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Impact of Climate Change on Water Resources

IWME 502

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Section 1: INTRODUCTION

One of the more important questions in hydrology is: if the climate warms in the future, will there be an intensification of the water cycle and, if so, the nature of that intensification? An intensification of the water cycle may lead to changes in water-resource availability, an increase in the frequency and intensity of tropical storms, floods, and droughts, and an amplification of warming through the water vapor feedback [1]. There is a general consensus that global average surface air temperature increased during the 20^{th} century. There is expectation that climate warming will result in an increase in evaporation and precipitation. The theoretical basis for this intensification is summarized in the Clausius– Clapeyron relation that implies that specific humidity would increase approximately exponentially with temperature. Tropical storms, floods, and droughts can affect human welfare directly through catastrophic damage or indirectly through adverse effects on crop productivity. Such threats are likely to occur disproportionately in developing countries with the fewest resources for mitigation and adaptation [1].

The effects of climate change is multi-scale, all-round, multi-level, both positive and negative effects. Climate change not only affects the hydrological, biological and ecological system, but also affects the economy. According to the Intergovernmental Panel on Climate Change (IPCC AR5, 2014), the global mean temperature may increase up to 4 °C by 2100 and will severely affect the availability of water resources and the water demand across the world. Climate change will change water quality due to change in temperature and rainfall and will redistribute water resources in time and space.

This report attempts to present a technical review of the scientific work done to assess the impact of climate change on our water resources. All the research work that has been covered under this study has been mentioned in the Reference section. The report is comprised of nine major sections. Introduction is followed by Relation between Climate & Water Resources, then few research methods will be highlighted that are used to assess the impact of CC (Climate Change) on Water Resources. The rest of the report will cover a few examples & comparisons, uncertainties in the process and strategies to adapt to this change. This will be concluded by highlighting some of the major issues and positive effects of climate change.

Section 2: RELATION BETWEEN CLIMATE & WATER RESOURCES

The climate system directly or indirectly affects the process of water circulation by precipitation, temperature, sunlight, wind, humidity and other factors. Increased intensities of precipitation will lead to higher rates of surface runoff, an increased risk of flood and decreased rates of groundwater recharge. Rise in temperature causes higher evapotranspiration, and, in turn, further enhances the demand for irrigation water, by far already the biggest water consumer under present conditions.

The effect of climate change on water resources is because of the water and water quality changes that caused by climate factors (mainly includes rainfall and temperature changes). And it is achieved by the changes of the various water cycle links. Climate change will change the world of the present situation of the hydrologic cycle. It also will have a direct effect on the evaporation, runoff, the soil humidity and so on. [2]
This relationship as shown in fig 1

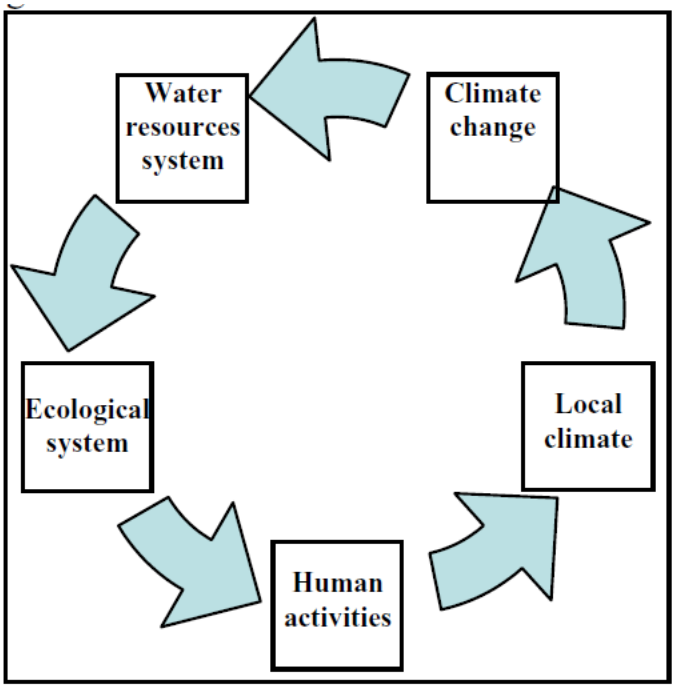

Figure 1: Cycle Diagram of Climate Change impacts

The impact of climate change on water resources have developed many researches on internal and external. In order to speed up the research, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) jointly set up the Intergovernmental Panel on Climate Change (IPCC) in 1988.The IPCC is specialized in evaluation of climate change, and it have completed five assessment report in 1990, 1995, 2001 and 2007 and 2015 [3].

Section 3: RESEARCH METHODS

The research of the impact of climate change on hydrology and water resources system is mainly through the basin temperature, precipitation and evaporation change caused by climate change such as to predict the trend may increase or decrease the runoff and its watershed water supply influence. Using the “what-if-then” pattern which assume that a change climate scenario as the hydrologic model input to find out each component in the water cycle in the change of scene [2]. The pattern often includes the following 4 steps:

(1) Define climate change scenarios;
(2) Establish, verification of hydrologic model;
(3) Make the climate change) hydrologic model of the scene as input and simulate the change process of internal water circulation;
(4) Using the simulation results of the hydrologic model to evaluate the climate change on the influence of hydrology and water resources.

Using the what-if-then model to find climate change on the influence of hydrology and water resources in river basin, climate change scene generation technology and hydrological model is the key to impact assessment.

The word “scenario” to describe the future climate change state. The “scenario” refers to predict or expectations the outline or pattern of a series of events, which describe the choose scene that what would the future like and is a kind of suitable tools that analysis of various factors driving how to affect future emissions and assessment of the related results of the uncertainty. Time series analysis methods is through the analysis of hydrological elements of the long history of climate data like temperature and precipitation, runoff series in statistical, and project the future climate scenarios. Global Climate Model is the most commonly used methods in exploring climate change influence on hydrology and water resources. The frequently-used GCMS including the United States Koda space research institute mode, the UK met office's mode, the United States Oregon state university mode, American geophysical fluid dynamics experimental mode, the Colorado State University mode, etc [2].

SECTION 4: EXAMPLES & COMPARISON

Example 1: Koshi River Basin, Nepal

The mean annual temperature of Nepal is expected to increase by 1.4◦C by 2030, 2.8◦C by 2060. Increased temperature leads to greater evaporation and thus surface drying which thereby increases the intensity and duration of drought. The water holding capacity of air increases by about 7% per 1◦C warming which leads to increased water vapor in the atmosphere. It consequently, produces more frequent and intense precipitation events. Frequent and intense extreme climate and weather events will lead to increasing climatic variability that significantly increases the intra-annual variability of stream flow. Developing countries are more vulnerable to extreme weather events under present day climatic variability which causes substantial economic damage.

Study Goal: To assess changes in the hydrological regime of the Koshi River Basin with & without climate change using the Soil and Water Assessment SWAT Tool

Study Region: Study focused on the middle hilly part of the basin. Because this region is a high rainfall receiving zone, rainfall-runoff (hydrologic simulation) study was carried out to assess the impact of the climate change on the hydrology.

Flow: Combination of snow melt runoff and rainfall
Feature: high rainfall receiving zone. The SWAT model was employed to assess the impact on the basin hydrology, and the Snow Runoff Model (SRM) for quantifying the boundary flows from the Himalayan region. [4]

Findings:
Comparison of the annual average flows between the historical data and future flows, show a slightly decreasing trend of about 15 m3/s per year. [4]

The study found that climate change is less likely to pose the threat on average water availability in the Koshi River Basin. Temporal variation in river flows is expected to increase in the future. Most of the flow is decreasing during the lean season and increasing during the high flow season.

It was concluded that any design based on a 100-year design flood flow (57,900 m3/s) may need to be changed to a design flood flow for a return period of more than 1000 years, when based on historical data (47,445 m3/s), in order to account for the impact of climate change [4]. The results in this study furthermore show that the 10,000-year return flood may occur on average every 500 years in the future [4].

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Comparison: Thames River Basin, Canada

The impact of climate change in a given basin depends on the land-use in the specific basin. Das and Simonovic (2012) conducted a study to assess the impact of climate change to assess in the upper Thames River Basin of Canada using the results of fifteen different climate models for the future conditions in 2020, 2050 and 2080.They stated that the 100-year and 250-year flood magnitudes were found to be respectively 12% and 32% higher than for the baseline period (1979–2005) with negligible impact for the 10-year return period. It indicates that the magnitudes of flood flow increase under climate change impact, with higher changes for higher return periods. [5]

Example 2: Impact of climate change on water resources of upper Kharun catchment in Chhattisgarh, India

Hydrological model used in this study is Soil and Water Assessment Tool (SWAT). It is expected that the impacts of future climate change will be severe in the UKC, because its economy largely depends on agriculture. It is evident that the amount of rainfall is significantly high in monsoon season compared to the rest of the months. Hence, a small percent change in water balance components in monsoon season represents a big change in the magnitude of water balance components whereas a big percentage change in rest of the season will reflect a small change in amount [6].

Goal: Assess impact on water balance component
Flow: Dependent on Monsoon Rain
Feature: Severe Water Stress, Core of Agro-economy
Simulations: SWAT Soil and Water Assessment Tool

Finding: Indicate over-proportional runoff-rainfall and under-proportional percolation rainfall relationships. [6]
Discharge (m3/s): For the 2020s, simulation results show an average annual decrease by 2.9% and for the 2050s results show an average annual increase by 12.4% (range from 17.6% decrease (q1) to a 39.4% increase (q0)).
Surface runoff (mm): For the 2020s, surface runoff shows an average annual decrease by 0.7% (in the range of 28.8% decrease (q1) to 26.8% increase (q0)). For the 2050s, the projections lead to an average annual increase by 14.6% .
Percolation: For the 2020s, average annual percolation is found to decrease by 0.8% (in the range of 12.8% decrease to 8.7% increase) compared to the baseline. Projections for the 2050s show an average annual increase by 2.5%

Actual Evapotranspiration: For the 2050s and 2080s, the projections show an increasing trend of 3.1% to 7.4%

Groundwater contribution to streamflow (mm): For the 2020s, annual groundwater contribution to

streamflow is in the range of 7.0% decrease to 14.7% increase (with an average annual increase by 1.5%). The simulations for the 2050s predict 13.3% decrease to 64.7% increase (with an average annual increase by 16.9%),

Water yield mm: annual water yield is in the range of 26.0% decrease to 23.8% increase (with an average annual decrease by 2.5%) for the 2020s. For the 2050s, a 17.4% decrease to 39.9% increase is simulated (with an average annual increase by 12.8%),

As the simulation results lead to an increasing runoff coefficient with an increasing rainfall, a rather high increase in discharge can be expected which will enhance the risk of floods in low lying areas, whereas the recharge (via percolation) remains nearly constant. [6]

Comparison:

Guhathakurta and Rajeevan (2008) performed monthly rainfall observations for linear trends across 36 climatological regions (representing different parts of India) during the period 1901–2003. [7]

Goal: Monthly rainfall observations for linear trends across 36 climatological regions (representing different parts of India) during the period 1901–2003

Findings: 8 regions showed significant increases. Any change in the climate would have a significant impact on the agricultural production.

Other Issues: Stress due to high population growth rates and problems related to water resources management

Climate Change on Water Resource Management of the Peribonka River System Canada

For the Peribonka water resource system, Quebec, Canada, the tendency is for a reduction in mean annual hydropower production and an increase in spills, despite an increase in the annual average inflow to the reservoirs. In general, the projections indicate an increase in annual inflow earlier peaks and greater volumes during the spring flood. The analyses show that a power plant managed with a reservoir is sensitive to the operating rules and that these rules should be re-examined to take account of new seasonal hydrological contexts. All the projections suggest increases in temperature and precipitation. [8]

SECTION 5: UNCERTAINITIES

There are uncertainties everywhere in modelling and acknowledging them is important. Uncertainty is related to the inaccurateness of humanly devised models and research tools to describe and represent the reality. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2014) defines uncertainty as a lack of complete information, as well as incomplete knowledge or disagreement on what is known and knowable. There are external climate drivers, such as the solar radiation, the Earth’s orbit, volcanic eruptions, collisions of celestial bodies with the Planet, properties of the atmosphere (therein atmospheric concentrations of greenhouse gases, GHGs) and land surface.

Uncertainty can be involved in the input data (due to data scarcity, measurement errors, lack of representativeness of the measurement site, or problems in aggregating or disaggregating data in order to cover areas of concern). Uncertainty can be inherent in the variables and their distributions, but also in uncertain model error resulting from selection of the form of the probabilistic sub models, the probability distribution, and the physical models, including empirical equations [9].

Uncertainty in projections of climate change impact on water resources is due to: (i) scenarios of future socio-economic development, (ii) GHG emission and sequestration scenarios, (iii) General Circulation Models, GCMs, (iv) Regional Climate Models, RCMs, or statistical downscaling methods, (v) choice of the bias correction method (if applied), (vi) input data for hydrological model(s), (vi) hydrological model(s) structure(s), and (viii) parameterization of hydrological model(s).

Uncertainty may be reduced by the act of obtaining more exact information by way of finding a relevant new fact, conducting additional observations or measurements. Critical problems are related to data availability and understanding of processes encapsulated in climate and hydrological models. The emerging availability of global datasets and remote sensing data enables model inter-comparisons and may lead to uncertainty reduction. Below is a framework for reducing uncertainty in assessment of climate change impact on water resources [9].

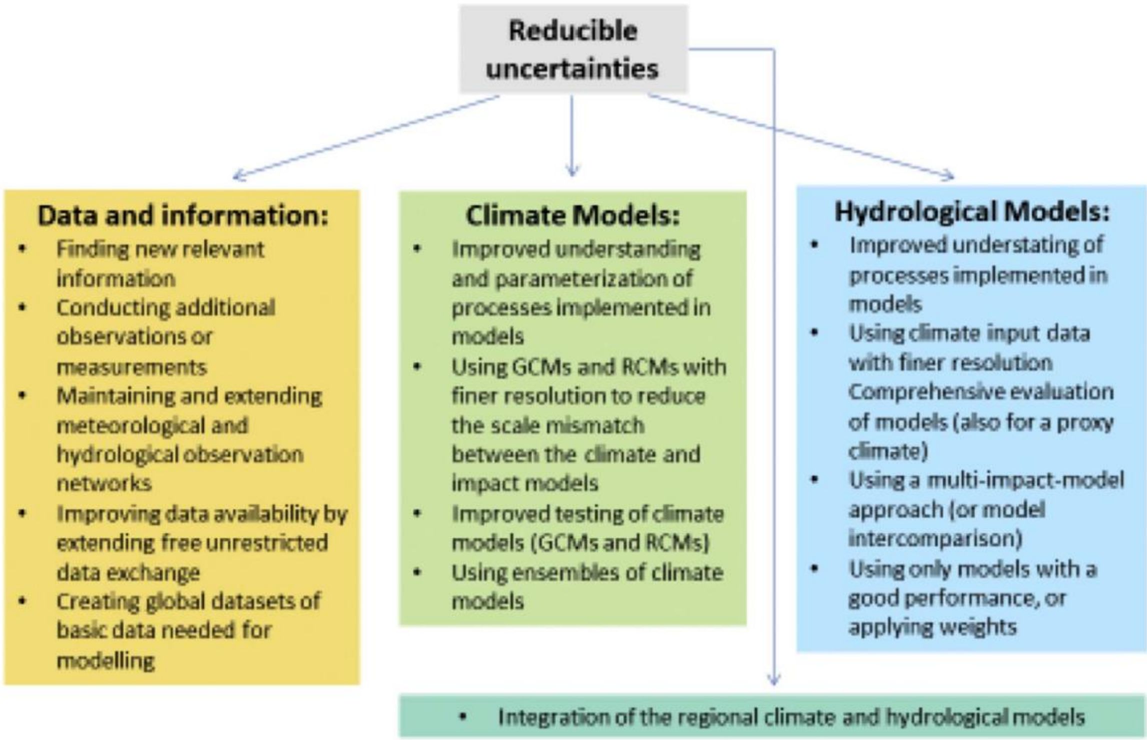

Figure 2: Framework for reducing uncertainty in assessment of impact of climate change on water resources

Climate impact assessments are usually being done by multiple model runs. Hence, the computational barrier, that used to hamper progress until quite recently, has been overcome. It is worth trying to reduce uncertainty by the use of open standards to share water information, such as the Open Water Data Initiative. Due to shortness and incompleteness of hydrological records, it is necessary to seek complementary data sources, in order to improve knowledge of past and ongoing system dynamics and to further our understanding of future situation, also in a context of climate change.

SECTION 6: ADAPTATION

- Using ensembles of climatic and hydrological models may allow to find more robust results, supported by several models, for some river basins or regions.
- Adaptive planning should be based on ensembles and multi-model probabilistic approaches rather than on an individual scenario and a single-value projection for the future.
- Irrigation of bioenergy crops and cooling technologies for electricity generation are among the most influential factors affecting future water demand in the context of climate change mitigation. [9]

- Intra-model uncertainty of projections (for the same model and different scenarios) can be lower than the inter-model uncertainty (for the same scenario and different models). [9]
- Development of water storage systems can be the strategies for climate change adaptation.
- Additional facilities and strategies to increase the storage capacity of the landscape should be considered. Concepts could combine technical facilities (reservoirs, infiltration sites) and land management practices towards enhancing landscape storage.
- Detailed consideration of the land use type, crop rotation and irrigation amount while estimating the impact of climate change is the option to conceive targeted recommendations on land use management which are appropriate to counterbalance the impact of climate change on the water balance.

SECTION7: ISSUES

- Climate models cannot be directly used in the realm of many real-world applications in the water management sector and infrastructure planning and design. [9]
- On the top of uncertainty related to future water availability, there is a considerable uncertainty about future water demand.
- The irregular distribution of precipitation in space also leads to notable disparities in water availability between different territories, aggravating the situation concerning water management.
- Uncertainty is essentially because anthropogenic greenhouse gas emission as well as some climate change effects and feedbacks cannot be predicted in a deterministic way [10].
- For climate change impact studies, uncertainty is linked to climate GCMs, GHGES, and natural variability and to the approaches and models used in realizing the impact study downscaling method, hydrological model, and its calibration. [9]

SECTION 8: POSITIVE EFFECTS

- Global agricultural productivity may increase during the first three degrees Celsius of warming, driven by gains in relatively wealthy high-latitude regions. [11] For example, decreasing ice could allow increased shipping through Arctic waterways, including the Northwest Passage.

- While a longer summer shipping season will generate more economic opportunities for Nunavut, it will also increase risks to the environment, most notably through spills and other pollution incidents. [12]

- The chief benefits of global warming include: fewer winter deaths; lower energy costs; better agricultural yields; probably fewer droughts; maybe richer biodiversity. It is a little-known fact that winter deaths exceed summer deaths — not just in countries like Britain but also those with very warm summers, including Greece. Both Britain and Greece see mortality rates rise by 18 per cent each winter. Especially cold winters cause a rise in heart failures far greater than the rise in deaths during heatwaves. [13]

- Another study shows that climate change from 2005 to 2050 in North Cameroon or Madagascar will have a positive effect on both cotton and rice yields. The predicted increase of 0.05 °C yr-1 in temperature will shorten crop cycles by 0.1 to 0.2 d yr-1 with no negative effect on yields. Moreover, the fertilizing effect of CO_2 enrichment will increase yields by approximately 30 to 50 kg ha-1. [14]

Good news is no news, which is why the mainstream media largely ignores all studies showing net benefits of climate change. Also, academics have not exactly been keen to push such analysis forward.

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