THE IMPACT OF CLIMATE CHANGE ON THE ECOSYSTEM SERVICES OF RIVERS

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ABSTRACT: In 2013, the United Nations' Intergovernmental Panel on Climate Change (IPCC) outlined climate change as the modification of the climate resulting from human activities that affect the composition of the global atmosphere. This phenomenon is separate from the natural climate variations observed over similar periods. The objective of this paper was to discuss the impact of climate change on river ecosystem services. Scientific research from the last ten years was reviewed. The 2005 Millennium Ecosystem Assessment report was used as the basis for the study. It is concluded that the ecosystem services of provisioning, regulation, support, and cultural services have been impacted by climate change, which anthropogenic factors have accelerated. Pollution in rivers has diminished the provisioning services for humans and the aquatic ecosystem. On the other hand, the ecosystem services of river regulation and support have been destabilized by the increase in natural phenomena such as hurricanes and more frequent flooding. Finally, the impact of climate change on rivers, such as reducing their flows, has resulted in the decrease of spaces for recreation and cultural development in society.

KEYWORDS: Anthropocene; biosphere; ecology; hydrology; nature

1 I INTRODUCTION

Climate change is one of the greatest challenges facing planet Earth in the 21st century. With the advent of industrialization and the excessive increase in anthropogenic activities, climate change has accelerated. According to the latest report from the Intergovernmental Panel on Climate Change (IPCC, 2021), scientists have been closely observing and studying the evolution and changes occurring in terrestrial and aquatic ecosystems and how climate change has impacted them **[1]**. Within aquatic ecosystems, rivers represent the main source of freshwater in the world. Climate change represents a threat to the ecosystem services provided by these ecosystems, especially for rivers that have low flow and are vulnerable to periods of drought. Overall, the destabilization of hydrological cycles, rising sea levels, snow melting in polar regions, and the increase in extreme droughts in various parts of the planet have led to a decrease in the availability of river ecosystem services for the present and future generations. The provision of freshwater, aquatic biodiversity, and recreational spaces are some of the ecosystem services at risk due to climate change. This essay aims to explore the impact of climate change on river ecosystem services, based on the concept of river ecosystem services established by the Millennium Ecosystem Assessment Report in 2005 **[2]**.

2 I BACKGROUND

2.1 Climate Change

Climate includes a set of changing states in the atmosphere that interact with oceans and continents on long-time scales, spatial scales, and other variables **[3]**. However, the naturally occurring long-term changes have been accelerated by anthropogenic activities **[4]**. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change of the United Nations in 2013 defined climate change as “a change in climate that is attributed directly or indirectly to human activity, which alters the composition of the global atmosphere and adds to the natural variability of climate observed over comparable time periods” **[4]**. On 9 August 2021, the IPCC issued a press release highlighting that climate change is intensifying the hydrological cycle, leading to increased intensity of precipitation, floods, and more severe droughts in many regions **[1]**. Similarly, the statement indicates that in high-latitude regions, precipitation is likely to increase, while it is expected to decrease in much of the subtropical regions. Additionally, according to the IPCC, there is a prediction that extreme sea-level events, which previously had a frequency of once every one hundred years, could become an annual occurrence by the end of the current century. All these changes have a negative impact on rivers and the biodiversity that inhabits them. Changes in their physicochemical parameters and adverse events such as wildfires, droughts, and hurricanes reduce their ecosystem services.

2.2 Rivers and Ecosystem Services

Rivers are ecosystems with continuous or discontinuous water currents and variable flow that discharge into another river, a lake, a reservoir, or the sea **[5]**. The term ecosystem can be defined as the sum of individuals from different species that form a community, together with the sum of functions and interrelationships that occur among them **[3]**. Within ecosystems, there are terrestrial ecosystems, which include forests and deserts, and aquatic ecosystems, which include rivers, lakes, and oceans, among others. Each component of ecosystems produces benefits for humans and the biosphere in general. These benefits were formally described through the Millennium Ecosystem Assessment (MEA) by the United Nations in 2005. The assessment defines ecosystem services as the benefits that the human population obtains, directly or indirectly, from the functions of ecosystems. Similarly, ecosystem services are classified into provisioning services, regulating and support services, and cultural services **[2,6]**. Climate change threatens the survival of aquatic ecosystems, their ecosystem services, and therefore, the societies dependent on them **[7]**.

2.3 Provisioning Ecosystem Services of Rivers

Provisioning ecosystem services refer to goods or products obtained directly from ecosystems **[2]**. River ecosystem services are vital for human well-being, providing a wide range of benefits that sustain our societies and economies. Rivers are the main source of freshwater that sustains society. The provision of this precious resource, as well as the food derived from it, such as fish and shrimp, is of vital importance, especially for communities with limited agricultural spaces. Additionally, in many regions with elevated levels of poverty, provisioning ecosystem services directly serves to supply communities and ensure their subsistence **[2, 8-9]**.

One of the primary provisioning ecosystem services of rivers is the provision of freshwater for domestic, agricultural, industrial, and recreational purposes. Rivers serve as natural reservoirs, storing and transporting water across landscapes, making it accessible to human populations. Surface water extracted from rivers serves as a reliable source for clean water supply systems, ensuring the availability of clean and potable water to communities **[10]**. Furthermore, rivers facilitate irrigation systems, supporting agricultural productivity and food security **[11]**. These services contribute significantly to human well-being and socioeconomic development. Similarly, rivers are crucial habitats for a diverse array of fish species, supporting valuable fisheries that provide sustenance, income, and employment opportunities for millions of people worldwide **[12]**. Rivers serve as spawning grounds and habitats for many fish species, ensuring their reproductive success and the maintenance of fish populations **[13]**. These freshwater fish resources contribute to the nutritional needs of local communities and function as an economic driver, particularly in rural areas where fishing is a primary livelihood activity.

In terms of power supply and the provisioning of materials and minerals, the flowing water in rivers possesses kinetic energy, which can be harnessed to generate electricity through hydropower systems. Hydropower represents a significant provisioning ecosystem service provided by rivers, offering a renewable and sustainable source of energy **[14]**. Dams and other large-scale hydropower plants harness the potential energy of water to produce electricity, thus enhancing energy security, reducing dependence on fossil fuels, and mitigating the emissions of greenhouse gases **[15]**. This service is particularly relevant in regions with abundant river resources and a need for affordable and clean energy.

Lastly, rivers function as carriers, transporting sediments, minerals, and nutrients from their catchment areas to downstream regions. This process results in the accumulation of valuable sediments and deposits along riverbanks, such as sand, gravel, and minerals. These raw materials serve as important resources for construction, infrastructure development, and manufacturing industries **[16]**. Riverine extraction of these materials supports economic activities, including building construction, road development, and the production of concrete and ceramics.

2.4 Impact of Climate Change on the Provisioning Ecosystem Services of Rivers

Global warming poses significant threats to rivers, impacting their hydrological patterns, water quality, and ecosystems. Rising temperatures have several adverse effects on rivers, including altered precipitation patterns, increased evaporation rates, and changes in snowmelt dynamics. These changes can lead to decreased water availability, reduced flow, and increased frequency of droughts in some regions **[17-18]**. Furthermore, the increase in global temperatures can amplify the occurrence and intensity of extreme weather phenomena, such as floods and storms. These events have the potential to inflict substantial harm to river ecosystems, including riverbank erosion and disruption of aquatic habitats **[19-20]**. Alterations in temperature and precipitation patterns can likewise impact the quality of water, as elevated water temperatures have the potential to reduce levels of dissolved oxygen, trigger a rise in nutrient pollution, and facilitate the proliferation of harmful algal blooms **[21-22]**. These impacts on rivers have far-reaching consequences for the provisioning and supporting ecosystem services they provide.

Climate change brings about numerous alterations in water bodies. These alterations occur at temporal and spatial scales. In a study conducted by Sabin-Shrestha et al. **[23]**, the impact of global climate change on low stream flows was examined in the Miami River watershed in Ohio, United States. The research aimed to evaluate the adaptability of prominent Global Circulation Models within a specific basin, specifically focusing on streamflow regimes. The authors employed the Soil and Water Assessment Tool (SWAT) and analyzed simulated historical and projected streamflow data from ten climate models. Three future periods (2016–2043, 2044–2071, and 2072–2099) were compared to a reference period (1988–2015). The study reported that an average of ten models projected a 19% increase in low 7-day stream flows in the watershed in the 21st century. Conversely, SWAT-simulated flows in response to most climate model projections showed a consistent increase in low-flow patterns. Wang et al. **[24]** studied the impacts of climate change on streamflow and water quality in a drinking water source area in northern China. The prediction of future climate change scenarios for the study area was conducted using long-term meteorological observation data and employing a combination of global climate models, a statistical downscaling model, and the Weather Generator of the National Climate Center/University of Gothenburg. The authors indicate an overall increase in future precipitation changes and air temperature. Likewise, the impact of climate change will result in an escalation of discharge, total nitrogen, and total phosphorus loads within the examined region over the next three decades, as indicated by model evaluations **[24]**. Compared to the average value of the period from 1961 to 1990, the discharge is projected to undergo the most significant increase (15%), while the increase in total nitrogen and total phosphorus loads will be less pronounced, accompanied by a broader range of annual fluctuations between 2021 and 2050. Socially, low-income communities whose livelihoods depend on rivers will be the most affected. People whose income relies on fishing and other water-related activities will be impacted and will have to seek alternative means to generate income that meets their basic needs **[22]**.

2.5 Supporting and Regulating Ecosystem Services of Rivers

Rivers provide crucial regulating and supporting ecosystem services that contribute to the overall health and functioning of ecosystems. These services play a vital role in maintaining ecological balance and supporting human well-being. Rivers function as natural flood regulators by absorbing and storing excess water during heavy rainfall or snowmelt events, thus reducing the risk of flooding downstream **[25]**. Additionally, rivers help recharge groundwater by allowing water to infiltrate and replenish underground aquifers, ensuring a sustainable supply of freshwater **[26]**. They also facilitate water purification and nutrient cycling processes, acting as natural filters that remove pollutants and sediments, thereby enhancing water quality **[27-28]**. These regulating ecosystem services provided by rivers are crucial for maintaining the resilience and functionality of both aquatic and terrestrial ecosystems **[2]**.

In terms of supporting ecosystem services, rivers are fundamental to the functioning and productivity of ecosystems. These services contribute to the overall biodiversity, stability, and resilience of riverine and adjacent habitats. Rivers serve as habitats for a diverse range of species, including aquatic plants, invertebrates, and fish, supporting their life cycles, reproduction, and feeding **[10]**. The diverse habitats within rivers, such as riffles, pools, and wetlands, offer refuge, breeding grounds, and foraging opportunities for a wide array of organisms **[10]**. Moreover, rivers facilitate nutrient transport and cycling, as they transport sediments, organic matter, and nutrients downstream, enriching floodplains and coastal ecosystems **[10,28]**. These supporting ecosystem services of rivers are essential for maintaining the ecological integrity and functioning of entire watersheds. Overall, both services form the foundations for creating natural spaces for ecosystems to exist and produce and conserve their diversity **[8]**.

2.6 Impact of Climate Change on the Regulation and Supporting Ecosystem Services of Rivers

Climate change is expected to increase its negative effects on the regulation and supporting ecosystem services provided by rivers. These effects will alter hydrological patterns, water availability, and the overall functioning of riverine ecosystems. Climate change-induced shifts in precipitation patterns, increased evaporation rates, and changes in snowmelt dynamics can result in altered river flows, reduced water availability, and increased frequency of droughts **[18,20]**. These changes in water availability can disrupt the regulating ecosystem services of rivers, such as their ability to regulate floods and maintain stable water levels. Furthermore, changes in temperature and precipitation patterns can affect groundwater recharge, which can impact the availability of freshwater resources **[26]**. These alterations in water availability and hydrological patterns can have cascading effects on water purification, nutrient cycling, and overall water quality regulation provided by rivers **[27-28]**.

Areces-Berazain et al. **[29]** evaluated the potential effects of climate change on the hydrographic basins of the Bacuranao and Guanabo rivers in Cuba. Their study reported that any variation in rainfall patterns and temperature in relation to the current climate context will impact the river and water body pollution, native forest cover, and soil agricultural productivity. Conversely, Boru et al. **[30]** investigated the consequences of climate change on streamflow and water availability within the Anger sub-basin of the Ethiopian Nile Basin. The study examined the potential impact of climate change on streamflow and water availability in the specific case of the Anger sub-basin, which is situated in the southern region of the upper Blue Nile River basin. Employing various logical models, including SWAT, the researchers projected streamflow under different scenarios for the study periods spanning the 2020s and 2080s, considering current conditions. The study revealed a reduction of 7.43% in water resources for the 2020s and a further decrease of 11.3% for the 2080s.

2.7 Cultural Ecosystem Services

Aquatic ecosystems provide spaces for human recreation, reflection, and artistic inspiration. This benefit is classified as a cultural ecosystem service **[2,9]**. Rivers are ideal settings for recreation, especially in ecosystems suitable for boating or swimming. They offer recreational opportunities such as boating, fishing, swimming, and nature appreciation, which promote physical and mental well-being and foster a connection to nature **[31]**. Additionally, the landscapes observed by visitors in these spaces are often inspiring and motivating for creating works of art. Rivers have been sources of inspiration for art, literature, and music, shaping cultural expressions and providing a sense of place and heritage **[32]**. Similarly, they are an ideal place for meditation and reflection. Rivers also hold cultural and spiritual significance for many Indigenous communities, playing a central role in their traditions, rituals, and belief systems **[33]**. Moreover, rivers have historically served as important transportation routes, facilitating trade, commerce, and cultural exchange between communities **[34]**.

2.8 Impact of Climate Change on the Cultural Ecosystem Services of Rivers

Climate change is anticipated to have significant impacts on the cultural ecosystem services provided by rivers, affecting the way people interact with and derive cultural values from these ecosystems. Changes in river flows, water availability, and water quality can have profound effects on recreational activities and cultural practices associated with rivers. Shifts in precipitation patterns and increased frequency of droughts may lead to reduced water levels and altered river flows, affecting activities such as boating, swimming, and fishing **[20]**. Changes in water temperature and quality can impact the suitability of rivers for recreational use and affect the abundance and distribution of fish species, impacting fishing traditions and cultural practices **[35]**. Additionally, changes in river ecosystems may disrupt the cultural and spiritual connections that Indigenous communities have with rivers, jeopardizing their cultural heritage and traditional knowledge **[33]**. In general, spaces to conduct these activities have been reduced due to climate change. According to a press release on 9 August 2021, about the latest report from the Intergovernmental Panel on Climate Change, increased temperatures, prolonged drought periods, and extreme weather events such as hurricanes will become more frequent. This endangers aquatic ecosystems as erosion and droughts could reduce river flow, rendering the space unsuitable for swimming and boating. Ecosystems represent a space for human recreation. For example, rivers provide an ideal setting for sports and boating. For instance, in Indonesia, the morphology of the Santirah River has allowed the development of water sports such as swimming and rowing. The morphological characteristics of this aquatic ecosystem have led to its development as a sports tourism destination **[36]**. Nonetheless, the presence of climate change-induced droughts has posed a significant threat to global water resources. An illustrative case is the Colorado River, where annual flows between 2000 and 2014 witnessed an average decline of 19% compared to the average recorded from 1906 to 1999 **[37]**.

3 | CONCLUSIONS

The ecosystem services provided by rivers have already begun to be affected by climate change. Ecosystem provisioning services such as freshwater and food provided by these ecosystems are increasingly threatened by climate change. Severe droughts, wildfires, and more frequent and intense weather events affect the quality of rivers and directly affect their ecosystem services. Similarly, the decline in aquatic biodiversity has an impact on the genetic diversity that flows among rivers. In the case of the regulation and supporting ecosystem services, the climate regulation provided by rivers, nutrient maintenance, and other supporting services is at stake due to industrialization and various human activities that have accelerated climate change. Lastly, cultural ecosystem services are the benefits that humans can derive from ecosystems to engage in activities such as meditation and artistic inspiration. The reduction in river flows, increasing temperature in ecosystems, and other factors decrease human use of these ecosystems. As shown in the latest IPCC report, most of the adverse effects we are experiencing, and future generations will experience are clearly linked to human influence. Immediate social action is the only way to help mitigate climate change and attempt to reverse its impact on future generations.

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