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Enhancing Rainwater Harvesting Sustainability in the Al-Basrah Basin, Iraq: A Two-Phased Approach Combining GIS-AHP for Site Suitability and Fog Computing for Dynamic Management

Alauldeen Taher Najm[1,*], Wei-Koon Lee[1], Abdulhussain Abdulkarim Abbas[2] and Suzana Ramli[1]

[1] *School of Civil Engineering, Universiti Teknologi MARA, Malaysia*

[2] *Department of Civil Engineering, University of Basrah, Iraq*

Abstract: The increasing issue of water scarcity worldwide calls for research into sustainable water management solutions. Using a two-phase methodology that makes use of geographic information systems (GIS) and analytical hierarchy process (AHP) method for multi-attribute decision-making (MADM), integrated with fog computing. This study explores the potential of rainwater harvesting (RWH) in the Al-Basrah Basin, Iraq. In the first phase, weights are assigned to the evaluation attributes represented by the thematic layers (elevations, slope, river buffer, well pads/urban area, and soil texture). The results demonstrate the feasibility of the southeast region in the study area to be used for RWH. Furthermore, a comparison between AHP and the fuzzy analytic hierarchy process (FAHP), the merit of AHP to reconcile discrepancies and expedite the collection of expert opinions, reduces the problems of uncertainty and inconsistency, and improves the appropriateness assessment credibility and reliability. In addition, a novel conceptual second phase integrates fog computing for dynamic RWH management in the candidate RWH site area. At the selected RWH sites, fog nodes with sensors might be deployed to enable real-time data collection of rainfall, water quality, tank levels, and maintenance demands. Local preprocessing and analysis of data by fog nodes facilitate near-real-time decision-making for the best possible use of water resources and system health. Long-term water security in the Al-Basrah Basin may be enhanced by this strategy, which has the ability to enable informed water management.

Keywords: geographic information systems (GIS), analytical hierarchy process (AHP), multi-attribute decision-making (MADM), rainwater harvesting (RWH), fog computing, sustainable water management

1. Introduction

Urbanization and industrialization exacerbate water scarcity, particularly in developing countries [1–3]. Rainwater harvesting (RWH) offers a secure and affordable alternative water resource, involving the capture, storage, and utilization of rainwater [1, 4]. Selecting suitable RWH sites requires consideration of socioeconomics, land use, rainfall patterns [5], operating expenses [6], and environmental attributes [7]. Geographic information systems (GIS) and remote sensing (RS) have become essential tools for water resource management, integrating variables like land cover and soil texture [8, 9]. Techniques such as weighted linear combination (WLC) simplify decision-making for site selection, while boolean overlay analysis refines the process [10]. The integration of the analytic hierarchy process (AHP) with GIS, popular since the early 21st century, combines decision-making support with powerful computational and mapping capabilities, offering an efficient approach to solving complex problems [11, 12].

The AHP is a widely used multi-attribute decision-making (MADM) methodology, particularly in decision-making related to water resource management [1, 13, 14]. Known for its flexibility, affordability, and simplicity, AHP has become one of the most frequently applied techniques for managing water supplies [1, 15]. Its integration with GIS enhances spatial decision-making, making it a powerful tool for analyzing complex scenarios [1, 16]. Effective MADM involves assessing alternative options and understanding the weights of non-substantial features [17–19]. Other MADM models, such as simple additive weight and ideal point methods, are also notable [13, 20]. The challenge of identifying suitable RWH sites is complex due to the interplay of hydrological, geological, and economic factors [6]. Despite extensive research on RWH, challenges remain in identifying the most suitable RWH sites within specific study areas. In dry environments, a significant portion of rainwater is lost to evaporation, reducing the amount captured. Thus, selecting the most productive sites using AHP and MADM

***Corresponding author:** Alauldeen Taher Najm, School of Civil Engineering, Universiti Teknologi MARA, Malaysia. Email: 2021828366@isiswa.uitm.edu.my

frameworks is a viable approach [1, 21–23]. However, many studies focus on static site selection and overlook the dynamic aspects of RWH management. To enhance system performance and water usage, real-time monitoring and data-driven decisions are essential [17, 18]. Integrating fog computing with RWH systems presents a potential solution [24, 25]. By deploying sensor-equipped fog nodes at suitable locations, real-time data on rainfall, water quality, and tank levels can be collected and processed locally to optimize water usage and address issues like low water levels or quality decline [26, 27]. This decentralized management approach supports long-term water security in water-scarce areas. This study addresses the following research questions: (1) How can GIS and the AHP method be applied to identify suitable rRWH sites in the Al-Basrah Basin, Iraq? (2) What are the comparative advantages of AHP and fuzzy analytic hierarchy process (FAHP) in enhancing the credibility and reliability of site selection for RWH? (3) How can fog computing be integrated to facilitate real-time management of RWH systems at selected sites? This study developed a decision matrix (DM) for selecting RWH sites in the Al-Basrah Basin, Iraq, based on factors like soil texture, slope, urban areas, elevation, and river buffers, using GIS and the AHP framework within the MADM approach. It also introduces fog computing integration with GIS-AHP for dynamic RWH management in the region. The present study is organized as follows: Section 2 presents the study area. Section 3 describes the materials and methods that were used. Section 4 offers the results of the proposed framework. While Section 5 provides sensitivity and comparative studies to support the efficiency and superiority of the suggested method. Whereas, Section 6 outlines the discussion. Finally, Section 7 provides the conclusion.

2. Study Area

The study area is located within the administrative borders of Al-Basrah Governorate, south of the Republic of Iraq, as shown in Figure 1. On the northern side, it is bordered by the Central Marshes, and on the southern side, it is bordered by the Arabian Gulf, while on the western side, it is bordered by DhiQar Governorate and the eastern side is the Iranian border. The Tigris and Euphrates rivers pass through this region and meet in the city of Qurna, north of Basrah Governorate, to form the Shatt al-Arab, which extends to the end of the study area. Its climate is characterized by dry, hot summer and cold, humid winter, extreme temperature, high solar radiation, little rain, and high humidity, and has homogeneous soil.

3. Materials and Methods

The proposed methodology involves 2 major phases: weighted-attributes evaluation for RWH site selection in Section 3.1 and Fog Computing [25] integration for dynamic management of the selected RWH sites in Section 3.2, as summarized in the flowchart as shown in Figure 2.

3.1. Weighted-evaluation attributes

This study identified five evaluation attributes for selecting suitable RWH sites, based on a literature review, data availability, and expert judgment. The attributes are:

1) Elevations: Higher elevations typically receive more precipitation, enhancing rainwater availability [28].
2) Slope: Slope influences surface water dynamics, runoff, and recharge. Steeper slopes reduce infiltration and increase runoff, limiting rainwater collection. Moreover, constructing RWH systems on steep slopes is economically challenging due to high earthwork costs [21, 28–30].
3) Soil Texture: Clayey soils with lower permeability are ideal for RWH, as they improve water retention [21, 28, 30, 31].
4) Exclusion Sites: Areas like well pads, urban zones, and river buffers are excluded from consideration due to infrastructure limitations and flood risks.

Satellite images from the USGS were used for site analysis, with high-resolution digital elevation models providing topographic data for slope and drainage analysis. Five elevation and slope classes were defined. Soil data were sourced from the FAO, and soil texture maps were created based on published tables. River courses were digitized with a 3.5-km buffer to exclude flood-prone areas. Well pads and urban areas were manually digitized from satellite images to identify infrastructure restrictions. SASPLANETS software processed the spatial data for the study area.

Figure 1
The study area

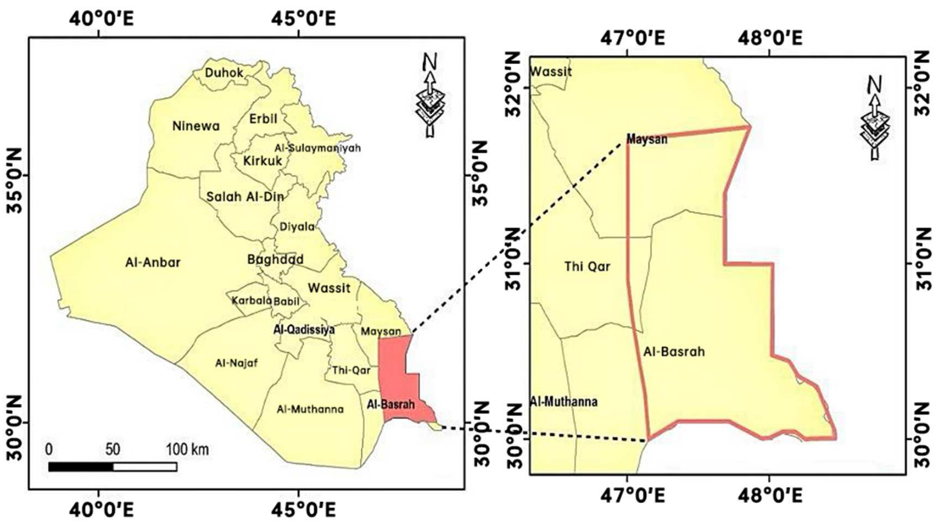
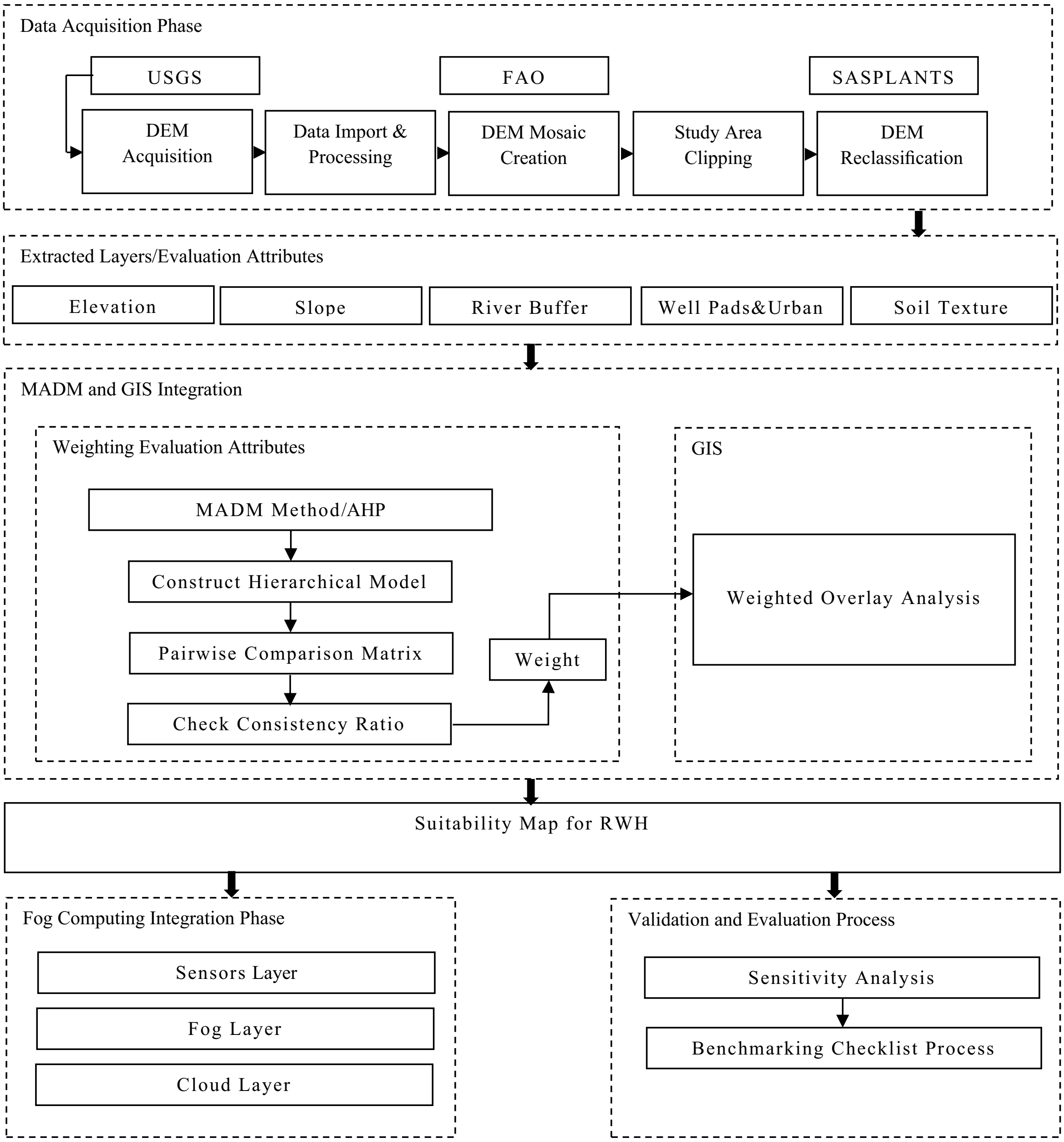


Figure 2
Graphical representation of the methods proposed



3.1.1. Decision matrix

The significance of each evaluation criterion for RWH suitability is assessed using the AHP [30]. The AHP process involves three main steps: weight assignment, weighted linear combination, and standardization [32, 33]. Three RWH sites (A, B, and C) were evaluated using five identified attributes. A panel of experts, experienced in RS, groundwater recharge, rainwater collection, soil conservation, and GIS, determined the relative importance of these attributes [34–38]. Their knowledge of the study area ensured both objective evaluation and expert insights in the weighting process. Due to differing measurement units across attributes (e.g., elevation in meters, soil texture as clay percentage), a standardized scale was applied [39, 40]. Evaluation attributes were reclassified on a scale from 1 (least suitable) to 5 (most suitable) [41]. A pairwise comparison matrix, using Saaty's 9-point scale, was employed to assess the relative importance of each attribute [42] (see Table 1). This systematic approach led to the determination of specific weights for each attribute in the final RWH suitability map [43] (see Table 2).

3.1.2. Consistency analysis

After developing the pairwise comparison matrix, the consistency of the decisions must be evaluated. A consistency ratio (CR) quantifies the extent of inconsistency in AHP, with some degree of inconsistency being acceptable [43]. The CR helps assess the validity of weights for RWH site selection by indicating agreement between the pairwise comparisons. Lower CR values indicate greater consistency, while higher values suggest less consistency. A CR below

Table 1
Scale of relative importance

Numeric scale	Linguistic measurement of importance
1	Equal importance
3	Moderate importance
5	Strong/Essential importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values

10% is considered acceptable [22, 44]. The final weights for each evaluation attribute and the CR are then calculated from the pairwise matrix [22, 45].

$$CR = \frac{CI}{RI} \tag{1}$$

where RI is the random index (RI) (Table 3) [42] and consistency index (CI) is the CI given as

$$CI = \frac{\lambda_{MAX-n}}{n-1} \tag{2}$$

where $\lambda_{\max}$ is the principal eigenvalue computed by eigenvector technique and n is the number of evaluation attributes.

The AHP uses the maximum eigenvalue ($\lambda_{\max}$) to evaluate the consistency of expert opinions within the pairwise comparison matrix (Equation (3)). This matrix (A) indicates the relative importance of each evaluation attribute, with size n × n. The eigenvector (X), of size n × 1, represents the weights for each evaluation attribute. The $\lambda_{\max}$ was computed in Equation (3).

$$\mathrm{AX} = \delta_{MAX} \tag{3}$$

Here, A is the comparison matrix for the evaluation attributes, and X is the eigenvector of size 1. The AHP method acknowledges that absolute consistency is often difficult in practice. Thus, a CR below 0.1 (10%) is considered acceptable for continuing the analysis. If the CR exceeds this threshold, revising the judgments is recommended to address inconsistencies and ensure the final weights reflect expert opinions accurately [36].

3.2. Fog computing integration

This phase introduces a dynamic approach to RWH site management using fog computing integration [25–27, 46]. Fog nodes equipped with sensors monitor rainfall, water quality, and levels in real-time [26, 47]. This data optimizes water usage and addresses issues such as low levels or declining quality [24, 25]. Sensors also detect maintenance needs based on predefined thresholds. A secure communication infrastructure will facilitate data transfer between fog nodes and a central server, utilizing technologies like Wi-Fi, cellular, or LPWANs. The central server enables monitoring, analysis, and informed decision-making.

4. Results

The feasibility of different sites in the Al-Basrah Basin, Iraq for RWH structures was assessed using the MADM framework, which incorporates weights from the AHP.

4.1. Soil properties

In the study area, clay loam is the dominant soil texture, covering over 62% (10,306.103 km²) of the region (Table 4, Figures 3 and 4). Loam is the second most common, accounting for 24.33% (4,012.71 km²) of the land. The remaining categories—clay, salty clay, sandy loam, and sandy clay loam—constitute less than 14% of the total area.

Table 4
Soil texture classes with their areas

Soil texture	Area (km^2)
Clay Loam	10,306.73
Clay	7.69
Loamy Sand	1,121.17
Salty Clay	1,041.47
Sandy Loam	0.31
Loam	4,012.71
Total	16,490.08

4.2. Obstacle classes

The presence of marshes (e.g., Hammar, Um Naj, Badi, Abu Samakh, Abu Zark, and Hor Ahwaiza), oil exploration areas

Table 2
The pairwise comparison matrix describing relative importance between identified evaluation attributes

RWH (Goal)	Elevations (A1)	Slope (A2)	River buffer (A3)	Well pads/ Urban (A4)	Soil texture (A5)
Elevations (A1)	1.000	1.000	4.000	4.000	3.000
Slope (A2)	1.000	1.000	4.000	4.000	3.000
River buffer (A3)	0.250	0.250	1.000	1.000	0.500
Well pads/Urban (A4)	0.250	0.250	1.000	1.000	0.500
Soil texture (A5)	0.333	0.333	2.000	2.000	1.000

Note: * A1 – A5 refers to Evaluation Attribute 1 to Evaluation Attribute 5

Table 3
Random index values

Order	1	2	3	4	5	6	7	8	9
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45

Figure 3
The percentage of each soil texture class's areas

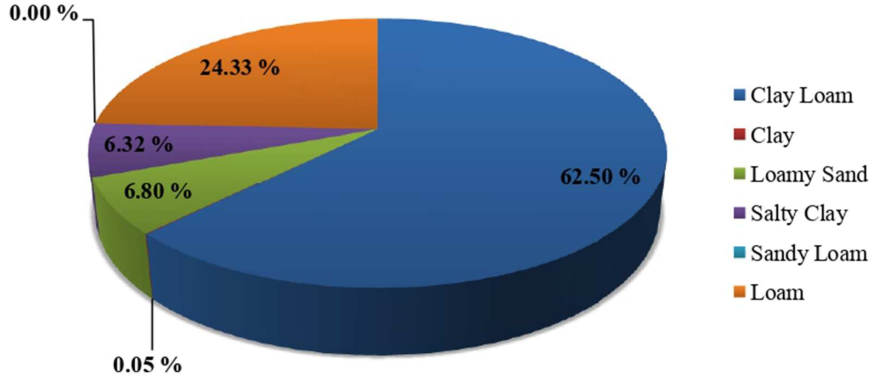
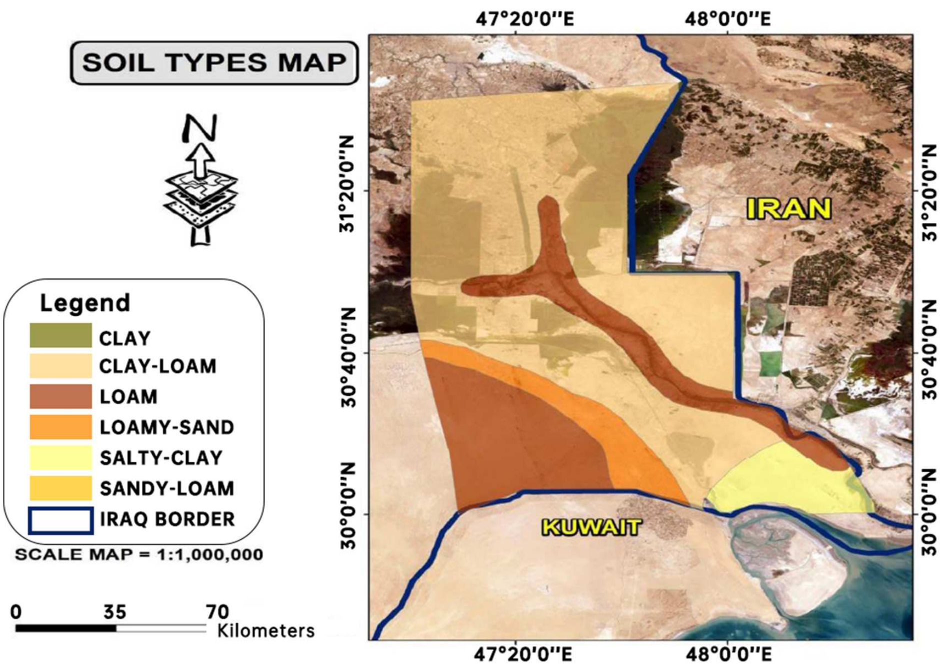


Figure 4
Spatial distribution of soil texture classes in the study area



(e.g., Rumaila and Majnoon), and urban zones presents obstacles to RWH development. Supervised image classification identifies two main obstacle classes: river buffers and well pads/urban areas (Table 5). The map (Figure 5) shows that well pads/urban areas cover 61.1% (6,970.78 km²) and river buffers cover 38.9% (Figure 6) (4,439.15 km²) of the region in addition to (Figure 7) that shows the well pads and urban of the study's area. These findings highlight challenges in urban areas, which have limited space for RWH infrastructure and impermeable surfaces that hinder infiltration. Special consideration is needed for well pads to avoid conflicts with existing infrastructure. While river buffers often restrict construction, some may offer opportunities for compatible rainwater collection methods, warranting further research into local laws and buffer characteristics.

Thus, optimizing RWH in the Al-Basrah Basin may require careful planning and exploring alternative solutions, especially in well pad/urban areas, while investigating river buffers could provide valuable opportunities.

Table 5
Obstacle classes and their areas

Obstacle classes	Area (km^2)
River buffer	4439.15
Well pads and urban	6970.78
Total	11409.93

4.3. Slope

The slope analysis in Table 6 and Figures 8 and 9 reveals the topography of the Al-Basrah Basin. The areal extent of the five slope categories is:

Figure 5
River buffer of study area

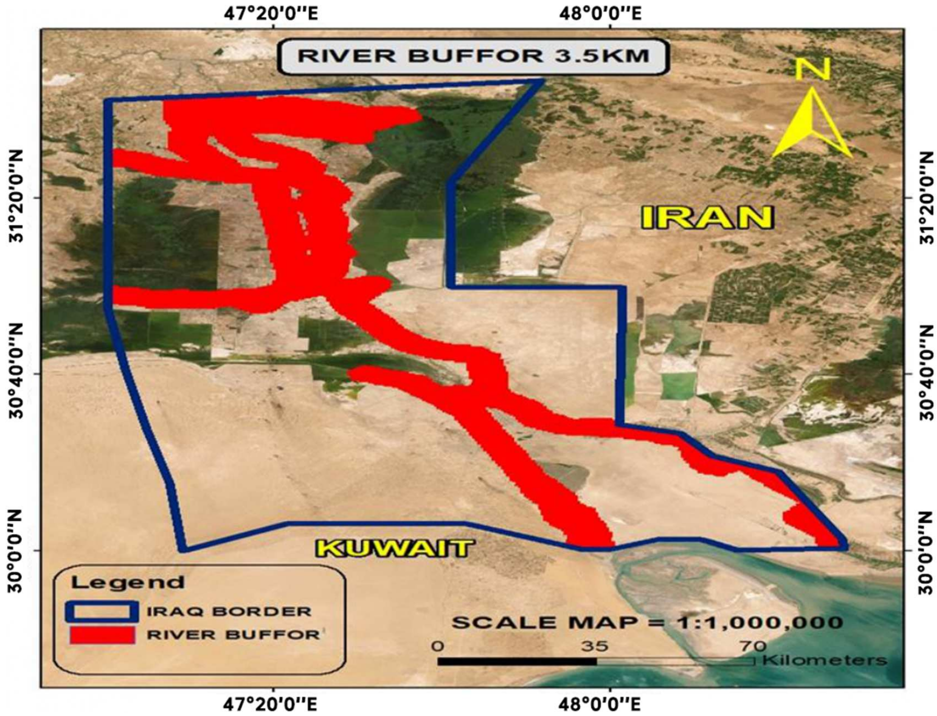
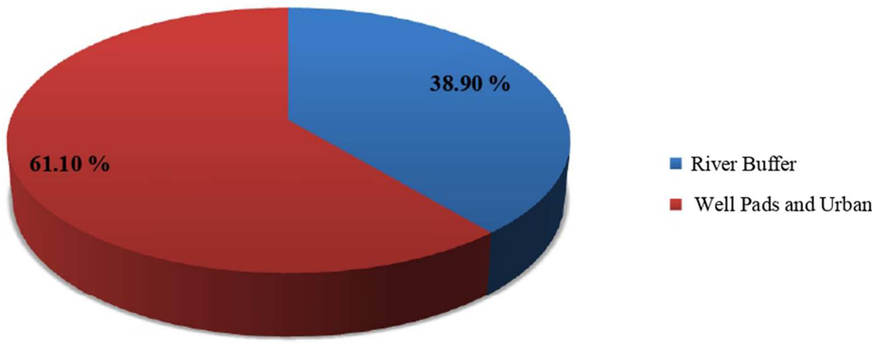


Figure 6
The percentage of each obstacle class's area



Nearly level (0–1°): Covers 54% (8,907.5 km²) of the area, ideal for RWH due to flat surfaces that reduce runoff and facilitate water collection.

Gentle slopes (1–2°): Makes up 33.4% (5,515.32 km²) and is also suitable for RWH, allowing efficient water capture with proper design.

Moderate slopes (2–3°): Comprises 10.4% (1,718.41 km²), presenting challenges due to increased runoff, requiring careful design for effective water storage.

Steep slopes (3–4°): Account for 1.8% (303.08 km²) and are less conducive to RWH, but may benefit from approaches like contour farming.

Very steep slopes (4-5°): Cover 0.3% (53.51 km²), generally unsuitable for RWH due to excessive runoff and installation challenges.

In total, over 87% of the study area is flat or gently sloping, offering high potential for RWH implementation in the Al-Basrah Basin.

4.4. MADM

The AHP assigns weights to the five evaluation attributes based on their importance for RWH suitability (Table 7). Higher eigenvalues indicate greater influence. Elevation and slope share the highest eigenvalue (2.169), making them the most critical factors for site selection. River buffer, well pads/urban, and soil texture have lower eigenvalues (0.500 and 0.350), showing they are less influential but still important. The weighted evaluation attributes are integrated into a weighted overlay map (Figure 10) to identify the most suitable RWH locations in the study area.

The analysis yields a CI of 0.007 and a RI) of 1.120, resulting in a CR of 0.588%, indicating acceptable consistency in the expert judgments, well below the 10% threshold. This ensures the validity and trustworthiness of the suitability analysis for RWH sites. Table 8 presents the MADM classification of site suitability for RWH in Al-Basrah Basin. About 59.3% (9,785 km²) is unsuitable, 33.6% (5,550 km²) (Figure 11) is excellent, and 7.1% (1,170 km²)

Figure 7
Well pads and urban of the study's area

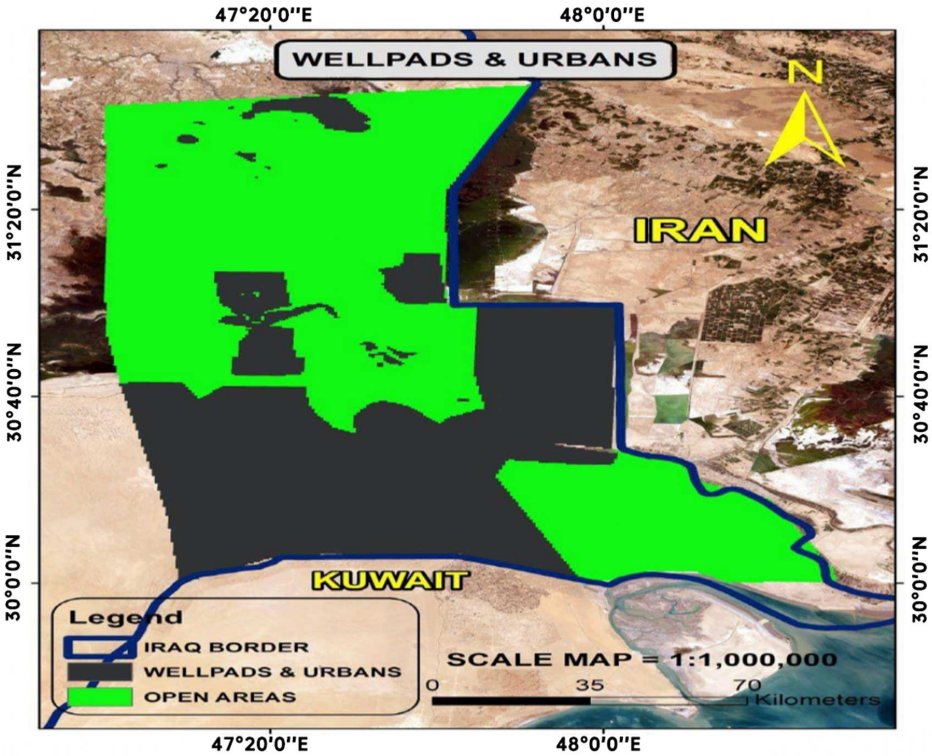


Table 6
Slope classification with their degrees and areas

Slope classification	Slope degree	Area (km^2)
Nearly level	0–1	8,907.5
Gentle	1–2	5,515.32
Moderate	2–3	1,718.41
High	3–4	303.08
Very high	4–5	53.51
Total		16,497.82

is suitable for RWH, given proper planning. These results highlight the importance of a spatially explicit approach for optimizing RWH potential across the diverse region. Figure 12 shows the most suitable regions in the northeastern, northwestern, central, and southeastern parts of the study area. The study concludes that RWH is feasible in the region, with field surveys recommended to confirm the selected locations.

4.5. Candidate sites

Based on the results, Area C is excluded from further evaluation. Areas A and B, shown in Figure 13, are located in highly

Figure 8
The ratio of each slope class's areas

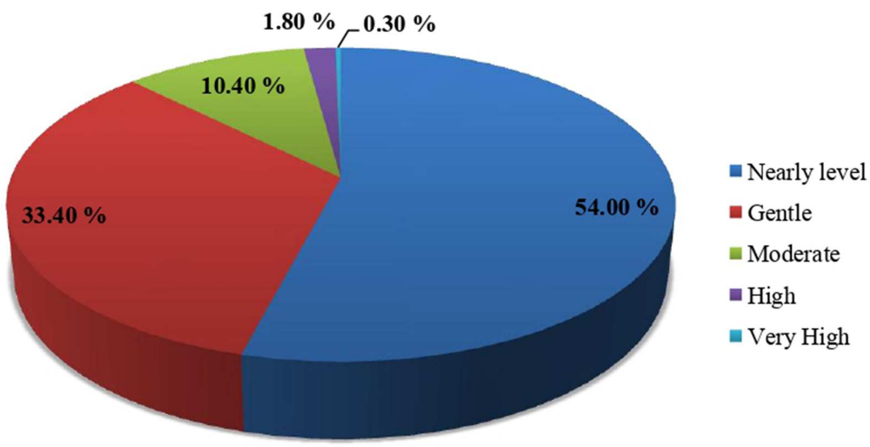


Figure 9
Classified slope degree in the study area

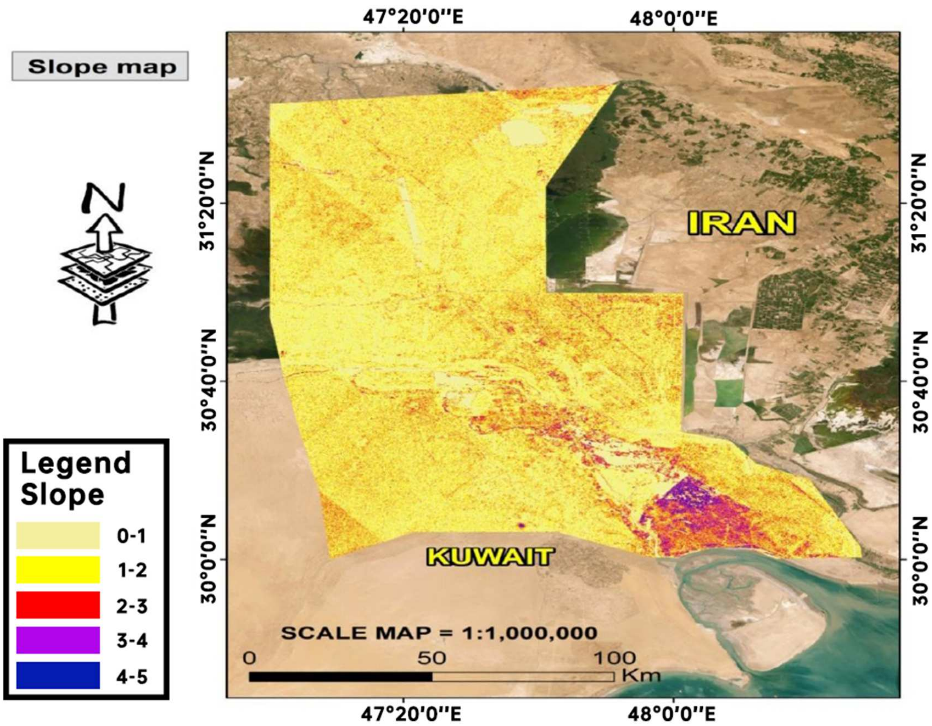


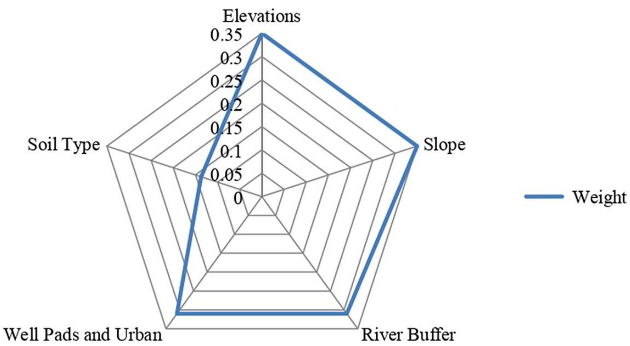
Table 7
The eigenvalue of selected evaluation attributes

Evaluation attributes	Eigenvalue
Elevations	2.169
Slope	2.169
River buffer	0.500
Well pads/Urban	0.500
Soil texture	0.350

Table 8
MADM classification with their areas

MADM classifications	Area (km^2)
Suitable for RWH	1,170
Excellent for RWH	5,550
Unsuitable for RWH	9,785
Total area	16,505

Figure 10
Site suitability assessment of evaluation attributes weights using AHP method



suitable regions and are free from obstacles, making them ideal for further assessment. Key factors for RWH implementation include available area, storage capacity, and proximity to water users. Practical deployment may involve constructing an embankment to create a rainwater detention and infiltration reservoir. Table 9 summarizes the candidate site's area, elevation, estimated storage capacity, and distance from the nearest populated area. These proposed dams provide a well-distributed solution for the study area, offering long-term usability. The findings will guide decision-makers in planning reservoir construction in the region.

4.6. Fog computing integration

The final phase of the proposed framework introduces a conceptual method for dynamic RWH management using fog computing. Although not implemented in this study, it suggests deploying sensor-equipped fog nodes at RWH sites in the Al-Basrah Basin, Iraq, to continuously collect real-time data on rainfall, water quality, and water levels. These nodes would preprocess data locally, enabling near real-time decision-making to optimize water usage and address issues proactively. This approach offers several benefits, including continuous monitoring of the RWH system and water quality, enabling data-driven decisions for optimized water distribution and maintenance. Additionally, the decentralized architecture of fog computing allows for quicker responses to local needs. However, the conceptual nature of this phase requires further research to validate its feasibility in the Al-Basrah Basin. This includes assessing suitable communication networks, ensuring robust data security, and conducting a cost–benefit analysis to evaluate the

Figure 11
The ratio of each MADM suitability class's areas

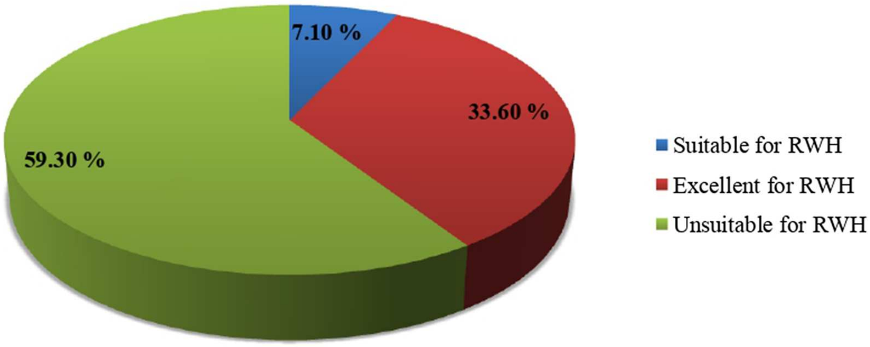
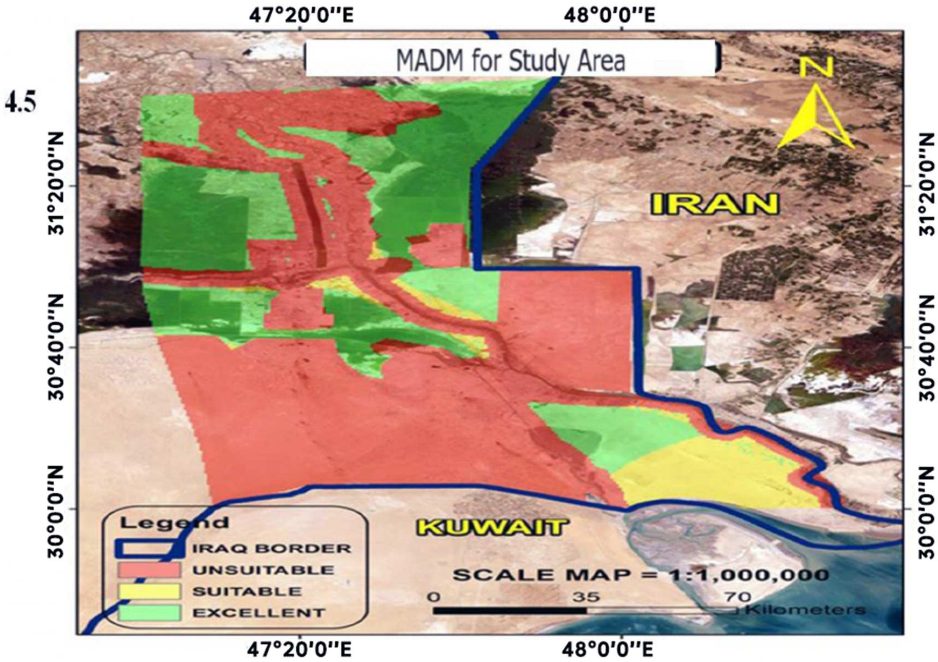


Figure 12
The ratio of each MADM suitability class's areas



financial viability of implementing fog computing in RWH systems. Despite its current conceptual status, this phase holds promise for enhancing RWH management and long-term water security in the Al-Basrah Basin. Future studies should explore its practical application while addressing the identified constraints.

5. Evaluation and Validation

By conducting a sensitivity analysis, this section validates the proposed method (Section 5.1). Using a 13-point as the proposed method is compared against benchmark studies (Section 5.2).

5.1. Sensitivity analysis

A sensitivity study [32] was conducted to assess the impact of weight adjustments on the final RWH suitability map for the Al-Basrah Basin, Iraq. Weights assigned to each evaluation attribute in the AHP framework were systematically altered to evaluate how different scenarios influenced the spatial distribution of suitable RWH sites. The pairwise comparison method was used again to reassess the relative importance of the attributes under these weight changes, identifying the most important factors for RWH site selection.

Table 10 presents the results of this analysis, which found that well pads/urban areas had the highest eigenvalue (4.518), followed by river buffers (1.593). In contrast, elevation and slope showed minimal influence (both 0.323), suggesting these factors are less critical in the Al-Basrah Basin for RWH site selection. Soil texture had moderate importance with an eigenvalue of 0.533. These results emphasize that avoiding well pads and urban development, along with considering river buffer zones, are key factors in optimizing RWH potential in the study area.

Figure 14 illustrates the weight distribution for RWH site suitability using the AHP method [32]. The x-axis represents attributes

Figure 13
The candidate area (A, B) for RWH in the Al-Basrah Basin, Iraq

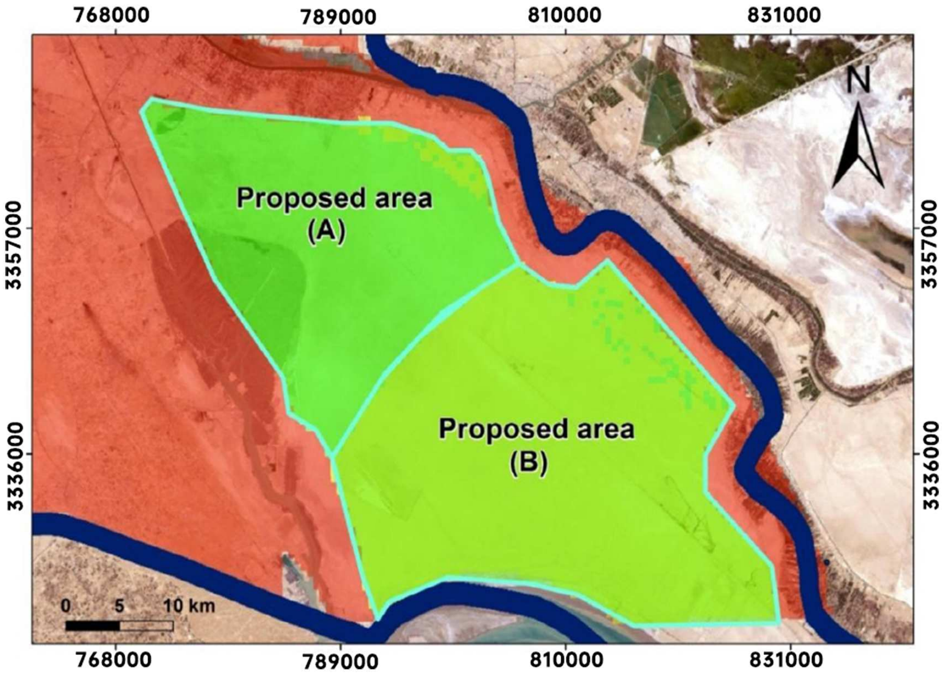


Table 9
The description of selected area

Areas	Area (km^2)	Height (m)	Estimated storage capacity (M3)	Distance to population area
Area A	628	1.5	942	4 km
Area B	949	1.5	1,423	35 km

Table 10
The eigenvalue of selected evaluation attributes in sensitivity analysis

Evaluation attributes	Eigenvalue
Elevations	0.323
Slope	0.323
River buffer	1.593
Well pads/Urban	4.518
Soil texture	0.533

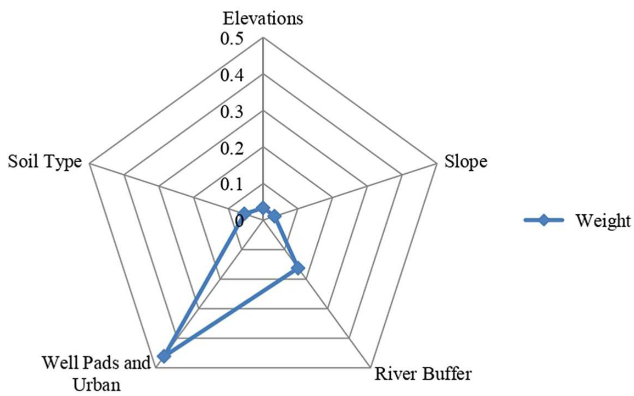
like soil type, slope, and proximity to features, while the y-axis shows their assigned weights. Some attributes have notably higher weights, indicating their greater influence on the suitability map. Figure 15 displays the RWH site suitability assessment, categorizing areas into four classes: very suitable (dark green), suitable (light green), moderately suitable (yellow), and unsuitable (dark red).

5.2. Comparative analysis

This study compares the use of the AHP with the FAHP as outlined by Alrawi et al. [45], across 13 main areas (theoretical and practical), as shown in Table 10. Three points in the application-based comparison are:

Point 1: The case study considered a range of evaluation attributes.

Figure 14
Weight distribution for RWH site suitability assessment in sensitivity analysis

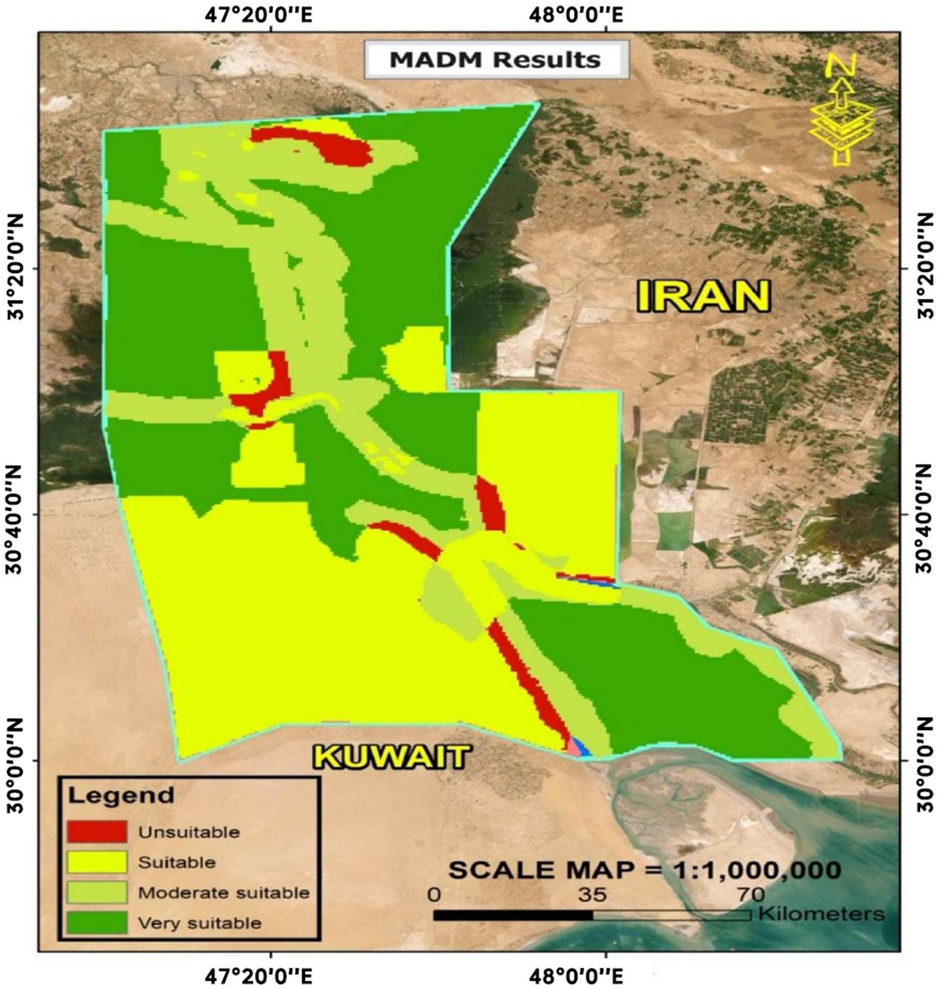


Point 2: The importance of each evaluation attribute was factored into the analysis.
Point 3: Data variation issues were addressed in the case study.

The theory-based comparison includes ten points, with six weighted and four modeled:

Point 1: AHP solved the inconsistency issue in weighting methods.
Point 2: Dependency problems among attributes were resolved.
Point 3: Pairwise comparisons were necessary for weighting.

Figure 15
The candidate areas for RWH in the Al-Basrah Basin, Iraq through sensitivity analysis



Point 4: Expert opinions were easily collected.
Point 5: Issues with unreliable, imprecise, and incomplete data were addressed.
Point 6: The AHP method offers a more consistent and replicable weighting scheme.
Point 7: AHP made FS extensions more universal.
Point 8: AHP clarified informational ambiguity.
Point 9: Normalizing the data reduced deviation from the optimal solution.
Point 10: AHP did not require additional methods for weighting attributes.

Our study demonstrates the advantages of AHP over FAHP for RWH suitability assessment, as shown in Table 11. While both methods account for evaluation attributes and data variation, AHP provides a more consistent and robust weighting scheme. AHP's pairwise comparisons ensure reliability, yielding a higher score of 84.6%, compared to FAHP's 76.9%. This indicates AHP's greater effectiveness in decision-making for RWH suitability. Additionally, AHP simplifies the collection of expert opinions, offering a more practical and less complex approach. Overall, AHP provides a more dependable and accurate assessment.

6. Discussions

6.1. Advantages of the study

This study offers several advantages in identifying suitable RWH sites in the Al-Basrah Basin:

Data-driven approach: The study employs GIS and MADM to create an objective, scalable method for selecting optimal RWH sites, ensuring transparency in decision-making.

Focus on water scarcity: By addressing the critical water scarcity issue in Basrah Province, Iraq, the study provides practical solutions for this water-stressed region.

Improved water management: The suitability maps generated enable local authorities to make informed decisions, promoting sustainable water management in the Al-Basrah Basin.

Reliable methodology: The approach combining GIS and MADM can be applied to other arid and semi-arid regions, offering a global solution to water scarcity challenges.

Dynamic RWH management: The study proposes integrating fog computing for real-time RWH management, using sensor-

Table 11
Comparison points between two studies

Comparison points		This study	Study by Martinez et al. [47]
Application-based comparison	The case study considered a variety of evaluation attributes	√	√
	The importance level of the case study's evaluation attribute was taken into consideration.	√	√
	The issue with the data variation in the case study was solved.	√	√
Theory-based comparison	The weighting method's inconsistency issue was solved.	√	√
	The weighting method's dependency problem among evaluation attributes was solved.	√	√
	Pairwise comparisons were necessary for the weighting method.	√	√
	Uncomplicated collection of the opinions of the experts.	√	√
	The weighing method's problems with unreliable, imprecise, and incomplete information were solved.	√	√
	The method offers a more consistent, replicable, and less complex weighting scheme.	√	X
	Other FS extensions were made more universal by the weighting method-applied FS.	X	√
	The method's informational ambiguous was solved.	√	X
	By normalizing the data, the method significantly decreased the likelihood of deviating from the optimal solution.	√	√
	The method necessitating the need for an additional method for evaluation attribute weighing because of its inability to offer weights to assess attributes in order of importance.	X	X
Total Score		84.615%	76.923%
Accumulative Difference		15.384%	23.076%

equipped fog nodes to optimize water usage and maintenance, improving overall RWH efficiency.

6.2. Limitations of the study

Addressing the study's limitations is crucial in order to provide a thorough evaluation of the viability of rainwater harvesting in the area. These limitations mainly address the following:

Limited scope: Focused on environmental factors; socioeconomic aspects like land ownership, costs, and maintenance were not considered. Future studies should include these factors for a more comprehensive evaluation.

Assessment of water needs deficient: Did not assess how RWH systems meet diverse water demands (agriculture, industry, and domestic). Future work should address this.

Data availability and quality: Results depend on the quality and availability of data. Gaps in precipitation, soil quality, and land use data could affect accuracy. Future research should aim for more localized data.

Potential biases in expert opinion: Relied on expert opinion for weight assignment, which may introduce bias. Future studies should consider more objective or community-driven data to reduce bias.

6.3. Managerial implications

This study offers crucial insights into water resource management in Basrah Province, Iraq, amid increasing water scarcity. The GIS- and MADM-generated RWH suitability maps serve as data-driven tools for water management companies and local governments, enabling informed investment decisions and strategic planning. These maps pinpoint the most suitable sites for RWH systems, promoting a more resilient and sustainable approach to managing the region's water resources.

The integration of MADM within a GIS framework for RWH site selection highlights its flexibility and applicability to other semi-arid and arid regions facing water scarcity. The study also emphasizes the importance of incorporating socioeconomic factors into planning for effective RWH implementation. Moreover, the study introduces the concept of integrating fog computing into dynamic RWH management. By using sensors to collect real-time data, fog nodes can optimize water use and maintenance, improving RWH efficiency. This approach, combined with the study's RWH suitability maps, offers a comprehensive framework for sustainable water resource management in Basrah Province. The methodology's applicability extends beyond Basrah, providing valuable insights into other water-scarce regions, such as Saudi Arabia, parts of India, and sub-Saharan Africa, facing similar challenges. In conclusion, this study equips water managers in Basrah Province with tools and insights to enhance resource allocation and develop sustainable RWH strategies. By integrating suitability maps, socioeconomic considerations, and fog computing, local governments can improve water security and build long-term resilience in the region.

7. Conclusion

Water scarcity is a significant challenge for communities and ecosystems in arid and semi-arid regions, impacting agricultural productivity and overall sustainability. Basrah Province in Iraq has faced recurring droughts and water shortages, particularly in its southern areas. This study emphasizes the potential of RWH as a solution to water issues in the Al-Basrah Basin. Using GIS and MADM, the study generated a suitability map to identify optimal sites for RWH structures. Key evaluation factors included soil characteristics, slope, well pads, and urban areas. The findings indicate that the southern regions are most suitable for RWH, while the central and northern regions face obstacles such as marshes, oil exploration zones, and urban development. Additionally, the study introduces a novel fog computing approach for real-time RWH management. Sensor-equipped fog nodes at selected sites would collect data on tank levels, rainfall, and water quality, enabling immediate decisions on water use and maintenance. Although still in the conceptual stage, this approach shows promise for enhancing water security in the Al-Basrah Basin. The results of this study can guide strategic decisions for RWH projects, contributing to better water resource management and sustainable agriculture in Basrah. The findings can also support urban planners in managing rainwater across the country. A sensitivity analysis was conducted to assess the reliability of the RWH suitability map, considering weight changes and uncertainties in thematic maps. This analysis can inform future data collection efforts and highlight key factors in RWH site selection. A comparison between the AHP and FAHP methods revealed the advantages of AHP, particularly its ability to address dependencies and inconsistencies in the weighting system, leading to a more reliable and replicable approach. Future research should explore the socioeconomic and financial viability of RWH systems, including cost analysis, land ownership, and community acceptance. Additionally, studies should examine how different RWH systems can meet water demands across sectors (agriculture, industry, and domestic use), to inform strategies for enhancing water sustainability in Basrah.

Recommendations

Future research should build on this study by examining the socioeconomic and financial feasibility of RWH systems in different regional contexts. This includes detailed cost analyses (labor, maintenance, and investment), land ownership, and community acceptance to ensure long-term viability. Additionally, studies should explore how various RWH systems can meet the water needs of agriculture, industry, and domestic sectors, accounting for different consumption patterns and seasonal demands. Combining social, economic, and technological factors with the geospatial methodologies used here will provide more comprehensive recommendations for RWH implementation, enhancing sustainability and resource governance.

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Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data are available on request from the corresponding author upon reasonable request.

Author Contribution Statement

Alauldeen Taher Najm: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing – original draft, Visualization. **Wei-Koon Lee:** Resources, Data curation, Writing – review & editing, Supervision. **Abdulhussain Abdulkarim Abbas:** Validation, Formal analysis, Data curation. **Suzana Ramli:** Writing – review & editing, Supervision.

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