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Influence of debris flows on channel processes in the foothill plains

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Abstract. The most debris flow-prone rivers in the Republic of Azerbaijan are the left-bank tributaries of the Kura River, which originate on the southern slopes of the Greater Caucasus. The basins of these rivers are primarily composed of sedimentary rocks. In recent years, climate change has led to an increase in the frequency of short-duration, high-intensity rainfall events, resulting in a significant rise in the occurrence of floods and debris flows. These hydrometeorological hazards not only cause damage to infrastructure and agricultural lands along the river corridors but also substantially alter the morphometric parameters and morphological characteristics of the riverbeds. To investigate riverbed deformations in the foothill plains of the Shirvan region, field studies were conducted during different phases of the hydrological regime (four times per year) between 2013 and 2021. Representative river sections were selected on seven rivers for detailed monitoring. Temporary benchmarks were established, and their geographic coordinates were recorded using handheld GPS devices. Cross-sectional profiles of each river channel were developed, water velocity was measured, and river discharge was calculated. By comparing the cross-sectional profiles obtained during successive field campaigns, vertical channel deformations were quantitatively assessed. It was determined that the rate of vertical channel deformation across the studied rivers ranged from 6.25 to 42.00 cm per year during the 2013–2021 period. To analyze long-term channel deformations, a comparative study was conducted using historical topographic maps from 1970 and high-resolution (1.5 m) satellite imagery obtained from the Azersky satellite operated by the Azercosmos Agency.

Key words: *debris flow, channel deformation, river morphology, foothill region, Azerbaijan*

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Влияние селевых потоков на русловые процессы на предгорных равнинах

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Аннотация. Наиболее селеопасными реками в Азербайджанской Республике являются левобережные притоки реки Кура, которые берут начало на южных склонах Большого Кавказа. Бассейны этих рек в основном сложены осадочными породами. В последние годы изменение климата привело к увеличению частоты кратковременных, интенсивных осадков, что привело к значительному росту возникновения наводнений и селей. Эти гидрометеорологические опасности не только наносят ущерб инфраструктуре и сельскохозяйственным угодьям вдоль речных коридоров, но и существенно изменяют морфометрические параметры и морфологические характеристики русел рек. Для изучения деформаций русла рек на предгорных равнинах Ширванского региона в период с 2013 по 2021 г. проводились полевые исследования в разные фазы гидрологического режима (четыре раза в год). На семи реках были выбраны репрезентативные участки рек для детального мониторинга. Были установлены временные реперы, и их географические координаты были зафиксированы с помощью портативных GPS-устройств. Были разработаны поперечные профили каждого речного русла, измерена скорость воды и рассчитан расход реки. Сравнивая поперечные профили, полученные в ходе последовательных полевых кампаний, количественно оценивались вертикальные деформации русла. Было установлено, что скорость вертикальной деформации русла через исследуемые реки составляла от 6,25 до 42,00 см в год в период 2013–2021 гг. Для анализа долгосрочных деформаций русла было проведено сравнительное исследование с использованием исторических топографических карт 1970 г. и спутниковых снимков высокого разрешения (1,5 м), полученных со спутника Azersky, эксплуатируемого агентством «Азеркосмос».

Ключевые слова: *сель, деформация русла, морфология реки, предгорный район, Азербайджан*

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Introduction

Channel processes encompass the complex and dynamic interactions that govern the morphological development and evolution of river channels over time, primarily through mechanisms such as erosion, sediment transport, and deposition [*Knighton, 2014*]. Channel processes in river systems are fundamentally shaped by the interaction of hydrological, geological, and geomorphological factors. Among these, extreme hydrometeorological events such as debris flows represent a critical yet often underexplored factor influencing channel morphology, sediment transport, and floodplain dynamics, particularly in foothill plains. Foothill plains, situated at the transitional zone between highland source areas and lowland depositional zones, are especially susceptible to the geomorphic and hydrological impacts of such flows due to their geomorphic gradient, sediment availability, and hydrological connectivity with upstream mountainous terrains [*Smith et al., 2015; Johnson, 2020*].

Debris flows are water-saturated slurries of sediment, usually a heterogeneous blend of clay, silt, sand, gravel, and large clasts are moved downhill because of intense rainfall, rapid snowmelt, or glacial outburst events [*Jakob & Hungr, 2005*]. Intermittently or continuously, these flows may happen as part of a series of sediment-rich floods associated with high concentration of sediments and high energy available for transport. Similarly, when these flows reach the river channels of the foothills, they present uncontrolled deposition accompanied with aggregational evolution of the contours of the channel system, lateral shifts, and avulsions resulting from excessive sediment supply [*Marchi et al., 2009*]. Resulting from the interplay of all these factors, which serve as the main basis for such variability, the overall orientation of the network of channels is rearranged, improves the hydraulic geometry of the system and increases ratio of bank overtopping events and reconfiguration of the channel layout.

The foothill plains, which serve as a transition area for sediment transport from the mountains to the lowland basins, are critical to channel development under the influence of debris flows. The deposited sediment is highly bras for debris flows and is highly responsive to episodic sediment replenishment and quick morphological shifts [*Brierley & Fryirs, 2005*]. The severe overload of poorly graded sediment caused by debris flows shifts the equilibrium state of a system — in this case the balance between erosion and sediment accumulation — leading to more pronounced vertical and lateral changes. Transition alluvial fans and lobes are frequently produced along with other incoherent channel fills due to bank failure and increased sediment deposition that meandering fine sediment flows create and are aggravated by cohesive fine cabin debris flows [*Costa & Williams, 1984*].

Multiple global studies have confirmed that debris flows can induce perpendicular and parallel changes to riverbeds impacting sediment transport, flow hydraulics, and channel equilibrium [*Jakob & Hungr, 2005; Rickenmann, 1999*]. In these regions, the shift from steep gradients to gentle ones increases the rate of sediment capture alongside channel aggradation [*Pierson, 2005*].

Dynamics of river morphology is influenced by destructive and rapid processes of mass wasting in the mountainous and hilly regions which incorporate debris flows. The study of these processes and their impact on channel dynamics has been done in many geoclimatic settings, including the south-east part of Greater Caucasus especially Shirvan zone river basins, where high topography, and easily erodible sedimentary rocks give abundant supply of sediments form ideal conditions for the occurrence of debris flows.

Studies in the Shirvan zone rivers have emphasized that sediment transport dynamics in foothill rivers are highly sensitive to external disturbances like debris flows, which alter cross-sectional geometry and increase the frequency of channel avulsions [*Jafarov & Ismayilov, 2015*]. The river basins on the southern slope of the Greater Caucasus are significantly influenced by debris flows. These rivers, formed in sedimentary rock basins, are highly susceptible to erosion and channel instability. In recent decades, climate change has led to an increase in short-duration, high-intensity rainfall events, causing a corresponding rise in flood and debris flow frequency. As a result, there has been growing concern regarding the impact of these processes on riverbed morphology, infrastructure, and agricultural productivity in the foothill plains.

This study seeks to address this research gap by examining the influence of debris flows on the channel processes of foothill plains. Specifically, it aims to identify and characterize the morphological changes induced by debris flows in foothill channel reaches, to analyze the spatial and temporal patterns of sediment deposition and channel migration, and to assess the implications for flood risk and channel management. Using a combination of field surveys, remote sensing data, and hydromorphological modeling, the research provides new insights into the role of episodic sediment-laden flows in reshaping alluvial environments at the mountain-front interface.

Understanding the influence of debris flows on foothill channel processes is vital for both scientific knowledge and practical applications. It informs sediment budget estimations, improves predictive modeling of channel evolution, and supports the design of resilient infrastructure and mitigation strategies in vulnerable foothill zones. As such, this investigation contributes to a more comprehensive framework for fluvial landscape management under conditions of increasing geomorphic instability [*Chalov, 2008*].

Channel processes encompass the dynamic morphological changes occurring within river channels because of both natural and anthropogenic influences. These processes include sediment transport and deposition, bank erosion, and the formation or alteration of various channel geomorphic features [*Chalov, 2016*]. The manifestation of channel processes varies seasonally, influenced by the river's hydrological regime, climatic conditions, geological structure of the riverbed, and environmental characteristics.

A key determinant of the temporal dynamics of channel processes is the seasonal variation in the phases of the river's water regime. During the spring-summer flood period, increased snowmelt and intense precipitation lead to a significant rise in river water levels. This rise, in turn, increases flow velocity, which accelerates bank erosion, intensifies sediment transport, and promotes the development of new channel features such as sandbars and islands. In contrast, during the low-water season, river discharge decreases markedly, resulting in lower flow velocities. These conditions favor the deposition of suspended sediments within the channel and significantly reduce the intensity of bank erosion [*Nuriyev et al., 2024*].

Channel processes occurring throughout the hydrological year result in progressive transformations of river morphology. Depending on hydrodynamic conditions, various forms of channel deformation can be observed, including changes in the longitudinal profile such as sediment deposition in the flow direction, formation of shallows, incision of the riverbed, or its infilling with silt. Simultaneously, the cross-sectional profile of the river channel may also be altered. Lateral erosion of one riverbank can coincide with sediment accumulation on the opposite bank, resulting in lateral channel migration [*Chalov, 2011*]. Vertical channel deformations, such as incision due to increased flow velocity or aggradation resulting from sediment deposition under reduced flow conditions, also play a significant role in shaping river morphology.

Study area

The Shirvan rivers were selected as the focus of this study due to their significant hydrological and geomorphological characteristics. The study area encompasses a total of 53 rivers, comprising five main rivers and 48 tributaries. The Girdimanchay basin hosts the greatest number of rivers, totaling 12, while the Agsuchay basin contains the fewest, with six tributaries. The remaining main river basins each include approximately 10 tributaries [*Mammadov, 2012*]. Geomorphologically, the young mountainous terrain of the Greater Caucasus is characterized by the development of canyons and V-shaped valleys. Typically, upstream segments of rivers such as the Türyanchay, Goychay, and Girdymanchay are incised canyons, transitioning to V-shaped valleys closer to the Shirvan plain. These valley forms reflect the steep longitudinal gradients and high flow velocities prevalent in these areas, combined with the presence of relatively erodible sedimentary rocks in the basins. Consequently, vertical erosion predominates, resulting in narrow valley bottoms flanked by steep slopes. During spring and rain floods, alluvial sediments deposited within valley bottoms are transported downstream. Moving into the plains, river gradients decrease, and valley cross-sections typically widen into box-shaped forms. However, variations in local relief and geological structure occasionally disrupt this pattern. Such deviations are evident along sections of Shirvan rivers that traverse the Ajinohur foothills. Climatic data indicate that the annual precipitation in the region varies substantially, ranging from 250 to 1700 mm. Similar to other mountainous regions in Azerbaijan, precipitation exhibits a distinct altitudinal pattern: it increases from the lowland plains toward the mid-mountain zones before decreasing again at higher elevations. Specifically, potential evaporation rates vary accordingly, measuring approximately 800–1000 mm in the plains, 600–800 mm in the mid-mountain areas, 300–400 mm in the high mountainous regions, and decreasing further to around 200 mm near the highest mountain peaks [*Mahmudov, 2018*].

Precipitation is predominantly concentrated in the summer months, coinciding with the rainy season. In the Gabala and Oguz settlements, for instance, 32.3% and 33.1% of the annual precipitation occur during summer, respectively. Conversely, the lowest precipitation levels are observed during winter, accounting for 14.9% and 15% of the annual totals in these areas. Spring and autumn contribute differently, with spring accounting for 21.6% and 20.4%, and autumn 31.2% and 31.5% of the annual precipitation in Gabala and Oguz, respectively [*Nuriyev, 2021, Mammadov, 2012*].

The development of the river network within the Shirvan region is intimately linked to the area's relief dynamics, particularly the large-scale morphostructural formations. Geological analysis of Tertiary rock formations revealed that within the Greater Caucasus Uplift zone, rivers developed predominantly parallel drainage systems that correspond to the underlying morphostructural divisions of the mountain ranges. The tributaries of major rivers dissect the ascending mountain slopes. During the Neogene period, rapid tectonic uplift combined with river confluences in the Shirvan zone resulted in the establishment of the contemporary river network.

All rivers in the Shirvan region – namely Alijanchay, Turyanchay, Goychay, Girdimanchay, and Agsuchay – are left-bank tributaries of the Kura River. The principal morphometric characteristics of these rivers and their respective basins are summarized in Table 1.

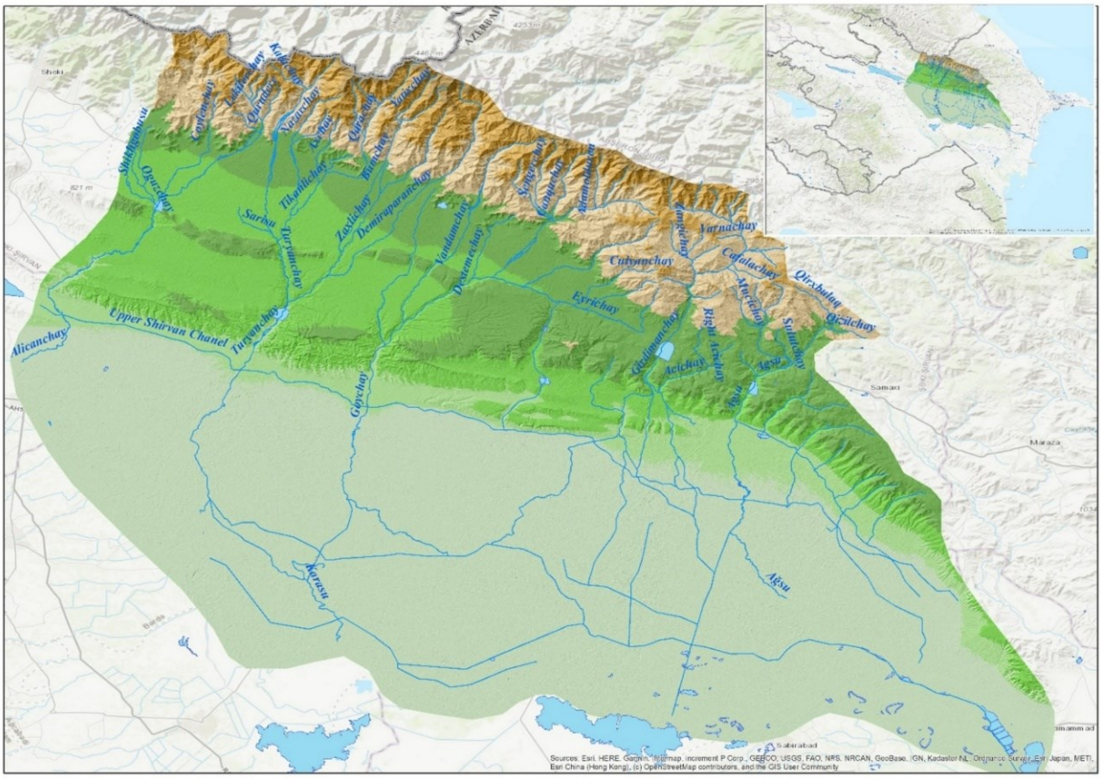

Fig. 1. Study area

Table 1. Main morphometric parameters of rivers and their basins

River name	Length, km	Catchment area, km^2	Source elevation, m	Month elevation, m	Average catchment elevation, m	Average river slope, ‰	River network density, km/km^2
Alijanchay	91	1010	3500	13	574	38.3	0.47
Türyanchay	170	1840	3680	-4	819	21.7	0.50
Goychay	113	1770	1980	-1	538	17.5	0.48
Girdimanchay	88	727	2900	15	810	32.8	0.48
Agsuchay	89	572	2100	-2	666	23.6	0.46

The average river network density within the Shirvan zone is 0.48 km/km², which exceeds the regional average for Azerbaijan (0.39 km/km²) by approximately 20% [*Museyibov, 1998*]. Among the rivers studied, river network density varies slightly, ranging from 0.46 km/km² in the Agsuchay basin to 0.50 km/km² in the Türyanchay basin [*Mammadov, 2012*]. The relatively short north-south extent and the steep gradients characteristic of the Greater Caucasus segment within the Shirvan zone contribute to an accelerated denudation process. This effect is especially pronounced in the Turyanchay basin, where the river network is subject to ongoing natural morphodynamic changes.

Materials and methods

To quantify the influence of debris flows on river channel deformation, comprehensive fieldwork was carried out from 2013 to 2021 in the Shirvan region. Seven rivers were selected for detailed study. Additionally, historical changes in river channel configuration were analyzed by comparing topographic maps from 1970 with modern high-resolution satellite imagery (1.5 m) obtained from the Azersky satellite, operated by the Azercosmos Agency.

Results and discussion

In recent times, anthropogenic influences have accelerated alterations within the natural hydrographic network. Although all Shirvan rivers are left-bank tributaries of the Kura River, historically, most did not discharge directly into the Kura's main channel. Instead, their waters were lost in the Garasu depressions — significant low-lying areas located south of the rivers' confluence. Two primary Garasu depressions exist in the study region: the Shirvan Garasu and the Zardab Garasu. The Shirvan Garasu, the larger of the two, formed within the ancient floodplain of the Kura River. It historically received substantial water inflows during spring floods and flood events, primarily due to breaches in the Kura's earthen banks. However, the construction of the Mingachevir reservoir, which regulates Kura River flows, effectively curtailed additional inflows to the Shirvan Garasu, resulting in its progressive drying. Stretching approximately 134 km, the Shirvan Garasu represents a continuation of the Goychay River. The Zardab Garasu, a direct extension of the Türyanchay, flows independently into the Kura near the city of Zardab. Presently, only the Alijanchay flows directly into the Kura River, whereas the other Shirvan rivers discharge into the Shirvan or Zardab Garasu depressions. Water accumulated in these depressions is subsequently channeled into the Kura River via artificial canals.

In the rivers of the Shirvan region, intensive channel processes have led to frequent channel migrations, flow bifurcations, and changes in the number and configuration of active channels. These dynamic conditions complicate the establishment of reliable stage-discharge relationships at hydrological observation stations. To address this challenge, an analysis of channel deformations in Shirvan rivers was conducted through the comparison of cross-sectional profiles obtained during field surveys.

Field investigations were carried out during four distinct phases of the water regime in 2013 — March, May, August, and December — across seven representative rivers. During each survey, characteristic cross-sections were selected for measurement. The reference points of each observation site were first established, and their geographical coordinates were determined using GPS technology (Garmin). Subsequently, detailed measurements were conducted to construct cross-sectional profiles of both the river valleys and their channels, using the temporary benchmarks as reference points.

Comprehensive information on the locations of the measured cross-sections, including the geographical coordinates and absolute elevations of the reference points, is presented in Table 2 [*Imanov, Nuriyev, 2012*].

Table 2. Geographic coordinates and absolute elevations of the reference points

No.	River – observation point	Geographic coordinates		Height of the reper, m
		Latitude	Longitude	
1	Aghsuchay – 3 km above the bridge	40°35.709’	48°24.347’	231
2	Girdimanchay – 100 m above the bridge	40°38.895’	48°14.387’	401
3	Goychay-Buynuz	40°55.717’	48°04.073’	791
4	Vandamchay – 30 m below the bridge	40°57.103’	47°55.932’	777
5	Demiraparanchay-Gabala	40°58.791’	47°51.863’	818
6	Tikanlychay-Tikanly	41°00.671’	47°45.221’	763
7	Bumchay-Bum	41°02.520’	47°46.981’	976

River discharge was determined using the velocity-area method [*Mammadov et al., 2000*], which involves calculating the product of the average flow velocity and the area of the cross-section. To measure flow velocity, GNSS-1 (Russian Federation) and PASCO (USA) flow meters were employed. Velocity measurements were conducted using both point-based and integration methods, with the arithmetic means of the obtained values used in the final calculations. The PASCO device offers a particular advantage due to its ability to account for velocity fluctuations, thereby providing a more precise and reliable estimate of the mean flow velocity.

Field investigations demonstrate that these rivers exhibit either single-thread or multi-thread channel patterns depending on the prevailing hydrological regime. Furthermore, their morphometric characteristics fluctuate periodically in response to seasonal and interannual hydrological variations.

In the case of Girdimanchay, observations indicate that the river develops a multi-thread structure during spring, while in summer, a marked reduction in both the number of active channels and discharge leads to the intensification of intra-channel erosion and sedimentation processes. A comparative analysis of measurements from 2013 and August 2021 documented vertical channel incision reaching up to 2 meters, with an estimated average rate of vertical erosion of approximately 10 cm per year.

Goychay River exhibits similar seasonal variability, displaying 2 to 5 channels during spring, and predominantly a single-thread configuration in winter and summer. Between 2013 and 2021, channel deepening up to 2 meters was observed, accompanied by increased lateral erosion, particularly along the left bank (Fig. 2). The thickness of alluvial deposits accumulated in certain segments exceeded 1 meter. The annual rate of vertical erosion was estimated at 6.25 cm per year.

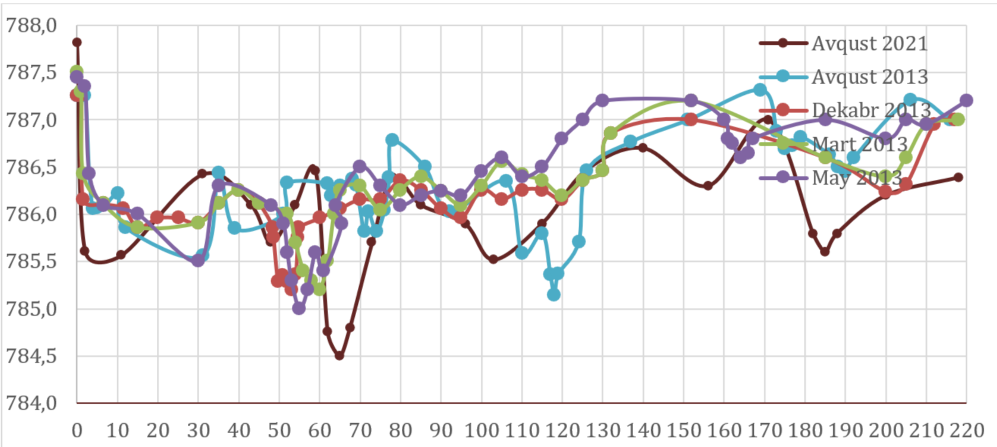

Fig. 2. Cross section of Goychay river

Damiraparanchay also demonstrates pronounced seasonal channel variability, with 2 to 3 branches present during spring and a single-thread configuration recorded in August and December. Over the eight-year period, bottom erosion amounted to 55 cm, corresponding to an average annual rate of 6.88 cm. Additionally, lateral migration of the channel was noted, with a discernible shift toward the left bank in certain sections.

In the Tikanlichay River, channel morphology appears to be strongly influenced by the hydrological regime. During the field surveys conducted in March and May 2013, the river exhibited a multi-thread structure comprising 2 to 3 branches. The height of sediment deposits accumulated between these branches reached up to 1.5 meters. Observations up to 2021 indicate that bed incision and sediment accumulation processes have continued to evolve in parallel.

Temporary monitoring of the Vandamchay River revealed that its channel morphology alternates between single- and double-branched configurations depending on the prevailing hydrological regime. During the spring and summer months of 2013, notable horizontal channel shifts and sediment accumulation were observed, whereas by August and December, the flow was confined to a single active channel. In contrast, observations from August 2021 indicated a return to a bifurcated channel pattern, accompanied by significant bed erosion measuring up to 140 cm, with an annual washout intensity estimated at 17.5 cm per year.

The Bumchay River is characterized by a V-shaped valley, where a single-branch flow was documented in 2013, transitioning to a double-branch flow by 2021. Intensive lateral erosion on the left bank led to a bottom deepening of 114 cm, corresponding to an annual erosion rate of 14.3 cm per year. Additionally, the influence of an active ephemeral stream, responsible for episodic flood events and substantial sediment transport, was noted in this section of the river.

Seasonal variability in channel morphology was also evident in the Agsuchay River. In 2013, a single-channel flow was recorded, whereas by December of the same year, three distinct channels had developed. Although the river remained predominantly single-branched in August 2021, bed erosion was pronounced, reaching 3.40 meters with an exceptionally high annual erosion intensity of 42 cm per year. These pronounced morphological changes are primarily attributed to the impacts of a hydroelectric facility constructed in the upper reaches of the river, alongside the planned Agsuchay reservoir. While the facility mitigated horizontal channel deformation processes, it concurrently accelerated vertical erosion, thereby altering the sediment transport dynamics within the river system.

Overall, comparative analysis across all four rivers between 2013 and 2021 underscores the high degree of morphodynamic activity and variability in channel structure, closely tied to seasonal and hydrological fluctuations. In particular, the spring-summer period is characterized by elevated discharge resulting in increased incision and erosion, while the dry seasons promote sediment deposition and accumulation. These findings reflect the dynamic behavior of river systems in the region and the influence of both climatic variability and anthropogenic factors on channel evolution.

The comparative analysis of cross-sectional profiles from 2013 to 2021 revealed notable vertical channel deformations ranging from 6.25 to 42.00 cm per year. These variations are largely attributed to debris flow activity, which contributes to both erosion and sediment deposition in different river sections.

Satellite and map-based analysis of long-term river dynamics also indicated significant lateral migration and morphological alterations, particularly in areas repeatedly affected by debris flows. This demonstrates the dual impact of debris flows: they both excavate and aggrade channel segments, leading to increased channel instability and frequent shifts in river alignment.

The assessment of spatio-temporal changes in channel morphology plays a crucial role in the management of alluvial river systems [*Andrew et al., 2000, Brierley et al., 2008, Downs et al., 2013, Gregory, 2006*]. In the Shirvan river basins, rapid agricultural development, the construction of reservoirs and canals, and riverbank reinforcement have led to significant anthropogenic alterations in river channels. To analyze long-term channel deformations, a comparative study was conducted using topographic maps from the 1970s and high-resolution satellite imagery (1.5 m resolution) acquired from the Azersky satellite, as part of the Azercosmos Agency's project titled "Promotion of Remote Sensing Services of the Earth's Surface for the Sustainable Development of Azerbaijan."

Unlike traditional ground-based observation methods, remote sensing enables the rapid acquisition of extensive spatial information, facilitating the resolution of numerous large-scale environmental and hydrological issues. The ability to access and utilize aerospace-derived data directly for practical applications underscores its growing importance in river basin management.

This analysis encompasses the entire course of the Turyanchay River, from its source to its mouth. In the upper reaches, particularly along the Galachay (Aghchay) tributary up to the village of Filfili (elevation: 1146 m), no significant morphological changes were detected. However, the expansion of the village and the development of agricultural areas within the river's floodplain were observed. Additionally, bank stabilization measures have disrupted the natural connection between the riverbed and the floodplain. Although a multi-channel system persists in this section, the riverbed width has narrowed significantly — from approximately 600 meters to 240 meters.

Below the village of Khachmaz, the valleys of Agchay and Nazarchay become narrower, and the formerly braided channel transitions into a single-thread stream, resulting in more concentrated flow. Following the confluence of the Daimadera River with Sarisu and subsequently with Agchay, and then the merger of Sarisu with Nazarchay near the village of

Tarkesh, the river assumes the name Turyanchay. In this segment, water withdrawals and anthropogenic influences on the river's regime have historically been minimal.

The construction of the first hydraulic structure in this part of the Turyanchay — the water intake facility near the village of Garabulaq—began in 2019 and was commissioned in 2021 (see Fig. 3). The primary function of this facility is to pump water from the river (at an elevation of 300 m) to the Boyuk Soyudlu reservoir, which is located at an altitude of 520 m and has a storage capacity of 750,000 m³. The reservoir supplies irrigation water to approximately 3,000 hectares of walnut, hazelnut, and olive orchards in the vicinity of the village of Boyuk Soyudlu.

(a) (b)

Fig. 3. Satellite images of the river section before (a) and after (b) the construction of the Garabulaq intake structure. a – Satellite image from 2012; b – Satellite image from 2023

A comparison of satellite images reveals that 312 meters upstream of the Garabulaq intake structure, the width of the river increased from approximately 160 meters to 248 meters. Field observations confirm noticeable subsidence of the levees in the upstream section of the dam, indicating possible hydromorphological responses to the construction.

Approximately 10 km downstream from the confluence of the Turyanchay and Karachay (Demiraparanchay), the Turyanchay watershed operates. Upstream of this watershed, two aggregate extraction sites were active on the river’s left bank in 2013, directly opposite the Turyanchay State Nature Reserve. These operations led to significant bottom erosion, with bank scouring ranging from 50 to 111 centimeters. The intensity of erosional processes increased further downstream of the watershed. In the lower reaches, extending to the confluence with the Garasu River, the valley progressively narrows, and vertical deformations of the riverbed become more pronounced.

In the 1970s, the lower reaches of the Shirvan rivers were characterized by a network of swamps and lakes forming part of the “Shirvan-Garasu” river-lake system. This system received inflow from smaller rivers – such as the Agsuchay, Girdimanchay, Goychay, and Turyanchay – originating from the southern slopes of the Greater Caucasus, ultimately discharging into Lake Hajigabul. At its peak, the Garasu river-lake system extended over 120 km and, prior to the regulation of the Kura River, would also receive floodwaters from its tributaries.

Following the construction and operation of the Mingachevir Reservoir, and the artificial diversion of the Turyanchay and Goychay rivers into the Garasu via man-made channels, floodwaters ceased to reach the Shirvan-Garasu system. Consequently, in line with the expansion of agricultural activities, the area was subjected to extensive drainage and land reclamation efforts.

A multi-year analysis of channel deformations indicates that horizontal channel shifts are largely absent in the upper reaches of the river. In these segments, the river maintains a relatively uniform flow pattern up to the upper boundary of the forest belt, suggesting a higher degree of channel stability.

In contrast, portions of the lower reaches exhibit limited meander migration, with most meanders showing a trend toward stabilization. This phenomenon can primarily be attributed to significant reductions in downstream flow, caused by the diversion and abstraction of river water for irrigation in the upper reaches or through artificial channel modifications. As a result, the river often fails to deliver water to its terminus, particularly at its confluence with the Agsuchay.

In the mouth sections of the rivers, the active channel narrows to a width of approximately 3–5 meters, and the riverbed and banks are predominantly composed of fine-grained clayey-silty sediments. In these areas, the influence of anthropogenic activities – such as irrigation infrastructure, channel modifications, and flow regulation – on channel deformation processes is more pronounced than the effects of natural hydrological or geomorphological dynamics.

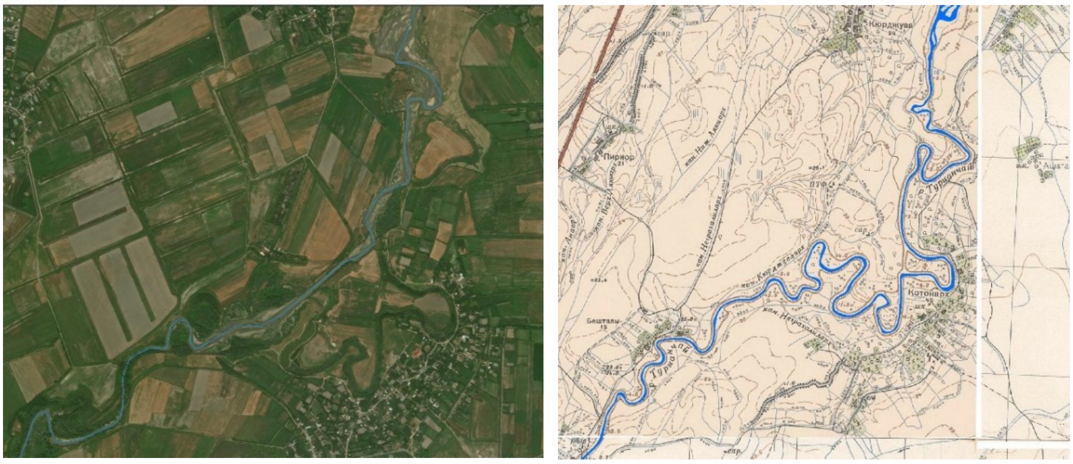

Fig. 4. Channel deformations in the lower reaches of the Turyanchay River

Conclusion

Recent anthropogenic activities have significantly altered the natural hydrographic network of the Shirvan region. Although all Shirvan rivers are left-bank tributaries of the Kura River, historically, most did not flow directly into the main Kura channel. Instead, their waters drained into two major low-lying depressions – the Shirvan Garasu and the Zardab Garasu. The Shirvan Garasu, located in the ancient floodplain of the Kura, historically received large inflows during spring floods, largely due to breaches in the Kura’s earthen banks. However, after the construction of the Mingachevir reservoir, which regulates Kura flows, the inflows to the Shirvan Garasu diminished drastically, causing progressive drying. Currently, only the Alijanchay River flows directly into the Kura, while other rivers discharge into the Garasu depressions, with water from these areas channeled artificially back to the Kura River.

Field investigations in 2013 across seven key rivers documented complex channel dynamics characterized by seasonal shifts between single-thread and multi-thread channels. These rivers show pronounced morphometric variability driven by seasonal and interannual hydrological changes. For example, Girdimanchay transforms into a multi-thread river during spring floods but reverts to fewer channels with lower flow in summer, enhancing erosion and sediment deposition. Over eight years, significant vertical incision, up to 2 meters deep, has been observed in several rivers, with erosion rates ranging from approximately 6 to 42 centimeters per year depending on the river and location.

The Goychay River similarly exhibits seasonal variability, with up to five channels during spring and a single-thread channel in dry seasons. Intensive lateral erosion has been noted, especially along the left banks, accompanied by alluvial sediment accumulation. Damiraparanchay and Tikanlichay rivers show comparable patterns of channel branch reduction and erosion, with lateral migration shifting channels predominantly toward one bank. Vandamchay and Bumchay rivers demonstrate alternating channel patterns influenced by hydrological conditions and sediment transport, with high erosion rates linked to episodic flood events.

The Agsuchay River presents some of the most dramatic channel changes, with the channel incision reaching 3.4 meters over eight years. This intense vertical erosion is associated with hydroelectric developments and reservoir construction, which have modified sediment transport and reduced lateral channel shifts.

Long-term comparative analysis of cross-sectional profiles between 2013 and 2021 confirms high morphodynamic activity across all studied rivers. These changes reflect complex interactions between natural hydrological variability and human interventions such as reservoir construction, water withdrawals, and bank reinforcements. Remote sensing analysis of the Turyanchay River basin corroborates these findings, revealing significant riverbed narrowing, channel stability in upper reaches, and channel constriction with increased erosion in lower reaches. Additionally, hydraulic infrastructure development, like the Garabulaq water intake, has altered river morphology, causing localized channel widening upstream and levee subsidence.

Historically, the lower reaches of the Shirvan rivers featured extensive wetlands and lakes as part of the Shirvan-Garasu river-lake system, which disappeared after regulation of the Kura River and land reclamation for agriculture. Presently, artificial diversions and flow reductions have led to narrowing and channel instability in the rivers' lower courses, with some sections unable to deliver water to their natural endpoints.

Overall, these findings highlight the dynamic and fragile nature of the Shirvan river systems, where both natural and anthropogenic factors drive rapid morphological transformations, necessitating careful management to balance environmental sustainability and regional water resource needs.

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