Training Course

Climate Change and its Impact on Water Resources

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LECTURE - 12

IMPACT OF CLIMATE CHANGE ON WATER DEMAND AND WATER QUALITY

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INTRODUCTION

Climate change is one of the major challenges to researchers in recent times. The impact of climate change on water resources around the globe has serious implications like, changing water levels and climatic temperatures which in turn affect the economy and future as a whole. In addition, water resources are depleting day by day due to the exponential demand from sectors like irrigation, domestic consumption and industry. Water availability and quality will be the main pressures on, and issues for, societies and the environment under climate change. Along with quantity, quality is also deteriorating mainly due to the indiscriminate use of ground water to hazardous levels, pollution of rivers and improper management of waste water. This necessitates water conservation strategies to be adopted at the national, state and local levels. Climate-related impacts on water resources are already being documented. In all corners of the world, there is growing empirical evidence of increased severe weather events, flooding, and diminished ice cover, all of which can be attributed to climate change. Numerous scientific studies also reports increases in the intensity, duration, and spatial extent of droughts, higher atmospheric temperatures, warmer sea surface temperatures, changes in precipitation patterns, and diminishing glaciers and snowpack. In the future, climate change will affect water supply, quality, and demand. This lecture highlights the impacts of climate change on water demand and water quality and to explore required research areas to minimize the impact of climate change on water demand and water quality.

EARTH'S WATER RESOURCES

The Earth's water resources are generally salt water, with only 2.5% being fresh water. Freshwater habitats cover little of the earth's surface and support high biodiversity per unit area. The Millennium Ecosystem Assessment (2005) summarizes extensive losses of wetlands globally and describes freshwater ecosystems as being over-used, underrepresented in protected areas, and having the highest portion of species threatened with extinction. Primary direct drivers of degradation and loss include infrastructure development, land conversion, water withdrawal, eutrophication and pollution, overharvesting and overexploitation, the introduction of invasive alien species, and global climate change. Approximately 70% of the fresh water available on the planet is frozen in the icecaps of Antarctica and Greenland leaving the remaining 30% (equal to only 0.7% of total water resources worldwide) available for consumption. From this remaining 0.7%, roughly 87% is allocated to agricultural purposes (IPCC 2007). These statistics are particularly illustrative of the drastic problem of water scarcity facing the world. Water scarcity is defined as per capita supplies less than 1700 m3/year (IPCC 2007).

Around 1.2 billion people, or almost one-fifth of the world's population, live in areas of physical scarcity, while another 1.6 billion people, or almost one quarter of the world's population, live in a developing country that lacks the necessary infrastructure to take water from rivers and aquifers (known as an economic water shortage). According to the Comprehensive Assessment of Water Management in Agriculture, one in three people are already facing water shortages (2007).

There are four main factors aggravating water scarcity according to the IPCC:

- Population growth: in the last century, world population has tripled. It is expected to rise from the present 6.5 billion to 8.9 billion by 2050. Water use has been growing at more than twice the rate of population increase in the last century, and, although there is no global water scarcity as such, an increasing number of regions are chronically short of water.
- Increased urbanization will focus on the demand for water among a more concentrated population. Asian cities alone are expected to grow by 1 billion people in the next 20 years.
- High level of consumption: as the world becomes more developed, the amount of domestic water used by each person is expected to rise significantly.
- Climate change will shrink the resources of freshwater.

Climate change impacts and freshwater

The global warming may affect the hydrological cycle which could result in further intensification of temporal and spatial variations in precipitation, snow melt and water availability. The report on "India's Initial National Communication to the United Nations Framework Convention on Climate Change" published by Ministry of Environment and Forests, Government of India identifies the following projected impacts of climate change on water resources.

"It is obvious that the projected climate change resulting in warming, sea level rise and melting of glaciers will adversely affect the water balance in different parts of India and quality of ground water along the coastal plains. Climate change is likely to affect ground water due to changes in precipitation and evapotranspiration. Rising sea levels may lead to increased saline intrusion into coastal and island aquifers, while increased frequency and severity of floods may affect groundwater quality in alluvial aquifers. Increased rainfall intensity may lead to higher runoff and possibly reduced recharge."

Possible key changes to the hydrological cycle (associated with an increased concentration of greenhouse gases in the atmosphere and the resulting changes in climate) include:

- Changes in the seasonal distribution and amount of precipitation.
- An increase in precipitation intensity under most situations.
- Changes in the balance between snow and rain.
- Increased evapotranspiration and a reduction in soil moisture.
- Changes in vegetation cover resulting from changes in temperature and precipitation.
- Consequent changes in management of land resources.
- Accelerated melting glacial ice.
- Increased coastal inundation and wetland loss from sea level rise.
- Effects of CO_2 on plant physiology, leading to reduced transpiration and increased water use efficiency.

Furthermore it is reported that the climate changing is impacting directly on the distribution of water. "Technical paper on climate change and water" (2008) from the Intergovernmental

Panel on Climate Change (IPCC) summarises the expected bio-physical impacts:

- *Precipitation and runoff is expected to increase in high latitudes, and decrease in mid and sub-tropical regions, exacerbated by greater evapotranspiration;*
- *Increased precipitation intensity and variability is projected to increase risks from floods and droughts;*
- *Melting glaciers may temporarily boost rivers flowing from major mountain ranges but reduced perennial base flows are anticipated in the long term;*
- *Increased temperatures and more intense rainfall are expected to aggravate pollution and sedimentation of water bodies;*
- *Changes in water quantity and quality are likely to affect food and availability, requiring demand and supply-side adaptations;*
- *The functions and operations of existing water infrastructure will be affected.*

WATER DEMAND BY DIFFERENT SECTORS

Water requirements of India

Agriculture sector is the major water user. It is estimated that 67% of the total water used in the world belongs to the Agriculture sector. Water used by different sectors is presented in Figure 1. India has an agriculture-based economy and hence, development of irrigation to increase agricultural production for making the country self-sustained and for poverty alleviation has been of crucial importance for the planners.

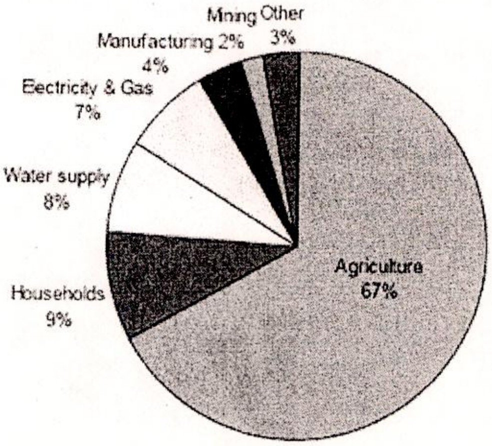

Figure 1: Water use in the world (2005)

Long-term planning has to account for the growth of population. It is estimated that by the year 2025, the population is expected to be 1333 million in high-growth scenario and 1286 million in low growth scenario. For the year 2050, high rate of population growth is likely to result in about 1581 million people while the low growth projections place the number at nearly 1346 million. The projected food-grain and feed demand for 2025 would be 320 million tonnes (high-demand scenario) and 308 million tonnes (low-demand scenario). The requirement of food grains for the year 2050 would be 494 million tonnes (high-demand scenario) and 420 million tonnes (lowdemand scenario). The availability of water in India shows wide spatial and temporal variations. Also, there are very large inter annual variations.

Pattern of water demand for Irrigation

Irrigation is still the largest consumptive water use sector in India. Groundwater irrigation, which expanded rapidly in the last few decades, forms a major part of the water withdrawals in many river basins. At present, more than 60 % of the total irrigated area is groundwater irrigated. However, with relatively higher project efficiencies than surface irrigation, groundwater contributed to only 45 % of the total irrigation withdrawals. The ultimate irrigation potential of India has been estimated as 140 Mha which includes 76 Mha from surface water and 64 Mha from groundwater sources. The quantum of water used for irrigation by the last century was of the order of 300 km^3 of surface water and 128 km^3 of groundwater, total 428 km^3. By the year 2025 and 2050, the water requirement for irrigation would be 561 km^3 and 628 km^3 for low-demand scenario and 611 km^3 and 807 km^3 for high-demand scenario.

Domestic use

One of the most important water requirements is the community water supply. It is about 5% of the total water use in India and it includes about 7 km^3 of surface water and 18 km^3 of groundwater. Increase in population and higher rate of urbanization results in increasing demand of community water. It is expected that by the year 2050 nearly 61% of the population will be living in urban areas as against 48% in low growth scenario. It is estimated that by 2050, water requirements per year for domestic use will be 90 km^3 for low demand scenario and 111 km^3 for high demand scenario. It is expected that about 70% of urban water requirement and 30% of rural water requirement will be met by surface water sources and the remaining from groundwater.

Industrial water requirement

Ppresent water use in the industrial sector is roughly of the order of 15 km^3. The water use by thermal and nuclear power plants with installed capacities of 40,000 MW and 1500 MW (1990 figures) respectively, is estimated to be about 19 km^3. The water requirement for industries in 2050 would be 103 km3 if the present rate of water use continues.

IMPACTS OF CLIMATE CHANGE ON WATER DEMAND IN THE FUTURE

Various studies on climate change have reported that higher temperatures and increased variability of precipitation would, in general, lead to increased irrigation water demand, even if the total precipitation during the growing season remains the same. The impact of climate change on optimal growing periods, and on yield-maximising irrigation water use, has been modeled assuming no change in either irrigated area and/or climate variability (Döll, 2002; Döll et al., 2003). Applying the IPCC SRES A2 and B2 scenarios as interpreted by two climate models, it was projected that the net irrigation requirements of India would change by −6% to +5% by 2020, depending on emissions scenarios and climate model (Döll, 2002; Döll et al., 2003). Different climate models project different worldwide changes in net irrigation requirements, with estimated increases ranging from 1–3% by the 2020s and 2–7% by the 2070s. The largest global-scale increases in net irrigation requirements result from a climate scenario based on the B2 emissions scenario. The increase in household water demand (for example through an increase in garden watering) and industrial water demand, due to climate change, is *likely* to be rather small, e.g., less than 5% by the 2050s at selected locations (Mote et al., 1999; Downing et al., 2003). An indirect, but small, secondary effect would be increased electricity demand for the cooling of buildings, which would tend to increase water withdrawals for the cooling of thermal power plants. A statistical analysis of water use in New York City showed that daily per capita water use on days above 25°C increases by 11 litres/°C (roughly 2% of current daily per capita use) (Protopapas et al., 2000). Table 1 presents future water demand under different sectors in various countries.

From the above discussions it is further concluded that the climate change will increase water demand. It will:

- Increase water demand for agriculture, primarily for irrigation, due to prolonged dry periods and severe drought. Some research estimates an over 40 percent increase in land needing irrigation by 2080.
- Increase water demand for hydration needs for billions of farm animals due to higher atmospheric temperatures.
- Increase quantities of water needed for industrial cooling due to increased atmospheric and water temperatures

Water Supply and Demand
1990 - 2025

Country	Population		Annual Water Resources (km^3)	1990 Total With-drawals (km^3)	Per Capita Water Withdrawals - 1990			Per Capita Water Withdrawals - 2025				2025 Total D&I Withdrawal Km^3	1990 Total Irrigation Withdrawal km^3	2025 S1 Total Irrigation WD (km3)	2025 S2 Total Irrigation WD (km3)	2025 S2 Total Withdrawal (km^3)	Add'l Withdrawal in 2025 (km^3)
	1990 (millions)	Growth 1990-2025 (%)			Domestic (m^3)	Industrial (m^3)	Irrigation (m^3)	Domestic (m^3)	Industrial (m^3)	Irrigation S1 (m^3)	Irrigation S2 (m^3)						
Central Asia																	
Kazakhstan																	
Kyrgyzstan																	
Tajikistan																	
Uzbekistan																	
East Asia																	
China	1,155.0	132%	2,800.0	533.0	28.0	32.0	401.0	46.0	38.0	401.42	261.71	126.0	463.0	612.0	399.0	527	0
Korea (Rep. of)	42.9	127%	66.1	27.1	120.0	221.0	291.0	126.0	221.0	290.00	145.00	18.9	12.5	15.8	7.9	26.8	0
Mongolia																	
Pacific																	
Fiji																	
Marshall Islands																	
Micronesia																	
Papua New Guinea																	
Solomon Islands																	
Vanuatu																	
Southeast Asia																	
Cambodia	8.8	223%	498.1	0.8	3.0	1.0	80.0	6.0	1.0	81.15	35.87	0.2	0.5	1.2	0.7	0.8	0.3
Indonesia	182.5	151%	2,530.0	17.5	12.0	11.0	73.0	25.0	21.0	72.82	41.66	12.7	13.3	20.1	11.5	24.2	6.7
Laos																	
Malaysia	17.9	176%	456.0	13.7	177.0	230.0	381.0	177.0	230.0	381.86	190.93	12.9	6.5	11.4	5.7	18.6	4.5
Myanmar	41.8	181%	1,082.0	4.2	7.0	3.0	91.0	16.0	6.0	91.20	50.23	1.5	3.8	6.9	3.8	5.4	1.1
Philippines	60.6	172%	323.0	41.7	123.0	144.0	418.0	123.0	144.0	417.88	209.42	28.0	25.4	43.7	21.9	49.8	8.1
Singapore	2.7	124%	0.6	0.2	41.0	43.0	-	82.0	86.0	-	-	0.6	-	-	-	0.6	0.3
Thailand	55.6	132%	179.0	33.8	24.0	38.0	542.0	48.0	72.0	543.66	284.77	6.9	30.1	39.9	20.9	29.7	0
Viet Nam	66.7	177%	376.0	27.6	54.0	37.0	323.0	54.0	37.0	323.57	172.79	10.8	21.6	38.2	20.4	31.2	3.6
South Asia																	
Afghanistan	15.0	301%	65.0	25.8	102.0	34.0	1,566.0	102.0	1.0	1,570.32	1,570.32	4.7	23.6	70.9	70.9	75.5	49.9
Bangladesh	108.1	181%	2,357.0	23.8	7.0	2.0	211.0	13.0	4.0	211.59	108.31	3.5	22.8	41.4	20.8	24.2	0.4
Bhutan																	
India	851.0	164%	2,085.0	518.0	18.0	24.0	569.0	28.0	24.0	567.48	376.17	73.0	484.0	792.0	525.0	598	80
Maldives																	
Nepal	19.3	211%	170.0	2.9	6.0	2.0	143.0	12.0	3.0	142.43	117.87	0.2	2.7	5.8	4.8	5.4	2.5
Pakistan	121.9	234%	418.3	155.7	28.0	28.0	1,226.0	28.0	28.0	1,224.21	991.07	14.5	149.0	349.2	282.7	297.3	141.6
Sri Lanka	17.2	145%	43.2	8.7	10.0	10.0	483.0	20.0	20.0	485.16	292.70	1.0	8.3	12.1	7.3	9.3	0

Source: International Water Management Institute

Table 1 presents future water demand under different sectors in various countries

Climate Change and Water quality

There is no doubt that water and sustainable development are inextricably linked. Once viewed as an infinite and bountiful resource, water today defines human, social, and economic development. Perhaps the most critical near- and long-term threat is the possible impacts of climate change on water quality and availability (Meehl 1996, East-West Center 2001). Higher water temperatures and changes in extremes, including floods and droughts, are projected to affect water quality and exacerbate many forms of water pollution –from sediments, nutrients, dissolved organic carbon, pathogens, pesticides and salt, as well as thermal pollution, with possible negative impacts on ecosystems, human health, and water system reliability and operating costs (*high confidence*). This will promote algal blooms (Hall et al., 2002; Kumagai et al., 2003), and increase the bacterial and fungal content (Environment Canada, 2001). This will, in turn, impact ecosystems, human health, and the reliability and operating costs of water systems.

A climate-related warming of lakes and rivers has been observed over recent decades. As a result, freshwater ecosystems have shown changes in species composition, organism abundance, productivity and phenological shifts (including earlier fish migration). Also due to warming, many lakes have exhibited prolonged stratification with decreases in surface layer nutrient concentration, and prolonged depletion of oxygen in deeper layers. Rising temperatures are likely to lower water quality in lakes through increased thermal stability and altered mixing patterns, resulting in reduced oxygen concentrations and an increased release of phosphorus from the sediments. For example, already high phosphorus concentrations during summer in a bay of Lake Ontario could double with a 3–4°C increase in water temperature (Nicholls, 1999). However, rising temperatures can also improve water quality during winter/spring due to earlier ice break-up and consequent higher oxygen levels and reduced winter fish-kill. More intense rainfall will lead to an increase in suspended solids (turbidity) in lakes and reservoirs due to soil fluvial erosion (Leemans and Kleidon, 2002), and pollutants will be introduced (Mimikou et al., 2000; Neff et al., 2000; Bouraoui et al., 2004). The projected increase in precipitation intensity is expected to lead to a deterioration of water quality, as it results in the enhanced transport of pathogens and other dissolved pollutants (e.g., pesticides) to surface waters and groundwater; and in increased erosion, which in turn leads to the mobilisation of adsorbed pollutants such as phosphorus and heavy metals. In addition, more frequent heavy rainfall events will overload the capacity of sewer systems and water and wastewater treatment plants more often. An increased occurrence of low flows will lead to decreased contaminant dilution capacity, and thus higher pollutant concentrations, including pathogens. In areas with overall decreased runoff (e.g., in many semi-arid areas), water quality deterioration will be even worse. In semi-arid and arid areas, climate change is likely to increase salinisation of shallow groundwater due to increased evapotranspiration. As streamflow is projected to decrease in many semi-arid areas, the salinity of rivers and estuaries will increase. For example, salinity levels in the headwaters of the Murray-Darling Basin in Australia are expected to increase by 13–19% by 2050 (Pittock, 2003). In general, decreased groundwater recharge, which reduces mobilisation of underground salt, may balance the effect of decreased dilution of salts in rivers and estuaries. In coastal areas, rising sea levels may have negative effects on storm-water drainage and sewage disposal and increase the potential for the intrusion of saline water into fresh groundwater in coastal aquifers, thus adversely affecting groundwater resources. For two small and flat coral islands off the coast of India, the thickness of freshwater lenses was computed to decrease from 25 m to 10 m and from 36 m to 28 m, respectively, for a sea-level rise of only 0.1 m (Bobba et al., 2000). Any decrease in groundwater recharge will exacerbate the effect of sea-level rise. In inland aquifers, a decrease in groundwater recharge can lead to saltwater intrusion from neighboring saline aquifers (Chen et al., 2004).

In addition, sea-level rise is projected to extend areas of salinisation of groundwater and estuaries, resulting in a decrease of freshwater availability for humans and ecosystems in coastal areas.

Water erosion and sedimentation

Various studies on soil erosion show that the expected increase in rainfall intensity would lead to greater rates of erosion. In addition, the shift of winter precipitation from less erosive snow to more erosive rainfall due to increasing winter temperatures enhances erosion, with this leading, for example, to negative water quality impacts in agricultural areas. The melting of permafrost induces an erodible state in soil which was previously non-erodible. Further indirect impacts of climate change on erosion are related to soil and vegetation changes caused by climate change and associated adaptation actions. The very few studies on the impact of climate change on sediment transport suggest transport enhancement due to increased erosion, particularly in areas with increased runoff. It is concluded that climate change will impact water quality. It will:

- Increase extreme precipitation and flooding, which will increase erosion rates and wash soil based pollutants and toxins into waterways.
- Contaminate coastal surface and groundwater resources due to sea level rise, resulting in saltwater intrusion into rivers, deltas, and aquifers.
- Increase water temperatures, leading to more algal and bacterial blooms that further contaminate water supplies.
- Contribute to environmental health risks associated with water. For instance, changes in precipitation patterns are likely to increase flooding, and as a result mobilize more pathogens and contaminants. It is estimated that by 2030 the risk of diarrhea will be up to 10 percent higher in some countries due to climate change.

RESEARCH AND DEVELOPMENT REQUIRED

Important area for research and development is the "Climate changes and water resources", to study and minimize the impact of climate change on water demand and water quality may classified under the following topics:

(a) to study impact of climate change on water resources

(b) to study the efficacy for various measures for mitigating the impact of the projected changes in the water resources

(c) to study changes needed in policy & planning and management practices to optimally utilize the resources; and

(d) to chalk out adaptation measures, their impacts and efficacy.

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