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Article

Channel Deformation Processes in the Amu–Bukhara Machine Canal

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Abstract: In this article, the channel deformation processes in the Amu–Bukhara Machine Canal and the main factors causing them were identified through field investigations and hydraulic modeling. The research results showed that during the period from January to May, the concentration of suspended sediments entering the canal is lower than the sediment transport capacity of the flow, which leads to channel erosion processes. From August to December, however, gradual sediment deposition can be observed within the channel. Field observations indicated that sediment accumulation in the canal mainly occurs in the section extending from the canal headworks to survey station PK1520. The measured suspended sediment concentration was found to decrease along the canal length, demonstrating that the volume of deposited sediment gradually decreases from the headworks toward PK1520.

Keywords: Channel Deformation, Suspended Sediments, Flow Transport Capacity, Sediment Concentration, Hydraulic Modeling using the HEC-RAS Software.

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1. Introduction

The "Concept for the Development of the Water Management Sector of the Republic of Uzbekistan for 2020–2030" was adopted as a ten-year strategy for the development of the country's water sector. According to this concept, it is planned to increase the efficiency coefficient of irrigation networks from 0.63 to 0.73 by 2030 [1]. To achieve these objectives, it is essential to identify the channel deformation processes occurring in existing irrigation systems and determine the main factors causing them [2], [3]. Although irrigation channels are required to be statically stable according to construction norms and regulations, variations in flow and sediment parameters throughout the year often lead to channel deformation, particularly in unlined channels [4].

At present, channel deformation processes are observed in major canals supplied by the Amu Darya River due to the high concentration of suspended sediments carried by the flow. In some reaches of the Amu–Bukhara Machine Canal, erosion processes are observed, whereas in other

reaches sediment deposition predominates [5]. To provide a scientific assessment of these processes and identify the factors responsible for channel deformation, field measurements and observations were conducted, and hydraulic modeling was performed for selected canal reaches using the HEC-RAS software [6], [7].

2. Materials and Methods

An analysis of the monthly average flow discharge diverted from the Amu Darya River into the Amu–Bukhara Machine Canal in 2023 shows that the highest discharges, ranging from approximately 330 to 360 m^3/s, occurred during June–August, while the lowest discharges, ranging from approximately 95 to 110 m^3/s, were observed during October–November (Figure 1).

Field observations indicate that channel deformation processes are occurring in certain reaches of the Amu–Bukhara Machine Canal (Figure 2).



Figure 1. Diagram of the variation in the total monthly average flow discharge diverted from the Amu Darya River into the Amu–Bukhara Machine Canal in 2023.



Figure 2. Erosion observed at channel station PK 1099 of the Amu–Bukhara Machine Canal.

The graph of flow discharge and the corresponding flow velocity calculated using the HEC-RAS software at survey station PK 1170 of the Amu–Bukhara Machine Canal during 2023 shows that these parameters varied significantly on a seasonal basis (Figure 3).

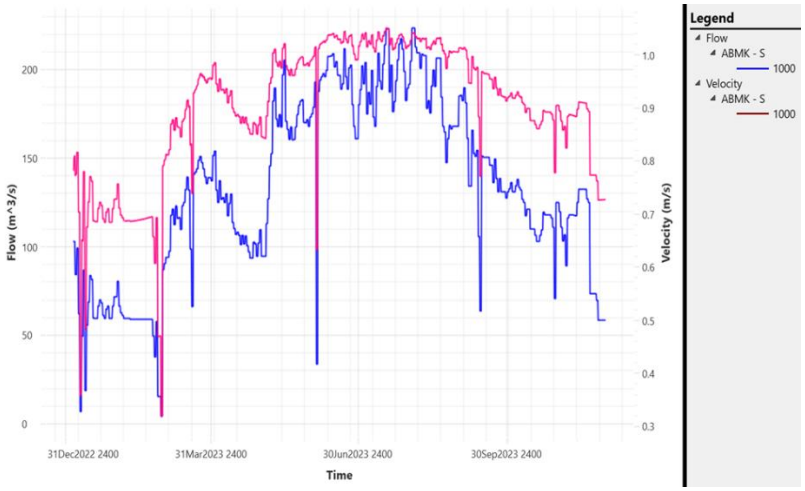


Figure 3. Variation of flow discharge and flow velocity at PK 1170 of the Amu–Bukhara Machine Canal during 2023.

During the winter months, the flow discharge was mainly observed in the range of 50–120 m^3/s, while the flow velocity was approximately 0.55–0.75 m/s. Starting from March, the discharge increased and reached 200–220 m^3/s during April–August, with flow velocities of about 0.95–1.05 m/s. The graph also shows some periods of sharp decreases in discharge and velocity; after September, both parameters gradually decreased.

Figure 4 presents the variation of the Froude number and shear stress at the PK1170 cross-section of the Amu–Bukhara Machine Canal during 2023. According to the graph, the Froude number remained mainly within the range of 0.14–0.34, indicating that the flow regime remained subcritical throughout the year.

The shear stress values were around 1–2 Pa at the beginning of the year, then increased to 3–5 Pa, and in some cases approached 8 Pa by the end of the year. This indicates that the forces acting on the canal bed increased due to the rise in flow discharge and velocity.

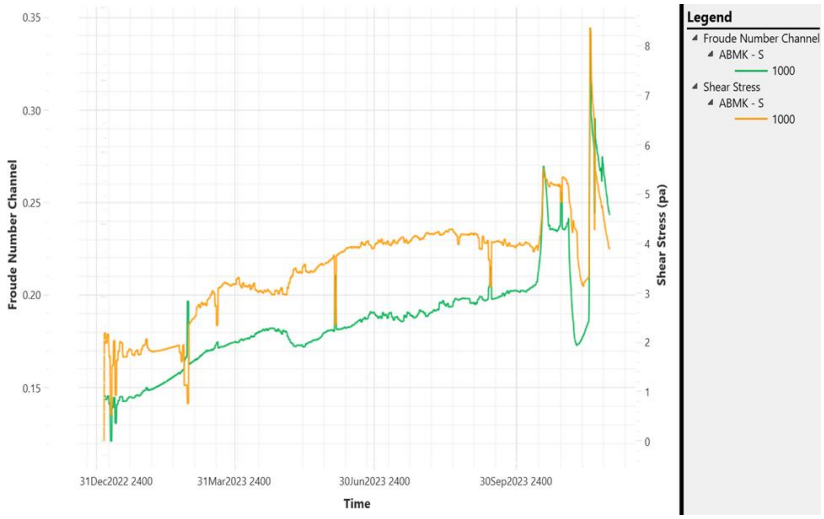


Figure 4. Variation of the Froude number and shear stress calculated using the HEC-RAS software at PK 1170 of the Amu–Bukhara Machine Canal during 2023.

Since the majority of suspended sediments in the Amu–Bukhara Machine Canal consist of fine-grained silt and fine sand particles, it was considered appropriate to use Laursen (Copeland) method for calculating the total sediment load in the suspended form when modeling sediment transport.

3. Results and Discussion

An analysis of the measured sediment concentration data at different flow discharges diverted from the Amu Darya River into the Amu–Bukhara Machine Canal during 2023 shows that the suspended sediment concentration increased correspondingly with an increase in flow discharge.

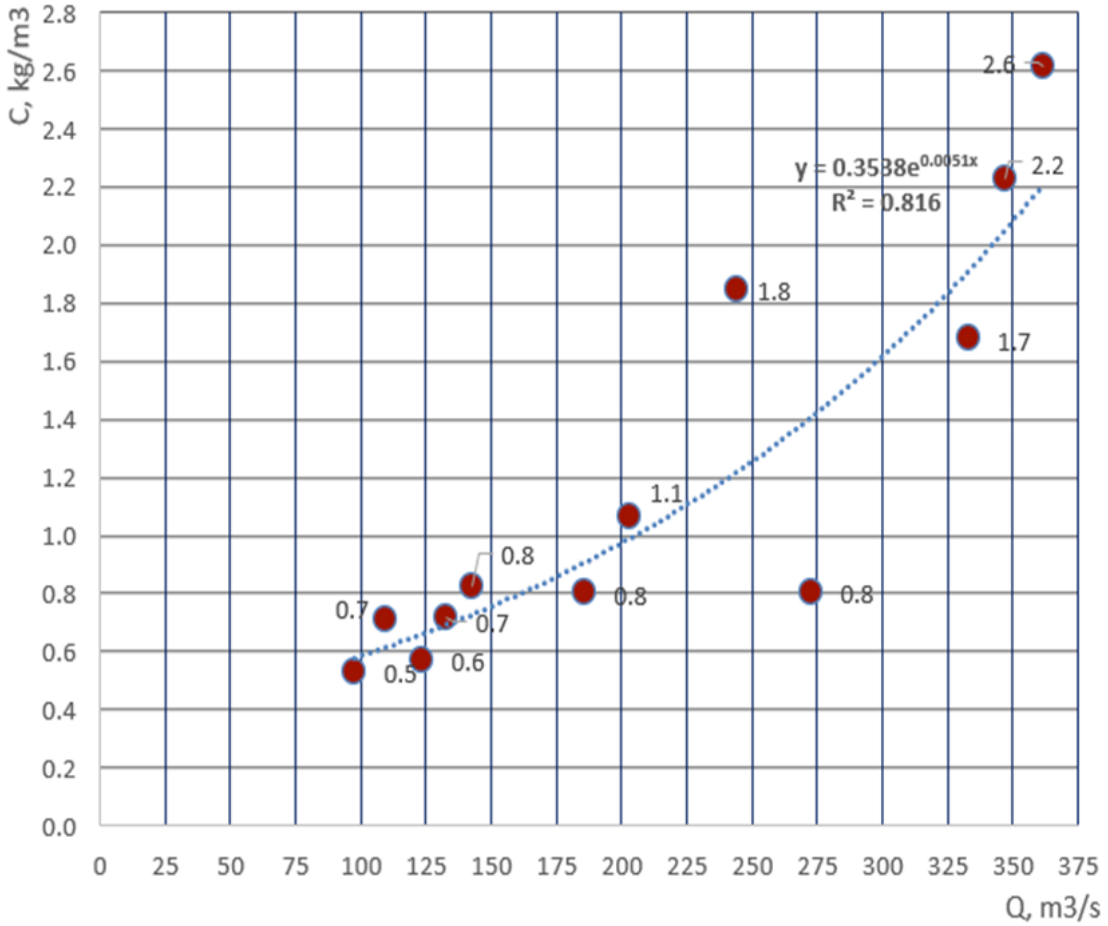


Figure 5. Measured sediment concentration at different flow discharges in the Amu–Bukhara Machine Canal during 2023.

According to the data obtained from the Amu–Bukhara Machine Canal Operation Department, the monthly amounts of sediments entering the Amu–Bukhara Machine Canal from the Amu Darya River and deposited along different sections of the canal are presented in Table 1. The data show that a total of 11,799,712 m^3 of sediment was deposited within the canal system during 2023. The highest sediment deposition was observed in June and July, amounting to 2,467,284 m^3 and 2,711,025 m^3, respectively. This indicates that during this period, both the flow discharge and sediment concentration were relatively high.

Table 1. Data on the amount of total sediment deposited along different sections of the Amu–Bukhara Machine Canal from the Amu Darya River during 2023, according to the ABMK Operation Department (m^3).

#	Months	From Amu Darya to station PK28+00. (m3).	From PK28+00 to station PK137+00	From station PK137+70 to station PK492+00, channel AB-1 (m3).	From station PK00+00 station PK311+00, channel AB-2. (m3).	AB1-AB2 channels up to station PK1520+00 (m3).	From stationPK1520 to Q.Mozor pumping station (m3).	From stationPK1520 to Q.Tepa pumping station (m3).	Total (m3)
1	January	164767	22343	23789	104638	11781	0	0	327318
2	February	308326	41283	21575	20136	33181	4749	0	429250
3	March	336054	57479	24066	15310	51672	3384	0	487965
4	April	506541	151849	64919	43066	74356	3023	0	843754
5	May	998456	230100	110765	83521	173244	9481	8189	1613756
6	June	1594627	311639	175076	128510	217030	18665	21737	2467284
7	July	1711130	346530	168913	94569	320979	27802	41102	2711025
8	August	1254224	246113	96093	82223	144473	13841	21155	1858122
9	September	258208	46442	18958	18709	49510	4796	4646	401271
10	October	155941	21158	11318	15811	40225	3064	2064	249581
11	November	105783	17599	7609	10074	22946	1164	528	165703
12	December	159568	18909	44269	0	19865	2072	0	244683
	Total	**7553625**	**1511444**	**767350**	**616567**	**1159262**	**92041**	**99421**	**11799712**

The analysis of the table data shows that sediment deposition is very high in the head section of the canal and gradually decreases along the canal length downstream. In particular, the sediment deposition volume has high values in the section from the Amu Darya River to the head structure and in the initial reaches downstream of the head structure.

As the flow moves toward the downstream sections, the amount of deposited sediment decreases because the larger and relatively heavier particles contained in the flow settle in the upstream reaches. In the downstream sections of the canal, only finer dispersed particles remain in

suspension; therefore, the sediment deposition volume is observed at relatively lower values [8], [9], [10], [11].

According to Table 1, no significant sediment deposition is observed in the section of the canal downstream of PK 1520, indicating that this part of the canal has already reached a state of near-dynamic stability. However, during the flow discharge periods from May to October, larger-diameter sediment particles capable of deposition can reach these sections, resulting in sediment accumulation.

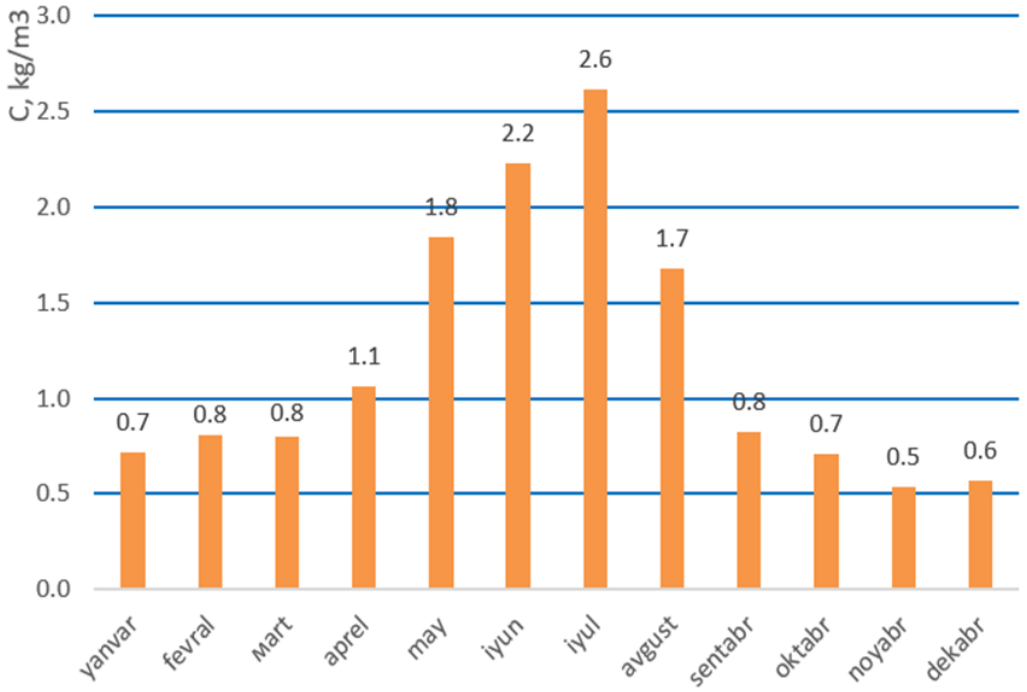


Figure 6. Suspended sediment concentration entering the AB-1 channel section from PK 492+00 to PK 1520+00 in 2023, kg/m³.

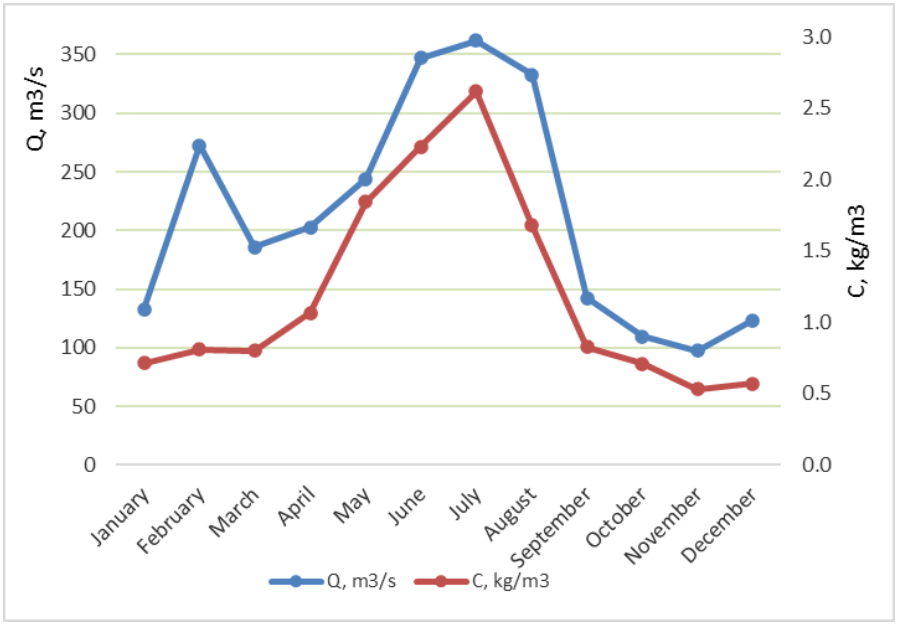


Figure 7. Observed flow discharge and sediment concentration values in the AB-1 channel section from PK 492+00 to PK 1520+00 during 2023.

The analysis of Figures 6 and 7 shows that although the flow discharge in the canal was relatively high at the beginning of the year, the sediment concentration remained low. In particular, in February, when the flow discharge reached 273 m^3/s, the sediment concentration was only 0.8 kg/m^3. A similar situation was observed in March, when the flow discharge was 186 m^3/s and the sediment concentration remained at 0.8 kg/m^3.

This situation resulted in an imbalance between the sediment transport capacity of the flow and the amount of suspended sediment entering the canal. In other words, due to the high flow discharge, the flow energy and sediment transport capacity increased; however, the amount of sediment in the flow was insufficient to satisfy this transport capacity. As a result, in order to maintain an equilibrium condition, the flow tended to erode material from the canal bed and banks [12], [13], [14], [15].

The results of sediment transport modeling using the HEC-RAS software also confirmed our field observations. When the sediment transport capacity of the flow was calculated using the Laursen (Copeland) method and the modeling was performed, erosion processes were observed along the PK1160–1182 section of the Amu–Bukhara Machine Canal during January–May 2023, while gradual sediment deposition processes occurred during August–December (Figure 8).

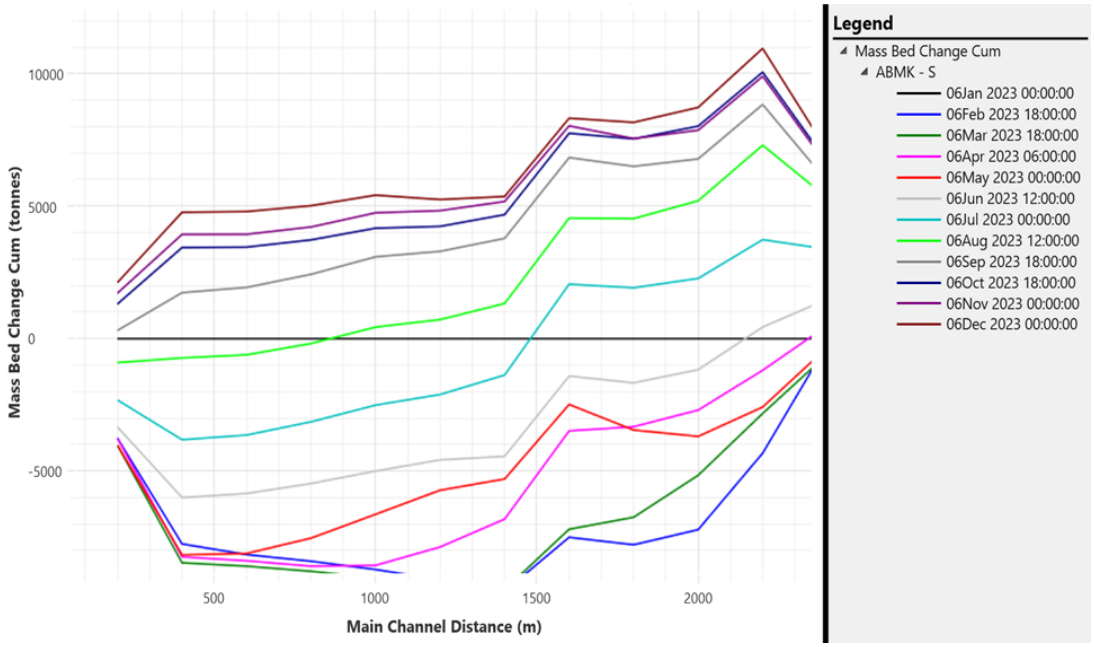


Figure 8. Variation of the total sediment mass along the PK1160–1182 section of the Amu–Bukhara Machine Canal during 2023 according to the Laursen (Copeland) method.

4. Conclusion

1. The results of field investigations and hydraulic modeling using the HEC-RAS software showed that the main factors causing channel deformation processes in the Amu–Bukhara Machine Canal are the variability of flow and sediment discharge, as well as the seasonal imbalance between the incoming sediment concentration and the sediment transport capacity of the flow.
2. The high flow discharge and relatively low sediment concentration observed at the beginning of the year intensified local erosion processes in the canal. In contrast, during the summer months, both flow discharge and sediment concentration increased significantly, leading to the activation of sediment deposition processes. Therefore, seasonal alternation of erosion and deposition processes was observed in the Amu–Bukhara Machine Canal throughout the year: channel erosion occurred during January–May 2023, while gradual sediment accumulation processes took

place during August–December.

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