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Impact of Climate Change on Hydrological Cycle and Water Availability in India

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ABSTRACT

Climate change, driven by rising greenhouse gas levels, has profound regional consequences. Key impacts include shifts in the hydrological cycle, altered water availability, changes in agricultural production, and shifts in energy usage. A warming climate intensifies the hydrological cycle, increasing evaporation and liquid precipitation rates. These changes, combined with shifting precipitation patterns, disrupt water distribution, impacting runoff, soil moisture, and groundwater. This can lead to more frequent droughts and floods. By 2025, most of India's irrigated areas are expected to require more water, with global irrigation needs increasing by 3.5-5% by 2025 and 6-8% by 2075. To address these challenges, balanced assessment of climate scenarios is essential. Accurate appraisal of India's water resources is critical for sustainable planning, development, and utilization. A focused examination of regional agricultural systems is needed to identify adaptation options for climate-induced changes.

Key words: *Indian climate, Hydrological cycle, Balance approach, Mitigation strategies, Spatial and Temporal impacts.*

Introduction

India with 2.4% of the world's total area has 16% the world's population; but has only 4% of the total available fresh water. Its geographical area of 328.726 Mha is covered by a large number of small and big rivers. Over 70% of India's population of more than one billion is rural and agriculture oriented, for whom these rivers are the source of their livelihood and prosperity. Rainfall in India is mainly dependent on the south-west monsoon between June to September, and the north-east monsoon between October and November.

Did you know??

- 3.575 million people die each year from water related disease.
- 84% of water related deaths are in children ages 0-14.
- 98% of water related deaths occur in the developing world.
- 2.5 billion people lack access to improved sanitation, including 1.2 billion people who have no facilities at all.

What do you mean by Hydrological cycle: Continuous circulation of water between hydrosphere atmosphere and lithosphere. The mountains of southern

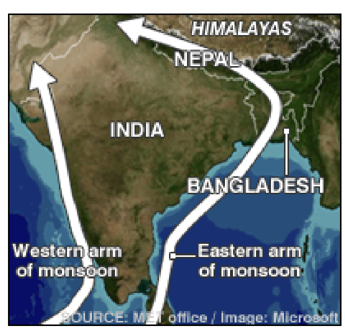

Fig. Flow of Wind in India

1. Assistant Professor

India split the summer winds. The western arm of the monsoon is deflected northwards, by the Western Ghats, to Mumbai and then on to Pakistan. The eastern arm travels up through the Bay of Bengal to Kolkata and Assam and is deflected north-westwards by the Himalayas. On average, the winds arrive in southern India about six weeks before they arrive in north-west India.

Thar desert and adjoining areas of the northern and Central Indian Sub continent heats up too much during summer. This causes a low-pressure area over the northern and central Indian subcontinent. To fill up this void, the moisture-laden winds from the Indian Ocean rush into the sub continent. These winds rich in moisture are drawn towards the Himalaya screating winds blowing storm clouds towards the subcontinent. The southwest monsoon is generally expected to begin around the middle of June and dies down by September.

How climate change effect water availability?

The hydrological cycle is intimately linked with changes in atmospheric temperature and radiation balance. Warmer climate may lead to intensification of the hydrological cycle, resulting in higher rates of evaporation and increase of liquid precipitation. Rising sea levels will also lead to salt water contamination of groundwater supplies, threatening the quality and quantity of freshwater access to large percentages of the population. Any adverse impact on water availability due to recession of glaciers, decrease in rainfall and increased flooding in certain pockets would threaten food security.

Effect of climate change on groundwater zones

Groundwater is directly affected by changes in the rate of precipitation and evapotranspiration. It is estimated that approximately 30% of global freshwater is present in the form of groundwater. Todd divided the groundwater occurrence in two zones – zone of aeration and zone of saturation.

The effect of climate change on both the zones has been discussed in the following

1. Zone of aeration
2. Soil water zone
3. Vadose zone
4. Zone of saturation

Soil water zone

This zone is important as it supports vegetation and all biogeochemical reactions. Climate change has an adverse effect on this zone. Higher temperature leads increased dryness in soils, resulting in severe droughts. The high precipitation promoting rapid soil erosion. Less infiltration, high evapotranspiration and high run-off will have a great impact on the water availability in this zone, which will affect the entire plant and animal kingdom.

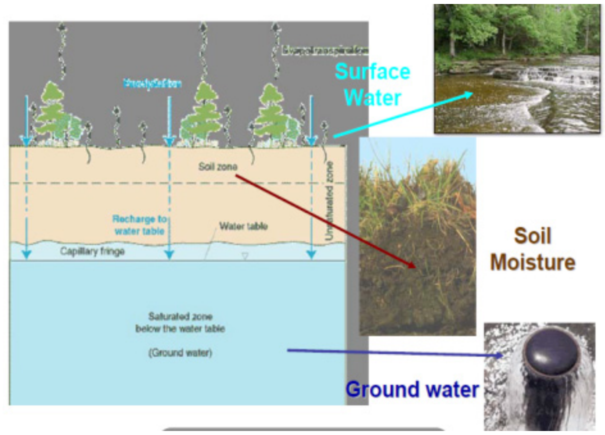

Fig. 2. Zone of aeration

Vadose zone

Changes in vadose zone due to climate change can be computed by studying the variations in **major cations, an-ions, trace elements** and isotopes from the pore water. Due to increase in surface temperature, groundwater temperature will increase. The change in temperature will affect poor water chemistry, residence time and volume of water in matrix and fractures, and thus the composition of the water.

Groundwater in the saturated zone is important as it is less polluted and has no effects of evapotranspiration. Sensitivity of this zone depends on the depth of the water table; shallow aquifers are more vulnerable to climate change than deeper aquifers.

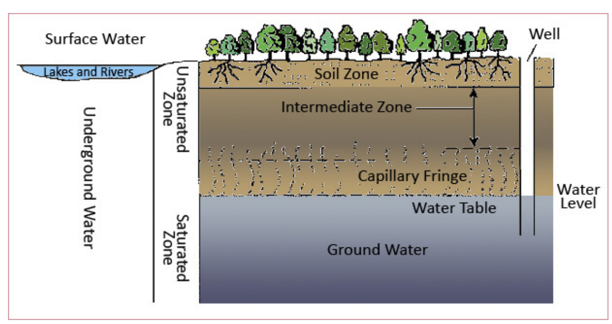

Fig. 3. Zone of Soil water

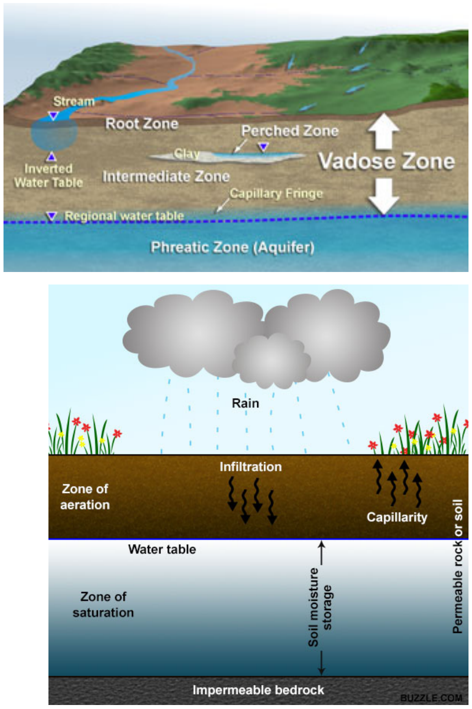

Fig. 4. Zone of Vadose

Effect of climate change on recharge and discharge

Groundwater Recharge

The changes in recharge patterns will affect discharge patterns, which will have a direct impact on groundwater supplies and on surface water availability. In case of dry scenario, the temperature and precipitation are inversely related to each other, as high temperature will result in less rainfall. Changes in recharge patterns will also alter the quality of water by affecting geochemical reactions and movement of water in the vadose zone.

An unconfined aquifer is recharged directly by local rainfall, rivers, and lakes, and the rate of recharge will be influenced by the permeability of overlying rocks and soils. Unconfined aquifers are sensitive to local climate change, abstraction, and seawater intrusion. However, quantification of recharge is complicated by the characteristics of the aquifers themselves as well as overlying rocks and soils. A confined aquifer, on the other hand, is characterized by an overlying bed that is impermeable, and local rainfall does not influence the aquifer. It is normally recharged from lakes, rivers, and rainfall that may occur at distances ranging from a few kilometers to thousands of kilometers. Determining the potential impact of climate change on groundwater resources in particular is difficult due to the complexity of the recharge process, and the variation of recharge within and between different climatic zones.

Under wet climate scenarios, run-off is considered as a most sensitive component and the combined effect of in-creased precipitation and high discharge will increase the risk of flooding. Due to changes in discharge, the quality of groundwater will be adversely affected, since during high discharge all the pollutants will be mobilized and may reach groundwater level. In the case of a dry climate

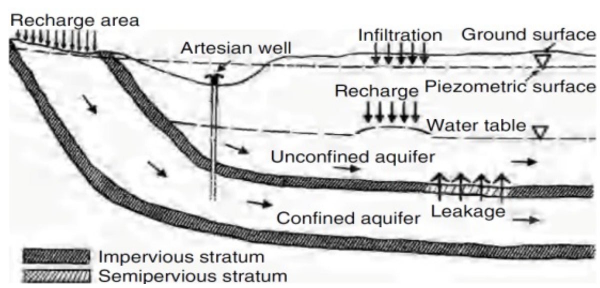

Fig. 6. Recharge area

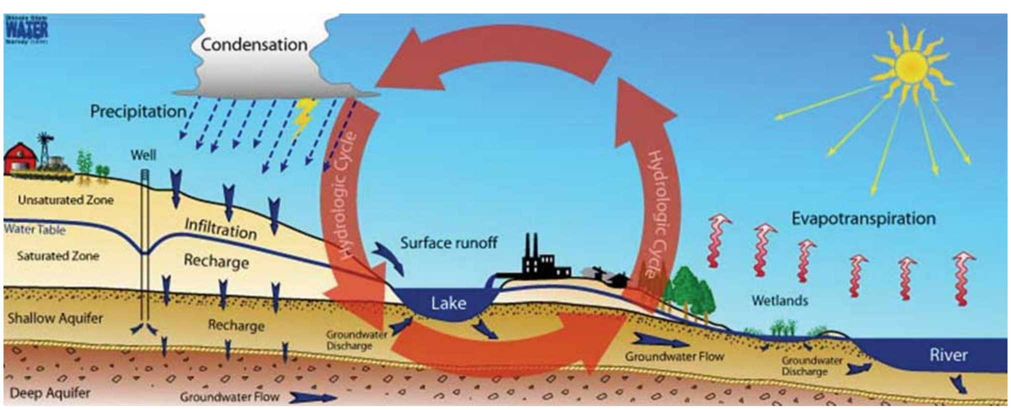

Fig. 5. Groundwater recharge pattern

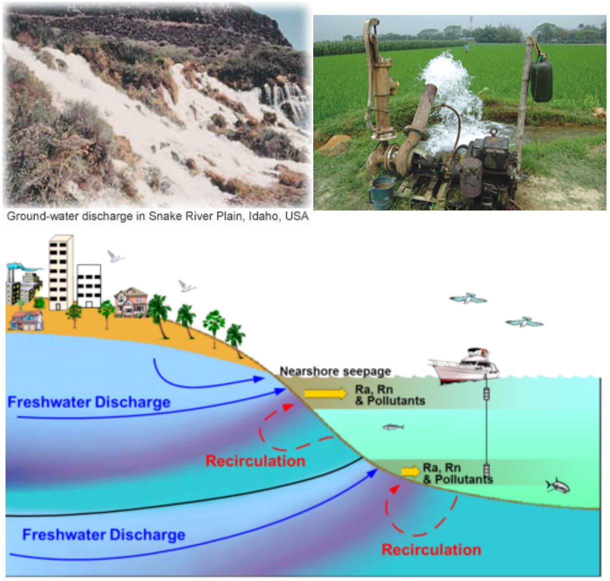

Fig. 7. Different types of groundwater discharge

scenario, generally the water level will fall and this will affect the needs of the people and may result in increased use of energy to ex-tract water.

Effects of climate change on groundwater quality

The groundwater quality relates to the physical, chemical and biological properties of the aquifers, which are controlled by climatic fluctuations. Changes in the recharge rate and the groundwater temperature in the vadose zone affect water chemistry, contaminant transport and residence time, thus affecting the quality of water. Under a climate change scenario, the following events can deteriorate the groundwater quality. During the wet scenario, increased infiltration can mobilize large pore-water chloride and nitrate reservoirs in the vadose zone of semiarid and arid regions. Increase in recharge leads to the dissolution of carbonates; increase in Ca content may increase the hardness of groundwater. During a dry scenario, the increase in total dissolved solids may deteriorate the groundwater quality by increased salt content

Effect of climate change on sea-water intrusion

The three major reasons for the sea-level rise are: expansion of oceans on warming, increase in discharge due to melting of glaciers and excessive pumping due to human settlements along the coasts. The rise in sea level is said to have a great impact on the man-grove forests of the world and aquatic life, affecting the fish stocks and planktons.

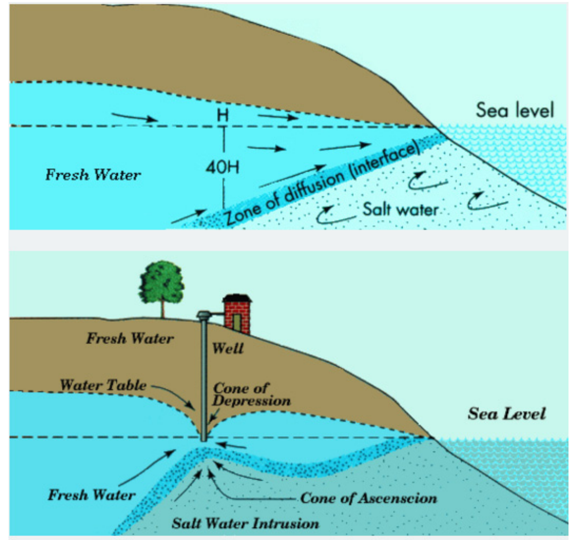

Fig. 8. Sea water Intrusion

It is estimated that 30% of coral reefs could be lost in the next 10 years, which will affect the food web of the aquatic environment.

Effect of climate change on groundwater resources of India

India's groundwater status and utilization

India was utilizing less groundwater compared to USA and Europe, but by 2000, India utilized around 220-230 billion m^3/ year, over twice that the USA. Groundwater level data for 2021 and 2022 reveals that the general depth to water level in the country ranges from 5 to 10 mbgl (metres below ground level), with very shallow water levels of less than 2 mbgl observed in few states, such as Assam, Andhra Pradesh, Meghalaya, Karnataka, Kerala, Jharkhand and Tamil Nadu in small patches. The annual ground water recharge, also known as dynamic groundwater resources, for the entire country has been assessed as 437.60 billion cubic meters (bcm) and natural discharges work out to be 36.85 bcm. Hence, the annual extractable ground water resources for the entire country are 398.08 bcm. The total annual groundwater extraction for the entire country in 2022 has been estimated as 239.16 bcm, with agriculture being the predominant consumer of groundwater resources, accounting for about 87% of the total annual groundwater extraction.

Mitigation strategies to reduce effects of climate change

Behavioral and structural adaptations: Structural

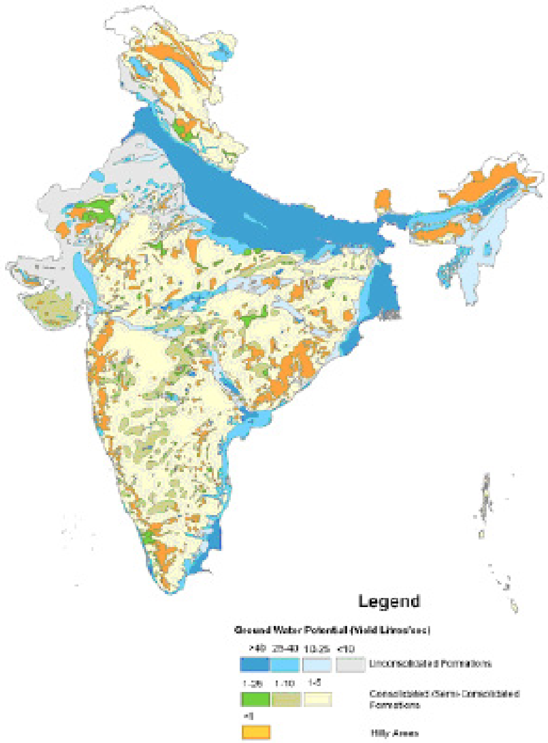

Fig. 9. India's Goundwater Resources

adaptation implies building infrastructure or techniques that can minimize the risk of climate change on groundwater and increase storage capacity of aquifers. Rainwater harvesting, artificial recharge of aquifers, underground dams, reservoirs and check dams, etc.

Defining groundwater risk zones and climate change mapping: Spatiotemporal effect of climate change on aquifers should be assessed and based on this risk assessment of each aquifer should be rated and actions and policies should be designed accordingly. Climate change mapping on different resources will give better results and answers about the vulnerability and risks involved over time for a specific area.

Promoting a forestation: Trees are the sinks for CO_2 on the Earth, and to minimize the effect of global warming, afforestation is the best way, with the aim of reducing deforestation. Land-use development planning should emphasize on planting more trees and increasing recharge area.

CO_2 sequestration: Due to unusually large amounts of CO_2 added to the atmosphere, carbon cycle is insufficient to maintain the balance. Annual carbon emissions from the use of fossil fuels in USA accounts for 1.6 giga tons, whereas the natural annual uptake is only about 0.5 giga tons, i.e. 1.1 giga tons per year remains in the atmosphere. This extra CO is responsible for global warming, which can be trapped in forests, grasslands, oceans and in the sedimentary formations such as coals. This sequestration processes is also beset with many environmental issues and concerns

Some of the Current Issues

- Latur water crisis worsens: City suffers more than rural areas - Business Standard, March 22, 2016.
- 19 Districts in Rajasthan in grip of a Water Crisis -NDTV India, April 18, 2016.
- 468 More Villages Declared Scarcity-Hit in Gujarat - India News, April 21, 2016.
- Severe water crisis in Madhya Pradesh's Betul, Section 144 imposed to avoidviolence - Times of India, June 6, 2016.
- 77 million lack access to safe water in India - A study by Water.org
- Water levels in country's reservoirs down at 21%: Government.

Concluding Remarks on the Research Studies

Brouyere *et al.* (2004) developed an integrated hydrological model (MOHISE) in order to study the impact of climate change on the hydrological cycle in representative water basins in Belgium.

Holman (2006) Described an integrated approach to assess the regional impacts of climate and socio-economic change on groundwater recharge from East Anglia, UK.

These studies are still at infancy and more data, in terms of field information, are to be generated. This will also facilitate appropriate validation of the simulation for the present scenarios. In summary, climate change is likely to have an impact on future recharge rates and hence on the underlying groundwater resources. The impact may not necessarily be a negative one, as evidence by some of the investigation. Quantifying the impact is difficult, and is uncertainties present in the future climate prediction. However, it is clear that the global warming threat is real and the consequences of climate change phenomena are many and alarming.

Conclusion

Changing climate its effect on continental surface water, oceans, ocean productivity, vegetation, etc. In addition, it has a significant effect on the energy cycle and groundwater. We perceive the immediate climate change effects in terms of floods, drought conditions, glacial melts, etc. The effect of climate change is significantly more on the semiarid, arid and coastal aquifers of the world. In India, the vulnerability is extremely high because of overexploitation of the groundwater and accompanied land subsidence in urbanized areas. Groundwater is one of the most utilized resources in India for drinking and irrigation purposes. Better planning and management of this vital resource.

Conflict of Interest: None

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