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Evaluation of the effectiveness of telaga-based rainwater harvesting in arid regions

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Abstract: This study evaluates the effectiveness of telaga-based rainwater harvesting (RWH) systems in Tepus and Semanu Sub-districts of Gunungkidul, Yogyakarta, Indonesia, in supporting water availability throughout the dry season. The methods included field surveys of 40 telaga/embung[1] (morphometric/depth measurements, inlet–catchment conditions, and operational status), descriptive statistical analysis, and estimation of water losses using the FAO-56 Penman–Monteith method (ET_o), which was converted into open-water evaporation (E_o). Results show an average designed storage volume of 14,870 m^3, while actual effective volume is only approx. 35% due to an average sedimentation rate of 48.25% (50% of telaga fall into the ≥51% sedimentation category). The theoretical rainwater-harvesting effectiveness is 20.85%, whereas actual effectiveness is 6.09% (actual range 0–33.8%; 37.5% of telaga have lost their function). At peak dry-season conditions, E_o ranges from approx. 5–7 mm per day (approx. 31–43 m^3 per day for an average surface area of 6,138 m^2). Accumulated evaporation over approximately 90 days is equivalent to approx. $2.76–3.87 \cdot 10^3$ m^3, or approx. 53–74% of the initial effective storage (approx. $5.20 \cdot 10^3$ m^3). Operationally, telaga retain their functional capacity for only ±2–3 months after the rainy season, rendering their supply insufficient to meet demand over the entire dry period.

Keywords: effectiveness, evaporation, karst ponds, rainwater harvesting, seasonal water security storage, sedimentation

INTRODUCTION

Karst landscapes are characterised by unique and highly complex hydrogeological behaviour (Anikeev *et al.*, 2015; Kuzichkin *et al.*, 2021) due to their porous carbonate lithology, rapid infiltration, and the dominance of subsurface flow pathways. In such terrains, rainfall rarely persists on the surface; instead, water quickly percolates through fractures and conduits, forming underground drainage networks that are difficult to access. As noted by Ford and Williams (2007), this phenomenon results in surface-water scarcity even in regions with relatively high annual rainfall (Wu *et al.*, 2018; Alene *et al.*, 2022; Umukizal *et al.*, 2023; Hasan *et al*, 2025). Consequently, a structural mismatch often arises between abundant rainfall and limited accessible surface water, creating chronic constraints for domestic and agricultural water supply in rural karst settings, a pattern similarly observed in traditional rainwater-harvesting (RWH) systems in semi-arid regions such as Rajasthan (Han and Ki, 2010; Quigley *et al.*, 2016; Balkhair and Rahan, 2018; Yadav *et al.*, 2022).

Gunungkidul District in southern Java, Indonesia – particularly the subdistricts of Tepus and Semanu – represents one of the most prominent examples of this hydrological paradox. Although the region receives 1,500–2,200 mm of rainfall annually (BMKG, 2024), its high infiltration rates result in rapid loss of surface water, compelling local communities to rely heavily on RWH systems as their primary water source. Among these systems, telaga – natural or constructed depressions designed to

[1] Telaga/embung – natural or constructed depressions designed to store direct rainfall and surface runoff.

store direct rainfall and surface runoff – serve as the principal infrastructure for water provision in the area (Sample and Liu, 2014; Cahyadi, 2017; Widyastuti and Haryono, 2017). Telaga remain vital for domestic use, livestock, fisheries, and small-scale agriculture, particularly during dry seasons, when alternative water sources diminish significantly.

However, the function of telaga is increasingly compromised by a range of technical and environmental challenges. One of the most prominent factors is evaporation; in tropical regions, open-water evaporation may remove substantial portions of stored water (Abdulla and Al-Shareef, 2009; Park and Um, 2018; Jamali *et al.*, 2020; Ruso, Akıntuğ and Kentel, 2024). This is especially true in reservoirs with large surface areas and limited shading, which is consistent with field observations in Gunungkidul (Lesmana, 2016). Sedimentation presents an additional challenge, as eroded materials from surrounding catchment areas progressively accumulate in the basin, reducing storage depth and volume, and shortening operational lifespan. Over time, several telaga in Gunungkidul have experienced severe sedimentation, with some losing more than half of their original capacity and others suffering complete functional loss (Endarto, Gunawan and Haryono, 2016).

Another constraining factor is the limited distribution infrastructure associated with telaga. Many units still rely on manual extraction or simple pumping systems that are insufficient for wider agricultural use. As highlighted in regional RWH assessments, inefficiencies in distribution systems often contribute to mismatches between supply and demand, particularly during extended dry seasons (Ghisi, Bressan and Martini, 2007; Brontowiyono, Lupiyanto and Malik, 2009; Basinger, Montalto and Lall, 2010; Karim, Bashar and Imteaz, 2015; Karim *et al.*, 2021). Likewise, recent hydrological analyses show that poorly optimised RWH systems in dryland and karst regions may exacerbate water imbalances when seasonal stress intensifies (Abdelkareem, Mansour and Akawy, 2023; Fu *et al.*, 2025).

Although telaga have long played a critical role in the local water-security framework, existing scientific literature still exhibits several gaps. First, quantitative assessments of rainwater-harvesting effectiveness relative to potential runoff inputs remain limited in karst environments. Second, few studies systematically evaluate the combined influence of evaporation and sedimentation on storage performance under tropical climatic conditions. Third, the seasonal reliability of telaga – specifically, how long stored water lasts after the rainy season – has not been rigorously assessed across multiple units. Finally, system-scale field data to guide rehabilitation priorities and adaptive water-management interventions remain sparse, despite growing attention to the hydro social importance of telaga in Gunungsewu (Martias, 2024).

This study addresses these gaps by conducting a comprehensive evaluation of 40 telaga in Tepus and Semanu. Field surveys included morphometric measurements, sediment-depth assessments, catchment analysis, and documentation of operational status. These data were integrated with rainfall records, reference evapotranspiration calculations using the FAO-56 Penman–Monteith method, and community interviews to produce a multi-dimensional evaluation of system performance.

Specifically, the study aims to: 1) quantify the theoretical and actual rainwater-harvesting efficiency of each telaga, 2) determine the effective storage capacity and its reduction due to sedimentation, 3) estimate evaporation losses during the dry season, 4) assess the functional duration (retention period) of stored water after the rainy season, and 5) identify technical and environmental factors contributing performance gaps across telaga units.

By synthesising hydrological analysis with field-based evidence, this research contributes to the advancement of RWH strategies in tropical karst regions. The findings also offer practical guidance for community organisations, local governments, and water-resource agencies working to enhance water security under increasing climatic uncertainty. Ultimately, the study underscores that achieving reliable telaga performance requires integrated interventions – combining desiltation, sediment-control structures, evaporative-loss mitigation, and improved operational management – to close the gap between theoretical potential and actual storage functionality in karst systems.

MATERIALS AND METHODS

STUDY AREA

The study was conducted in the Tepus and Semanu subdistricts of Gunungkidul Regency, Yogyakarta (Fig. 1), Indonesia – an extensively developed tropical karst terrain positioned outside the designated Groundwater Basin (non-CAT). The area contains 42 telaga within a 5-km radius, serving as the primary rainwater-harvesting (RWH) infrastructure for local communities. The region is characterised by highly porous carbonate formations with rapid infiltration (Ford and Williams, 2007), limited perennial surface flow, and high seasonal dependence on stored rainfall. Annual rainfall ranges from 1,500–2,200 mm (BMKG, 2024), while surface-water scarcity during the dry season necessitates community reliance on telaga (Cahyadi, 2017; Widyastuti and Haryono, 2017).

Field investigations and hydrological analyses were conducted over a six-month period spanning the late rainy season through mid–dry season to capture both storage conditions and depletion dynamics.

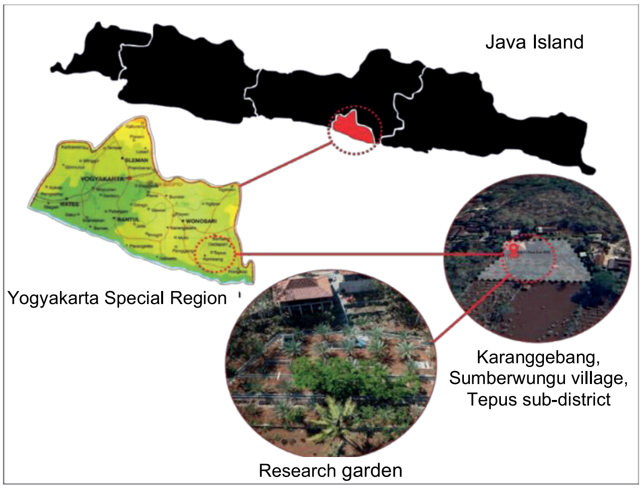

Fig. 1. Map of research location; source: own elaboration based on GPS and Google Earth

DATA SOURCES

Primary data

Primary data were collected through systematic field surveys on 40 telaga, covering:
- **morphometric characteristics:** surface area, water depth, and basin geometry measured using depth probes and tape measure/digital meter;
- **catchment characteristics:** delineation of micro-catchments using GPS and topographic field verification;
- **sedimentation assessment:** comparison between historical design depth and present measured depth to quantify volume loss, following the sedimentation-assessment approaches applied in karst depression (Endarto, Gunawan and Haryono, 2016);
- **water-level monitoring:** repeated observations during the early dry season to assess storage depletion and estimate functional duration;
- **evaporation inputs:** water-level fluctuation data combined with meteorological parameters for Penman–Monteith computations;
- **water-use survey:** semi-structured interviews with farmers and households to document agricultural, fisheries, livestock, and domestic extraction patterns.

Secondary data

Secondary datasets included:
- **rainfall records** (daily record) from the Tepus Rainfall Station (BMKG, 2024; BBWS Serayu Opak, 2024);
- **topographic and geological maps**, used for catchment delineation and permeability assessment;
- **historical telaga profiles** (storage capacity, use patterns, bathymetry) from BBWS Serayu Opak.

Instruments used

To ensure accuracy of field measurements, the study employed:
- GPS handheld device for spatial referencing;
- tape/digital depth meters for morphometric and sediment-depth measurement;
- digital camera for photographic documentation of inlet condition, catchment status, and operational structures.

ANALYTICAL PROCEDURES

Rainwater-harvesting effectiveness

Rainwater-harvesting (RWH) effectiveness was defined as the proportion of potential runoff captured by each telaga. Runoff volume (V_{runoff}) was calculated using Equation (1):

$$V_{\text{runoff}} = P \cdot A_c \cdot C \tag{1}$$

where: P = annual rainfall (mm), A_a = catchment area (m^2), C = runoff coefficient depending on surface type (0.1–0.6).

To reduce uncertainty in theoretical runoff estimation, the runoff coefficient (C) was determined individually for each of the 40 telaga rather than using a generalised average value. Micro-catchments were delineated through GPS-based field tracking and topographic verification, and land-cover characteristics were identified via field observation and cross-checked with regional land-use maps. Runoff coefficients were then assigned according to hydrological standards for tropical rural catchments, with values ranging from 0.10–0.20 for forested karst slopes, 0.20–0.35 for mixed agricultural land, 0.35–0.50 for sparsely vegetated or compacted soil, and 0.50–0.60 for built-up or compacted inlet zones.

For heterogeneous catchments, an area-weighted coefficient (C_{weighted}) was calculated using the Equation (2):

$$C_{\text{weighted}} = \frac{\sum(C_i \cdot A_i)}{A_{\text{total}}} \tag{2}$$

where: C_i = runoff coefficient for a single telaga, A_i = area of a single telaga, A_{total} = total area of 27 telaga.

The weighted approach was applied to 27 of the 40 telaga with mixed land cover. This procedure minimises estimation bias and ensures that theoretical harvesting efficiency reflects the spatial variability of infiltration and surface conditions typical of karst landscapes (Ford and Williams, 2007; Yadav *et al.*, 2022).

Harvesting effectiveness (H_{eff}) was computed acc. to Equation (3):

$$H_{\text{eff}} = \left(\frac{V_{\text{telaga}}}{V_{\text{runoff}}}\right) 100\% \tag{3}$$

where: V_{telaga} = capacity of telaga.

This metric provided both theoretical efficiencies (design capacity) and actual efficiencies (current effective storage).

Storage effectiveness and water-loss quantification

- **Evaporation losses**

Evaporation was estimated using the FAO-56 Penman–Monteith reference evapotranspiration (ET_o):

$$ET_o = \frac{0.408\varDelta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\varDelta + \gamma(1 + 0.34 u_2)} \tag{4}$$

where: R_n = net radiation at the crop surface (MJ·m^{-2}·d^{-1}), G = soil heat flux density (MJ·m^{-2}·d^{-1}), g = psychrometric constant (kPa·°C^{-1}), T = air temperature at a 2 m height (°C), u_2 = wind speed at a 2 m height (m·s^{-1}), e_a = actual vapour pressure (kPa), e_s = vapour pressure of air at saturation (kPa), $e_s - e_a$ = saturation vapour pressure deficit (kPa), $\varDelta$ = slope of the vapour pressure curve (kPa·°C^{-1}).

Open-water evaporation (E_o, in mm) was then obtained using:

$$E_o \text{approx } \mathrm{K_e} \cdot \mathrm{ET_o} \tag{5}$$

where: K_e = coefficient (K_e = 1.05–1.20).

Daily evaporation loss (E_{daily}, in m^3·day^{-1}):

$$E_{\text{daily}} = E_0 \frac{A_s}{1000} \tag{6}$$

where: A_s = telaga surface area (m^2).

Evaporation assessment follows regional karst evaporation studies conducted in Gunungkidul (Brontowiyono, Lupiyanto and Malik, 2016) and supported by general RWH loss analyses in semi-arid environments (Alene *et al.*, 2022).

• **Reduction of telaga capacity**

Capacity reduction (V_{red}) caused by sediment accumulation and another factors was quantified by comparing actual depth-based volume (V_{current}) with designed volume from historical records (V_{designed}) (BBWS Serayu Opak, 2024), and the capacity reduction estimated with:

$$V_{\text{red}} = \frac{V_{\text{design}} - V_{\text{current}}}{V_{\text{design}}} 100\% \tag{7}$$

Sedimentation categories were adapted using sedimentation thresholds documented in karst catchments (Endarto, Gunawan and Haryono, 2016; Lesmana, 2016).

Dry-season storage reliability (functional duration)

Functional duration was defined as the period between the end of the rainy season (when inflow ceases), and the point when a telaga becomes empty.

Triangulated data sources:
1) field water-level observations,
2) community interviews (dry-season depletion patterns),
3) meteorological data for evaporative decline modelling (BMKG, 2024).

The approach is consistent with RWH reliability assessments in karst landscapes (Abdelkareem, Mansour and Akawy, 2023; Fu *et al.*, 2025).

Data validation

Cross-validation procedures included:
– comparison of measured storage capacity with BBWS design records;
– verification of rainfall data between station-level and regional BMKG datasets;
– repeated depth measurements to minimise sedimentation-survey error;
– consistency checks between observed and modelled evaporation decline.

Methodological framework

Overall, the study integrates morphometric analysis, catchment hydrology, evaporation modelling, sedimentation quantification, and socio-hydrological assessment to evaluate telaga effectiveness across three dimensions: 1) harvesting efficiency (capture performance); 2) storage performance (capacity loss and water-loss processes); and 3) seasonal reliability (dry-season functional duration).

Storage capacity was determined using geometric field measurements of length, width, and average depth, validated through visual bathymetric approximation for irregular depressions. Sedimentation percentage was calculated by comparing current measured depth against original design depth recorded in local administrative data and community records. Evaporation loss was estimated using regional climatological data and converted into volume loss based on telaga surface area. Seasonal reliability was assessed by estimating the duration of water retention during the dry season through direct observation and community interviews.

This framework enables system-level diagnosis of RWH performance in tropical karst settings with high infiltration and strong climatic seasonality.

RESULTS AND DISCUSSION

STORAGE CAPACITY AND HARVESTING EFFECTIVENESS

Morphometric characteristics and storage degradation

Field surveys of 40 telaga revealed substantial degradation in storage morphology. The average designed storage was 14,870 m^3, with mean surface area 6,138 m^2 and depth 2.5 m. However, actual current storage averaged only approx. 35% of the design capacity due to sediment accumulation. Sedimentation reached a mean of 48.25%, with half of the telaga exhibiting ≥51% infilling – classified as moderate to very high sedimentation according to previous criteria applied in Gunungkidul (Endarto, Gunawan and Haryono, 2016; Lesmana, 2016).

Some units exhibited extreme sedimentation (≥81–100%), effectively eliminating their function as water-storage bodies. These findings align with earlier work showing rapid sedimentation in open karst catchments lacking vegetation cover (Endarto, Gunawan and Haryono, 2016).

The reduced actual volume (approx. $5.2 \cdot 10^3$ m^3 per telaga) not only lowers annual harvesting potential but increases vulnerability to evaporative losses. As depth decreases while surface area remains wide, the surface-area-to-volume ratio increases – a known driver of rapid dry-season depletion in small tropical reservoirs (Lesmana, 2016).

Theoretical vs actual rainwater-harvesting efficiency

Theoretical harvesting efficiency averaged 20.85%, based on catchment area size, rainfall (BMKG, 2024), and runoff coefficients. However, actual harvesting efficiency averaged only 6.09%, indicating that over 93% of potential runoff fails to be captured.

Key causes include: 1) sedimentation-induced capacity loss, reducing room for incoming runoff; 2) disconnected or poorly maintained inlet channels; 3) karstic leakage pathways in unlined basins (Ford and Williams, 2007). Limited micro-catchment management is allowing infiltrative losses upstream (Yadav *et al.*, 2022; Abdelkareem, Mansour and Akawy, 2023).

Of the 40 telaga, 15 units (37.5%) were classified as non-functional – registering an actual harvesting efficiency of 0%. Conversely, Embung Nangsri recorded the highest efficiency (33.8%), highlighting the strong role of maintenance, catchment condition, and inlet integrity.

These performance gaps underscore the need for structured rehabilitation prioritisation. The priority index used in this study showed that 33 telaga (82.5%) fall within high to very high rehabilitation priority, consistent with degradation patterns identified in earlier research in the Gunungkidul karst region (Cahyadi, 2017; Widyastuti and Haryono, 2017).

WATER-LOSS PROCESSES: EVAPORATION AND SEDIMENTATION

Evaporation losses during the dry season

Evaporation was identified as the dominant loss mechanism during the non-inflow period. Based on FAO-56 Penman–Monteith estimations, peak dry-season ET_o reached 5–7 mm per day, consistent with tropical karst climatic conditions (Muso *et al.*, 2024). Applying the open-water correction coefficient (K_e = 1.05–1.20), daily E_o for the average telaga translated to: $E_{o\text{approx}}$ 31–43 m^3 per day. Over a 90-day dry-season window, cumulative evaporative losses reached: (2.76–3.87)·10^3 m^3. This equals 53–74% of the initial effective storage, demonstrating that evaporation alone can eliminate more than half of stored water before mid-dry-season.

The combination of: 1) shallow post-sedimentation water depths; 2) large surface areas; and 3) high air temperatures (27–30°C) creates ideal conditions for rapid evaporation, consistent with findings in similar tropical reservoirs (Brontowiyono, Lupiyanto and Malik, 2009).

Sedimentation impacts on storage reliability

Sedimentation reduces long-term performance in two ways: 1) direct reduction of effective storage volume, limiting harvested runoff; and 2) indirect acceleration of evaporative loss, due to increased surface-to-volume ratios.

With average sedimentation of 48.25%, empirical storage measurements show that several telaga never reach their intended water levels even during peak rainy season. This dual effect explains the widening gap between theoretical (20.85%) and actual (6.09%) harvesting effectiveness.

Excessive sediment also promotes premature overflow during rainfall events, shortening the retention period of collected water. These findings reflect sedimentation-driven declines observed in the Gunungkidul karst landscape (Endarto, Gunawan and Haryono, 2016; Lesmana, 2016).

The mean sedimentation rate of 48.25% observed in the studied telaga is relatively higher than values commonly reported for small reservoirs in non-karst regions, which generally range between 15–40% depending on catchment conditions and monitoring period (Brontowiyono, Lupiyanto and Malik, 2009; Alene *et al.*, 2022; Yadav *et al.*, 2022). However, direct comparison should be interpreted cautiously due to differences in basin characteristics and assessment methods. Most telaga in the study area have been operational for more than 15–25 years, suggesting that the observed sedimentation represents cumulative long-term infilling rather than short-term episodic events.

The elevated sedimentation in Gunungkidul may partly reflect geomorphological features typical of tropical karst systems, including thin and erosion-prone soils, concentrated runoff into closed depressions, and limited sediment-control structures. Such conditions can accelerate infilling processes (Endarto, Gunawan and Haryono, 2016). Nevertheless, longer-term monitoring would be required to fully distinguish geomorphological effects from land-use and rainfall variability influences.

SEASONAL WATER RELIABILITY

Functional duration after the rainy season

Across all 40 telaga, observational and interview-based analyses showed that functional water availability lasts only 2–3 months after the rainy season ends. Complete drying typically occurs by mid-season (June–August), consistent with patterns reported by local communities and monitoring records (Martias, 2024).

Primary drivers of short functional duration include: 1) deep sedimentation, reducing initial volume; 2) evaporation rates removing approx. 30–40 $m^3·day^{-1}$; 3) karst percolation losses typical of limestone depressions (Ford and Williams, 2007); 4) high withdrawal intensity due to multipurpose use (agriculture: 100%; fisheries: 60%; livestock: 40%; domestic: 30%).

These findings align with broader observations that telaga in karst landscapes often underperform during prolonged dry seasons (Cahyadi, 2017).

Water budget and depletion estimates

With an average effective volume of approx. 5,200 m^3, and combined evaporative and withdrawal losses estimated at approx. 100–110 $m^3·day^{-1}$, projected endurance ranges from: 46–59 days, depending on evaporation (5–7 mm·day^{-1}) and daily demand (50–100 $m^3·day^{-1}$). Once there are the withdrawals for farming peak, many telaga deplete even faster, reducing agricultural productivity during critical growth periods.

The sensitivity tables for evaporation and water demand (Tabs. 1, 2) corroborate that even small increments in climatic stress or demand significantly shorten availability – a key vulnerability under climate variability (Abdelkareem, Mansour and Akawy, 2023; Fu *et al.*, 2025). These results confirm that traditional telaga cannot reliably support dry-season agriculture without technological intervention, echoing conclusions from broader tropical dry land research (Yadav *et al.*, 2022).

Table 1. Estimated telaga water endurance – evaporation sensitivity (fixed demand 70 $m^3·day^{-1}$ and effective telaga volume 5,204.5 m^3)

Scenario	Evaporation loss ($m^3·day^{-1}$)	Total loss ($m^3·day^{-1}$)	Estimated endurance (days)
Evaporation 5 mm·day^{-1}	30.7	100.7	51
Evaporation 6 mm·day^{-1}	36.8	106.8	48
Evaporation 7 mm·day^{-1}	43.0	113.0	46

Source: own study.

Table 2. Estimated telaga water endurance – demand sensitivity (fixed evaporation 6 mm·day^{-1} and effective telaga volume 5,204.5 m^3)

Scenario	Total loss ($m^3·day^{-1}$)	Estimated endurance (days)
Demand 50 $m^3·day^{-1}$	86.8	59
Demand 70 $m^3·day^{-1}$	106.8	48
Demand 100 $m^3·day^{-1}$	136.8	38

Source: own study.

Synthesis: drivers of performance gaps

Across all lines of evidence, the main factors reducing telaga performance are:
1) high sedimentation (mean 48.25%) → lost storage + increased evaporation;
2) high evaporation (5–7 mm·day^{-1}) → >50% of stored water lost in three months;
3) poor catchment connectivity → low actual harvesting (6.09%);
4) karst percolation → leakage through limestone floors;
5) lack of operational management → unregulated multipurpose withdrawals.

The interaction of these factors creates a self-reinforcing decline in performance. Restoration will require integrated sediment control, desiltation, evaporation mitigation, and operational reforms, consistent with global RWH best practices for karst drylands (Yadav *et al*., 2022; Abdelkareem, Mansour and Akawy, 2023; Fu *et al*., 2025).

Limitation of the study

This study is subject to several limitations. First, the observation period covered one hydrological cycle and may not fully represent interannual climatic variability. Second, historical design capacity data were derived from administrative records that may contain minor measurement uncertainty. Third, percolation losses were inferred from depletion behaviour rather than directly instrumented subsurface monitoring. Future studies incorporating longer-term hydrological monitoring and subsurface flow measurements would improve accuracy.

Recommendations

Improving the reliability of telaga-based RWH systems requires integrated structural and operational interventions. From a structural perspective, priority should be given to sediment removal in reservoirs experiencing capacity loss above 50%, accompanied by inlet rehabilitation and upstream erosion control to reduce further sediment inflow. Strengthening catchment connectivity and incorporating sediment-trapping structures may substantially enhance effective storage restoration. Measures to mitigate evaporation, including basin deepening, optimisation of surface-to-volume ratios, and selective shading strategies, should also be evaluated to extend dry-season water retention.

In areas where rapid percolation significantly reduces storage reliability, technical solutions such as geomembrane lining or clay-based sealing layers may be piloted to improve retention efficiency. However, such interventions should be assessed carefully to ensure environmental compatibility within karst ecosystems.

Operational improvements are equally important. The promotion of water-efficient irrigation technologies, such as drip irrigation and low-pressure piping systems, can significantly enhance agricultural water productivity. Community-based water allocation mechanisms and seasonal withdrawal regulation should be institutionalised to prevent premature depletion during peak dry months. Rehabilitation prioritisation should focus on high-impact telaga classified as high to very high priority, particularly those serving multipurpose agricultural functions.

Future research should incorporate longer-term hydrological monitoring and subsurface flow assessment to refine evaporation and infiltration estimates and to strengthen predictive modelling of storage reliability under climate variability. Through such integrated approaches, telaga-based RWH systems can be repositioned as more reliable infrastructure for sustaining agricultural productivity in tropical karst drylands.

CONCLUSIONS

This study demonstrates that the effectiveness of telaga-based rainwater harvesting (RWH) systems in the karst region of Semanu and Tepus remains substantially constrained by the combined effects of sedimentation, evaporation, and karst infiltration. Although the theoretical harvesting efficiency reaches 20.85%, the actual effectiveness declines sharply to 6.09%, indicating a significant performance gap between hydrological potential and operational reality. The mean sedimentation rate of 48.25% has reduced effective storage capacity to approximately 35% of the original design volume, thereby limiting the ability of the reservoirs to retain runoff during the rainy season.

Evaporation further exacerbates storage unreliability, with seasonal losses reaching 30–65% of effective capacity in several telaga. As a result, most reservoirs are only capable of supplying water for two to three months after the rainy season, which is insufficient to sustain agricultural activities throughout the dry period. In addition, rapid infiltration through karst substrates and inefficiencies in distribution systems contribute to premature water depletion before critical crop growth stages. These interacting constraints indicate that storage degradation in Gunungkidul telaga is attributable not only to maintenance deficiencies but also to structural limitations associated with tropical karst geomorphology and current management practices.

Overall, the findings highlight that improving agricultural resilience in dry karst regions requires addressing the entire harvesting–storage–utilisation chain rather than focusing solely on increasing storage volume.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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