ENVIRONMENTAL GEOSCIENCES

Prof. Prasoon Kumar Singh

Department of Environmental Science and Engineering

Indian Institute of Technology (Indian School of Mines), Dhanbad

Lecture-64

Impact of Climate Change on Water Resources – Part 2

Welcome to the SWAYAM NPTEL course on Environmental Geosciences. We are discussing the module twelve. Module twelve consists of remote sensing and GIS applications, impact of climate change on water resources. We have discussed the lecture one to four. Today we will discuss the lecture five, that is impact of climate change on water resources.

The important concepts in this lecture will be covered like overview of water resources, impacts of climate change in water sector, observed climate change and its impact during the past century, climate change is a global challenge to human development, then measures of adaptation and mitigations, strategies for policy making, and lastly the impact of climate change on water resources-globally. Overview of water resources. The first is the surface water resources. India is gifted with many rivers. As many as twelve of them are classified as major rivers.

Total catchment area is two fifty two point eight million hectare and average annual potential in river is one thousand five hundred seventy point nine eight billion cubic meter. Many of these rivers are perennial, though few are seasonal. This is because precipitation over a large part of India is strongly concentrated in the summer monsoon during June to September or October and the tropical storm season that is from May to October. In the graph also you can see year versus population in millions. We are seeing in the graph that the graph of population versus water availability.

Second is the groundwater resources. India is a vast country having diversified geological, climatological and topographical setup giving rise to divergent groundwater situation in different parts of the country. The prevalent rock formations ranging in age from Archaean to recent which control occurrence and movement of groundwater, are widely varied in composition and structure. Similarly, not too insignificant are the variations of landforms from the rugged mountainous terrains of the Himalayas, Eastern and Western

Ghats, to the flat alluvial plains of the river valleys and coastal tracts and the aeolian deserts of the Rajasthan. The rainfall patterns too show similar region-wise variations.

The topography and rainfall virtually control run-off and groundwater recharge. Now impacts of climate change in water sector. Climate change affects people and nature in countless ways, such as through social disruption, economic decline, and displacement of populations, among others. Besides this, health impacts associated with such socioeconomic dislocation and population displacement are also substantial. The risks of climate change are sector specific and depend not only on changes in climate system but also on the physical and socio-economic implications of a changing climate.

The water sector is one that often mediates the climate change impacts. Climate change will alter patterns of water ability by intensifying the water cycle. As the water cycle intensifies, severe floods droughts and storms occur more often. Water resources and climate change in Indian perspective. In recent times, several studies around the globe show that the climate change is likely to impact significantly upon freshwater resources availability.

In India, demand for water has already increased manifold over the years due to the urbanization, agriculture expansion, increasing population, rapid industrialization, and economic development. At present, changes in cropping pattern and land use pattern, over exploitation of water storage, and changes in irrigation and drainage are modifying the hydrological cycle in many climate regions and river basins of India. An assessment of the availability of water resources in the context of future national requirements and expected impacts of climate change and its variability is critical for relevant national and regional long-term development strategies and sustainable development. You can see in the diagram also the conceptual model of the effect of greenhouse gases and global warming on the hydrogen cycles. You are seeing at the top that because of the increase of the greenhouse gases, the, It is heating, surface heating is there because of the increase in temperature and increase in evaporation. We are getting the increase in atmospheric water holding capacity and then we are seeing that the enhanced precipitation rates that is giving us the increased runoff and increased flooding.

And right side you can see and left side you can see that gives rise to increased runoff and increased flooding. So groundwater has been the mainstay for meeting the domestic needs of more than eighty percent of rural and fifty percent of urban population, besides fulfilling the irrigation needs of around fifty percent of irrigated agriculture. It has been estimated that seventy to eighty percent of the value of irrigated production in India comes from groundwater irrigation. Around two-fifths of India's agricultural output is contributed from areas irrigated by groundwater. Contribution from groundwater to India's gross domestic product has been estimated as about nine percent.

Now, observed climate change and its impact during the past century. Factor is the temperature and rainfall. Many reports confirm increase in temperature and change in rainfall pattern during the twentieth century. Change in river course. This is an environmental problem of serious concern in the Indo-Gangetic Plain region during different times in the past, different rivers changed their course in a number of times. During the period seventy thirty one to nineteen sixty three, the course of the Kosi river, which is also called the sorrow of Bihar, has shifted westward by about one twenty five kilometer; courses of Ganga, Ghaghra and Son at their confluence have shifted by thirty five to fifty kilometer since the epic period, and that of the Indus and its tributaries by ten to thirty kilometer in twelve hundred years in the same direction.

Next is the sea level rise. UNEP has identified India among the twenty seven countries that are most vulnerable to sea level rise. India has a coastline that stretches about five thousands four hundred twenty two kilometer on the mainland and exhibits most of the known geomorphologic features of coastal zones. Major loss of wetlands is projected in the states of Gujarat, West Bengal and Karnataka by the possible sea level rise. Projected climate change.

Generally, all reports showed changing patterns in rainfall and an increase in temperature. Utility of precipitation primarily depends upon its spatial as well as temporal distribution. Uniform precipitation over a large area is more useful than its occurrence over a smaller region. Also, precipitation occurring over a larger time period would be more effectively utilized rather than when it occurs within a short time span. Therefore, projected changes in precipitation pattern over the Indian subcontinent come as bad news for the water resources sector.

First, decrease in winter precipitation would reduce the total seasonal precipitation being received during December to February, implying greater water stress during the lean monsoon period. Secondly, intense rain occurring over fewer days besides causing increased frequency of floods during the monsoon season will also mean that much of the monsoon rain would be lost as direct runoff, resulting in reduced groundwater recharging potential. Now, climate change is a global challenge to human development. The highly industrialized countries are the most responsible for the emission of greenhouse gases that is made responsible for climate change. Therefore, it is now essential that they react to climate change in order to cope with its impacts.

It is fundamental to find ways of mitigating climate change and to look for possibilities of adaptation. For developing countries, climate change will be more severe, hitting already the most vulnerable populations of the world. While at the same time the need for development and resilience is greater in these countries, the capacity to encounter and anticipate effects are generally inadequate. Higher temperatures increase evaporation and therefore reduce water availability for humans and ecosystems. Climate change is more costly in many regions of the world and reinforce already existing water shortages and economic inequalities.

Globally, locations most at risk of freshwater supply problems due to climate change are small islands, arid and semi-arid developing countries, regions whose freshwater is supplied by rivers fed by glacier melt or seasonal snow melt, and countries with a high proportion of coastal lowlands and coastal megacities, particularly in the Asia-Pacific region. Therefore, even if there are still uncertainties of the immediate and long-term climate change, measures, tools and strategies have to be developed in order to mitigate the impact and adapt to the changes that are taking place. Groundwater is a key resource for human development. On a global scale, one-third of the population depends on groundwater for their drinking water in urban as well as rural areas. Groundwater also plays a pivotal role in agriculture and an increasing portion of groundwater extracted is used for irrigated agriculture.

It is estimated that at least forty percent of the world's food is produced by groundwater irrigated farming, both in low-income as well as high-income countries. In arid and semi-arid areas, the dependency on groundwater for water supply is between sixty and hundred percent. Therefore, the aim of having the number of people without sustainable access to safe drinking water and basic sanitation depends very much on how groundwater resources are developed and managed. However, the importance of groundwater has been marginalized and often neglected in many development strategies and projects. In general, support for groundwater management has not yet received much attention from donors.

A general change in the approach to water management is required, including groundwater within integrated water management resources, that is, IWRM concepts. In many cases, groundwater provides a secure, sufficient, and cost-effective water supply, often more reliable than traditional surface water-based supplies. However, groundwater, as with surface water, is increasingly stressed due to human development, population growth, increased reliance on groundwater and climate change. Also, once the groundwater resources are contaminated, it is very difficult and costly to clean them. This reinforces a development in which water is treated as a luxury item, where only those who can afford, they will have access, which means the gap between rich and poor will widen extensively.

A new understanding of what climate change means and what impacts it has on this very special resource upon which we all depend should be promoted as a basis for better management. Now, how will groundwater be affected by climate change? We predict the climate to be less predictable, which is a paradox, but yet something we have to relate to and base our planning on. Despite the lack of detailed knowledge, there is a consensus on qualitative changes of climate. Higher variability in precipitation is very likely to occur, along with more frequent extreme events like storms, floods and droughts.

Groundwater will be less directly and more slowly impacted by climate change as compared to surface water that is rivers. This is because river gets replenished on a shorter time scale and drought and floods are quickly reflected in river water levels. Groundwater on the other hand will be affected much slower only after prolonged droughts groundwater levels will show declining trends. Groundwater levels of many aquifers around the world show a decreasing trend but this is generally due to the groundwater pumping exceeding groundwater recharge rate and not to a climate related decrease in groundwater recharge. Increased variability in rainfall may decrease the groundwater recharge in humid areas because more frequent heavy rain will result in the infiltration capacity of the soil being exceeded thereby increasing the surface runoff.

In semi-arid and arid areas, however, increased rainfall variability may increase groundwater recharge because only high-intensity rainfalls are able to infiltrate fast enough before evaporating and alluvial aquifers are recharged mainly by inundations during floods. In many places, groundwater wells are already contaminated, unprotected or close to becoming dysfunctional due to a lowering of the groundwater table close to or below the bottom of the well or due to the low and poor maintenance. Those wells which serve as the basic water supply to millions of livelihoods will not be able to supply water in times of disasters and emergencies. They will either be contaminated by floods or dry up due to droughts. Projected sea level rise and excessive groundwater extraction in coastal areas and on small islands combine to increase the risk of salinity problems in water supplies.

Global warming as part of the climate change will affect the groundwater indirectly. Vast areas of permafrost at high latitudes will thaw, releasing huge quantities of methane gas and acidic pore water. Glaciers and snowcaps on mountains previously giving rise to runoff during prolonged seasonal periods may disappear and rivers will be fed more by intermittent rains. Groundwater resources will be less recharged from such rivers and may in fact lose rather than give water from such streams. Higher temperatures will mean higher evaporation and transpiration rates and hence more drying up of soils.

This will entail higher losses of soil moisture and groundwater recharge and greater exposure to desertification and soil erosion in already hot and arid areas; these are all negative impacts for the integrity of groundwater storage systems. Overall, climate change has already and will increasingly have an impact on groundwater quantity and quality. Adaptation is substantial for a sustainable use of the precious groundwater resource. Measures of Adaptation and Mitigation Both the mitigation and adaptation to climate change are essential.

They are both interconnected and not mutually exclusive. The driving force for global warming is the emission of greenhouse gases. Thus, more efforts in mitigating climate change should be undertaken to reduce the emissions and to develop new technologies. A lot of energy is used for groundwater extraction. In this context, large potential lies in the promotion of renewable energy, like solar energy, which can be used for both groundwater extraction and for the distillation of water of inferior quality.

Also, the large and long-term storage capacities of natural groundwater systems offer a wide range of adaptation measures. Protection of groundwater. Groundwater needs to be protected and its use and maintenance adapted to climate change. Preventing groundwater degradation and unwise exploitation will prove more cost effective than trying to clean up and restore mismanaged aquifers. Monitoring and research have to be done to achieve a better understanding of groundwater systems and their dynamics.

Wise land use, the protection and maintenance of groundwater systems and technical installations for the simple access to groundwater resources are key to prevent groundwater contamination, ensure sustainability of economic investments and groundwater availability during extreme conditions. Second is the securing soil infiltration. Land use and human activities greatly influence groundwater conditions.

Changing land use from forest to agricultural crops may have significant impacts on groundwater levels. Because these effects are long-term and not directly obvious, they are often disregarded or only perceived and recognized.

Most urbanization processes come along with vast soil sealing together with sewers and stormwater drainage systems, which are associated with very rapid peak discharge of very often bad chemical water quality. Both the reduced groundwater discharge and the bad quality of discharge water represent a threat to underlying groundwater bodies. In rural areas, soil management, soil moisture retention measures and continuous vegetation help in supporting soil infiltration and groundwater recharge besides reducing erosion risk. Especially in hilly areas, forests should be protected. Afforestation in these areas represents always the best measure to improve the physical soil properties and to increase infiltration.

Furthermore, forests in catchment areas improve the dynamics of discharge while subduing fast peak discharge events, reducing the menace of flooding for the population living downstream. Erosion in hilly regions can be avoided by terracing farmland and earth mounds along the contour lines. Wherever possible, monocultures should be converted into ecologically sound arable land. A very important alternative or supplement to the preservation or restoration of natural infiltration conditions is artificial groundwater recharge. Artificial groundwater recharge is also described as a kind of groundwater banking.

Protected from evaporation and contamination, recharged water can be used for different purposes, but first of all for drinking water supply. Generally, the costs of artificial groundwater recharge are less than the investments necessary for large traditional dams. In poor arid rural areas, the local population can build small earth dams for surface water retention and infiltration. Surface water will be treated while percolating through the soil horizons. However, clogging may occur and therefore the infiltration basin has to be cleaned during the dry season. The substrate can be used as a valuable fertilizer when free of contaminated substances. Water can be stocked in the upper aquifer layers and thus the energy needed to pump it up again is limited. Depending on the amount needed, cheap solar energy pumps or wind pumps can be used.

Water saving. Advocated strategies of water saving and the use of recycled, treated water becomes even more relevant in times of climate change. Instead of relying on precious and finite groundwater for all kinds of water supply, groundwater usage for irrigation purposes should be reduced and substituted with treated municipal waste water for irrigation in peri-urban areas. By using good quality groundwater, preferably for drinking water, the resource is used in a more sustainable way. The amount of water needed for agricultural use is still incredibly high and today is estimated to be seventy percent of all human water extraction. Therefore, sound irrigation systems could contribute to avoid the waste of this precious resource.

Open canals should be replaced by closed pipes in order to protect against evaporation. To reduce evaporation the soil should be covered completely with plants, and therefore a multilayer storey is suggested. Virtual water stored in agricultural products makes up part of our water footprint. Whatever we eat, a certain amount of water was used to make our food grow. Efficient water use must be the main objective in agriculture and the cultivation of drought resistant plants could be an option.

Strategies for policy making. Many principles applicable for the sustainable management of surface water is equally valid for groundwater management. Thus, capacity development, good governance and transparency are keystones which have to be considered. Often the insufficiency of supplying drinking water and sanitation is driven by an inefficient supply of services rather than by water shortages. Mismanagement, corruption, lack of appropriate institutions and a shortage of new investments in building, human capacity and physical infrastructure contribute to this development. For decision makers, the available data and information concerning the water balance and changes due to the climate change have to be comprehensive and easily accessible.

Still, not only knowledge should increase and data collected, but it is absolutely important that the data is comprehensive and easily accessible. Due to increasing investments in the global water market, governments should support strong regulatory systems which are based on monitoring, data collection and sharing of knowledge by national water authorities. In rural areas of semi-arid or arid regions, often conflicts concerning the access to groundwater are not unusual. Often it is the extraction of groundwater resources of different conflicting parties, heavily dependent on already stressed groundwater resources, which spark off violent conflicts. For the trans-boundary management of groundwater resources, the exchange of data and relevant information has to be institutionalized.

Thus, a harmonization of national laws across borders is critical. Overall good water governance and the political will to implement common agreements are the fundamental cornerstones for adaptation and mitigation measures. The use of non-renewable groundwater resources has to be avoided as far as possible. However, in humanitarian emergency situations, the use of non-renewable water resources can be the only option in order to save lives if available renewable water resources are quantitatively and qualitatively not sufficient. For long-lasting humanitarian interventions, alternative options are to be introduced to slow down the excessive use of fossil groundwater that is desalination, reuse, purification.

Open areas have to be made available in order to catch water in polder and inundation plains. Promoting public parks and reducing soil ceiling to a minimum necessary could be an option to increase infiltration. Rainwater harvesting should be increased by catching runoff in basins or by infiltration wells in the underground. Every new settlement should take groundwater resources into account and the protection of aquifers should have high priority. Dump sites and solid waste handling also have to do with groundwater.

This also applies to fertilizer and pesticide use in agriculture. Measures need to be developed in order to prevent the excessive leaching of contaminants into groundwater resources. In order to be prepared, financial facilities have to be made available to construct dams for infiltration basins, infiltration wells, and for the renaturation of riverbeds and wetlands. Now we will learn about the impact of climate change on water resources globally. Water resources are used in various areas of the economy, society and environment.

This means that the management of water resources is critical for achieving sustainable development. A significant portion of the world's population suffers from severe water shortages. Currently, about three point six billion people in the world face inadequate access to water resources at least a month per year and by twenty fifty this number is expected to rise to five billion people as per the record of WMO, two zero two two. The impact of climate change on hydrological cycles is likely to create a greater need for water as surface and groundwater levels diminish over time. Globally, hydrological cycles are shifting, creating drier days, severe floods, erratic rainfall patterns, and accelerated melting of glaciers.

More areas of the world recorded drier than normal conditions in two zero two one compared with the average of the thirty-year hydrological base period. In the same year two zero two one, areas such as India and China experienced severe floods with numerous casualties. Tropical cyclones also affected areas such as Mozambique, Indonesia, and the Philippines, as per the WMO two zero two two record. Areas such as Ethiopia, Kenya, and Somalia faced below-average rainfall, which caused severe drought in these economies in two zero two one. Also in Africa, rivers such as Nile, Niger, and Congo experienced less than normal discharge in two zero two one.

In addition, territorial water storage was below normal in central parts of South America, North Africa, Patagonia, Madagascar, Central Asia, the Middle East, Pakistan and North India and above normal in areas such as the central part of Africa, the northern part of South America and the northern part of China. Now we will discuss the case of China. Climate change affects water resources unevenly across China. Southern China experiences a decline in water availability for agriculture, while Northern China remains relatively stable. Rising temperatures lead to reduced snowfall and altered seasonal water flow, impacting river basins crucial for irrigation and hydropower.

The accelerated melting of glaciers in the Tibetan Plateau, a key water source for major rivers like Yangtze and Yellow Rivers, is likely to alter seasonal river flows affecting water supply and hydropower generation. The Chinese government has implemented strategies such as South to North Water Diversion Project and investments in water conservation technology to mitigate the impacts of climate change on water resources. Next is the case of Zambia. The temperature is projected to increase by one point nine degree Celsius and two point three degree Celsius by twenty fifty and two one zero zero respectively in Zambia. Rainfall is projected to decrease by approximately three percent by mid-century but only marginally by approximately zero point six percent by the end of the century across the country.

These changes in rainfall and temperature will decrease water availability by thirteen percent by two one zero zero at the national level. At the river basin level, the northern basins are projected to remain the same or experience slight gains in water resources compared with those in the southern and western parts of the Zambia, where a reduction of up to nine percent are projected. In particular, the Zambezi, Kafue, and Luangwa river basins are projected to have fewer water resources due to reduced rainfall and higher temperatures. Next is the case of Africa. The impact of climate change on water resource availability in a transboundary basin in West Africa, for the RCP four point five scenario that is representative concentration pathway four point five scenario on overall decline in monthly precipitation compared to the baseline until two zero seven zero and then a slight recovery in two zero nine zero. The RCP eight point five scenario predicts a shortened rainfall pattern and a lengthened dry season.

In terms of annual rainfall, their model predicts that for both scenarios, annual rainfall will decline with the worst case occurring under the RCP eight point five scenario. This indicates that the climate change is likely to create a serious water shortage in West Africa. In West Africa, under the RCP four point five scenario, climate change will increase precipitation by fifty percent. However, under the RCP eight point five scenario, climate change will decrease precipitation by ten point nine percent. In terms of impact of climate change on river discharge, it showed a negative impact until two one zero zero for both scenarios compared to the baseline that is from nineteen sixty one to one nine eight zero. For the RCP four point five scenario, the observed values vary from minus one point two percent in two zero three zero to minus two point three percent in two zero seven zero and minus two point one percent in two zero nine zero. Under the RCP eight point five scenario, it saw the changes in river discharge varying from plus four point two percent to minus seven point nine percent in two zero three zero and two zero nine zero respectively.

Next is the case of Ethiopia. The future annual seasonal rainfall will show increasing and decreasing trends, but they are statistically insignificant. Furthermore, future temperatures in the sub-basins show a significant increase. For the applied scenarios, an increasing and decreasing trend of the future rainfall and increased temperatures would decrease the water yield by four point nine to fifteen point three percent in the Katar sub-basin and six point seven to seven point four percent in the Mekhi sub-basin. Furthermore, annual water yields will increase in the range of zero point three eight to fifty seven point one percent, and six point five seven to forty nine point nine percent for the Katar and Meki sub-basins respectively. It is further noted that rainfall and temperatures in the study region are anticipated to increase by two zero four zero and two zero seven zero under both the RCP four point five and RCP eight point five climate scenarios.

Next is the case of Mauritius. For the period two zero two zero to two zero five zero under a business as usual scenario, the freshwater sector remained in a state of moderate vulnerability. Under the effects of climate change, this shifted to high vulnerability. The finding indicates that the country is likely to enter water scarcity, that is water availability of less than one thousand cubic meters per capita, by twenty thirty and face over-exploitation of water resources, that is a water exploitation rate greater than hundred percent by twenty forty. Now let us conclude the module twelve, we have discussed in this module about the remote sensing and GIS.

We have seen that remote sensing and GIS are powerful technologies that work together to collect, analyze, and visualize spatial data. Remote sensing provides real-time and large-scale data, while GIS helps in organizing and interpreting this data for decision-making. These technologies have widespread applications in fields such as agriculture, environmental monitoring, disaster management, urban planning, and natural resource management. They help in improving efficiency, accuracy, and informed decision making across various sectors. With advancement in satellite technology, AI, artificial intelligence, and machine learning, remote sensing and GIS continue to evolve.

Their future applications will enhance precision, automation, and predictive analytics, making them even more valuable tools for addressing global challenges. Climate change significantly disrupts water resources by altering precipitation patterns, reducing freshwater ability and increasing the frequency of extreme weather events leading to water scarcity and heightened competition for water access. Now, these are the list of the references you can see here. It has been taken from the books, the important journals, etc. You can see Chandra A.M., then Chakrabarty D., then Hetzel F., IPCC two zero two one, NCDC two zero zero eight, Dwivedi D.N. two zero zero five, then Philip kofi Adom two zero two four, WMO two zero two two. Thank you very much to all.