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Hydrological and Geometric Analysis of a Proposed Reservoir on the Upper Zab River Using GIS and Remote Sensing Techniques

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Keywords:
Geographic information systems; Water resource management; Digital elevation model; Global mapper.

Highlights:

- *Dams are generally considered among the most important strategic projects moving development and progress in countries aspiring to economic development and seeking to provide an integrated water resource management system.*
- *The idea of building a dam on the Upper Zab River represents a qualitative leap for Iraq because this important river does not contain any storage projects along its course.*
- *The proposed study indicated the possibility of establishing a water reservoir on the Upper Zab River with a storage capacity exceeding 5 billion cubic meters.*

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Abstract: Iraq and many countries are currently facing complex challenges concerning desertification and scarcity of water resources due to the increased demand for water and climate change. This study proposes establishing a water reservoir to address Iraq's water resource deficit, focusing on selecting the optimal location along the Upper Zab River. This river supplies approximately 26.6% of the Tigris River's water, yet it lacks any existing dams or reservoirs in its Iraqi stretch. The study has two main parts: First, it identifies the ideal dam reservoir location using GIS and other tools, determining a minimum capacity of 5.5 billion cubic meters. The study's second part involves gathering extensive meteorological and hydrological data from the upstream basins of the reservoir. This data supports the choice of the dam location as it is ideal for a water reservoir. The study also factors in the local population and nearby villages and essential data on multi-year water discharge and seasonal variations to determine dam filling time and create suitable management plans. At a water level of 372.5 meters, there is a significant change in positive lake areas and volumes. The positive volume increased substantially from 4.1 to 23.75 million cubic meters compared to 370 meters. Similarly, the positive surface area expanded notably from 1.22 to 2.28 million square meters. This trend is also seen in the positive surface area, which shifts from 1.23 to 2.54 million square meters at the same water levels. The current study considered the support of water management strategies in accordance with the principle of balance between the needs of society, the protection of the ecosystem, and the economic system. It also ensured insignificant population displacement and harm to agricultural lands in the dam basin area.

التحليل الهيدرولوجي والهندسي لخزان مقترح على نهر الزاب الاعلى باستخدام نظم المعلومات الجغرافية وتقنيات الاستشعار عن بعد

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الخلاصة
يواجه العراق والعديد من دول العالم حاليا تحديات معقدة فيما يتعلق بالتصحر وشح الموارد المائية بسبب الطلب المتزايد على المياه والتغير المناخي. تقترح هذه الدراسة إنشاء خزان مياه لمعالجة نقص موارد المياه في العراق، مركزة على اختيار الموقع الأمثل على نهر الزاب العلوي. يُمد هذا النهر بنسبة تقريبية ٢٦,٦٪ من مياه نهر دجلة، ومع ذلك، فإنه لا يوجد أي سدود أو خزانات حالية عليه في الجزء العراقي. تتكون الدراسة من جزأين رئيسيين: الأول يتعلق بتحديد الموقع المثالي لسد الخزان باستخدام نظم المعلومات الجغرافية وأدوات أخرى، حيث يتم تحديد السعة الدنيا للخزان بمقدار ٥,٥ مليار متر مكعب. الجزء الثاني من الدراسة يتضمن جمع بيانات جوية وهيدرولوجية شاملة من حوض الرياح للسد. تلك البيانات تدعم اختيار موقع السد كمكان مثالي للخزان المائي. الدراسة أيضاً تأخذ في الاعتبار السكان المحليين والقرى القريبة من موقع السد المقترح، بالإضافة إلى بيانات أساسية حول تصريف المياه على مدار عدة سنوات وتقلبات المواسم لتحديد وقت ملء السد وإعداد خطط إدارية مناسبة. وجدت الدراسة الحالية انه عند مستوى مياه يبلغ ٣٧٢,٥ متر، هناك تغيير كبير في المساحات والحجوم الموجبة للبحيرة، حيث يزداد الحجم الموجب بشكل كبير من ٤,١ إلى ٢٣,٧٥ مليون متر مكعب مقارنة بارتفاع مستوى المياه إلى ٣٧٠ مترًا. بالمثل، تتوسع المساحة المستوية الموجبة بشكل ملحوظ من ١,٢٢ إلى ٢,٢٨ مليون متر مربع. وفي السياق ذاته يُلاحظ هذا الامر في المساحة السطحية الموجبة، حيث تتغير من ١,٢٣ إلى ٢,٥٤ مليون متر مربع عند نفس مستوى المياه. تناولت الدراسة الحالية دعم استراتيجيات إدارة المياه وفق مبدأ التوازن بين احتياجات المجتمع وحماية النظام البيئي والنظام الاقتصادي، كما ضمنت عدم حدوث نزوح كبير للسكان وإلحاق أضرار بالأراضي الزراعية في منطقة حوض السد.

الكلمات الدالة: نظم المعلومات الجغرافية، إدارة الموارد المائية، نموذج الارتفاع الرقمي، Global mapper.

1.INTRODUCTION

The importance of strategic water resource management is highlighted by the pressing issue of water scarcity. Dams and reservoirs, initially intended to meet domestic and agricultural demands, have adapted to fulfill industrial and energy requirements. The task of identifying the most suitable dam locations continues to be a pivotal challenge, bearing extensive consequences. Constructing dams remains essential to ensure sustainable water resources for the future [1]. Despite the importance of building dams to maintain the country's water security, awareness of the control and review of the safety of tailings dams has increased due to disasters resulting from the failures of such dams, which have been exacerbated by increased waste tailings and the construction of larger dams. The necessity of emphasizing safety control programs for waste disposal must be highlighted, and the methods of failures and the factors leading to them should be described. The basic principles of such programs are examined describing all phenomena that need to be observed and their effects explained, as in traditional dams [2]. Analyzing the geometric aspects of water storage in dams, in conjunction with relevant criteria, is crucial in reservoir design, operation, and management [3]. GIS and remote sensing have been widely utilized in numerous projects and research endeavors. For instance, they have been applied to calculate the precipitation rate in Kirkuk using data obtained from these programs [4]. Quantitative studies in mechanical sciences drive competition for sustainable development and meeting human needs. Integrating disciplines like geomorphology and hydrology is crucial, yielding accurate data for water projects. Advanced technologies, including remote sensing and software, lead to better planning and lower costs, leading to efficient use of resources and meeting the population's needs [5]. Successful engineering project planning requires scientific and practical expertise to navigate risks and challenges during construction. The success of the project depends on the efficiency of design and implementation in determining the appropriate location for constructing this project within an area that may contain some natural obstacles that require a careful solution [6]. Due to incorporating modern methodologies in designing diverse water projects, including dams and irrigation systems, implementing techniques like the Preston method in designing irrigation reservoirs is feasible. Moreover, alternative programs that align with the objectives in this domain can also be employed [7]. Through scientific development in various fields, modern systems must be used in morphological mapping and different land-use maps at a large level. Land-use planning and necessary supporting data have become critical for developing countries, which often face severe environmental and demographic pressures. Approaches and methods for charting natural resource inequality are important tools to guide sound spatial planning [8]. Iraq's downstream location relative to the Tigris and Euphrates Rivers poses challenges for implementing water-related projects due to actions taken by upstream countries, affecting Iraq's water revenue and agricultural environment. The country's water resources are interconnected with Turkey and Iran, the main water sources for these rivers and their tributaries [9]. Around 62% of the water resources in Arab nations originate from Turkey. Due to Turkey's water policies, roughly 80% of Arab territory is affected by desertification, as reported by the UNDP [10]. As the downstream state, Iraq is significantly impacted by upstream nations' irrigation and industrial projects on the Tigris and Euphrates Rivers basins. Dams constructed by Turkey and Syria have reduced Iraq's water imports, affecting agriculture and soil quality [11].

2.HYPOTHESIS OF THE STUDY

The current study focuses on constructing a proposed dam on the Upper Zab River in northern Iraq. Building this dam is strategically essential for Iraq, as it is expected to address the annual water resource crisis in drought-prone areas by providing a water storage capacity of approximately 5.5 billion cubic meters. Additionally, the presence of this dam will lead to hydroelectric energy generation, enhance irrigation systems, and stimulate economic growth through agriculture and tourism. It should be noted that this type of structure reduces the risk of floods by correctly applying optimal water management laws. Furthermore, this structure plays a fundamental role in ensuring the safety of cities near water bodies by developing plans for their protection during future floods [12]. Through this study, modern analytical tools and data, including digital elevation models from satellite data, will be utilized. These tools will enhance the understanding of hydrology and geomorphology and ensure precise planning for dams' efficient design and implementation.

3.DESCRIPTION OF THE STUDY AREA

In this study, the Upper Zab River region between the provinces of Nineveh and Erbil was recommended for constructing a dam, proposing that the dam's reservoir stretches along the channel of the Upper Zab River. The study area has been defined within specific geographic coordinates, where it is bounded between two longitude lines, with lengths ranging from (43° 51' 0") to (44° 15' 0") east. Additionally, it is delimited by two latitude circles, with widths ranging from (36° 27' 0") to (36° 41' 0") north, as depicted in Fig. 1. The total area of the study region is approximately 157,919,442 km².

4.STUDY OBJECTIVES

This study aims to achieve the following objectives related to the proposed dam:

- Conduct a comprehensive geomorphological survey of the reservoir, analyzing geometric and morphometric aspects, informing the dam's design, including its optimal location, height, and aid in calculating geometric elements, such as reservoir volume and surface area.
- Analyzing the hydrology of the dam basin to understand the patterns and dynamics of water flow.
- Implement effective measures to improve the management and optimization of water resources.

The study's findings and information will help successfully plan, design, and construct dams, facilitating the region's effective management of its water resources.

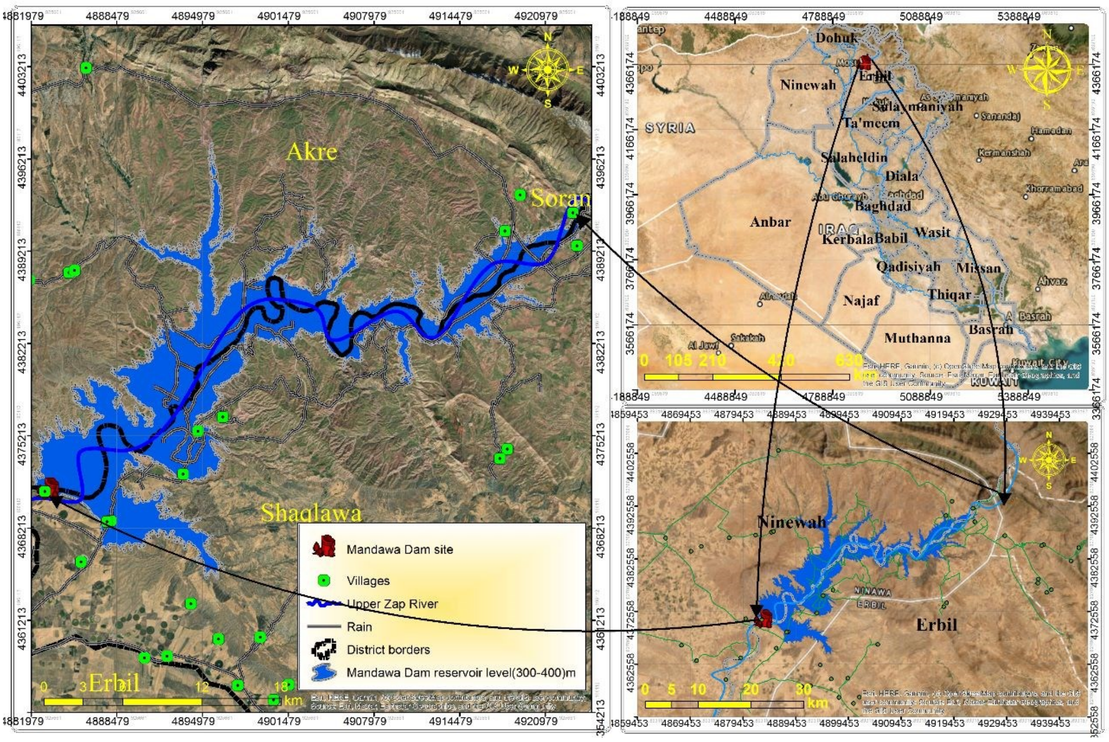

Fig. 1 The Study Area.

5.SETUP METHODOLOGY

5.1.Geometric Elements Extraction of the Proposed Dam Reservoir Using Digital Elevation Model (DEM)

To analyze the geometric elements of the proposed dam reservoir, the study relies on the digital elevation model (DEM) with a distinct capability of 25 meters, as shown in Fig. 2. Application software, such as GLOBAL MAPPER, SURFER, and GIS, is utilized for spatial analysis, geospatial data extraction, and processing, all based on remote sensing data from satellites. These software tools transform the data collected into numerical representations of the Earth's dimensions in 2D and 3D formats. The geometric element data is derived from an elevation range of 295 meters above sea level (where the dam is situated) to an elevation of 400 meters, with intervals of 2.5 meters. The results of the digital processing for the geometric elements of the proposed dam reservoir include various parameters, such as surface area, water levels within the dam reservoir, positive and negative volumes, positive and negative surface areas, positive and negative planar areas, average depth, and average island thickness. These geometric elements are defined below and illustrated in Fig. 3.

- Surface Area: This area represents the total area covered by the water within the dam reservoir.
- Water Levels within the Dam Reservoir: This level shows the different water levels at various points within the dam reservoir.
- Positive Volume: This volume indicates the volume of water present when the reservoir is filled up to a specific level.
- Negative Volume: This volume represents the volume of space within the dam reservoir that remains empty when water levels are below a certain point.
- Positive Surface Area: This area denotes the area covered by water at different levels when the reservoir is filled.
- Negative Surface Area: This area shows the area above the water level that remains exposed when the reservoir is not filled
- Positive Planar Area: This area represents the total area of the reservoir bed covered with water when the reservoir is at a specific level.
- Negative Planar Area: This area denotes the area of the reservoir bed that remains dry when water levels are below a certain point.
- Average Depth: This depth indicates the average depth of the water within the reservoir at a particular level.

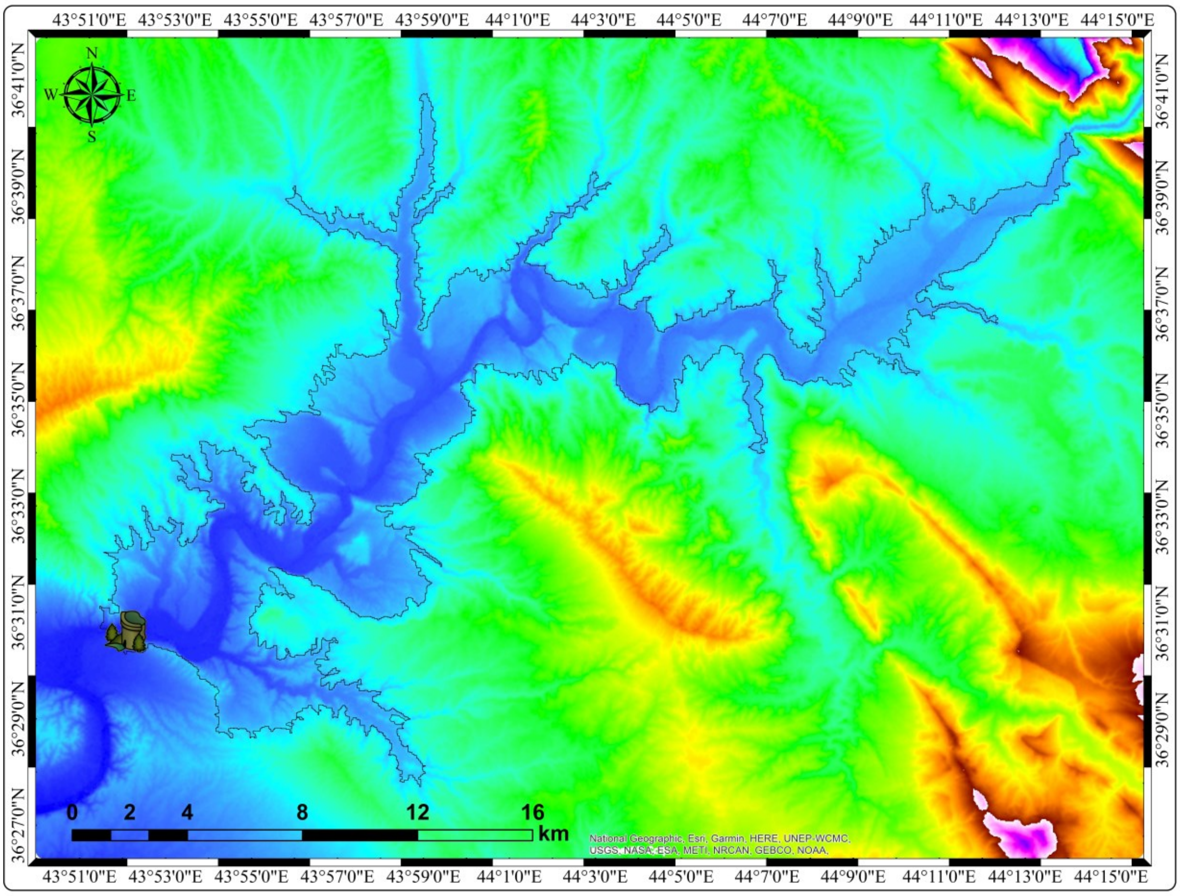

Fig. 2 Digital Elevation Model (DEM) of Dam Reservoir.

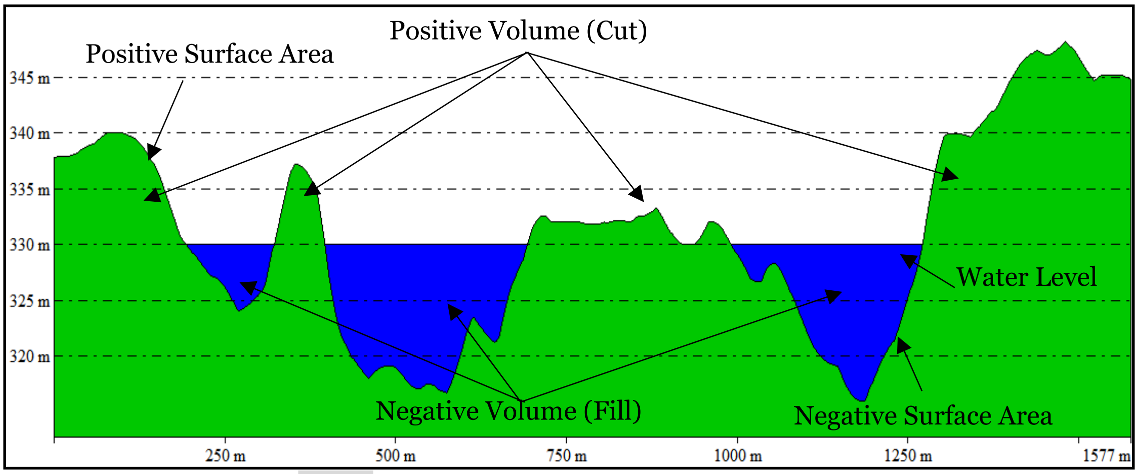

Fig. 3 Geometric Elements of Dam Reservoir.

6.RESULTS AND DISCUSSION

6.1.Relationship of Water Level with Positive Volume

The positive volume related to islands varies as new islands can emerge while existing ones may submerge within the reservoir's periphery. This process corresponds to water level changes and occurs gradually over time. Based on the illustration in Fig. 4, the significant note is the remarkable variation in positive volume when the water level reaches (327.5 m). At this specific level, there is a discernible shift in the positive volume compared to the level immediately preceding it. Precisely, at a water level of (327.5 m), the positive volume amounts to (2,891,292.39 m^3), whereas at the previous water level of (325 m), the positive volume equates to (344,831.74 m^3), signifying a substantial difference of (2,546,460.65 m^3) between the two volumes. This trend is reiterated at a water level of (355 m), where another substantial volume shift occurs. The positive volume at this water level experiences a considerable increase, amounting to (4,123,801.86 m^3). Notably, this volume increment surpasses the previous alteration due to the enlarged water coverage area at this stage. A notable spike in the positive volume occurs at a water level of (372.5 m). It is important to highlight that the positive volume experiences a remarkable increase of (19,652,237.49 m^3) from the preceding water level (370 m). Specifically, at the water level of (372.5 m), the positive volume measures (23,747,340.38 m^3), whereas at the previous water level, it was (4,095,102.89 m^3).

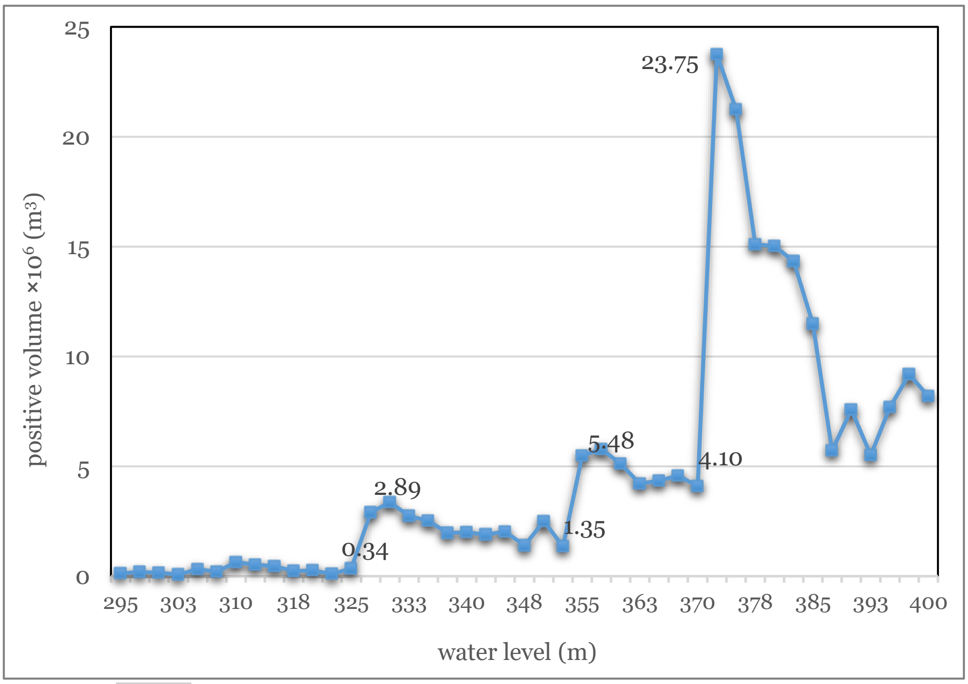

Fig. 4 Relationship between Water Level and Positive Volume.

6.2.Relationship between Water Level and Positive Planner Area

The positive planner areas refer to the horizontal section area formed by the water level on the islands within the reservoir. These areas generally increase at higher water levels in the reservoir and decrease at lower levels. It is important to note that the maximum area of these islands does not exceed (220,000 m²) during low water levels, attributed to the fact that many islands remain outside the boundaries defined by the water levels, as depicted in Fig. 5. Between average water levels ranging from (330 m-370 m), these positive planner areas experience a significant increase, expanding from (591,000 m²) to (1,220,000 m²). This increase reaffirms the earlier observation regarding the influx of additional islands within the updated reservoir boundary. Contrastingly, a distinct pattern emerges with the increase in water level, particularly in the last set of positive areas. This set showcases a significant difference, exceeding (2,500,000 m²), primarily due to including large islands on the reservoir's edge. Of utmost importance is the observation that positive planner areas decrease as water levels rise. This phenomenon underscores the appropriateness of the chosen reservoir location. The reduction in level areas at higher water levels indicates the submergence of most islands within the reservoir's boundaries and limited access to new islands from the reservoir's periphery.

6.3.Relationship between Water Level and Positive Surface Area

The study explores the connection between water levels and positive surface areas, validating the relationship with positive level areas. Positive surface area refers to irregular island areas, while positive level area relates to the water outline's horizontal section at a specific level. Positive surface area is expected to surpass positive level area, similar to a hemisphere where the curved surface area exceeds the circular base area. If the areas are close, the islands have a relatively flat shape. Contrarily, significant differences suggest conical or elevated island forms. Figure 6 illustrates the water level and positive surface area relationship, demonstrating that the surface areas closely resemble positive level areas, indicating low island elevations. A significant finding emerges through the analysis of positive level and positive surface areas, along with their specific shapes. Higher water levels increase positive areas up to a certain point. However, as water levels reach the operational reservoir level, positive areas decrease. This reduction indicates that the reservoir's water remains contained without extensive expansion, potentially benefits in terms of cost reduction, population displacement, and environmental impact. A smaller reservoir surface area reduces evaporation and has fewer negative environmental consequences. However, as water levels rise to the designated storage level, also known as the operational reservoir level, the positive areas noticeably decrease. This decline confirms that no extensive areas are far from the reservoir's body. The decrease in positive volume signifies the reservoir's containment, with its water not extending to new areas.

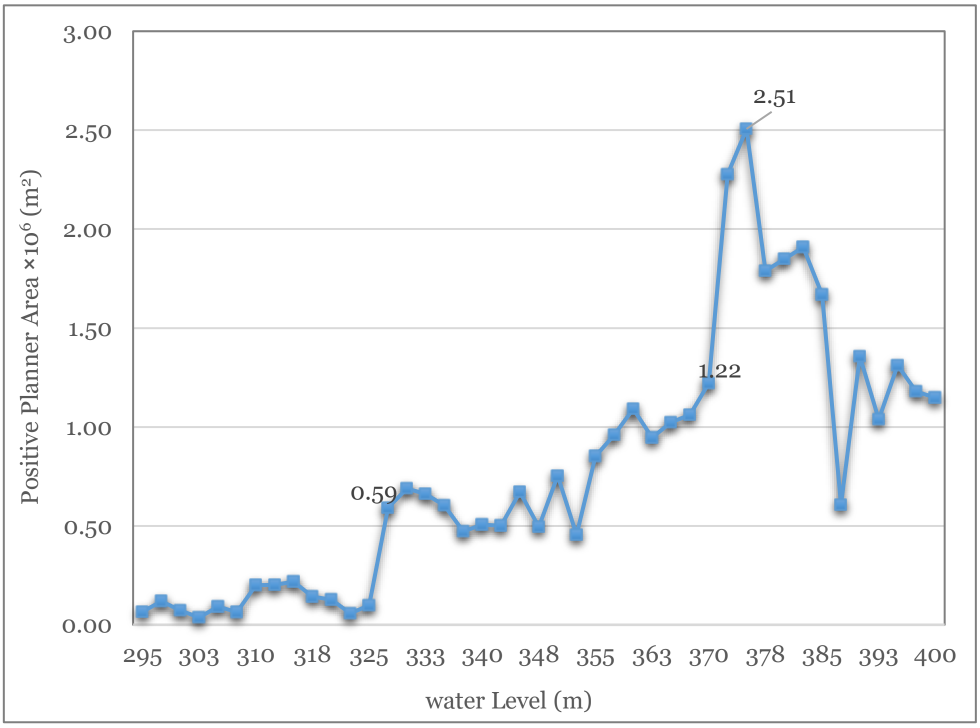

Fig. 5 Relationship between Water Level and Positive Planner Area.

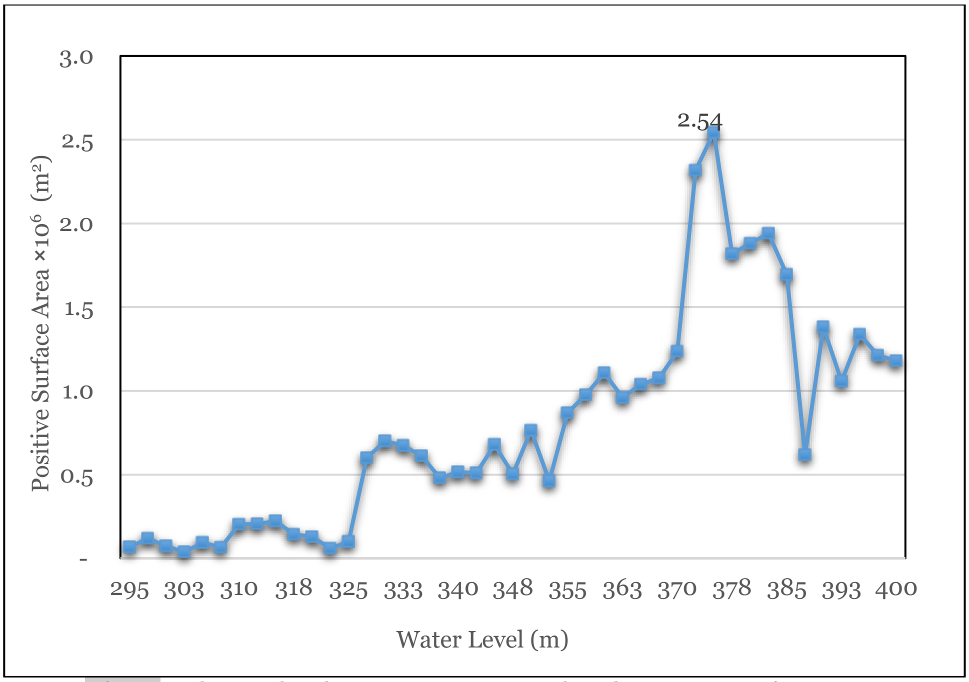

Fig. 6 Relationship between Water Level and Positive Surface Area.

Consequently, this reduction in flooded areas, whether agricultural or residential, can curtail compensatory costs, population displacement, and potential social issues. Furthermore, the environmental aspect is vital in this context. A reduction in the reservoir's surface area results in less evaporation and diminishes the presence of shallow water with its associated negative environmental impacts. By comparing Fig. 4 with Fig. 5, it is evident that they share significant similarities, providing strong evidence that the positive planner area and the positive surface area closely resemble each other. This observation suggests that the areas in question, including islands, have a flat rather than pointed terrain. Such information holds great significance for safe navigation within the lake once it is filled with water.

6.4.Relationship between Water Level and Negative Volume (Storage)

The relationship between water levels and reservoir volume is crucial in dam and reservoir engineering. It informs design decisions, operational strategies, and broader water policies. This correlation guides the dam's capacity, water release rates, flood management, and secure water policies. It is pivotal in determining dam specifications, spillway design, and discharge capacity. Figure 7 visually confirms the reliability of software tools in estimating reservoir volume as negative volume increases with rising water levels.

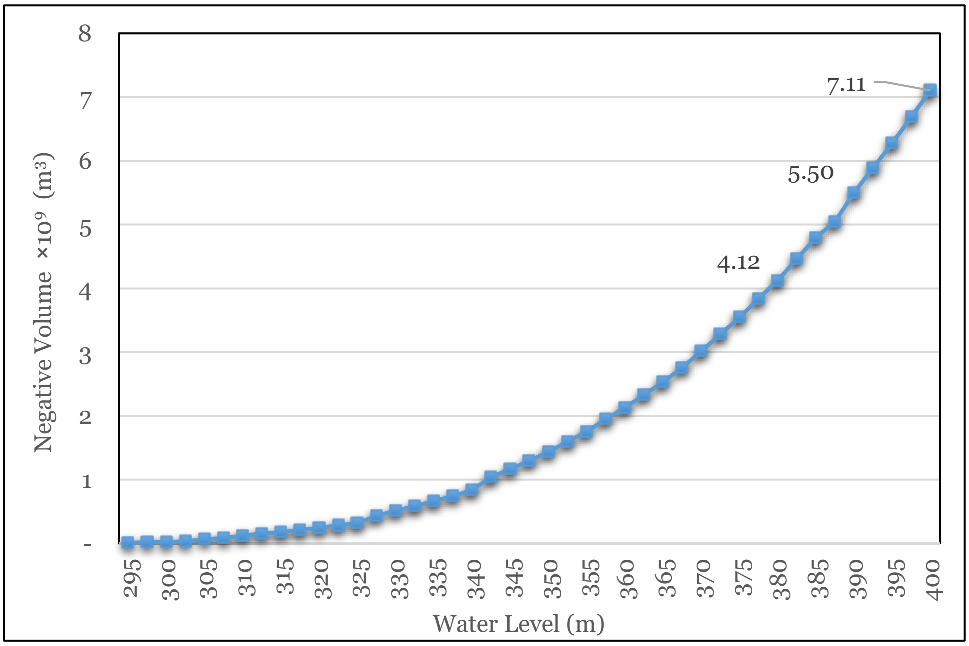

Fig. 7 Relationship between Water Level and Negative Volume (Storage).

Comprehending varying water levels in the reservoir is crucial for operational decisions, affecting water release rates, flood management, and water policy security. Effective policies are vital to reduce dam failure risks. Moreover, this connection aids significant design choices like dam structure, gate specifications, and spillway placement. Accurate determinating spillway location and capacity is vital for managing high water levels, especially during flooding or substantial inflow. The negative reservoir volume will amount to (7,105,215,373 m^3) at a water level of (400 m). This discrepancy highlights the inconsistencies in the available information. If the authorities decide not to raise the water level to (400 m) due to potential future considerations, operating the dam at (390 or even 380 m) becomes a viable option. At these levels, the projected water storage would be (5,501,820,736 m^3) and (4,124,732,273 m^3), respectively. Compared to others within the country, this dam can be classified as a medium-sized dam, ranking below the Dukan dam in terms of storage capacity.

6.5.Relationship between Water Level and Negative Planner Area

Comparing negative volume and storage volume with negative surface area and negative planner area highlights significant differences. While a direct comparison between volume and area is intricate, an important inference emerges: the chosen reservoir area for the water dam is highly suitable. The minimal variation between the negative planner area and the negative surface area suggests a consistent relationship. In contrast, comparing these areas with negative volume reveals substantial disparity. This discrepancy supports the conclusion that the selected reservoir area is a confined and non-expansive valley, implying significant depth with limited surface area, reducing inundated land loss. For instance, at a water level of 390 m, Fig. 8, the reservoir volume is 5,501,820,736.93 m^3, while the negative planner area is 141,181,558.74 m^2. Dividing volume by area yields an approximate depth of 38.97 m. Though not precise for all calculations, this estimate offers insight into the potential water depth in the proposed dam reservoir area. Actual depths may vary; however, this value provides a general understanding of the reservoir's water capacity.

6.6.Relationship between Water Level and Negative Surface Area

The negative surface area pertains to the submerged portion of the Earth's surface covered by water, and its value slightly increases with rising water levels. As indicated in Fig. 9, the negative surface area reaches approximately 143,812,966.69 m^2 at a water level of 390 m. This value closely aligns with the level area mentioned earlier, highlighting the limited expanse that will be submerged concerning the reservoir's volume. Consequently, this limited area reduces water exposure to evaporation, leading to altered stored water quality and an elevation in dissolved salt percentages. Conversely, the continuous expansion of the surface area results from the water's encroachment beyond the boundaries of the Upper Zab River valley. This expansion leads to the flooding of additional regions as a consequence of the reservoir's escalating volume. This dynamic process contributes to the observed increment in surface area as water levels rise.

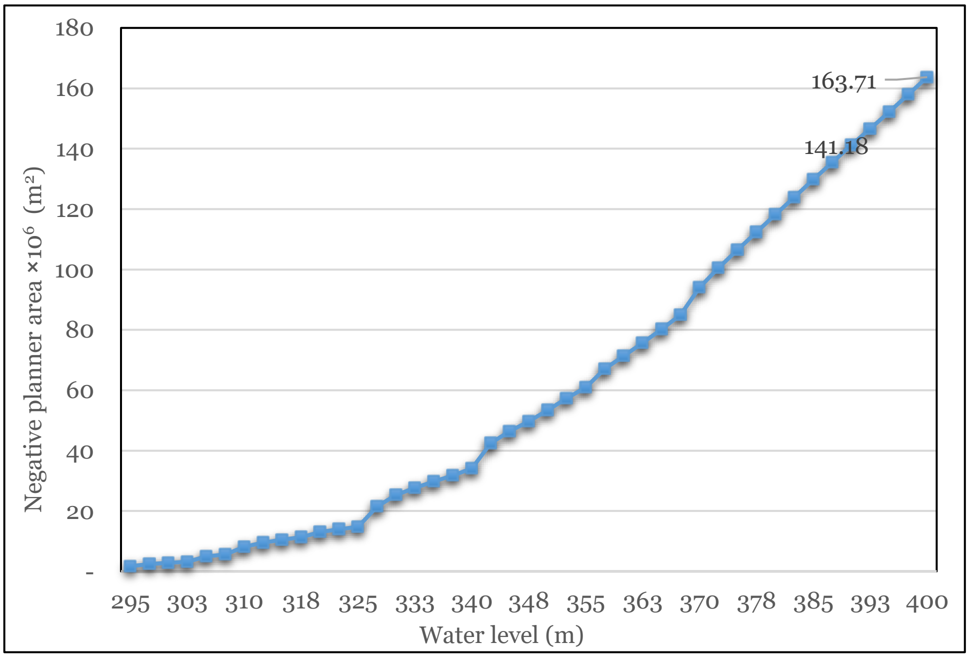

Fig. 8 Relationship between Water Level and Negative Planner Area.

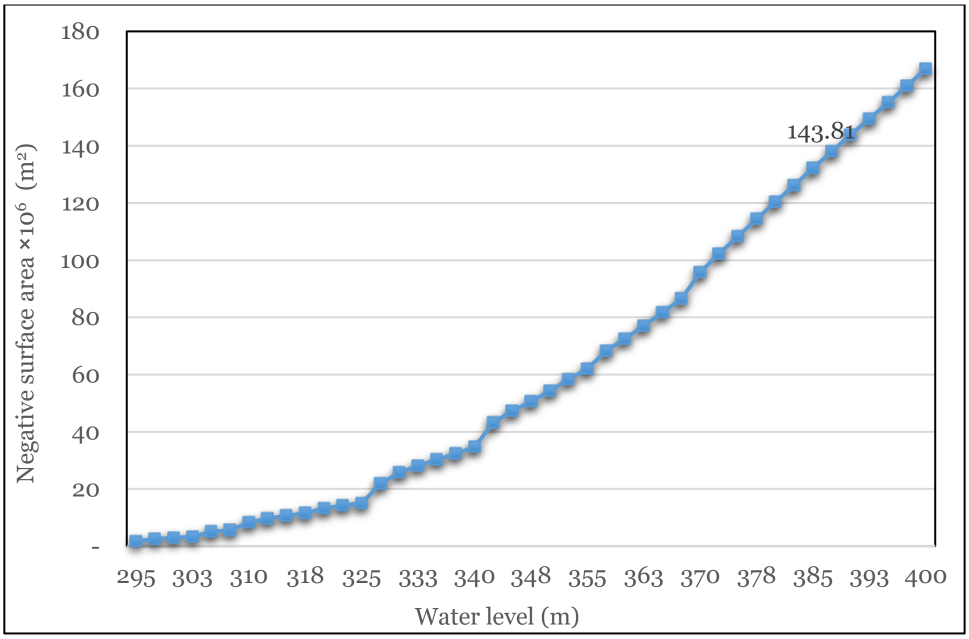

Fig. 9 Relationship of Water Level with Negative Surface Area.

7.HYDROLOGICAL ANALYSIS OF THE WATER DISCHARGE OF THE DAM BASIN

The negative study and recording of river stream water discharge is vital for hydrology experts. Water discharge, measured as the volume of water (m^3/s) passing a river cross-section over time, holds key importance. The present study aims to clarify hydrological data, particularly discharge, to support dam construction. These data are influenced by the climate in the Upper Zab River basin, causing yearly variations. Fluctuations depend on factors like rainfall, snowfall, temperature, and snow melting. Geological features in the basin impact drainage and runoff. Ministry of Water Resources data from 2010 indicates that the Zab River's highest annual flow was 14.1 billion cubic meters. Iraq's dominance lies in its four basin estuaries and abundant water resources. Coupled with local precipitation data, it plays a vital role as a major tributary to the Tigris River, impacting the nation's water resources. Discharge data for drainage stations was collected from Iraq's Ministry of Water Resources, with varying measurement years. For example, Deir Lock station data spanned 17 years, Balenda 16 years, Rayzan 11 years, and Rawanduz basin stations 10 years, with occasional gaps. Table 1 illustrates the basin areas and their percentages in the study region across Iraq and Turkey.

7.1.Annual Water Discharge of the Deir Lock Basin

The Deir Lock Basin's yearly water discharge varies, as shown in Fig. 10. The lowest recorded discharge was in 2008 at 1,733,459,705 m^3, contrasting with 2019's remarkable 9,284,468,183 m^3 due to abundant rainfall (a wet year). In 2020, the discharge was 8,584,761,451 m^3, and 2018 recorded 6,723,012,962 m^3.

7.2.Shamdinan Basin (Balinda Station)

The water discharge of the Shamdinan basin displays varying trends over different years, as seen in Fig. 11. The lowest recorded discharge was in 2008 at 2,802,109,349 billion cubic meters, similar to Deir Lock's 2008 discharge. Conversely, the highest discharge was in 2015 at 8,494,803,978 m^3 due to extensive rainfall. 2019 had the second-highest discharge at 6,972,415,317 m^3, and 2016 recorded 6,079,573,045 m^3. Discharge remained relatively steady from 2005 to 2015, followed by a decrease, except for 2019's exceptional discharge due to heavy rainfall.

Table 1 The Areas and Percentages of the Area of Basins of the Study Area in Iraq and Turkey.

No.	Name of Basin	Total Area (km^2)	Turkish Area (km^2)	Percentage of Turkish Area %	Iraq's Area (km^2)	Percentage of Iraq's Area %
1	Der Lock	7311	6828	93%	483	7%
2	Shamdinan	3331	2198	66%	1133	34%
3	Haji Beck	1848	435	24%	1413	76%
4	Rawanduz	2589	-	0%	2589	100%

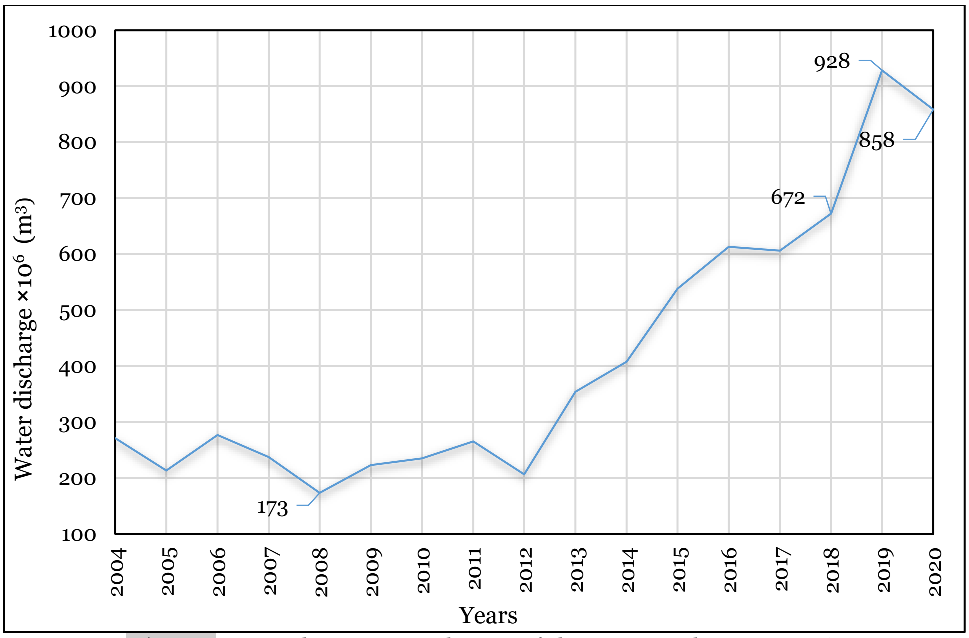

Fig. 10 Annual Water Discharge of the Deir Lock Basin (m³).

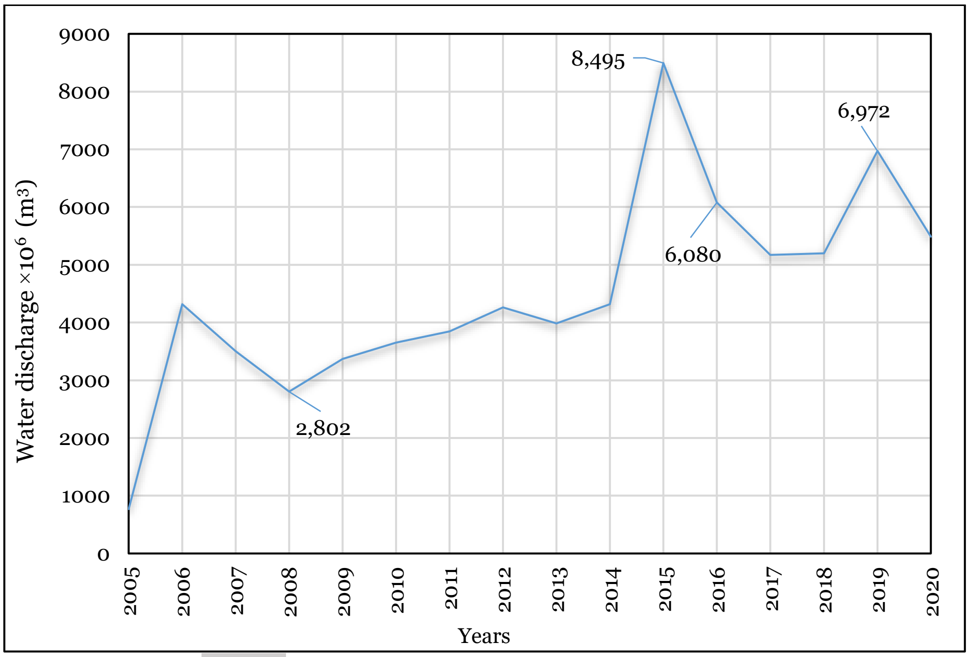

Fig. 11 Annual Discharge of the Station Balinda.

7.3.Haji Beck Basin (Rezan Station)

The station's lowest discharge was 627,135,610 m³ in 2008, akin to other stations in the same year, excluding incomplete 2001 data. Subsequent years, like 2009 and 2010, also witnessed low discharges. In contrast, 2002 marked the highest discharge at 1,386,606,735 m³ due to extensive rainfall. 2006 and 2003 followed with notable discharges, as shown in Fig. 12. After excluding incomplete 2001 data, water discharge showed convergence, with 2002 being the highest and 2008 being the lowest. Subsequent years witnessed gradual increases. Monthly discharge fluctuations mirror periods of water flow changes, impacting the Upper Zab River's water resource, while the rest of the year displays moderate discharge based on yearly climatic conditions.

7.4.Rawanduz Basin (Juman Stations)

The annual water discharge data for the Rawunduz basin show fluctuations and variations, with both increases and decreases in water flow, as presented in Fig. 13. The lowest discharge occurred in 2003 due to missing data, followed by 2008 and 2009, which had the slowest annual discharges due to water scarcity. Conversely, the highest discharge was in 2004, a wet year with significant rainfall. The diagram indicates generally consistent discharge, excluding incomplete 2003 data. The highest discharge was recorded in 2006.

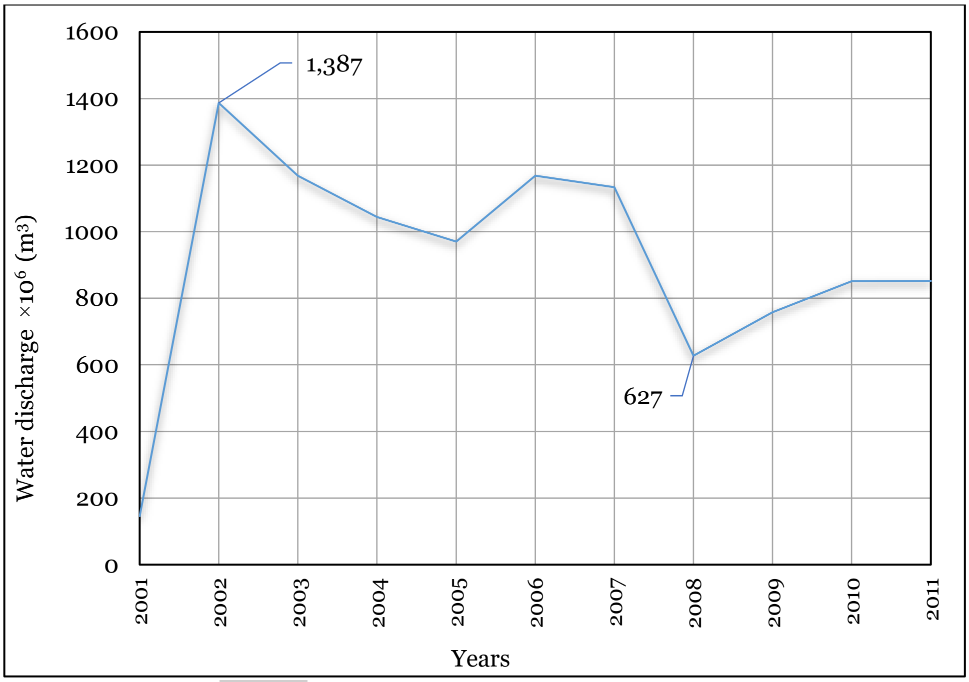

Fig. 12 Annual Discharge of Haji Beck Basin.

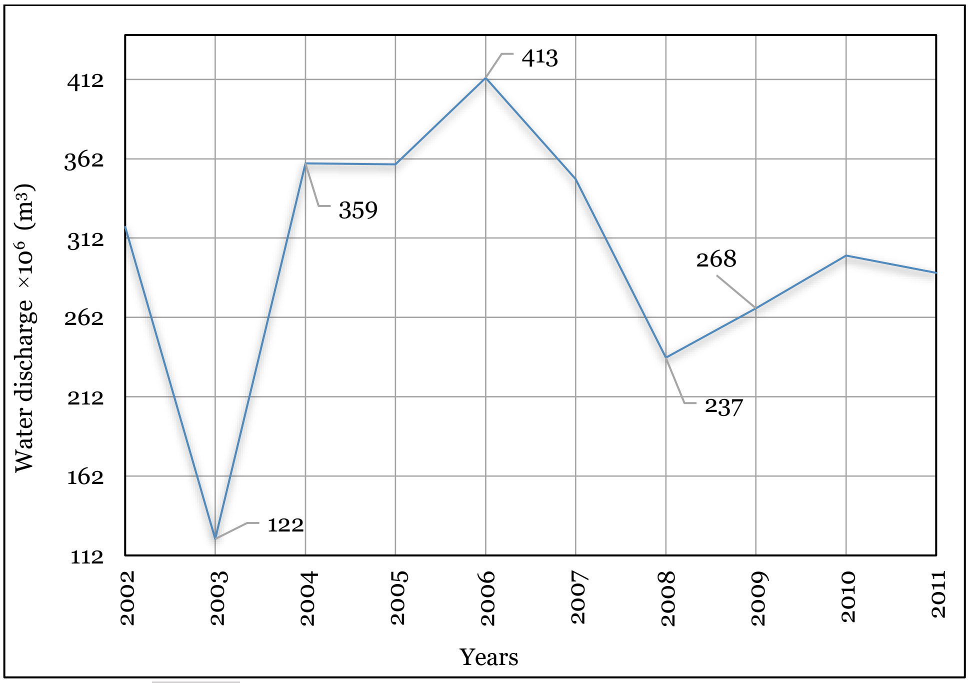

Fig. 13 Annual Water Discharge of the Rawunduz Basin.

Studying and analyzing the hydrological system of river formations is essential for understanding water flow patterns. This analysis reveals spatial and temporal variations in water drainage, influencing water supply patterns. Examining water discharge in the study area basins can identify productive basins and main water sources, discern seasonal discharge fluctuations, and address water deficit periods. This knowledge aids in formulating effective water release policies from the dam gates, optimizing water utilization during scarcity and abundance. The compiled data for the study area basins cover varying durations, reflecting fluctuations in total water discharge, even during scarcity years. Despite incomplete data, stations like Rezan displayed significant drainage, particularly during peak water years like 2019 and 2020. Over the seven years, variations in water discharge were observed among the study area basins and stations. Rawanduz station maintained consistent discharge levels, while Rezan station exhibited semi-regulated discharge with minor fluctuations over two years. The der Luke basin in Shamdinan featured higher and progressively increasing water discharge, particularly in the higher discharge years, setting it apart from other basins.

8.CONCLUSIONS

The main conclusions of the present study could be summarized as follows:

1- Certain areas along the Upper Zab River have been identified as suitable for reservoir lakes, which can store significant water amounts for use during dry seasons. Notably, the Upper Zab River, a major tributary of the Tigris River, lacks any storage projects along its course.
2- The dam site was chosen using field observations, Geographic Information Systems (GIS), and remote sensing, providing precise data for elevation modeling.
3- The water storage capacity at the proposed dam site was calculated to be 5,501,820,736.93 cubic meters at a water level of 390 meters. The surface area of the dam's lake at this water level was estimated to be 141,181,558.74 square meters.
4- Given its storage capacity, the dam's lake size was ideal. Its compactness minimized evaporation and maintained water quality. The region's geomorphology also reduced shallow water areas.
5- The watercourses feeding into the Upper Zab River were mapped to identify upstream basins contributing to the dam's lake, spanning Iraq and Turkey.
6- Crucial data about water basins, including rainfall amounts, were collected. These data are vital for estimating the dam lake's filling time.

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