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The Impact of Climate Change and Changes in The Runoff of the Yellow River in Recent Years

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Abstract: At 5,464 kilometers, the Yellow River is the second-longest river in China. It supports domestic, industrial, and agricultural water demands while passing through nine provinces, acting as northern China's lifeline. This paper's goal is to examine how net flow has changed recently in the Yellow River Basin and how climate change has affected it by examining data from earlier studies. This paper finds that the basin's sustainable growth and water security are significantly impacted by variations in the Yellow River's flow. According to the study, the Yellow River's flow generally exhibits a declining tendency, particularly in the upstream region and during the period of ample water, even though precipitation has increased. The primary cause is climate change, which has a substantial impact on runoff due to altered precipitation patterns (a decrease of around 11.29% in the percentage of snowfall) and temperature increases (up to 30% in some places). While vegetation degradation made water scarcity worse by lowering soil water storage capacity and wetland management, decreased snow and ice melt contributions, and increased evapotranspiration further weakened runoff. Future scenario projections indicate that runoff depth in the Yellow River Basin will generally grow, but the source area and the northwest region are probably going to experience increasingly severe water resource stress. Therefore, it is advised that ecological preservation, efficient water resource allocation, and adaptive management techniques be used to improve the basin's sustainable water resource use.

Keywords: Runoff, yellow river, climate change

1. Introduction

Changes in the discharge from the Yellow River have a major impact on the water security and sustainable development of the basin, which is an important ecological barrier and economic lifeline in northern China. According to recent research, the combined effects of climate change and human activity have caused the runoff in the Yellow River basin to generally decline. This is particularly true in the middle reaches of the river, where runoff drastically declines during the flood season, and it highlights how sensitive the upper reaches of the river are to runoff at high elevations. There are still research gaps despite the fact that runoff attribution has been examined from the standpoints of vegetation restoration and precipitation reduction. These include the lack of knowledge about multi-timescale dynamic response mechanisms, the inadequate quantification of interactions between climate change and human activity, and the poor prediction accuracy of future scenarios.

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This study demonstrates the role of different climatic changes in runoff and carefully examines the geographical and temporal evolution of runoff in the Yellow River using hydrometeorological data and remote sensing information from recent years. The study also shows how different climate changes affect runoff and offers pertinent recommendations for adaptive management of water resources in the Yellow River Basin.

2. Trend analysis of Yellow River runoff

2.1. Trends in the overall runoff of the Yellow River

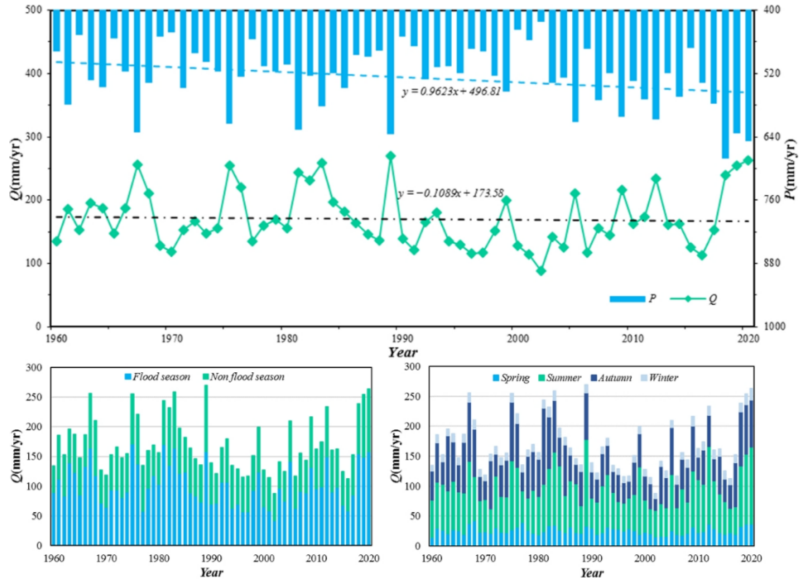

Figure 1: Trend of hydrometeorological elements in the Yellow River source area [1]

The Yellow River's total runoff (Q) and precipitation (P) long-term trends are depicted in Figure 1, along with the distribution of runoff during abundant and non-abundant seasons. According to the general trend, the runoff volume (Q) exhibits a declining trend (trend line (y=-0.1089x + 173.58)), whereas the precipitation (P) shows a notable increasing trend (trend line (y= 0.9623x + 496.81)). This indicates that the runoff volume is declining even as precipitation is increasing [1].

Additionally, Figure 1 demonstrates that runoff is somewhat steady during times of low water abundance but varies dramatically during times of high-water abundance. While runoff changes during the non-abundant water season remain relatively moderate, they have decreased in recent years during the ample water period. Spring and winter runoff are less varied in their seasonal distribution, while summer runoff is the most abundant but has decreased recently. These modifications might point to a connection between the seasonal distribution of runoff and climate change [1].

2.2. Differences in runoff variability across river reaches

The Yellow River Basin's runoff variations exhibit notable spatial variations across several river segments. The flood season and fall saw the biggest runoff changes in the Yellow River headwaters area (upper reaches), with the runoff reduction during the flood season accounting for 88.40% of the annual runoff reduction and the fall runoff reduction for 75.79%. Changes in the subsurface, such as vegetation deterioration and permafrost thawing, are the primary causes of runoff variations during the non-flood season and winter [1].

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The upstream region's runoff is most vulnerable to climate change, particularly variations in temperature and precipitation. According to the study, runoff in the upstream region is most sensitive to variations in precipitation, declining by 13% to 15.7% for every 10% drop in precipitation and 2.1% to 4.2% for every 1.0°C rise in air temperature. This implies that the mountains and highlands are experiencing a more noticeable response from runoff to climate change [2].

On the contrary, human activity has a greater impact on runoff changes in the mid- and downstream zones. For instance, the middle reaches' vegetation cover rose dramatically as a result of soil and water conservation initiatives and the strategy of converting cropland back to forests, but this also resulted in a drop in runoff. Furthermore, with a contribution rate of almost 50%, the development of water conservation projects was a major factor in the decrease of runoff. The geographical distribution pattern of temperature and precipitation is compatible with the runoff depth, which was higher in the lower reaches and lower in the middle reaches [3].

2.3. Distribution characteristics of runoff depth and its future trends

It has been discovered that the trends and runoff depth distribution features of China's Yellow River Basin exhibit notable variations depending on the climate. The mean annual runoff in the Yellow River Basin is predicted to increase under all four climate scenarios (SSP126, SSP245, SSP370, and SSP585), with increases of 0.008 mm/year, 0.065 mm/year, 0.25 mm/year, and 0.24 mm/year, respectively, based on data from the CMIP6 climate model [4]. Under the SSP245 and SSP370 scenarios, the rate of change of runoff in the upstream area increased between 2022 and 2040. In the Qin River and Longmen areas, the rate of change of runoff ranged from 6.00 to 8.61 mm/year [4].

Additional research revealed that, under the SSP126 and SSP245 scenarios, the runoff depth in the river source area grew significantly between 2061 and 2080, whereas the runoff depth in the middle reaches showed a trend of decline, with a change rate ranging from 4.52 to 11.39 mm/year. In contrast, the midstream region exhibits an increasing tendency while the runoff depth in the river headwaters declines under the SSP370 and SSP585 scenarios [4].

Furthermore, the study noted that while the Yellow River Basin's runoff depth is generally trending upward under future warming scenarios, there are notable regional variations in these patterns. Under the SSP370 scenario, the runoff depth in the river's headwaters is anticipated to drop more dramatically, while the northwest and middle sections are predicted to stay comparatively dry and water-scarce [4].

2.4. Spatial and temporal variations in the depth of runoff from the Yellow River

The runoff depth in the Yellow River headwaters region fluctuated greatly between seasons and years, according to an analysis of runoff and precipitation data from 1960 to 2019 as well as permafrost temperature and water content monitoring data from 2013 to 2019 [5]. In particular, the runoff depths during the surface thawing period (May–October) and the freezing period (November–April) decreased by 1.5 mm and 1.2 mm, respectively, in comparison to the two typical periods of 1960–1965 and 1992-1997. These decreases accounted for 4.2% and 3.4% of the multi-year average runoff depths, respectively [5]. The increase in the depth of the multi-year permafrost thaw and the decline in the water table are strongly linked to this trend, which is primarily manifested in the drop in runoff depth from August to December.

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3. Mechanisms of climate change impacts on Yellow River runoff

3.1. Impact of precipitation changes on Yellow River runoff

Runoff has recently been greatly impacted by fluctuations in precipitation in the Yellow River source area. Research indicates that while precipitation has grown in the Yellow River source area over the past few decades, the percentage of snowfall has been trending downward, with the average annual percentage of snowfall declining at a pace of 0.24%/10a [6]. The primary cause of this shift in precipitation type is climate change, as warmer temperatures result in more precipitation in the form of rainfall as opposed to snowfall. The runoff in the Yellow River source area was significantly impacted by the change in precipitation type; 11.29% of the change in runoff was due to the drop in the percentage of snowfall [6].

Furthermore, there was notable geographical variability in the precipitation variations, with the snowfall fraction fluctuating more in regions above 3500 m above sea level and being steadier in areas below 3500 m. The plateau's terrain and climate may have a direct bearing on this regional variation [6]. All things considered, the Yellow River source area's runoff is significantly impacted by changes in precipitation type, and future water resource management strategies must take this into account.

3.2. The role of warming temperatures on Yellow River runoff

Temperature rises are directly linked to changes in the Yellow River's runoff in the context of global warming. An analysis of the upper Yellow River's runoff trend between 1961 and 2019 revealed that the temperature increases greatly increased evapotranspiration and glacier melting, which in turn caused a notable rising trend in runoff [7].

In particular, at locations like Maqu and Tangnaihe in the upper Yellow River, the yearly runoff fluctuations attributable to climate change (CT index) contributed more than 15%, and at some locations, it even approached 30%. These findings suggest that the western region, particularly the basins where precipitation and glacial meltwater interact, is most affected by the driving force of rising temperatures on Yellow River flow [7].

The report also notes that rising temperatures have an impact on the Yellow River's average flow as well as increasing the frequency and severity of exceptional runoff occurrences.

3.3. Mechanisms of increasing evapotranspiration on the Yellow River runoff

Using the coupled water-energy balance equation under Budyko's assumption and hydrometeorological data from 1954 to 2015, some researchers examined the mechanism of ET's influence on runoff changes in the Huangfu River basin in the middle reaches of the Yellow River. According to the study, an increase in ET lowers runoff since it has a substantial negative elasticity coefficient on runoff change. ET's contribution to runoff reduction varied from -8.54% to -12.94% in the 1997-2015 change period and from -54.91% to -62.68% in the 1979-1996 change period [8]. This suggests that while ET's impact on runoff was minimal during the study period, it was detrimental during both change periods. Surface variables (such as changes in land use and vegetation cover) have a major impact on ET changes, and these conditions are directly tied to human activity. For instance, the watershed's surface ET processes were considerably changed by the addition of plant cover and the building of hydraulic projects (such as terraces and silt dams), which had an impact on runoff distribution and generation. Overall, even while variations in evapotranspiration have a negligible effect on runoff, they nevertheless have a major detrimental impact on the watershed's hydrological cycle, particularly when there are notable changes in the surface condition [8].

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3.4. Contribution of snow and ice meltwater to the Yellow River runoff

The contribution of snow and ice meltwater to runoff in the Yellow River's source region exhibits notable temporal and spatial fluctuations. According to the study, snow and ice meltwater contribute significantly to runoff in the Yellow River source area; in the Maqu and Tangnaihe stations, their respective contribution ratios are 26% and 23%. With 53%–64% of the spring runoff coming from snow and ice melt, spring is the primary season that contributes to this water. The percentage of snow and ice meltwater that contributed dropped as the temperature rose, particularly in the downstream region [9].

The Yellow River basin's spring irrigation could be negatively impacted by this development. In addition, warmer temperatures cause the peak flow of snow and ice melt water to arrive earlier; this is particularly noticeable upstream [9]. The seasonal buffering impact of snow and ice meltwater may be diminished as a result of future climate change, which is why water resource management must prioritize this.

3.5. Indirect effects of vegetation degradation on the runoff of the Yellow River

The main ways that vegetation degradation affects the Yellow River runoff indirectly are by altering the soil's ability to retain water, decreasing the ability of lakes and wetlands to regulate runoff, and making the decline in surface runoff worse [10]. According to studies, the loss of plant cover has weakened the soil's ability to retain water by increasing soil moisture evaporation and decreasing soil water content. Regional water scarcity is made worse by this shift, which reduces surface runoff and lowers groundwater recharge capability [10].

Regional water scarcity is made worse by this shift, which reduces surface runoff and lowers groundwater recharge capability. Additionally, one of the direct effects of vegetation degradation is the shrinkage of wetlands and lakes [10]. These areas are crucial hydrological regulators, and their shrinkage greatly impairs their capacity to control runoff, increasing seasonal variations in runoff. By altering the surface roughness and soil permeability, vegetation degradation may also have an indirect impact on the Yellow River's runoff volume by influencing precipitation infiltration and runoff distribution.

In spite of endangering the biological balance of the Yellow River's source region, these alterations could have a significant effect on downstream ecosystem stability and water resource use. Therefore, it is crucial to highlight and reduce the indirect effects of vegetation degradation on the Yellow River's runoff through ecological restoration and water resource management strategies.

4. Conclusion

Changes in the Yellow River's flow have a significant effect on the basin's water security and sustainable development because it serves as northern China's lifeline. Despite an increase in precipitation, studies have found that the Yellow River's discharge has typically been declining in recent years. This decline is most noticeable in the upper reaches and during times of abundance. The primary causes of runoff variations are human activity and climate change; variations in precipitation types, rising temperatures, a decline in the contribution of snow and ice melt, and an increase in evapotranspiration all have a major effect on runoff.

In particular, the Yellow River's source area saw a decrease in runoff of roughly 11.29% as a result of a decrease in the percentage of snowfall that came in the form of precipitation; in other places, the temperature increase made evapotranspiration and glacier melting worse, contributing up to 30% to the change in runoff. Additionally, increasing evapotranspiration further weakened flow by changing surface hydrological processes, whereas the contribution of snow and ice melt to runoff declined

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dramatically in the spring. Furthermore, by decreasing soil water storage capacity and wetland control, vegetation degradation indirectly exacerbates runoff reduction and regional water scarcity.

Future scenario projections indicate that the Yellow River Basin's runoff depth is generally increasing, while there are noticeable regional variations, and the source region and the northwest of the nation are likely to see more intense constraints on their water resources. Therefore, it is advised that ecological preservation, efficient water resource allocation, and adaptive management techniques be used to improve the basin's sustainable water resource use in response to the combined effects of climate change and human activity.

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