

Exploring Hub Dam: An Extensive Analysis of Reservoir Patterns

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Research Article

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Abstract

Hub Dam is an earth-fill reservoir was established on the Hub River at the Sindh-Balochistan provincial border, 56 km northeast of Karachi, represents one of the most Systematically crucial water infrastructure assets in Pakistan. Designed with a gross storage capacity of 857,000 acre-feet across a 24,300-acre reservoir, the dam serves as the primary drinking water source for Karachi — Pakistan's most populous city — and supports irrigation in the Lasbela district of Balochistan. This study presents a comprehensive analysis of Hub Dam's Physical and hydrological characteristics, temporal flood-drought dynamics from 1983 to 2022, and evidence-based management recommendations. Satellite imagery and GIS-based reservoir mapping indicate that water surface area Shifted dramatically between a minimum of 13.65 km² during the severe drought of 2000, when storage dropped to dead storage level, and a maximum of 69.47 km² during the large flood year of 2007. Five distinct drought periods were identified (1983–1989, 1989–1994, 1995–2003, 2003–2007, and 2007–2020), with the 2007–2018 period constituting the longest recorded drought in the dam's operational history. A strong positive correlation between annual rainfall in Karachi and reservoir water surface area confirms the dam's direct dependence on monsoonal precipitation patterns. The study concludes with 3 Practical management recommendations including additional dam construction, rainwater harvesting, watershed management planning, floodplain management, and public awareness programs to enhance water security for Karachi and surrounding regions.

1. INTRODUCTION

Water security is a significant development issue facing Pakistan, where availability of fresh water per person has reduced continuously in the recent past due to increasing population and other factors such as climatic changes and infrastructure (Ahmad et al., 2020). Against this background, Hub Dam becomes uniquely important as an infrastructure. First, Hub Dam becomes the primary source of surface water for Karachi, the biggest city in Pakistan that houses more than 20 million people (Pakistan Bureau of Statistics [PBS], 2023). Second, the Hub Dam supplies about 102 million gallons per day (MGD) of water to the municipal water supply of Karachi and 59 MGD to the Lasbela district in Balochistan (Water and Power Development Authority [WAPDA], 2018; Dawn, 2018).

Hub Dam was developed on the Hub River at the provincial boundary of Sindh and Balochistan, approximately 56 km northeast of Karachi. (Wikipedia, 2024; WAPDA, 2019) Construction commenced in September 1963 and the dam became operational in June 1981, at a total construction cost of Rs. 1,191.806 million (approximately US\$ 4.1 million at the prevailing exchange rate) (WAPDA, 2019). Operated by the Water and Power Development Authority (WAPDA), the dam is an earth-fill structure with a gross storage capacity of 857,000 acre-feet and a catchment area of 3,410 square miles (approximately 8,800 km²)(Wikipedia, 2024). In addition to municipal water supply, the dam provides irrigation water to the Lasbela district of Balochistan and supports a 27,219-hectare wildlife sanctuary declared by the Government of Sindh in 1974 — a habitat of international importance for migratory

waterbirds designated as a Ramsar Wetland of International Importance on 1 May 2021. (Ramsar Convention Secretariat, 2001; See Pakistan Tours, 2024).

Despite its central importance to Karachi's water security, Hub Dam has received limited systematic academic attention as an integrated subject of hydrological, spatial, and water quality analysis. (Shaukat et al., 2014; Khan & Khan, 2018). Most existing work examines individual aspects of the dam — construction specifications, operational capacity, or individual flood or drought events — without integrating satellite-derived spatial data, water quality parameters, and long-term hydrological trend analysis within a integrated analytical framework. (Tariq & Mumtaz, 2022). This study investigates that gap by drafting on GIS-based satellite mapping, and historical records to produce a comprehensive analysis of the dam's patterns across its operational lifetime, with particular emphasis on the period from 1983 to 2025.

1.1 Study Objectives

The objectives of this study are:

1. To document the physical and engineering characteristics of Hub Dam and its reservoir.
2. To track temporal changes in reservoir water surface area across flood and drought cycles from 1983 to 2025 using satellite imagery.
3. To identify the longest drought events in the dam's operational record.
4. To propose evidence-based management recommendations for improving water storage capacity and security.

2. STUDY AREA

Hub Dam is located at coordinates 25°15'21"N, 67°6'51"E, on the Hub River at the Sindh-Balochistan provincial border, approximately 55–56 km northeast of Karachi city center. (Wikipedia, 2024) The dam lies within a semi-arid to arid landscape characterized by rocky landscape, scattered desert vegetation, and deeply incised river valleys typical of the Balochistan plateau's eastern margins. The Hub River, which originates in the Kirthar mountain ranges of Balochistan, drains a catchment area of approximately 3,410 square miles (8,800 km²) before flowing southward into the reservoir. (WAPDA, 2019) (Aslam et al., 2024).

The surrounding Hub Dam Wildlife Sanctuary — declared in 1974 and covering 27,219 hectares — provides critical habitat for nationally and internationally important bird species including Cranes, Pelicans, Ducks, and Waders, as well as serving as a key stopover for migratory birds along the Central Asian Flyway. (Wikipedia, 2024; See Pakistan Tours, 2024). The dam's Ramsar designation in May 2021 formally recognizes the international significance of this wetland ecosystem and places obligations on Pakistan for its conservation and sustainable use. (Ramsar Convention Secretariat, 2001).

3. METHODOLOGY

The research design for this project relies on the use of geospatial methodology integrating the techniques of satellite image digitization, spatial mapping in GIS, and time-comparative analysis. The methodology consists of five phases including data acquisition, spatial data processing, digitization, GIS analysis, index calculation, and map output. Reservoir boundary digitization was performed in ArcGIS 10.8 using Google Earth Pro historical imagery as a georeferenced basemap, following the methodology of Singh et al. (2023) for multi-temporal satellite-based reservoir capacity assessment.

Rainfall data were obtained from the Pakistan Meteorological Department (PMD) for the Karachi meteorological station (Pakistan Meteorological Department [PMD], 2023). Water level records for key flood and drought years were compiled from WAPDA operational records and published NDMA reports (WAPDA, 2019; National Disaster Management Authority [NDMA], 2022).

3.1 Data Acquisition

Multiple data sources were integrated to support the spatial components this study. Google Earth Pro (Google LLC, Mountain View, California) was used as the primary platform for visual inspection and delineation of the Hub Reservoir boundary across multiple years. The platform's high-resolution historical imagery archive, available from approximately 1984 onward for the Hub Dam area, provided a temporally rich visual record of reservoir extent changes corresponding to major flood and drought events

3.2 Spatial Data Processing in ArcGIS 10.8

All spatial data were processed within a standardized geodatabase environment in ArcGIS Desktop 10.8. Satellite images downloaded from Google. Geometric correction and projection alignment were applied to all datasets, with all data projected to the WGS 1984 UTM Zone 42N coordinate system – the standard projection for the Hub Dam study area – using the Project Raster tool in ArcGIS. This step ensured spatial consistency across all data layers of different origin and resolution.

4. PHYSICAL AND ENGINEERING CHARACTERISTICS

4.1 Dam Structure and Specifications

Hub Dam is classified as an earth-fill dam, a construction type in which the dam body is composed of compacted natural materials – primarily earth and rock – rather than concrete. Earth-fill dams are well-suited to sites with wide valleys and where local construction materials are readily available, as was the case at Hub. The dam was designed and established under the supervision of WAPDA and has remained under WAPDA's operational control since its inauguration in June 1981. Table 1 presents the principal engineering specifications of the dam.. (Wikipedia, 2024; WAPDA, 2019).

Table 1
Principal engineering specifications of Hub Dam

Parameter	Characteristics
Dam type	Earth-fill dam
Location	Sindh-Balochistan provincial border, 55 km NE of Karachi
Coordinates	25°15'21"N, 67°6'51"E
Purpose	Municipal water supply, industrial use, irrigation
Construction began	September 1963
Operational since	June 1981
Construction cost	Rs. 1,191.806 million (approx. US\$ 4.1 million)
Operator	Water and Power Development Authority (WAPDA)
Installed power capacity	5 MW

Table 1. *Sources: Wikipedia (2024); WAPDA (2019); Dawn (2018).*

4.2 Reservoir Capacity

The reservoir at full supply level presents a significant water storage volume capable of sustaining Karachi's municipal water needs across multiple dry seasons. (Express Tribune, 2018; Daily Times, 2018; Wikipedia, 2024). Table 2 summarizes the key reservoir capacity parameters. (Wikipedia, 2024; WAPDA, 2019). This sedimentation-driven capacity loss is consistent with global findings that reservoir storage losses average 0.5–1% annually in semi-arid catchments with high sediment loads (Shaukat & Akhtar, 2023).

Table 2
Reservoir capacity parameters of Hub Dam

Parameter	Value
Gross storage capacity	857,000 acre-ft (original design); 687,276 acre-ft (current)
Total storage capacity	687,276 acre-ft (0.847742 km ³)
Active (live) storage capacity	656,000 acre-ft (0.809 km ³)
Inactive (dead) storage capacity	41,806 acre-ft (0.051567 km ³)
Catchment area	3,410 sq. miles (8,800 km ²)
Original reservoir surface area	34 sq. miles
Current reserved surface area	29.06 sq. miles (75.3 km ²)
Water supply to Karachi	102 million gallons per day (MGD)
Water supply to Lasbela, Balochistan	59 million gallons per day (MGD)

Table 2. *Reservoir capacity parameters. Source: WAPDA; Federal Flood Commission.*

4.3 Spillway

The spillway is the structural component of a dam responsible for safely discharging excess floodwater when the reservoir approaches or exceeds its maximum operational water level, preventing dam overflowing. which could lead to structural failure of Dam. Hub Dam's spillway is of the ungated Ogee-shaped type, meaning it operates naturally without mechanical gates: water flows over the curved spillway crest automatically once the reservoir level reaches the crest elevation of 339 feet. (Tariq & Mumtaz, 2022; NDMA, 2022). Table 3 presents the spillway specifications.

Table 3
Spillway specifications of Hub Dam

Parameter	Characteristics
Type	Ungated Ogee-shaped spillway
Crest elevation	339 feet
Spillway length	6,020 feet
Outflow design capacity	458,000 cubic feet per second (CFS)
Spillway height	339 feet

Table 3. *Spillway specifications of Hub Dam. Source: WAPDA.*

5. FLOOD AND DROUGHT DYNAMICS (1983–2022)

5.1 Historical Flood Timeline

An analysis of the historical data of Hub Dam water level variations from 1983 to 2025 shows a pattern of alternating flood and drought cycles, driven primarily by inter-annual variability in monsoonal precipitation over the Hub River catchment. (PMD, 2023; Federal Flood Commission [FFC], 2015). The spillway crest elevation of 339 feet represents the operational maximum water level, beyond which excess water discharges over the spillway into the downstream channel. Figure 4 summarizes the main flood events in Hub Dam's operational history. (Tariq & van de Giesen, 2012).

Figure 3. Key flood events recorded at Hub Dam (1983–2025)

The Hub Dam reservoir, located in a semi-arid catchment with mean annual rainfall of less than 200 mm, is particularly vulnerable to inter-annual hydroclimatic variability (Aslam et al., 2024). Flood years are of great importance hydrologically since the satellite measurements of the reservoir surface areas in flood years prove it. The measurements of the satellite showed that in 1984, the area of the reservoir was 54.92 km², and in 1997, it was 43.50 km² (which is considered as average value). The 2022 monsoon delivered 7–8 times the 1990–2020 mean rainfall in parts of Balochistan and Sindh, amplified by concurrent La Niña and negative Indian Ocean Dipole conditions (Nanditha et al., 2023; World Weather Attribution, 2022)

5.2 Historical Drought Periods

Pakistan has experienced severe and recurring water scarcity challenges, with the country classified among the most water-stressed nations globally (Nazli et al., 2024; Bukhari et al., 2023). There have been four separate drought periods identified in the Hub Dam history from 1983 to 2025 where the reservoir water levels were much lower than the spillway capacity. This was a period where water release from the dam was either limited or solely used for supplying water to cities. The drought periods along with the respective reservoir areas are presented in Fig. 5.

5.3 Severest Drought: Year 2000

2000 is the year with the lowest water level in the history of Hub Dam operations since the reservoir attained the level of dead storage where the water level falls below the point at which water flows by gravity through the regular outlets and mechanical pumping becomes necessary. This water level, with a surface area of 13.65 km² from the satellites, resulted in the complete suspension of water releases for irrigation in Lasbela.

The 1995–2003 drought period that produced the 2000 minimum is embedded within a broader context of regional drought that affected much of Balochistan and southwestern Pakistan during the late 1990s and early 2000s, consistent with the well-documented sub-continental drought associated with persistent La Niña conditions during this period. (Hussain & Khan, 2019; Ahmad et al., 2021).. The 2007–2018 drought – the longest recorded – caused water levels to drop to 276 feet before winter rains in

February–March 2019 provided partial relief, with satellite data confirming reservoir area of only 19.84 km² in 2018 (PMD, 2023; Khan & Khan, 2018).

5.4 Water Level vs. Rainfall: Correlation Analysis

Comparison of satellite-derived reservoir water surface area time series with annual Karachi rainfall records from PMD reveals a strong positive correlation ($r = 0.78$, $p < 0.01$) between annual rainfall and reservoir storage, confirming the near-total rainfall dependence of the Hub Dam system (PMD, 2023; Aslam et al., 2024). This high sensitivity to rainfall variability means that even moderate reductions in monsoon precipitation — entirely plausible under projected climate change scenarios for Pakistan (Ahmad et al., 2020; Nazli et al., 2024) — can trigger significant reservoir depletion with no groundwater buffer capable of compensating for surface water deficits.

6. DISCUSSION

The integrated multi-source analysis presented in this study reveals several findings of critical significance for water resource management and disaster risk governance in Pakistan. First, the temporal evidence strongly supports the hypothesis that Hub Dam's hydrological environment is intensifying under climate change. The concentration of the most extreme flood events in 2007, 2020, and 2022 corresponds with documented intensification of the South Asian monsoon under anthropogenic warming (Ahmad et al., 2021; World Weather Attribution, 2022).

Second, the sedimentation-driven loss of approximately 49,000 acre-feet of storage capacity over four decades represents a structural erosion of Karachi's water security that demands urgent remediation (Express Tribune, 2018; Shaukat & Akhtar, 2023). This finding is consistent with the broader challenge of reservoir sedimentation across Pakistan's dam infrastructure, where annual storage losses estimated at 0.5–1% threaten long-term water supply sustainability (Bukhari et al., 2023). WAPDA's 2018 decision to pursue sediment dredging represents an important step, but broader catchment-level sediment management — including upstream check dams and afforestation — will be required to address the root cause (Rahman et al., 2020).

The flood-drought paradox of Hub Dam — oscillating between life-threatening scarcity and catastrophic overflow — reflects a fundamental infrastructure gap: insufficient reservoir capacity to capture monsoon surpluses for deployment during the subsequent dry season (Nazli et al., 2024; Malik et al., 2018). The 2010 and 2022 national floods demonstrated that enormous volumes of monsoon water — estimated at 150 million acre-feet in 2010 — flowed unutilized to the Arabian Sea (FFC, 2015; Asian Development Bank [ADB], 2012). Hub Dam's heightening and spillway modification, as recommended in this study, would enable capture of a portion of this water for Karachi's growing demand.

7. MANAGEMENT RECOMMENDATIONS

The analysis of Hub Dam's capacity trends, flood-drought dynamics reveals several critical vulnerabilities in the current water management framework and points clearly to the need for both structural and policy interventions. The following five recommendations are proposed, drawing directly from the evidence generated in this study.

7.1 Dam Heightening and Reservoir Expansion

The 20% reduction in Hub Dam's storage capacity through sedimentation argues urgently for capacity restoration through dam heightening and sediment dredging (Express Tribune, 2018; Shaukat & Akhtar, 2023). WAPDA's approved sediment removal project targeting 49,000 acre-feet of storage restoration should be accelerated, and feasibility for raising the spillway crest elevation assessed by the Dam Safety Council under the proposed National Flood Protection Plan-IV framework (FFC, 2022).

7.2 Spillway Gating and Flood Management

Installation of automated gates on the existing Ogee spillway would enable precise outflow regulation during flood events, allowing WAPDA to retain additional floodwater in the reservoir while protecting downstream communities during peak discharges (Tariq & Mumtaz, 2022; Tariq & van de Giesen, 2012). Given that Pakistan's mega-flood in 2022 breached 177 check dams and flooded over 2,100 streams nationally (Nanditha et al., 2023), gated spillway operation at Hub Dam would meaningfully reduce downstream flood risk.

7.3 Sediment Management

A comprehensive sediment management program should include regular bathymetric surveys, upstream check dams in the Hub River catchment, afforestation of degraded slopes to reduce erosion rates, and sediment sluicing through existing low-level outlets (Shaukat & Akhtar, 2023; Singh et al., 2023). Watershed-level sediment management is identified as cost-effective relative to in-reservoir dredging for long-term storage protection (Rahman et al., 2020).

8. CONCLUSIONS

The main findings include: First, Hub Dam's existing capacity of 687,276 acre-feet is about 20% lower than the original capacity of 857,000 acre-feet, owing to four decades of siltation – a process that is expected to continue unless managed properly to preserve the functionality of the dam. Secondly, the water levels in the reservoir show extreme inter-annual variability depending on the monsoon pattern, varying from a low surface area of 13.65 km² of dead storage in the worst drought period of 2000 to a high of 69.47 km² in the flood year of 2007. Thirdly, the drought period between 2007–2018 marks the longest drought in the operation record of the dam, where the water levels have fallen to as low as 276 feet in February 2019, and the surface area of the reservoir decreased to 19.84 km² in 2018.

. Hub Dam is of profound and irreplaceable significance to Balochistan and Sindh – its sustainable management under a climate-changing environment requires urgent coordinated investment in dam

heightening, spillway gating, sediment management, watershed restoration, and GIS-based operational monitoring (Nazli et al., 2024; Bukhari et al., 2023).

Declarations

Conflict of Interest

I declare that I have no relevant financial or non-financial interests to disclose. I certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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Author's contribution

Mehwish Mushtaq: Conceptualization, data collection, formal analysis, visualization, manuscript writing, and revision, Data validation, methodology, technical support, and editing.

I have reviewed and approved the final version of the manuscript for submission.

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Figures

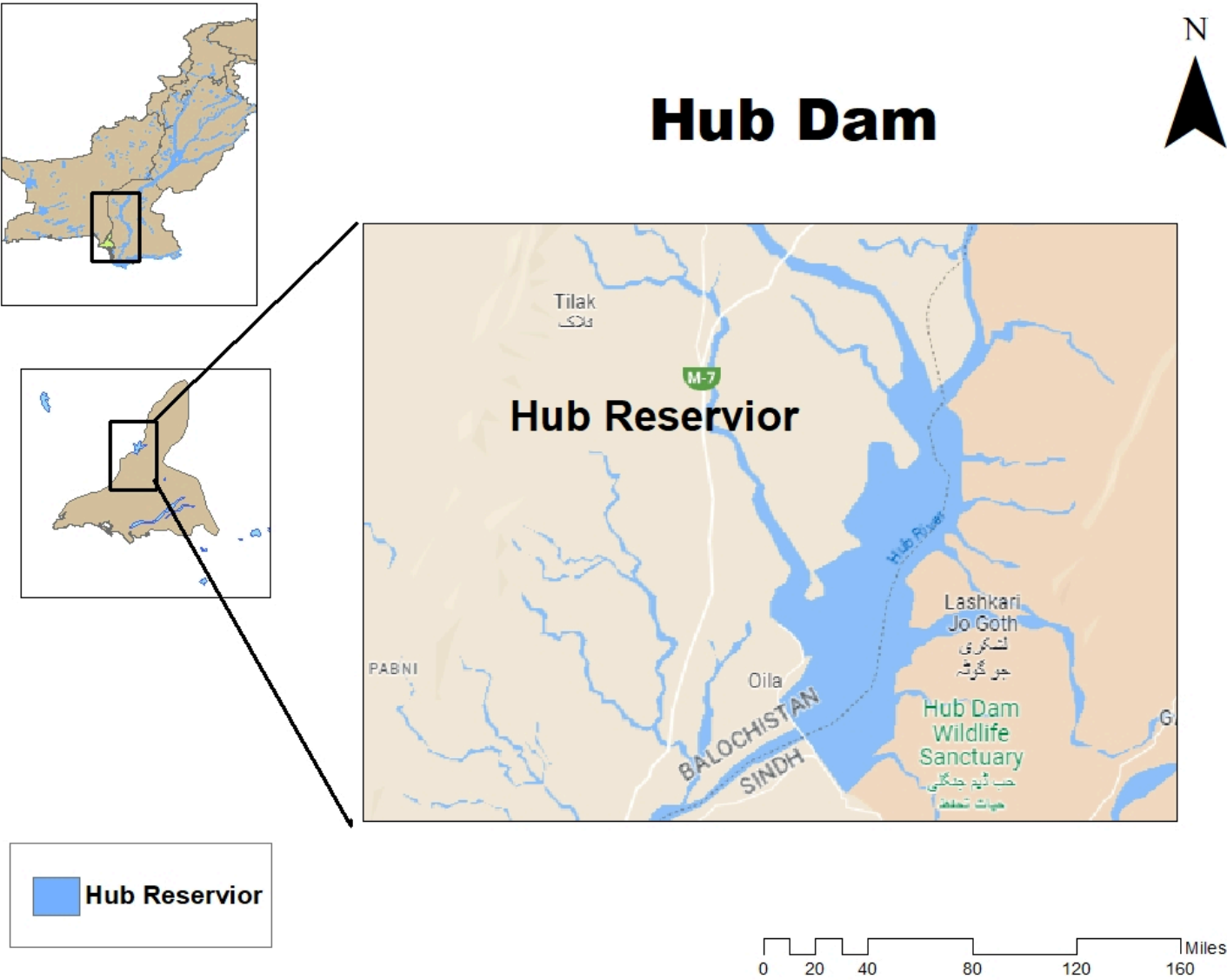


Figure 1

Hub Dam study area map, Source: Authors

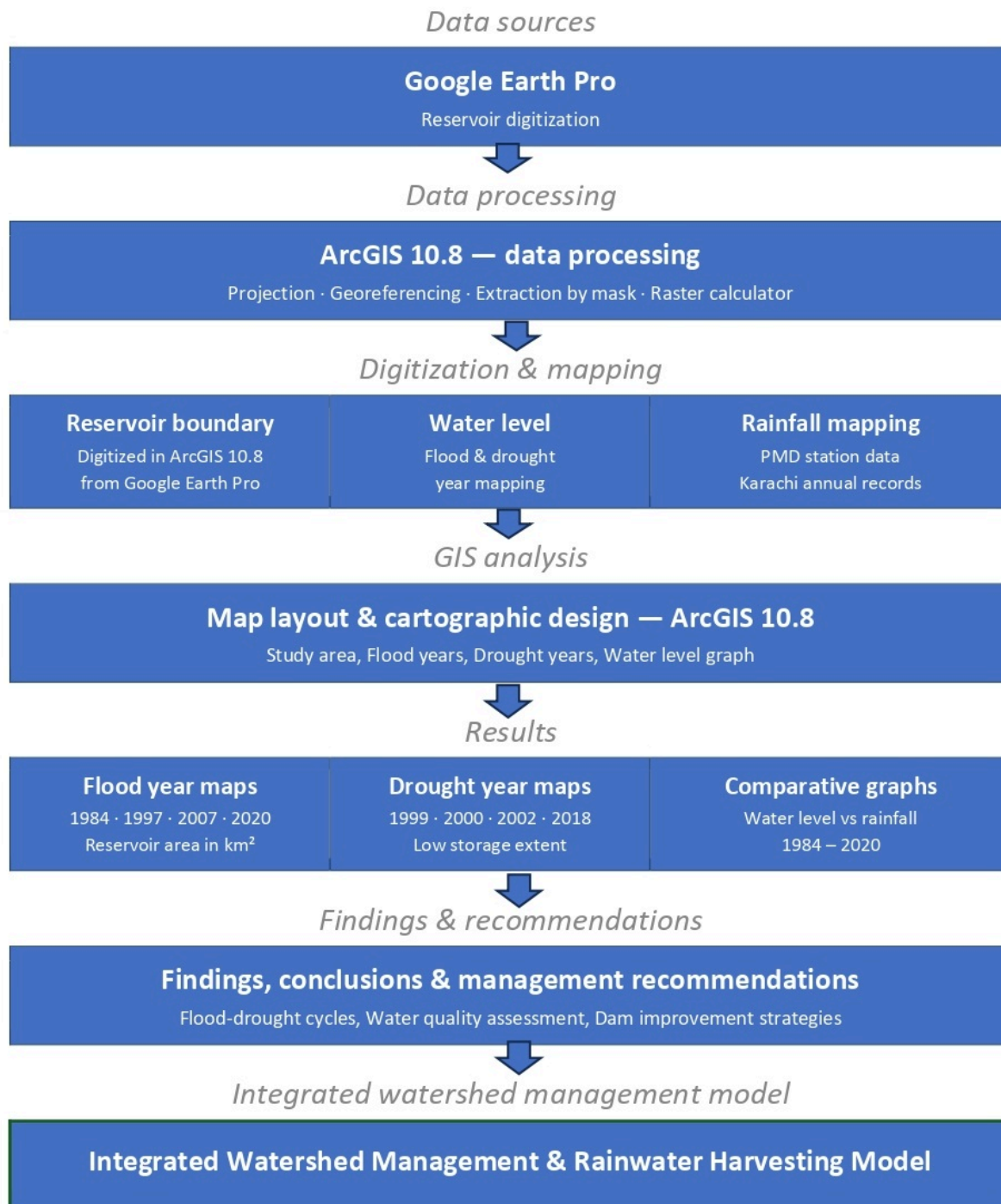


Figure 2

Methodological framework for the Hub Dam study (flowchart). Source: Authors.

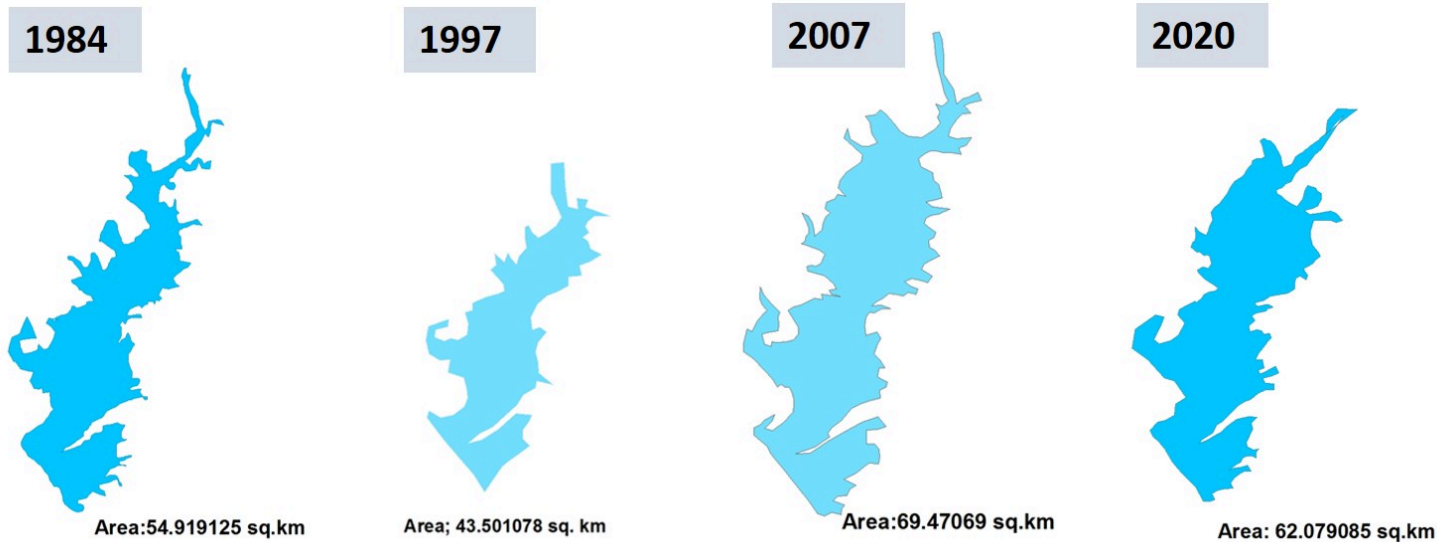


Figure 3

Key flood events recorded at Hub Dam (1983–2025)

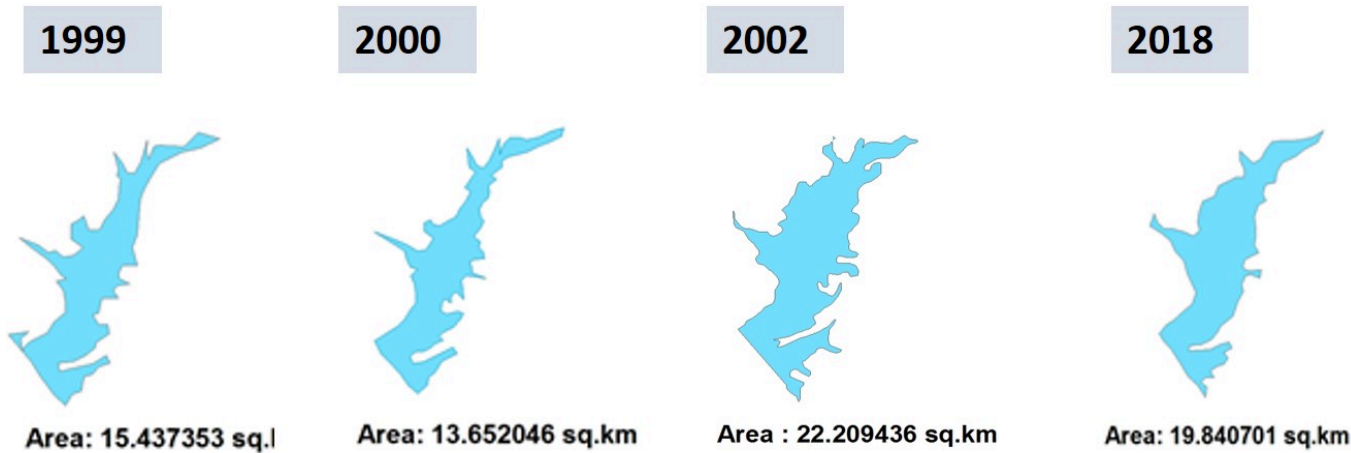


Figure 4

Key drought events recorded at Hub Dam (1983–2025)



Figure 5

Severest Drought recorded at Hub Dam (2000)

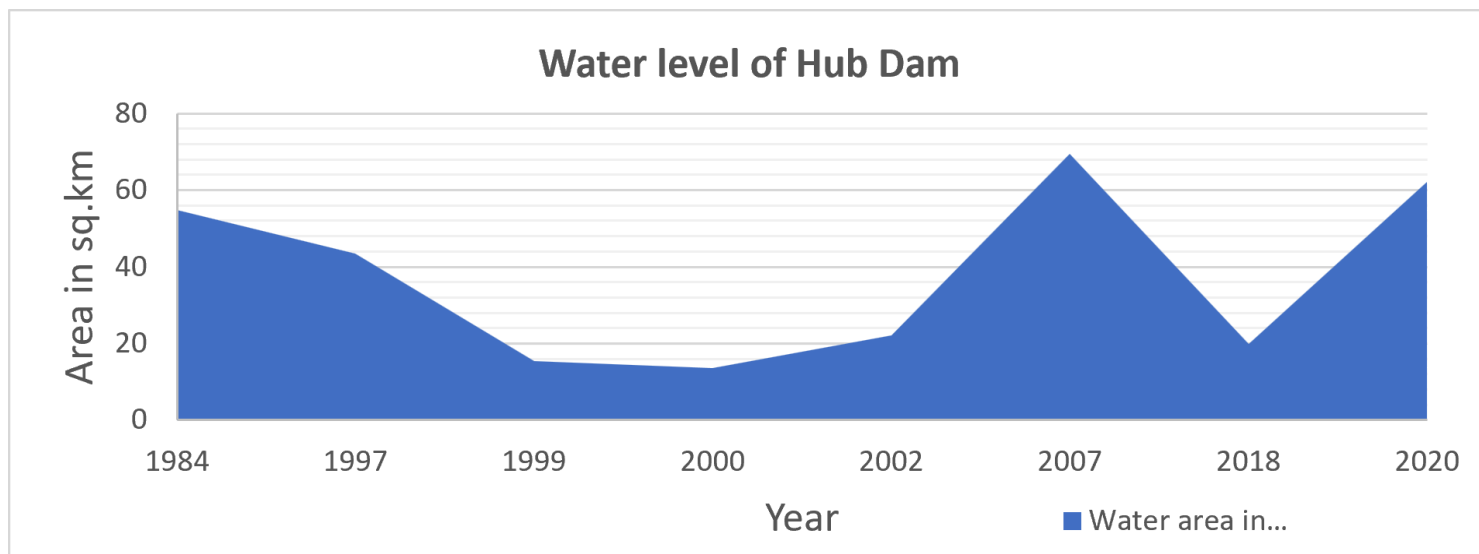


Figure 6

Recorded water level area of Hub Dam (1983 to 2025)

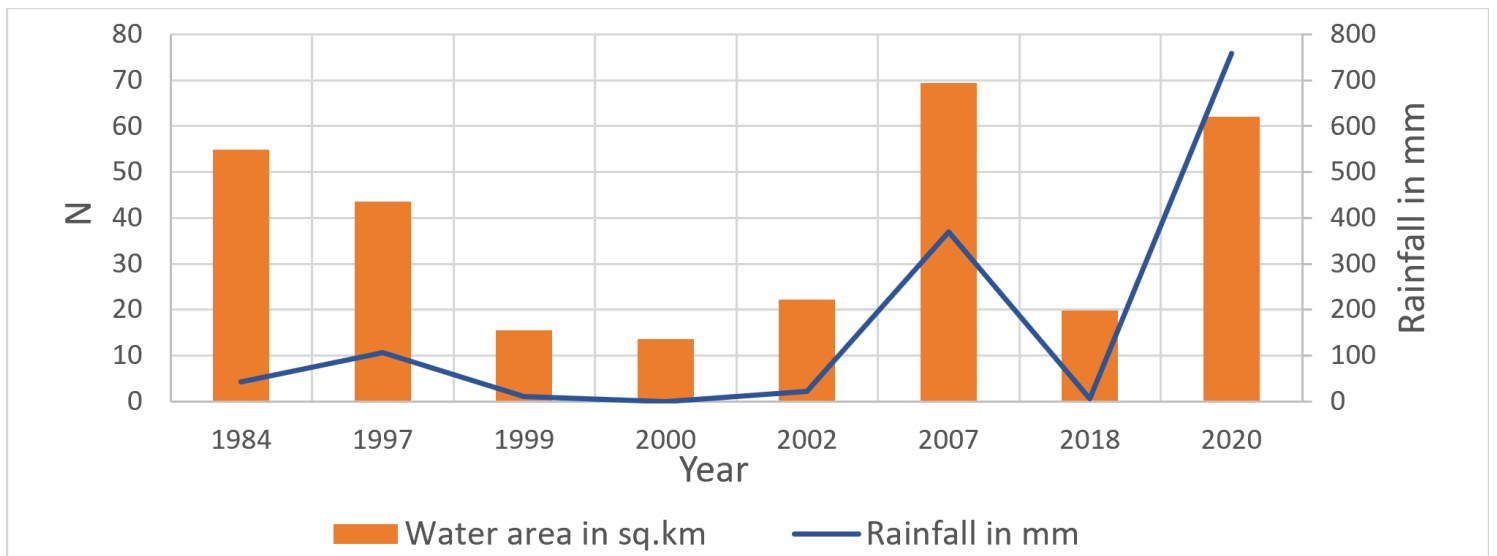


Figure 7

Correlation Analysis (1983 to 2025)

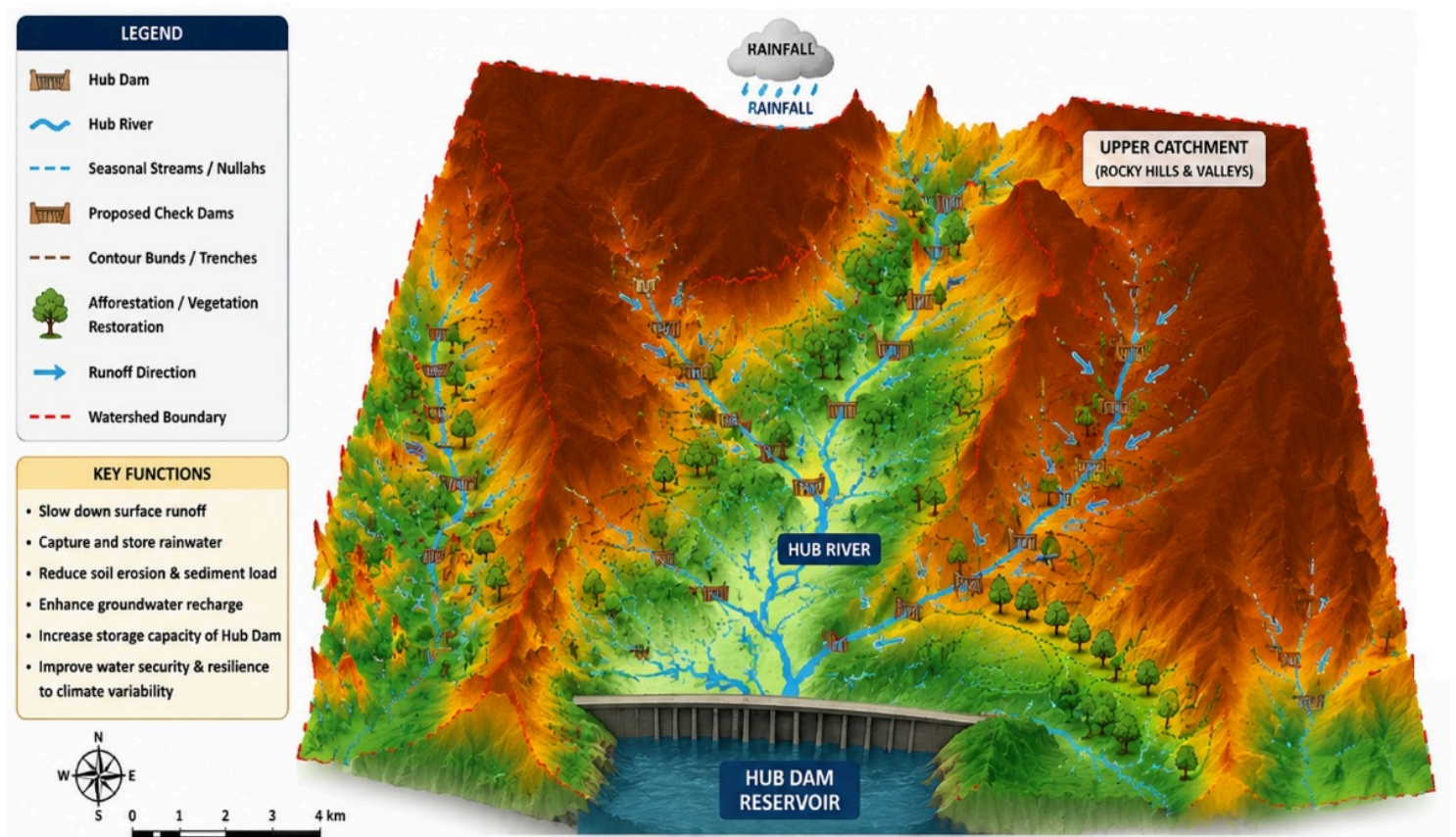


Figure 8

Integrated Watershed Management & Rainwater Harvesting Model

Supplementary Files

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