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Review Article

# Dynamic Geomorphology of the Amu Darya Basin in Afghanistan: A Study of Physiography, Basin Erosion, and Channel Development

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ABSTRACT

The morphological dynamics of rivers are motivated by way of a number of things, including floodplain sedimentation, channel migration, sediment transport, and hydrodynamics. A considerable information of the complicated dynamics of river structures is important to layout river initiatives which can be sustainable and environmentally conscious. Implementing thorough river control plans that include hydraulic infrastructure and ecological restoration projects is important to overcoming these boundaries. This solution will effectively manipulate competing needs for water resources whilst ensuring the preservation of the location's herbal heritage. In the cease, this study affords essential new understandings of the complex interactions between hydrological patterns, human hobby, and geological procedures within the Amu Darya Basin. The application of sustainable land control and water useful resource making plans in Afghanistan might be appreciably impacted with the aid of those findings. Afghanistan has a lot of freshwaters because the Hindu Kush Mountains receive a significant quantity of precipitation. An estimated 75 billion cubic meters of potential water resources, consisting of 57 billion cubic meters of surface water and 18 billion cubic meters of groundwater, are found in Afghanistan. The Amu Darya, Northern River Basin, Helmand River Basin, Harirud-Marghab River Basin, and Kabul River Basin make up the Indus River Basin, which provides around two-thirds of Afghanistan's freshwater resources. All of Afghanistan's rivers, with the exception of the Northern River, flow across international borders into neighboring countries. The distribution of water from the Amu Darya River was subject to limitations imposed by the USSR, which was previously known as the Union of Soviet Socialist Republics. The majority of the water is used mostly for farming. Protocol 566, formally ratified by the former USSR, allowed the transfer of water from the Amu Darya River to the four Central Asian Republics (CARs) of Tajikistan, Uzbekistan, Turkmenistan, and the Kyrgyz Republic. By investigating the bodily functions of the basin, which includes land erosion and channel development, this looks at seeks to enhance our understanding of the landscape evolution of the basin. Our intention is to improve our information of the landforms, tectonic activity history, and the consequences of climate change inside the region by utilizing geological studies and facts from faraway sensing.

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## Introduction

The dynamics of rivers are laid low with several factors, including the charge of water drift, the motion of sediment and debris, changes to the river channel, and tactics of erosion and deposition Human sports can purpose modifications in land use that without delay have an effect on river flows. Human moves have handed the significance of herbal tactics. (Langat, Kumar, & Koech, 2019) Acquiring a thorough knowledge of the dynamics of river channels is vital for developing fluvial tasks that are each feasible and environmentally fantastic. Researchers have evaluated the alterations inside the river by means of analyzing records and employing remote sensing strategies. The primary objective of this observe is to have a look at modifications within the upper Amu Darya River channel. This river channel constitutes a section of Afghanistan's northern border with Tajikistan, Uzbekistan, and Turkmenistan (Hagg et al, 2013). A huge examination of the converting land cowl within the look at vicinity has been done, alongside the method of mapping and tracking the rivers. The usage of Landsat-5 and Landsat-eight imagery has been included with Google Earth Engine (GEE) to accomplish this venture. GEE is a specialized cloud computing platform that is specially created to store and analyze vast portions of statistics, facilitating knowledgeable choice-making and analysis. Since its status quo in 2010, GEE has been widely

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employed in numerous medical fields, along with agricultural packages water monitoring, land cover mapping, vegetation mapping and tracking and lots of greater. This article analyzes the physical attributes of the Amu Darya River, the motives that contribute to erosion in its basin, and the hard undertaking of creating a channel. The main goals are to highlight the significance of the Amu Darya as a viable waterway and as a representation of strength, interconnectedness, and the fragile equilibrium between the natural world and human civilization. To do this, a variety of strategies will be employed.

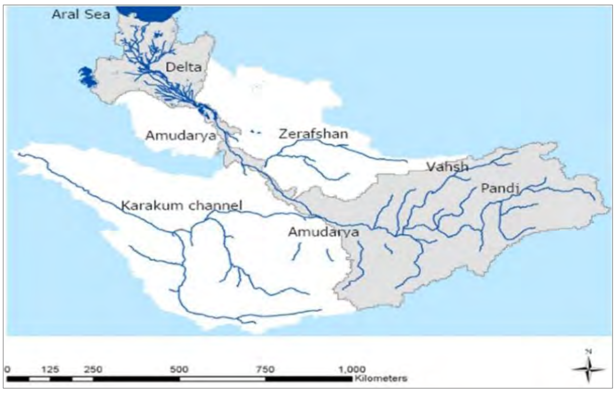


**Fig 1.** Map of the Amu darya River Basin. The grey shading indicates the catchment area of the Amu darya river (Schlüter, 2011)

## STUDY AREA

The Amu Darya is the longest river in Central Asia, spanning 1,400 kilometers. The river is formed by the confluence of the Pyandzh and Vakhsh rivers. The Aral Sea, once the fourth largest lake in the world, derived most of its water from the Amu Darya and Syr Darya before being diverted (Kostianoy, Lebedev, & Solovyov, 2013). Although the estimated total catchment area is 465,000 km2, the effective drainage basin has a surface area of 300,000 km2. The river starts in the Tigrovaya Balka Nature Reserve, which is situated on the border between Afghanistan and Tajikistan, and empties into the Aral Sea (Asarin, Kravtsova, & Mikhailov, 2010). Along the upstream portion of the river lies a portion of Afghanistan's northern border with Tajikistan, Uzbekistan, and Turkmenistan.

## Amu Darya River Basin

The Amu Darya basin in Central Asia is often associated with the Silk Road and past civilizations. This area is unique because of its vast desert areas, including the Karakum and Kyzylkum deserts, and its breathtaking mountain ranges with snow on top, like the Pamir, Alai, Zarafshan, and Hindu Kush. The region is home to several significant historical sites, including Balkh, Merv, Termez, Samarkand, Bukhara, and Sogdiana. Two other noteworthy natural features are the Aral Sea's untamed, swift-moving rivers. The Amu Darya river has received international interest due to the Aral Sea problem, in addition to its noteworthy hydroelectric, irrigation, and water engineering projects. Throughout the Soviet era, delegations of experts warned of the hazardous effects of the rapid and extensive growth of cotton monoculture throughout Central Asia. The Aral Sea's surrounding environment is shrinking and deteriorating. Because of these reasons, it is more crucial than ever that the government take swift action to halt the disappearance of the sea and the resulting socioeconomic disaster. Numerous international conferences and missions headed by foreign experts over the past 20 years have documented the deteriorating socioeconomic and environmental conditions, especially in the Amu Darya delta region. Numerous research and publications have addressed the difficulties in managing water resources in the Central Asian region. The Amu Darya basin was selected as a top priority by the Environment and Security Initiative (ENVSEC) due to several factors, including the growing number of conflicts brought on by water use and hydropower projects. According to Klötzli's 1994 assessment, the Amu Darya delta is a significant area that raises safety and environmental issues. According to studies, areas that experience environmental degradation are also more susceptible to instability. These locations are typically found in hazardous regions like desert plains, the intersection of high- and low-lying terrain, and international river basins (Klötzli, 1994). All these features are present in the Amu Darya River basin. Due to the region's growing environmental and security concerns in recent years, academics, public authorities, international organizations, and the general people have expressed concerns for the future.

## Denudation Processes

The term "basin denudation" describes the combined processes of sedimentation and erosion that sculpt a river basin's terrain and structure. Both manmade and natural factors affect the Amu Darya River Basin's dynamics (Sidle, 2023). Water is transported by river channels and tributaries, which results in the slow erosion of the soil and rock beneath them and the downstream movement of silt. The movement of debris downstream acts as a natural abrasive, causing the riverbed and banks to continue to erode. The process by which rocks and minerals are broken down both chemically and physically, leading to the breakdown of geological formations, is called weathering. The river's silt buildup is facilitated by this. More sediment is deposited into river systems as a result of mass-wasting events like rock falls and landslides, particularly in hilly regions with sharp inclines. Because they progressively change the terrain and move sediment downstream, natural erosion processes are essential to the health of river basins. Because of logging, agriculture, and urbanization, deforestation reduces vegetation, which makes soil erosion from wind and water easier to achieve. Soil erosion is more likely to occur when natural landscapes are transformed into urban areas, infrastructural projects, or agricultural fields. Additionally, these changes upset the hydrological balance. Significant ecological changes, such as silt accumulation in water bodies, soil erosion, and the devastation of natural ecosystems, can result from the mining and use of minerals and resources. The usual patterns of water flow, sediment transport, and floodplain dynamics are upset by the building of dams, river channelization, and irrigation projects. As such, these changes have an impact on the basin's erosion rates as well.

## River Channel

River channels are the means by which surface runoff is eliminated from the land. Because water moves across the landscape, it erodes the rock and soil, causing rivers to carry and spread sedimentary deposits. River sediment transport activities determine the short-term morphologies of streams and rivers, and they also have an impact on the water quality in these channels. This process is what forms the entire terrain over a very long time. The source of channeled water flows is found in highland regions where topography causes soil drainage to converge. Concave depressions are often the first places on slopes where channel building begins. However, a large portion of the initial concentration of flow rises to the surface in seepage zones and springs after occurring below in massive soil pores. These areas are created when subsurface flow convergence causes the surface conditions to become saturated. varying regions of the Earth require varying drainage spaces before a canal may start, depending on the climate and topography of the area. There is a mention of Vadillo, (1978), he form and longevity of river channels are influenced by various factors such as the quantity and timing of water flow, the size and mass of material carried by the stream, the nature of the bank and riverbed, and the slope of the valley the river flows through. The physical properties of the channel, such as its breadth and shallowness with a gravel bed or its depth and narrowness with silt, are determined by the amount and size of sediment present (Vadillo, 1978). The size of the canal needed to manage larger flows depends on the amount of water and when it flows. The stability and form of the channel are determined by the sediment that the stream transports from the bed and bank. Only flows capable of eroding the materials that comprise the channel boundary can change the channel's position or shape. The topographical gradient dictates the rate at which the river must dissipate energy throughout its descent. A river cannot be stable if there isn't balance between the rate of potential energy expenditure and the rate of energy consumption when water and sediment move over the uneven channel barrier. When the number of channels in a drainage basin increases, the governing conditions of the basin systematically change. Because headwater streams naturally follow the sharpest channel of the fall, they are small and have an extremely steep gradient. Their small drainage area is the cause of this. Because of their steepness, these streams may remove a significant amount of silt that is brought to them. They can either pass through channels that have been worn all the way to the bedrock, or they can pass through the remains of objects that are too large for the stream to transport. As tributaries unite to form a network that resembles a tree, the channels grow downstream. Moreover, the channels become flatter and have a higher probability of holding onto part of the silt they transport. Consequently, the sediments they may have carried into the region start to move along the channels. These channels are known as alluvial channels and are represented in hydraulic geometry. They exhibit significant changes to the related drainage system.

Because of the organized form of the system, we can distinguish between main streams and highland river systems. The former is characterized by small, slightly slanted features that are mostly caused by erosion from the stream wearing away at the underlying material. Gathering rainfall from the soil and directing it into the river drainage system is their primary goal. The locations of headwater wetlands that may empty into channels that are level, have low erosive power, and are mostly surrounded by organic matter differ greatly from level terrain. Approximately 80 percent of the drainage system's length consists of upland canals due to their frequent occurrence in the topography. Trunk channels facilitate the collection and transportation of silt and water from rivers at higher altitudes to lakes or the ocean. Since most flows cannot carry the majority of the sediment load during conveyance due to the lower valley gradient, silt is temporarily held and deposited along the route. Consequently, silt makes up the majority of the material that flowing water deposits in these channels. The river can be further split into "transport reaches," which are farther out and have the ability to hold sediment for longer periods of time, and "storage reaches," which are mid-course parts that usually occur in small valleys and convey sediment quickly. The silt accumulations along the lower course of most major rivers are known as floodplains and deltas, and they are significant places where human development occurs frequently.

## Geomorphology

The study of Earth's landforms and landscapes and the processes that have shaped them over a vast range of time and space ranges is known as geomorphology (from the Greek geo Earth and morphos form). It is significant in a variety of settings (Fairbridge, 1968). When it comes to shifting landforms, landform systems, landscapes, and landscape systems, geomorphology has a special duty to inform humanity about how much disturbance Earth's landforms and landscapes can withstand and how long it will take for the landscape to recover from disturbance. Sea level, climate, relief, and human activity are the four main factors that cause environmental change. At various temporal and geographical scales, geomorphology functions as an independent variable and has a significant impact on each of the drivers (Fairbridge, 1968). Because this relationship is reflexive, it is crucial to avoid drawing conclusions about it that are restricted to deterministic interactions. "Climatic" and "process" geomorphology are two important philosophical schools in the study of geomorphology that typically concentrate on distinct spatiotemporal scales of investigation.

## Climate Change

Climate change has already resulted in a reduction in the Amu Darya Basin's irrigation water supply. Early snowmelt makes spring floods more potent, and summer and early fall are the most likely times for water shortages, especially in drought-prone years. The ability of nature to maintain and regulate the water supply year-round is diminished by climate change. Enhancement and supplementation of this function in water management requires human intervention. For instance, new reservoirs need to be constructed in order to regulate seasonal fluctuations in stream flow and supply enough water for summer and fall use by agriculture and residential areas. Data indicate that by 1980, Afghanistan had used more than five million cubic meters of Amu Darya water for northern agricultural uses. Most of the construction was finished along the Panj River, which is a part of the Amu-Panj Basin, and in the Kokcha and Kunduz tributary river basins, which are close to the Amu Darya River.

An estimated 385,000 hectares of land were being irrigated during that time. This comes to about 4,000 million cubic meters of water needed for irrigation, accounting for the water that seeps back from the irrigated fields on the Amu Darya alluvial aquifer and improved on-farm water management. The worldwide hydrological cycle has been worsened by climate change since the 1970s and 1980s, according to data that is now accessible. Evapotranspiration, precipitation, and runoff have all changed significantly as a result (Huntington, 2006). As the hydrological cycle intensifies, more hydrological extremes are expected, as the IPCC predicted in 2001. River regimes are directly impacted by differences in the frequency distribution of rainfall; these variations also have an effect on the availability and flow of water in the surface environment. These characteristics are in addition to the results of human decisions regarding land use and attempts to control water supply for a variety of purposes, which have altered river courses and the water quality that flows through them (Bates, 2008). The amount of water and sediment rivers receive depends on the state of the land surface, which also affects the rivers' morphology, stability, and sediment deposition. Additionally, humans alter the terrestrial hydrological cycle by purposefully creating reservoirs, using water for household needs, and discharging it into river systems. Furthermore, we actively alter watercourses through dredging, river "training" initiatives, bank restorations, dike construction, and realignment. Rivers and the ecosystems that surround and rely on them are greatly impacted by each of these variables. The consequences of climate change on the overall water supply will be felt at a regional level in areas where the water supply is already scarce or insufficient. However, human activity usually has a major impact on the amount, quality, and condition of water as well as the state of rivers.

## Climate and Hydrology:

The vast Amu Darya River Basin has a very diverse climate; the highlands have continental temperatures, while the desert regions experience dry and semi-arid weather. The orographic effect, which implies that hilly locations receive more precipitation than lowland ones, has a significant impact on rainfall patterns. The river's flow is facilitated in the spring and summer and its water levels are maintained during the dry season by the melting of snow and glaciers in the Hindu Kush and Pamir Mountains (Bolch, 2019). The Amu Darya River receives its hydrological nourishment from an intricate system of glacial meltwater, springs, and tributaries. Because of glacial runoff and snowmelt, its flow varies yearly, reaching its maximum in July. Human activity, such as the construction of dams and water diversion projects, has dramatically changed the river's flow, raising concerns about ecological degradation and water scarcity (Froebrich, 2006). Comprehending the physiography of the Amu Darya River Basin helps facilitate your appreciation of the intricate interplay among the region's geological, hydrological, and climatic characteristics. According to Salehie et al. (2022), it offers a framework for considering the dynamics, changes, and difficulties of basin water resource management in a sustainable manner (Salehie et al, 2022).

## Conclusion

Undoubtedly, climate change is impacting the world's waterways. The overall volume and seasonal distribution of water flow in rivers can be significantly influenced by variations in precipitation patterns and evapotranspiration from the land surface. This suggests that these advancements could have a significant impact on both the local and global economies. Widespread catastrophic outcomes will occur as the value of the few resources increases. However, considering that human civilizations are not inherently equipped to effectively manage any form of change, this assumption may not consistently hold true. The outcomes of this study will significantly impact the management of environmentally protected areas and the sustainable utilization of water resources in the Amu Darya basin. Comprehensive approaches to watershed management must take into account both natural processes and human actions to minimize the accumulation of sediment, preserve the quality of water, and enhance ecological resilience. The Amu Darya River and its basin's long-term sustainability hinges on policy recommendations that encourage sustainable land use practices, facilitate stakeholder engagement, and bolster adaptive management strategies. Human activity, both historical and contemporary, will significantly influence the physical characteristics of rivers and the ecosystems they sustain, rather than being only attributed to climate change. The objective of this chapter is to illustrate the direct influence of human activities on rivers in order to substantiate this assertion. These operations have an impact on river silt deposition, water quality, and runoff discharge. This chapter also discusses the repercussions of direct human intervention in river channels, due to various factors. In conclusion, we would like to make some remarks regarding the dismal outcomes of human endeavors to "restore" or, at the very least, rejuvenate rivers. The high population density of the globe requires continuous and proactive management. The effective management of rivers is still an area that requires additional investigation. One object stands out among the others. Human activity disrupts every stage of the natural river process, starting from the generation of runoff on the land surface to the release of water into river estuaries and deltas that ultimately flow into the ocean. In order for river management to be effective, it is essential to incorporate all impacts and functions of the drainage system. This was a significant cause for alarm in a society that prioritized growth and advancement during the mid-20th century. The main goal should be to give priority to the conservation of resources and the judicious utilization of them.

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