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HYDROMORPHOMETRIC AND GEOMETRIC ANALYSIS AND ASSESSMENT OF THE PRELIMINARY TOPOGRAPHICAL POTENTIAL FOR WATER HARVESTING: A CASE STUDY OF THE WADI AKOZ BASIN, EASTERN SALAH AL-DIN, IRAQ

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Abstract: This study examines the hydromorphometric characteristics of the Wadi Akoz Basin in Al-Alam District, Salah Al-Din Governorate, Iraq, and the topographical storage capacity of a proposed water-harvesting site within the basin. A 30-m spatial-resolution digital elevation model (DEM) and geographic information system (GIS) techniques were used to extract the drainage network and calculate morphometric parameters. Gridded CHIRPS precipitation data for 2008–2025 were used to characterise the basin's rainfall regime. The relationships among water level, inundated area, and storage volume were then analysed for the proposed site. The basin covers 13.53 km² and has a fifth-order drainage network according to the Strahler classification, with a drainage density of 5.02 km/km² and a stream frequency of 47.38 streams/km². The shape indices—circularity ratio (0.36), form factor (0.21), and elongation ratio (0.92)—indicate an elongated basin with a basin relief of no more than 61 m. Mean annual precipitation is 200.09 mm, with a coefficient of variation of 21.64%, equivalent to approximately 2.71 million m³ of precipitation annually over the basin. The total topographical storage capacity of the reservoir increases from 2,981 m³ at an elevation of 110 m to 2,305,301 m³ at 125 m. This capacity is equivalent to approximately 85% of the basin's mean annual precipitation volume. Filling the reservoir to this level in an average year would therefore require conversion of a large proportion of precipitation into runoff, which is unlikely in a semi-arid basin. The site is consequently considered a promising candidate that warrants detailed hydrological, geotechnical, and engineering investigations before any implementation decision.
Keywords: Wadi Akoz; hydromorphometric analysis; geometric analysis; water harvesting; geographic information systems; storage capacity

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1. Introduction

Water is one of the most important natural resources for sustaining life and supporting economic and social development. Iraq faces increasing water-related challenges arising from climate change, rainfall variability, and declining inflows from transboundary rivers as a result of water-development activities in upstream countries. These pressures have heightened interest in water-harvesting projects as a means of collecting surface runoff and storing it for use during periods of drought[1].

Numerous studies have highlighted the importance of water-harvesting structures and small dams in storing surface runoff and mitigating water scarcity. Geographic information systems (GIS), remote sensing, and digital elevation models (DEMs) have been employed to identify suitable locations for such structures and estimate their storage capacities. Studies in Iraq have integrated hydrological, topographical, and geological criteria within a GIS environment to select potential sites for water-harvesting structures and dams[2][3][4]. Geospatial techniques have also been used to assess rainwater-harvesting sites in semi-arid regions[5] while DEM and GIS approaches have been applied to identify proposed small-dam sites and estimate their storage volumes[6].

Hydromorphometric studies are an essential tool for understanding the natural characteristics of drainage basins. They examine basin shape and area, drainage-network configuration, and relief, all of which influence water movement and surface-runoff behaviour[7] [8]. Geometric analysis of proposed reservoirs provides a basis for estimating storage capacity and establishing stage–area–volume relationships before water infrastructure projects are implemented[9][10].

The objectives of this study are to: (1) characterise the hydromorphometric properties of the Wadi Akoz Basin; (2) describe the basin's rainfall regime for 2008–2025; (3) analyse the stage–area–volume relationship at a proposed storage site; and (4) compare the gross topographical storage capacity with the precipitation volume over the basin to assess the plausibility of filling the reservoir and identify the data required to complete the assessment..

1.1. Study Area

The Wadi Akoz Basin is located in the northeastern part of Salah Al-Din Governorate, within the administrative boundaries of Al-Alam District and east of the Tigris River (Figure 1). The basin covers 13.53 km² and lies between Eastings 366,000 and 372,500 m and Northings 3,861,500 and 3,870,000 m. Surface-water resources in the basin are limited, and mean annual precipitation is approximately 200 mm, indicating a semi-arid climate. Agricultural activity in the area therefore depends largely on rainfall.

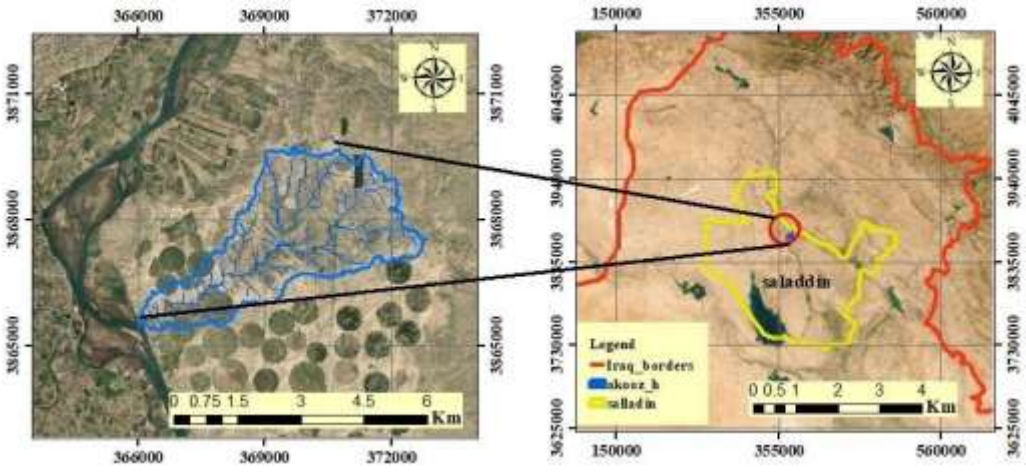


Figure 1. Location of the study area.

2. Materials and Methods

2.1. Data

This study used the SRTM 1 Arc-Second Global digital elevation model (SRTMGL1 v3.0), with an approximate spatial resolution of 30 m. The dataset was generated by the Shuttle Radar Topography Mission (SRTM) and distributed by NASA/USGS.[11] It was used to derive the drainage network, delineate the watershed boundary, analyse hydromorphometric characteristics, and conduct the geometric assessment of the proposed site. Rainfall analysis was based on daily gridded CHIRPS precipitation data[12] for 2008–2025. CHIRPS integrates satellite-derived precipitation estimates with ground-station observations and has a spatial resolution of 0.05° × 0.05°.

2.2. Drainage-Network Extraction and Morphometric Characteristics

The drainage network and watershed boundary were derived from the DEM, and stream segments were classified using the Strahler ordering system. A flow-accumulation threshold of [insert the threshold value as a number of cells or contributing area] was applied. Stream lengths, basin area, and perimeter were measured in a GIS environment. The parameters listed in Table 1 were then calculated, where A is basin area (km²), P is basin perimeter (km), Lb is basin length (km), ΣL is the total length of streams (km), N is the total number of stream segments, Nu is the number of streams of order u, Lc is the sinuous length of the main channel, Ls is its straight-line length, and H is the relief difference between the highest and lowest points in the basin (km)..

2.3. Hydrological Analysis of Rainfall

Daily gridded rainfall data were obtained from the UCSB CHIRPS product for the Wadi Akoz Basin for the period 2008–2025. CHIRPS is a gridded precipitation product that combines satellite-derived estimates with ground-based station observations and is provided at a spatial resolution of 0.05° × 0.05°.

Daily precipitation values were extracted from the grid cells located within the basin boundary. The basin-wide spatial mean of daily precipitation was then calculated, and the daily values were aggregated to obtain monthly and annual totals. The mean annual precipitation, standard deviation, and coefficient of variation were calculated for 2008–2025. The annual precipitation volume over the basin area of 13.53 km² was also estimated by converting precipitation depth into an equivalent water volume.

Table 1. Annual spatially averaged precipitation over the basin based on CHIRPS and the equivalent precipitation volume over the basin.

Year	Basin-average annual precipitation based on CHIRPS (mm/year)	Estimated annual precipitation volume over the basin (m³)
2008	148.524	2,009,530
2009	187.680	2,539,310
2010	168.223	2,276,057
2011	164.136	2,220,760
2012	207.136	2,802,550
2013	219.108	2,964,531
2014	178.440	2,414,293
2015	185.874	2,514,875
2016	190.339	2,575,287
2017	212.886	2,880,348
2018	332.002	4,491,987
2019	231.736	3,135,388

2020	183.108	2,477,451
2021	149.702	2,025,468
2022	184.987	2,502,874
2023	262.283	3,548,689
2024	204.013	2,760,296
2025	191.355	2,589,033

The data show a clear concentration of rainfall during the wet season, with the largest proportion of total precipitation occurring between October and April. December, November, March, and January make substantial contributions to the annual total.

The precipitation volume falling over the basin does not represent direct surface-runoff volume. The conversion of rainfall into runoff depends on soil properties, land cover, and antecedent moisture conditions. Accordingly, neither an SCS-CN value nor a final runoff volume is reported in this version because no documented Curve Number (CN) value was available for the basin in the source dataset.

3. Results and Discussion

3.1. Drainage Characteristics

The hydromorphometric analysis indicates that the Wadi Akoz Basin is a fifth-order watershed according to the Strahler classification. The extracted drainage network comprises 641 stream segments with a total length of 68 km. Most stream segments belong to the first and second orders, as shown in Table 2. The progressive decrease in the number of streams with increasing order reflects the hierarchical organisation of the drainage network.

Drainage density is 5.02 km/km², stream frequency is 47.38 streams/km², and drainage intensity is 9.44, as shown in Table 3. These values indicate a well-developed drainage network and provide a spatial basis for assessing the potential for runoff collection. However, these indices do not quantify actual runoff, which is also influenced by soil properties, land cover, and precipitation. This finding is consistent with the importance of morphometric indicators in contemporary watershed-assessment studies (Shekar & Mathew, 2024).

Table 2. Stream orders, number of streams, stream lengths, and bifurcation ratios.

Bifurcation ratio	Total stream length (km)	Number of streams in each order	Stream order
14.8	36	592	1
6.67	17	40	2
3	8	6	3
2	2	2	4
1	5	1	5
	68	641	المجموع

Table 3. Drainage characteristics of the study basin.

Sinuosity ratio	Drainage intensity	Drainage density (km/km²)	Stream frequency (streams/km²)
1.20	9.44	5.02	47.38

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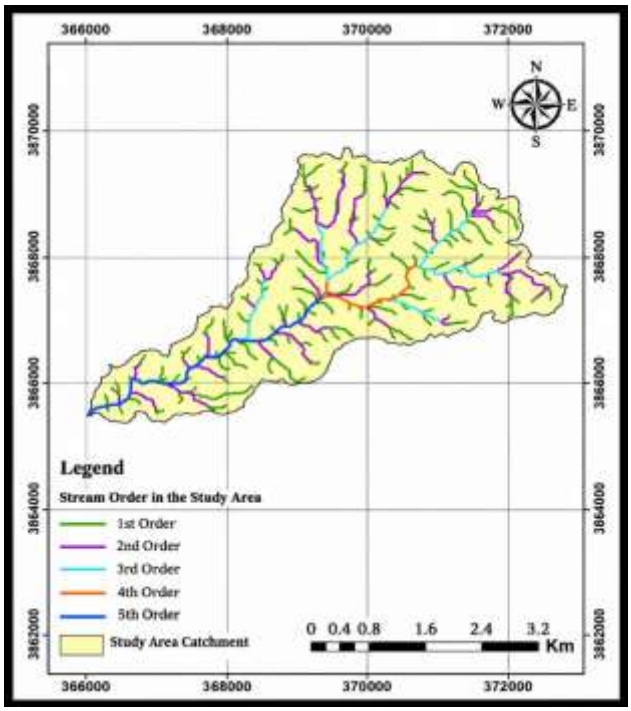


Figure 2. Drainage network and stream orders in the study area, derived from the imagery using ArcGIS 10.4.

3.2. Areal and Shape Characteristics

The basin covers 13.53 km² and has a perimeter of 21.84 km. The actual sinuous length of the main channel is 8.06 km, while its straight-line length is 6.73 km (Table 4). These parameters provide the geometric basis for describing basin shape and the area contributing to water collection.

The form factor is 0.21, the circularity ratio is 0.36[13], the elongation ratio is 0.92, and the compactness coefficient is 1.62 (Table 5). Taken together, these indices indicate that the basin does not have a clearly circular shape. Basin form should therefore be interpreted using the combined set of indices rather than relying on a single indicator, consistent with the integrated approach adopted in recent morphometric studies[14].

Table 4. Areal characteristics of the study basin.

Basin perimeter (km)	Straight-line channel length (km)	Sinuous main-channel length (km)	Basin area (km²)
21.84061	6.73	8.06	13.53236

Table 5. Shape characteristics of the study basin.

Form factor	Elongation ratio	Compactness coefficient	Circularity ratio
0.21	0.92	1.62	0.36

3.3. Relief Characteristics

The relief ratio is 0.061[15], drainage texture is 29.35 streams/km², and the ruggedness number is 0.306 (Table 6). These values reflect topographic variation and the development of the drainage network, and they illustrate the role of relief in directing water towards the main channel. Nevertheless, they are morphometric indicators and are not sufficient, on their own, to estimate the actual volume of surface runoff..

Table 6. Relief characteristics of the study basin.

Ruggedness number	Relief ratio	Drainage texture (streams/km)
0.306	0.061	29.35

3.4. Rainfall Analysis

Mean annual precipitation during 2008–2025 was approximately 200.09 mm/year, with a standard deviation of 43.30 mm and a coefficient of variation of 21.64%, calculated using the equation below. The highest annual precipitation was 332.00 mm in 2018, while the lowest was 148.52 mm in 2008. The mean annual precipitation volume over the basin area was approximately 2.71 million m³. Most rainfall occurred during the wet season, from October to April.

$$SD = 43.304 \text{ mm}$$

$$CV = (SD / Mean) \times 100$$

These results indicate interannual variability in the basin's rainfall resource, which is an important factor in assessing water-harvesting potential. It should be emphasised that the calculated precipitation volume does not represent surface-runoff volume or the quantity of water directly available for storage, because documented data required to convert rainfall into runoff are not available.

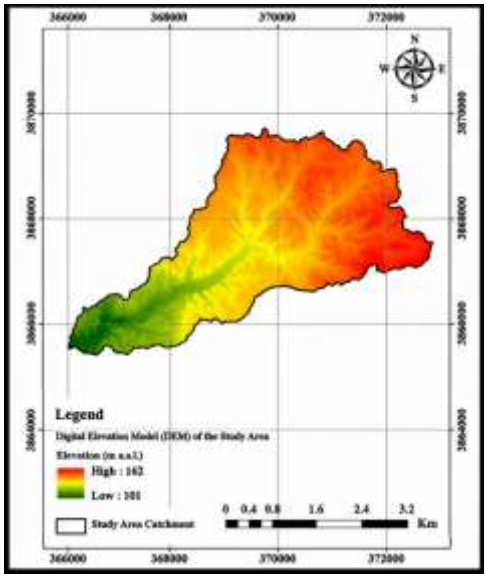


Figure 3. Digital elevation model of the study area.

3.5. Geometric Analysis of the Proposed Site

The geometric analysis shows that reservoir surface area and storage volume increase as the water level rises. The calculated volume increases from 2,981 m³ at an elevation of 110 m to 2,305,301 m³ at 125 m, while the reservoir surface area increases from 2,935 m² to 471,872 m² (Table 7 and the accompanying stage-dependent reservoir-area figures).

These results indicate preliminary topographical potential for water storage at the proposed site. However, the capacity of 2.305 million m³ is a geometric estimate derived from the DEM; it does not necessarily represent the quantity of water that can reach the reservoir or its actual operational storage capacity. Further hydrological, geotechnical, and engineering investigations are therefore required before the site can be approved.

Table 7 and the accompanying figures illustrate the relationship between water level and the geometric parameters of the proposed site. The negative volume (topographical storage) and

inundated areas increase as the water level rises, whereas the residual volume decreases. This indicates that raising the water level leads to rapid expansion of the inundated area. Accordingly, the selection of a water level should be accompanied by an assessment of the additional storage gained relative to the additional area inundated.

The data show that the increase in storage between successive water levels ranges from 8,776 m³ to 454,687 m³ per metre of rise, while the increase in inundated surface area ranges from 4,494 m² to 88,554 m² per metre. The highest value of the ΔV/ΔA indicator is approximately 5.79 m for the increase from 123 to 124 m, compared with 5.13 m for the increase to 125 m. This suggests that 124 m provides the highest marginal topographical efficiency according to this indicator alone, whereas 125 m provides the greatest total capacity. Neither level can be adopted as the final operating level without considering available inflow, affected land areas, and geotechnical and engineering safety requirements.

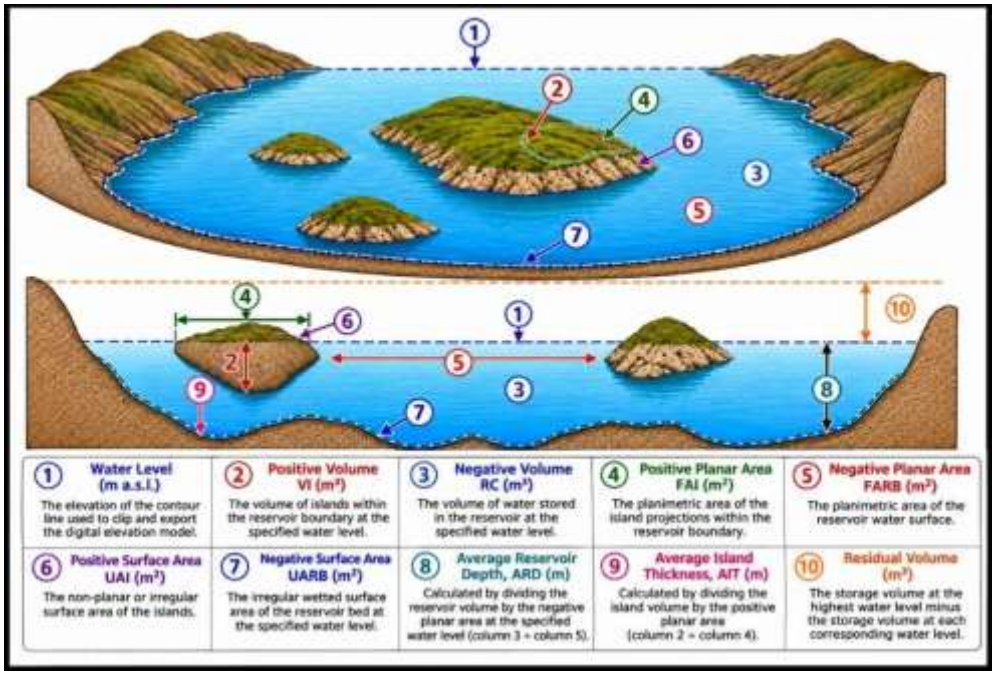


Figure 4. Geometric components of the reservoir.

- Water level (m a.s.l.): the elevation of the contour line used to clip and export the digital elevation model.
- Positive volume, VI (m³): the volume of islands within the reservoir boundary at the specified water level.
- Negative volume, RC (m³): the volume of water stored in the reservoir at the specified water level.
- Positive planar area, FAI (m²): the planimetric area of the island projections within the reservoir boundary.
- Negative planar area, FARB (m²): the planimetric area of the reservoir water surface.
- Positive surface area, UAI (m²): the non-planar or irregular surface area of the islands.
- Negative surface area, UARB (m²): the irregular wetted surface area of the reservoir bed at the specified water level.
- Average reservoir depth, ARD (m): calculated by dividing the reservoir volume by the negative planar area at the specified water level (column 3 divided by column 5).

- Average island thickness, AIT (m): calculated by dividing the island volume by the positive planar area (column 2 divided by column 4).
- Residual volume (m³): the storage volume at the highest water level minus the storage volume at each corresponding water level.

Water level (m a.s.l.)	VI: positive volume (m³)	RC: negative volume (m³)	FAI: positive planar area (m²)	FARB: negative planar area (m²)	UAI: positive surface area (m²)	UARB: negative surface area (m²)	ARD (m)	AIT (m)	Residual volume (m³)
110	0	2981	0	2935	0	2937	0.00	0.00	2302320
111	5	11757	1	7412	1	7431	11757.00	5.00	2293544
112	15	24809	6	12184	6	12229	4134.83	2.50	2280492
113	10	47611	2	22886	2	22980	23805.50	5.00	2257690
114	2	85880	6	38469	6	38619	14313.33	0.33	2219421
115	16	139324	4	51644	5	51848	34831.00	4.00	2165977
116	15	211558	8	68708	8	68974	26444.75	1.88	2093743
117	24	297245	8	84730	8	85105	37155.63	3.00	2008056
118	70	410371	92	107834	92	108350	4460.55	0.76	1894930
119	56	547446	31	136108	31	136773	17659.55	1.81	1757855
120	968	712372	941	168683	945	169456	757.04	1.03	1592929
121	131	912145	197	204456	198	205392	4630.18	0.66	1393156
122	289	1162368	1209	253277	1211	254460	961.43	0.24	1142933
123	72	1472786	47	318702	48	320054	31335.87	1.53	832515
124	61	1850614	157	383836	157	385314	11787.35	0.39	454687
125	187	2305301	635	471872	636	473868	3630.40	0.29	0

Table 7. Geometric parameters of the selected site.

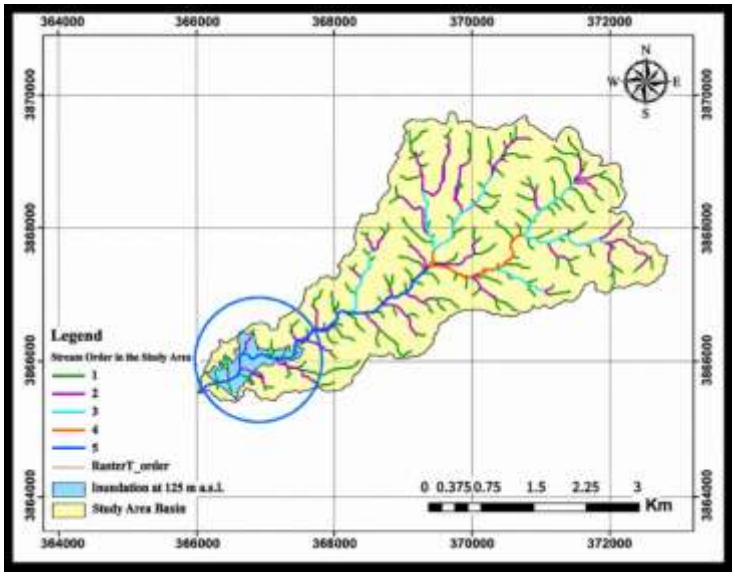


Figure 5. Proposed candidate site for constructing a water-harvesting dam within Wadi Akoz.

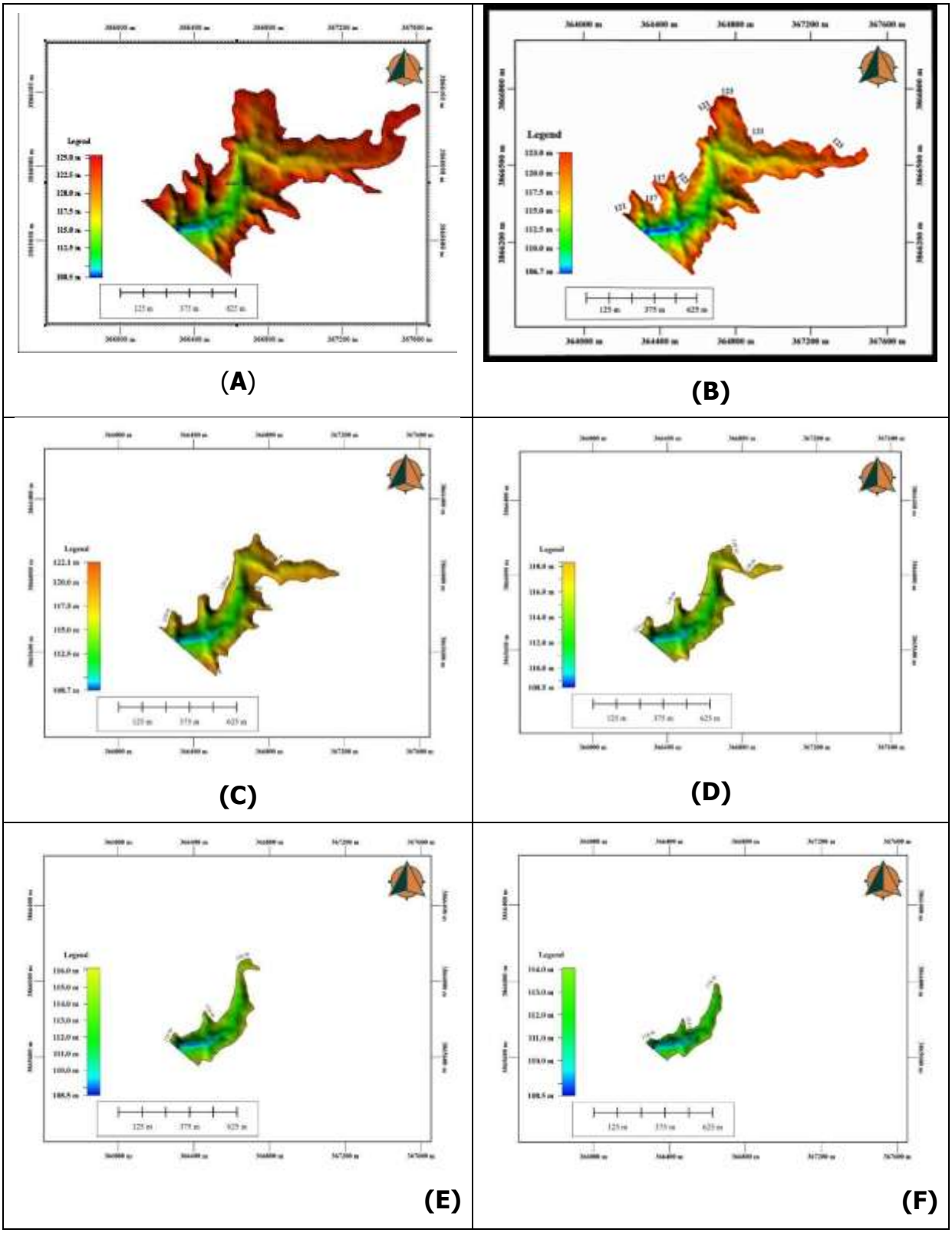


Figure 6. Reservoir configuration at different water levels: (A) 125 m; (B) 123 m; (C) 120 m; (D)118m; (E) 116 m; and (F) 114 m.

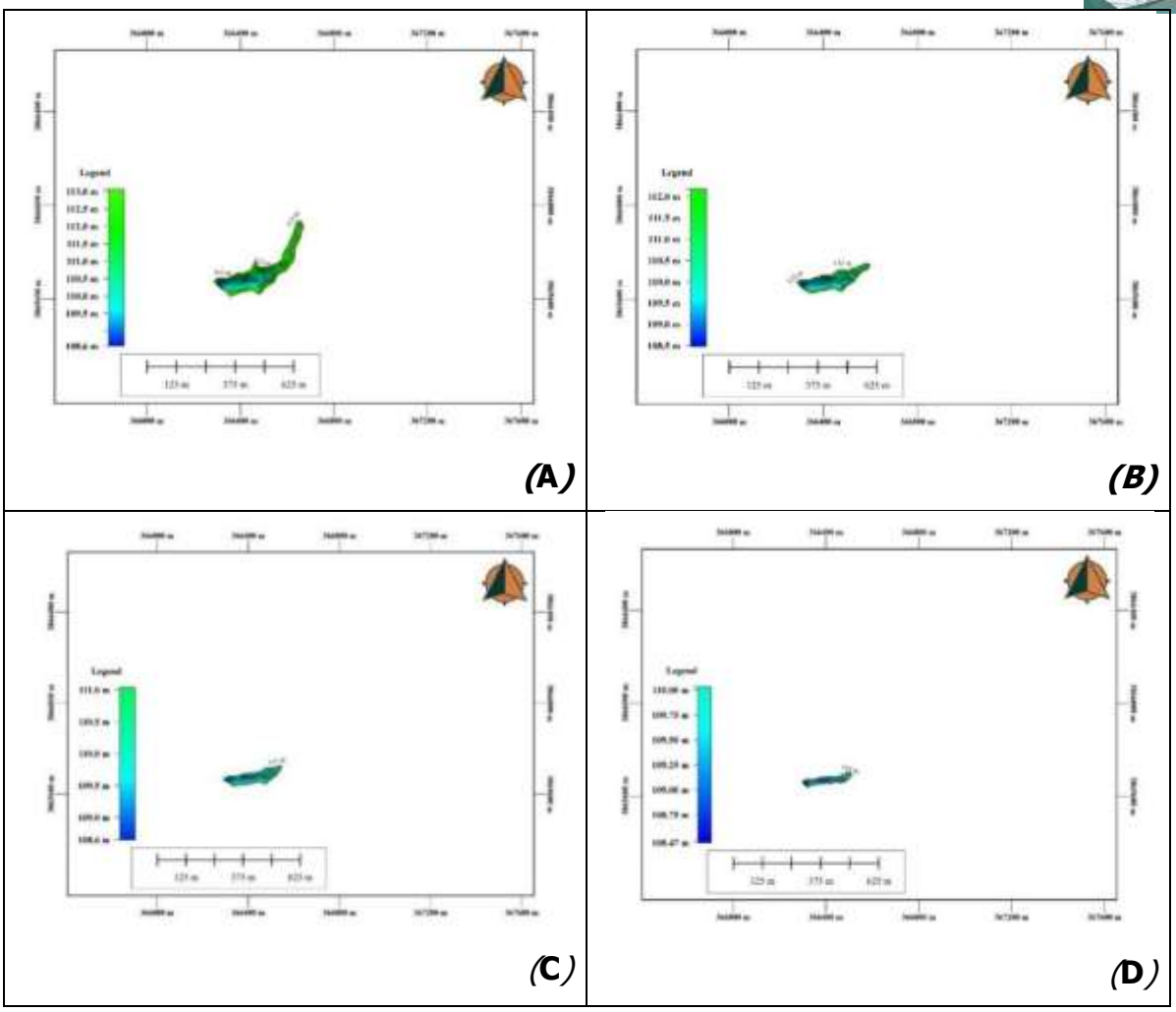


Figure 7. Reservoir configuration at different water levels: (A) 113 m; (B) 112 m; (C) 111 m; and (D) 110 m.

The positive and negative volumes and their associated areas generally increase as the water level rises, whereas the residual volume gradually decreases until it reaches zero at 125 m. This pattern reflects the expansion of the area included within the storage domain as the water level increases.

The positive- and negative-volume curves illustrate changes in island volume and reservoir storage with water level. Negative volume (RC) represents the component associated with topographical storage, whereas positive volume represents elevated areas that remain above the water surface within the analysed boundary.

The positive and negative planar-area curves show changes in the areas included in the analysis as the water level rises. The inundated area increases markedly with increasing water level.

The positive and negative surface-area curves illustrate the difference between the surface areas associated with elevated landforms and inundated areas. The wetted surface area increases clearly as the water level rises.

The residual volume decreases progressively from 2,302,320 m³ at 110 m to zero at 125 m. This indicates that the entire reference volume used in the analysis is progressively incorporated into the calculated storage domain up to the highest analysed level.

The ARD and AIT values fluctuate across the different water levels, reflecting the irregularity of the reservoir's internal topography and changes in the geometry of the islands within the storage area.

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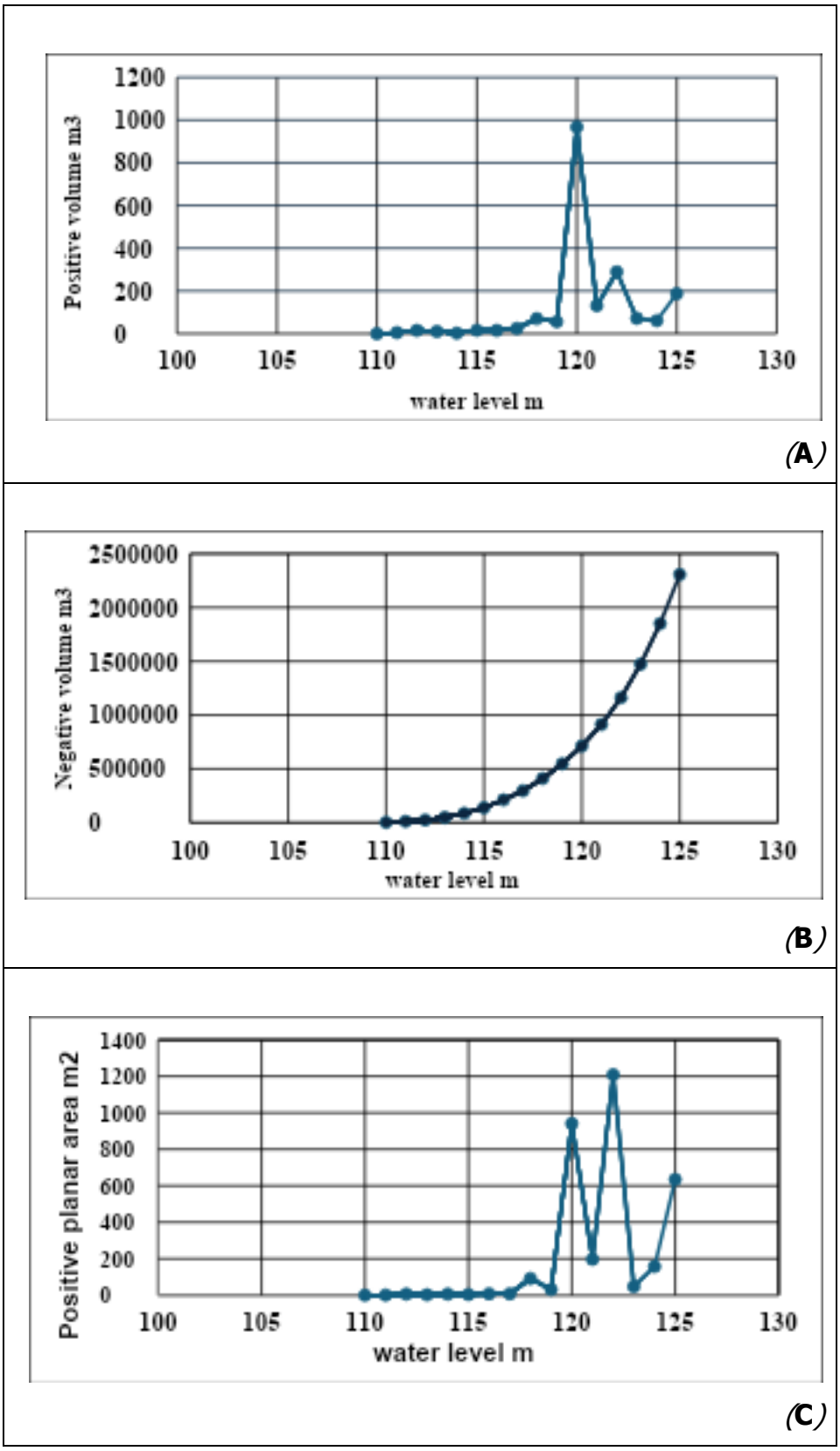


Figure 8. Geometric relationships: (A) island volume (positive volume) versus water level; (B) reservoir storage (negative volume) versus water level; and (C) positive planar area versus water level.

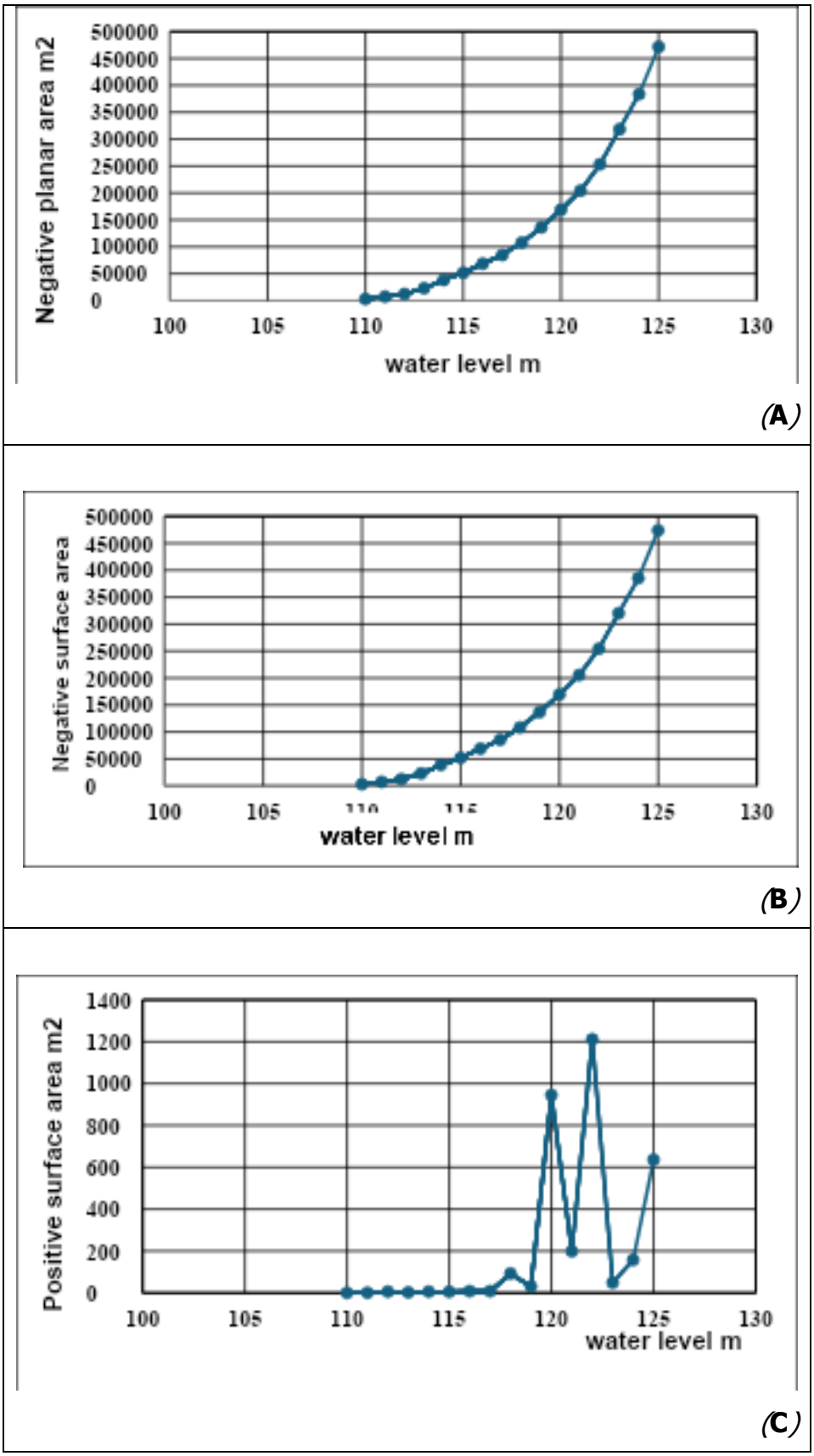


Figure 9. Geometric relationships: (A) negative planar area versus water level; (B) negative surface area versus water level; and (C) positive surface area versus water level.

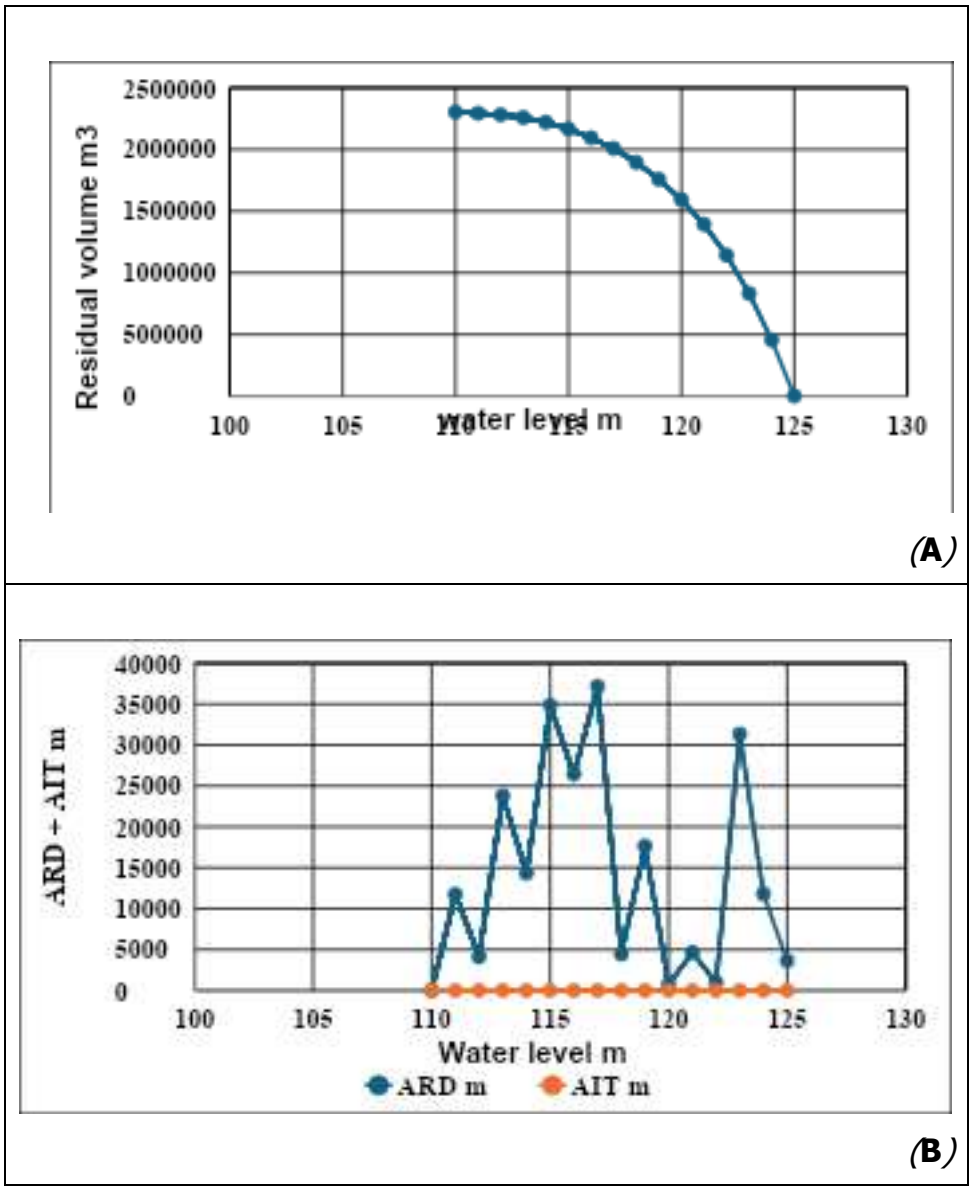


Figure 10. Geometric relationships: (A) residual volume versus water level; and (B) average reservoir depth and average island thickness versus water level.

3.6. Comparison with Previous Studies

The findings of this study are consistent with recent water-harvesting research in Iraq regarding the value of GIS, DEMs, and morphometric analysis. Al-Kakey used spatial analysis and multi-criteria evaluation to identify locations for runoff-harvesting structures, whereas Ahmad integrated GIS, remote sensing, and multi-criteria analysis to select dam sites. The present study differs in its emphasis on linking basin hydromorphometric characteristics with a geometric assessment of storage capacity at a specific site. This provides a preliminary evaluation that can inform subsequent detailed hydrological and engineering investigations.

4. Conclusions and Recommended

The Wadi Akoz Basin has a fifth-order drainage network comprising 641 stream segments with a total length of 68 km. Its drainage density is 5.02 km/km² and its stream frequency is 47.38 streams/km², Mean annual precipitation is 200.09 mm/year, equivalent to approximately 2.71 million m³ of precipitation over the basin annually, with noticeable interannual variability (CV = 21.64%), The shape indices show differing implications: the elongation ratio is 0.92, compared with a

circularity ratio of 0.36 and a form factor of 0.21. Basin shape should therefore be interpreted using the combined set of indices, The calculated topographical storage volume increases from 2,981 m³ at 110 m to 2,305,301 m³ at 125 m, while the inundated surface area (UARB) increases from 2,937 m² to 473,868 m², The highest value of the marginal storage increase relative to the increase in inundated area (ΔV/ΔA) is approximately 5.79 m for the transition to 124 m. Although 125 m provides the greatest total topographical capacity, neither level represents a final operating level, The capacity of 2.305 million m³ is a gross topographical capacity derived from the DEM; it does not represent effective or operational storage, nor does it represent the volume of runoff actually available for storage, The proposed site is a preliminary candidate warranting detailed assessment. Its suitability for implementation cannot be established before the completion of hydrological, geotechnical, and engineering investigations, Assess the inundation area at alternative water levels and intersect it with agricultural land, settlements, roads, and infrastructure to evaluate the trade-off between additional storage and spatial impacts**,** Conduct a sedimentation assessment to estimate long-term storage loss, distinguishing between gross storage, active storage, and dead storage, When comparing alternative sites, apply multi-criteria decision analysis (MCDA/AHP) using documented criteria and traceable weights rather than relying on topographical capacity alone, Test the sensitivity of the results to DEM resolution, watershed boundaries, and the drainage-extraction threshold, and independently validate the drainage network and watershed boundary before proceeding to the design stage.

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