ENVIRONMENTAL GEOSCIENCES

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Lecture-63

Impact of Climate Change on Water Resources – Part 1

Welcome to the SWAYAM NPTEL course on Environmental Geosciences. We are discussing the model twelve. Model twelve consists of remote sensing and GIS applications and impact of climate change on water resources. Today we will discuss the lecture four, that is impact of climate change on water resources, first part. The important concepts in this lecture will be covered like introduction to climate change, causes of climate change, greenhouse effect-a major factor for climate change, importance of groundwater, effects of climate change on groundwater zones, effects of climate change on groundwater quality, impact of climate change on water resources, remote sensing and GIS for climate impact analysis, and coping strategies for changing water resources.

Now, we will start from the introduction to climate change. Climate is weather averaged over an extended period of time nearly thirty years intervals are typically used in establishing baseline climatology. During the Earth's history, the climate has changed many times and has included ice ages and periods of warmth. Before the Industrial Revolution, natural factors such as volcanic eruptions, changes in the Earth's orbit, and the amount of energy released from the sun were the primary factors affecting the Earth's climate. However, beginning late in the eighteenth century, human activities associated with the industrial revolution and burning fossil fuels began changing the composition of the atmosphere.

Climate change is a change in the usual weather found in a place. This could be a change in how much rain a place usually gets in a year, or it could be a change in place's usual temperature for a month or season. Climate change is also a change in Earth's climate. This could be a change in Earth's usual temperature or it could be a change in where rain and snow usually fall on Earth. Now global climate change.

Global mean temperatures over land and ocean have increased over the past three decades. The global average surface temperature has risen between one point zero eight degree Fahrenheit to one point two six degree Fahrenheit since the start of the twentieth century. This is the report of the NOAA that is National Oceanic and Atmospheric Administration. The rate of increase since nineteen seventy six has been approximately three times faster than the century scale trend as given by the National Climatic Data Center. The Intergovernmental Panel on Climate Change, that is IPCC, projects that the average surface temperature of the Earth is likely to increase by three point two degree Fahrenheit to seven point two degree Fahrenheit, that is one point eight to four degree Celsius, by the end of the twenty first century relative to nineteen eighty-nineteen ninety, as per the IPCC record.

Warming is not predicted to be evenly distributed around the globe. Land areas will warm more than the oceans in part because of the ocean's greater ability to store heat. High latitudes will warm more than low latitudes in part because of positive feedback effects from melting ice. Most of the North America, all of Africa, Europe, Northern and Central Asia and most of the Central and South America are likely to warm more than the global average. Projections suggest that the warming will be close to the global average in South Asia, Australia and New Zealand and Southern South America. Warming will differ by season with winters warming more than summers in most areas.

We will see what are the causes of climate change. The global carbon cycle involves billions of tons of carbon in the form of CO_2. Carbon dioxide is absorbed by oceans and living biomass and is emitted to the atmosphere annually through natural processes. When in equilibrium, carbon movement among these various reservoirs is roughly balanced. Most scenarios of future emission of CO_2 involve increases of CO_2.

In two thousand four, twenty six point nine billion metric tons of CO_2 were emitted and thirty three point nine billion metric tons are projected to be emitted in two thousand fifteen. But by two thousand thirty, forty two point nine billion metric tons of CO_2 are projected to be emitted. You can see the graph also. Now, greenhouse effect, a major factor for climate change. Let us understand Greenhouse effect first.

Sunlight passes through the atmosphere and warms the earth's surface. Some of this solar radiation is reflected back by the earth and the atmosphere. Greenhouse gases in the atmosphere such as CO_2 absorb heat and further warm the surface of the earth. This is called the greenhouse effect. As more greenhouse gases are emitted into the atmosphere, heat that would normally be radiated into space is trapped within the Earth's atmosphere, causing the Earth's temperature to increase.

So gases that trap heat in the atmosphere are generally called the greenhouse gases. CO_2 is the principal greenhouse gas but other gases can have the same heat trapping effect. You can see the diagram also of the greenhouse effect. Some of these other greenhouse gases, however, have a much stronger greenhouse or heat-trapping effect than CO_2. For example, methane is twenty one times more potent a greenhouse gas than CO_2. Different greenhouse gases have different atmospheric lifetimes and therefore actions to reduce emissions will take time to effect reductions of gases in the atmosphere.

The principal human generated greenhouse gases that enter the atmosphere are first the carbon dioxide. Carbon dioxide enters the atmosphere through the burning of fossil fuels that is oil, natural gas and coal. Methane is emitted during the production of transport of coal, natural gas and oil. Methane emissions also result from livestock and other agricultural practices and by the decay of organic waste in municipal solid waste landfills and anaerobic wastewater treatment plants. Nitrous oxide. Nitrous oxide is emitted during agriculture and industrial activities as well as during the combustion of fossil fuels and solid waste. Nitrous oxide is also emitted from wastewater treatment plants during nitrification and denitrification processes. Nitrous oxide is three hundred ten times more potent as a greenhouse gas than CO_2 and has an atmospheric lifespan of one twenty years as per the EPA two zero two one.

Fluorinated gases, hydrofluorocarbons (HFCs) , perfluorocarbons (PFCs) and sulfur hexafluoride that is SF6 are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes. Fluorinated gases are sometimes used as substitutes for ozone-depleting substances that is CFCs, HCFCs and halons. These gases are typically emitted in smaller quantities, but because they are potent greenhouse gases, they are sometimes referred to as high global warming potential gases. HFCs are one forty to eleven thousand seven hundred times more potent than CO_2 and have atmospheric lifespans of one to two sixty years. Most commercially used HFCs remain in the atmosphere less than fifteen years.

PFCs are six thousand five hundred to nine thousand two hundred times more potent than CO_2 and have an atmospheric lifespan of several thousand years. Sulphur hexafluoride is twenty three thousand nine hundred times a more potent greenhouse gas than CO_2 and is extremely long-lived as per the EPA two zero one nine. Now, importance of groundwater. We must understand the importance of groundwater, although groundwater accounts for a small percentage of Earth's total water, but it comprises approximately thirty percent of Earth's fresh water. Groundwater is the primary source of water.

Depletion of groundwater may be the most substantial threat to irrigated agriculture, industrial activities, and even for potable purposes. Water stresses. It leads to a decrease in per capita ability of water. Water stress causes extremely low efficiencies of water use, especially in irrigated agriculture. Water stress is the reason for the indiscriminate use of groundwater. The stress also comes from rapid urbanization with little scope for increasing infrastructure, limited water ability for urban sustenance in many cities.

The stress is also due to the lack of adequate quality and quantity of data and trained manpower to arrive at informed decisions at regional or river basins or local levels. Climate change is most likely to aggravate the situation. Effect of climate change on groundwater zones Groundwater is directly affected by changes in the rate of precipitation and evapotranspiration. The response of groundwater to climate change may be less compared to surface water, however, it is still a matter of concern because groundwater is one of the largest available resources of freshwater and potable water on the earth.

It is estimated that approximately thirty percent of global freshwater is present in the form of groundwater. Generally, the occurrences of groundwater is divided into two zones, that is zone of aeration and zone of saturation. The effect of climate change on both the zones has been discussed here. You can see in the diagram also, the zone of aeration just starts from the earth's surface to down. In zone of aeration, the soil water zone and Vadose zone is coming, whereas zone of saturation remains fulfilled with the water.

Now effect on zone of aeration. First is the soil water zone. This zone is important as it supports vegetation and all biogeochemical reactions. Climate change has an adverse effect on this zone. Higher temperature leads to higher evapotranspiration rates resulting in less moisture content in the soil water zone.

Little or no moisture in the soil leads the penetration of solar radiation into the deeper soils and increased dryness in soils resulting in severe droughts. The high precipitation in wet climate change scenario will increase surface runoff and promoting rapid soil erosion. Less infiltration, high evapotranspiration and high runoff will definitely have a great impact on water availability in this zone, which will affect the entire plant and animal kingdom. Second is the Vadose Zone. Changes in Vadose zone due to climate change can be computed by studying the variations in major cations, anions, trace elements and isotopes from the pore water.

Due to increase in surface temperature, groundwater temperature will increase. The change in temperature will affect pore water chemistry, residence time, and volume of water in matrix and fractures, and thus the composition of the water. The increase in recharge rate will help in mobilizing the contaminants into greater depths. The diurnal temperature fluctuation may be detectable at depths of less than one meter in the unsaturated zone and seasonal fluctuations at depths of ten meter or more, indicating that the climate change effects depend on depth and are slow in the deep Vadose zone. Then effect on zone of saturation.

Groundwater in the saturated zone is important as it is less polluted and has no effects of evapotranspiration. The sensitivity of this zone depends on the depth of the water table; shallow aquifers are more vulnerable to climate change than deeper aquifers. This zone responds to climate change by showing changes in its amount, quality and flow of water depending on the trends of precipitation, evapotranspiration, recharge and discharge. It is generally observed that the climate change has less effect on this zone in comparison to human activities on groundwater exploitation such as excessive pumping, reduction in recharge rate and contamination. Now, effects of climate change on groundwater quality.

The groundwater quality relates to the physical, chemical and biological properties of the aquifer which are controlled by climatic fluctuations. Changes in the recharge rate and the groundwater temperature in the Vadose zone affect its pore water chemistry, contaminant transport and residence time, and overall affecting the quality of the water. Under a climate change scenario, the following events can deteriorate the groundwater quality: That is, during the wet scenario, increased infiltration can mobilize large amount of pore water. Increase in recharge leads to the dissolution of carbonates; increase in calcium content may increase the hardness of the groundwater.

During a dry scenario, the increase in total dissolved solids may deteriorate the groundwater quality by increasing the salt content. Now, impact of climate change on water resources. Few factors are affecting the water resources like first factor is temperature, second the precipitation, third is the sea level rise, fourth is the ocean and coastal changes and fifth is the ocean acidification. So first is the temperature. An increase in the air temperature will cause water temperatures to increase as well.

As water temperature increases, water pollution problems will increase and many aquatic habitats will be negatively affected. Temperature variations significantly influence the rainfall patterns in India primarily through their impact on the Indian monsoon system.

Changes in temperature both globally and regionally affect the atmospheric circulation, moisture retention and the intensity of rainfall. Rising temperatures lead to greater evaporation, increasing atmospheric moisture content and this results in intense but localized rainfall events, especially during the monsoon season. Studies show a ten to fifteen percent increase in heavy rainfall episodes over Central and Western India in recent decades.

While extreme events increase, moderate and consistent rainfall patterns have declined, affecting the agriculture and water availability. Western and Central India are more frequent and intense short-duration storms because of the warming of the Arabian Sea. Northern India, higher pre-monsoon temperature reduces the soil moisture, delaying monsoon onset and affect the Indo-Gangetic plains. Northeast India, declining rainfall due to weaker monsoon currents and changing wind patterns. In the map also it shows the variation in precipitation and soil moisture due to the variation in temperature.

Then increases in temperature are expected to result in lower levels of dissolved oxygen due to the inverse relationship that exists between dissolved oxygen and temperature. As the temperature of the water increases, dissolved oxygen levels decrease. Increases in pathogens, nutrient and invasive species. Increases in concentration of some pollutants such as ammonia and pentachlorophenol due to their chemical response to warmer temperatures. Increase in algal blooms.

Lots of aquatic species whose survival and breeding are temperatures dependent. Change in the abundance and spatial distribution of coastal and marine species and decline in population of some species. Increased rates of evapotranspiration from water bodies resulting in sinking of some water bodies. Now second is the precipitation. As the air temperature warms, the rate at which water evaporates from soils and water body increases and that increases the amount of water being held in the atmosphere.

Because there is more atmospheric moisture, then there are heavier downpours when it rains. Changes in the amount of precipitation will affect the water availability and water quality. You can see in the diagram also, the higher temperature, and the more moisture in the clouds are giving the heavier rainfall whereas in this case you can see more infiltration and less rainfall is the normal condition but when less infiltration and more runoff it is a drought condition giving the flash flood. Now water availability. The net impact on water availability will depend on changes in precipitation that is including the changes in total amount, form, and seasonal timing of precipitation. In areas where precipitation increases sufficiently, net water supplies might not be affected or they might even increase. If the precipitation remains the same or decreases, though net water supplies would decrease.

This is in part due to the predicted temperature rise in most areas which will cause evaporation rates to increase. Where water supplies decrease, there is also likely to be an increase in demand as a result of higher temperatures, which could be particularly significant for agriculture and energy production, and also for municipal, industrial and other uses. You can see in the diagram also, in the case of drought, you can see the water quality reduced ground water and surface water supply in some areas, and increased water demand due to the higher temperatures. And in case of water quality, you can see increased runoff resulting in erosion and sedimentation, and overwhelmed water infrastructure due to flooding. Now water quality changes in the timing intensity and duration of precipitation can negatively affect the water quality. Flooding, a result of increased precipitation and intense rain storms, transports large volumes of water and contaminants into water bodies. Flooding also can overload storm, combined sewer, and wastewater systems, resulting in untreated pollutants directly entering the waterways.

In regions with increased rainfall frequency and intensity, more pollution and sedimentation might be produced because of runoff. Reduced rainfall can also result in more frequent wildfires and land areas where wildfires have occurred are more vulnerable to soil erosion. Then adverse impact on water resources. Tropical storms and hurricanes are likely to become more intense, produce stronger peak winds, produce increased rainfall and cause larger storm surges because of warming sea surface temperatures. The relationship between sea surface temperatures and the frequency of tropical storms is direct and near exponential.

Increased tropical storm intensity will have negative effects on water resources. More intense tropical storms can damage the infrastructure, cause increased flooding which can overwhelm water infrastructure and cause pollutants to directly enter the waterways and contaminate the water supplies. Coastal erosion is also often a result of storms. Next is the sea level rise. Rising sea levels could also reduce water quality and availability in coastal areas.

Recent projections of sea level rise by the end of twenty first century range from nineteen to fifty eight centimeter. A more dramatic increase in sea level on the order of meters rather than centimeters is possible, but most scientists consider it a low-probability risk.

For example, complete melting of the Greenland ice sheet or West Antarctic ice sheet would trigger such a large rise. Rising sea levels could affect the groundwater quality directly via saltwater intrusion. Radical changes to the freshwater hydrology of coastal areas caused by the saltwater intrusion would threaten many coastal regions' freshwater supplies.

Rising sea levels could also affect the water availability in coastal areas indirectly by causing water tables in groundwater aquifers to rise, which could increase surface runoff at the expense of aquifer discharge. Water shortages will cause the price of water to rise through monthly water bills or one-time connection fees for new homes and businesses. A sufficiently large price increase could affect the extent and pattern of urban growth throughout the United States. Costly water supply projects such as desalination plants, pipelines, and dams will also become more economically attractive. The factors driving sea level rise include the ocean water expansion caused by warmer ocean temperatures and mountain glaciers and ice caps melting.

Rising sea levels will increase erosion rates and cause the displacement of coastal wetlands after shorelines and cause high value habitat to be lost. Low-lying coastal areas such as wetlands, deltas, coastal plains, salt marshes, mangrove forests and coral reefs will be affected by sea level rise. Rising sea level increases the salinity of both surface water and groundwater through saltwater intrusion. Next is the ocean and coastal changes. In addition to rising sea levels, the characteristics of the oceans are expected to change as the planet warms.

Corals are believed to be surviving at or close to their temperature tolerance levels. If air and water temperatures continue to increase, corals might not be able to survive. So biological habitat changes other than sea level rise are expected in the oceans as the air temperatures increase. Estuarine water become more saline as sea levels rise. Ocean temperature increase posing a threat to ocean life. For example, corals.

Oceans become more acidic. The abundance and spatial distribution of saltwater species might change with the changes in water temperature and salinity levels in estuarine systems. Also, oceans are expected to become more acidic. And then the ocean acidification. It occurs, oceans naturally absorb carbon dioxide from the atmosphere.

When there are increased levels of carbon dioxide in the atmosphere, oceans increase the absorption of carbon dioxide in a process called ocean acidification. The mixture of ocean water and the carbon dioxide forms the carbonic acid. Carbonic acid reacts with carbonate ions that are also found in seawater, which are a vital component to the structure of corals and the shells of marine organisms such as calcifying phytoplankton that form the first tier of the ocean food web. In other words, elevated levels of carbon dioxide in the atmosphere lead to loss of building blocks that are needed to form the calcium carbonate skeletons of corals and other organisms that require calcium carbonate to make their shells. The response of marine biota to ocean acidification is not yet clear, both for the physiology of the individual organisms and for the ecosystem functioning as a whole.

Extinction thresholds will likely to be crossed for some organisms in the coming century. Ocean acidification is not a direct consequence of warming temperatures, but like warmer temperatures, it is caused by increased levels of carbon dioxide in the atmosphere. Ocean acidification, warmer ocean water and more saline estuaries are expected to have several impacts on coastal and ocean resources. Like potential marine food web breakdowns from ocean acidification. Coral, calcifying phytoplankton and zooplankton growth will be inhibited or slowed because of the ocean acidification.

Habitat loss with the loss of coral reefs because of the coral bleaching. Aquatic plants and animals that cannot tolerate increased salinity levels are lost. Now remote sensing and GIS for climate impact analysis. Remote sensing and geographic information system technologies play a crucial role in assessing and mapping the impact of climate change on groundwater resources. By integrating multi-temporal satellite data with geospatial analysis, these technology enable comprehensive monitoring of groundwater dynamics. Climate data, including temperature, precipitation, and evapotranspiration trends from satellite sensors, combined with groundwater data, such as well logs, groundwater levels, and aquifer characteristics, provide a robust dataset for analysis. Additionally, geospatial data like land use, land cover, topography, that is, DEM and drainage patterns are essential for spatial modeling.

The methodology involves integrating remote sensing and field data within GIS platforms for spatial analysis. Temporal change detection helps to identify groundwater fluctuations over time, while groundwater recharge is estimated under varying climate scenarios. Vulnerability mapping using models like DRASTIC identifies high-risk zones susceptible to climate-induced groundwater stress. These approaches enable monitoring of groundwater depletion, identification of recharge potential zones, and support for sustainable groundwater management. The remote sensing and GIS-based approach is advantageous due to its large-scale, cost-effective monitoring capability, accurate spatial and temporal analysis, and predictive modeling for future groundwater scenarios.

It provides essential tools for understanding and mitigating the effects of climate change on groundwater resources, supporting sustainable water management. Now coping strategies for changing water scenarios, although subject to uncertainty, forecasts of climate change offer a glimpse into possible future water resource impacts and challenges. Predicted impacts vary by region but include increased temperatures and evaporation rates, higher proportions of winter precipitation arriving as rain, not snow, earlier and more severe summer drought and decreased water quality. Water shortages, which currently result in substantial economic losses, will be more common in many regions because of these impacts. Such economic losses, which occur across a range of sectors, from agriculture to energy and recreation, have profound effects on local communities.

More frequent shortages imply increased costs to society, although adaptation by water users will mitigate some portion of these costs. Water resource users can reduce the negative effects of water shortages through a number of strategies. These include revising water storage and release programs for reservoirs, adopting crops and cropping practices that are robust over a wider spectrum of water availability, expanding and adjusting crop insurance programs, adjusting water prices to encourage conservation and the expansion of water supply infrastructure and supporting water transfer opportunities. Then next is the damage from drought induced wildfires can be minimized by using long range soil moisture forecasts to pre-position fire suppression resources and in the longer term by changing land use regulations to restrict development in areas facing increased fire risk. Then improvements in climate projections and long-term weather forecasts offer potential for reducing economic losses associated with climate change.

And then more specifically improvements in the ability to detect water shortages to more precisely forecast their location, intensity and duration and to use such forecasts to inform management strategies which would enhance the water users' confidence in regional forecasts and their ability to efficiently prepare for and adapt to future water resource management challenges. Now let us summarize the lecture. We have first discussed the understanding of climate change in which we have seen climate change refers to long-term shifts in temperature, precipitation and weather patterns worldwide. Human activities, especially greenhouse gas emissions, are the primary drivers of recent climate change. Then we have discussed the causes and major factors of climate change.

We have seen that the main causes of climate change include burning fossil fuels, deforestation and industrial activities. The greenhouse effect caused by the gases like CO2 and methane traps heat and accelerates global warming. Then we have discussed the impact of climate change on groundwater and water resources. Climate change affects groundwater zones by altering recharge rates and increasing drought risk. It also impacts groundwater quality through rising temperatures and pollution, affecting water availability and sustainability.

Then we have discussed the role of remote sensing and GIS for climate impact analysis. The remote sensing and GIS technology provide effective tools for mapping and analyzing the climate change impacts on groundwater. They help to monitor spatial variations, detect changes, and support sustainable water resource management. And lastly, we have discussed the coping strategies for changing water resources. Adapting to changing water resources involves sustainable water management, conservation practices and policy measures.

Using advanced monitoring tools and community-based approaches is essential for long-term resilience. Thank you very much to all