Training Course

Climate Change and its Impact on Water Resources

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LECTURE - 9

CLIMATE CHANGE EFFECT ON RUNOFF AND SEDIMENT YIELD

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CLIMATE CHANGE EFFECT ON RUNOFF AND SEDIMENT YIELD

There is a robust scientific consensus that Earth's climate has changed and will continue to change as human activities increases the concentrations of green house gases in the atmosphere. Since the beginnings of concern over the possible consequences of global warming, it has been widely recognized that changes in the cycling of water between land, sea, and air could have very significant impacts across many sectors of the economy, society, and the environment. The hydrologic system is an integrated component of the earth geophysical system and both affects and is affected by climatic conditions. Water vapor is one of the main greenhouse gases, and changes in climate affect all aspects of the hydrologic cycle. As the atmosphere warms due to human-induced greenhouse gas emissions, water vapor increases, further enhancing the warming. Changes in temperature affect evapotranspiration rates, cloud characteristics, soil moisture, and snowfall and snowmelt regimes. Changes in precipitation affect the timing and magnitude of floods and droughts, shift run off regimes, and alter groundwater re charge characteristics. Synergistic effects alter cloud formation and extent, vegetation patterns and growth rates, and soil conditions. On a larger scale, climatic changes can affect major regional atmospheric circulation patterns and storm frequencies and intensities. All of these factors are, in turn, very important for water planning and management decisions.

Erosion is a natural geomorphic process occurring continually over the earth's surface and it largely depends on topography, vegetation, soil and climatic variables and, therefore, exhibits pronounced spatial variability due to catchment heterogeneity and climatic variation. Soil erosion by water is one of the most important land degradation problems and a critical environmental hazard of modern times worldwide. Accelerated erosion due to human-induced environmental alterations at a global scale is causing extravagant increase of geomorphic process activity and sediment fluxes in many parts of the world. Land use beyond its capability and without proper conservation measures enhances erosion in uplands and sedimentation downstream. One of the principles of watershed management is to use the land as per its capability or suitability. So that erosion therefore water pollution from sediment remains low. This helps to protect the water source such as springs, lakes/ ponds, and rivers and enhance their suitability for human use.

It has been estimated that about 113.3 m ha of land is subjected to soil erosion due to water and about 5334 m tonnes of soil is being detached annually due to various reasons in India. The process of soil erosion involves detachment, transport and subsequent deposition. Sediment is detached from soil surface both by the raindrop impact and the shearing force of flowing water. The detached sediment is transported downslope primarily by flowing water, although there is a small amount of downslope transport by raindrop splash also. Once runoff starts over the surface areas and in the streams, the quantity and size of material transported depends on transport capacity of runoff water. However, if transport capacity is less than the amount of eroded soil material available, then the amount of sediment exceeding the transport capacity gets deposited. The amount of sediment load passing the outlet of a catchment is known as the sediment yield. Urbanization, agriculture expansion and deforestation predominantly change the land use due to which soil erosion takes place. A proper assessment of the erosion problem is greatly dependent on its spatial, economic, environmental and cultural context. The information on sources of sediment yield within a catchment can be used as perspective on the rate of soil erosion occurring within that catchment. Because of their close links to land cover, land use and the hydrology of a river basin, erosion and sediment transport processes are sensitive to changes in climate and land cover and to a wide range of human activities. These include forest cutting and land-clearance, the expansion of agriculture, land use practices, mineral extraction, urbanization and infrastructural development, sand mining, dam and reservoir construction, and programmes for soil conservation and sediment control. Although recent concern about the impact of global change on the Earth system has emphasized the impact of climate change resulting from the increased emission of greenhouses gases and associated global warming, it is important to consider other measures of the functioning of the system. Soil erosion rates and the sediment loads transported by the world's rivers provide an important and sensitive indicator of changes in the operation of the Earth system and, as indicated above, widespread changes in erosion rates and sediment flux can have important repercussions and give rise to significant socio-economic and environmental problems.

Modeling of Runoff and Sediment Yield from a Catchment

Rainfall-runoff-sediment yield is the most complex hydrological phenomenon to comprehend due to tremendous spatial variability of watershed characteristics and precipitation patterns, making the physical modeling quite complex and involved. The quantity of runoff and sediment yield resulting from a given rainfall depends mainly on rainfall intensity, duration, and distribution besides other factors, such as initial soil moisture, land use, slope, etc. The estimation of runoff is critical to many water resources activities, for example, design of flood protection works, protection of agricultural lands, planning of water storage and release, etc. The erosion of soil in the watershed may be occurring due to rainfall and runoff. Uncontrolled and excessive soild erosion degrades land resources of a catchment. The sediment transport and deposition causes reduction of carrying capacity of rivers and storage capacity of reservoirs. Also, sediments can carry pollutants such as radioactive materials, pesticides and nutrients, and hence their transportation should be limied or controlled to the extent feasible.

A number of linear and non-linear hydrological models have been developed since 1930's for describing the processes of rainfall-runoff, runoff-sediment yield, and rainfall-runoff-sediment yield in a watershed fluvial system, and these are also useful in forecasting. These models can be broadly classified as lumped, conceptual, hydrological, and hydraulic models. The physically based classical models requires wide range of parameters related to land uses, soil characteristics, soil horizon, watershed treatment, man made activities, conservation practices, soil moisture variation, topographic data, surface roughness, etc. These parameters vary significantly over space and time, and are very difficult to monitor. Under these circumstances, classical models require assumption of the parameters. Most common assumption to be made for describing the rainfall-runoff-sediment yield process is: sediment produced in the catchments is uniformly distributed over the catchment area, uniform soil group, approximation of slopes, etc. These assumptions create lumped-ness in the physically based distributed classical model. The other-modelling approach is the use of data driven models such as the Artificial Neural Networks (ANNs). ANN based approach yields satisfactory results without going into the details of catchments characteristics. ANN approach comprises both linear and non-linear concepts in model building, and can be operated with the dynamic or memory less input-output system.

Impact of Climate Change on Runoff and Soil Erosion

Surface runoff and soil erosion as well as many of the factors controlling both will be directly or indirectly affected by climate change impact. Increasing precipitation amounts and intensities cause non linear responses of runoff and soil. The variation of local precipitation and temperature regimes implicate shifts in vegetation cover, soil conditions, land use and management which will affect runoff, erosion and the translocation of sediments and environmental pollutants to surface water.

Precipitation is the main driver of variability in the water balance over space and time, and changes in precipitation have very important implications for hydrology and water resources. Hydrological variability over time in a catchment is influenced by variations in precipitation over daily, seasonal, annual, and decadal time scales. Flood frequency is affected by changes in the year-to-year variability in precipitation and by changes in short-term rainfall properties (such as storm rainfall intensity). The frequency of low or drought flows is affected primarily by changes in the seasonal distribution of precipitation, year-to-year variability, and the occurrence of prolonged droughts. Evaporation from the land surface includes evaporation from open water, soil, shallow groundwater, and water stored on vegetation, along with transpiration through plants. The rate of evaporation from the land surface is driven essentially by meteorological controls, mediated by the characteristics of vegetation and soils, and constrained by the amount of water available. Climate change has the potential to affect all of these factors—in a combined way that is not yet clearly understood with different components of evaporation affected differently. The primary meteorological controls on evaporation from a well-watered surface (often known as potential evaporation) are the amount of energy available (characterized by net radiation), the moisture content of the air (humidity—a function of water vapor content and air temperature), and the rate of movement of air across the surface (a function of wind speed). Increasing temperature generally results in an increase in potential evaporation, largely because the water-holding capacity of air is increased. Changes in other meteorological controls may exaggerate or offset the rise in temperature, and it is possible that increased water vapor content and lower net radiation could lead to lower evaporative demands. The relative importance of different meteorological controls, however, varies geographically.

The impacts of climate change on hydrology are usually estimated by defining scenarios for changes in climatic inputs to a hydrological model from the output of general circulation models (GCMs). The three key developments here are constructing scenarios that are suitable for hydrological impact assessments, developing and using realistic hydrological models, and understanding better the linkages and feedbacks between climate and hydrological systems. The heart of the scenario "problem" lies in the scale mismatch between global climate models (data generally provided on a monthly time step at a spatial resolution of several tens of thousands of square kilometers) and catchment hydrological models (which require data on at least daily scales and at a r e solution of perhaps a few square kilometers). A variety of "downscaling" techniques have been developed and used in hydrological studies.

An investigation of climate change effects on regional water resources, therefore, consists of three steps: (1) using climate models to simulate climatic effects of increasing atmospheric concentration of greenhouse gases, (2) using downscaling techniques to link climate models and catchment- scale hydrological models or to provide catchment scale climate scenarios as input to hydrological models, and (3) using hydrological models to simulate hydrological impacts of climate change. Errors occur at every step of the investigation.

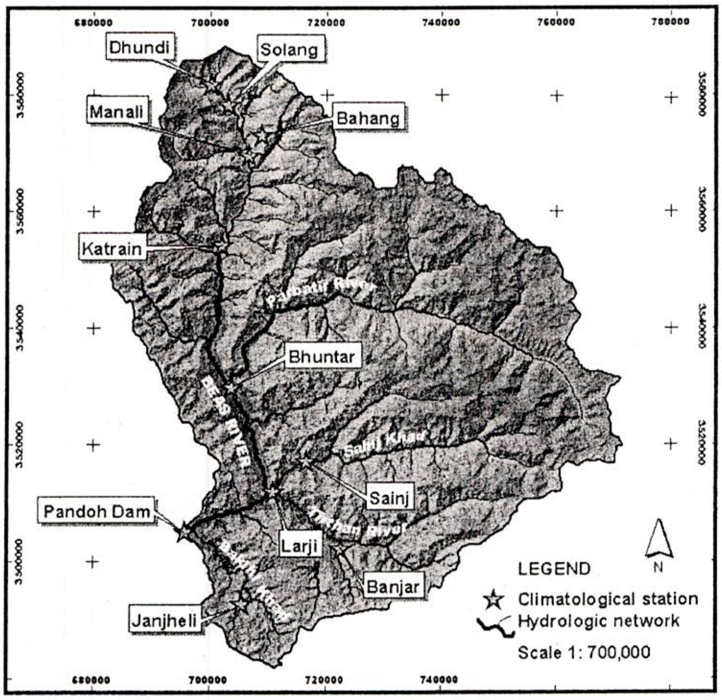
Ice and snow are important components of the Earth's climate system and are particularly sensitive to global warming. Over the last few decades, the amount of ice and snow, especially in the Northern Hemisphere, has decreased substantially, mainly due to human-made global warming. The snow line and glacier boundaries are sensitive to changes in climatic conditions. Changes in the volumes and extents of ice and snow have both global and local impacts on climate, ecosystems and human well-being. Air temperatures are projected to continue increasing in many mountainous regions, which will raise snow lines and cause other changes in mountain snow cover. Concerning the impact on the hydrological cycle and runoff, the temperature rise will reduce the fraction of precipitation in the form of snow vs. rain. Temperature appears to be the primary control and rates of retreat generally are accelerating.

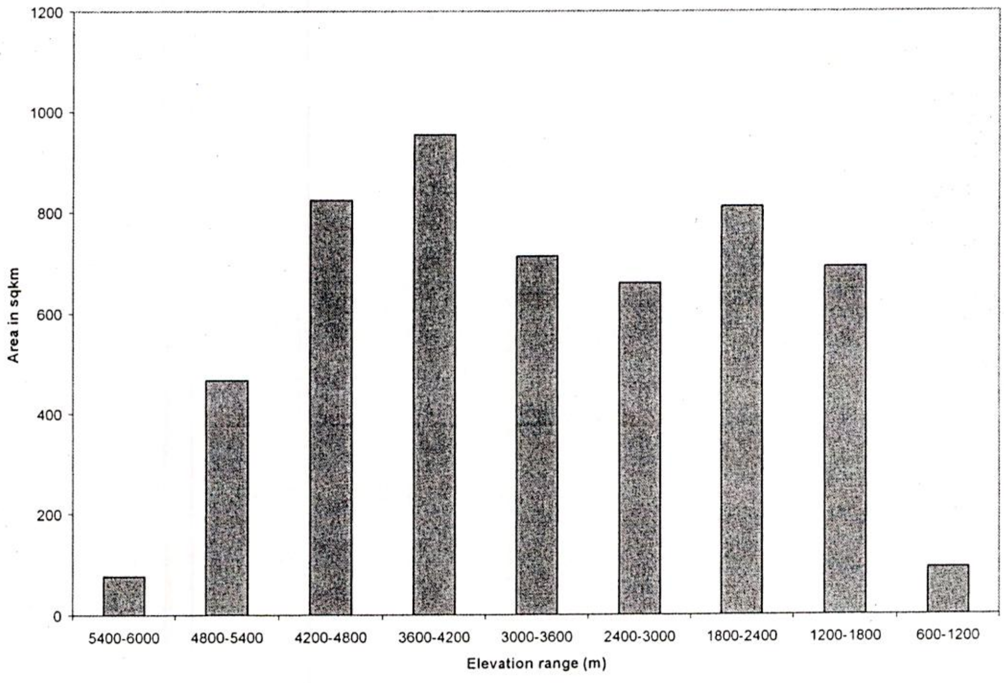
It is estimated that the Himalayan mountains cover a surface area of permanent snow and ice in the region which is about 97,020 km2 with 12,930 km2 volume. In these mountains, 10 to 20% of the total surface area is covered by glaciers, while an area ranging from 30 to 40% has seasonal snow cover. These glaciers provide snow and the glacial melt waters keep the Himalayan rivers perennial. A warming is likely to increase the melting more rapidly than the accumulation. Glacial melt is expected to increase under changed climate conditions, which would lead to increased summer flows in some river systems for a few decades, followed by a reduction in flow as the glaciers reduce.

As discussed above, regions having a large fraction of runoff driven by snowmelt would be especially susceptible to changes in temperature, because temperature determines the fraction of precipitation that falls as snow and is the most important factor in determining the timing of snowmelt. The Himalayan water system is highly dependent on snow storage and hence susceptible to suffer from the effects of global warming. There are two major steps involved in this process: (1) Determining changes in temperature, precipitation and other climatologic variables such as evapotranspiration and; (2) Using these changes to determine the resulting changes in stream flow.

Assessing Climate Change Impact on Runoff – Case Study of Beas Basin

A study of Beas basin has been carried out with the aim of better understanding the effects of climate change scenarios on the runoff regime and water availability in mountain areas. In order to provide an indication of the extent of impacts of climatic change on water resources, Stream flow represents an integrated response to hydrologic inputs on the drainage basin. The model applied in the present study simulates melt runoff as well as rainfall runoff. However there is effect mainly on snowmelt runoff due to change in climate. The Beas River is an important river of the Indus river system. The Beas basin up to Pandoh dam is selected in this study and shown in figure given below. It originates from the eastern slopes of Rohtang pass of Himalayas at an elevation of 3900 m and flows in nearly north-south direction up to Larji, where it nearly takes a right angle and turns towards west and flows in the same direction up to the Pandoh dam. The length of the river up to the Pandoh dam is 116 km. The catchment of the Beas basin up to Pandoh dam is 5278 km^2 out of which only 780 km^2 is under permanent snow. In this study, Terra/Aqua-MODIS satellite data have been used for SCA estimation. The Moderate Resolution Imaging Spectroradiometer (MODIS) employed by Terra and Aqua satellites provides spatially snow covered data with 500m and daily temporal resolution. For snow melt runoff modeling, basin is divided into a number of elevation zones. In the present study, the basin is divided into 9 elevation zones with an altitude difference of 600 m for convenience and shown in following figure.


Dhundi
Solang
Manali
Bahang
Katrain
Bhuntar
Pandoh Dam
Sainj
Larji
Banjar
Janjheli
BEAS RIVER
Sainj Khad
LEGEND
Climatological station
Hydrologic network
Scale 1: 700,000
N
680000
700000
720000
740000
760000
780000


Area in sqkm
1200
1000
800
600
400
200
0
5400-6000
4800-5400
4200-4800
3600-4200
3000-3600
2400-3000
1800-2400
1200-1800
600-1200
Elevation range (m)

Snow cover is directly related to temperature of the area and rise in temperature accelerates the melting of snow. Hence for hydrological modeling of climate change assessment which uses SCA as input, it is very essential to prepare modified SCA depletion curve under the changed climatic scenario. Since the study area is divided into nine zones and four of them are partially snow covered, modified SCA depletion curves were prepared for four zones.

Snow cover depletion is a cumulative effect of climatic conditions in and around snow cover area, the cumulative mean air temperature (CMAT) at a nearby station should represent depletion of SCA. In this study also an exponential relationship between SCA and CMAT in the following form has been adopted.

$$Y=a*\exp(-bX)$$

Where Y denotes the SCA and X stands for the CMAT, whereas a and b are the coefficients to be determined.

Melting starts around beginning of March, therefore, reference date for computing CMAT was considered March 1. The above relationship has been developed for each year and found that it is not exactly same for each year, because snow cover varies each year.

In the Beas basin, the SCA for zone 1, 2 and 3 are having almost no snow cover while zones 8 and 9 are having almost 100% snow cover area. The remaining zones 4,5, 6 and 7 are having snow cover area which changes with time during ablation period. Therefore relationships for these four elevation zones have been developed. The station Manali having an altitude of 2100 m has been considered in zone 4. Mean daily air temperature was obtained using maximum and minimum temperature. No station is available above the altitude of 2500m. Therefore for zones 5, 6 and 7 also temperature of Manali station have been used and computed with the help of lapse rate (0.6°C).

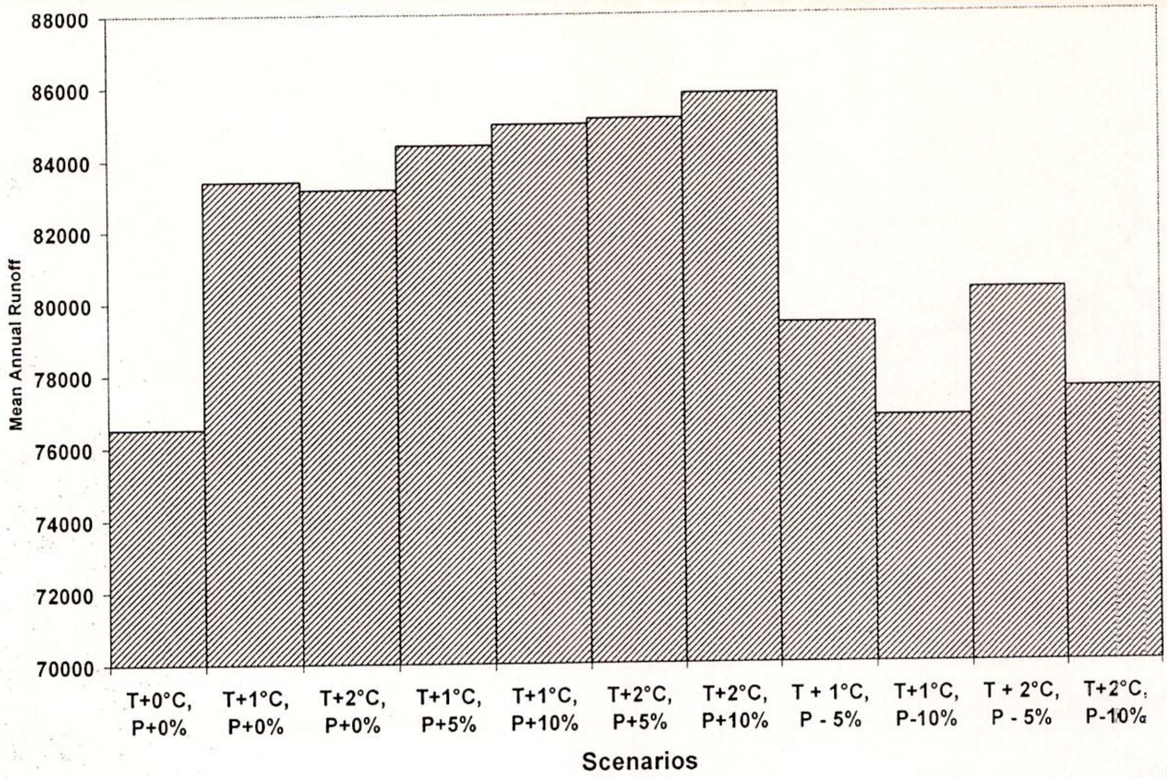
As such, there is no actual scenario for the study basin. Therefore, in order to cover a wide range of climate variability, ten hypothetical climate change scenarios were derived from combinations of two temperature increases and four precipitation changes. Keeping in view of the projections given by different investigators, this study considers the following scenarios:

T + 0, P + 0% Reference Scenarios (RS)

T + 1°C, P + 0%	T + 2°C, P + 0%
T + 1°C, P + 5%	T + 2°C, P + 5%
T + 1°C, P + 10%	T + 2°C, P + 10%
T + 1°C, P - 5%	T + 2°C, P - 5%
T + 1°C, P - 10%	T + 2°C, P - 10%

In order to simulate the runoff in a changed climate, it is necessary to determine a new set of SDC (modified depletion curves) that would result from modified climatic condition. There will be a shift of the conventional SDC for a new warmed climate because in this situation, a greater part of the winter precipitation will be rain instead of snow. The relationship developed as above can be used to prepare modified SDC. In the above relationship, change in temperature due to climate change will be considered to estimate the corresponding snow cover area. For example, if temperature is increased by 1°C, then corresponding SDC will advance by about 15-20 days. In this study, SDC for hypothetical climate change scenarios such as increase of temperature by 1 and 2°C have been generated.

Streamflow as well as snowmelt runoff have been computed for a number of hypothetical scenarios. With the increase in temperature, stream flow increases in the beginning of the melt season and produces small peaks. In the later part of the summer, these peaks increase and was found to be reduced without much change in their timings. These peaks are mainly because of heavy rainfall with a small contribution from snowmelt. It can be seen that streamflow and also snowmelt runoff increases when temperature is increased. This is because; the snowmelt runoff will increase because of more melting of snow as shown in the following figure.



In general, it is inferred that climate processes are quite intricate which affect the hydrological components in diverse ways. Increase in temperature may increase the snow and glacier melt but this trend depends on the extent of snow and glaciers in the catchment and may not last long.

Concluding remark

Global climatic changes will have major effects on precipitation, evapotranspiration, and run off. Estimating the nature, timing, and even the direction of the impacts at the regional and local scales of primary interest to water planners and managers involves many uncertainties.

Among the most significant uncertainties are the changes in precipitation and run-off projected by large scale general circulation on models. The impacts of climatic changes on future water supplies are uncertain, and runoff is sensitive to changes in temperature and precipitation.

Once the runoff has been modeled, it is automatically possible to evaluate the effect of any climate change scenario on the seasonal snow cover and runoff.

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