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REVIEW PAPER

Runoff Management based Water Harvesting for Better Water Resources Sustainability: A Comprehensive Review

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Abstract
The exacerbation of drought conditions has significantly enhanced water scarcity, notably impacting arid and semi-arid regions globally. Consequently, effective runoff management has emerged as a critical and formidable challenge. This comprehensive review addresses the critical challenge of runoff management for water resources sustainability, specifically through the lens of dam site selection employing MCA. A systematic investigation into the origins and methodologies of runoff management highlights the prevalent application of MCA models, with an in-depth literature review providing insights into various approaches, their advantages, limitations, and suitability for specific contexts. Through an extensive literature review, 63 criteria affecting dam site suitability were identified and analyzed, with slope, land use/land cover, and soil type identified as the most significant factors. The findings revealed an exponential increase in the application of MCA for dam site selection over the past two decades, emphasizing its growing importance in the field. Further, the review highlights the varied outcomes of dam site evaluations due to differing expert opinions on criteria weightings, pointing to the necessity for a unified approach to criteria weighting. It is recommended that future research focus on harmonizing these weights and incorporate high-resolution observational data to enhance the accuracy of dam site suitability assessments. Moreover, the integration of climate adaptability into runoff management models is suggested to ensure long-term water resource sustainability. This comprehensive review not only outlines the current state and challenges in runoff management and dam site selection but also proposes a direction for future research aimed at resolving these critical issues.

Keywords: Multi-criteria Analysis; Dam Site Suitability; Weighting Scale; Remote Sensing; Literature review.

1. Introduction

1.1 Research Background

In the field of contemporary global challenges, the sustainable management of water resources stands as a crucial significance [1], [2]. The present uncontrollable decline in freshwater sources is causing substantial disruption to the environment [3]. As the population grows and climates shift, the dependable supply of water for agriculture, industry, and everyday life becomes increasingly priceless [4]. The complicated dynamics of runoff management and water sustainability hold the key to

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declining these pressing issues [5]. Proper management of runoff not only ensures a consistent supply of freshwater but also plays a pivotal role in preventing floods, conserving ecosystems, and addressing the increasing demands of growing communities [5]. The importance of this research extends far beyond the immediate confines of any specific region or research project, as it resonates with the fundamental and universal necessity for a flexible and sustainable water resource management approach [6]. Further, water often referred to as the 'blue gold' of the 21st century, underpins human civilization, sustains ecosystems, and fuels economic development [7]. Its availability and quality have severe consequences for food security, public health, energy production, and environmental sustainability [7]. Consequently, the responsible management of water resources has become a crucial challenge, particularly in regions where water scarcity emerges as a growing threat [8].

Runoff, the flow of rainwater and snowmelt over the land's surface into rivers, lakes, and aquifers, forms a significant component of the global water cycle [9]. Effective management of runoff is essential for harnessing its potential benefits while minimizing the risks associated with flooding, erosion, and pollution [10]. Runoff management strategies range from constructing reservoirs and dams to capturing rainwater in urban settings, employing green infrastructure, and adopting sustainable land use practices [11]. These strategies must be customized to the unique geographical, climatic, and socio-economic conditions of each region [12]. One of the primary objectives of runoff management is to ensure a consistent and reliable supply of freshwater [13]. This is particularly vital in regions that face chronic water scarcity or are prone to droughts [14]. By capturing and storing excess runoff during wet periods, communities can better withstand periods of reduced rainfall and maintain essential water services [15], [16]. This adaptability is essential for supporting agriculture, industry, and domestic water needs, as well as for sustaining ecosystems that rely on consistent water flows [17]. Moreover, runoff management is crucial for floods risk mitigation [18]. In many parts of the world, heavy rainfall and rapid snowmelt can lead to destructive floods that result in loss of life, damage to infrastructure, and economic losses [19]. By implementing effective runoff management measures, such as dams, levees, floodplains, and retention ponds, communities can reduce the risk of catastrophic flooding events [20].

Conservation of ecosystems and biodiversity is another compelling reason to prioritize runoff management [21]. Natural habitats, such as wetlands, rivers, and lakes, depend on stable water flows to sustain diverse plant and animal species [22]. Changes in runoff patterns can disrupt these ecosystems, leading to habitat loss and declines in biodiversity [23]. Therefore, runoff management strategies must take into account the preservation of natural areas and the protection of vital ecological processes [24]. Furthermore, responsible runoff management can contribute to the reduction of water pollution [25]. Urban runoff, for example, often carries contaminants such as oil, heavy metals, and pesticides into water bodies, reducing water quality and harming aquatic life [26]. Implementing sustainable urban design practices and stormwater management systems can mitigate these adverse effects, protecting both human health and the environment [27].

In an era of climate change, runoff management assumes even greater significance [28]. Changing precipitation patterns, including more intense and irregular rainfall events, create new challenges to water resource managers [29]. Climate adaptability requires flexible runoff management strategies that can accommodate shifting hydrological patterns and minimize vulnerability to extreme weather events [30]. Additionally, the importance of runoff management extends well beyond the technical and scientific domains [31]. It intersects with social, economic, and political dimensions, as access to water is intricately linked to human well-being, social equity, and geopolitical stability [32]. As the global population continues to grow, the competition for water resources intensifies, making sustainable runoff management a critical factor in conflict prevention and peacebuilding efforts [33]. In conclusion, runoff management for sustainable water supply is a multifaceted attempt that surpass geographical boundaries and disciplinary silos [34], [35]. It is a base for addressing global challenges related to water scarcity, flood mitigation, ecosystem conservation, pollution prevention, and climate adaptability [36]. As we navigate the complex waters of the 21st century, the responsible and innovative management of runoff emerges as a defining factor in shaping a more sustainable and equitable future for all [37].

Table 1: *Comprehensive review of similar works.*

Ref.	Study focus	Type of study	Period	Method	Key findings	Future research directions
[38]	Defining a general method for selecting suitable RWH sites in arid and semi-arid regions by reviewing methodologies and criteria developed over the last three decades.	Review	1986 - 2016	> GIS/RS. > Hydrological Modelling with Geographic Information Systems/Remote Sensing. > MCA integrated with Hydrological Modelling and GIS/RS. > MCA integrated with GIS	> Identified three main sets of criteria for RWH site selection: biophysical and socio-economic. > Emphasis on slope, land use/cover, soil type, rainfall, proximity to settlements/streams, and cost. > Trends towards integrating socio-economic with biophysical criteria post-2000, enhancing success rates. > A move towards using Geographic Information Systems combined with hydrological models and MCA for site selection	> Combine hydrological models and GIS/Remote Sensing with MCA for more precise RWH site selection. > Use GIS-based hydrological modeling and MCA in data-rich areas to improve RWH site selection accuracy. > Apply MCA, specifically the Analytic Hierarchy Process, in data-sparse regions to effectively identify RWH sites.
[41]	Reviewing various criteria and methodologies for identifying suitable dam sites, emphasizing the integration of GIS/RS, Hydrological Modelling with GIS/RS, and MCA integrated with HM and GIS/RS.	Survey	Not explicitly mentioned	> GIS/RS. > Hydrological Modelling with GIS and RS. > MCA integrated with Hydrological Modelling and GIS/RS	> Three major methodologies for dam site selection identified with advantages and disadvantages. > Common criteria for dam site selection include slope, rainfall, land cover, soil type, and distance to settlement/road/stream. > Importance of considering more relevant criteria for more reliable and accurate site selection, emphasizing the role of MCA.	> Explore multi-criteria optimization methods based on soft computing techniques for improving MCA in dam site selection. > Address the challenge of user bias in MCA by developing more objective and transparent methods for criteria weighting. > Enhance the accuracy and resolution of data gathered from GIS/ RS, especially slope data from DEMs, for more precise land surface modeling and slope data extraction.

[39]	Reviewing the application of Multiple Criteria Analysis (MCA) in water resource management, analyzing 113 published studies from 34 countries.	Review	Not explicitly mentioned	> Fuzzy set analysis, paired comparison, outranking methods, multi-criteria value functions, distance to ideal point methods, analytic hierarchy process (AHP).	> MCA heavily used for water policy evaluation, strategic planning, and infrastructure selection. > The fuzzy set analysis, paired comparison, and outranking methods were the most common. > MCA aids in addressing multi-objective decision-making in water resource management.	> Improve decision maker interaction with MCA models. > Develop methods for incorporating multiple decision maker input and resolving conflicts. > Enhance initial structuring of the MCA model for better criteria and option selection. > Find better ways to handle risk and uncertainty in MCA models.
[40]	The paper evaluates existing RWH site selection frameworks in arid and semi-arid regions by analyzing 68 studies, emphasizing common biophysical and socio-economic criteria and methodologies.	Systematic Literature Review	The review does not specify the exact years of study coverage, but it reviewed 68 studies	> GIS/RS. > MCDA	> A significant variation in the criteria and methodologies used across studies, with a notable absence of ecological criteria in RWH site selection frameworks. > The common use of both biophysical (e.g., slope, soil texture) and socio-economic (e.g., land tenure) criteria, yet a marked lack of integration of ecological impacts in these frameworks. > Suitability scores varied widely, with some frameworks employing simple binary indicators and others utilizing more nuanced graded scales.	> Incorporate ecological criteria into RWH site selection frameworks to ensure environmental sustainability. > Develop standardized methodologies that can be applied universally while allowing for adjustments based on local conditions. > Conduct longitudinal studies to assess the long-term sustainability and effectiveness of RWH systems established using these frameworks.

1.2 Review of similar works

Under the light of review for similar works, in the exploration of methodologies for runoff management and selecting suitable RWH and dam sites, especially within arid and semi-arid regions, a substantial body of work has been analyzed to unify existing knowledge and specify the most effective strategies. Studies, as summarized in Table 1, have mostly focused on the integration of GIS, RS, and MCA to enhance the accuracy and reliability of site selection processes. Particularly, a review paper underscores the evolution of criteria for RWH site selection over the past three decades, stressing a shift towards integrating socio-economic with biophysical factors, therefore improving success rates of RWH implementations [38]. Furthermore, the application of MCA, as reviewed in another article, it heavily emphasized for its utility in water resource management, indicating a broad adoption for water policy evaluation and infrastructure selection [39]. Additionally, a comprehensive review paper calls attention to the diversity in factors and methodologies utilized across studies, pointing out the lack of ecological criteria in existing frameworks [40]. This comprehensive review uncovers an agreement on the need for more precise, inclusive, and sustainable methodologies for site suitability, directing future research to focus on improving decision-making models, employing ecological considerations, and enhancing data resolution for better site analysis. The unified insights and suggestions drawn from these reviews are fundamental for advancing the field and are detailed further in Table 1, which serves as a core reference for this review.

1.3 Research Motivation

The necessity to manage runoff more efficiently came out by coming closer of global challenges that jeopardize water security, environmental stability, and socio-economic advancements. The motivation behind the current study lies in addressing the complicated crisis settled by the dual pressures of climate change and fast population growth, both of which amplify the strain on water resources worldwide. As traditional water sources become more and more scarce and unprotected, the need to make use of, control, and employ runoff water as a sustainable resource has never been more significant. This study is motivated by the identification that innovative, flexible, and unified approaches to runoff management can suggest solutions to some of the most pressing environmental and societal problems of the 21st century. These challenges include reducing the impact of urbanization on natural water cycles, mitigating the risk of flood disasters, protecting essential ecosystems, and making sure the availability of clean water for all. The necessity of these challenges calls for a re-assessment of existing runoff management practices and the investigation of new policies that are both accurate and sustainable. Furthermore, motivation arises from the examination that while vital improvements have been made in the field of water resource management, gaps still exist in the implementation of these innovations beyond multiple geographical and socio-economic contexts. There is a specific need for a study that links the gap between theoretical approaches and practical, on the ground applications that can be adapted to local environment and problems. This review paper aims to contribute to fulfill these limitations by merging current knowledge, recognizing best practices, and revealing new frameworks for runoff management that are informed by the up-to-date scientific visions and technological improvements. Above all, the motivation for current research is fixed in the conviction that accurate runoff management is key to securing a sustainable water future. By addressing the intricacies of runoff management through a holistic and integrative lens, this research aspires to contribute to the development of flexible water systems that not only meet human needs but also secure and protect the natural environment.

1.4 Research contributions

In the light of a comprehensive review of runoff management scheme and their important role in intensifying water resource sustainability, this article makes numerous key contributions to the field. These contributions are coming out from a detailed analysis of existing literature, methodologies, and practices encompassing runoff management, particularly with a focus on dam-based WH and the utility of MCA for site selection: (i) Integrating runoff management approaches: This paper offers a concentrated view of current runoff management policies, providing a integrated of knowledge that connects gaps between disparate studies. It purifies complex information into actionable understanding, making it an invaluable resource for both scientists and practitioners. (ii) Assessing the application of MCA in dam site suitability: An important contribution of this review is the evaluation of MCA methods in the context of dam site selection for runoff management. By analyzing different MCA methodologies, the review article highlights their limitations, strengths, and the criteria most frequently used in the decision-making process, suggesting guidance for future applications. (iii) Identifying criteria for dam site selection: This research critically evaluates the criteria utilized in dam site selection through MCA models, outlining the most employed and their respective weightings. This not only helps in perception the priorities within the field but also offers areas where standardization could improve decision-making approaches consistently. (iv) Offering future research directions: By identifying the current problems and gaps in runoff management practices, especially in the employment of MCA, this study paves the way for future research. It calls for a unified method to criteria weighting in MCA and the synthesizing of high-resolution observational data to smooth dam site selection processes. (v) Emphasizing the role of runoff management in resolving global water issues: The review situates runoff management as a significant component in addressing global water scarcity, ecosystem conservations, and flood risk. It signifies the importance of innovative management policies in ensuring sustainable, adaptive, and equitable water resources for future generations. Basically, the current paper enriches the academic and practical perception of runoff management, offering a potent foundation for future investigations and advancements in the field. By stating mentioned contributions, it helps to inspire sustainable innovation and collaboration in the journey of sustainable water resource management.

1.5 Research objectives

In the view of comprehensive review and analysis held in this study, the research sets forth four main objectives aimed at improving the area of runoff management and contributing to the practices of sustainable water resources. These objectives are elaborately designed to resolve the nuances and challenges determined in the current state of knowledge, hopeful to fill gaps, thrive methodologies, and provide effective insights for future measurements. Specifically, this study aims to: (i) Define and contextualize runoff management techniques: To classify and analytically evaluate the range of existing runoff management strategies, placing a specific focus on dam-based WH. This involves studying the aspect of approaches to managing runoff, considering their usefulness in various environmental and socio-economic contexts. (ii) Analyze the application and efficacy of MCA: To assess the application of MCA in the framework of dam site selection, identifying the advantages, strengths and limitations of different MCA methods. This goal seeks to clarify how MCA can be optimally used to make knowledgeable decisions in runoff management, especially in identifying and selection of dam sites. (iii) Providing details on criteria for dam site selection using MCA: To logically identify and explain the criteria used in dam site selection through MCA, emphasizing the most crucial factors considered in the decision-making process. This includes an exploration into how these factors are weighed and the implications for the results of dam site selection. By following these aims, the research tries to enrich the understanding rule of runoff management in intensifying water resource sustainability, suggesting a solid foundation for future work in the field.

2. Literature Review

The study was precisely formed to progress through a systematic three-phase approach, systematically explaining the complexities of dam site selection. The first phase of the study was dedicated to mapping out the origination of runoff, carefully analyzing the diverse factors influencing its generation.

This phase involved a comprehensive assessment of hydrological, geological, and topographical aspects contributing to runoff patterns. Transitioning seamlessly into the second phase, the study thoroughly navigated the management of runoff through the establishment of dam base infrastructure and the contemporary methodologies of MCA models. This pivotal stage delved deeply into the methodologies employed in the evaluation of dam locations, exploring the details of various MCA models. The exploration of these methodologies involved examining their applicability, strengths, and limitations in the context of diverse dam site selection scenarios. The third phase is dedicated to a comprehensive discussion of the findings obtained from the study. This phase critically synthesized the results derived through the utilization of MCA models, shedding light on the prevalence and distribution of criteria employed in dam site selection. Additionally, it provided a platform for extracting future research directions, focusing on the imperative need for clarifying potential trends and aggregating expert's opinion to establish a unified framework for criteria weightage. This phase was instrumental in concluding the study, summarizing its core outcomes and articulating a roadmap for future scientific endeavors in the realm of optimized dam site selection methodologies (Figure 1).

2.1 Water Harvesting (WH)

In the literature, distinctions between water harvesting (WH) concepts concerning their functionality in domestic and agricultural contexts are occasionally blurred [42]. As a result, WH is often employed interchangeably with RWH [43], [44], [45], [46]. Rainwater harvesting (RWH) serves as a comprehensive term encompassing diverse processes, including the concentration, collection, storage, and utilization of rainwater runoff for a wide range of applications, encompassing both domestic and agricultural purposes [47]. Beyond its agricultural utility, RWH systems can be expanded to cater to human consumption, household necessities, environmental conservation, and various small-scale productive activities [48].

A research Article as indicated in the Figure 2 subdivided the WH into overland flow, water in the air, and groundwater [49]. While the study subdivided the overland flow into two subcategories, of rainwater harvesting, and floodwater harvesting [49]. It is evident that WH encompasses RWH, thus subsuming floodwater harvesting, underscoring the importance of not using the terms RWH and WH interchangeably. Additionally, a research delineates in situ water conservation, flood irrigation, and storage for supplemental irrigation as WH methods embraced by rural communities for agricultural purposes [50]. Likewise, FAO (2003) classifies WH into micro-catchment, macro-catchment, and floodwater harvesting [51]. While these categorizations serve their purposes, they can potentially create confusion by positioning flood WH, a significant WH category, alongside subcategories of RWH (micro and macro catchments) at similar hierarchical levels.

Traditional irrigation practices primarily rely on utilizing rainfall after it has percolated into the ground or accessing underground water and perennial river flows [49]. The methods discussed in this chapter, on the other hand, focus on harnessing rainfall before it penetrates the soil specifically, by capturing surface runoff or overland flow [49]. Rainfall is systematically collected, concentrated, and harnessed for various purposes, including irrigating crops, nourishing pastures and trees, sustaining livestock, and serving household needs [49]. To implement each of these systems effectively, two critical components are essential:

i. A designated 'runoff area' or catchment characterized by a sufficiently high runoff coefficient.

ii. A designated 'run-on' area for the efficient utilization and/or storage of the accumulated rainwater.

2.1.1 Rainwater Harvesting (RWH)

Rainwater harvesting (RWH) systems can serve as a significant alternative or supplementary water source, and they have been employed globally to provide water for various purposes, including household use, agricultural needs, and livestock [52], [53], [54]. Generally, there are two types of

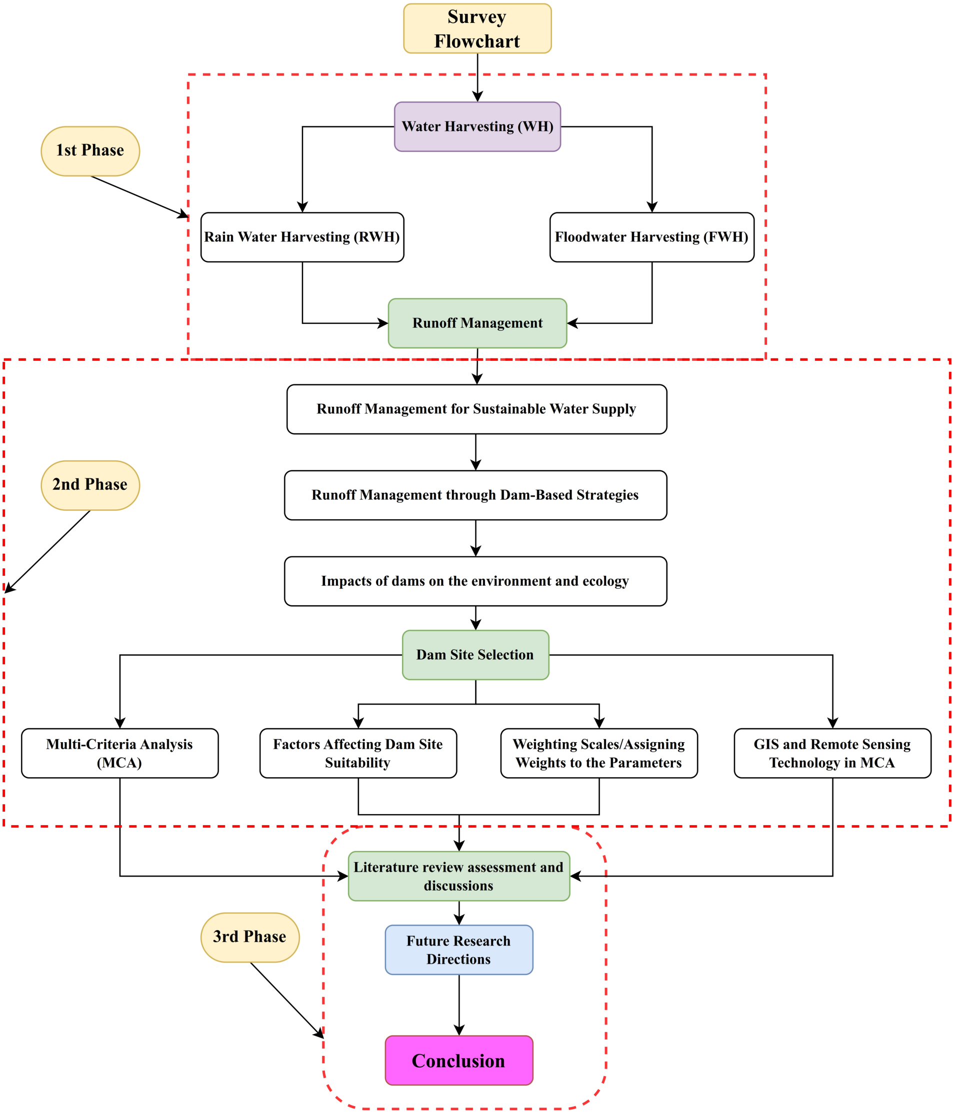

Figure 1: *Methodology framework adopted for the literature review survey.*

rainwater harvesting based on the catchment size (Figure 3). First, micro-catchment: It entails a technique for gathering surface runoff, which can include sheet or rill flow, originating from a limited catchment area and directing it into the root zone of a nearby infiltration basin. Within this basin, one can find the cultivation of a solitary tree or shrub or the planting of seasonal crops [49]. Second, macro-catchment: This approach is alternatively referred to as 'water harvesting from extended slopes' or harvesting from external catchment systems [55]. In this scenario, runoff originating from hillslope catchments is channeled to a cultivation area situated downstream, typically located on level ground below the base of the hill [55].

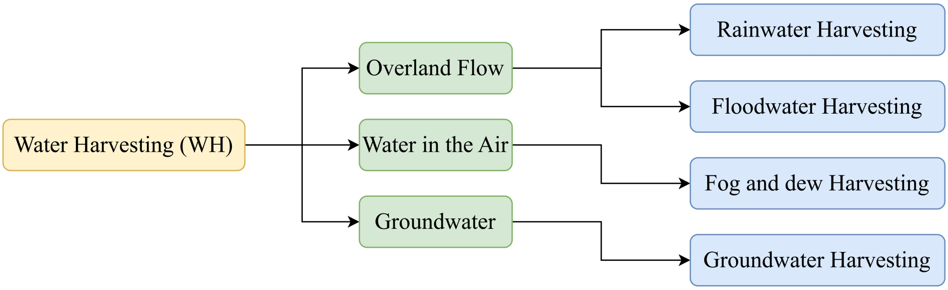

Figure 2: *Water Harvesting Classification.*

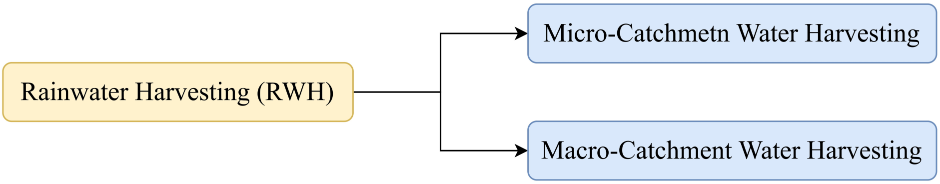

Figure 3: *Rainwater Harvesting (RWH) Classification.*

2.1.2 Floodwater Harvesting (FWH)

Floodwater Harvesting, alternatively referred to as 'Large catchment water harvesting' or 'spate irrigation,' represents a comprehensive strategy for harnessing excessive surface water during periods of intense rainfall or flooding [49], [56]. This approach comprises two primary forms (Figure 4), each designed to optimize water utilization and mitigate flood-related damage:

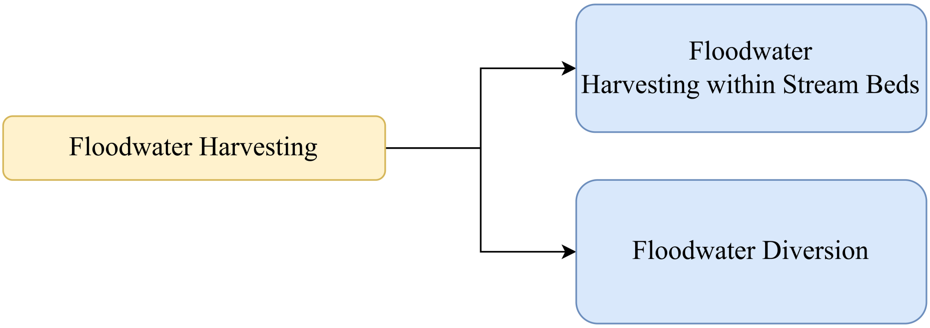

Figure 4: *Floodwater Harvesting (FWH) Classification.*

Floodwater Harvesting within Stream Beds: This technique involves strategically obstructing the natural flow of water within a stream or river using dams or barriers. By doing so, the water flow is temporarily halted, leading to the inundation of the adjoining valley bottom or floodplain. In response to this controlled inundation, the collected water infiltrates the surrounding soil, creating a fertile area suitable for agricultural cultivation or pasture improvement. This form of floodwater harvesting capitalizes on existing topography, making it relatively simpler in terms of infrastructure requirements [49], [56].

Floodwater Diversion: In contrast, floodwater diversion entails altering the course of water within a wadi or flood-prone area. The primary objective is to redirect the water away from its natural path, guiding it toward nearby crop fields or designated reservoirs for controlled use. These systems often encompass extensive catchment areas, spanning many square kilometers. Due to their scale and intricacy, floodwater diversion initiatives demand the construction of more sophisticated infrastructure, including dams, diversion channels, and distribution networks. This method requires a higher degree of technical expertise and coordination to efficiently capture, transport, and employ floodwaters [49], [56].

In essence, floodwater harvesting, comprising these two distinct forms, serves as a critical component of water resource management. It leverages seasonal surges of water abundance to enhance agricultural productivity and bolster overall water security. This multifaceted approach seamlessly integrates natural processes with human-engineered systems, offering adaptability and resilience in harnessing transient floodwater resources.

As we explore the intricacies of floodwater harvesting and its diverse applications, it becomes evident that harnessing the potential of water abundance during periods of heavy rainfall and floods is a vital aspect of sustainable water resource management. In this pursuit, we now transition our focus towards the overarching domain of runoff management, a comprehensive approach aimed at optimizing the utilization of surface runoff across varied landscapes. Within the realm of runoff management, our inquiry will delve into the strategic utilization of a series of dams, presenting an innovative and effective strategy for capturing, storing, and channeling runoff. This transition underscores the pivotal role of runoff management in ensuring water sustainability, environmental preservation, and the overall well-being of communities dependent on these critical water resources.

2.2 Runoff Management

Runoff management plays a pivotal role in sustainable water resource management, necessitating accurate and reliable runoff calculations. These calculations are fundamental for designing effective WH systems, including dams, and ensuring the sustainable management of water resources. Different methods have been developed for calculating runoff, each with specific applications, advantages, and limitations. This section provides a comprehensive examination of these methods, directly addressing the concerns raised regarding the inclusion of runoff calculation in the study of runoff management.

2.2.1 Runoff estimation methods

Estimating runoff, a critical component in hydrological studies and water resource management. Critical exploration is essential for understanding how different methodologies cater to varying watershed characteristics, data availability, and analytical needs. From traditional techniques that leverage simple empirical formulas to sophisticated modeling frameworks and cutting-edge machine learning algorithms, the spectrum of runoff estimation methods demonstrates a rich history of scientific advancement. These methods vary significantly in terms of complexity, data requirements, and applicability across different hydrological contexts, each offering unique advantages and facing distinct limitations. As we navigate through these diverse approaches, it becomes apparent that the choice of method is not merely a technical decision but a strategic one, reflecting a deep understanding of the watershed under study and the specific objectives of the analysis. For a detailed comparison of these runoff estimation methods, including their advantages, limitations, and best use cases, refer to table 2. This table serves as a comprehensive guide, aiding researchers and practitioners in selecting the most appropriate method for their specific hydrological investigations.

Table 2: *Comparison of Runoff Estimation Methods.*

Ref.	Method	Advantages	Limitations	Best Use Case
[57]	Rational Method	> Simple and widely used for preliminary design. > Requires minimal data: runoff coefficient, area, and rainfall intensity. > Simple, quick estimates	> Assumes a uniform rainfall intensity over the entire catchment. > Less accurate for large or complex watersheds. > Less accurate for large areas.	> Ideal for designing small to medium-sized urban drainage systems and storm sewers. > Small catchments.
[58], [59], [60]	Rainfall-Runoff Models (SCS-Curve Number)	> Simplifies runoff estimation by using a single curve number. > Accommodates various land uses and conditions.	> May not accurately reflect all types of rainfall events. > Initial abstraction ratio is a generalization that might not suit all conditions. > Data-intensive.	> Suitable for a wide range of watershed conditions, especially for agricultural and urban areas. > Medium to large watersheds.
[561]	HEC-HMS modelling of runoff	> Capable of simulating various hydrological processes. > Flexible and user-friendly GUI. > Can be calibrated and validated with local data for increased accuracy. > Suitable for analyzing urban flooding, flood frequency, and for planning reservoir spillway capacity. > Models quality and quantity.	> Requires reliable data for calibration and validation. > Not calibrated and validated for all regions, requiring local adjustments. > Selection of loss methods and transformation methods can significantly impact model performance. > High computational cost	> Ideal for runoff simulation in both urban and natural watersheds, especially where detailed analysis of hydrological responses to precipitation is needed. > Applicable for long-term flow data generation in rivers and their tributaries. > Comprehensive watershed analysis
[62]	SWAT (Soil and Water Assessment Tool)	> Simulates complex watershed hydrology. > Integrates various data sources.> Detailed spatial analysis via HRUs.	> Needs comprehensive data for accuracy. > Sensitive to data quality and model setup.	> Rainfall-runoff simulation in large basins. > Impact assessment of land-use changes. > Detailed hydrological studies.
[58], [59], [63], [64]	Remote Sensing/GIS-Based	> Integrates large datasets effectively. > Provides spatially distributed analysis for land cover, soil, and slope.> Utilizes satellite rainfall estimates to extend simulation periods in data-scarce regions. > Large-scale applications.	> Reliant on the quality of remote sensing data and its spatial resolution. > Calibration and validation require reliable ground measurements, which may be scarce. > Dependent on remote sensing data.	> Suitable for large-scale hydrological modeling and flood management in regions with limited in-situ data. > Large watershed management.
[65]	Machine Learning Models (ANFIS, ANN, SVM)	> Effective in modeling non-linear and complex hydrological processes. > Capable of handling large datasets and various input types.> Provides accurate and robust runoff predictions. > Handles complex relationships.	> Requires significant data preprocessing and selection of model parameters. > Potential for overfitting with complex models (especially ANN and ANFIS). > Requires extensive data for training.	> Suitable for runoff modeling and prediction in diverse hydrological conditions and for various time scales. > Predictive modeling.

2.2.2 Justification for the selection of runoff method

Based on the outlined methods in the table 2 comparing runoff estimation methods, each method presents distinct advantages, limitations, and optimal use cases, guiding the selection process towards a model that best aligns with specific project requirements. The Rational Method, praised for its simplicity and minimal data requirements, is particularly effective for small to medium-sized urban drainage systems, making it a go-to for preliminary design efforts despite its reduced accuracy over larger areas. Rainfall-Runoff Models, especially those utilizing the SCS-Curve Number, offer a more nuanced approach by accommodating various land uses, thus being preferable for agricultural and urban areas across a broader spectrum of watershed sizes. For intricate hydrological analyses, the HEC-HMS modeling framework stands out due to its capability to simulate diverse processes and its adaptability through calibration, although it demands substantial data input and computational resources. Similarly, the SWAT model excels in simulating complex watershed hydrology and integrating diverse data sources for comprehensive studies, albeit requiring detailed data for precision. Remote Sensing and GIS-Based methods leverage large datasets and spatial analysis to extend their application to large-scale hydrological modeling, particularly beneficial in data-scarce regions. Lastly, Machine Learning Models like ANFIS, ANN, and SVM demonstrate remarkable proficiency in capturing non-linear relationships within hydrological data, offering robust predictions for a variety of conditions, albeit necessitating meticulous data preparation and risk of overfitting. Thus, the selection of a runoff estimation method hinges on a balance between the scope of analysis, available data, computational resources, and the specific hydrological nuances of the watershed in question, aligning with the references provided to ensure a grounded and well-informed choice.

2.2.3 Runoff Management for Sustainable Water Supply

Runoff management for sustainable water supply is a multifaceted approach aimed at securing reliable and clean water resources for present and future generations [66]. This practice involves the careful collection, storage, treatment, and distribution of runoff water stemming from diverse sources such as rainfall, snowmelt, and surface runoff [67]. Its primary objective is to optimize the utilization of this valuable resource while minimizing wastage and environmental impacts [68]. Against the backdrop of mounting global challenges including population growth, climate change, and escalating water scarcity, runoff management plays a pivotal role in ensuring the sustainability of water supply systems [68].

One of the most pressing challenges to sustainability in water supply is the ever-increasing global population [69]. As the world's population continues to grow, so does the demand for freshwater resources [69]. Runoff management becomes essential to meet the rising water needs of urban, industrial, and agricultural sectors while simultaneously preserving the integrity of ecosystems and the environment [69]. Additionally, Climate change further compounds the complexities of runoff management [70]. Altered precipitation patterns, prolonged droughts, and intensified rainfall in certain regions necessitate a dynamic approach to runoff management [70]. Adaptation to shifting hydrological conditions is imperative for sustainable water supply [70].

In conclusion, runoff management for sustainable water supply is indispensable in addressing the multifaceted challenges posed by population growth, climate change, and water scarcity [71]. By integrating various facets of this practice and emphasizing environmental stewardship, societies can ensure a dependable and environmentally responsible water supply system for current and future generations. Sustainable runoff management stands as a cornerstone in building resilience to the uncertainties of a changing world [71]

2.2.4 Runoff Management through Dam-Based Strategies

Runoff Management through Dam-Based Strategies involves the strategic deployment of dams as versatile solutions to address a myriad of water-related challenges [72]. Dams, as engineering marvels, are pivotal in regulating the flow of rivers and streams, effectively managing the runoff generated by precipitation and snowmelt [73]. These structures serve multifaceted purposes, from flood control to hydropower generation, irrigation, and even ecosystem restoration [74]. For instance, flood control dams like the Hoover Dam are designed to safeguard communities and agricultural land by storing excessive runoff and releasing it gradually [75]. In contrast, dams like the Three Gorges Dam in China harness the kinetic energy of flowing water to generate clean electricity while providing flood protection [76]. Moreover, dams often play a crucial role in sustaining agriculture by supplying controlled irrigation water, exemplified by the Aswan High Dam in Egypt [77]. These dam-based strategies, with their diverse applications in runoff management and water resource utilization, are emblematic of the pivotal role dams play in addressing a wide range of water-related challenges [78]. From flood control and hydropower generation to irrigation, ecosystem restoration, and beyond, dams exemplify the adaptability and versatility of engineering solutions in managing runoff. Now, let us delve into specific examples that highlight the various facets of dam-based runoff management strategies.

i. Flood Control Dams

Flood control dams are instrumental in mitigating the devastating impacts of flooding in various regions [79]. For example, the Hoover Dam in the United States serves as a prime illustration of a flood control dam with a capacity of 30.5 million acre-feet [79], [80], [81]. Its massive reservoir, Lake Mead, captures excess runoff during periods of heavy rainfall or snowmelt, preventing downstream flooding and safeguarding communities and agricultural land [79], [80]. Flood control dams are designed to store and release water strategically, offering an effective solution to manage runoff during extreme weather events [79].

ii. Hydropower Generation

Dams designed for hydropower generation harness the energy of flowing water to produce electricity while simultaneously managing runoff [82], [83]. The Three Gorges Dam in China stands as a prominent example, generating vast amounts of clean energy, producing 18200 MW total capacity and with 84.7 terawatt-hours as annual average [84]. By regulating water flow and ensuring a steady supply, these dams contribute significantly to both energy production and runoff management, showcasing the dual benefits of such infrastructure [84].

iii. Irrigation Reservoirs

Dams often play a critical role in sustaining agriculture in arid regions [85], [86]. The Aswan High Dam in Egypt is a notable case in point which its storage for irrigation is 87.4 BCM [86]. This dam regulates the flow of the Nile River, allowing controlled releases of water for irrigation purposes [86]. This managed irrigation enhances crop yields, fosters agricultural sustainability, and provides a consistent water supply to support the needs of farmers and their communities [86].

iv. Water Supply Reservoirs

Cities and urban areas often rely on dams to capture and store runoff for municipal water supplies [85]. The Oroville Dam located in California, USA [87]. This massive concrete gravity dam was constructed on the Feather River and is a key component of the California State Water Project [87]. Such dams contribute to urban water resilience by ensuring a reliable water source for residents [87].

v. Ecosystem Restoration

In an effort to restore natural river systems and improve aquatic ecosystems, dam removal projects have gained momentum [88]. The removal of the Elwha Dam in Washington state, for instance, allowed the Elwha River to regain its natural flow, revitalizing fish habitats and promoting biodiversity [89]. These projects demonstrate how the strategic removal of dams can help rejuvenate ecosystems and support wildlife conservation [89].

vi. Salinity Control

In regions grappling with saline intrusion into freshwater sources, dams can be strategically positioned to control the inflow of seawater [90]. The Krishna River in India is a prime example, where dams help safeguard freshwater quality [91], [92]. By preventing saltwater intrusion, these dams ensure that agricultural and drinking water supplies remain suitable for use, addressing salinity-related challenges effectively [91], [92].

vii. Recreational Opportunities

Dams and their associated reservoirs often provide recreational opportunities for communities [93]. A notable instance is the Glen Canyon Dam and Lake Powell in the United States [94]. These areas offer various recreational activities, including boating, fishing, and swimming, enriching the quality of life for local residents and attracting tourists from afar [94].

viii. Erosion Control

Dams serve as vital tools for preventing soil erosion and sedimentation downstream [95]. By trapping sediment within the reservoir, dams safeguard waterways from clogging and protect aquatic ecosystems [95]. This erosion control aspect ensures the long-term health and stability of downstream environments [95].

ix. Water Release Schedules

Dams follow carefully planned water release schedules to balance the ecological and human needs of downstream areas [96]. The Glen Canyon Dam in the United States, for example, releases water to mimic natural flow patterns in the Colorado River, benefiting the Grand Canyon ecosystem [97]. Such schedules ensure that water resources are managed in a way that sustains both natural environments and human communities [96], [97].

x. Water Quality Improvement

Dams contribute to improved water quality by allowing sediments to settle and pollutants to be filtered out [98]. For instance, a dam designed to enhance water quality is the Itaipu Dam located on the Paraná River, which forms the border between Brazil and Paraguay [98]. This environmental benefit helps maintain the overall health of aquatic ecosystems downstream, ensuring that water resources remain safe and suitable for various uses [98].

2.2.5 Impacts of dams on the environment and ecology

Wetlands across the globe have faced alarming decline or outright disappearance, and this phenomenon has drawn attention to its multifaceted causal factors [99], [100], [101], [102], [103], [104], [105]. Predominantly, the transformative force behind this ecological shift has been extensive water resource development initiatives [106], [107], [108], [109], [110], [111]. Notably, large-scale dam construction projects on major rivers across the world have assumed pivotal roles in diverting water for various purposes, such as hydroelectric power generation, navigation facilitation, and flood control [107], [112], [113]. These alterations in riverine flow patterns have reverberated into estuarine and coastal ecosystems [110] and have critically reduced the vital water supply reaching floodplain wetlands, thereby exerting profound ecological implications. Among these, the emblematic case is the Aral Sea, which serves as the terminal floodplain for the Amu-Darya and Syr-Darya Rivers in Uzbekistan and Kazakhstan. Over a span of 27 years, from 1960 to 1987, extensive upstream irrigation practices led to a staggering 13-meter drop in water levels within this colossal inland sea, covering 68,000 square kilometers. This reduction translated into a 40% decrease in wetland coverage and unleashed a devastating blow to biodiversity in the region [114]. Analogously, water resource development, primarily driven by irrigated agriculture [115], [116], has been instrumental in shaping the destiny of floodplain wetlands in Australia [111].

Lakes and reservoirs hold critical significance within Earth's hydrosphere, carrying invaluable ecological importance and representing the largest accessible store of surface freshwater, readily available for human use [117], [118], [119]. Nevertheless, extensive transformations in river flow patterns and hydrological processes in downstream regions have ensued, primarily due to prolonged human interventions in the form of anthropogenic dams and ongoing alterations associated with climate change. These shifts have led to substantial modifications in lakes across the globe in recent decades. Furthermore, dam construction has brought about notable changes in water quality, both in reservoirs and downstream lakes [120], [121], [122].

In the context of Afghanistan, the construction of the Qarqa Dam on the Kabul River has raised concerns about the vulnerability of several freshwater lakes in the area to these transformations. As exemplified by [123], remote observations suggest that the Three Gorges Dam (TGD) might have significantly impacted China's two largest freshwater lakes between 2000 and 2009. A multitude of prior investigations have explored diverse effects stemming from dam construction, encompassing alterations in lake size, temperature dynamics, water storage, wetland characteristics, optical attributes, and a range of water parameters within the Yangtze River basin downstream of the Three Gorges Dam (TGD) [124], [125], [126], [127], [128]. This extensive body of research collectively underscores the multifaceted consequences of dam construction on aquatic ecosystems and water quality.

2.3 Dam Site Selection

Dam site selection is a crucial and intricate process within the realm of runoff management for sustainable water supply [129]. It involves a meticulous assessment of potential locations for the construction of dams, which serve as pivotal infrastructure for capturing and managing rainfall runoff [130]. The selection of an appropriate dam site is multifaceted, incorporating a comprehensive analysis of factors such as geographical terrain, hydrological characteristics, environmental impacts, and socio-economic considerations [130]. Advanced technologies, including GIS and remote sensing, along with decision-making tools such as Multi-Criteria Decision Analysis (MCDA), play a pivotal role in evaluating candidate sites [131], [132]. Ultimately, the choice of a dam site profoundly influences the success of runoff management initiatives, impacting water supply, flood control, power generation, and ecological preservation in the region [133]. In the pursuit of identifying optimal dam sites for effective runoff management and sustainable water supply, the integration of MCA emerges as a pivotal approach.

Multi-Criteria Analysis (MCA) is a robust decision-making methodology that has gained prominence in various fields, including environmental management, urban planning, and water resource management [134]. MCA provides a structured framework for evaluating complex projects, policies, or alternatives by considering multiple criteria or factors simultaneously [135]. This comprehensive approach aims to facilitate well-informed decision-making processes, especially in scenarios where multiple, often conflicting, objectives need to be balanced [135].

One of the key strengths of MCA is its ability to incorporate diverse criteria that encompass economic, social, environmental, and technical dimensions [136]. By assigning appropriate weights to each criterion, stakeholders can quantitatively assess the performance of various alternatives, allowing for a more holistic understanding of the trade-offs and implications associated with each choice [137].

In the context of dam site selection for runoff management, MCA plays a pivotal role [138]. It allows decision-makers to consider an array of factors, such as hydrological characteristics, environmental impacts, socio-economic aspects, and technical feasibility, when evaluating potential dam sites [139]. Through the integration of GIS and remote sensing technologies, spatial data can be leveraged to enhance the accuracy and objectivity of the analysis [140]. Furthermore, MCA provides a transparent and systematic approach, which is particularly valuable when dealing with complex and controversial decisions. Stakeholder engagement and consensus-building are facilitated through MCA, as it offers a structured platform for discussing priorities, values, and concerns [141].

While MCA offers significant advantages in decision-making, it is not without challenges [142]. Selecting appropriate criteria, assigning weights, and handling uncertainties require careful consideration [143]. Additionally, the success of MCA heavily relies on the quality of data and the effectiveness of the decision support system (DSS) used [143]. This section delves into the theoretical foundations of MCA, exploring its various methodologies and applications in the context of dam site selection. Through an extensive review of relevant literature, this section aims to provide insights into the strengths, limitations, and best practices associated with the use of MCA in runoff management and sustainable water supply initiatives.

MCA is a versatile decision-making approach that offers several types or methods. A comprehensive review conducted on Scopus website using Boolean operator of (MCA AND dam AND site OR location AND selection OR suitability OR siting OR assessment) to compile an extensive literature review on the various types of MCA methods employed in the assessment of dam site suitability. Table 3 presents the frequency of usage of different MCA methods in the assessment of dam site suitability. Among the methods, the Analytic Hierarchy Process (AHP) was the most frequently employed, appearing in 81 instances. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was the second most utilized method, appearing 21 times. The ELECTRE model ranked third in frequency, with seven occurrences. Other MCA methods were less commonly used for dam site suitability assessments, and the last three methods listed in table 3 were not utilized for this purpose.

Table 3: *MCA methods used in dam site selection*

No	MCA Method	Results
1	Analytic Hierarchy Process (AHP)	81
2	TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution)	21
3	ELECTRE (Elimination and Choice Expressing Reality)	7
	WLC (Weighted Linear Combination)	6
4	ANP (Analytic Network Process)	6
5	VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje)	4
6	Promethee (Preference Ranking Organization Method for Enrichment Evaluation)	2
7	Multi-Attribute Utility Theory (MAUT)	2
8	Weighted Sum Model (WSM)	1
9	Simple Additive Weighting (SAW)	1
10	Weighted Overlay Analysis (WOA)	1
11	MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique)	0
12	Multi-Objective Decision Making (MODM)	0
13	Grey Relational Analysis (GRA)	0

In the light of an extensive review of 23 highly academic journal articles, a comprehensive analysis of the most commonly used Multiple Criteria Analysis (MCA) methods and their associated advantages and limitations has been conducted. Among the MCA methods employed in these studies, Analytic Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Weighted Sum Model (WSM), and Simple Additive Weighting (SAW) emerged as the most frequently utilized techniques. Notably, these methods shared several key advantages, including flexibility in site selection, effective combination of criteria, standardized and reclassified maps, quantifiable suitability levels, and seamless integration with GIS software. AHP, in particular, leveraged expert knowledge for factor weighting, ensured statistical reliability through robust analysis, and promoted judgment consistency. Furthermore, it facilitated suitability mapping and offered versatile site selection options while remaining cost-effective. However, these methods also exhibited common limitations, such as subjectivity in weighting, limited consideration of interactions between criteria, a lack of comprehensive data integration, limited adaptability to diverse scenarios, and an inability to capture uncertainty effectively. AHP's reliance on subjective expert expertise introduced bias, potential inconsistency in judgments, omitted important variables like soil type and climate, assumed uniform factor importance across regions, and faced challenges in capturing field complexities. Similarly, the Weighted Linear Combination (WLC) method demonstrated flexibility in site selection and geospatial data integration, serving as a valuable decision support system but faced challenges related to subjective weighting, criteria independence, and scoring. Meanwhile, the Boolean Overlay Method utilized Boolean operations and exclusion of unsuitable areas, gaining popularity among researchers, yet posed limitations in strict site selection criteria alignment, equal treatment of all criteria, and constraints associated with handling continuous data. These findings are detailed in Table 4 for reference and provide valuable insights into the application of MCA methods in decision-making processes.

2.3.1 Factors Affecting Dam Site Suitability

In the pursuit of sustainable runoff management and the development of effective water supply solutions, the selection of an appropriate dam site is a critical decision [130]. The success of any dam project hinges upon a comprehensive understanding of various factors that influence site suitability [167]. This section delves into the intricate web of considerations that must be evaluated when assessing the feasibility of a dam site. From hydrological and geological aspects to environmental, socioeconomic, and regulatory factors, each element plays a pivotal role in determining the viability of a potential dam location. In order to make informed decisions and address the complex challenges of modern dam construction, it is imperative to explore and comprehend the multifaceted factors that shape dam site selection.

In the light of extensive review of 25 high quality research papers and the rigorous analysis conducted, a comprehensive understanding of the factors influencing dam site suitability has been exposed. As Figure 5 vividly illustrates, these factors span a wide spectrum of 63 factors, encompassing geological, hydrological, environmental, and socioeconomic aspects. The ranking system applied to these factors has emphasized their significance, with the most frequently encountered variables receiving the highest rank. Notably, factors such as slope, land use/land cover, and soil type, which appeared prominently in 23, 19, and 17 of the reviewed papers, respectively, have been accorded the highest ranks. Additionally, factors including distance from roads, which featured in 12 papers, drainage density in 10 papers, precipitation/rainfall in 9 papers, runoff in 8 papers, and distance from villages in 8 papers, have also received elevated rankings. This nuanced approach to factor prioritization ensures that the evaluation process accounts for the recurring determinants that have been proven instrumental in past dam site suitability assessments.

Furthermore, to provide a clear and organized overview of these crucial factors, Table 5 below presents a comprehensive compilation of the 15 highest-repeated factors identified during this extensive literature review. These factors serve as the cornerstone for assessing dam site suitability and are instrumental in guiding site selection decisions for sustainable water resource management. It's important to note that while these 15 factors were highly repeated, the remaining factors, although included in the analysis, were encountered less frequently across the reviewed literature and have not been included in Table 5 to maintain focus and relevance.

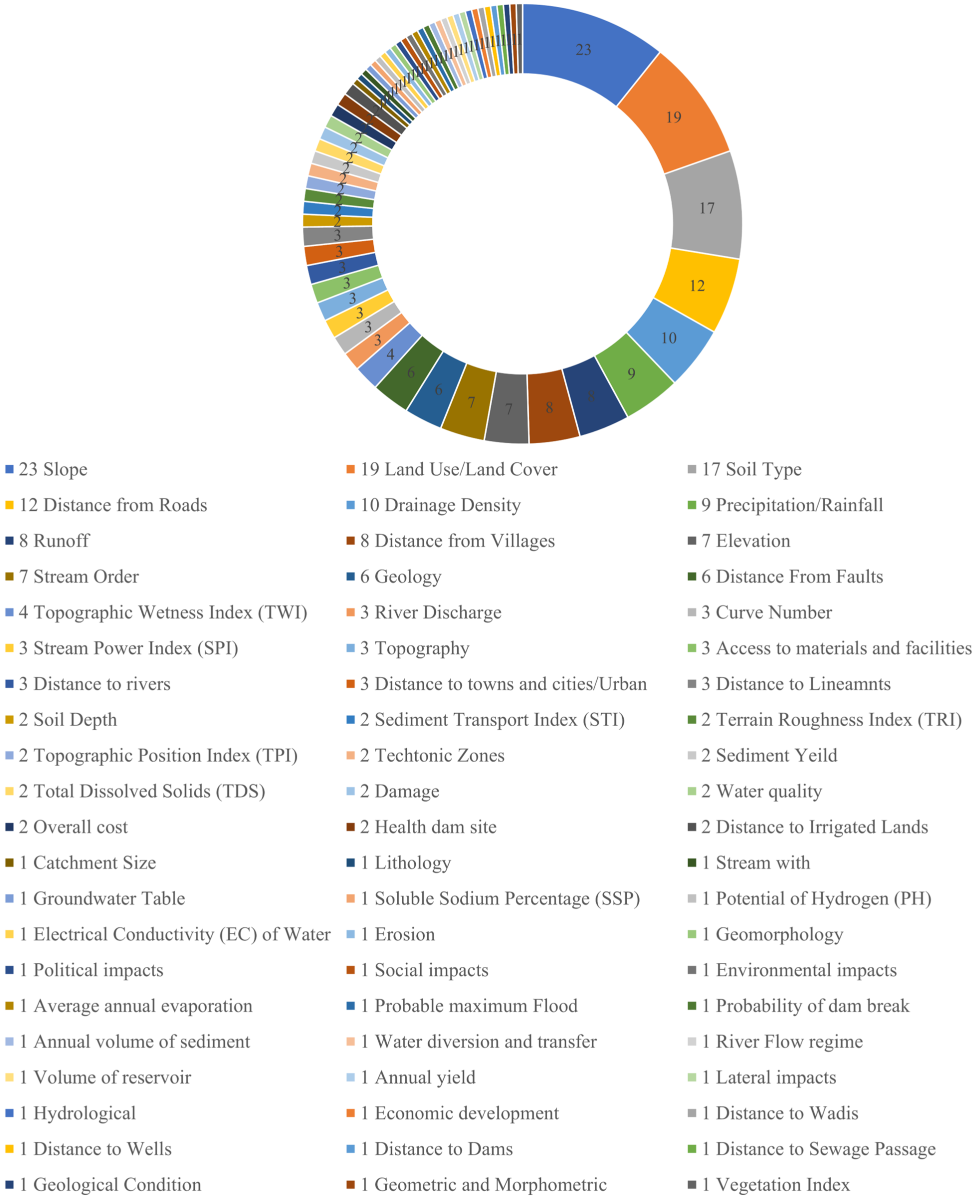

Figure 5: *Repetition Frequency of Factors Affecting Dam Site Suitability in Reviewed Literature.*

Table 4: *Comprehensive review of similar works.*

Res.	Study Area	MCA Method	Application	Technology	Advantages	Limitations
[144]	Great Western Sydney, Australia	WLC	RWH	GIS and RS	> Flexibility in site selection > Effective combination of criteria > Standardized and reclassified maps > Quantifiable suitability levels > Integration with GIS software	> Subjectivity in Weighting > Limited Consideration of Interactions > Lack of Data Integration > Limited Adaptability > Inability to Capture Uncertainty
[145]	Khenifra Province, Morocco	AHP	Check dams	GIS and RS	> Expert Knowledge: AHP leverages expert knowledge for factor weighting. > Statistical Reliability: It uses robust statistical analysis. > Consistency: The method ensures judgment consistency. > Suitability Mapping: Generates high/low suitability maps. > Versatile Choices: Offers flexible site selection options. > Cost-Effective: An economical and practical approach.	> Subjective Expertise: AHP relies on expert judgment, introducing bias. > Inconsistency Risk: Judgments may still be inconsistent. > Limited Factors: Important variables like soil type and climate are omitted. > Spatial Uniformity: Assumes factor importance is uniform across the region. > Validation Constraints: Accuracy may not capture field complexities.
[146]	Haditha City in the western part of Iraq	> WLC > BOM	RWH	GIS and RS	(WLC) Method: > Flexibility in Site Selection > Geospatial Data Integration > Decision Support System Boolean Overlay Method: > Utilization of Boolean Operations > Exclusion of Unsuitable Areas > Researcher Adoption	WLC Method: > Subjective Weighting > Independence: Criteria evaluated independently. > Scoring Challenge: Difficulty in assigning scores. Boolean Overlay Method Limitations: > Strict Site Selection: Requires criteria alignment. > Equal Treatment: All criteria treated equally. > Data Limitation: Restricts continuous data handling.

[147]	Wadi Horan, Western Desert of Iraq	> Variance Inverse (VI) > Rank Order Method (ROM) > AHP > Fuzzy-AHP	RWH	GIS and RS	> Statistical Method: Reduces uncertainty, providing balanced and reliable rankings. > RS and GIS Integration: High-quality data and thematic maps enhance site evaluation. > AHP: Systematic approach, considers relative importance of criteria. > Fuzzy-AHP: Flexible approach, accounts for inherent uncertainty. > ROM: Simple method for baseline comparison with other methods.	> Method Uncertainty: AHP, fuzzy-AHP, ROM are subjective and biased. > Data Uncertainty: Measurement uncertainties affect accuracy. > Index Variability: Fluctuations in indexes can alter rankings. > Limited Data in Remote Areas: Scarce data restricts site selection. > Subjective Weighting: Relies on subjective criteria weighting. > Criteria Sensitivity: Changes in importance impact rankings.
[148]	Wadi Al-Gahdaf, located in the western desert of Iraq	> WLC > Boolean	RWH	GIS and RS	> Cost-Effective Method: WLC and Boolean methods in GIS, with NDVI and LDI analysis, efficiently combat desertification risk. > Quick Site Identification: Rapidly determines suitable RWH sites, aiding decision-makers in desertification risk assessment.	> Data Limitations: Incomplete or unavailable data can hinder accuracy. > Simplifications: Assumptions may oversimplify desertification complexity. > Data Uncertainties: Errors in data processing can affect accuracy. > Generalization: Weighted combination may oversimplify site selection. > Validation Absence: Lack of validation impacts reliability assessment. > Limited Applicability: Tailored to Iraq's western desert. > GIS Dependency: Varying GIS resources pose challenges.
[38]	Dohuk Province in the far northwest of Iraq	AHP	RWH	GIS	> Precision: Identifies optimal water harvesting areas for dam construction. > Rainfall Patterns: Uses IDW for rainfall data, revealing crucial patterns. > GIS Integration: Enhances accuracy through GIS, remote sensing, and elevation models. > Quantitative Assessment: Categorizes suitability for informed decisions. > Cost Optimization: Considers expenses and drainage for efficient site selection.	> Selective Criteria: Limited criteria considered, omitting geology and socioeconomics. > Feasibility Concerns: Practical dam height not fully addressed. > Data Reliance: Multiple data sources may affect accuracy. > Validation Gap: Lack of external validation limit's reliability assessment. > Temporal Limitations: Short rainfall data timeframe may miss long-term trends.

[150]	KhRB (Al-Khabur River Basin) within the Duhok governorate in the northwestern part of Iraq	> WSM > AHP	Dam Site Selection	GIS	Advantages of AHP: > Simplifies complex decisions through comparisons. > Widely used and effective for multiple factors. > Highly suitable for dams. Advantages of WSM: > Simplicity with equal weights. > Useful for method comparisons. > Demonstrated efficiency in previous dam site studies.	Limitations of WSM: > Equal weighting risks inaccuracies. > Fixed weights may not reflect true importance. > Ignores factor relationships. Limitations of AHP: > Complex implementation. > Subjective judgments introduce bias. > Demands extensive data. > Accuracy depends on data quality.
[151]	Rwanda	> SWAT > AHP	RHW	GIS	Advantages of Integrated Geospatial and MCDM Techniques: > Comprehensive site assessment. > Accurate runoff estimation. > Prioritization through AHP. > Enhanced assessment with varied data. > Data-driven decision-making.	> Limited discharge data can affect accuracy. > Scarcity of RWH tech research limits effectiveness. > Data scarcities introduce uncertainties. > Institutions' linkages hinder structure establishment. > Data quality issues impact accuracy. > Lack of dataset guidelines introduces subjectivity.
[152]	southern part of Sistan and Baluchestan Province in Iran	> AHP > TOPSIS	Dam Site Selection	GIS	Advantages of TOPSIS Method: > Considers non-linear relations. > Handles variable units. > Provides deterministic weightings. Advantages of AHP Method: > Offers flexibility. > Provides intuitive appeal. > Includes consistency checking. > Uses convenient pairwise comparisons.	TOPSIS Method Limitations: > Non-linear relations. > Different units of measurement. > No uncertainty consideration. AHP Method Limitations: > Time-consuming decomposition. > Subjective pairwise comparisons. > Complex data input. > Lack of consistency checking. > Limited flexibility compared to TOPSIS.
[38]	Sharjah, United Arab Emirates (UAE)	AHP + Machine Learning	Dam Site Suitability	GIS	> Prioritizes and evaluates factors for decision-making. > Quantifies criteria importance through weight assignment. > Versatile and adaptable across domains and techniques. > Streamlines decision-making, saving time and resources. > Allows validation and sensitivity analysis.	> Relies on subjective judgments, introducing bias. > Involves a multi-step, time-consuming process. > May not be suitable for large-scale decision-making. > Challenging when criteria are not easily quantifiable. > Sensitive to changes in preferences. > Complex and lacks transparency for non-experts. > Limited consideration of uncertainty.

[154]	Northeastern Maysan Governorate, Iraq	> AHP > WLC	Water Harvesting Zones	GIS	> GIS flexibility and power > AHP for complex decision-making > Fuzzy logic for uncertainty > Integration of multiple factors > Standardization of factors > WLC for suitability mapping > Use of available data > Guidance for decision-makers > Comprehensive suitability mapping	> Limited data availability > Subjective weighting > Simplified factors > Assumptions in fuzzy logic > Limited validation
[155]	Greater Zab River in northern Iraq	> AHP > Fuzzy Logic	Dam Site Suitability	GIS	> Efficiency and flexibility > Effective decision-making > Comparative analysis > Spatial distribution > Field visit requirement	> Influence of AHP weights > Lack of consideration for other factors > Need for field visit > Spatial distribution of suitable areas > Accuracy assessment
[156]	Panjkora Basi,Eastern Hindu Kush,Northwest Pakistan	> AHP > WOA	Potential Sites for a Multi-Purpose Dam	GIS	> GIS, Remote Sensing, and AHP integration > Multi-Criteria Decision-Making (MCDM) > Suitability Mapping > Efficiency and Timesaving > Improved Accuracy > Multiple Purposes Consideration > Reduction of Flood Disasters > Water for Agriculture > Cost Efficiency > Complementary Approach	> Excludes Economic and Accessibility Factors > Limited Parameter Consideration > Potential Model Parameter Inaccuracy > Generalization of Results > Limited Validation
[157]	Mashhad Plain Basin (MPB), located in the northeast of Iran	> AHP +GIS > AHP+GIS+SWAT	RWH	GIS	> Comprehensive Analysis > Reduced Uncertainty > Improved Reliability > Comparison and Validation > Sensitivity Analysis > Potential Water Security	> Data Variability > Modeling Cost > Calibration Challenges > Limited Comparisons > MCDA Method Influence > Scope and Specificity
[158]	Sana'a Basin, Yemen	WLC	RWH	GIS	> Comprehensive Assessment > Incorporation of Local Expertise > Validation and Sensitivity Analysis > GIS-Based Approach > Flexibility and Adaptability	> Limited Field Data > Lack of Investigation > Subjectivity in Method Selection > Socioeconomic Criteria Disagreement > Socioeconomic Constraints
[159]	Northern Pakistan	> AHP > FIM Locating	Suitable Sites for Construction of Subsurface Dams	GIS	AHP Method: > Robustness > Scientific Knowledge > Reproducibility FIM Method: > Factor Interactions > Weight Flexibility > Knowledge Integration	> Expert judgment bias > Uncertainty in weighting > Varying accuracy > Results sensitivity > Field investigation necessity > Expert judgment reliance > Varying accuracy

[160]	Poldokhtar watershed, located in the Lorestan province of Iran	AHP	check dams	GIS	> Quantitative and qualitative data handling > Multiple criteria for informed decisions > Easy for local stakeholders to understand. > Supports participatory watershed management modeling. > Facilitates co-developed planning and decision-making	> Complexity in decision-making > Subjectivity and potential bias > Reliability of consistency ratio > Limited consideration of criterion interactions > Resource and time-intensive > Lack of built-in accuracy assessment
[161]	Kakareza watershed, west if Iran	> AHP > WLC	RWH	GIS	Advantages of AHP: > Multi-criteria decision-making > Weighting factors > Consistency analysis Advantages of WLC: > Land suitability analysis > GIS integration > Quantitative analysis	Limitations of AHP: > Subjectivity to expert judgment > Complexity > Consistency > Limited scope > Limitations of WLC: Weighting > Data requirements > Sensitivity to weights > Limited interaction consideration > Lack of transparency
[162]	Tete Province, Mozambique	> AHP > WLC	Dam Site Suitabilit	GIS	> Comprehensive Analysis > Incorporation of Expert Knowledge > Validation through Abandoned Dams/Reservoirs > Flexibility for Additional Criteria and Data > Spatial Decision Support > Integration of GIS and RS Technologies	> Additive Model Limitation > Lack of Sensitivity Analysis > Limited Number of Experts > Lack of Fieldwork and Detailed Data > Data Limitations > Need for Participatory Process > Future Developments
[163]	west of Iran	AHP	Earth dam site selection	eigenvector method	> Structured decision-making > Considers multiple criteria > Relative weight calculation > Consistency checking > Flexibility and adaptability	> Subjectivity and bias > Complexity > Inconsistency > Limited scope > Lack of transparency > Data quality dependency > Assumption of independence
[164]	Harsin city, Iran	AHP + VIKOR	Dam Site Selection	GIS	Advantages of AHP: > Simplicity in multi-criteria analysis. > Adaptability to diverse decisions. > Effectiveness in group choices. Advantages of VIKOR: > Handles conflicting criteria. > Widely applicable for ratings. > Provides compromise solutions	Limitations of AHP: > Subjectivity: Relies on subjective judgments. > Complexity: Involves intricate pairwise comparisons. > Lack of transparency: Decision process may be unclear. Limitations of VIKOR: > Limited applicability: Designed for specific problems. > Lack of flexibility: Assumes complete knowledge. > Sensitivity to weights: Ranking can change with small weight changes.

[165]	Sivas in Turkey	AHP+WLC	Dam Site Suitability	No	Advantages of AHP: > Effective multi-criteria decision-making. > Consistency control. > Widely used in dam site selection. Advantages of WLC: > Determines suitability based on criteria importance. > Easily applied in GIS environments. > Effective for decision support.	AHP Limitations: > Subjectivity and bias from subjective judgments. > Complexity and time consumption with many criteria. > Limited scalability for numerous criteria or alternatives. WLC Limitations: > Weighting bias due to subjective weight assignments. > Weight assignment challenges, especially with diverse criteria. > Sensitivity to weight changes that impact results. > Ignores potential criterion interactions. > Lack of transparency in the weighting process.
[166]	upper Benue River watershed, Nigeria	> AHP used for Weighing > Weighted Overlay Analysis (WOA) for overlay	Dam Site Suitability	GIS	> High predictive accuracy (AUC: 79.67%) > Validated with existing dam locations. > Identified 636 suitable dam sites. > Suitable for hydropower > Cost-effective V-shaped valleys > Supports rural development. > Maps areas for affordable electricity > Confirmed accuracy through field measurements	> Lack of flow data > Spatial resolution variation > Data processing impact > Focused validation on dam presence > Limited generalizability beyond the study area

Table 5: *Fifteen highly repeated factors in the literature of high-quality journal papers influencing dam site suitability*

Refe	Slope	LULC	ST	DfR	DD	R	Runoff	DfV	E	SO	Gelogy	DfF	TWI	RD	CN
[144]	√	√	√	√	√		√			√					
[145]	√				√					√			√		
[146]	√	√	√	√			√	√		√		√			
[147]	√	√	√	√			√	√							
[168]	√	√	√	√			√			√		√			
[149]	√	√	√				√								
[169]	√	√	√	√		√		√	√			√			√
[151]	√	√	√	√	√		√	√							
[152]	√	√									√			√	
[170]	√				√	√			√		√	√			√
[154]	√	√	√				√								
[155]	√		√	√		√		√	√		√	√		√	
[156]	√	√							√	√	√				
[157]	√	√	√			√									
[158]	√	√	√	√	√	√									
[159]	√	√											√		
[160]	√				√					√			√		
[161]	√	√	√		√		√								
[162]	√	√	√	√	√	√		√	√						
[165]	√	√	√	√	√	√		√	√						
[171]	√	√	√	√		√		√		√		√			√
[172]	√	√	√	√							√				
[59]	√	√	√	√	√	√	√	√	√	√	√				√

ST: Soil Types; DfR: Distance from Road; DD: Drainage Density; R: Rainfall; DfV: Distance from Village; E: Elevation; SO: Stream Order; DfF: Distance from Fault; TWI: Topographic Wetness Index; RD: River Discharge; CN: Curve Number.

2.3.2 Weighting Scales/ Assigning Weights to the Parameters

Weighting scales or assigning weights to parameters is a crucial step in the process of Multiple Criteria Analysis (MCA) [173], [174]. In MCA, decision-makers often need to evaluate multiple criteria or parameters when making a decision [174]. These criteria can have different levels of importance, and assigning appropriate weights to them helps reflect their relative significance in the decision-making process [174]. The process of assigning weights involves giving each criterion a numerical value that represents its importance or priority compared to other criteria [174]. These weights are typically assigned on a scale from 0 to 1, where 0 indicates that a criterion is not important at all, and 1 signifies that it is of utmost importance [175]. Intermediate values between 0 and 1 are used to represent varying degrees of importance [175].

In a comprehensive review of 35 high-quality journal articles, it became evident that diverse criteria were employed with varying weightings during the dam site selection process. Among these 35 research papers, only 11 utilized a somewhat similar set of criteria, whereas the remaining studies incorporated significantly divergent criteria. In certain cases, the discrepancies among criteria were so pronounced that consolidating them into a single table proved impractical, as it would have led to excessive table length. Consequently, table 6 provides a detailed record of the normalized weights assigned to these criteria across all studies, which were derived from expert opinions, for reference. The literature reveals a lack of consensus regarding the weighting of criteria in the context of dam site suitability. Each study used a distinct and often entirely different weight-scale for the same set of criteria. Consequently, these variations in weights produced significantly divergent outcomes in the dam site selection process, as vividly tabulated in table 6. This gap in results has been a subject of scrutiny and criticism within the framework of MCA.

Table 6: *Normalized Weights of Diverse Criteria for Dam Site Selection in Reviewed Studies*

Refer	Slope	LULC	ST	DfR	DD	R	Runoff	DfV	E	SO
[144]	10	20	20	5	20		20			5
[156]	27	10							18	39
[158]	22	8	14		9	47				
[161]	15.8	26	9.6		5.9		42.7			
[171]	22	18	10	2		5		2		7
[172]	36.29	4.6	13.68	2.54						
[151]				16.5			30	17		
[154]	6.9	11.7	24.8				36.8			
[162]	8	10	6	2	31	24		2	7	
[166]	8	3	5		9	21			4	
[165]	10.14	6.25	8.53	2.99	36.63	16.48		3.23	5.37	
[59]	8.33	8.07	8.53	6.6	7.1	8.61	7.98	7.05	6.79	7.54

Refer	G	DfF	TWI	Discharge Q	CN	DtR	CZ	SY	DtL	SPI
[144]										
[156]	6									
[158]										
[161]										
[171]		3			31					
[172]	29.24					3.08	10.57			
[151]						16.5		20		
[154]						19.8				
[162]									10	
[166]	11		5	27						7
[165]									10.38	
[59]	8.1				7.43				7.87	

ST: Soil Type (%;) DfR: Distance from Roads (%); DD: Drainage Density (%); R: average precipitation/Rainfall (%); DfV: Distance from Villages (%); E: Elevation (%); SO: Stream Order (%); G: Geology (%); DfF: Distance From Faults (%); CN: Curve Number (%); DtR: Distance to rivers (%); CZ: Catchment Size (%); SY: Sediment Yield (%); DtL: Distance to Lineament (%); SPI: Stream Power Index (%).

In the field of multi-criteria decision-making (MCA), a research study have categorized the methods for determining criteria weights into three main categories: subjective weighting methods, objective weighting methods, and combination weighting methods [176]. These methods play a crucial role in helping decision-makers evaluate and prioritize alternatives in various domains, including water resources management.

a) Subjective Weighting Methods

Subjective weighting methods involve deriving criteria weights based on the preferences and judgments of decision-makers [177]. These methods are widely used in MCDM, particularly in the context of water resources management. They provide a clear elicitation process and are adaptable to the specific needs and expertise of decision-makers [178]. Some popular subjective weighting methods include:

i. Direct Rating
ii. Ranking Method
iii. Point Allocation
iv. Pairwise Comparison
v. Ratio Method
vi. Swing Method
vii. Graphical Weighting
viii. Delphi Method
ix. Simple multi-attribute ranking technique (SMART)
x. SIMOS Method

b) Objective Weighting Methods

Objective weighting methods, on the other hand, determine criteria weights using mathematical algorithms and models, without relying on the decision-maker's judgments or preferences [176], [179]. These methods provide an unbiased approach to weight determination but may not consider important qualitative aspects. Objective weighting methods are less influenced by the subjectivity of decision-makers and are particularly useful when the decision problem requires a more quantitative and data-driven approach [179]. However, they may not capture nuanced qualitative factors. Some popular objective weighting methods include:

i. Entropy method.
ii. Criteria Importance Through Inter-criteria Correlation (CRITIC).
iii. Mean Weight.
iv. Standard Deviation.
v. Statistical Variance Procedure.

c) Combination Weighting Methods:

Combination or optimal weighting methods are hybrid approaches that combine elements of both subjective and objective methods. They often use a mix of multiplication and additive combination to determine criteria weights. These methods seek to strike a balance between the decision-maker's preferences and mathematical modeling [174], [176].

In summary, the choice of weighting method in MCDM depends on the nature of the decision problem, the availability of data, and the preferences of decision-makers. Subjective methods involve decision-maker input and expertise but can be influenced by biases. Objective methods rely on mathematical models and provide objectivity but may overlook qualitative aspects. Combination methods aim to combine the strengths of both approaches to achieve a more robust decision-making process [174].

2.3.3 GIS and Remote Sensing Technology in MCA

The use of GIS has emerged as a powerful tool in addressing various environmental and energy-related challenges around the world [180]. Researchers have harnessed the capabilities of GIS to make informed decisions and optimize the placement of critical infrastructure [181]. Several notable studies have employed GIS to tackle issues ranging from water scarcity to renewable energy resource allocation. These studies not only highlight the versatility of GIS but also underscore its importance in sustainable development and resource management.

A research study demonstrated the utility of GIS in addressing water shortage problems in South Sinai [182]. Their work involved the development of a decision-making tool for the strategic construction of desalination units [182]. This early application of GIS showcased its potential in solving complex water resource issues [182]. Another investigation shifted the focus to the renewable energy sector, specifically in Colorado, USA. By utilizing GIS, Janke identified suitable locations for the installation of solar power plants [183]. This research marked a pivotal moment in the integration of GIS with renewable energy planning, opening new avenues for sustainable energy development [184]. Further, a journal paper ventured into the realm of concentrated solar power (CSP) technology, combined with seawater desalination, in Oman [185]. They harnessed GIS to pinpoint the best site for a CSP and desalination plant, illustrating how GIS can optimize the deployment of advanced technologies in remote areas [186]. The application of GIS extended to Brazil in 2010 a study employed GIS-based decision tools for renewable energy management [187]. This study emphasized GIS's role as a valuable instrument in the optimization of renewable energy resources in diverse geographical settings [188]. Moreover, In 2012, another research proposed a model for selecting optimal locations for solar power plants, underscoring the continued relevance of GIS in the renewable energy sector [189]. Salim's work in the same year focused on Egypt, utilizing GIS to select groundwater sites for desalination powered by solar energy, a critical step towards addressing water scarcity in arid regions [190]. In 2013 a study identified optimal locations for combined wind and solar photovoltaic (PV) systems in western Turkey, highlighting GIS's ability to facilitate integrated renewable energy planning [191]. In a research study, authors applied GIS multi-criteria techniques to evaluate solar farm locations in Spain and Iran [192]. These studies demonstrated the global applicability of GIS in optimizing solar energy infrastructure [193]. Devi and Devi's 2016 research in India proposed a suitable site for a new desalination plant and optimized the pipeline route from the desalination site to the water network, showcasing GIS's role in improving water resource management [194].

Collectively, these studies illustrate the diverse applications of GIS in addressing critical environmental and energy challenges, underscoring its value as a decision-support tool for sustainable development and resource management across the globe.

3. Literature review assessment and discussions

3.1 Runoff Management

The findings of this study indicate that runoff management constitutes a component of water harvesting distinct from direct rainfall harvesting. Upon precipitation, a fraction thereof undergoes evaporation, infiltration, retention in depressions, and the residual portion proceeds as surface runoff across the terrain. Dams function with the primary objective of accumulating and storing this runoff. Consequently, it is appropriate to consider the utilization of the term 'dams' within the framework of runoff management rather than rainwater harvesting.

3.2 Multi Criteria Analysis

The employment of the Boolean search query "Dam Site selection OR Dam site Suitability Using MCA OR MCDM" in the Google Scholar platform yielded findings encompassing the years 2000 through 2023. Analysis of these outcomes demonstrated a significant increase in the utilization of MCA over time for the purpose of selecting dam sites. This upward trajectory followed an exponential pattern, as evidenced by the observed trend, exhibiting a strong correlation coefficient (R2) of 0.9745 (Figure 6). This substantial increase indicates ongoing growth within the field of MCA, suggesting that it has not yet reached a point of saturation. It is apparent that ongoing research endeavors are consistently enhancing and refining MCA models on an annual basis, contributing to its sustained expansion and development.

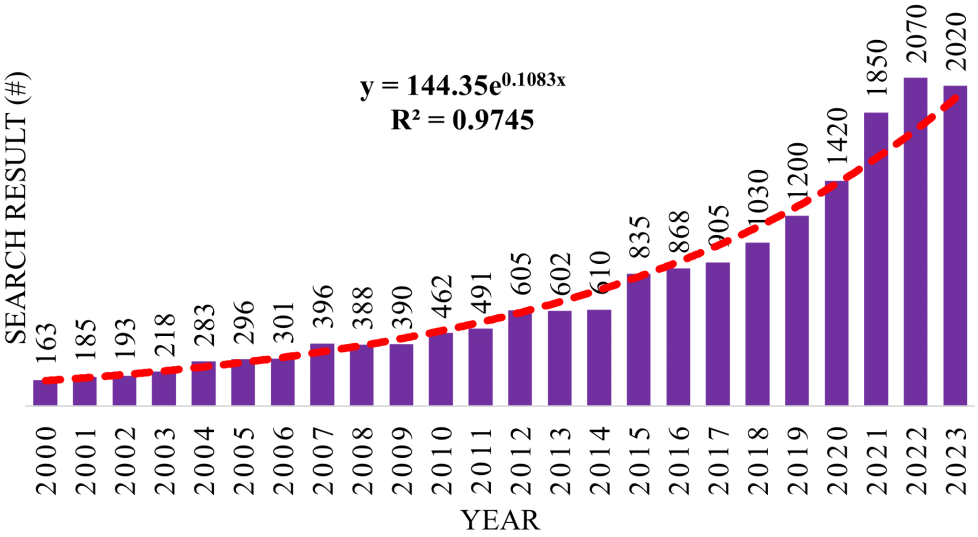

Figure 6: *Published Articles on Dam site suitability/Selection Using MCA/MCDA.*

In conclusion, the MCA approach further solidifies its significance in the field of dam site selection. As evidenced by this review's findings, the MCA methodology emerges as a potent tool for identifying optimal dam sites. Its exponential growth rate signals a trajectory poised for significant advancement in the foreseeable future. This trajectory suggests imminent dramatic enhancements and refinements, reinforcing its pivotal role in the ongoing evolution of dam site selection methodologies.

3.3 *Criteria selection*

In the light of literature review for runoff management and dam site selection using MCA, an important focus was placed on the careful selection and weighting of criteria vital to the decision-making process. The selection of criteria for dam site suitability originated from an extensive literature review, where 63 criteria influencing dam site suitability were identified. Among these, slope, LULC, and soil type emerged as the most significant factors, reinforced by their frequent utilization, and assessing across different studies. The reason behind selecting these factors hinges on their direct impact on the environmental compatibility, feasibility, and sustainability of potential dam sites. For example, the slope for dam sites significantly affects the applicability, design, and safety of the dam structure. A steeper slope may necessitate more exhaustive engineering precaution to ensure stability, increase construction costs, and as indicated in a study more than 45 degree slopes are not applicable for dams [59]. This is because of sediment transport, and low reservoir capacities. Furthermore, LULC plays a significant role in dam site selection. LULC map helps in assessing the potential for sedimentation and water quality impacts up-stream and down-stream of the dam. Regions with heavy vegetation cover, for instance, are likely to have less sedimentation rates than those with lighter vegetation. Beyond dam site selection, LULC can have vital impacts on other environmental dimensions. As an illustration, changes in LULC have been directly linked to groundwater fluctuations [3]. Moreover, soil type is another essential factor, as it influences the hydrological characteristics of soils and the stability of foundations for dam structures. For example, certain soil types, such as clay, may provide better sealing properties for a dam's reservoir but lay out challenges in terms of stability that may require specific engineering techniques. In conclusion, these examples signify the complexity of dam site selection and the essential role played by a explicit assessment of LULC, slope, soil type, and other factors.

3.4 Weighting of criteria in MCA

The process of assigning weights to the criteria includes a systematic strategy that maximizes experts' opinions and quantitative approaches to indicate the relative importance of each factor. This method ensured a stable consideration of technical, environmental, social, and economic factors. The weighting process was achieved through methodologies such as Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Fuzzy, and direct rank sum method which are well-known for their potential to handle complicated decision-making scenarios by making easy the comparison and ranking of multiple criteria. For example, a research article highlighted the application of the AHP in the process of dam site selection [195], where AHP was employed to identify rainwater harvesting sites, proving its effectiveness in dealing with sophisticated environmental and engineering evaluation. Similarly, another study utilized the direct rank sum method, where it was employed to evaluate dams' sites [59], illustrating its straightforwardness, simplicity and in ranking and decision-making processes. These studies intensify the effectiveness, and versatility of these methodologies in contributing to balanced, and informed decision-making in dam site selection and beyond. Consequently, in the MCA model, the criteria selection and weighting process for dam site selection originated in a rigorous analysis of related literature, methodological robustness, and expert knowledge.

3.5 Validation of criteria and their assigned weights in MCA

Validation of the selected criteria and their assigned weights can be accomplished through a dual approach: (i) by cross validating the outcomes with existing dams and their documented successes or challenges. This technique involves comparing the MCA model's predictions or evaluations against the real-world performance of existing dams. By assessing how well the criteria and weights predicted the dam's outcomes, scholars can measure the accuracy and reliability, and precision of MCA models. For instance, a scientific study evaluated the effectiveness of existing dams in Iraq employing criteria a like to those in their MCA model for dam site suitability [155]. However, the study examined the performance of the models used to predict the location of dams. But this approach is exactly the evaluating of criteria and their weights. This is because MCA is nothing without criteria and their corresponding weights. By comparing predictions of the models with actual locations of existing dams. (ii) through site feasibility studies, this technique involves the process of matching the outcomes of the MCA models with the real sites. By matching the model's predictions with actual dams' performance data, including details such as valley width, water storage capacity, sedimentation rates, slopes, elevations, and flood management, to be able to validate the effectiveness of their criteria and weighting system. This is totally in consistent with the findings of a scientist investigation, where the study suggests its findings has to be compared with the actual sites through a feasibility study for more reliability of the predicted locations [59]. in conclusion, the influence of criteria and their weights on the ultimate selection process was profound. The MCA approaches facilitated a smooth, transparent, and objective evaluation of potential dam locations, empowering the identification of sites that best satisfied the predefined objectives and conditions.

3.6 Mitigating bias and subjectivity in expert opinions for MCA

Reducing bias and subjectivity in the opinions of experts within the MCA models is vital to ensuring the validity, and reliability of dam sites. MCA integrity largely depends on the objectivity with which criteria are weighted and assessed. Identifying the essential subjectivity in expert judgments, numerous techniques have been adopted to minimize the biases and enhance the decision-making process. One effective approach is the use of structured expert elicitation methods, such as the Delphi technique, which involves multiple rounds of anonymous feedback among experts. The application of structured expert elicitation methods, such as the Delphi method, helps in meeting expert opinions through a process of iterative feedback, efficiently mitigating individual biases [196]. Further, cross-validation with reliable existing dams serves as a practical approach for validating the selected criteria and their weights. Comparing the MCA model's predictions with the actual performance and outcomes of established dams offers a real-world assessment on the assumption of model and the experts' judgments. This method grantees that the criteria and weights utilized in the model are not only theoretically sound but also practically applicable and reflective of real-world challenges and complexities. In conclusion, mitigating bias and subjectivity in expert opinions for MCA requires a multi-aspects approach that integrates methodological rigor, empirical data integration, iterative consensus-building processes, and real-world validation. These strategies collaboratively enhance the reliability, and objectivity of the MCA process, resulting in more powerful and defensible decisions in dam site selection.

3.7 *Addressing limitations and final model selection*

Identifying the different methodologies available for MCA in dam site selection analysis, this review extensively evaluated the advantages, and limitations of common models, as outlined in table 4 of the paper. A vital step in final model selection includes integrating these insights to recognize a model that best fits the specific objectives and limitations of the dam's sites. This requires considering factors such as the model's potential to handle complicated datasets, its sensitivity to alterations in input criteria, and the degree of transparency it offers. Equally important is acknowledging the trade-offs between methodological complications and practical applicability, satisfying that the selected model not only addresses theoretical aspects but is also feasible within the operational context.

A research paper preferred the WLC model for its robustness in handling a high number of criteria with minimized bias [59], the decision signified by a comparative assessment detailed in the referenced study [59]. The study emphasized the efficiency of WLC with obtaining the expert's opinion by using direct rank sum method over the AHP in situations where the number of criteria increases, acknowledging this to WLC's adaptability and reduced susceptibility to bias due to expert's opinion [59]. AHP, while robustness for its structured pairwise comparison and the power to manage less extensive sets of criteria, experiences limitations with scale [59]. The decision to employ WLC was further validated by its tangible success in a case study within the Harirud River Basin (HRB), where its employment leads in a coherent and scientifically substantiated selection of dam sites [59]. Consequently, the final model selection should be directed by a balanced consideration of both the empirical proof observed in the literature and the details of the project at hand.

4. Practical implications of the review findings

On the comprehensive analysis of runoff management through dam site selection using MCA, this section dived into the practical implications of findings, outlining practical strategies to enhance sustainability of water resources in the real world. (i) Policy and strategic planning: The review highlights the exponential increase in the MCA applications for dam site suitability, guiding to its crucial role in strategic water resources management. This emphasizes the needs for strategic planners and policymakers to combine MCA methodologies in the planning phases of WH projects. Policies should support the evolution of frameworks that formalize the application of MCA, insuring reliability and consistency across various projects and regions. (ii) Technological advancements: The findings highlight the importance of integrating GIS and RS data into MCA frameworks for dam site selection. This hybridization not only thrives on the accuracy of site suitability evaluation but also suggests a more elaborated analysis of geographical, hydrological, and environmental factors. Practical implications include investing in cutting-edge technologies and delivering training for professionals to harness these tools efficiently, enhancing the precision of WH projects. (iii)

Environmental sustainability: the review recognized slope, LULC, soil type and some other factors outlined in the table 5 as vital criteria influencing dam site suitability, intensifying the environmental considerations in dam site selection. It offers that future projects should incorporate environmental impact evaluations more powerfully into the decision-making process. Practically, this means focusing on sites that minimize conserve biodiversity, ecological disruption, and maintain ecosystem services, thereby harmonizing WH projects with broader environmental sustainability goals. (iv) Social and economic considerations: The divers' outcomes of dam site assessments due to alterations in experts' opinions on criteria weighting highlight the importance of using social and economic considerations into MCA. Practically, this requires engaging with local communities to comprehend their values, and prerequisites, ensuring that WH projects support local economies, improve water availability, and do not negatively affect the social fabric. (v) Adaptation to climate change: Given the suggestions for the synthesizing of climate adaptability into runoff management methods, practical applications should emphasize on designing adaptable and flexible WH systems. This involves harnessing climate projections to evaluate future water availability and integrating adaptive management practices that can respond to changing conditions. Projects should help for resilience, ensuring that WH infrastructures can survive extreme weather events and fluctuations in water supply. In conclusion, the practical implications of this review extend further technical and methodological adaptations in dam site selection. They are spanning a complete approach to water resources management that evaluates environmental sustainability, economic viability, social equity, and climate resilience. Adopting these recommendations necessitates a focused effort from engineers, policymakers, environmental scientists, and the communities they serve, ensuring that WH projects contribute to sustainable development goals and the well-being of present and future generations.

5. Future research direction

While this study has contributed valuable insights into runoff management using MCA in combination of GIS software, several promising avenues for future research emerge, warranting further investigation and exploration. The following outlines potential directions that could enhance and expand upon the current understanding of dam-based runoff management. This study signifies the need for future investigations, specifically focusing on discerning potential trends and aggregating expert's opinions to establish a unified scale for criteria weights. Addressing this discrepancy holds promise in refining the MCA methodology for more consistent and reliable dam site selection processes.

Further, environmental Impact Assessment: While the current study uncovered a powerful methodology for runoff management, future investigation should consider assessing the specific environmental aspects of dam construction and creation of reservoir. This assessment needs to consider the long-term ecological impacts on local ecosystems, and biodiversity.

Climate Change Adaptation: Given the increasing concerns and uncertainties related to climate change, future research could incorporate predictive models to evaluate the impact of changing the patterns of precipitation, extreme weather events, and alteration in runoff dynamics on the optimized dam series, and selected sites. This would enable proactive measures for adapting the dams to potential future climatic variations.

Social and Economic Implications: In continuation with the need for engagement of stakeholders, future investigations should focus research on the socio-economic implications of dams. This involves analyzing the impacts on local communities, livelihoods, and the economic landscape in the region. Understanding the cultural, social, and economic dynamics can guide more comprehensive and sustainable for the better implementing such projects.

High-resolution, and observational data: confirming the limitations on the resolution of available data, future studies could pay attention to acquire higher-resolution data to enhance the accuracy of results. By utilizing cutting-edge technologies such as remote sensing (RS), light detection and ranging (LiDAR), and more advanced mapping techniques, the precision and accuracy of the suitability maps and storage capacity evaluations can be crucially enhanced. Further, future research should focus on obtaining soil data, lithology data and runoff data based on the region observational techniques rather than using remotely sensed data.

In conclusion, the potential future research directions outlined above aim to address the gaps, limitations, and exposing challenges in the field of sustainable water resource management, granting a more comprehensive, adaptive, and forward-looking method towards the runoff management.

6. Conclusion

In the pursuit of enhancing water resources sustainability through effective runoff management, this comprehensive review has meticulously navigated through the multifaceted landscape of dam site selection methodologies, with a particular focus on the application of MCA. The depth of analysis undertaken in this study has unveiled an extensive spectrum of 63 criteria utilized across various studies, predominantly leveraging the MCA approach for discerning optimal dam locations. This exploration, drawing from a wealth of sources including Science direct, Scopus, and Google Scholar, has illuminated the most frequently employed criteria within this domain, identifying a subset of 15 criteria that have emerged as paramount in the selection process. Remarkably, this subset has consistently recurred in the literature, whereas the majority of the identified criteria have been referenced in fewer than three scientific papers, showcasing a wide yet focused array of factors pivotal for dam site evaluation.

Building upon this extensive groundwork, it becomes imperative to highlight the unique contributions and insights that delineate the novelty of our investigation. (i) The study's novel contribution is highlighted by its exhaustive review and critical synthesis of the diverse criteria employed in MCA for dam site selection, pinpointing those most imperative for consideration. This depth of analysis is unprecedented, offering a granular understanding that is crucial for refining future research and application methodologies in the field. (ii) Another novel insight gleaned from this comprehensive review is the exponential growth in the utilization of MCA models over recent decades. The study presents a detailed examination of this growth trajectory, supported by a robust correlation coefficient (R2 = 0.9745), showcasing an upward trend in the adoption of MCA methodologies, notably those models including AHP, TOPSIS, WLC, Fuzzy, and SWAT. This trend not only highlights the escalating importance of MCA in water resources management but also underscores the study's unique contribution to chronicling the evolution of MCA applications in dam site selection. (iii) Furthermore, the study embarks on a critical discourse regarding the lack of consensus on criteria weighting within MCA models, an aspect not thoroughly explored in prior research. The variability in expert opinions and the resulting divergent outcomes underscore the imperative for a more unified and standardized approach to criteria weighting, an insight that marks a significant stride toward enhancing the reliability and consistency of MCA applications in this domain.

In identifying the imperative to translate the insights gained from this comprehensive review into actionable strategies for decision-makers and stakeholders in the field of water resources management, it becomes necessary to have adequate support for a collaborative and informed approach. This entails the integration of MCA with GIS in the decision-making processes, focusing the importance of a participatory approach that includes stakeholders at all levels. By adopting the insights emphasized through this review, specifically the extensive spectrum of factors utilized in MCA for dam site selection, stakeholders can enhance their decision-making processes. This will enable the advancements of more equitable, sustainable, and effective water resource management strategies. Accordingly, these tactics should help not only at optimizing dam site selection for runoff management but also at satisfying the sustainability of water resources in the face of climate change conditions and increasing water demand pressures. Emphasizing the role of continuous innovation, research, and stakeholder engagement is crucial in this endeavor.

Having delineated the novelty of current review, now transitioning into a discussion of its key findings, underscoring the practical implications and future research avenues. Intriguingly, despite the diversity of criteria and methodologies encountered, all reviewed studies have demonstrated satisfactory outcomes in dam site selection, a testament to the robustness and adaptability of the MCA approach. The meticulous review process employed in this study, drawing from esteemed academic sources, has not only enriched the understanding of current practices but also pinpointed gaps and inconsistencies, particularly in the weighting of criteria, thereby charting a course for future research endeavors. As we look to the horizon, this research illuminates several promising directions for further investigation, including the need for a harmonized approach to criteria weighting and the integration of high-resolution observational data to bolster the accuracy of dam site evaluations. This foresight, coupled with the detailed insights into the most effective MCA models and their nuanced application in the field, sets a new precedent for scholarly inquiry and practical application in the sustainable management of water resources through optimized dam site selection.

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