A Hydraulic Performance Model of Khassa Chai River under Varying Flow Conditions

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Received: 20 November 2024 | Revised: 25 December 2024 and 9 January 2025 | Accepted: 12 January 2025

 DOI: https://doi.org/10.48084/etasr.9675

ABSTRACT

The increasing deterioration of rivers highlights the need for effective restoration mechanisms and flow management strategies to sustain the local ecosystems. This study evaluates the hydraulic performance of rivers under varying flow conditions using the Hydraulic Engineering Center-River Analysis System (HEC-RAS) model, with the Khassa Chai River as a case study. A Differential Global Positioning System (DGPS) survey was conducted along a 14 km distance, capturing 73 cross-sections of the river. The model results indicate that several reaches are at risk of flooding, revealing the need for river restoration to ensure that the cross-sections can accommodate the design discharge (1200 m³/s). These findings emphasize the importance of sediment removal and channel maintenance to enhance the river's hydraulic capacity.

Keywords-HEC-RAS model; hydraulic performance; flood risk; varied flow; climate change

I. INTRODUCTION

Rivers, often regarded as nature's lifeblood, are indispensable global resources that play a vital role in sustaining life and ecosystems. They contribute significantly to the ecological balance, human prosperity, and overall health of the planet. Recognizing and preserving their critical functions is essential for ensuring sustainable coexistence [1]. Historically, civilizations have grown near rivers. Being fundamental to life, water has shaped the development of ancient cities worldwide. Nearly all great civilizations -from the Sumerians and Assyrians to the Egyptians and Romans-recognized that their survival depended on a stable water supply. To support the growing populations, these civilizations expanded river branches and constructed canals to transport water to distant settlements [2, 3]. In recent times, the study of river flow variations has gained increasing importance, particularly as many rivers face deterioration. Addressing this issue requires the development of effective restoration mechanisms and methods to determine the necessary drainage to revitalize them. A key aspect of this process is identifying the optimal discharge levels needed to sustain the local ecosystems [4].

Extensive research has been conducted to simulate river hydraulics and unsteady flow using the One-Dimensional (1-D) HEC-RAS model. These studies have been applied to various rivers and watershed areas worldwide to evaluate river performance under different flow scenarios.

An early study on the Zaringol River Flood Plain Zoning (FPZ) project in Golestan province, Northern Iran, utilized the HEC-RAS hydraulic model to assess and manage potential flood threats. Researchers conducted a detailed analysis of a 24-kilometer stretch of the river using topographical sheets at a 1:10000 scale. This study demonstrated the importance of HEC-RAS in floodplain zone analysis, identifying flood-prone areas and proposing strategies to mitigate flood risks [5]. Similarly, the flow behavior of the Hilla River (upstream of Hilla City in Iraq) was investigated employing an unsteady flow scenario in HEC-RAS. The study focused on estimating Manning's roughness coefficient (n) along the river. The results indicated that the computed n for the Hilla River was approximately 0.027, demonstrating a high degree of agreement between the observed and computed hydrographs [6]. To analyze diverse river geometry situations, including riverbed slopes and cross-sectional variations, researchers used the Seine River in France as a case study. A 1-D unsteady hydraulic model was applied along an 89-kilometer stretch of a Seine River sub-tributary using HEC-RAS. The study assessed sub-tributary channel geometry and bed level slopes to ensure the precision of the simulated water levels and maximum depths using the Saint-Venant model. The findings suggested that the cross-sectional variations had less impact on water level simulations compared to the longitudinal description of the bed level profiles [7].

Furthermore, flood occurrences downstream of the Al Wahda dam in the Ouergha River in Morocco, were analyzed using 1-D hydraulic modeling in HEC-RAS. The study demonstrated that integrating hydraulic simulations with Geographic Information Systems (GIS) could enhance flood management strategies, particularly in cases where dam overflow remains a concern [8]. Another study evaluated eleven vegetation roughness computation techniques by incorporating them into the popular 1-D hydrodynamic flow of the San Joaquin River reach in Central California. Compared to all other techniques, a little more accurate forecast of the river stages was provided with the HEC-RAS model, as it accounted for the reconfiguration of the flexible vegetation and measured vegetation projected area. This improvement was particularly evident during flood flows surpassing the maximum calibration levels, where HEC-RAS accurately predicted the actual river stages compared to manually calibrated Manning's n values [9].

In Missouri, USA, researchers examined the impact of discharge factors on riverbank stability using the BSTEM model integrated with HEC-RAS. The study focused on a 130-kilometer section of the Lower Osage River downstream Bagnell Dam, analyzing three outflow characteristics: peak flow duration, flow drawdown rate, and low flow duration [10]. The results indicated that: (1) riverbank stability was not significantly affected by peak flow duration, especially in reaches far from the dam, (2) riverbank stability was significantly affected by sudden flow drawdown, though its effect diminished with distance from the dam, and (3) the riverbank stability value was influenced by the low-flow duration following the peak flow, with longer durations delaying dam failure at lower flows [11]. A study on the Lower Mekong River, Cambodia, utilized flood hazard maps developed from a statistical floor frequency analysis in conjunction with the HEC-RAS model. The results indicated that the Log Pearson Type III distribution provided the best fit for the historical flood data, closely aligning with both the HEC-RAS model predictions and field measurements [12].

The Khazir River in Iraq was analyzed employing an integrated HEC-RAS model extended in the Hydrological Model System (HEC-HMS) to enhance floodplains resilience. The study demonstrated a strong correlation between the HEC-HMS hydrological modeling and HEC-RAS hydraulic modeling, reinforcing the model's reliability in flood risk assessment and future flood prediction [13].

A recent review on flood risk management highlighted that HEC-RAS is a credible tool for flood modeling when compared to other hydrodynamic models [14]. In light of this, a 2-D hydrodynamic model was developed for the Tigris River in Tikrit City, Iraq, using HEC-RAS. The results showed that the western riverbanks were less susceptible to flooding due to their higher elevation, whereas the eastern banks were at greater risk [15]. A GIS-based study in Kirkuk City, Iraq, explored rainfall variability and its impact on water balance. The study predicted that the region is likely to experience rainfall shortages, increasing the risk of river drying and potentially affecting the hydraulic performance of local rivers [16]. Finally, a study on the Al-Hilla River in Iraq used HEC-RAS to evaluate the river capacity and predict future floods under various scenarios. The findings suggested that floods were more likely to occur in northern Babil Province due to the lower elevation of the terrain in this area [17]. An effective river management requires consideration of the operational and environmental constraints. Hydrodynamic models, like HEC-RAS, play a crucial role in developing river management strategies, provided that sufficient and accurate data are available.

In recent years, climate change has significantly altered river inflows worldwide, disrupting the natural flow patterns and affecting the water availability. In Iraq, this issue has been further exacerbated by the construction of dams in neighboring countries, leading to a reduction in the water supply not only in the Tigris and Euphrates Rivers, but also in their tributaries. One such affected river is the Khassa Chai River, which flows through the heart of Kirkuk City (located between latitudes 34° 35' - 35° 50' North and longitudes 43° 10' - 46° 00' East). The river experiences significant variations in the water inflow throughout the year, posing challenges to its hydraulic performance and sustainability. Figure 1 illustrates the geographical location of the Khassa Chai River within Kirkuk City. This study aims to analyze the hydraulic performance of rivers under varying flow conditions using the HEC-RAS model, with the Khassa Chai River as a case study.

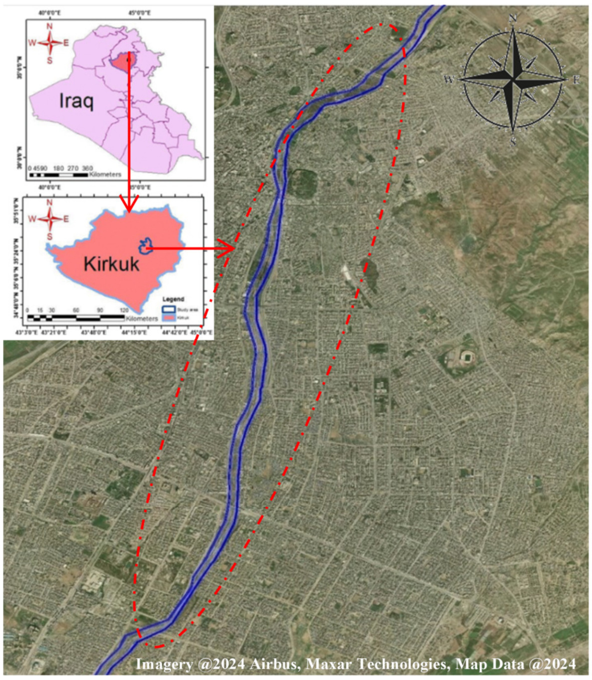

Fig. 1. The profile map of Khassa Chai river.

II. METHODOLOGY AND FIELD WORK

This section outlines the concepts and terminology related to hydraulic modeling and methodology, with a focus on the open channel flow theory and the implementation of the HEC-RAS model. The core mathematical framework of HEC-RAS is based on the Saint-Venant equations, which govern the unsteady open-channel flow by integrating the principles of mass conservation and momentum conservation [18]:

$$\frac{dy}{dt} + D_h \frac{dv}{dx} + V \frac{dy}{dx} = 0 \qquad (1)$$

$$\frac{dy}{dt} + V\frac{dv}{dx} + g\left(\frac{dy}{dx} - S_b + S_f\right) = 0 \quad (2)$$

where y is the depth of flow, v is the velocity, S_b is the bed channel slope, S_f is the water surface slope, x is the distance along the channel, t is the time, and g is the acceleration due to gravity.

The process of calculating the water surface profiles involves progressing from one cross-section to another while applying the energy equation, as portrayed in Figure 2. This calculation is performed through an iterative technique known as the standard step method, which systematically evaluates the energy terms for each section [19].

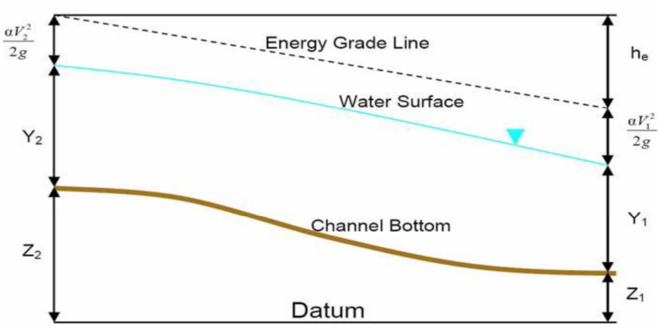

Fig. 2. Representation of terms in the mass and momentum equations.

In order to obtain numerical results and use the HEC-RAS program, the user must enter data by creating three main files within the program. The first file is the Geometric File, which contains data about the river sections and their geometrical properties, including cross-sections, channel dimensions, and the river's roughness and presence of rocks. The second file is the Flow File, which contains data about the river sections and their geometrical properties, including cross-sections, channel dimensions, and the river's roughness and presence of rocks. Finally, the third file is the Boundary Condition File, which contains parameters that define the flow and its type, whether upstream or downstream.

The field data collection for this study began with the collection of the geometrical properties. The DGPS was utilized to gather these data. The DGPS is widely employed in surveying, agriculture, and marine navigation to provide high-precision location tracking [20].

The study involved taking 73 cross-sections of the channel along the study area, covering a total surveyed distance of approximately 14 km. The distance between the cross-sections varied to capture the details of the channel and its cross-section features. Several measurements were taken on the shoulders and bed of the channel in regions with significant elevation variations. The advantage of this scanning method is that it helps capture the changes in the channel section over time. This is particularly important because the last survey of this channel was conducted in 1976 [21]. Given that more than 50 years have passed since that survey, changes to the channel section, such as erosion from rain or other factors, were expected. The locations of the selected cross-sections are shown in Figure 3.

Fig. 3. Location of surveying study area using DGPS.

Additionally, a sample of the collected data for the geometrical cross-section at Section 64 is presented in Figure 4.

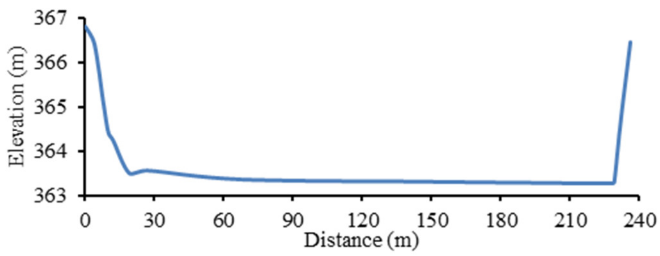

Fig. 4. Geometry of Section 64 at study area.

Previous investigations of the Khassa River's soil attributes found the Manning's coefficient (n) to be approximately 0.035, which aligns with the range of previously documented values for similar soil types [22]. In Khassa River soil, the Manning's coefficient (n) ranges from 0.028 to 0.035, with the specific values for vegetation, short channels, shallow depths, and Bermuda grass being selected in/for this study. However, due to the limited available flow data for the Khassa River, these values of Manning's coefficient were applied to assess their validity.

Furthermore, Table I presents nine discharge scenarios to be applied in this study area. The maximum flow is 1200 m^3/s and was chosen based on the maximum allowable flow proposed by the designing company [21]. Each scenario includes a work plan to demonstrate the influence of various flow rates and their impact on the Khassa River, incorporating the most recent updates to the cross-sectional geometry of the study area.

TABLE I. THE APPLIED FLOW FOR THE STUDY AREA

No. of Scenarios	Flow (m^3/s)
1	1200
2	800
3	500
4	400
5	300
6	200
7	100
8	50
9	20

III. RESULTS AND DISCUSSION

In order to present the results that demonstrate the situation of the river under different flow scenarios, as displayed in Table I, a sample model of the flow cross-section along the river is provided, covering three cases. The first case is when both riverbanks of the river are flooded. The second case is when only the right riverbank floods while the left riverbank remains safe from flooding. The third case is for sections that have flooded from the left riverbank, while the right side remains secure from the risk of flooding.

The discharge in these scenarios ranged from 1200 m^3/s to 20 m^3/s, based on previous data, which suggest that this is the maximum discharge the river can handle without flooding. The steady-state model analysis yielded the following results: Figure 5 presents a two-dimensional diagram of cross-section No. 73 in the studied area, showing the extent of the water resulting from a discharge of 1200 m^3/s in the waterway. It can be observed that certain sections remain free from flooding, with water extending from both the right and left sides of the river.

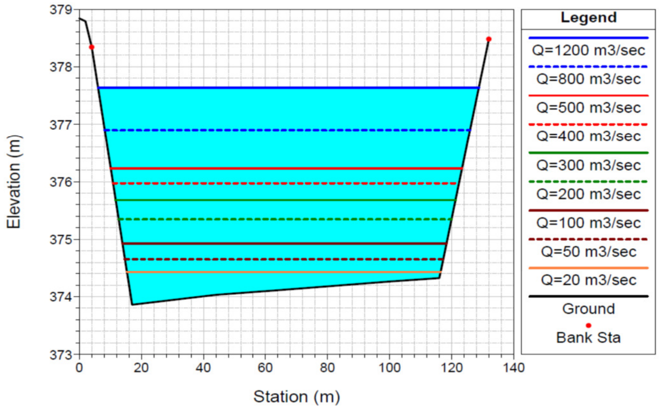

Fig. 5. Flooding of the riverbanks form two sides at station No. 73.

Figure 6 illustrates cross-section No. 52 which is subject to flooding when the flow of the river exceeds 800 m^3/s. In this case, flooding occurs only on the right side, while the left riverbank remains safe from flooding under all scenarios. Furthermore, Figure 7 represents cross-section No. 45, which floods when the upstream flow exceeds 800 m^3/s, with flooding occurring only through the left side only. The right riverbank remains unaffected by flooding in all scenarios.

According to the French Consulting Company (Scoria) [21], Khassa Chai River can handle a discharge of 1200 m^3/s without flooding. However, the hydraulic performance model of the river, in its current state, indicates that some cross-sections are unable to safely accommodate this flow. This change in the river's ability to manage the flow is attributed to the sediment accumulation within the riverbed, which has altered the river's hydraulic performance. Specifically, the riverbed is now higher than the surrounding sections, which affects the flow dynamics. This issue could be addressed by dredging and clearing the riverbed of the accumulated sediment over time. Additionally, encroachments by farmers on the river basin have led to changes in the cross-sectional levels at various locations along the river.

Table II summarizes the flooding status for each cross-section along the study area during each scenario of flow (Q). The cells with a (-) sign indicate that the riverbank remains safe during the flow, while the boxes with "*F*" indicate that this riverbank is at risk of flooding during the given flow scenario. It is evident that most of the Khassa Chai River is secure against the risk of flood. However, some of the cross-sections face certain issues, e.g. being unsafe during underestimated flow. Therefore, a series of efforts should be taken to enhance the ability of the river waterway to handle the designed flow.

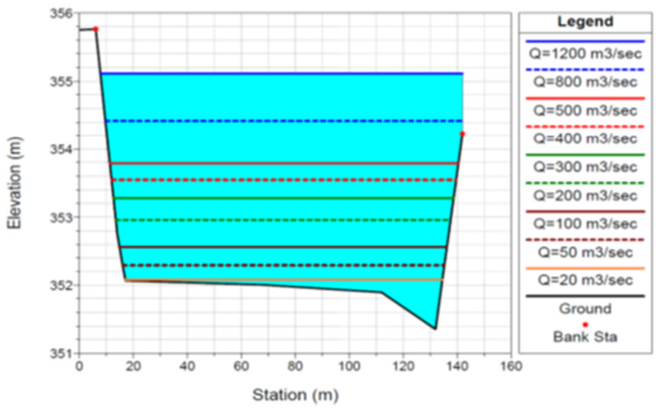

Fig. 6. Flooding of the riverbanks from two sides at station No. 52.

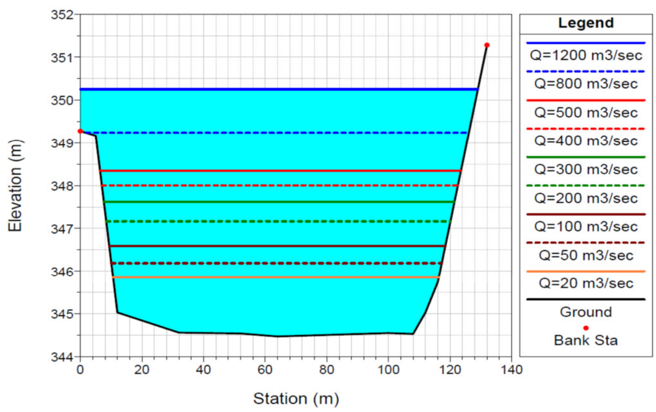

Fig. 7. Flooding of the riverbanks from two sides at station No. 45.

TABLE II. SUMMARY OF THE FLOODING STATUS OF THE RIVERBANK

Q	**1**		**2**		**3**		**4**		**5**		**6**		**7**		**8**		**9**	
St.	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**
73	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
72	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
70	-	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
69	F	F	-	F	-	F	-	F	-	F	-	-	-	-	-	-	-	-
68	F	F	-	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-
67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
66	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
65	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
63	-	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
61	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
59	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
58	-	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
57	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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52	-	F	-	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	-	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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48	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
46	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45	F	-	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
44	F	-	F	-	F	-	F	-	-	-	-	-	-	-	-	-	-	-
43	F	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
41	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
38	F	-	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	-	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	F	F	F	F	F	F	-	-	-	-	-	-	-	-	-	-	-	-
7	F	F	F	F	F	F	-	F	-	F	-	F	-	-	-	-	-	-
6	F	F	-	F	-	F	-	F	-	F	-	F	-	F	-	-	-	-
5	-	F	-	F	-	F	-	F	-	-	-	-	-	-	-	-	-	-
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IV. CONCLUSION

This study applied the One-Dimensional (1-D) Hydraulic Engineering Center-River Analysis System (HEC-RAS) model to evaluate the hydraulic performance of the Khassa Chai River under different flow conditions. Using Differential Global Positioning System (DGPS), 73 cross-sections were surveyed along a 14 km stretch of the river to obtain accurate geometric data. The model was calibrated with Manning's n values ranging from 0.028 to 0.035, based on the river's soil and vegetation characteristics.

Nine discharge scenarios were analyzed, with flow rates ranging from 1200 m³/s (maximum design flow) to 20 m³/s. The results revealed that:

- Several cross-sections are at risk of flooding, particularly when the flow exceeds 800 m³/s.
- Some cross-sections fail to accommodate the design discharge (1200 m³/s), contrary to previous assessments.
- Flooding patterns varied, with some sections experiencing right-bank flooding, others left-bank flooding, and some others flooding on both sides.
- The accumulation of sediments has significantly altered the riverbed profile, reducing the channel's capacity.
- Unauthorized encroachments by farmers have contributed to changes in riverbed elevation, further impacting the flow performance.

These findings indicate that the Khassa Chai River's current condition does not fully support its original design flow. To restore its hydraulic performance, interventions, such as sediment removal, riverbed maintenance, and stricter regulations of encroachments are necessary. Future studies should further investigate the sediment deposition patterns and explore potential flood mitigation strategies.

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