UNIT 6 ENVIRONMENTAL INDICATORS AND INSTRUMENTAL RECORDS

Structure

6.1 INTRODUCTION

Climate change is one of the serious issues being faced by humanity across the globe. Climate change has a wide-range of effects on the environment, socio-economic life influencing several sectors like water resources, agriculture and food security, human health, terrestrial ecosystems, biodiversity and coastal zones (https://unfccc.int/resource/docs/publications/impacts.pdf). According to the published reports during the last 100 years Earth's average temperature has raised by more than 1.4^0F with much of this occurred during the last 35-40 years (NRC, 2012). There are ample evidences of such warming that brought out unpredicted drought and anomalous rainfall, impacting the floral and faunal diversity pattern in diversified geographical parts of world. The 4% - 12% variability of daily monsoon rainfall in India is expected to be with 1^0C of warming. There is a chance of 13% - 50% change in variability which will take place if greenhouse gases continue to be emitted unabated. Over the last century, atmospheric concentrations of carbon dioxide increased from a pre-industrial value of 278 parts per million to 379 parts per million in 2005 (NRC, 2011). As a result of global warming, with relatively small rise in the average temperature, the type, frequency and intensity of extreme events, such as tropical cyclones, droughts, floods and heavy precipitation events are expected to increase.

Changes in rainfall pattern are likely to lead to flooding or drought conditions. Melting of glaciers can result into flooding and soil erosion. A shift in crop growing seasons is witnessed and expected at large scale with rising temperatures which will pose great threat to food security and may result in the widespread of diseases. With a 2° C rise in temperature, there is a risk of loss of 30% of habit and habitats resulting into the extinction of species especially in the coral reefs, boreal forests, Mediterranean region and mountains. Increasing sea levels pose grave danger to the coastal life and increase great risk of storm surge, inundation and wave damage to coastlines, particularly in small island states and countries with low lying deltas. A rise in extreme events will have effects on health and lives as well as associated environmental and economic impacts. Through this unit, you will be learning various facets of environmental indicators and instrumental records.

6.2 OBJECTIVES

After studying this unit, you will be able to:

- explain the significance of instrumental records and proxy climate indicator; and
- elucidate the contributions of proxy climate indicator to decipher the past climate.

6.3 FACTORS AFFECTING THE EARTH'S CLIMATE SYSTEM

Climate induced changes have severely impacted various biotic and abiotic components of ecosystem and thus, resulted into the altered nature of Earth's climate system. Biotic processes, variations in solar radiation received by the Earth, long-term changes in the tilt of the Earth and its orbit around the sun, plate tectonics and volcanic eruptions, human activities play a vital role in governing the Earth's climate system. According to the World Metrological Department (WMD) climate is the average of weather conditions at a place for at least a period of 30 years. A deviation in the mean standard of climate for a longer period of time (i.e., millions of years) is called climate change. Climate is a complex system of interactions between various components of earth like atmosphere, hydrosphere, cryosphere, land surface and biosphere (IPCC 2007). There are several internal and external factors that influence and affects the climate of the Earth. Thus, it becomes necessary to understand these components, functioning and their influence in altering the climate dynamics and behavioral analysis of these external and internal forcing to understand the climate change at spatial and temporal scale.

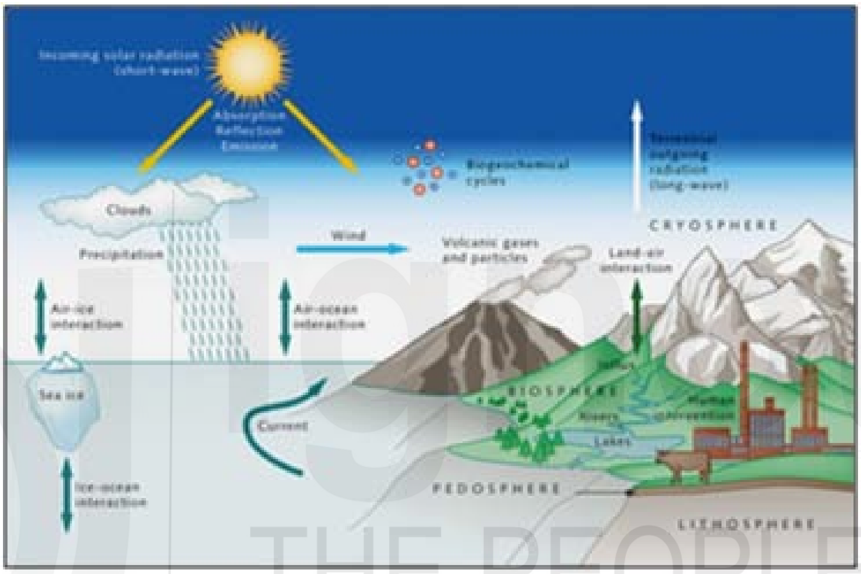

Fig. 6.1. Factors affecting Earth's climate system

(source:https://worldoceanreview.com/en/wor-1/climate-system/earth-climate-system/)

6.3.1 Internal forcing

Internal forcing are the natural processes that operate from within the climate system like the ocean and atmospheric interactions and interaction among the biotic (living) components. The ocean and atmosphere work together and result in internal climate variability that lasts from years to decades. By redistributing heat between the deep ocean and the atmosphere and altering the cloud/water vapor, sea ice distribution, these circulations affect global average surface temperature and the total energy budget of the earth. While living components play a vital role in albedo, evapo-transpiration, cloud formation, weathering, water and carbon cycle, etc.

6.3.2 External forcing

Anthropogenic impacts like increased emissions of greenhouse gases and dust along with natural processes like changes in solar output, Earth's orbit, volcano eruptions, etc. act as the external forces that affects the climate of the Earth.

6.3.2.1 Human influences

Human induced pressures in the form of agriculture, land clearance, shifting cultivation, deforestation, urbanization and industrialization have resulted into the irreversible changes like increase in the amount of greenhouse gases, ozone depletion, production of methane, etc. and have badly impacted the microclimate, and measures of climate variables

6.3.2.2 Orbital variations

Orbital variation plays a vital role in governing the climate system of Earth. The shape of the Earth's orbit changes every 100,000 years, it varies from being elliptical to nearly circular and then back. Slight variations in Earth's motion led to changes in the seasonal distribution of sunlight reaching the Earth's surface and its distribution across the globe. Milankovitch cycle (a resultant of combination of Earth's eccentricity, changes in the tilt angle of Earth's axis of rotation, and precession of Earth's axis) is notable to understand the past climate change and various climatic episodes of glacial and interglacial cycles in geological past.

6.3.2.3 Solar output

The Sun is the ultimate source of most of the energy that drives the biological and physical processes around us. Earth-Sun orbital relationship has a direct impact on geographical distribution of the Sun’s energy over the Earth’s surface. Other sources include geothermal energy from the Earth's core, tidal energy from the Moon and heat from the decay of radioactive compounds. Both long- and short-term variations in solar intensity are evidenced to affect global climate. Over the time-scale of millions of years, the change in solar intensity is a critical factor influencing climate (Schroder et al. 2008). Review of studies shows that solar output played an influential role in triggering the geological events like Little Ice, marked by relative cooling and greater glacier from 1550 to 1850 AD (Miles et al. 2004).

6.3.2.4 Volcanism

The volcanic eruptions that can inject over 100,000 tons of SO_2 into the stratosphere are considered to affect the Earth's climate (Wignall, 2001). Due to the optical properties of SO_2 and sulfate aerosols, a global layer of sulfuric acid haze is created which results in cooling conditions by partially blocking the transmission of solar radiation to the Earth's surface for several years (Graff et al. 1997). For instance, eruption of Mount Pinatubo in 1991, affected the climate substantially, and subsequently global temperatures decreased by about 0.5 °C (0.9 °F) for up to three years (IPCC 2007). This resulted in reduction of surface temperatures in 1991–93 which is equivalent to a reduction in net radiation of 4 watts per square meter (AGU, 2011).

Volcanoes also contribute in the extended carbon cycle. A large amount of carbon dioxide is released for very long (geological) time period to counteract the uptake by sedimentary rocks and other geological carbon dioxide sinks. A review of published studies indicates that annual volcanic emissions of carbon dioxide, including amounts released from mid-ocean ridges, volcanic arcs, and hot spot volcanoes, are only the equivalent of 3 to 5 days of human-caused output (Bruckschen et al., 1999; IPCC, 2007; AGU, 2011; AAS, 2017)

6.3.2.5 Plate tectonics

Over a wide range of timescale, horizontal and vertical displacements of tectonic plates reconfigure global land and ocean areas and generate varying topography which affect the global and local patterns of climate and atmosphere-ocean circulation (Atri & Melott, 2014). There are several factors associated with the role of plate tectonics in climate change like the position and size of the continents, geometry of the oceans and patterns of ocean circulation. The locations of the seas are important in controlling the transfer of heat and moisture across the globe, and therefore, in determining global climate. For example, formation of the Isthmus of Panama about 5 million years ago closed the direct mixing of Atlantic and Pacific Oceans. This strongly affected the ocean dynamics of Gulf Stream and may have led to Northern Hemisphere ice cover (Sindbaek, 2007; Demenocal, 2001).

6.3.2.6 Other mechanisms

The Earth receives an influx of ionized particles known as cosmic rays from a variety of external sources, including the Sun. There is a hypothesis that an increase in the cosmic ray flux would increase the ionization in the atmosphere, leading to greater cloud cover which in turn would cool the surface.

6.4 THE MEASUREMENT OF CLIMATE CHANGE

6.4.1 Instrumental records

A climate element, is any one of the various properties or conditions of the atmosphere which together specify the physical state of the climate at a given place, for a particular period of time (Linacre, 1992). To understand the dynamics of climate change and associated events, it is necessary to have a better understanding of the present scenario of climate by studying and observing the factors controlling or contributing in climate change. In this regard, multi-disciplinary and interdisciplinary studies (oceanography, meteorology, geomorphology, geology and pale climatology) give good amount of quantitative and qualitative information. This information along with the observational and instrumental records from diversified geographical location contribute a lot in making predictive climatic models. Analysis of instrumental records of common climate elements such as temperature, precipitation (rain, snow and hail), humidity, wind, sunshine and atmospheric pressure taken together proved to be very useful to specify the physical state of the climate at a given place, for a certain period of time. Such records of climate elements collected over time are known as "time series" (enviropedia). Temperature data gives an insight into Earth's surface and sea surface temperature (SST). Precipitation data in the form of rainfall, snowfall, etc. is yet another important factor that shows relative climate variation, including humidity, water balance and water quality etc. Vegetation studies pertaining to loss, increase or change in biomass reflect the ecosystem change under varied climatic regimes. Sea level measurements help in tracing the shore line fluctuation. Solar activity influence climate, primarily through changes in the intensity of solar radiation. Volcanic eruptions, like solar radiation, can alter climate due to the aerosols that are emitted into the atmosphere and alter climate patterns. Chemical composition of air or water can be measured by tracking levels of greenhouse gases such as carbon dioxide and methane, and measuring ratios of oxygen isotopes. Studies show that there is a strong correlation between the percent of carbon dioxide in the atmosphere and the Earth's mean temperature.

But these available instrumental weather records are spanning for short time period in most parts of the country and they do not provide benchmark information to discriminate between natural and human-induced climatic impact. Since climate, in general, shows high spatial and temporal variability, long-term climate records from different geographic regions of the country are required so that we can have a better insight into the climate change. In this connection, high-resolution long-term proxy records are required. There exists inconsistency in the amplitude of climate records derived from different proxies therefore multi-proxy approach proved to be better because the individual records could be cross-verified and robust climate reconstructions can be derived. Such high-resolution proxy climate records spanning centuries to millennia would be useful to understand the natural course of climate, climate sensitivity to forcing, spatial variability, lead and lag relationship, recurrence behavior of extreme climate events and their ecological impact.

6.4.2 Proxy records

It is not possible for us to travel back in time to understand and measure temperatures, rainfall and other environmental conditions. Thus, we need to rely on various proxies from ancient geological materials to understand the conditions locked up in. There are many such proxies like ice cores, tree rings, sub-fossil pollen, boreholes, corals, lake, ocean sediments, and Speleothems that proved to be very useful to mankind to understand the long term vegetation and climate dynamics at spatial and temporal scale. Thus, multi-proxy study is needed to resolve several issues related to present, past and future directions in climate change studies.

6.5 ANNUAL RESOLUTION DATA FROM PROXY RECORD

Since the proxy records gives an indirect information about the past climate, temperature, and rainfall, etc. each proxy responds variably to the changing climatic scenario and thus record palaeoclimate data accordingly. The finer the resolution of data the more information we gather from it. Among the various proxies used in palaeoclimate studies, some of the proxies that give annual resolution data includes Speleothems, corals and tree rings.

6.5.1 Speleothems

The word Speleothems is a Greek word 'Spelaion' meaning cave and 'thema' meaning deposit through flowing, dripping, or seeping water (Moore, 1952; Schwarcz, 1986). Thus, they may be defined as the mineral deposits formed in karstic caves, where the water table is significantly lowered, and favoring air exchange with atmosphere. On the basis of competition between the dynamics of the water and the crystal growth habits of the constituent minerals, they attain different shapes viz. stalagmites and stalactites or slablike deposits known as flowstones (Sasowsky, 2012). Stalactites are the deposits which hang from the ceilings of caves, they often have a hollow core, with growth occurring around the central orifice. On the other hand, stalagmites are solid and grow incrementally at the drip site. They are primarily composed of calcium carbonate, precipitated from groundwater that has percolated through the adjacent carbonate host rock. The most commonly occurring minerals are calcite, aragonite, and gypsum (Sasowsky, 2012). Certain trace elements may also be present that often gives the deposit a characteristic color. Deposition of a Speleothems results from evaporation of water or degassing of carbon dioxide from water droplets.

Under the high seasonal climatic variations inside (humidity, CO_2 partial pressure, air ventilation) or outside (precipitation, temperature, snow melting) the cave. For example, annual laminas are formed in the Speleothems (Fairchild and Treble 2009, Bradley, 2015; Tan et al. 2006; Baker et al. 2008). Therefore, Speleothems have the potential to record past climate with annual resolution.

Annual laminas in Speleothems: In Speleothems four types of laminas have been reported.

1) Fluorescent laminas: They are observed by using conventional mercury light-source UV reflected-light microscopy and confocal laser fluorescent microscopy (Shopov et al. 1994; Orland et al. 2012)

2) Visible laminas: They are observed using conventional transmitted and reflected-light microscopy (Genty and Quinif 1996)

3) Calcite-aragonite couplets: They show seasonal alternations of calcite and aragonite growth layers (Railsback et al. 1994)

4) Geochemical laminas: It is defined by the annual variability of their chemical constituents such as stable isotopes ($\delta^{18}O$, $\delta^{13}C$) and trace elements (e.g., Mg, Sr, Ba) (Johnson et al. 2006).

The number of layers formed are counted in a Speleothems and are then compared with the duration of growth measured independently by radiometric dating techniques viz., ^{230}Th dating is most commonly used for the late Pleistocene samples (Baker et al. 1993; Tan et al. 2000), while with ^{210}Pb and ^{226}Ra methods samples younger than 150 years can be dated (Baskaran and Iliffe 1993; Condomines and Rihs 2006) or with the atomic bomb testing 14C signature that characterizes the last 50 years (Genty et al. 1998; Mattey et al. 2008).

6.5.2 Corals as palaeoclimate proxy

Coral reefs have been a part of the Earth's oceans for millions of years and are very sensitive to changes in climate. By extracting calcium carbonate from the ocean waters, they form skeleton like structure. When the water temperature changes, calcium carbonate densities in the skeletons also change. Studies shows that the coral formed in the summer has a different density than coral formed in the winter. This creates seasonal growth rings on the coral (like rings on a tree). These rings are used to determine the temperature of the water, and the season in which the coral grew and by studying the growth bands, coral samples can be dated to an exact year and season. The density of the coral skeleton, or how many minerals are present in a piece of a certain size, changes with temperature.

Check Your Progress 1

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

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

1) What are Speleothems?

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2) How coral act as palaeoclimate proxy?

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6.5.3 Dendrochronology (Tree rings study)

Climate change during the past 1000 years is important to reconstruct as it can be correlated with the historical archives and extent to which climate affected civilizations can be deduced. Of the several proxies used for paleoclimate (e.g., ice cores, lake sediments, corals and Speleothems) reconstructions, tree rings have special advantages: they record seasonal monsoonal variability, they preserve continuous record and can be easily dated using ring-counting. An individual tree ring records contemporaneous climate changes in the year of formation over the life-span of the tree. Cross correlation and matching of ring patterns of different (dead, archived and growing) trees of the same climate regime can extend the climate reconstructions to past several thousands of years. Significant contributions to climate science within the last decade have firmly established tree-rings as valuable sources of proxy data for evaluating long-term climate variability/trends and as useful tools for developing long-term records of extreme climatic events [Mann et al., 1999]. Previous monsoon reconstructions using tree rings were based on ring width. The analogy used was: trees from high latitude or altitude regions, with wider (narrower) rings correspond to higher (lower) temperature/ precipitation (Managave and Ramesh, 2012). However, the presumably simple relation between width and climate is rather complex and is influenced by non-climatic factors such as light availability, topography, soil type and forest thinning, ecological parameters and also genetic variability among trees of the same species (e.g., Kress et al. [2009], Fritts [1976]). Paleoclimate proxies are affected by ecological parameters and considered to be better measures for climate reconstruction. Tree cellulose $\delta^{18}O$ is more sensitive to rainfall fluctuations as compared to ring-width and ring density [Sano et al., 2010]. Several researches and reviews on tree rings isotopes by Farquhar et al. (1989), Ramesh et al. (1986), Dawson et al. (2002), McCarroll and Loader (2004), Managave and Ramesh (2012) highlight that oxygen and hydrogen of cellulose from individual growth rings can be used as proxies for climatic parameters such as rainfall, humidity and temperature. The oxygen isotope composition of plants is influenced by various physiological and climate processes. It is mainly controlled by $\delta^{18}O$ of the source water, the level of ^{18}O enrichment in leaf due to evaporation, biochemical fractionation of ^{18}O due to synthesis of sucrose in the leaf and the isotopic exchange between carbohydrate and xylem water during cellulose synthesis. The $\delta^{18}O$ of rainfall is inversely related to the amount of precipitation in the tropics (Dansgaard, 1964; Rozanski et al., 1993; Schmidt et al., 2007; Yadava and Ramesh, 2007) hence tree cellulose $\delta^{18}O$ is a powerful tool to reconstruct past monsoon rainfall.

Dendrochronology is the science which belongs to the study of trees' annual growth rings, or in a more scientific way dendrochronology (dendros: trees or growth ring of trees, chronos: time or past event, logy: the study of) is the study and dating of trees annual growth rings to understand the past event and processes. Trees are the natural archives and have the potential to reflect the past atmospheric conditions through annual growth-rings. Tree-ring study could be useful to understand the different aspect of environment like climate, ecology, geophysical process, etc. To study the different disciplines of dendrochronology, it has been divided into several branches based on various parameters and the important applications are as follows:

a) Dendroclimatology: Developing records of past climate using living and dead tree-annual growth rings.

b) Dendrohydrology: Developing records of past water availability and flooding.

c) Dendroarchaeology: Dating of Archaeological dwellings.

d) Dendrogeomorphology: Dating of land movements in the past in the form of landslide, creeping and debris flow.

e) Dendroglaciology: Dating of glacial movement and fluctuations in the past.

f) Dendrovolcanology: Dating of volcanic eruptions in the past.

g) Dendrochemistry: Monitoring of the chemical composition of the soil.

h) Dendroecology: Determine the ecological process in terms of tree-line movements, etc.

i) Dendropyrochrnonology: Dating of forest fires in the past.

j) Dendroentomology: Reconstruction of population level of insects in the past.

k) Dedromastecology: Reconstruction of trees fruiting events.

Dendroclimatology is a special branch of dendrochronology. Development of past climatic records with the help of annual tree-growth rings is called Dendroclimatology. Trees' annual growth rings are studied to understand the past climatic fluctuations and environmental process prevailing over the region. Atmospheric conditions and influence of climate can be observed in tree rings by variation in ring-width. This tree-growth and climate relationship was first recognised by the Leonardo da Vinci in sixteenth century (Stallings et. al, 1937). However annual tree-ring development and wood structure were studied to the mid-1800s when Hartig' son and others published their research paper (Schweingruber, 1988). Hartig's son Robert had also studied anatomy and ecology of tree-rings in the end of nineteenth century and date the damage by insects, hail and frost in trees (Schweingruber, 1988). Andrew E. Douglass was the pioneer worker of this science and known as the "Father of Dendrochronology". He realized that the narrow rings of trees formed during the dry years and the variation in tree-ring pattern can be used to cross-date different sites of tree-ring sequence and to exactly fit them into the calendar year. In the twentieth century, tree-ring study became a useful tool and has been used widely in the world to understand past climatic process. H. C. Fritts (1976) introduced statistical procedures for the reconstruction of past climate on the basis of climatic signal preserved in the tree-ring sequences.

Annual growth-rings are actually secondary xylem and one ring consists of earlywood and latewood. The light and large sized cell which forms during the spring season are called as earlywood and comparatively small in size and dark in colour cells are developed during summer period called latewood. Dendroclimatic studies require trees which produce annual growth ring like conifers including some broad leaf trees are highly useful for the climatic reconstructions. To understand the climate growth relationship, trees from the climate sensitive sites are used where tree-growth is directly influenced by the climatic parameters such as temperature and precipitation. Generally steep slopes, where water table is far from the tree roots are used due to negligible influence of water logging on trees and increasing dependency over climate. Trees grown over such condition are very vulnerable to climate change and therefore very sensitive too. Methodology consists of that two-increment core sample perpendicular to the natural slope from a tree generally taken and for the coring in trees breast height (~1.4m) is used. Increment cores are very fragile and to support the sample wooden frames are used to hold the cores safely and this process is known as mounting of tree-ring samples. Mounted samples are air dried for few days on room temperature and then surfaces are polished with different grit of abrasive to make cross-surface visible under microscope. To assign true calendar year to each ring's skeleton, plot method is used to cross date tree-ring sequence of each sample (Stokes and Smiley, 1968). Using dated samples, tree-ring chronologies developed from each site and climatic signal with the help of metrological data in the chronologies identified. Calibration and verification analysis are performed and ultimately climatic variable is reconstructed.

The tree-ring based climatic reconstruction provides valuable window to look in the past to understand the climatic variability. Actually, in the era of global warming, climate is continuously changing and there is huge temporal and spatial difference exist in a regional scale. Observational record from all over the globe shows that temperature is continuously increasing whereas precipitation shows heterogeneity in the trend. Earth's climate is changing since long back but in the last ~150 years, the anthropogenic activity enhances the variability and due to the influence of anthropogenic practices, climatic observational records show turbulence in their normal pattern. The instrumental records are restricted our understanding in terms of climatic changes in past because of the availability of very sparse and patchy climatic data. Meteorological data records go up-to last one and half century which are not sufficient to understand long term climatic changes. In the absence of proper network of metrological station, tree-ring data have potential to supplement the existing records up-to the last millennium and more.

Resolution of tree ring data is very high and this character makes it unique among the other climatic proxies.

Several tropical and temperate tree species growing in different climatic zones in India with distinct seasonality are known to have datable growth rings. Early studies on tree-rings in India were aimed to understand tree productivity and rotation cycles (Gamble, 1902). Chowdhury (1939, 1940a, b) first attempted to study the effect of environmental factors on growth-ring formation in several species. However, climatic aspect of tree-ring studies in India began only around late 1970s (Pant, 1979). Since then, subsequent tree-ring studies have indicated enormous dendroclimatic potential of different species and several chronologies and reconstructions developed (Yadav et al., 2004, 2006, 2014a, 2014b, 2015, 2017; Misra et al., 2015).

6.6 CENTENNIAL TO MILLENNIAL SCALE DATA FROM PROXY RECORDS

To understand the long-term climate and vegetation dynamics and to understand the influence of human being in altering the landscape dynamics, etc. we need to look into the proxy records that can help in reconstructing the geological past, whether its climate, vegetation, ecosystem or human interference. The proxies that give annual resolution data fetch good information about the changing landscape dynamics for the past few thousand years. But to have the long-term information, we have to rely on proxies that gives information from centennial to millennial scale. So as the gap in the data sparsity at spatial and temporal scale could be filled and a better scenario for further research and policy framing could be done. In this connection, palynological analysis from the sub-surface sediment samples from lakes, swaps, wetlands and ocean cores proved to be very potential archive to reconstruct the wide spectrum of knowledge about the past climate and vegetation relationship as well as the socio-economic status of the past societies.

6.6.1 Palynology as a proxy record

Since the early 1990s, palynology (study of pollen/spores, diatom, phytoliths, etc.) has been used to address several issues like vegetation dynamics, landscape evolution, agriculture, socio-economic status, past dietary pattern, etc. from a wide variety of sediment samples collected from diversified geographical location across the globe.

Analyses of pollen, diatoms and phytoliths data and identification of other organic remains from lacustrine sediments at close interval from the sediment profile would portray the pattern of vegetation changes. The identification of the spores/pollen, diatom and phytoliths help not only in the reconstruction of climate based on changes of past vegetation but also provide great help in understanding the advent of agriculture and role of the various anthropogenic impacts on vegetation dynamics vis-à-vis climate change in a region. This can be done on the basis of morphological variation (in pollen) between wild vs cultivated grasses, abrupt decline in tree taxa in the landscape, records of weeds known to be associated with the cultivation and forest clearance. In a study from Kolleru lake by Misra et al., (2013), palynological investigation showed that during early to mid-Holocene time, Kolleru lake was a part of sea and under the varying sea level and other geological processes and human interference, it got disconnected from the sea and eventually turned into the present-day fresh water lake. Presence of rice phytoliths and record of cultural pollen (more than 40µ) recorded during 6000 years BP indicate towards the paddy cultivation and agricultural practice in the vicinity of the study area. Diatoms being very sensitive to pH and salinity variation will reflect into the past salinity variation, present and past ecological status of wetlands and associated fresh environment etc., in the region.

Application of phytolith as climatic proxy is based on different ecological preferences of the C_3 and C_4 type. C_4 type of plants favour conditions of aridity and low soil moisture whereas the C_3 plants dominate areas of higher soil moisture (Tieszen et al., 1979). These changes are linked with climatic changes in respect to time scale provided by C-14 dates (both conventional and AMS) of corresponding sediments analyzed.

6.6.2 Stable isotopes

Plants vary not only on the morphological basis but also vary in their methods of food preparation. Thus, the perennial grasses are be classified as either C_3 or C_4 plants. These terms refer to the different pathways that plants use to capture carbon dioxide during photosynthesis. Thus, on the basis of the photosynthetic pathway, the plants are broadly classified as -

1) C_3 Plants: The majority of plants (85%), for example are rice, wheat, soybeans are C_3. They have no special features to combat photorespiration and the first stable compound formed is 3 carbon compound. They are adapted to cool season establishment and growth in either wet or dry environments. C_3 species also tend to generate less bulk than C_4 species. C_3 grasses are known for their greater tolerance of frost compared to C_4 grasses.

2) C_4 Plants: C_4 plants initially produce a 4-carbon molecule that then enters the C_3 cycle. Plants are more adapted to warm or hot seasonal conditions under moist or dry environments.

3) CAM: In some plants, as an adaptation to arid conditions, carbon fixation pathway varies. In such plants to reduce evapo-transpiration, stomataremain closed during the day, but open at night to collect carbon dioxide (CO_2) which is stored as the four-carbon acid malate in vacuoles at night, and then in the daytime, the malate is transported to chloroplasts where it is converted back to CO_2, to get utilized during photosynthesis.

Even the isotopic signatures of the C_3 and C_4 plant varies. The C_3 plants have $\delta^{13}C$ in the range of 22.6‰ to 22.8‰, whereas the C_4 types of plants have $\delta^{13}C$ values in the range of sample 211‰ to 213‰ (Smith and Epstein, 1971; O'Leary, 1988). In a lacustrine system, both terrestrial and aquatic plants contribute to the organic matter. To understand the autochthonous and allochthonous inputs in the region, C/N ratio is very useful and would be used. It is known that autochthonous organic matter comprising aquatic plants and algae has a C/N ratio of less than 10, whereas allochthonous organic matter comprising terrestrial plants has a C/N ratio normally higher than 20 and may be up to 200 (Meybeck, 1982; Hedges et al., 1986, in Talbot and Johannessen, 1992).

6.6.3 Biomarkers analysis

Among the various proxies used in palaeoclimate studies, use of biomarkers has increased for the last few decades and has been widely used to address several issues related to palaeo-humidity, palaeo-temperature, palaeo-vegetation, wet and humid phases, etc. A typical biomarker molecule is made up of a hundred or so covalently-bound atoms of carbon and hydrogen, sometimes also including oxygen, nitrogen, etc., (Eglinton and Eglinton, 2008). These biosynthesized molecules released from precursor organism directly, or upon its death get readily dispersed in the environment. Dispersion of biomarkers is greatly influenced by their entrapment within mineral matrices such as shell, teeth, bone etc., or encapsulation in resistant biopolymer matrices such as cell walls, leaf and insect cuticles and pollen grains, or packaging in environmentally ephemeral entities such as fecal pellets, "marine snow" or other detrital debris and colloidal matter (e.g., humic acids) (Eglinton and Eglinton, 2008). Thus, the number of carbon atoms varies from source to source.

6.6.4 Ancient DNA

Among the various emerging potential proxies, ancient DNA proved to be very useful to scientific as well as archaeological community to resolve several issues related to origin, evolution, dispersal, and migration of plants and humans in ancient past. It plays a vital role in identification of the samples that are morphologically difficult to identify. Sedimentary DNA is also been in use to know about the past vegetation scenarios and thus climate of several sites across globe. Like other fields, this field also requires lot of standard protocol right from the site selection, sample collection, storage to data generation and interpretation. Avoiding the contamination of the samples is the pre requisite for DNA analysis.

6.7 LET US SUM UP

Climate change is one of the serious issues being faced by humanity across the globe. Climate change has a wide-range of effects on the environment, socio-economic life influencing several sectors like water resources, agriculture and food security, human health, terrestrial ecosystems, biodiversity and coastal zones. To understand the dynamics of climate change and associated events, it is necessary to have a better understanding of the present scenario of climate by studying and observing the factors controlling or contributing in climate change. In this regard, multi-disciplinary and interdisciplinary studies (oceanography, meteorology, geomorphology, geology and pale climatology) give good amount of quantitative and qualitative information. This information along with the observational and instrumental records from diversified geographical location contribute a lot in making predictive climatic models. Analysis of instrumental records of common climate elements such as temperature, precipitation (rain, snow and hail), humidity, wind, sunshine and atmospheric pressure taken together proved to be very useful to specify the physical state of the climate at a given place, for a certain period of time. Nevertheless, available instrumental weather records are spanning for short time period in most parts of the country and they do not provide benchmark information to discriminate between natural and human-induced climatic impact. Since climate, in general, shows high spatial and temporal variability, long-term climate records from different geographic regions of the country are required so that we can have a better insight into the climate change. In this regard, high-resolution long-term proxy records are required. We have seen that proxies like ice cores, tree rings, sub-fossil pollen, boreholes, corals, lake, ocean sediments, and Speleothems had proved to be very useful to mankind to understand the long term vegetation and climate dynamics at spatial and temporal scale.

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6.8 KEY WORD

Proxy: A proxy climate indicator is a record that is interpreted, using physical and biophysical principles, to represent some combination of climate related variations back in time. Climate-related data derived in this way are referred to as proxy data.

6.9 SUGGESTED FURTHER READING/REFERENCES

Atri, Dimitra; Melott, Adrian L., 2014. Cosmic rays and terrestrial life: A brief review. Astroparticle Physics. 53, 186–190.

Bruckschen, Peter; Oesmanna, Susanne; Veizer, Ján 1999. Isotope stratigraphy of the European Carboniferous: proxy signals for ocean chemistry, climate and tectonics. Chemical Geology. 161, 127–163.

Chowdhury, K. A. 1939. The formation of growth-rings in Indian trees, Part-1. Indian Forest Records 2, 1-39.

Chowdhury, K. A. 1940a. The formation of growth-rings in Indian trees, Part-2. A study of the effect of locality. Indian Forest Records 2, 41-57.

Chowdhury, K. A. 1940b. The formation of growth-rings in Indian trees, Part-3. A study of the effect of locality. Indian Forest Records 2, 59-75.

Christensen J H, Hewitson B, Busuioc A, Chen A, Gao X, Held I, Jones R, Kolli R K, Kwon W-T, Laprise R, Magaña Rueda V, Mearns L, Menéndez C G, Räisänen J, Rinke A, Sarr A and Whetton P. 2007. Regional Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt K B, Tignor M and Miller H L (eds)]. Cambridge University Press.Cambridge, United Kingdom and New York, NY, USA.

Demenocal, P.B. 2001. Cultural Responses to Climate Change during the Late Holocene. Science. 292, 667–73

Fritts, H. C. 1976. Tree Rings and Climate. Academic Press, New York.

Gamble, J. S. 1902. A Manual of Indian Timbers. Sampson Low Marston and Co. Ltd., London.

Gornitz, V. 2009. Paleoclimate Proxies: An Introduction. In: Gornitz V. (eds) Encyclopedia of Paleoclimatology and Ancient Environments. Encyclopedia of Earth Sciences Series. Springer, Dordrecht

http://www.enviropedia.org.uk/Climate_Change/Instrumental_Records.php

https://earthobservatory.nasa.gov/glossary

https://en.wikipedia.org/wiki/Climate_change#cite_note-msu_milankovitch-46

https://news.agu.org/press-release/human-activities-emit-way-more-carbon-dioxide-than-do-volcanoes/

https://volcanoes.usgs.gov/vhp/gas_climate.html

Hulme M and Jones PD. 1994. Global climate change in the instrumental period. Environment Pollution.83, 23-36.

IPCC AR4 WG1, 2007.FAQ 6.1: What Caused the Ice Ages and Other Important Climate Changes Before the Industrial Era?

Joseph Romm (2016). Climatic change. What everyone needs to know.2nd Edition. Oxford University Press, 302 pages

Magrin G, Gay García C, Cruz Choque D, Giménez J C, Moreno A R, Nagy G J, Nobre C and Villamizar A. 2007. Latin America. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Parry M L, Canziani O F, Palutikof J P, van der Linden P J and Hanson C E (eds). Cambridge University Press. Cambridge, UK. pp. 581–615.

Miles, M.G.; Grainger, R.G.; Highwood, E.J. 2004. The significance of volcanic eruption strength and frequency for climate. Quarterly Journal of the Royal Meteorological Society. 130: 2361–76

Misra, K.G., Yadav, R.R., Misra., S. 2015. Satluj river flow variations since AD 1660 based on tree-ring network of Himalayan cedar from western Himalaya, India. Quaternary International 371, 135-143.

National Research Council (1994). Solar influences on Global Change. Washington, DC: The National Academic Press. https://doi.org/10.17226/4778

National Research Council (2010).Advancing the science of climate change. Washington, DC: The National Academic Press. https://doi.org/10.17226/12782

Pant, G. B. 1979. Role of tree-ring analysis and related studies in Palaeoclimatology: preliminary survey and scope for Indian region. Mausam 30, 439-448.

Raymond S. Bradley. 2015. Paleoclimatology: Reconstructing Climates of the Quaternary (Third Edition) Academic Press.

Schröder, K.-P.; Connon Smith, Robert, 2008. "Distant future of the Sun and Earth revisited", Monthly Notices of the Royal Astronomical Society, 386 (1): 155–63

Schweingruber, F. H. 1988. Tree Rings: Basics and Applications of Dendrochronology. D. Reidel, Dordrecht, The Netherlands.

Sindbaek, S.M. 2007. Networks and nodal points: the emergence of towns in early Viking Age Scandinavia. Antiquity. 81, 119–132.

Soroosh sorooshian and Douglas G. Martinson.1995.Proxy indicators of climate.Natural climate variability on decade to century time scale.The National Academy Press, Washington, D.C.

Stallings, J. 1937. Some early papers on tree rings. Tree-Ring Bulletin 3, 27–28.

Stokes, M. A., and Smiley, T. L. (1968).An Introduction to TreeRing Dating, p. 73. University of Chicago Press, Chicago.

Tan LC et al. 2013. Quantitative temperature reconstruction based on growth rate of annually-layered stalagmite: a case study from central China. Quaternary Science Reviews 72: 137-145.

Tieszen, L.L., Hein, D., Qvortrup, S.A., Troughton, J.H., Imbamba, S.K.1979.Use of δ_{13}C values to determine vegetation selectivity in East

African ungulates. Oecologia (Berl.) 37, 351–359.

Timothy I. Eglinton and Geoffrey Eglinton, 2008.Molecular proxies for paleoclimatology.Earth and Planetary Science Letters. 275, 1–16.

UNFCCC 2007. Climate Change: Impacts, Vulnerabilities and adaptation in developing countries. UNFCCC Secretariat. Bonn, Germany.

UNFCCC 2007a. Vulnerability and adaptation to climate change in small island developing states – Background paper for the expert meeting on adaptation for small-island developing States. UNFCCC Secretariat. Bonn, Germany.

UNFCCC 2007b.Background paper – Impacts, vulnerability and adaptation to climate change in Asia.UNFCCC Secretariat. Bonn, Germany.

UNFCCC 2007c. Report on the expert meeting on adaptation for small-island developing States. FCCC/SBI/2007/11.UN Office at Geneva, Switzerland.17 pp.

Wignall, P., 2001. Large igneous provinces and mass extinctions. Earth-Science Reviews. 53, 1–33.

William B. White and David Ira D. Sasowsky. 2012. Encyclopedia of Caves (Second Edition).

Yadav, R.R., Gupta, A.K., Kotlia, B.S., Singh, V.,Misra, K.G., Yadava, A.K., Singh, A.K., 2017. Recent Wetting and Glacier Expansion in the Northwest Himalaya and Karakoram.Scientific Reports.DOI: 10.1038/s41598-017-06388-5.

Yadav, R.R., Misra, K.G., Kotlia, B.S., Upreti, N., 2014a. Age of Himalayan cedar outside its natural home in the Himalayas. Current Science 106, 932-935.

Yadav, R.R., Misra, K.G., Kotlia, B.S., Upreti, N., 2014b. Premonsoon precipitation variability in Kumaon Himalaya, India over a perspective of ∼300 years.Quaternary International 325, 213-219.

Yadav, R.R., Misra, K.G., Yadava, A.K., Kotlia, B.S., Misra, S., 2015. Tree-ring footprints of drought variability in last ~300 years over Kumaun Himalaya, India and its relationship with crop productivity. Quaternary Science Reviews 117, 113-123.

Yadav, R.R., Park, W-K., Singh, J., Dubey, B., 2004. Do the western Himalayas defy global warming? Geophysical Research Letters 31, L17201, doi 10.1029/2004GL020201.

Yadav, R.R., Singh, J., Dubey, B., Mishra, K.G., 2006. A 1584-year ring width chronology of juniper from Lahul, Himachal Pradesh: prospects of developing millennia long climate records. Current Science 90, 1122–1126.

6.10 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress 1

1) Speleothems are defined as the mineral deposits formed in karstic caves, where the water table is significantly lowered, and favoring air exchange with atmosphere. On the basis of competition between the dynamics of the water and the crystal growth habits of the constituent minerals, they attain different shapes namely stalagmites and stalactites or slab-like deposits known as flowstones. Stalactites are the deposits which hang from the ceilings of caves, they often have a hollow core, with growth occurring around the central orifice. Stalagmites are solid and grow incrementally at the drip site.

2) Coral reefs are very sensitive to changes in climate. Corals by extracting calcium carbonate from the ocean waters, they form skeleton like structure. When the water temperature changes, calcium carbonate densities in the skeletons also change. It has been reported that the coral formed in the summer has a different density than coral formed in the winter. This creates seasonal growth rings on the coral (like rings on a tree). These rings are used to determine the temperature of the water, and the season in which the coral grew and by studying the growth bands, coral samples can be dated to an exact year and season. The density of the coral skeleton, or how many minerals are present in a piece of a certain size, changes with temperature.

Check Your Progress 2

1) Dendrochronology is the science which belongs to the study of trees' annual growth rings. In other words, dendrochronology is defined as the study and dating of trees annual growth rings to understand the past event and processes. Trees are the natural archives and have the potential to reflect the past atmospheric conditions through annual growth-rings. Tree-ring study could be useful to understand the different aspect of environment like climate, ecology, geophysical process, etc.

2) Dendroclimatology is a special branch of dendrochronology. Development of past climatic records with the help of annual tree-growth rings is called Dendroclimatology. Trees' annual growth rings are studied to understand the past climatic fluctuations and environmental process prevailing over the region. Atmospheric conditions and influence of climate can be observed in tree rings by variation in ring-width.