Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/16333
DOI URL: http://dx.doi.org/10.21474/IJAR01/16333

RESEARCH ARTICLE

EFFECT OF CLIMATE CHANGE ON SOIL EROSION: A REPORT

Shubhi Kulsrestha
M.E. (Control System) from Electrical Engineering Department, M.B.M. Engineering College, Jodhpur and is Presently Working in Arid Forest Research Institute, Jodhpur, India.

Manuscript Info

Manuscript History
Received: 25 December 2022
Final Accepted: 27 January 2023
Published: February 2023

Key words:-
Climate Change, Organic Matter, Soil Erosion, Global Warming

Abstract

Climate change refers to the changing Earth's climatic system lasting from over a few decades to millions of years. The formation of soil is a complex and a long process involving the multifarious interaction of the number of forces viz; relief, climate, parent material, organisms all acting over time. Climate is one of the most important factors affecting the formation of soil with important implications for their development, use and management perspective with reference to soil structure, stability, topsoil water holding capacity, nutrient availability and erosion. Assuming constant inputs of carbon to soils from vegetation, different estimate predicts that expected changes in temperature, precipitation and evaporation will cause significant change in organic matter turnover and CO_2 dynamics. In conclusion, increased productivity would generally lead to greater inputs of carbon to soil, thus increasing organic matter in soil.

Introduction:-

The earth is surrounded by a thin layer of air held to it by gravity and consists of nitrogen (78% by volume) and oxygen (21%).Climate, whether of the earth as a whole or of asingle country or location, is often described as thesynthesis of weather recorded over a long period oftime. It is defined in terms of long-term averagesand other statistics of weather conditions, includingthe frequencies of extreme events. Climate is farfrom static. Just as weather patterns change fromday to day, the climate changes too, over a range oftime frames from years, decades and centuries tomillennia, and on the longer time-scales correspondingto the geological history of the earth. Increase in atmospheric carbon dioxide (CO_2) concentrations, air temperatures, significant and/or abrupt changes in daily, seasonal, and inter-annual temperature, changes in the wet/dry cycles, intensive rainfall and/or heavy storms, extended periods ofdrought, extreme frost and heat waves are the effects of climate change that significantly affect soil properties and fertility**.** Depletion of the SOC (Soil organic Carbon) pool in soil leads to soil degradation. It comprises physical degradation (i.e., reduction in aggregation, decline in soil structure, crusting, compaction, reduction in water infiltration capacity and water/air imbalance leading to anaerobiosis) and erosion, chemical degradation (i.e., nutrient depletion, decline in pH and acidification, build up of salts in the root zone, nutrient/elemental imbalance and disruption in elemental cycles), and biological degradation (i.e., reduction in activity and species diversity of soil fauna, decline in biomass C and depletion of SOC pool). Soil degradation decreases biomass productivity, reducing the quantity (and quality) of biomass returned to the soil, and as a consequence decreases the SOC pool. Among all soil degradative processes, accelerated soil erosion has the most severe impact on the SOC pool.

Corresponding Author:- Shubhi Kulsrestha
Address**:-** M.E. (Control System) from Electrical Engineering Department, M.B.M. Engineering College, Jodhpur and is Presently Working in Arid Forest Research Institute, Jodhpur, India.

This paper starts with describing the basic components of climate system, thereby describing the impacts of climate change on its components. The anthropogenic and natural activities have lead to the increased green house effect thus leading to global warming. Changes in the environment have significant impacts on soil structure thus leading to soil erosion and land degradation. Soil erosion is defined as eroding of field's topmost layer of soil by the certain physical forces like water and wind or through forces associated with farming activities such as tillage. Erosion is always associated with three distinct actions soil detachment, movement and deposition. The factors affecting the erosion are further described including slope, soil structure, organic matter etc. In order to reduce the effect of soil erosion certain conservation measures are described, which when adopted tends to reduce the destructive effects of soil erosion.

Climate System

The atmosphere is not an isolated system. It interacts with other components of the Earth system. The global climate system is composed of the atmosphere, the oceans, the ice sheets (cryosphere), living organisms (biosphere) and the soils, sediments and rocks (geosphere), all are responsible for the movement of heat around the Earth's surface. All of these elements together compose the climate system, whose individual components and processes are connected and influence each other in diverse ways(Dr.ThomasBosch et. al.). At the planetary scale, the global climate is regulated by the amount of energy the Earth receives from the Sun. However, the global climate is also affected by other flows of energy which takes place within the climate system itself. There are three basics that dictate Earth's climate, and our environment. These are:

(a) Solar heating of the planet balanced by energy loss to space;

(b) Atmosphere, ocean, land, and ice responses to heating which provide feedbacks that either mitigate or accentuate planetary temperature changes; and

(c) Regional environmental systems which have innate patterns of climate variability dictated by their unique physical-chemical-biological conditions. These systems respond to the planetary energy balance and also interact with one another.

The atmosphere plays a crucial role in the regulation of Earth's climate. It is a mixture of different gases and aerosols (suspended liquid and solid particles) collectively known as air. Air consists mostly of nitrogen (78%) and oxygen (21%). The presence of greenhouse gases, including carbon dioxide and methane, has a dramatic effect on the amount of energy that is stored within the atmosphere, and consequently the Earth's climate. These greenhouse gases trap heat within the lower atmosphere that is trying to escape to space, thus making the surface of the Earth hotter.The movement of heat or the flow of energy takes place between the atmosphere and other parts of the climate system most significantly by the world's oceans. For example, ocean currents move heat from warm equatorial latitudes to colder polar latitudes. Heat is also transferred via moisture. Water evaporating from the surface of the oceans stores heat which is subsequently released when the vapor condenses to form clouds and rain. The significance of the oceans is that they store a much greater quantity of heat than the atmosphere. The top 200 metersof the world's oceans store 30 times as much heat as the atmosphere. Therefore, flow of energy between the oceans and the atmosphere can have dramatic effects on the global climate. (Fig. 1)

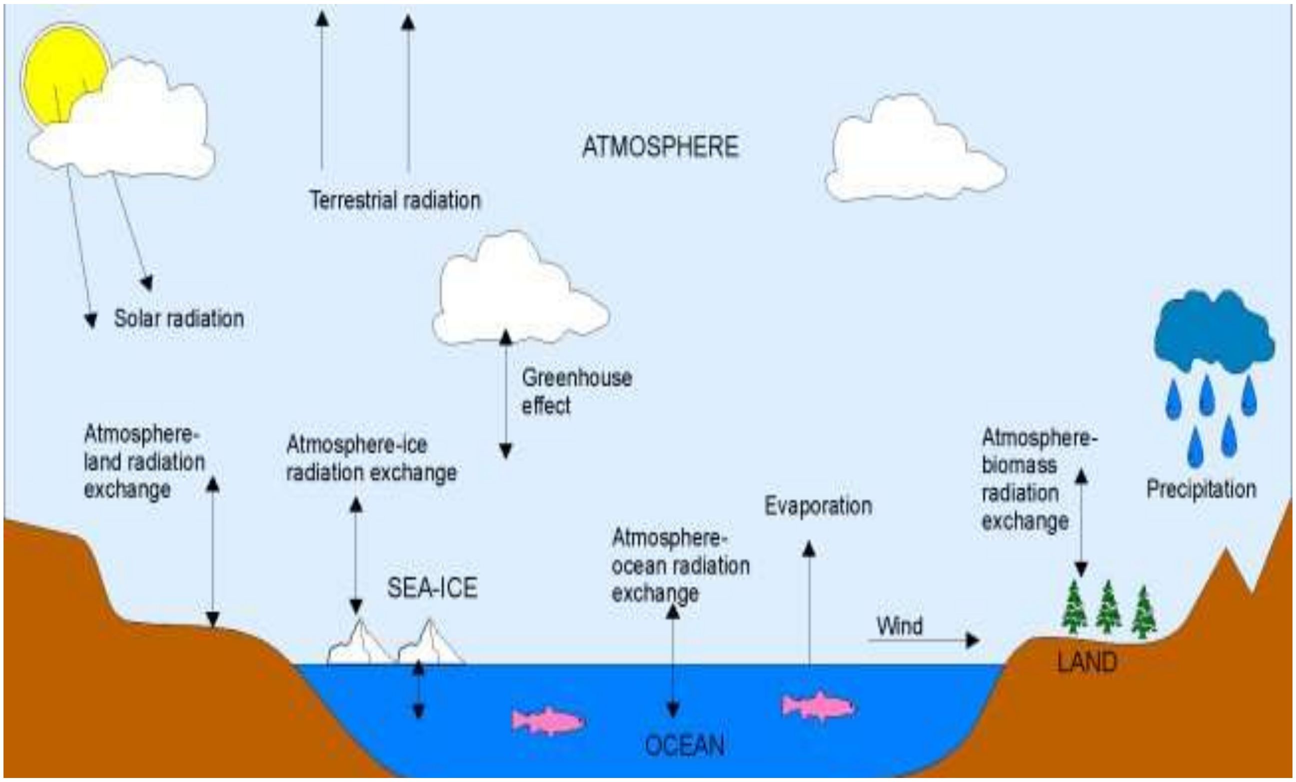


Fig. 1:- The Earth's climate system responds to changes not just in the atmosphere but also the oceans and the ice sheets, and over longer periods of time, movements of the Earth's crust and even the evolution of life itself. (Dr. Thomas Bosch et. al.)

Green House Effect:

The Sun powers Earth's climate, radiating energy at very short wavelengths, predominately in the visible or near-visible (e.g., ultraviolet) part of the spectrum. Roughly one-third of the solar energy that reaches the top of Earth's atmosphere is reflected directly back to space. The remaining two-thirds are absorbed by the surface and, to a lesser extent, by the atmosphere. To balance the absorbed incoming energy, the Earth must, on average, radiate the same amount of energy back to space. Because the Earth is much colder than the Sun, it radiates at much longer wavelengths, primarily in the infrared part of the spectrum (Fig.3). Much of this thermal radiation emitted by the land and ocean is absorbed by the atmosphere, including clouds, and re-radiated back to Earth. This is called the greenhouse effect.The certain gases in the Earth's atmosphere, including carbon dioxide, methane, nitrous oxide, water vapor called as green house gases. The list of green house gases along with their source is tabulated below:

Table 1:-List of green house gases and their sources.

GHG Name	**Source**
Carbon Dioxide(CO_2)	Burning of fossil fuels and wood
Nitrous oxide (NO_2)	Use of fertilizer and decomposition of animal wastes
Methane (CH_4)	Sediments, swamps, landfills and in flooded rice/paddy fields
Chlorofloro carbons (CFCs)	Freon (a refrigerant)
Halons, such as Halocarbons	Fire extinguishers
Water Vapor	Clouds radiate heat back to the earth
Nitrous Triflouride (NF_3)	Used most frequently in the electronics industry during various processes

Thesegases are transparent to the high-frequency, high-energy solar radiation, but are much more opaque to the lower frequency infrared radiation leaving the surface of the earth. Thus heat is easily let in, but is partially trapped by these gases as it tries to leave.Earth's surface, warmed to a temperature around 255 K, radiates long-wavelength, infrared heat in the range of 4–100 μm.(Fig. 2) (Mitchell, John F. B. (1989)) At these wavelengths, greenhouse gases that were largely transparent to incoming solar radiation are more absorbent.(Mitchell, John F. B. (1989))

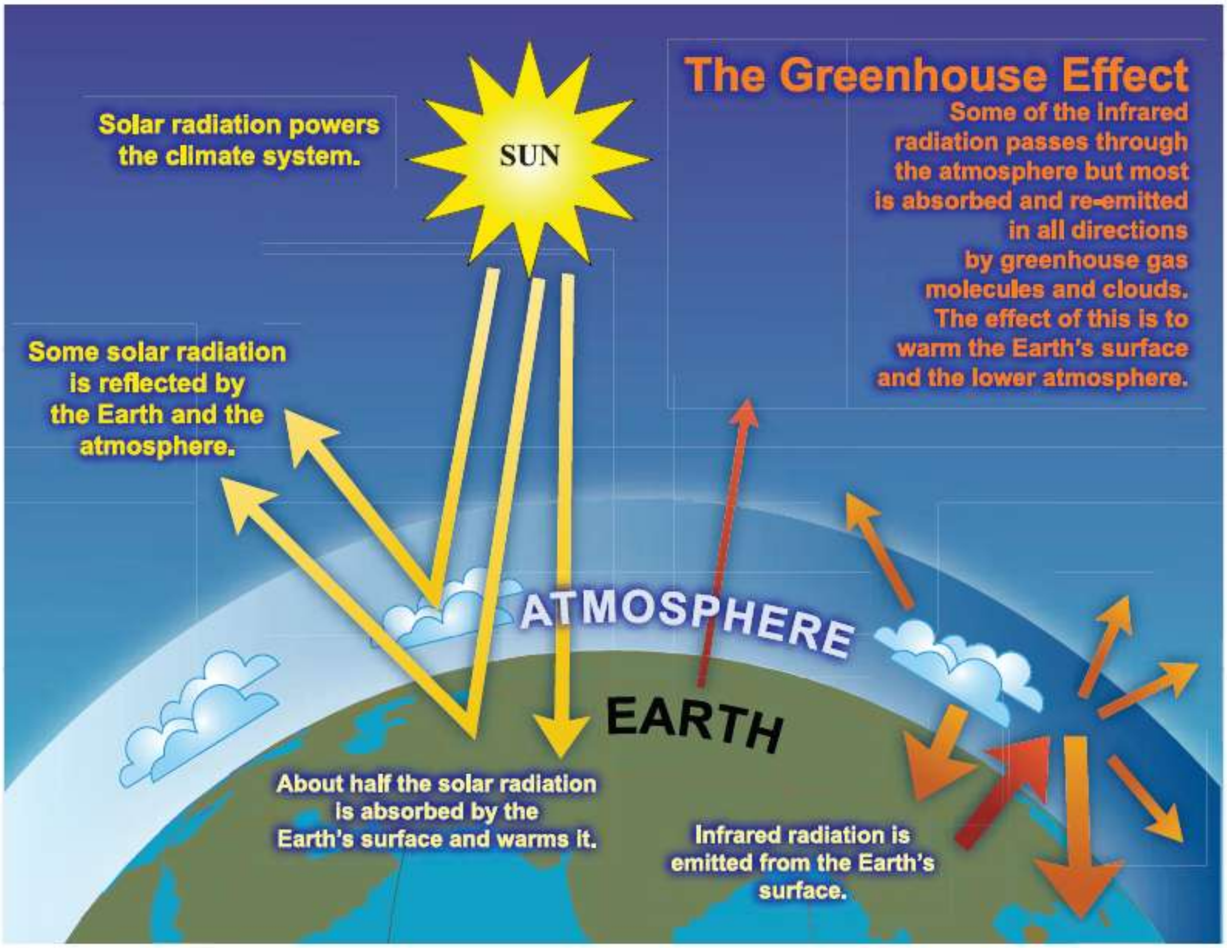


Fig. 2:- Greenhouse gases in the atmosphere, including water vapor, carbon dioxide, methane, and nitrous oxide, absorb heat energy and emit it in all directions (including downwards), keeping Earth's surface and lower atmosphere warm. (An idealized model of the natural greenhouse effect)

Kirchhoff's law of thermal radiation postulated by a German physicist Gustav Robert Kirchhoff, states that the emissivity and the absorptivity of a surface at a given temperature and wavelength are equal. So the gases of the atmosphere which are absorbed have to be re-emittedin the atmosphere both upwards into space as well as downwards back towards the Earth's surface. Thermal equilibrium is reached when all the heat energy arriving on the planet is leaving again at the same rate. Adding more of a greenhouse gas, such as CO_2, to the atmosphere intensifies the greenhouse effect, thus warming Earth's climate. The amount of warming depends on various feedback mechanisms. For example, as the atmosphere warms due to rising levels of greenhouse gases, its concentration ofwater vapor increases, further intensifying the greenhouseeffect. This in turn causes more warming, which causes an additional increase in water vapor, in a self-reinforcing cycle. This water vapor feedback may be strong enough to approximately double the increase in the greenhouse effect due to the added CO_2 alone (IPCC FAQ 1.3).

Additional important feedback mechanisms involve clouds. Clouds are effective at absorbing infrared radiation and therefore exert a large greenhouse effect, thus warming the Earth. Clouds are also effective at reflecting away incoming solar radiation, thus cooling the Earth. A change in almost any aspect of clouds, such as their type, location, water content, cloud altitude, particle size and shape, or lifetimes, affects the degree to which clouds warm or cools the Earth. (IPCC 2007).

Climate Change timescale

Climate will change very slowly in the future because the oceans with their immense volumes of water react very gradually to change. Therefore, many but not all of the consequences of climate change triggered by human activity will only gradually become noticeable. Some of these consequences could actually be irreversible when certain thresholds are crossed. At some point it will no longer be possible, for instance, to stop the complete melting of the Greenland ice sheet and the resulting seven-meter rise of sea level. The position of the threshold, however, is not precisely known. Carbon dioxide is extremely long lived i.e. the carbon dioxide sinks in oceans is not as quickly as it is produced. The situation is different for short-lived trace gases like methane (CH_4). If methane emissions were stabilized at the present level, the methane concentration in the atmosphere would also stabilize, because methane diminishes in the atmosphere at about the same rate as it is emitted. In order to maintain the carbon dioxide concentration at a given level, the emissions have to be reduced to a fraction of the present amounts. Different components of the climate system react to perturbations at different rates. The deep ocean, for example, is an important cause of the slow response of climate (Fig. 3). The colored area on the top scale represents the short time span of a human life.

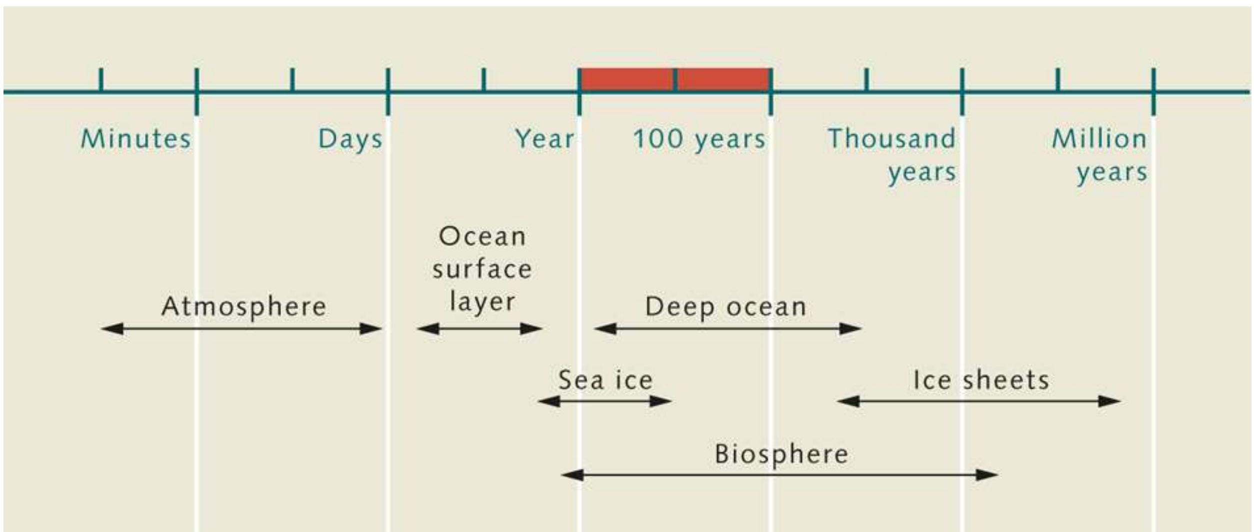


Fig. 3:- Impact of climate change on different components (ref).

Modeling climate and climate change

Climate models use quantitative methods(DOE, 2008b, 2009b; Donner and Large, 2008) to simulate the interactions of the important drivers of climate, includingatmosphere, oceans, land surface and ice. They are used for a variety of purposes ranging from study of the dynamics of the climate system to projections of future climate.All climate models take account of incoming energy from the sun as short wave electromagnetic radiation, chiefly visible and short-wave (near) infrared, as well as outgoing long wave (far)infrared electromagnetic. Any imbalance results in a change in temperature.

It is an essential tool for exploring possible future climate, particularly for producing projections of the long-term global trends that might be expected from the build-up of greenhouse gases. Such a model must incorporate the best-available knowledge of the relevant physical, chemical and biological processes. Confidence in the output of such models depends on their demonstrated ability to represent the major features of the present-day climate realistically, as well as those of the well-documented climates of the past.

Models vary in complexity:

1. A simple radiant heat transfer model treats the earth as a single point and averages outgoing energy
2. The above model can be expanded vertically (radiative-convective models) and/or horizontally
3. Finally, (coupled) atmosphere–ocean–sea ice global climate models solve the full equations for mass andenergy transfer and radiant exchange.
4. Box models can treat flows across and within ocean basins.

5. Other types of modelling can be interlinked, such as land use, allowing researchers to predict the interaction between climate and ecosystems.

While there are many different kinds of climate models, all are based fundamentally on the laws of physics that govern atmospheric and oceanic motions, including the conservation of mass, energy, and angular momentum and laws that govern the propagation of radiation through the atmosphere. Most modern climate models also include representations of the oceans, cryosphere, and land surface, as well as the exchanges of energy, moisture, and materials among these components. Earth system models additionally simulate a wide range of biophysical processes including atmospheric chemistry and the biogeochemistry of ecosystems on land and in the oceans.

Climate models range in type from simple, one dimensional energy balance models, which can be used to test relatively simple hypotheses, through tocomplex three-dimensional numerical models which incorporate a broad range of processes within the atmosphere-geosphere-biosphere climate system (Fig. 4). Climate models are used to simulate both natural climate variability and the evolution of the climate system under specified climate forcing, including both historical data and scenarios of future forcing changes.A major achievement in climate modelling over recent years has been the development of coupled models. These bring together atmospheric, oceanic, land-surface and sea-ice model components, and progressively others, into a single interacting global climate model.

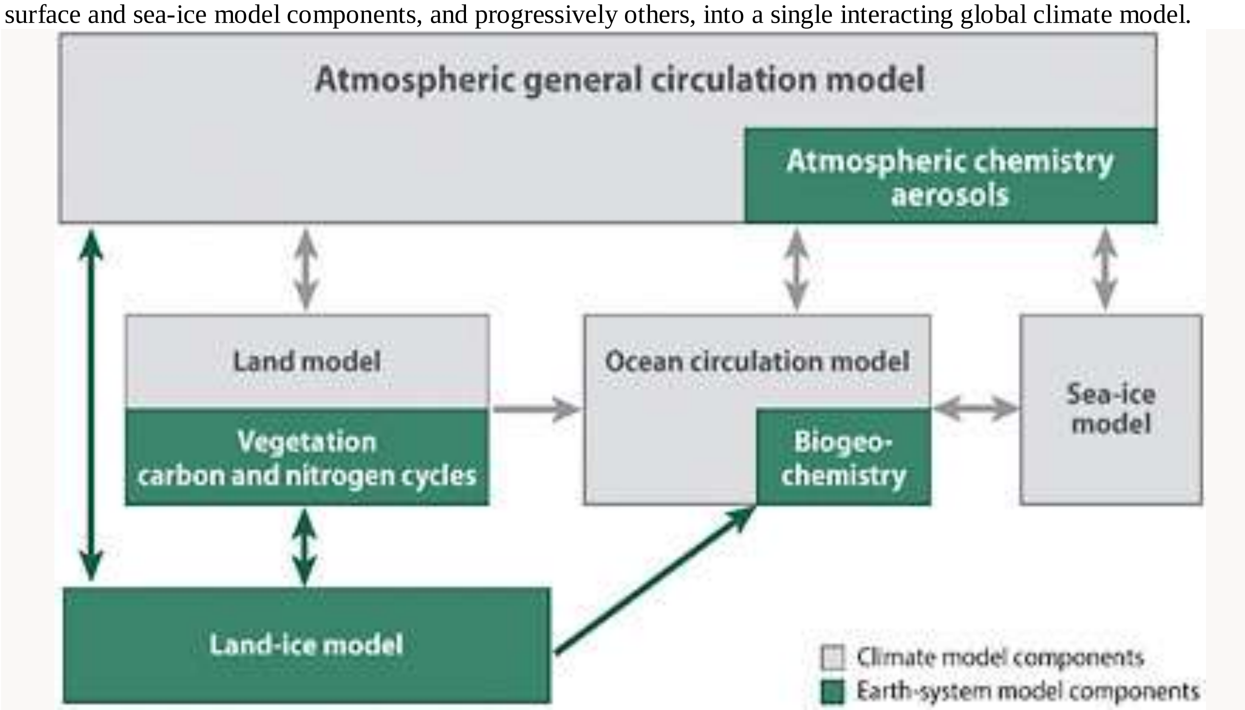


Fig. 4:- Schematic illustration of the components of climate and Earth system models. The components of climate models are in gray and the additional components in Earth system models are in green. The connecting arrows indicate exchanges that couple the model components. SOURCE: Donner and Large (2008).

Numerical models (General Circulation Models or GCMs), representing physical processes in the atmosphere, ocean, cryosphere and land surface, are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. While simpler models have also been used to provide globally- or regionally-averaged estimates of the climate response, only GCMs, possibly in conjunction with nested regional models, have the potential to provide geographically and physically consistent estimates of regional climate change which are required in impact analysis.Atmospheric and oceanic GCMs (AGCM and OGCM) are key components along with sea ice and land-surface components in understanding the climate and forecasting climate change.

A GCM contains prognostic equations that are a function of time (typically winds, temperature, moisture, and surface pressure) together with diagnostic equations that are evaluated from them for a specific time period. As an example, pressure at any height can be diagnosed by applying the hydrostatic equation to the predicted surface pressure and the predicted values of temperature between the surface and the height of interest.

Atmospheric GCMs have several practical applications including medium-range (typically 3–10 days) weather forecasting, seasonal forecasting (typically 3–12 months) when coupled to models of other components of the climate system such as the global ocean, and climate prediction (typically 10–1,000 years) when models of the various components of the climate system, such as sea and land ice, carbon-cycle, and biosphere models, are incorporated.Finally, climate forcing scenarios that project human influences on local and regional climate, such as regional aerosol loading and land use change, are needed because these forcings may have a large influence on local and regional climate change (CCSP, 2008).

Greenhouse Gases and Global Warming

Emission of green house gases through natural and anthropogenic activities has lead to the heating of the atmosphere thereby leading to global warming. Greenhouse gases (GHGs) such as carbon dioxide, methane, nitrous oxide, and halogenated compounds acts like a blanket thus captivating thermal infrared radiations and preventing it from evading into outer space.The net effect is the steady heating of Earth's atmosphere and surface, and this process is called global warming. Since the dawn of the Industrial Revolution in the early 1800s, the heating of fossil fuels like coal, oil, and gasoline have greatly increased the concentration ofgreenhouse gases in the atmosphere, specifically CO_2, (Kweku et al).Atmospheric CO_2 intensities have increased by more than 40% since the beginning of the Industrial Revolution, from about 280 parts per million (ppm) in the 1800s to 400 ppm today. The last time Earth's atmospheric levels of CO_2 reached 400 ppm was during the Pliocene Epoch, between 5 million and 3 million years ago, according to the University of California, San Diego’s Scripps Institutions of Oceanography (Environmental Protection Agency (EPA 2009-2012). Deforestation is the second largest anthropogenic basis of carbon dioxide to the atmosphere ranging between 6% and 17%, (European Environment AgencyTechnical Report). Some human activities like the production and consumption of fossil fuels, use of various chemicals agriculture, burning bush, waste from incineration processes and other industrial activities have increased the concentration of greenhouse gases (GHG), particularly CO_2, CH_4,and N_2O in the atmosphere making them harmful (El-FadelM et. al.).

The greenhouse effect, collective with growing levels of greenhouse gases and the resultant global warming, is expected to have profound consequences, according to the near-universalconsensus of scientists (Murray, Brian C, et al.). If global warming undergoes unimpeded, it will cause noteworthy climate change, a rise in sea levels, increasing ocean acidification, lifethreatening weather events and other severenatural and societal impacts, according to NASA, the Environmental Protection Agency(EPA) andother scientific and governmental bodies (National Green-House Emission Data;2011, Archer David). This increase in atmospheric GHG concentration has led to climate change and global warming effect, which is motivating international efforts such as the Kyoto Protocol, signing of Paris Agreement on climate change and other initiatives to control negative outcomes of the greenhouse effect.

Effects of climate change on soil

Climate change can have a very large impact on soils and the functions that soil performs. The main potential changes in soil-forming factors (forcing variables) directly resulting from global change would be in organic matter supply from biomass, soil temperature regime and soil hydrology, the latter because of shifts in rainfall zones as well as changes in potential evapo-transpiration.

Climate change is global phenomena and occurring continuously since the earth came into existence. Climate change has become a major scientific and political issue during the last decade. Climate change is threatening food security globally. Countries like India are more vulnerable in view of the tropical climate and poor coping capacity of the small and marginal farmers. Climate change is projected to have significant impacts on agriculture through direct and indirect effects on crops, soils, livestock and pests. Though, climate change is a slow process involving relatively small changes in temperature and precipitation over long period of time, nevertheless these slow changes in climate influences the various soil processes particularly those related to soil fertility. At the ecosystem level, the soil affects vegetation through its influence on water availability, elemental cycling and soil temperature regime (Cheddadi et al., 2001). The effects of climate change on soils are projected to have variable effects on soil processes and properties important for restoring soil fertility and productivity.Changes in soil moisture and temperature regimes can affect species composition in the ecosystem. These changes may affect the SOC pool and soil physical properties because of the changes in biomass (detritus material, above ground and below ground biomass) returned to the soil.Inagriculture, climate change will affect crop production as changes in soil, air temperature and rainfall affect the ability of crops to reach maturity and their potential harvest.

Oils contain largest pool of terrestrial soil organic carbon which helps to counteract the increasing levels of CO_2. Carbon gets accumulated in soil as soil inputs through many years of plant processes associated with root growth and is lost from soil as microscopic organisms mostly bacteria and fungi which decompose soil carbon converting it back to carbon dioxide and releasing it back to the atmosphere. Further environmental conditions such as N, water and CO_2avaibility affects the quantity and quality of plant biomass and thus soil carbon. The balance of these two processes i.e. accumulation and loss of carbon from soil becomes uncertain with increasing levels of CO_2 in the atmosphere. The higher levels of atmospheric carbon dioxide increases both carbon's input and release from soil thus making it more unstable and further enhancing the soil microbial activities and depleting the carbon storage. This increase in microbial activity has a potential negative effect on the accumulation of organic C in soils and thus on potential sequestration of soils (NavneetPareek 2017).Soil-climate models predicts the expected changes in temperature, precipitation and evaporation with a naturally occurring increase in organic matter turnover facilitating increased losses of carbon in mineral and organic soils. These losses of soil carbon will also affect other soil functions like poorer soil structure, stability, topsoil water holding capacity,nutrient availability and erosion. The loss of soil carbon is also accelerated by the increase in temperature. However, these effects could be counteracted by enhanced nutrient release resulting in increased plant productivity vis-a-vis litter inputs. Increased rainfall could expect increased peat formation and methane release, whilst areas experiencing decreased rainfall could undergo peat, CO_2 loss, increased moisture deficit for arable crops (especially on shallow soils) and for forest soils thereby affecting foraging patterns, reproduction and survivability of the soil invertebrates (Table 2)(Chander, S., 2012).

Table 2:- Summary of expected effects of individual climate change variables on soil processes.

Increasing temperature	Loss of soil organic matter
	Reduction in labile pool of SOM
	Reduction in moisture content
	Increase in mineralization rate
	Loss of soil structure
	Increase in soil respiration rate
Increasing CO_2 concentration	Increase in soil organic matter
	Unstable soil carbon
	Increase in soil microbial activities
Increasing rainfall	Increase in soil moisture or soil wetness
	Enhanced surface runoff and erosion
	Increase in soil organic matter
	Nutrient leaching
	Increased reduction of Fe and nitrates
	Increased volatilization loss of nitrogen
	Increase in productivity in arid regions
Reduction in rainfall	Reduction in soil organic matter
	Soil salinization
	Reduction in nutrient availability

(NavneetPareek 2017)

Climate change impacts on soil water and soil temperature

Soil water

The main effects of climate change on soils will be through changes in soil moisture regimes. Soil moisture is a key driver to most soil processes and is instrumental in the use that can be made of soil. As climate changes, soil moisture levels will be influenced by direct climatic effects (precipitation, temperature effects on evaporation), climate induced changes in vegetation, different plant growth rates and different cycles, different rates of soil water extraction and the effect of enhanced CO_2 levels on plant transpiration. Changes in soil water fluxes may also feed back to the climate itself and even contribute to drought conditions by decreasing available moisture, altering circulation patterns and increasing air temperatures.Soilwater can be influenced in a number of ways by climate change. Changes in precipitation will rapidly affect soil water since the time-scale for response to rainfall in the soil is usually within a few hours. Increasing temperatures will also lead to greater evapo-transpiration and hence loss of water from the soil. Several soil forming processes, including organic matter turnover, structure formation, weathering, podzolisation, clay translocation and gleying, are strongly affected by soil moisture contents. The type of soil structure that develops under a particular climatic regime is particularly important because it affects the processes of run off, infiltration, percolation and drainage, processes that are vital in the distribution of water across the landscape.

Those areas predicted to have warmer temperatures and less rainfall will have less soil moisture with potentially large implications for the crops that can be grown and the natural and semi-natural ecosystems that can continue to exist. The temporal nature of changes in climatic variables is particularly important, for example less soil moisture in summer, more soil moisture in winter (DEFRA., 2005).

Soil temperature

There is a close relationship between air temperature and soil temperature and a general increase in air temperature will inevitably lead to an increase in soil temperature. The temperature regime of the soil is governed by gains and losses of radiation at the surface, the process of evaporation, heat conduction through the soil profile and convective transfer via the movement of gas and water. As with soil moisture, soil temperature is a prime mover in most soil processes. Warmer soil temperatures everywhere will accelerate soil processes, leading to more rapid decomposition of organic matter, increased microbiological activity, quicker release of nutrients, increased rates of nitrification and generally increased chemical weathering of minerals. However, soil temperatures will also be affected by the type of vegetation occurring at its surface, which may change itself as a result of climate change, or adaptation management.

Time-scale for change

The diverse range of physical, chemical and biological processes that affect soil formation and modify soil properties will respond to climate change according to varying timescales (Table 3). Parameters such as bulk density, porosity, infiltration rate, permeability, nitrate content and composition of soil air can change on a daily basis, depending on the weather. At the other end of the time scale, weathering of minerals as part of soil formation and changes in soil texture are more likely to be on millennial time scales. The effect of climate change will be to modify the rates of these processes and lead to changes in soil properties with a range of implications for soil formation, soil genesis, and the way in which soils can be used. Increasing damage to the land, or land degradation, will occur in the form of soilerosion, desertification, salinization, or loss of peat soils, further impacting on the capability of soils to support the need of production (Karmakar Rajeev et al, 2016). Its potential impact on some of the major processes and properties is described below.

Table 3:- Time scale for changes in soils with change in climate.

Time scale categories	Soil parameter	Properties and characteristics	Regimes
$<10^{-1}$yr	Temperature; moisture content; bulk density; total porosity; infiltration rate; permeability; composition of soil air; nitrate content	Compaction; drainage; workability	Aeration; heat regime
10^{-1}-10^{0}yr	Total water capacity; field capacity; hydraulic conductivity; pH; nutrient status; composition of soil solution	Microbiota	Microbial activity; human controlled plant nutrient regime; erosion
10^{0}-10^{1}yr	Wilting percentage; soil acidity; cation exchange capacity	Type of soil structure; meso-fauna;gleying, litter, slickensides	Moisture; natural fertility; salinity-alkalinity; desertification; permafrost
10^{1}-10^{2}yr	Specific surface; clay mineral association; organic matter content	Tree roots soil biota; salic, calcareous, sodic, vertic properties	
10^{2}-10^{3}yr	Primary mineral composition; chemical composition of mineral part	Tree roots; colour (yellowish/reddish); iron concretions; soil depth; cracking; soft powdered lime	
$>10^{3}$yr	Texture; particle-size distribution; particledensity	Parent material; depth; abrupt textural change	

Source: DEFRA., 2005

Climate Change and Soil Erosion:

Soil is the most fundamental resource to fulfill basic requirements and is a major factor responsible to tackle climate change as it is the second largest carbon pool after the oceans. Human and ecological systems rely on soil for the provision of water and nutrients for plant growth, the regulation of the water cycle and the storage of carbon. A change in the atmospheric carbon dioxide concentrations, temperatures, and precipitation patterns determines the decomposition rates, modifying the soil-plant system. This in turn, will have an impact on the amount of organic carbon levels in soils. This is particularly important because organic carbon determines important soil qualities, such as soil fertility, structure and microbial population in soils. Secondly, precipitation and temperature typically affect the amount of carbon in soils as well as the distribution of organic matter in soils. Restoring key ecosystems on land, and a sustainable use of the land in urban and rural areas, can help us to mitigate and adapt to climate change. The Earth's topsoil contain approximately **2,500 gigatons of carbon**,(Climate counts) which is more than three times the amount of carbon in the atmosphere and about four times the amount of carbon stored in all living animals and plants. However, thousands of years of deforestation, erosion and ploughing have damaged the topsoil, causing it to emit large amounts of carbon dioxide (CO_2) gas into the atmosphere, contributing to climate change (global warming), as well as ocean acidification, which is harmful to marine life.

Soil erosion refers to the wearing away of a field's topsoil by the natural physical forces of water (Fig.5) or through forces associated with farming activities such as tillage. Erosion, whether it is by water, wind or tillage, involves three distinct actions — soil detachment, movement and deposition. Topsoil, which is high in organic matter, fertility and soil life, is relocated elsewhere "on-site" where it builds up over time or is carried "off-site" where it fills in drainage channels. Soil erosion is influenced by political, economic, social conditions, climate, land use and management and topography. Energy fluxes, erosion control, moderation of climate and ecosystem stabilization are the essential ecosystem services provided by forest. It is caused due to urbanization, Intensive farming or cultivation, overgrazing etc. There is significant effect of urbanization because most of the productive agricultural land near cities has been converted into residential and commercial area. Raindrop is absorbed into soil pore spaces as it falls on the soil. When all the pore spaces are filled with water soil becomes saturated and extra water will either standon surface or flow down as runoff. The moving water will flow soil particles away and starts the process of erosion. As the intensity of rain increases, the runoff increases and the force exerted on soil particles also increases. As the slope steepness increases, the velocity of runoff and force on soil particles also increases. The soilswhich have less or no vegetation on the surface are more vulnerable to erosion caused by flowing water.

Soil erosion reduces cropland productivity and contributes to the pollution of adjacent watercourses, wetlands and lakes. It is more problematic in dry areas. Soil erosion disturbs agricultural, environmental and ecological functions performed by the soil thus resulting in depletion of soil fertility, decreased moisture storage capacity and consequently decreased crop productivity. In addition to loss of soil fertility and crop yields, soil erosion also increases environmental pollution, increasing the sediment load in streams and rivers, thereby disturbing the aquatic life, particularly fish. In the long run, soil erosion affects socio-economic conditions of the society by causing floods, silting up of water reservoirs and disruption of communication systems. Soil erosion is a naturally occurring process that affects all landforms. Soil erosion can be classified into two major types, i.e., accelerated and geological erosion.

a) **Accelerated Soil Erosion:** In accelerated erosion, soil erosion becomes a main anxiety and a specific threshold level is exceeded by the erosion rate and soil loss through erosion exceeds the soil formation through pedogenic processes. Anthropogenic activities such as slash-and burn agriculture, intensive and uncontrolled grazing, deforestation and burning of biomass and intensive ploughing are main factors which trigger accelerated soil erosion.

b) **Geological Soil Erosion:** The normal process of weathering is geological erosion that usually happens as a part of natural soil-forming mechanisms at low rates in all soils. It is not affected by human activities as well as it happens at the period of long geological time. The processes influenced by the slow but constant geological erosion are the development and disintegration of rocks.

Fig. 5:- The erosive force of water and wind.

Factors determining Soil Erosion:

Slope:

Length and steepness of slope are the main factors that affect soil erosion. As the steepnessincreases the erosion increases similarly, as the length of slope increases the eroded effect of running water increases. The water conservation practices such as terraces and buffer strips reduce the intensity of flowing water by reducing the slope. Runoff velocity of water and discharge is more from channels that have relatively more smooth surfaces. On the other hand, construction of water catchments reduces water runoff and thus decreases the erosion.

Soil Structure:

The arrangement or aggregation of soil particles is termed as soil structure. Soil texture and structure greatly influence water infiltration, permeability, and water-holding capacity. Soil texture refers to the composition of the soil in terms of the proportion of small, medium, and large particles (clay, silt, and sand, respectively) in a specific soil mass. For example, a coarse soil is sand or loamy sand, a medium soil is a loam, silt loam, or silt, and a fine soil is a sandy clay, silty clay, or clay. Soil structure refers to the arrangement of soil particles (sand, silt, and clay) into stable units called aggregates, which give soil its structure. Aggregates can be loose and friable, or they can form distinct, uniform patterns. For example, granular structure is loose and friable, blocky structure is six-sided and can have angled or rounded sides, and plate like structure is layered and may indicate compaction problems.

Soil porosity refers to the space between soil particles, which consists of various amounts of water and air. Porosity depends on both soil texture and structure. For example, a fine soil has smaller but more numerous pores than a coarse soil. A coarse soil has bigger particles than a fine soil, but it has less porosity, or overall pore space. Water can be held tighter in small pores than in large ones, so fine soils can hold more water than coarse soils. Intensive cultivation and large compaction results in deterioration of soil structure and particles binding and thus make them susceptible to erosion. Soil structure results from the symmetrical arrangements of soil particles, which keep pore spaces, micro and macro-organisms, and different sized aggregates, shapes and stability within a limit.(Fig. 6)

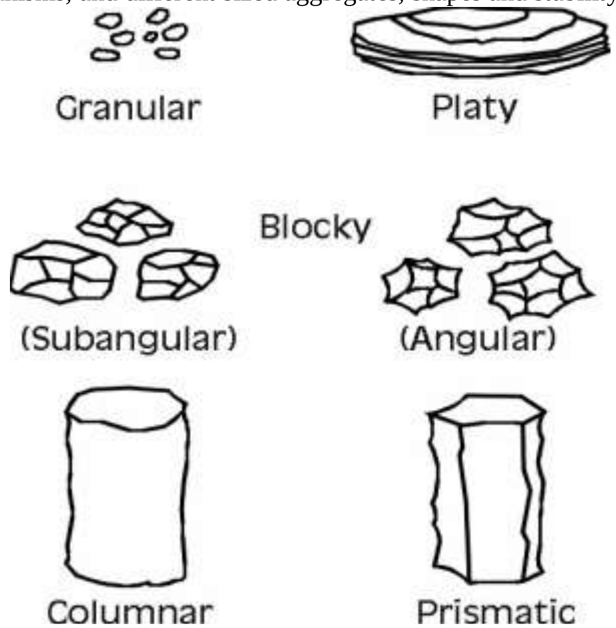


Fig. 6:- Illustration of principle soil aggregates.

The resilience of soil to erosion is largely dependant upon its structure. The soils with poor structure more are weekly aggregated easily compacted and have high runoff with low infiltration. The quantitative measurement of soil structure is difficult therefore water infiltration, air permeability, and soil organic matter dynamics are usually related to soil structure development. Measurement of properties of aggregate is also a helpful way if soil structural stability at the aggregate level determines the macro scale structural attributes of the whole soil to withstand erosion. There are numerous techniques for characterization and modelling of soil structure. Advanced techniques for soil structure modelling aim to capture the heterogeneity of soil structure and correlate these quantifications with various processes such as erosion. The focus on soil-based techniques, coupled with the characterization of aggregates, can provide additional insight into soil structure dynamics. Current technologies include tomography, neural networks and fractals. Tomography allows the investigation of soil interior architectural design and allows for three-dimensional visualization of soil structures. By using this method, the geometry and distribution of macro pores and microporous networks in the soil can be examined, which facilitates the flow of air and water. The use of neural networks is another way to observe the structural properties of the soil to conserve water, store organic matter and resist erosion. Soil debris and its sensitivity to soil erosion are controlled by fractal theory in the process of cultivation. This theory involves the study of the complexity of soil particle arrangement and soil pore abundance which is the key to explain the process of water flow through the soil. These relatively new technologies can help quantify the structural properties of the soil. (NavneetPareek 2017)

Organic matter

Organic matter is the binding agent that binds the soil particles together in the organic matter and it plays an important role in soil erosion prevention. The protection of soil from compaction and erosion, improvement in soil structure, water and nutrient holding capacity increase are supported with the frequent addition of organic matter. Crop rotations that contains high plant residues, leaving crop residues in the field growing cover crops, using low or no tillage systems, mulching, growing perennial forage crops, using optimum nutrient and water management strategies for healthy plant production with large number of residues and roots, growing cover crops and applying compost or manure are the practices that increase organic matter in soil. For example loss of soil organic matter increases water runoff which reduces the soil's water storage capacity that diminishes nutrient levels in soil and also reduces the natural biota, biomass and biodiversity of soil ecosystem (Brevik, 2013)

Vegetation cover

Vegetation cover is an important index to evaluate the soil's sensitivity to erosion. Vegetation acts as an interface between the atmosphere and the soil. It increases the permeability of the soil to rainwater, thus decreasing runoff. Uncovering the soil exposes it to the vagaries of erosion ranging from rain-splash to gully erosion.Soil is prevented from being swept or blown away by the plant roots that hold the soil in place. Soil's ability to erode is reduced by plants that protect the soil from the abrasive effect of raindrops. Vegetation cover provides a blanket cover to soil against raindrops and runoff that detach and transport soil particles.Loss of protective vegetation through ploughing and overgrazing makes soil susceptible to being washed away by water and wind. The areas that are most subjected to erosion are fallowed areas where entire residue has been incorporated into the soil and no crop is grown.

Soil Conservation and Management Measures

Certain conservation measures can reduce soil erosion. Soil erosion is prevented by several agronomic and biological properties. Soil / land management practices such as tillage and cropping practices, directly affect the overall soil erosion problem and solutions on a farm. When crop rotations or changing tillage practices are not enough to control erosion on a field, a combination of measures might be necessary. For example, contour ploughing, strip cropping, or terracing may be considered. There are differences among these biological practices in relation to their mechanisms of erosion control. Biological measures such as buffers or thin films (e.g., conditioners), conditioner application in direct contact with the soil surface, crop residues using manure protect the soil fromerosion. The raindrop is intercepted above the soil surface by the protective effect of canopy cover and standing vegetation reduces soil erosion. Growing vegetationproduce the mulching effect.

Types of conservation measures:

Soil conservation helps protect the land, prevent erosion and preserve soil nutrients on land. Soil conservation techniques also help minimize the damage that development can do to surrounding open space. Soil conservation structures are permanent features made of Earth, stones ormasonry, designed to protect the soil from uncontrolled runoff and erosion and retainwater where needed. Selection and design of structures depend on:

1. Climate and the need to retain or discharge the runoff
2. Farm sizes
3. Soil characteristics (texture, drainage, and depth)
4. Availability of an outlet or waterway
5. Labour availability and cost
6. Adequacy of existing agronomic or vegetative conservation measures.

The various types of conservation measures are given below:

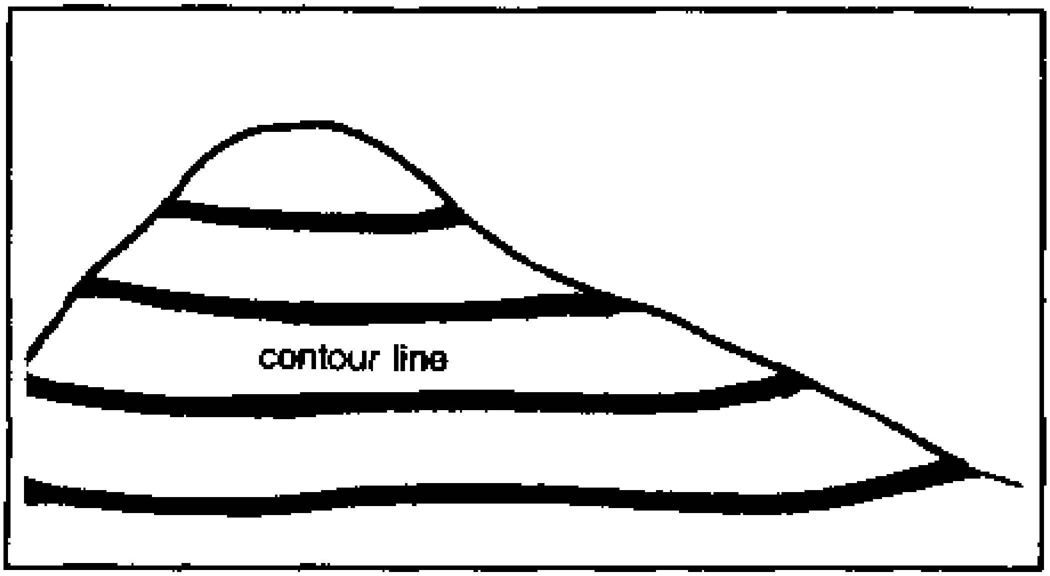
1. **Agronomic:** such as plant / soil cover, conservation farming methods, contour farming
2. **Vegetative:** such as planting barriers (vegetative strips), live fences, windbreaks
3. **Structural or Mechanical Engineering:** such as terraces, banks, bunds, cut off drains, barriers and
4. **Bio engineering method**

Agronomic:

There are three major principles on conservation agriculture: minimal soil disturbance, permanent soil cover and crop rotations. Soils under conservation agriculture tend to improve their soil organic matter (SOM) content after applying the technology for certain years. SOM can be considered as the most important soil fertility and quality factor influencing other soil properties as infiltration, water holding capacity or soil structure. Crops are beneficial as they:

1. Stabilize soil moisture and temperature
2. Protect the soil during fallow periods
3. Mobilize and recycle nutrients
4. Improve the soil structure and break compacted layers and hard pans
5. Permit a rotation in a monoculture
6. Can be used to control weeds and pests
7. Produce additional soil organic matter and improve soil structure

Contour farming a type of agronomic conservation measureinvolves ploughing, planting and weeding along the contour, i.e, across the slope rather than up and down. Contour lines are lines that run across a (hill) slope such that the line stays at the same height and does not run uphill or downhill. As contour lines travel across a hillside, they will be close together on the steeper parts of the hill and further apart on the gentle parts of the slope. (Fig. 7)



A contour line follows the same height so that it neither falls down the hill nor rises uphill.

Fig. 7:- Contour farming.

Vegetative:
Grasses or trees can be used as vegetative strips or cover in various ways. Vegetative strips can be planted to catch soil, excess nutrients, and chemical pesticides moving over the land's surface before they enter waterways. It is the practice of growing alternate strips of row crops and inter-tilled crops in the same field. In this, the crops are grown in strips at right angles to the slope of land. Erosion is largely limited to row - crop strips and soil removed from these is trapped in the next strip, which is generally planted with a leguminous or grass crop. Strip cropping reduces soil erosion due to both water and wind erosions. Strip cropping is generally of three types, namely, contour strip cropping, field strip cropping and buffer strip cropping (Fig. 8).The effect of dispersed vegetative cover is multiple, including increasing ground cover, improving soil structure and infiltration, as well as decreasing erosion by water and wind.Vegetative barriers are narrow, parallel strips of stiff, erect, dense vegetation planted on or close to the contour. These barriers cross concentrated flow areas at convenient angles for farming or are used in the same manner as terraces. Vegetative barriers differ from conventional grass buffer strips: they are narrow (less than 5 feet wide) and use perennial stiff-stemmed vegetation. They reduce the velocity of runoff water, causing deposition of sediments on the upslope side of the barriers. Reduced velocity also prevents scouring and lessens ephemeral gully development.

In recent years, a similar practice has been promoted with trees and shrubs rather than grass being grown in contour strips. The idea is that the trees and shrubs will act as barriers in the same way as grass strips, with the additional advantage that the trees and shrubs can also provide a valuable asset to farmers, particularly in developing countries where the timber is needed for fuel and building material. In addition, these trees and shrubs used areusually legume plants that have the ability to “trap” nitrogen from the air, return it to the soil and make it available to other plants.

(a) Buffer strip cropping (b) Contour strip cropping

(c) Field strip cropping

Fig. 8:- Vegetative Farming.

Structural or Mechanical Engineering Techniques:
Terracing is one of the old method of soil conservation practice applied to prevent rainfall runoff on sloping land from accumulating and causing serious erosion. Terraces consist of ridges and channels constructed across-the-slope.The major benefit is the conservation of soil by wind and water. Terraces reduce both the amount and velocity of water moving across the soil surface, which greatly reduces soil erosion.

Contour banks have been used successfully to control erosion over large areas of cultivated land, particularly. These often involve complex systems with earthen banks carefully built on grades close to the contour, but with a sufficient slope to allow excess water to gently run away. The excess water is usually diverted to artificial waterways through which the water can safely run until it reaches a natural stream or watercourse. These systems have proved to be very effective on cultivated land where the farms and the fields are large. However, it is a system that has failed to be accepted where the fields are generally small and fragmented. Under these conditions, the complex contour systems are too hard to manage as they must cross numerous field boundaries.

Cut-off drains are made across a slope for intercepting the surface runoff and carrying it safely to an outlet such as a canal or stream. Their main purpose is the protection of cultivated land, compounds, and roads from uncontrolled runoff, and to divert water from gully heads.

Retention ditches are made along the contours to capture and retain incoming runoff water and hold it until it seeps into the ground. They are alternate to cut-off drains when there is no channel to discharge the water nearby. Sometimes these are for water harvesting in semiarid areas.

Infiltration ditchesare used to harvest water from roads or other sources of runoff is infiltration ditches. They comprise dug along the contour, up-slope from a crop field and a ditch of 0.7-1.5m deep. Water is blocked at the other end when it is diverted from the roadside into ditch and seep into soil after it is being trapped.

Water-retaining pits allow runoff water to seep into soil after being trapped by the water. The run-off normally occurs into a series of pits which are dug into ground. Banks around the pits are made by the soil from the pit. Excessive water carry from one pit to next by furrows. The amount of runoff determines the size of pit and its typical size is 2 m square and 1 m deep.

Mechanical engineering techniques are also used in other ways besides the many applications of the "contour principle." Structures of various types are frequently used to stop the growth of and to heal gullies that have been formed by water erosion. The structures used include dams, silt traps, and structures to protect eroding gully and stream banks. Dams are popular with farmers as they serve two purposes: dams catch and hold water that is used for domestic purposes, livestock, and sometimes irrigation, but they also slow down the movement of water and catch silt that would otherwise cause problems in streams or on fields further down the slope.

Bio-Engineering Method

Biotechnical engineering techniques are combined with biological knowledge to build geotechnical and hydraulic structures and to secure unstable slopes and banks. Whole plants or their parts are used as construction materials to secure unstable sites, in combination with other (dead) construction material. Bio-Engineering methods using willows and other woody plants are especially appropriate for constructing several soil conservation structures. This structure stabilizes the soil, reduce the movement speed of running water, and thus reduce the surface erosion. Maintenance of these structures is a very important aspect as compared with other methods of soil conservation. The maintenance cost of bioengineering structures is somewhat high in initial period and later on it becomes very less. Bio engineering methods of soil conservation have the following advantages.

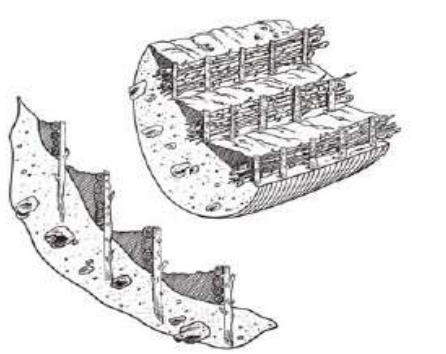
1. Immediately effective after installation
2. Material easily available as structures also serves as a nursery for new plant material
3. Flexibility in preparation and protection

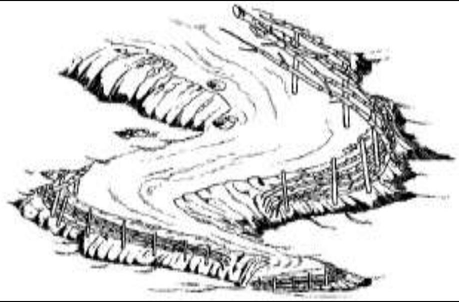
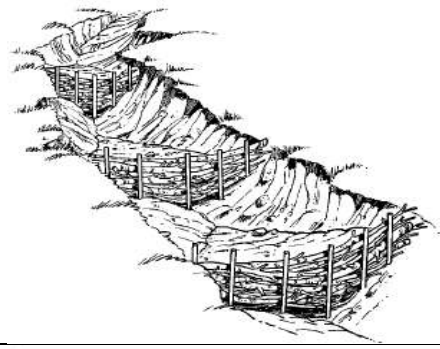
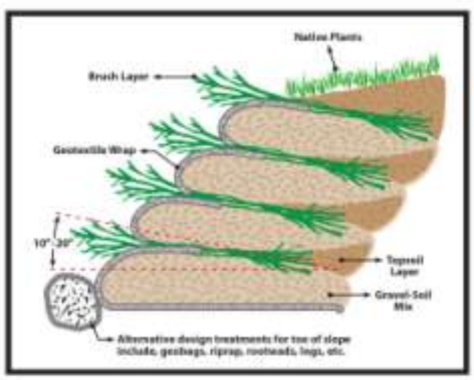
Bio engineering methods also have some disadvantage

1. High demand on material and labour
2. Occasionally thinning of thicket necessary
3. Labour intensive

Table 4 below presents brief description and applications of some of the bio-engineering measures.

Table 4:- Bio-Engineering techniques and their description.

Techniques		Application	Description
Wattle fence		Over-steepened slopes where vegetation cannot naturally establish	Long cuttings (e.g. willow) laid horizontally and supported with larger vertical plant stakes or rebar. Soil is filled in behind the fence; creates a series of terraces.

Live bank protection		Along stream banks, to protect against further erosion.	Live bank protection are contoured around bends in the stream, in areas that are susceptible to erosion; soil is then backfilled behind the fences. They are very useful in stabilizing roadside ditches and culvert inlets and outfalls.
Live Gully Breaks		They can be used to stabilize gullies that have already experienced debris torrents.	Live gully breaks act to slow the velocity of water movement down a gully and thus to trap sediments.
Brush layering		Stabilizing shallow earth slumps, loose soil slopes and gullies	Benches are excavated in the slope, willow branches are laid, on a slight angle, on the benches; branches are covered with soil, with just the tips sticking out.
Prevegetated mats		Lakeshores and wetlands	Plants are grown on mats made of a slowly biodegradable material such as coconut fibre; the mats are then simply placed on the slope.

Conclusion:-

Climate Change poses serious interlinked challenges in times to come with reference to scale and scope, which was never anticipated in the last century.A number of factors are affected by climate change which involves changing air temperatures, increase in atmospheric carbon dioxide (CO_2) concentrations, significant and/or abrupt changes in daily, seasonal, and inter-annual temperature, changes in the wet/dry cycles, intensive rainfall and/or heavy storms, extended periods ofdrought, extreme frost and heat waves that significantly affect soil properties and fertility**.**Soil degradation is majorly caused by depletion the SOC (Soil organic Carbon) pool in soil. This soil degradation leads to physical degradation i.e., reduction in aggregation, decline in soil structure, crusting, compaction, reduction in water infiltration capacity and water/air imbalance and erosion, chemical degradation i.e., nutrient depletion, decline in pH and acidification, build up of salts in the root zone, nutrient/elemental imbalance and disruption in elemental cycles, and biological degradation i.e., reduction in activity and species diversity of soil fauna, decline in biomass C and depletion of SOC pool.

Soil erosion is one of the several major deteriorative processes which results in deterioration of the soil. Soil erosion is removal of soil due to movement of water and/or air. Soil erosion may lead to the significant loss of soil productivity and thus may lead to the desertification under severe conditions. Water and wind are the major agencies which are responsible for soil erosion. Deforestation, over-grazing, mismanagement of cultivated soils, intensive cultivation and intensive urbanizationare major factors triggering the soil erosion.Although climate change can be overwhelming, proper soil management practices can help remove carbon dioxide from the atmosphere, preventing the adverse effects of climate change. Additionally, healthy soils sequester and hold carbon dioxide, preventing it from escaping into the atmosphere. The organic matter in soils plays a vital role in sequestering soils. On the other hand, soil degradation through practices such as deforestation, excessive use of pesticides and fertilizers, monocropping, erosion and frequent tillage cause soils to emit carbon into the atmosphere, leading to climate change.There are various types of soil conservation methods like Agronomic, Vegetative, Structural or Mechanical Engineering and Bio engineering methods. These methodsare designed to protect the soil from uncontrolled runoff and erosion and retain water where needed**.** These methods use natural components of pioneering plant communities and thus integrate well with ecological restoration principles.

References:-

1. Archer David. Global warming: Understanding the forecast. Malden, MA: Blackwell Pub; 2007
2. Blanco, H. and R. Lal (2008). Soil and water conservation. Principles of soil conservation and management, Springer, the Netherlands.
3. CCSP. 2008 Climate Models: An Assessment of Strengths and Limitations. Synthesis and Assessment Product 3.1 by the U.S. Climate Change Science Program, D. C. Bader, C. Covey, W. J. Gutowski, I. M. Held, K. E. Kunkel, R. L. Miller, R. T. Tokmakian, and M. H. Zhang, authors. Washington, DC: U.S. Department of Energy.
4. Safdar Bashir, AtifJaved, IrshadBibi and Niaz Ahmad, 2017, Soil and Water Conservation, Research gate
5. Chander, S., 2012. Impact of Climate Change on Insects. In: Climate Change Impact, Adaptation and Mitigation in Agriculture: Methodology for Assessment and Application, Pathak, H. and P.K. Aggarwal (Eds.). Indian Agricultural Research Institute, New Delhi, India, pp: 131.
6. Cheddadi, R., Guiot, J., Jolly, D., 2001. The Mediterranean vegetation: what if the atmospheric CO2 increased? Landscape Ecology 16, 667 – 675.
7. DEFRA., 2005. Impact of climate change on soil functions. Final Project Report, Research and Development, London, UK.
8. Donner, L. J., and W. G. Large. 2008. Climate modeling. Annual Review of Environment and Resources 33(1):1-17.
9. El-Fadel M, Massoud M. Methane emissions from wastewater management. Environ. Pollut. 001;114:177–185.
10. Environmental Protection Agency (EPA). (2009-2012). United States Greenhouse Emission Gases.
11. Environmental Protection Agency (EPA). National Green-House Emission Data;2011.
12. European Environment Agency. Annual European Union greenhouse gas inventory 1990–2012 and inventory report 2014 (Submission to the UNFCCC Secretariat) –Technical Report 09/2014. Brussels, Belgium; 2014.
13. Fauchereau N, Trzaska M, Rouault M, et al. Rainfall variability and changes in Southern Africa during the 20th century in the global warming context. Natural Hazards. 2003;29(2):139–154.
14. Intergovernmental Panel on Climate Change (IPCC). Climate change 2001: The Scientific basis. Cambridge University Press, Cambridge, UK; 2001.
15. IPCC. 2007. Forestry. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK & New York, USA, Cambridge University Press.
16. Karmakar Rajeev, Indranil Das, DebashisDutta and AmitavaRakshit, 2016, "Potential Effects of Climate Change on Soil Properties: A review, Science International- 4, pp. 51-73
17. DOI: 10.17311/sciintl.2016.51.73
18. Mitchell, John F. B. (1989). "The "Greenhouse" effect and Climate Change" (PDF). Reviews of Geophysics. 27(1): 115 139 . doi:10.1029/RG027i001p00115. Retrieved 2008-03-23.
19. Murray, Brian C, et al. How effective are us renewable energy subsidies in cutting greenhouse gases? American Economic Association. JSTOR. 2017;569-574. Available:libproxy.uww.edu:2075/stable/pdf /42921000.pdf (Accessed 10 May, 2017)

20. Prof.Dr.ThomasBosch et al,WorldOceanReviw 1 Living with the oceans. A report on the state of the world's oceans | 2010
21. ROBERT BRINKMAN AND WIM G. SOMBROEK Land and Water Development Division. FAO, Rome, Italy
22. Schroeder, Daniel V. (2000). An introduction to thermal physics. Addison-Wesley. pp. 305–7. ISBN 978-0-321-27779-4.