Climate Change, Its Impact on Water Resources and Adaptation Strategies

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United Nations Framework Convention on Climate Change (UNFCCC) defines “climate change” as: “a change of climate which is attributed directly or indirectly to human activities that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.”

General Definition: Any systematic change in the long-term statistics of climate elements (such as temperature, pressure, or winds) sustained over several decades or longer.

Climate Change

- Increasing Temperatures
  - Global Warming; Greenhouse Effect
- Change in Precipitation Patterns
- Change in patterns of other climatological variables

Impact of Climate Change on Hydrological Cycle...

- Change in spatial and temporal pattern of precipitation
- Change in evapotranspiration
- Change in natural recharge pattern
- Change in runoff pattern
Climate Change & Runoff

- Runoff influenced by precipitation, evaporation and soil moisture.
- High-latitude regions may see more runoff due to greater precipitation.
- Tropics and subtropics regions are expected to receive less runoff.
- This coincides with the existing water stress in tropical and subtropical regions.

IPCC 2001

Consequences of Climate Change

- Temporal and spatial water availability may be affected (SW and GW).
- Frequent occurrence of Flood and Drought (Intensity, Frequency and Magnitude).
- Increase in Glacier retreat rates.
- Reduction in snow precipitation.
- Due to sea level rise, problem of sea water intrusion in coastal areas.

Climate Related Disasters

GLOF

A glacial lake outburst flood (GLOF) can occur when a lake contained by a glacier or a terminal moraine dam fails. The breasting of moraine-dammed lakes is often due to the breaching of the dam by the erosion of the dam material as a result of overtopping by surging water or piping of dam material.

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<table>
<thead>
<tr>
<th>S.No</th>
<th>Basin</th>
<th>No of Glacial Lakes</th>
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<tbody>
<tr>
<td>1</td>
<td>Tons</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>Yamuna</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>Bhagirathi</td>
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</tr>
<tr>
<td>4</td>
<td>Bhilangana</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Mandakini</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>Alaknanda</td>
<td>43</td>
</tr>
<tr>
<td>7</td>
<td>Pinder</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Goriganga</td>
<td>10</td>
</tr>
<tr>
<td>9</td>
<td>Bhagirathi</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>Kedarnath</td>
<td>4</td>
</tr>
<tr>
<td>11</td>
<td>Beas</td>
<td>59</td>
</tr>
<tr>
<td>12</td>
<td>Chenab</td>
<td>33</td>
</tr>
<tr>
<td>13</td>
<td>Satluj</td>
<td>40</td>
</tr>
<tr>
<td>14</td>
<td>Kavli</td>
<td>17</td>
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<tr>
<td>15</td>
<td>Taksilinga</td>
<td>7</td>
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<tr>
<td>16</td>
<td>Teesta</td>
<td>266</td>
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The adaptation and mitigation process of the GLOFs can be broadly categorized in the following manner:

- Creation of a decentralised information system that includes identification of areas most at risk etc., monitoring and early warning (and prediction) and support to decision makers in terms of policy recommendations on adaptation options etc. This will include the information sharing and experiences dissemination about the early warning and adaptation measures for the GLOF events at the local and national levels.
- Development and testing of adaptation and mitigation measures, such as land use planning for GLOFs, siphoning, pumping, excavation of a channel, etc.
- Building capacity of national, district and local institutions to access and use this information and measures as well as to provide information on local indicators/measurements, which would make the system more interactive and easy to update.

Sea Level Rise

Current sea level rise has occurred at a mean rate of 1.8 mm per year for the past century, and more recently at rates estimated near 2.8 ± 0.4 to 3.1 ± 0.7 mm per year (1993-2003).

[Sea Level Rise Graph]

[Image of GLOF event]
Impacts on coastal areas

- Coastal erosion and inundation of coastal lowland as sea level continues to rise, flooding the homes of millions of people living in low lying areas
- In India, potential impacts of 1 m sea-level rise include inundation of 5,763 km²
- Significant losses of coastal ecosystems, affecting the aquaculture industry, particularly in heavily-populated mega-deltas

Impacts on human health

Endemic morbidity and mortality due to diarrheal disease primarily associated with floods and droughts

Exacerbation of the abundance and toxicity of cholera due to increase in coastal water temperature

Increased deaths, disease and injury due to heat waves, floods, storms, fires and droughts

National Issues of Interest

- Water availability
  - How do water fluxes vary on catchment scale in response to global climate events?
  - Impacts on Water Quality
  - Water Demands
  - Crop Evapotranspiration

- Association of Hydrologic Extremes of Floods and Droughts with Large Scale Global Climate Events

  - Change in Frequency and Magnitude of extreme events
  - Impact of year to year variation of the Monsoon will continue to be dominant even in the presence of global warming

GLOBAL CLIMATE CHANGE OVER LAST CENTURY

IPCC (2007) indicated that the average global surface air temperature increased by 0.74±0.18°C since the late 19th century. The linear warming trend over the last 50 years (0.13°C per decade) is twice that for the last 100 years.
GLOBAL CLIMATE CHANGE OVER LAST CENTURY

- The extent of snow cover decreased by 10% since 1960s.
- The area extent of glacierization in the European Alps reduced by 30-40%, whereas the volume of ice reduced by nearly 50%.
- Global average sea level rose at 1.8 mm per year between 1961 and 2003. The total 20th Century sea level rise estimated to be 0.17 m.

TRENDS OF CLIMATE CHANGE IN INDIA

**Temperature**

- The trend and magnitude of global warming over Indian sub-continent over last century has been consistent with the global trend and magnitude.
- Warming is mainly observed during the post-monsoon and winter seasons.
- Mean annual air temperature rose at 0.57°C per 100 years during 1881-1997. (IITM, 2004)

**Rainfall**

No clear trend in average annual rainfall over the country
Mathematical Modelling for Prediction of Climate Change and its Impact on Water Resources

- Global Circulation Models (GCM)
- Downscaling of GCM Climate Output for use in Hydrological Modeling on basin/catchment scale
- Application of Hydrological Models for making future predictions
  - Uncertainty Analysis

The Dokriani Glacier (Central Himalayas)

- Total drainage area up to the gauging site ~ 16.13 km²
- 9.66 km² (60%) is covered by snow and ice.
- Elevation range - 3950-5800 m.
- Length ~ 5.5 km, Width ~ 0.1-2.0 km.
- Maximum glacier area (12.86%) lies in 5000-5100 m range and 12.44% in the 5100-5200 m.

Physical Characteristics

Simulation of hydrographs for ablation periods of 1997 and 1998 with different components of runoff.
CONCLUSIONS

The contribution of glacier melt and rainfall in the runoff is 87% and 13%, respectively. For a temperature rise of 2°C, the increase in summer stream-flow would be about 28%.

- The steeper slope of flow duration curves indicated that streamflow is fed by direct runoff and there is negligible amount of storage in the basin.
- Also there is marked variability in flows because of rise in temperature.

The flow currently exceeded 60% of the time (3.2 m³/s in 1998) would be exceeded 70% of the time under a warming of 2°C.

- Temperature has greater influence than rainfall on water availability
- Under different rainfall scenarios - rainfall influences low flows more in comparison to high flows

Chenab Basin Study
Elevation of the study area ~ 305 m to 7500 m.
Mean elevation of the basin ~ 3600 m.s.l.
Total catchment area up to Akhnoor ~ 22,200 km².
Total Number of Glaciers is 989.
Glacierized Area is 2280 sq km.
In general, the timing of peak streamflow is not affected; however, there is a change in the magnitude of peak streamflow, depending upon the spring melting conditions.

It also indicates that no significant change in the winter streamflow could be produced for this basin.


Changes in streamflow for all the seasons are linearly related to the increase in temperature. The maximum increase in streamflow is computed to be in pre-monsoon (snowmelt season).

A larger increase in the pre-monsoon season is due to higher amount of snow/ice melt runoff under a warmer climate.

Changes in distribution of melt runoff were more pronounced during the summer months; a decrease of about 10% runoff for a temperature increase by 2°C, annual decrease is about 5%.

The Sutlej River Basin

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Adaptation issues in water resources sector

- Hydrological Design Practices
- SW and GW resources assessment (Basin Scale)
- Water resources planning
- SW and GW resources Development
- Operation Policies including real time operations of existing as well as proposed water resources projects
- Flood and Drought Management (Short term and Long term strategies)
- Cropping pattern and water demands for irrigation
- Water Demand Management in different sectors
- Water Use efficiency
- Groundwater Management in coastal areas
- Evacuation and rehabilitation
CLIMATE CHANGE ISSUES AND NATIONAL WATER MISSION

National Water Mission – objective
Conservation of water, minimizing wastage and ensuring its more equitable distribution both across and within States through integrated water resources management.

National Water Mission – identified goals
- Ensure basin level management
- Increase water use efficiency by 20%
- Optimize efficiency of irrigation systems
- Expand irrigation, wherever feasible

National Water Mission – identified goals (Contd.)
- Meet considerable share of water needs of urban area through recycling of wastewater
- Adopt desalination techniques for coastal cities with inadequate alternative source of water
- Promote water neutral and water positive technologies

National Water Mission – activities identified in technical document
- Studies on management of surface water resources
- Management and regulation of GW resources
- Upgrading storage structures for fresh water and drainage systems for waste water
- Conservation of wetlands
- Development of desalination technologies

Mission Document – strategies and action plan
- Reliable assessment of impact of climate change on water resources
- Basin level planning and management
- Increasing water use efficiency by 20%
- Optimize efficiency of irrigation systems
- Expand irrigation, where ever feasible
Mission Document – strategies and action plan (Contd.)

- Recycling of water
- Adoption of desalination techniques
- Promote water neutral and water positive technologies
- Other important action points like awareness programme, review of acceptability/design criteria etc.

Actions/studies being taken (MOWR)

- Establishment of Climate Change Cells in CWC, NIH, BB, CGWB to give impetus to R&D
- Establishment of Chair Professors in six academic Institutions viz., IIT, Roorkee, Kanpur, Guwahati, Kharagpur and NIT, Srinagar and Patna.
- Preparation of report “Preliminary Consolidated report on Effects of Climate Change on Water Resources

NIH- NODAL AGENCY

Strategy 1.5
Research and studies on all aspects related to impact of climate change on water resources including quality aspects of water resources with active collaboration of all research organizations working in the area of climate change

Nodal Agency: NIH

<table>
<thead>
<tr>
<th>Research area</th>
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<tbody>
<tr>
<td>1. Basin efficiency</td>
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<tr>
<td>2. Possibilities of increasing dam heights</td>
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<tr>
<td>3. Identification of minor tanks where FRL can be raised without raising dam heights by installing gates and evaluation of the same</td>
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<tr>
<td>4. Identification of tanks and water bodies which can be effectively de-silted, where silt has commercial value and evaluation of the same</td>
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<tr>
<td>5. Improving intra-national equity in usable water for drought management like conducting economics considering land, water and livelihood to plan how much water is necessary to yield reasonable income</td>
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<td>6. Water harvesting, provided this is socially desirable and provided that corresponding water saving is possible elsewhere in the region</td>
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<td>7. Impact on Intensity-Duration-Frequency relationships in urban areas</td>
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Nodal Agency: NIH

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<tr>
<td>8. Impact on Magnitude-Duration-Frequency of drought (agricultural, meteorological and hydrological)</td>
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<td>9. Study of Water-energy-Climatic Change relationships</td>
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<tr>
<td>10. Planning tidal embankments to protect against tides and increased flood frequency and increased sea level</td>
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<tr>
<td>11. Effect of sea level rise on ground water salinity and prospective measures like groundwater recharge</td>
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<tr>
<td>12. Possible tidal channels for fresh water storage</td>
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<tr>
<td>13. Preparation of sediment budgets and accounts for each basin</td>
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<td>14. Review the interpretation of regime maintenance on Ganga, after climate change</td>
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<td>15. Isotope applications in GW dating and contaminant transport</td>
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<tr>
<td>16. GW basin models for conjunctive use of SW &amp; GW and application of R/GIS in GW management</td>
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<tr>
<td>17. Assessment and strategies for development potential of deeper aquifers</td>
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<tr>
<td>18. Coastal aquifer management including use of hydraulic barriers for control of sea water ingress</td>
</tr>
<tr>
<td>19. Assessment of feasibility and viability of rainwater harvesting in existing domestic and commercial buildings</td>
</tr>
<tr>
<td>20. Atmospheric Science Groups towards downscaling of GCM or RCM to basin/project level and also understanding the effect of climate change on monsoons</td>
</tr>
<tr>
<td>21. Supporting water and climate related researches towards studying the sensitivity of different hydrologic types of water projects to different climate change scenarios and improvements required in hydrometric networks to incorporate climate change</td>
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**NODAL AGENCY: NIH**

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<thead>
<tr>
<th>Research Area</th>
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<tbody>
<tr>
<td>22 Building a Universal Soil Loss model depicting erosion and sediment transport etc. Proving the model based on sediment flow and reservoir sedimentation data. Actuating the above model for changed rainfall regime and changed management practices.</td>
</tr>
<tr>
<td>23 Developing, through R&amp;D effort, a combined unsteady flow hydraulics-cum-sediment transport model capable of depicting river erosion in each flood event. Using the model to test river management works.</td>
</tr>
<tr>
<td>24 Water quality modelling for each major river and aquifer, and</td>
</tr>
<tr>
<td>25 Hydrochemical and solute transport modelling in areas vulnerable for seawater ingress and water quality problems.</td>
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**CONCLUDING REMARKS**

- Better observational data and data access
- The development of indicators of climate change impacts on freshwater, and operational systems to monitor them
- There remains a scale mismatch between the large-scale climatic models and the catchment scale
- Impact studies of climate change at the monthly or higher temporal resolution scale is desirable rather than only on annual scale
- The impact of climate change on snow, ice and frozen ground considering non-linear and physically- and process-based hydrological models coupled with the downscaled output of atmospheric models.

**CONCLUDING**...

- Develop local scale data sets and simple climate-linked computerized watershed models.
- Climate change impacts on water quality are poorly understood.
- Groundwater has received little attention in climate change impact assessment compared to surface water resources.
- Adaptation processes and methods which can be usefully implemented in the absence of accurate projections, such as improved water-use efficiency and water-demand management, offer no-regrets options to cope with climate change.
- An integrated approach is needed, given the diversity of interests to arrive at sustainable solutions.
- R&D studies are needed for the identified thrust Areas under National Water Mission to achieve the envisaged objectives and goals.

*Gandhi was once asked if he expected India to attain the same standard of living as Britain. He replied:*

*It took Britain half the resources of the planet to achieve this prosperity. How many planets will a country like India require!*