Soil formation**
  - Organic matter accumulation; soil formation.
- **Biogeochemical cycle**
  - Cycling of nutrients
- **Biodiversity**
  - Ecological niches to many species

- **Wetlands are key habitat for migratory species and important source of food**

  In fact, most of the water birds depend on the wetlands for the purpose of feeding, and breeding. Since the migratory birds travel long distances, covering even many countries, there is a need for concerted action by countries towards wetland conservation. Wetlands are generally rich in biodiversity. The diverse group of organisms in fact increase the biological productivity of the ecosystem. For instance, lowland paddy cultivation, in addition to providing food crop, the system provides habitat to variety of organisms such as fish, molluscs and crustaceans. These organisms aid in nutrient cycling and biological pest management.

**Check Your Progress 1**

**Note:**

1) Use the space given below for your answers.

2) Check your answers with those given at the end of this unit.

1. Define wetlands. List the types of wetlands?

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2. Discuss the ecosystem services provided by the wetlands.

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7.4 WETLANDS AND CLIMATE CHANGE INTERACTIONS

“Current ecosystem services from the ocean are expected to be reduced at 1.5°C of global warming, with losses being even greater at 2°C of global warming”. The risks of declining ocean productivity, shifts of species to higher latitudes, damage to ecosystems (e.g., coral reefs, and mangroves, seagrass and other wetland ecosystems), loss of fisheries productivity (at low latitudes), and changes to ocean chemistry (e.g., acidification, hypoxia and dead zones) are projected to be substantially lower when global warming is limited to 1.5°C. Similar is the case with another aquatic ecosystem - the wetlands.

Despite this, within the last century, the destruction of wetlands has accelerated rapidly. For their ability to simultaneously sequester CO$_2$ and emit CH$_4$, wetlands are unique ecosystems that may potentially generate large negative climate feedbacks over centuries to millennia and positive feedbacks over years to several centuries. Wetlands are among the major biogenic sources of CH$_4$, contributing to about 30% of the global CH$_4$ total emissions, and are presumed to be a primary driver of inter annual variations in the atmospheric CH$_4$ growth rate. Meanwhile, peatlands, the main subclass of wetland ecosystems, cover 3% of the Earth’s surface and are known to store large quantities of carbon (about 500 ± 100 Gt C). The controversial climate footprint of wetlands is due to the difference in atmospheric lifetimes and the generally opposite directions of CO$_2$ and CH$_4$ exchanges, which leads to an uncertain sign of the net radiative budget. Wetlands in fact have a great potential to preserve the carbon sequestration capacity because near water-logged conditions reduce or inhibit microbial respiration and promote CH$_4$ production. Potential variations of the CO$_2$/CH$_4$ stoichiometry in wetlands exposed to climate and land use change require the development of mitigation-oriented management strategies to avoid large climatic impacts.

Wetlands and climate change are interlinked. As regards the interactions, climate change greatly impact the “water flow and volumes”, temperature, “nutrient balance”, and “invasive species” as well. Intergovernmental Panel on Climate Change projected climate change to “significantly reduce surface water and groundwater resources in dry subtropical regions, intensifying competition for water; increasing extinction risk in freshwater species, especially due to synergistic effects with other drivers; posing a high risk of abrupt and irreversible regional-scale change in the composition, structure, and function of freshwater ecosystems; and damaging coastal ecosystems through sea level rise” (IPCC 2014). Use of wetlands for carbon sequestration can eventually lead to conservation and also restoration of wetlands. Though the ecosystem services provided by wetlands are significant, due to anthropogenic activities, land-use changes, climate induced changes, wetlands are challenged. Further, people dependent on the wetlands for their livelihood are struggling to exist in the era of climate change.
Due to climate change effects, wetland dependent communities are adopting other land-use practices and aquaculture for their livelihood. However, the aquaculture by itself is affected by climate change. Also, the coastal communities experience multiple stresses such as sea-level rise, sea water intrusion, and extreme weather events.

It is reported that carbon sequestration benefits of wetlands are partially offset by methane release. It is estimated that wetlands produce about 100 Tg of methane per annum which amounts to about 20-25% of total global methane emissions. The global methane emissions also varies based on the structure and function of wetlands. Generally, while methane emissions are more in freshwater wetlands, they are low in saltwater wetlands. It is projected that the warming temperature may melt the permafrost leading to the increase in methane emissions from the permafrost regions.

7.5 VULNERABILITY AND IMPACT ASSESSMENT OF WETLANDS TO CLIMATE CHANGE

Climate change may have its most pronounced effect on wetlands through alterations in hydrological regimes: specifically, the nature and variability of the hydroperiod and the number and severity of extreme events. However, other variables related to climate may play an important roles in determining regional and local impacts, including increased temperature and altered evapotranspiration, altered biogeochemistry, altered amounts and patterns of suspended sediment loadings, fire, oxidation of organic sediments and the physical effects of wave energy. Pressures on wetlands are likely to be mediated through changes in hydrology, direct and indirect effects of changes in temperatures, as well as land-use change. Examples of impacts resulting from projected changes in extreme climate events according to Ramsar (2002) includes:

- “change in base flows; altered hydrology (depth and hydroperiod);
- increased heat stress in wildlife;
- extended range and activity of some pest and disease vectors;
- increased flooding, landslide, avalanche, and mudslide damage;
- increased soil erosion;
- increased flood runoff resulting in a decrease in recharge of some floodplain aquifers;
- decreased water resource quantity and quality;
- increased risk of fires;
- increased coastal erosion and damage to coastal buildings and infrastructure; and
- increased damage to coastal ecosystems such as coral reefs and mangroves and increased tropical cyclone activity”.

Wetland systems are vulnerable and particularly susceptible to changes in quantity and quality of water supply. Climate change will affect the hydrology of individual
wetland ecosystems mostly through changes in precipitation and temperature regimes with great global variability. Given the diversity of wetland types and their individual characteristics, the impacts resulting from climate change will vary according to different temperature and precipitation regimes and so will the restoration remedies.

### 7.6 ROLE OF WETLANDS IN CLIMATE CHANGE ADAPTATION

Although the importance of wetland ecosystems is widely acknowledged, the Ramsar Secretary General, Martha Rojas Urrego recently stated that “wetlands are being lost faster than forests.” In fact, it is estimated that approximately 64% of wetlands have been lost globally since 1900 (Ramsar 2017). According to WWF (2017) “principal threats to wetlands on a global scale are drainage and development of wetlands for industrial and agricultural use, invasive species, pollution, climate change and the erection of dams”.

Billions of people rely on the wetlands for their livelihood. Nevertheless, due to ever increasing demand for food, water, land resources, and climate variability and climate change, the wetlands are under severe stress. Due to the declining areal extent and productivity of wetlands, the environment, integrity and health, and human wellbeing may be affected. This may lead to social tensions and conflicts and eventually migration due to water shortage and water crisis.

Adaptation to climate change is defined as “the adjustment of natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities”. Vulnerability is a central concept to adaptation and is defined as “the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes” (IPCC 2014). In other words, non-success to climate change adaptation would increase the vulnerability of wetlands and also dependent communities to climate change. So, it is essential to adapt the wetlands to climate change, as they provide diverse ecosystem services such as flood protection, food security, and livelihood security. Further, the degraded wetlands have potential to augment the vulnerability of the communities, as the degraded wetlands constrain the adaptive capacity of the communities. Also, adaptation of wetlands to climate change is essential so that the ecosystem functions and services are maintained. For the success of adaptation programme pertaining to wetlands, there is a need to minimise the threats to wetlands including anthropogenic threats.

#### 7.6.1 Priorities on Wetlands for Enhancing Climate Action

- Protection and restoration of production systems associated with wetlands
- Improving the integrity of peatlands, floodplains and mountain lakes.
- Augmenting the investments in the green infrastructure.
- Protect and restore the floodplains, salt marshes, mangroves, and coastal wetlands.
• Conservation and restoration and sustainable use of inland wetlands.
• Identifying, protecting, restoring and conservation of wetland hotspots.

Source: https://unfccc.int/sites/default/files/resource/77_Wetlands%20International%20input%20into%20the%20Talanoa%20Dialogue.pdf

Check Your Progress 2

Note: 1) Use the space given below for your answers.
       2) Check your answers with those given at the end of this unit.

1. Identify the inter-linkages between climate change and wetlands?

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2. Enlist the priorities on wetlands for enhancing climate action?

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7.7 WETLAND RESTORATION FOR CLIMATE CHANGE RESILIENCE

The climate is changing at an unprecedented rate and the effects of a changing climate can be widely seen in all the ecosystems including terrestrial, aquatic or marine ecosystems. The effect of climate change on wetland varies by location. It is reported that across the world, the climate-related risks and disasters are increasing recently, and about 90% of such disasters are linked to water. In this regard, it is important to note here that there is a dire need to protect and restore wetlands so as to mitigate climate change and at the same time to adapt to changing climate. Wetlands such as peatlands, salt marshes, mangroves, etc. are repository of carbon. Such wetlands, if degraded, not only release carbon, but also lose its ability to sequester carbon substantially. In the era of climate change, as regards the wetlands management, responses like “sustainable use of wetlands”; and “restoration of degraded wetlands”; are essential.

Ramsar Convention on Wetlands (Resolution X.24) “Climate change and wetlands” highlights “how wetlands deliver a wide range of ecosystem services that contribute to human well-being, climate change mitigation and/or adaptation and calls upon Parties to include in national climate change strategies the protection of all types of critical wetlands”. Resolution XII.13, “Wetlands and Disaster Risk Reduction” points at “the devastating impacts of disasters on the maintenance of healthy wetlands, and the role of fully functioning wetland ecosystems in enhancing local resilience, and calls for the integration of wetland-based disaster risk reduction into national strategic plans and relevant policies and planning”.

41
The recent Paris Agreement on climate change categorically recognises the importance of ecosystems and biodiversity for climate change mitigation and adaptation. The important component of Sustainable Development Goals is to protect the planet Earth from degradation, and this has been addressed as part of Goals 2, 6, 8, 11, 14 and 15. Further, the goals are interlinked and the successful achievement of the many SDGs is intricately linked to the protection, and sustainable use of wetlands. The Global Land Outlook, UNCCD, 2017 underscores the important role of wetlands from the perspective of “water security”, “social instability” and “political insecurity”. Also the UNCCD’s 10-year Strategic Plan and Framework (2008-2018) underlines the ecosystem services rendered by wetlands in semi-arid ecosystems for drought proofing and climate resilience.

Wetland Restoration for Climate Change Resilience

1. “The wise use and restoration of wetlands is essential to protect stored carbon and reduce avoidable carbon emissions.

2. Prioritizing wetland protection and restoration can enhance climate adaptation and resilience.

3. Wetlands play a vital role in retaining water on the landscape, maintaining local climate and water cycles and reducing temperature extremes.

4. Protecting and restoring wetlands to increase climate mitigation and resilience delivers many co-benefits.

5. Protecting and restoring wetlands for climate mitigation and adaptation reflects a key tenet of Ramsar’s Strategic Plan and represents progress towards meeting the Sustainable Development Goals and the Paris Agreement on Climate Change”.

Source: Ramsar Briefing Note No.4; www.ramsar.org

7.8 LET US SUM UP

Wetlands are considered fundamental for human well-being and environmental sustainability. They are one of the most productive ecosystems of the world. Life sustaining services provided by the wetland include maintenance of water quantity and quality, source and sink for greenhouse gases, retention of soils and sediments, livelihoods, food security and provide a wide range of ecological niches, supporting extensive biodiversity, etc. Anthropogenic climate change is one of the main drivers of wetland loss or decline. Climate change along with industrialization, urbanization, resource exploitation, and environmental pollution threaten the wetlands across the world. In this unit, we have learned about wetland and their significance in maintaining hydrological cycle and ecosystem services provided by them in detail. In this unit, we have discussed about the interactions between wetlands and climate change, including the climate change impacts. Further, we have discussed role of wetland restoration and conservation for climate change resilience and sustainable development.
7.9 KEYWORDS

**Carbon Sequestration**: Removal of carbon from the atmosphere and its storage in an ecosystem in a given area over a given time.

**Carbon Sink**: Long term (of at least one year) sequestration of carbon by an ecosystem (i.e., more carbon is taken up than is released). Living and dead vegetation, as well as soil carbon, constitute the carbon sink.

**Carbon Stock**: Carbon stored in an ecosystem, regardless of the time it took to build up this stock.

**Resilience**: The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation.

7.10 SUGGESTED FURTHER READING/ REFERENCES


P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1757-1776.

Web Links


https://mafiadoc.com/global-wetland-outlook-2018_5c188a43097c47250b8b46a7.html

www.ramsar.org


https://www.globalpeatlands.org/

http://www.ramsar.org/pdf/info/services_07_e.pdf

7.11 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress 1

1. Wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres. Wetlands can be grouped into marine and coastal wetlands; inland wetlands; and human-made wetlands.

2. Wetlands are essential as they provide many ecosystem services such as water purification, flood attenuation, and climate change mitigation. Wetland ecosystems provide nutritional and food security through provision of food such as rice, fish, and etc. As regards the regulating services, wetlands provide ecosystem services such as climate regulation, and regulation of hydrological regimes. Additionally, the services provided by wetlands have both cultural and spiritual connotations. In addition to providing recreational services, the wetlands act as a repository of carbon, and hence playing a vital role in regulating global climate. They regulate water quality, groundwater recharge, and can contribute to regulating floods and the impacts of storms. Wetlands also help in erosion control and sediment transport, thereby contributing to land formation and increasing resilience to storms.

Check Your Progress 2

1. Wetlands and climate change are interlinked. As regards the interactions, climate change greatly impact the “water flow and volumes”, temperature, “nutrient balance”, and “invasive species” as well. Use of wetlands for carbon sequestration can eventually lead to conservation and also restoration of wetlands. Though the ecosystem services provided by wetlands are significant, due to anthropogenic activities, land-use changes,
climate induced changes, wetlands are challenged. Further, people dependent on the wetlands for their livelihood are struggling to exist in the era of climate change. Due to climate change effects, wetland dependent communities are adopting other land-use practices and aquaculture for their livelihood. Carbon sequestration benefits of wetlands are partially offset by methane release. It is projected that the warming temperature may melt the permafrost leading to the increase in methane emissions from the permafrost regions.

2. The priorities on wetlands for enhancing the climate action are as follows:
   - Protection and restoration of production systems associated with wetlands
   - Improving the integrity of peatlands, floodplains and mountain lakes.
   - Augmenting the investments in the green infrastructure.
   - Protect and restore the floodplains, salt marshes, mangroves, and coastal wetlands.
   - Conservation and restoration and sustainable use of inland wetlands.
   - Identifying, protecting, restoring and conservation of wetland hotspots.
UNIT 8  MOUNTAIN AND HILL ECOSYSTEM

Structure

8.1  Introduction

8.2  Objectives

8.3  Glacier Melting and its Impacts
     8.3.1  Impact on Water and River Systems

8.4  Impacts on Biodiversity

8.5  Changes in Crop Production and Livelihood Support System
     8.5.1  Crop Production
     8.5.2  Vulnerability of Traditional Agricultural Cycle
     8.5.3  Livelihood Support System
     8.5.4  Migration

8.6  Soil Erosion and Problems of Sedimentation

8.7  Bank Cutting and Fury of Floods

8.8  Frequent Landslides

8.9  Vulnerability of Traditional Agricultural Cycle

8.10  Let Us Sum Up

8.11  Keywords

8.12  Suggested Further Reading/References

8.13  Answers to Check Your Progress

8.1  INTRODUCTION

Mountains are unique geomorphic features of the Earth. They are characterized by high altitude, steep slope and rugged features. Mountain ecosystems contain a series of climatically very different zones within short distances and elevations. This makes mountains an extremely heterogeneous ecosystem of the world. They display a range of micro-habitats with great biodiversity. This heterogeneity, in turn, influences the spatial distribution, growth, physiology and life cycles of plants and animals including micro-organisms and human beings. Mountain ecosystems also harbor a wide range of significant natural resources and play a critical role in the ecological and economic processes of the planet Earth.

Mountains and uplands cover about 24% of the Earth’s surface, and influence most of the planet. These areas are homes of about 12% of the world’s human population. Amongst the most fragile environments in the world, the influence of the mountains extends far beyond their geographical limits to the surrounding lowlands that need their goods and services. The most important influence is on the hydrological cycle. Mountains act as an orographic barriers to the flow of moisture-laden winds and control
precipitation in neighboring regions. For example, the Himalayas are one of the important reasons of the monsoon in northern India. They are also responsible for occurrence of the continental arid conditions in Central Asia.

It is important to note that mountain environments are likely to be among the most severely impacted ecosystems as a result of climate change. A warmer climate will cause lower-elevation habitats to move into higher zones encroaching on alpine and sub-alpine habitats. High-elevation plants and animals will lose habitat area as they move higher with some ‘disappearing’ off the tops of mountains. Rising temperatures may cause mountain snow to melt earlier and faster in spring shifting the timing and distribution of runoff. This in turn may affect the availability of freshwater for natural systems and for human uses. Earlier melting may lead to drier conditions with increased fire frequency and intensity. On the whole, glaciers around the world have been shrinking. In equatorial high altitude areas, the rate of shrinking has been particularly rapid. Retreating glaciers implies a decrease in the reliability of water flows and change in habitats.

### 8.2 OBJECTIVES

After studying this unit, you should be able to:

- explain the distinct features of mountain ecosystem;
- describe the potential threats of climate change on glaciers’ melting, biodiversity, crop production, livelihood support system; and
- discuss soil erosion, sedimentation, bank cutting, floods, traditional agriculture and migration of people due to climate change.

### 8.3 GLACIER MELTING AND ITS IMPACTS

Glacier is defined as a mass of ice consisting of compacted and recrystallized ice on land that flows down under its own weight due to gravity. Glaciers move largely or wholly on land and show evidence of past or present movement. Glaciers originate from accumulations of snow and ice and flow down the slope in response to gravitational forces, and grow or shrink as a result of exchanges of mass and energy. Glaciers gain mass mainly by snowfall, and lose mass mainly by melting in their lower reaches. The world’s mountain ranges encompass a huge range of topographic and climatic environments, and each glacier has a unique relationship with local terrain and microclimate. Indeed, local variation is so great that it is impossible to make general statements about glacier response even within single mountain ranges.

In recent decades, there is growing concern about impacts of climate change on high mountain glaciers and snow ablation, and the effects of glacier recession on sea-level rise, natural hazards and water resources. Climate change is causing significant mass loss of glaciers in high mountains worldwide. Although glacier systems show a great amount of inherent complexity and variation, there are clear overall trends indicating global glacier recession. This trend is likely to accelerate in coming decades. However, there are large gaps in our understanding the key processes and cause-effect relationships driving glacier response to climate change. Further, till now we have not been able to model these processes and relationships accurately.
The water is present in the glaciers as snow and ice. The water in the glaciers is released due to melting. The melting involves at the first instance, the recent snow cover and later snow from the zone of accumulation melts. When the glacier is said to be in balance with the prevailing climate, the amount of ice melting at the “glacier tongue” is equal to the amount of ice that accumulates. As the mass balance of the glacier is the function of atmospheric conditions, the changing climate influences the retreat/advance of glaciers.

**Box 8.1**

Himalayan glaciers are receding faster today than the world average. In the last half of the 20th century, 82% of the glaciers in western China have retreated. On the Tibetan Plateau, the glacial area has decreased by 4.5% over the last twenty years and by 7% over the last forty years (CNCCC, 2007), indicating an increased retreat rate. Glacier retreat in the Himalayas results from precipitation decrease in combination with temperature increase. The glacier shrinkage will speed up, if the climate warming and drying continues. Geological Survey of India (1999) has updated the following inventory data on retreating of important glaciers in Himalaya:

<table>
<thead>
<tr>
<th>Glacier</th>
<th>Location</th>
<th>Period</th>
<th>Average Retreat (m/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milam</td>
<td>Uttarakhand</td>
<td>1849-1957</td>
<td>12.5</td>
</tr>
<tr>
<td>Pindari</td>
<td>Uttarakhand</td>
<td>1845-1966</td>
<td>23.0</td>
</tr>
<tr>
<td>Gangotri</td>
<td>Uttarakhand</td>
<td>1935-1976</td>
<td>15.0</td>
</tr>
<tr>
<td>Gangotri</td>
<td>Uttarakhand</td>
<td>1985-2001</td>
<td>23.0</td>
</tr>
<tr>
<td>Bada-Shigri</td>
<td>Himachal Pradesh</td>
<td>1890-1906</td>
<td>20.0</td>
</tr>
<tr>
<td>Kolhanni</td>
<td>Jammu &amp; Kashmir</td>
<td>1857-1909</td>
<td>15.0</td>
</tr>
<tr>
<td>Kolhanni</td>
<td>Jammu &amp; Kashmir</td>
<td>1912-1961</td>
<td>16.0</td>
</tr>
<tr>
<td>Machoi</td>
<td>Jammu &amp; Kashmir</td>
<td>1906-1957</td>
<td>8.1</td>
</tr>
<tr>
<td>Chota-Shigri</td>
<td>Himachal Pradesh</td>
<td>1970-1989</td>
<td>7.5</td>
</tr>
</tbody>
</table>

*Source: Shiva, Vandana, and Bhatt, Vinod Kumar, 2009.*

### 8.3.1 Impact on Water and River Systems

In view of growing water scarcity, the capture and storage of excess water during periods of high water availability would be one of the major challenges in the coming decades. It is more likely that the extreme weather events would occur more frequently. In the event of changing land use and human activities in the mountain region, and extreme weather events, there is need for innovation in water capture and storage technologies and
also adoption of traditional technologies. Glaciers play vital role in the river flow. Nevertheless, factors such as precipitation, evaporation, etc. along with glaciers’ characteristics influence river flow (Immerzeel et al., 2010).

The glacial contribution to river flow varies greatly, both annually and within and between catchments. The hydrological significance of glacier runoff also depends on other components of the hydrological cycle, such as precipitation, evapo-transpiration, and groundwater flow. In consequence, the impacts of glacier mass loss will be highly variable both locally and worldwide. Some regions would undoubtedly be affected by water shortage whereas others are unlikely to be significantly affected by glacial melt. Much detailed work remains to be done to adequately predict regional and local hydrological responses to climate change.

The shrinkage and eventual disappearance of glaciers in the mountain region exhibit impacts in the form of “changes in the glacier fed river characteristics”; and “occurrence of Glacier Lake Outburst Floods (GLOFs). In the Himalayan region, there is increase in the number of proglacial lakes which are “dynamic glacial lakes system”. In the past decades, GLOFs have been common in those areas of the Himalayas and Andes mountains where glaciers are receding. In the last century, there were more than 35 GLOFs events in Nepal, China, Bhutan and Pakistan (Richardson and Reynolds, 2000). GLOFs threaten the lives, infrastructure including power sector through flash floods.

Water scarcity is more likely to prevail in the future (UNEP 2010). Further, increasing population combined with the need for agricultural crop production and changing climate aggravates the water scarcity issue (Nellemann and Kaltenborn, 2009). Increase in consumerism and change in the life styles would put additional burden on water resources.

8.4 IMPACTS ON BIODIVERSITY

The term biodiversity refers to combinations of life forms and their interactions. These interactions occur at different levels (genetic, species, and ecosystem) and depend upon the physical environment. The mountain ecosystem is rich in biodiversity due to the diversity in the habitats, and variations in the micro-climatic conditions. There is near consensus among the scientific community that climate change would affect the biodiversity. Climate change has already produced significant and measurable impacts on almost all ecosystems and ecological processes, including changes in species distribution, timing of biological behaviour, assemblage composition, ecological interactions and community dynamics. Notably, species have evolved over millions of years to adapt to specific climatic conditions and variations in climate thereof, but the current increase in temperature and differing weather patterns has occurred over an extremely short period of time which evolutionary processes are not able to match. Therefore, many species of plants and animals are not able to adapt to changing climate. Although there is scarcity of authentic and scientific data on the impacts of climate change on biodiversity of mountain ecosystems, however, some of the well-recognized impacts of climate change on biodiversity are enumerated as under:
Natural Ecosystems

**Shifts in Distribution of Plants and Animals**

At the simplest level, changing patterns of climate would alter the natural distribution limits for species or communities. In the absence of barriers, it may be possible for species or communities to migrate in response to changing conditions. Vegetation zones may move towards higher latitudes or higher altitudes of mountain following shifts in average temperatures. Movements will be more pronounced at higher latitudes where temperatures are expected to rise more than nearer the equator.

**Rapid Changes and Adaptation**

Rates of climate change and species adaptation will be important, and these will vary at regional and even local levels. The maximum rates of spread for some sedentary species, including large tree species found in mountainous settings, may be slower than the predicted rates of change in climatic conditions. This is likely to lead to localized extinctions of these species.

**Species Interaction**

In many cases, further complications are arising from the complexity of species interactions and differential sensitivities to changing conditions between species. Certain species may rapidly adapt to new conditions and may act in new competition with others.

**Invasive species**

Humans have been introducing animals from one part of the world to another for species by eating them, competing with them, hybridizing with them, or introducing pathogens or parasites. Global climate change creates conditions that may be suitable for some invasive species to become established in new areas.

### 8.5 CHANGES IN CROP PRODUCTION AND LIVELIHOOD SUPPORT SYSTEM

Agriculture in mountain ecosystems is quite unique because of their distinct geographical environment. A great genetic variability among plants and domestic animals and the whole spectrum of biodiversity ranging from alpine pastures to sub-tropical forests to marginal foodgrain crops to domesticated animals is of great potential value as a gene pool for the worldwide farming solutions for the future. Agriculture and other traditional sources of livelihoods like forestry have been and continue to be the greatest concerns to mountain communities since time immemorial. However, climate change has started affecting these most fragile ecosystems of the world. Climate change may severely affect water supplies and biodiversity. Consequently, agriculture in mountain and highlands ecosystems is also likely to be affected.

#### 8.5.1 Crop Production

Climate change and agriculture processes are closely interrelated processes. The effect of climate on agriculture is mainly related to variability in local climates rather than in global climate patterns. Climate change is likely to affect crops
differently in different regions. Irrigated croplands in the watersheds of many rivers of Asia mainly depend on runoff from the high mountain regions in addition to monsoon rains which also recharge groundwater reservoirs. Given the high level of uncertainty regarding future runoff levels and also the highly variable contributions of glacial water and snowmelt from the mountains, future agricultural production also faces considerable uncertainty. A major decline in the water flow of the Ganges, Indus, Syr Darya and Amu Darya would have devastating impacts on food production.

More favourable effects on yield depend to a large extent on realization of the potentially beneficial effects of carbon dioxide on crop growth and increase of efficiency in water use. Decrease in potential yields is likely to be caused by shortening of the growing period and decrease in water availability. In the long run, the climatic change could affect agriculture in several ways:

- Productivity, in terms of quantity and quality of agricultural crops.
- Agricultural practices, through changes of water use and agricultural inputs such as fertilizers, herbicides and insecticides.
- Environmental effects, particularly in relation of frequency and intensity of soil drainage (leading to nitrogen leaching), soil erosion, reduction of agro-diversity.
- Rural space, through the loss and gain of cultivated lands, land speculation, and hydraulic amenities.
- Adaptation, competitiveness in organisms may either increase or decrease; humans may develop urgency to develop more competitive organisms, such as flood resistant or salt resistant varieties of crops such as rice.

8.5.2 Vulnerability of Traditional Agricultural Cycle

Large uncertainties exist on the impact of climate change over traditional agricultural cycle in the mountains. This is because of lack of information about climate change at specific local regional levels. There are also uncertainties on the magnitude of climate change, the effects of technological changes on productivity, global food demands and numerous possibilities of adaptation. Many agronomists believe that agricultural production would mostly be affected by the severity and pace of climate change, not so much by gradual trends in climate.

Climate change may increase the amount of arable land in high-latitude region. This would be possible due to reduction of the amount of frozen lands. A study in 2005 reported that average temperature in Siberia has increased by 3°C Celsius since 1960. However, findings of the studies about the impact of global warming on Russian agriculture indicate conflicting probable effects. While they expect a northward extension of cultivable lands, they are fearful of possible productivity losses due to increased risk of drought. According to one estimate, sea levels are expected to increase one meter higher by 2100, though this projection is disputed. A rise in the sea level would result in loss of agricultural land, particularly in the coastal areas due to the submergence of shorelines. Inundation of sea water in low-lying lands and intrusion of salinity in water table could adversely affect
agricultural land. Low lying areas such as Bangladesh, India and some South East Asian countries will experience major loss of rice crop due to rise in sea levels.

8.5.3 Livelihood Support System

Climate change poses threats to the livelihood support systems in a number of ways. It has made the future of mountain people and their livelihoods more vulnerable and uncertain. The term ‘livelihood’ comprises the capabilities, assets (material and social resources), and activities required for ensuring a means of living (Carney, 1998). The concept of sustainable livelihood includes the idea of coping with and recovering from stresses and shocks, and maintaining or enhancing existing capabilities and assets. Climate change and increasing variability in water flow may result in either too much water or too little water. This would increase the vulnerability of mountain livelihoods. Agricultural Production System would be affected by climate change induced water scarcity. Similar is the case with forest systems and forest productivity. Further, climate change has potential to impact human health through spread of many vector-borne diseases. As regards the tourism sector, the impacts of climate change are both positive and negative.

Mountain communities depend for their livelihood on agriculture, livestock and the natural resources. Climate change impacts on the agro-ecosystem, make the community more vulnerable. However, the traditional agricultural practices were resilient to climate change. The biodiversity loss due to climate change would affect the livelihood of mountain communities immensely as their agricultural practices and traditional practices are dependent on biodiversity. It is reported that the changes in the biodiversity in the Tibetan region, affect the Tibetan medicine (Salick et al., 2009).

8.5.4 Migration

Migration from mountains is generally a livelihood strategy adopted by the people to cope with chronic scarcity and insecurity. The migration results both from push and pull factors. Among the push factors are included physical insecurity, mass poverty and food insecurity. On the other hand, there are employment opportunities available in the comparatively better developed towns and cities of the plain areas.

Population growth coupled with environmental (mainly forest resource) degradation and inequality over access to environmental resources deprives the poor and the marginalized people of the environmental foundations of their livelihood. Population pressure in the hills is a major issue. Population pressure has led to deforestation and soil erosion. People have become more and more consumerist. They tend to exploit their environmental resources without caring for the future generations. Throughout the Himalayas, a rapid environmental degradation, such as deforestation, glacier melting, soil erosion, bank cutting, sedimentation, landslides, overgrazing biodiversity loss and floods are regular phenomena. Environmental degradation is a direct threat to the natural resource and economy of the mountain areas. In recent years, infrastructural development projects like roads, railways airports and factories also displace people from their habitat. An increase in inequality over access to environmental resources implies that the large majority of the people and the marginalized population are denied access to resources.
Migration is both seasonal and permanent over varied distance with both good and bad effects. There is generally a working age-group of male population selective outmigration from the mountains. This has repercussions on family and society of the mountainous areas. The positive contributions of out-migrants to their own society and locality are considerable. These include remittances, pensions and reduced pressure on scarce resources, particularly land. Many hill and mountain societies of the world are largely dependent on remittances from outside. Therefore, economy of the mountain region in India is also known as ‘money-order economy’.

Check Your Progress 1

Note: 1) Use the space given below for your answers.
2) Check your answers with those given at the end of this unit.

1. Define mountain ecosystem.

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2. Discuss the impacts of climate change on mountainous livelihood support systems.

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8.6 SOIL EROSION AND PROBLEMS OF SEDIMENTATION

Soil erosion is a process by which productive surface soils are removed from the underlying rocks, transported and accumulated in a distant place. This process results in exposure of subsurface soil and sedimentation in lowlands. Soil erosion also causes decline in the fertility of soil and by extension agriculture production. Globally, large areas of cultivable land have been abandoned because of the erosion of topsoil. The reduction in groundwater storage resulting from the erosion of the pervious soil horizons also causes drying up of perennial hill springs during the non-rainy seasons. The process of soil erosion is universal as it occurs in plains, plateaus and mountains. However, mountains and highlands ecosystems of the world are most vulnerable to soil erosion due to steep slope and river gradient. In these ecosystems, soil erosion is caused by both natural and anthropogenic factors. Of all mountains regions of the world, the Himalayas is the most prone to soil erosion. The rivers originating from the Himalayas are among the largest sediment transporting rivers of the world. The Himalayan and Tibetan regions cover only about 5% of the Earth’s land surface, but supply about 25% of the dissolved load to the world oceans (Raymo and Ruddiman, 1992).

The Himalaya as a whole is tectonically very active, geologically very weak and hence highly prone to soil erosion. Steep slope, relatively steep river gradient
and absence of vegetation cover are natural factors responsible for large scale soil erosion in the Himalayas. The most important human-induced causes of soil erosion in the Himalayan are changes in land use and land cover, expansion of infrastructures and mining.

The process of deposition of eroded soils in low-lying areas is known as sedimentation. Sedimentation is responsible for the siltation of lakes and reservoirs and thereby reducing their capacity to hold water. The sedimentation of reservoirs is the most important problem resulting from soil erosion in their catchment areas. Large numbers of big and small dams have been completed in India mainly for irrigation, hydropower generation and flood control. Many of these dams now contain considerable accumulation of sediment eroded from their catchments. As a result, the capacities of several reservoirs in India have decreased considerably since their construction. According to one estimate, every year about 330 MT of sediments are deposited in the Bhakhra Nangal Dam. Aggradation of sediments below bridge of rivers or canals chokes the clearance below the soffit. The deposition of soil eroded from upland areas in the downstream reaches of rivers cause aggradation. This results in an increase in the flood plain area of the rivers, reduction of the clearance below bridges and culverts and sedimentation of reservoirs.

8.7 BANK CUTTING AND FURY OF FLOODS

River bank cutting refers to any break or breach in the bank of a river. When water flows in a particular river is more than the capacity of the valley to hold its water, it may cause either overflow of water and break of the bank. River bank cutting can be triggered by natural physical processes such as heavy or prolonged rainfall in the catchment areas, glacial lake outburst floods. They can also be triggered by man-made activities such as bank excavation.

Bank cutting and associated floods are commonly occurring geomorphic hazards in the mountain belts of the world. Bank cutting associated floods in the mountain areas are caused by heavy precipitation and cloud burst as well as glacial bursts in the catchment areas of mountainous rivers. Rivers originating from high altitude are fed by rain water, melt water of snow and glacier ice. While rain water in the catchment areas is directly discharged through the river in a relatively short period of time, snow accumulates on the ground and melts gradually. In this way, melt water from snow and ice contributes significantly to the sustained base flow of mountain areas throughout the dry period of the year.

Cloudburst in the upper catchment areas of a river is an important reason of river bank cutting in the mountain. Cloudbursts trigger debris flow resulting from mass wasting and landslides. These debris is often released into river channels and temporarily dam them. When a dam is breached, a peak flood of short duration results. These floods cause heavy damage along river bank for several kilometres downstream of the point of origin until it is attenuated when the flood wave reaches wider river reaches. The occurrence of cloudburst and associated flood is common in the catchment of the river Kosi originating from the Himalayas. However, their occurrence is too rapid to permit sufficient warning time.

Glacial lake outburst in the upper catchment areas of a river is another important cause of river bank cutting and associated flood in the mountain. In the high Himalayas, glacial lake outburst floods (GLOFs) are a regular phenomenon. The
rapid retreat of glaciers in the past several decades has often formed ice-core moraine-flanked lakes of melt water. Occasionally, a moraine dam breaches and a lake empties in a very short time. The result is floods of great magnitude in downstream river reaches. The water carries with it sediments from the moraine dam as well as earth from the riverbed and banks scratched by the rapid flow. The combined action of sudden flooding and debris movement washes away people, farmland, settlements and infrastructure. In this way, cloud burst, glacial lake outburst and landslide dam causes cutting of river bank and outflow of water from river channel in the form of outburst flood.

The main effects of bank cutting in the highlands are landslides, floods and socio-economic dislocations and destructions. Though there are many causes of occurrence of landslides, they are also triggered by natural physical processes of undercutting of river banks. The river bank cutting-induced landslide causes damage to infrastructure, houses, properties and human lives. River bank cutting and associated flood are also responsible for socio-economic dislocations and destructions of people. For example, a study of Tinau Watershed in western Nepal report that out of 6716 households in the watershed, 2327 households are exposed to river bank cutting, channel shifting and flood in this area mainly inhabited by poor landless tenant families.

8.8 FRIEQUENT LANDSLIDES

Many hazards are associated with mountain-building and mountain environmental processes. These hazards are mainly in the form of earth surface processes, such as snow avalanches, rock falls, debris flows, volcanic mudflows, glacial lake outburst and other types of floods. These processes are influenced by relief (steepness of slopes, ruggedness of topography), lithology, landform history, and precipitation events. Some natural hazards occur only or largely in mountain areas, such as snow avalanches and catastrophic landslides.

Landslides, the downward and outward gravitational displacement of slope-forming materials, may damage any human structure and may even cause the loss of lives when they occur in a catastrophic way. Two relevant peculiarities of this hazardous geomorphic process are its widespread spatial distribution; there are landslide-prone slopes almost everywhere, and its high sensitivity to human-and natural-induced changes in the slopes and controlling factors. Among the mountain environments, Indian Himalayan region presents a perfect example of occurrence of landslides. This region is prone to landslips, landslides, flash floods and other changes in the surface topography owing to high seismic activity and fragility of the land mass. Recurrent landslides cause heavy damage to property, disruption of road communication and loss of human lives every year. Notable among such events are Malpa landslide in the Kali valley (1998), Varunavrat landslide in Uttarkashi (2003) and a series of landslides and flash floods in the Sutlej valley during 2000 and 2005. The landslide and other mass movement activities are essentially periodic, generally limited to the monsoon rainfall which acts as trigger for inducing the slope instability. The number, frequency and damage due to landslides are determined mainly by geological, geo-morphological, hydrological, land-use, climatic and anthropogenic factors.

The atmospheric temperature increase caused by global climate change has resulted in the shift of monsoon pattern accompanied by an increase in intensity of rainfall and cloudbursts and heavy landslides during recent years.
Earthquakes are also responsible for generating landslides on an extensive scale and further augmentation of the same during the monsoon period, as is evident in many parts of the Garhwal Himalaya during recent earthquakes. Among the four belts in the Indian Himalayan region, rock falls and avalanches are common in the Higher Himalaya due to high relief. On the other hand, the Lesser Himalaya, a belt of medium-high relief features comprising sedimentary rocks overlain by nappes of crystalline rocks, is prone to landslides and other mass movements.

Check Your Progress 2

Note: 1) Use the space given below for your answers.
2) Check your answers with those given at the end of this unit.

1. Differentiate between soil erosion and sedimentation

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2. Describe the reasons for migration of people from the mountains

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8.10 LET US SUM UP

Mountain ecosystems play a critical role in the ecological and economic processes of the Earth. They are likely to be among the most severely impacted ecosystems as a result of climate change. Climate change is causing significant mass loss of glaciers in high mountains worldwide. Rising temperatures may cause mountain snow to melt earlier and faster in spring shifting the timing and distribution of runoff. This in turn affects the availability of freshwater for natural systems and for human uses. Retreating glaciers decrease the reliability of water flows and change habitats. In the future, many regions will undoubtedly experience water scarcity. A warmer climate will cause lower-elevation habitats to move into higher zones encroaching on alpine and sub-alpine habitats. High-elevation plants and animals will lose habitat area as they move higher with some ‘disappearing’ off the tops of mountains.

Climate change, deforestation and glacial melting would result in increasing rate of soil erosion, sedimentation and floods. These would adversely affect crop diversity and decrease agricultural productivity. In fact, climate change has made the future of mountain people and their livelihoods more vulnerable and uncertain. Increase in temperatures and increasing unpredictability in water flow may increase the vulnerability of mountain livelihoods. Since mountain people are highly dependent on natural resources to meet household needs, any loss of biodiversity increase their livelihood and health insecurity.
8.11 KEYWORDS

**Mountain Ecosystem**: It contains a series of climatically very different zones within short distances and elevations, displaying a range of micro-habitats with great biodiversity.

**Glacial Lake Outburst Flood**: It occurs when a lake contained by a glacier or a terminal moraine dam fails or if a large enough portion of a glacier breaks off and displaces the waters in a glacial lake at its base.

8.12 SUGGESTED FURTHER READING/REFERENCES


Natural Ecosystems


Shiva, Vandana, and Bhatt, Vinod Kumar, 2009. Climate Change at the Third Pole: The Impact of Climate Instability on Himalayan Ecosystems and Himalayan Communities, Navdanya, New Delhi.


8.13 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress 1

1. Mountain ecosystems are distinct physiographic units of the earth characterized by high altitude, steep slope and rugged features. They consist of a series of climatically very different zones within short distances and elevations. This makes mountains an extremely heterogeneous ecosystem of the world.

2. The effect of climate on agriculture is mainly related to variability in local climates rather than in global climate patterns. Climate change is likely to affect crops differently in different regions. Climate change and more variability in water flow resulting in either too much water or too little water increases the vulnerability of mountain livelihoods. At the same time, crop yields may increase at higher altitudes and latitudes because of decreased frost and cold damage.

Check Your Progress 2

1. Soil erosion is a process by which productive surface soils are removed from the underlying rocks, transported and accumulated in a distant place. This process results in exposure of subsurface soil and sedimentation in lowlands thereby causing decline in the fertility of soil and by extension agriculture production.

   The process of deposition of eroded soils in low-lying areas is known as sedimentation. Sedimentation is responsible for the siltation of lakes and reservoirs and thereby reducing their capacity to hold water. The sedimentation of reservoirs is the most important problem resulting from soil erosion in their catchment areas.

2. Migration from the mountains and highlands is caused by both from push and pull factors. Push factors include physical insecurity, mass poverty and food insecurity. There are employment opportunities available in the comparatively better developed towns and cities of the plain areas. The combination of push and pull factors impels people to migrate from mountains and highland ecosystems.