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# An Integrated Conceptual Framework for Interconnected Dam Reservoirs Systems Implementation: A Case Study from Morocco

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## ABSTRACT

Water resources management is increasingly becoming a significant challenge on global and regional scales. Due to the spatiotemporal irregularity of rainfall, exacerbated by climate change, many countries have adopted water transfer systems between dam reservoirs located in water-excess areas towards reservoirs in deficit ones. However, considering the intricate difficulties involved in the implementation and management of Interconnected Dam Reservoir Systems (IDRS), it is necessary to conceptualize a holistic, integrated, coherent, and flexible approach allowing systematic and organized assessment and justification of those megaprojects. This paper presents such approach based on a detailed benchmark of criteria and methods proposed by the scientific community. The proposed approach highlights seven aspects to be studied namely justification of the real need, ecological and social impacts, resilience of the IDRS to climate change, economic viability, legal and regulatory considerations, and technical feasibility. This assessment process has been illustrated using a case study from the Water Transfer Project between Beni Mansour and Mohammed V dam reservoirs in Morocco. As a result, the work carried out will make it possible to better refine the studies in progress, conducted by the Water Department in Morocco, and to include this project in a sustainable development framework.

**KEYWORDS:** interconnected dam-reservoirs system (IDRS); IDRS assessment process; IDRS justification criteria; interbasin water transfer; sustainability

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## ABBREVIATIONS

$AWA_{75\%\ dep}$, annual water availability at 75% dependability; BM-MV WTP, Beni Mansour-Mohammed V water transfer project; DH, dirhams; DH/m³, Moroccan dirhams per cubic meter; Ha, hectares; IBWT, inter-basin water transfer; IDRS, interconnected dam-reservoirs system; NPV, Net Present Value; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; UNESCO, United Nations Educational, Scientific and Cultural Organization; WA, water availability

## INTRODUCTION

Since the middle of the last century, water scarcity was considered as a serious challenge in several regions around the world [1,2]. Under the combined effects of the spatio-temporal irregularity of rainfall, further exacerbated by the climate change impacts, and the growing water needs, the development of unconventional methods for water resources management should be a major concern [3]. Generally, water managers have opted for dams' construction to alleviate the water shortage problem in areas marked by temporal variability and spatial heterogeneity. However, local reservoirs are still insufficient for areas where the water demand outstrips the produced water amounts. In this context, Inter-Basin Water Transfer (IBWT) projects are implemented to address the uneven temporal and spatial distribution of water resources and demands by redirecting water from surplus regions to deficit areas [4]. When water transfer occurs specifically between dams and reservoirs within the donor and recipient basins, it is classified as an Interconnected Dam-Reservoirs System (IDRS), representing a specialized case of IBWT.

IBWT projects have already existed for millennia; the Egyptians, Chinese and Romans built huge aqueducts to supply cities with water from very distant sources. Currently, more than 80 IBWT megaprojects already exist around the world [5]. Some of them extend over several hundreds of kilometers, with annual transferred volumes of water that can reach billions of cubic meters [6]. While IDRS have the potential to alleviate water scarcity and restore the balance between demands and resources in deficit areas, they also raise environmental, economic, and social concerns [7]. Therefore, they deserve to be highlighted, well verified and scientifically assessed in order to decide on the justification of these projects.

Due to its geographical location in a semi-arid area, Morocco is highly affected by the negative impacts of climate change. These are reflected, on the hydrological level, in intense and increasingly frequent periods of drought, as well as in the decrease and irregularity of precipitation [8]. These phenomena slow down the renewal of available water and aggravate the country's water vulnerability. Consequently, Morocco has moved over the past two decades from a "water stress" to a "water scarcity" situation. According to current estimates, the average fresh water supply per inhabitant does not exceed 600 $m^3$/year, compared to 1000 $m^3$ at the beginning of the 2000s. In 1960, this rate reached 2500 $m^3$/year per inhabitant [9]. This situation is aggravated by the decline in water quality due to the pollution generated by the production system [10].

Moroccan hydrological context is very influenced by an annual irregularity and interannual variability of precipitations, and a disparity of their spatial distribution. In fact, two basins located in the northwest of the country, which cover only 7% of the total area, have 51% of the water resources [11]. These areas have significant surpluses and much of the water resources are lost at sea during the wet seasons. However, the central and eastern basins, marked by very important industrial and agricultural poles with unprecedented population growth, have an increasingly negative water balance. To deal with this challenging situation, Moroccan Water Research and Planning Directorate has opted, since 2009, for the idea of transferring surplus water from the north-west basins to the deficit basin in the North-east of the country. Despite the project being currently under study, no scientific research or academic articles have been published to verify its justification, assess its necessity, provide guidance on maximizing its benefits, analyze approaches to mitigate potential negative impacts, or evaluate its sustainability in the face of climate change. This represents a critical knowledge gap in the scientific literature concerning one of Morocco's most significant water management initiatives.

In this regard, this paper establishes an exhaustive inventory of the different criteria proposed by the scientific community. Then, the paper proposes an integrated, holistic, coherent and flexible framework to assess interconnected dams-reservoirs systems. Afterwards, this approach is applied to the Beni Mansour-Mohammed V Water Transfer Project (BM-MV WTP) in Morocco.

## STATE OF THE ART

### Search strategy

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [12] guidelines were followed to systematically collect, evaluate, and synthesize the available academic literature on "Interconnected Dam Reservoir Systems Implementation", allowing for the identification of key trends and the most promising research directions. The PRISMA framework is a standardized methodology used to enhance the transparency and rigor of systematic reviews. It consists of four main stages: (1) Identification—gathering relevant studies from various databases based on predefined keywords and search criteria. (2) Screening—removing duplicates and assessing titles and abstracts to exclude irrelevant or low-quality studies. (3) Eligibility—conducting a full-text evaluation of the remaining studies to ensure they meet the inclusion criteria. (4) Inclusion—synthesizing and analyzing the selected studies to extract meaningful insights and identify research gaps [12].

To conduct this systematic review, we began by defining the search keywords, carefully selecting primary terms relevant to the field of study, such as "Inter-Basin Water Transfer", "assessment process", and various impacts associated with these projects. A range of keyword combinations, as outlined in Table 1, was employed to identify pertinent scientific articles. The systematic search was carried out across three well-established academic databases: (1) Scopus, (2) Web of Science, and (3) ScienceDirect. In total, 228 articles were retrieved, comprising 95 from Scopus, 18 from Web of Science, and 115 from ScienceDirect.

**Table 1.** Relevant keywords used in the systematic search.

| Category | Relevant Keywords |
| --- | --- |
| Inter-Basin Water Transfer (IBWT) | Inter-Basin Water Transfer, Water Diversion, Water Transfer Projects, Hydrological Connectivity, Water Redistribution, Water Highway project, reservoir water transfer project, interconnected Dam Reservoirs |
| Assessment Process | Evaluation Framework, Decision-Making Criteria, Sustainability Assessment, justification criteria, Feasibility Study |
| Impacts of IBWT Projects | Environmental Impact, Ecological Consequences, Socioeconomic Effects, Water Quality Changes, Climate Change Resilience, social impact |

To achieve the article selection phase, we implemented a rigorous screening process based on predefined inclusion criteria (IC) and exclusion criteria (EC). Table 2 presents the IC and EC applied in this study.

**Table 2.** Inclusion ad exclusion criteria.

| Inclusion Criteria (IC) | Exclusion Criteria (EC) |
| --- | --- |
| IC 1: The article must be indexed in one of the selected databases. | EC 1: Duplicate publications |
| IC 2: The keywords must fall within at least two of the three identified categories. | EC 2: Studies not published in English |
| IC 3: The title, abstract, and full text must align with the research scope. | EC 3: Full text unavailable. |
| IC 4: The study should propose a model, prototype, or implementation | EC 4: Not relevant to Inter-Basin Water Transfer |

Upon initial acquisition, articles were screened to exclude those unrelated to Inter-Basin Water Transfer, duplicate entries, and non-English publications, yielding 120 studies. Abstract evaluation further eliminated papers that lacked modeling, prototyping, or implementation components, resulting in 80 articles. Following comprehensive full-text examination against research objectives and questions, 40 papers were ultimately selected for analysis. The PRISMA chart of the adopted selection process is shown in Figure 1.

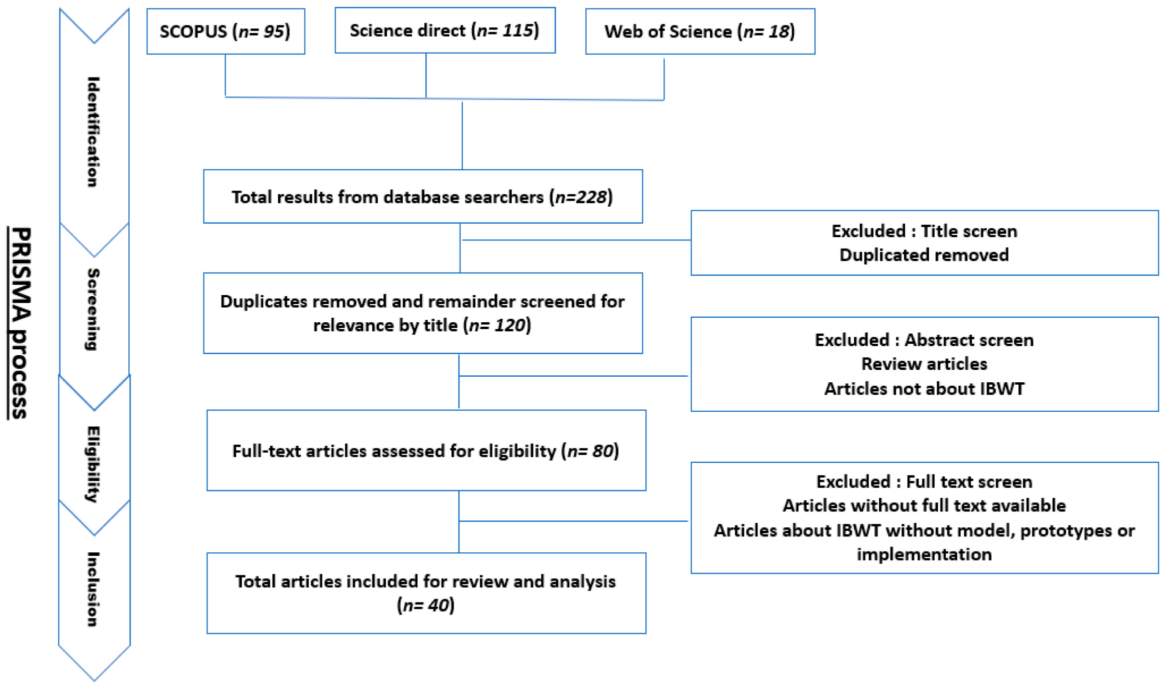


**Figure 1.** Flowchart of the selection process.

### Investigation and Analysis of the Proposed Justification Criteria

Justification, simulation and optimization of IBWT projects, especially the IDRSs have been discussed in a vast of literatures. Zhang et al. [6] carried out a bibliometric analysis of global IBWT research from 1900 to 2014. The study findings revealed that the frequency of annual publications on IBWTs exhibited a consistent increase after 1972 and is currently expanding rapidly. Through this analysis, it is remarkable that the countries having adopted the IBWT projects have known the most publications in this concern as China, the USA, and India [13–16].

Using systematic review methodology, Faúndez et al. [17] investigated the impacts that most often influence the sustainability of IBWTs with a focus on the social, political, and economic impacts. The authors selected 68 documents out of an initial total of 1567 for information quality analysis and content assessment. Results showed that the environmental dimension of sustainability had the highest frequency of positively coded impacts, whereas the social pillar had the highest frequency of negatively coded impacts. Furthermore, the positive impact that was most frequently identified overall was associated with the economic advantages of IBWTs. In concordance with this study, Wang et al. [18] revealed, through a systematic review, that IBWTs have the potential to endanger subsistence conditions, threaten the sustainability of local cultures, and disturb communities through forced relocation. The authors added that these effects are influenced by the politicization of water, the prioritization of economic concerns, and the imbalanced involvement of stakeholders.

Many authors have suggested some approaches and methodological frameworks to evaluate IBWT systems. Cox [19] presented a set of criteria for evaluating interbasin water transfer (IBWT) projects during a specialist workshop organized by United Nations Educational, Scientific and Cultural Organization (UNESCO) in Paris. These criteria include: (1) the recipient basin should experience water shortage that cannot be resolved through other non-conventionnel methods; (2) the water resources in the donor basin must be widely sufficient to meet all water needs; (3) significant environmental damage should not occur in either the delivery or origin areas; (4) there should be no significant socio-cultural disruption in both areas; and (5) the benefits of the IBWT should be distributed fairly between the donor and the receiver regions [19]. Despite the relevance of the criteria noted above, Cox [19] did not mention the aspects linked to the economic profitability of the project as well as the need to provide a legislative and institutional framework for the effective management of this project.

In addition to the concepts related to sustainability and verification of the real need, Gupta and Zaag [20] added the following criteria to evaluate inter-basin transfer schemes in the context of integrated water resources management: (1) good governance; (2) Considering both current rights and needs; and (3) sound science. Smakhtin et al. [21] proposed the criteria of the UNESCO namely: (1) reducing the water demand in the deficit basin and considering other alternatives; (2) water transfer must not penalize the development of the donor basin; (3) ecological degradation should be limited in both basins; (4) socio-cultural impacts must be minimized; and (5) distribute the water transfer’s net gains fairly across the donor basin and the receiving basin.

Kibiiy and Ndambuki [22] have proposed an approach to assess IBWTs, which is no exception to what has already been proposed. They recommended to justify the reel need for water transfer, reduce the negative impacts, and increase the positive ones.

Sinha et al. [5] have suggested the following four criteria for evaluating the IBWT projects: (1) the donor basin must have surplus Water Availability (WA) after fulfilling all its present and future Water Demand; (2) the receiving basin must experience a water shortfall after exhausting all WA options; (3) the completed project must be backed up by a multidisciplinary assessment designed to lessen negative effects, boost positive effects, with an equitable distribution among basins; (4) Data that is freely available in the public domain and should be made available for inspection must be included in analysis wherever possible.

More recently, Laassilia et al. [23] tried to re-arrange the listed principles and concepts into a more coherent set of criteria, based on a comparison of many disciplinary, political, scientific, and legal perspectives.

Based on this comprehensive literature review, it becomes evident that existing approaches to evaluating Inter-Basin Water Transfer projects often address isolated aspects without providing a unified assessment framework. To address this gap, we propose a holistic, integrated framework for IBWT justification that synthesizes and expands upon previous methodologies. Our framework encompasses seven essential dimensions: demonstration of water imbalance (confirming both surplus in the donor basin and deficit in the recipient basin), assessment of ecological impacts, evaluation of social implications, analysis of economic viability, consideration of the governance structure for transfer management, assessment of system resilience under climate change scenarios, and verification of technical implementation feasibility. This multifaceted approach enables a more robust and comprehensive evaluation of proposed water transfer projects, ensuring that decision-making processes account for the complex interplay of hydrological, ecological, social, economic, and governance factors.

### An Overview of Existing Approaches for Evaluating Some Justification Criteria

*Real need*

Verifying the availability of surplus water in the donor basin and the actual water deficit in the recipient basin, both currently and in the future, is a crucial initial step in assessing the feasibility of an IBWT project. Sajil Kumar et al. [24] have elaborated an exhaustive state of the art to estimate the water balance with a critical review. Many authors have suggested methods and approaches to calculate the transferable water volume, including non-cooperative dynamic game of water transfer [25], decision stochastic approach to determine quantity and price by simulating the recipient's demand curve and the donor's supply curve for transferable water [26], estimation of the surplus water in the donor region by deducting the water need from the water availability (WA) [5] , and use of rainfall-runoff mechanism conceptualization coupled with simulation-optimization model [11,27]. Before deciding on the water surplus of the donor basin, it is important to consider the environmental flow requirements, which means the amount of water that must be purposefully left in or released into an aquatic ecosystem to maintain its ecological functions [28,29].

*Environmental impacts*

Considering the ecological impacts, inter-Basin-Transfers certainly involve the redistribution of water resources in both the donor and recipient basins, and may cause changes of the ecosystems [30,31]. Such changes are two-sided, namely, the positive impacts, including adding new water potential for deficient areas, improving meteorological conditions, restoring the damaged ecological system, and preserving the endangered wild fauna and flora, as well as the negative impacts, including salinization, aridification, and soil degradation of the donor basins, influence on the aquatic ecosystem downstream of donor dams, damage to the ecological environment of the donor basins and both sides of the conveying channel system, the loss of biogeographical integrity, the frequent introduction of alien and often invasive aquatic and terrestrial plants and animals, the genetic intermixing of once separated populations, the implications for water quality, the frequently drastic alteration of hydrological regimes, and the implications for marine and estuarine processes, etc. [32,33].

Because Inter-Basin-Transfers have enormous ecological risk, it is necessary to comprehensively analyze the inter-basin water balance relationship, coordinate the possible conflicts and environmental quality problems between regions, and strengthen the argumentation of the ecological risk of water transfer and eco-compensation measures. In this regard, several methods and measures could be considered to assess and mitigate the impacts of Inter-Basin-Transfers systems namely; comprehensive Environmental Impact Assessments, allowing to evaluate potential impacts on ecosystems, water quality, aquatic habitats, and communities [34], habitat restoration and creation to offset the loss of wetlands, riparian zones, and other habitats due to infrastructure construction [35]. Employ strategies to maintain or improve water quality, such as using natural filtration systems (wetlands, vegetated buffers) to mitigate sediment and nutrient runoff [36]. Monitoring and treatment systems can be implemented to prevent pollution and salinization. Non-native species management by establishing strict control measures, quarantine systems, and invasive species management plans [37]. Hydrological modeling and adaptive management in order to predict potential impacts and assess various scenarios [27]. These models can inform adaptive management strategies that allow project managers to make adjustments based on real-time monitoring and changing conditions. Establish and maintain minimum flows in rivers and water bodies to sustain aquatic ecosystems and downstream communities, etc.

*Social impacts*

IDRSs reshape social structures in source and recipient areas, affecting ecosystems, water availability, and communities [5,38]. Displacement due to IBWT infrastructure disrupts livelihoods, cultural practices, and social bonds, especially for indigenous and rural populations [39]. Traditional activities like agriculture and fishing decline, impacting economic stability and cultural identity. Social conflicts arise from competition over water and displacement, deepening societal divisions. Resettled communities face health risks due to inadequate sanitation and clean water access [40]. Economically, recipient areas benefit, while source areas suffer, exacerbating social inequalities and forcing migration to urban centers.

To mitigate these impacts, IBWT projects require thorough social impact assessments with active community participation [41]. Inclusive decision-making fosters ownership and tailored solutions. Just compensation, beyond monetary aid, should preserve social cohesion and cultural heritage. Alternative livelihoods, vocational training, and cultural heritage preservation aid smooth transitions [7]. Equitable benefit-sharing ensures fair distribution of advantages. Access to clean water, sanitation, education, and awareness programs empowers communities to engage and advocate for their rights [18].

## MATERIALS AND METHODS

### Study Area

The chosen design of the BM-MV WTP consists in transferring water between four dam reservoirs, in service and projected, via perhaps 242 km of pipes, canals and tunnels (Figure 2). Indeed, the water transfer scheme links the Beni Mansour projected dam (Laou basin) to the Mohammed V dam (Moulouya basin), with two water intakes from Bouhmed (Kannar basin) and Dar Maimoun (Bouhaya basin) projected dams. The transfer will therefore take place from the northern region of Morocco to the eastern region. The volume to be transferred is estimated at 500 million cubic meteres per year [42].

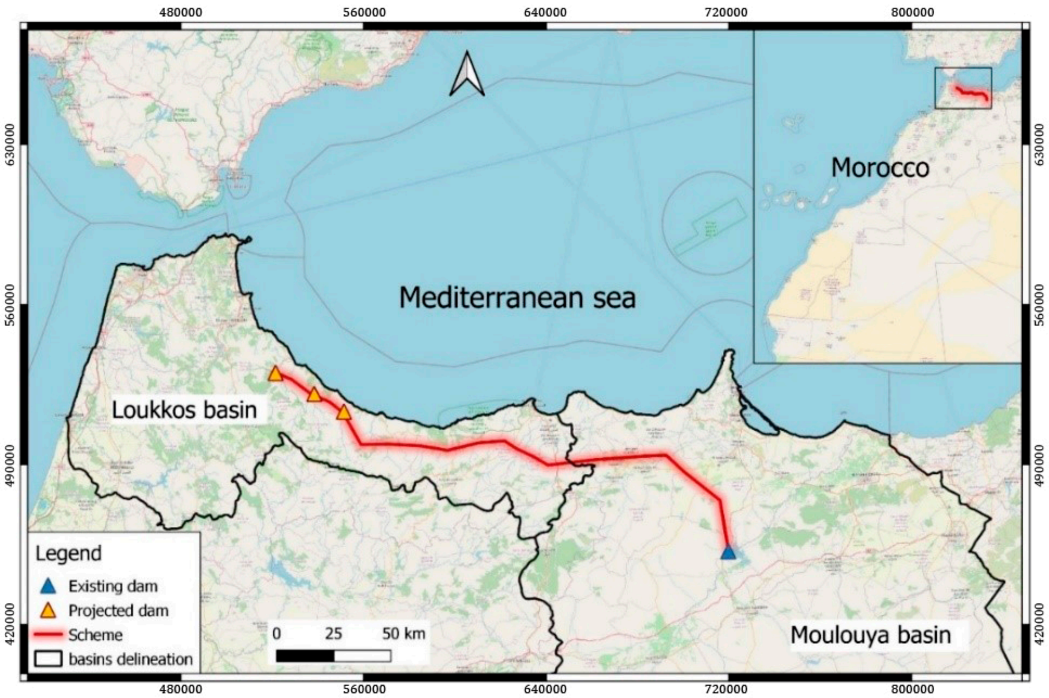


**Figure 2.** Map of the planned BM-MV WTP in Morocco.

### Methods

*Criterion No. 1: real need*

Confirm the availability of excess water in the donor basin and the real deficit of water in the recipient basin, both in the present and the future, is critical for evaluating the feasibility of an IBWT project. the classical approach involves calculating the water balance of the concerned catchments, by considering all components of the water cycle within the basin: precipitation, evaporation, runoff, and groundwater discharge. The difference between the inputs and outputs represents the net water availability in the basin. This analysis must be complemented by incorporating climate change projections to avoid erroneous assessments of surplus resources.

Secondly, assessing current and future water demands in both basins is essential. This requires understanding water needs across different sectors (agriculture, domestic, industrial) requires harmonious coordination between concerned departments. Demand estimation should integrate dynamic factors influencing water consumption, including evolving lifestyles, technological advancements, and potential water conservation and efficiency measures.

Once the water balance, water demands, and environmental flow requirements are assessed, the excess water available for transfer to the receiving basin could be estimated. The available water for transfer should be sufficient to meet the needs of the receiving basin while ensuring that the present and future needs of the donor basin are totally met.

In addition to analyzing water balances, we opt for an alternative quantitative method to confirm the transferable water volume. This method calculates the surplus water in the donor basin by the subtracting Water Needs (WN) from the water availability [9,26]. The WN represents the sum of domestic, irrigation, and environmental water demands. WA is calculated based on annual natural water yields at 75% dependability (indicating the projected water flow available for 75 years out of 100 years [9]). The Monthly Water Availability at 75% dependability ($MWA_{75\%\ dep}$) for the month i is calculated according to the following equation:

$$(MWA_{75\ \%\ dep})_{\ i} = 3600 * 24 * \text{Days per month} * MMQ_{75\%\ dep} \quad (1)$$

While: $MMQ_{75\%\ dep}$ is the Monthly Mean Flow at 75% dependability ($m^3/s$).

Then, the Annual Water Availability at 75% dependability ($AWA_{75\%\ dep}$) is calculated by summing the MWAs as follow:

$$AWA_{\ 75\%\ dep} = \sum_{1}^{12} (MWA_{75\ \%\ dep})_{\ i} \quad (2)$$

*Criterion No. 2: environmental impact*

This section comprises a critical review of the environmental impact assessment report for BM-MV WTP in Morocco. Our methodological approach focused on a systematic document review of the official environmental impact assessment documentation provided by the Water Research and Planning Directorate of Morocco [43]. We examined the assessment methodology, baseline data collection, impact identification, and proposed mitigation measures presented in the report. The review evaluated the comprehensiveness and adequacy of the environmental impact assessment in addressing potential environmental impacts across various ecological dimensions.

We developed a structured evaluation framework to identify potential gaps in the environmental assessment. This framework focused on several key environmental components, namely hydrological alterations, aquatic ecosystem impacts, sediment transport dynamics, biodiversity considerations, infrastructure corridor effects, and socio-ecological implications. For each component, we assessed whether the environmental impact assessment sufficiently characterized baseline conditions, adequately quantified potential impacts, and proposed appropriate and feasible mitigation measures.

The evaluation also considered whether the assessment adhered to international best practices for water transfer projects and incorporated principles of sustainable water resource management. We compared the methodology and findings against similar projects and relevant scientific literature to identify potential oversights or areas requiring additional attention.

Based on the identified gaps, we formulated recommendations for enhancing the environmental assessment. These recommendations aimed to guide researchers and project planners toward a more comprehensive understanding of the potential environmental implications and to develop more effective mitigation strategies.

*Criterion NO. 3: economic viability*

The economic viability of IDRS is a critical determinant shaping these projects' feasibility and sustainability [35]. The costs of construction and operation must be carefully evaluated against the potential benefits. As communities, industries, and ecosystems depend on the reasonable allocation of water resources, assessing whether the costs incurred in executing these transfers are justified by the benefits they offer is imperative. This intricate analysis delves into a multifaceted evaluation encompassing factors ranging from infrastructure expenses and energy requirements to environmental repercussions and socio-economic considerations. Economic analyses should also consider the impacts on existing water users and industries in both basins.

Based on similar studies [15,44], we propose the following methodology to assess the economic profitability of Inter-Basin-Transfers . The first step is to define the project's objectives and the criteria for economic profitability. These objectives may include improving water supply, increasing agricultural productivity, generating hydropower, and reducing flood risk. The next step is to estimate the costs of the IBWT project. This includes capital costs (e.g., construction of dams, pipelines, and treatment plants), operating costs (e.g., maintenance, labor, and energy), and any other associated costs (e.g., environmental mitigation measures, compensation for affected communities).

Then, estimate the benefits of the project which may include increased agricultural productivity, increased hydropower generation, improved access to water for households and industries, and reduced flood risk [45]. The benefits can be estimated using different techniques, such as cost-benefit analysis, economic impact analysis, and environmental valuation. Fourthly, calculate the Net Present Value and Internal Rate of Return. The Net Present Value is a measure of the economic profitability of the project over time, and it takes into account the time value of money. The Internal Rate of Return is a measure of the project's rate of return.

Finally, it's important to conduct a sensitivity analysis to assess the project's robustness to changes in key assumptions, such as the discount rate, project costs, and benefits. This helps to identify the key drivers of the project's economic profitability and any potential risks.

*Criterion No. 4: social impact*

The social impact assessment of the BM-MV WTP follows a structured 11-step framework to ensure a comprehensive and evidence-based evaluation (Table 3).

**Table 3.** Methodological framework for assessing the social impact of an Interconnected Dam Reservoir System.

| **Step** | **Action** | **Focus** |
| --- | --- | --- |
| 1. Define objectives | Establish scope & goals | Key social dimensions |
| 2. Identify stakeholders | Map affected groups | Inclusivity & diversity |
| 3. Collect data | Conduct surveys & interviews | Representativeness & accuracy |
| 4. Assess baseline | Analyze pre-project conditions | Historical & economic data |
| 5. Identify impacts | Determine direct & indirect effects | Short- & long-term consequences |
| 6. Compare & analyze | Benchmark & evaluate | Counterfactual analysis |
| 7. Engage communities | Consult stakeholders | Transparency & participatory feedback |
| 8. Assess risks | Identify potential threats | Social vulnerabilities |
| 9. Review policies | Examine legal & governance frameworks | Compliance & institutional capacity |
| 10. Recommend actions | Develop mitigation strategies | Sustainable and adaptive solutions |
| 11. Monitor & adapt | Track progress & refine approach | Continuous evaluation & improvement |

The process begins by defining objectives and identifying key social dimensions. Stakeholder mapping is then conducted to promote inclusivity and integrate diverse perspectives. Data collection follows, and a baseline assessment is carried out to analyze pre-project conditions, providing a reference for evaluating future changes. The next step involves identifying both direct and indirect social impacts, considering short- and long-term consequences.

To enhance analytical rigor, benchmarking and counterfactual analysis are employed. Engaging communities through stakeholder consultations ensures transparency and participatory feedback. Risk assessment focuses on identifying social vulnerabilities that may arise from the project. The review of legal and governance frameworks ensures compliance and institutional alignment. Based on the findings, mitigation strategies are developed to promote sustainable and adaptive solutions. Finally, continuous monitoring and adaptive management allow for refining the approach over time, ensuring effective long-term impact management.

*Criterion No. 5: technical feasibility*

IDRSs require sophisticated engineering and construction techniques, and the technical feasibility of these projects should be carefully evaluated based on the available technology, infrastructure, and resources in both basins.

Selecting a route for interbasin water transfer is a multifaceted process, demanding a thorough evaluation of technical and engineering criteria to guarantee project feasibility, efficiency, and sustainability [46–48]. This entails determining the maximum transfer flow for hydraulic structures design, assessing terrain and geological challenges, estimating infrastructure needs for construction and operation, considering the energy demands linked to distance and elevation variations, calculating pumping energy requirements for cost-effective transfer, mitigating environmental impacts on habitats and water quality, designing for operational adaptability to address changing demands, and evaluating intersections with existing infrastructure such as roads and rivers [49]. For this, the route selection process must holistically weigh these criteria to make informed decisions that ensure the project's long-term viability and success.

*Criterion No. 6: climate change resilience*

To evaluate the impact of climate change on the sustainability of the IBWT project, a comprehensive approach was adopted. First, climate projections were analyzed using existing studies and reports, particularly focusing on precipitation and temperature changes in both the donor and recipient basins. These projections were then linked to expected variations in water availability, including surface water inflow, groundwater recharge, and evaporation rates.

Hydrological data from past decades were examined to identify trends and assess changes in flow regimes. The assumptions used for water resource projections were compared with official estimates from the The Integrated Water Resources Master Plan in the Moulouya Basin [50], ensuring consistency in methodology.

Additionally, recommendations were formulated based on hydrological modeling approaches to improve adaptability and resilience. These include developing dynamic management strategies, integrating additional reservoirs into the transfer scheme, and optimizing water distribution under different climate scenarios. The methodological approach ensures that climate risks are systematically considered in evaluating and managing IBWT projects.

*Criterion No. 7: legal and regulatory consideration*

Interbasin water transfer projects may be subject to a range of legal and regulatory frameworks at the local, national, and international levels. These frameworks should be carefully evaluated to ensure compliance with relevant laws and regulations, as well as to identify potential conflicts and challenges.

The success and sustainability of IBWTs hinge on well-structured legal and regulatory frameworks [51]. The latter ensure equitable resource allocation, safeguard the environment through impact assessments, address socioeconomic implications, promote transparency and accountability, support long-term sustainability, and provide mechanisms for conflict resolution. In essence, legal and regulatory considerations are the cornerstone of effective and responsible water resource management in the context of interbasin water transfers, aligning the interests of stakeholders, safeguarding the environment, and ensuring the efficient and equitable utilization of water resources.

To evaluate these aspects, we adopt the following methodology. First, we will review the legal and institutional framework that governs water resource management in Morocco. This includes an analysis of key legislative texts, such as Law 36-15 on water, and an evaluation of the roles played by the Ministry of Water and the Hydraulic Basin Agencies.

Next, we will examine Morocco's historical and current water transfer projects. This will involve a comprehensive review of past projects, focusing on their infrastructure, technical specifications, and the impact they have had on water supply for both urban and agricultural purposes. We will also assess ongoing large-scale projects, particularly those that involve the interconnection of dams across different basins, including the technical capacities of the pumping stations and their expected performance.

Subsequently, we will assess the compliance of these water transfer projects with the country's water management regulations, evaluating their alignment with the principles outlined in the National Water Plan. This will involve evaluating the degree of coordination among stakeholders and the promotion of regional solidarity through these projects.

Finally, we will synthesize our findings, providing a detailed analysis of the strengths and challenges of Morocco's legal and institutional frameworks in supporting the effective implementation of water transfer systems. Based on this analysis, we will propose recommendations aimed at enhancing the sustainability and scalability of these systems, ensuring optimal water distribution in the face of future challenges.

## RESULTS AND DISCUSSION

Considering the proposed integrated, holistic, and coherent set of criteria for evaluating IDRS justification, the BM-MV WTP can be assessed as follows:

### Criterion No. 1: Real Need

In order to justify this criterion, it is needed to confirm the excess of water resources in the donor basin (Laou) and the deficit in the recipient basin (Moulouya). To assess the water resource balance in the Moulouya basin, we conducted a thorough comparison between the available water resources and the water demands expressed by various user sectors. Based on data furnished by the Moulouya Basin Hydraulic Agency, the analysis of hydraulic balances reveals a significant annual deficit in this basin, amounting to approximately −440 million cubic meters. This deficit is projected to escalate to −630 million $m^3$ in 2050. Accounting for the influence of climate change, this shortfall surges to −955 million $m^3$ annually [50]. The observed deficit is structural in this basin because of the insufficiency of water resources relative to the growing water demand.

It is to be noted that an important portion of these deficits is being mitigated through the overexploitation of groundwater, jeopardizing its long-term sustainability and viability of associated uses. Extractions from aquifers are estimated to reach nearly 500 million $m^3$ annually, resulting in an overexploitation of 130 million $m^3$ [50]. Moreover, the current status of available water resources raises concerns about the ability to meet the drinking water supply requirements of major cities such as Nador, Oujda, Berkane, and Taourirt. Consequently, exploring alternative water supply options is imperative to bridge the impending water gap and address the escalating water demand anticipated by 2050. To this end, the Moulouya Basin Hydraulic Agency, responsible for water resource management in this basin, envisages the construction of three major dams (Machraâ Safsaf, Targa or Madi, and Bani Azimane), the localized water collection through small dams, seawater desalination, the reutilization of treated wastewater, and the interconnection of the MV dam with the BM complex situated in the northwest of the country.

This analysis highlights that the Moulouya basin faces a persistent deficit in both the present and the future. Furthermore, the proposition of sourcing water through interbasin water transfer, as delineated in this study, forms an integral component of an overarching development plan designed to ensure the fulfillment of water requirements in this basin over the short and long term.

Regarding the donor basins, the Laou system has an annual rainfall potential of 800 mm and an average annual contribution of 1367 million $m^3$/year [52]. Despite these significant water potentials, these basins currently lack major hydraulic developments. Drinking water needs are met through the exploitation of underground aquifers, primarily the Laou and Bouhmed aquifers, as well as some local water springs.

The planned developments under the national program for drinking water supply and irrigation (2020–2027), which are related to the Laou system, include some infrastructures mainly the construction of three large dams: Beni Mansour on the Laou River, Dar Maimoun on the Bouhaya River, and Bouhmed on the El Kanar River, with a total capacity of 1400 million $m^3$ [52]. According to the data provided by Loukkos Hydraulic Basin Agency the resource-demand balance in the Laou system is summarized in the Table 4.

**Table 4.** Resource-demand balance in the Laou system with and without climate change scenarios [52].

| **Scenario** | **Year** | **Current water resources × $10^6$ ($m^3$/year)** | | | **Water demand × $10^6$ ($m^3$/year)** | | | **Gap × $10^6$ ($m^3$/year)** |
|---|---|---|---|---|---|---|---|---|
| | | **Dams' supplies** | **Underground water** | **Total** | **Drinking water** | **Irrigation water** | **Total** | |
| Without climate change | 2020 | 0 | 19 | 19 | 6 | 13 | 23 | 0 |
| | 2030 | 386 | 52 | 438 | 6 | 33 | 39 | 399 |
| | 2040 | 554 | 52 | 606 | 7 | 33 | 40 | 566 |
| | 2050 | 554 | 52 | 606 | 7 | 33 | 40 | 566 |
| With climate change | 2020 | 0 | 19 | 19 | 6 | 13 | 23 | 0 |
| | 2030 | 367 | 50 | 417 | 6 | 34 | 40 | 377 |
| | 2040 | 498 | 49 | 547 | 7 | 35 | 42 | 505 |
| | 2050 | 470 | 47 | 517 | 7 | 36 | 43 | 474 |

Therefore, this system can easily meet all its local and regional needs while remaining surplus in the short and long terms. This suggests the possibility of transferring a part of this excess water to more deficit areas. In this regard, the The Integrated Water Resources Master Plan in Loukkos basin proposes the transfer of the surplus water, estimated at 500 million $m^3$, to the Moulouya basin [52].

Additionally, to implement the quantitative method outlined in section 3.1 (Study Area). within the context of the studied project, the calculation of the Monthly Mean Flow at 75% dependability was based on time series data of monthly flow rates spanning the period from 1940 to 2018 [53]. Figure 3 illustrates the interannual fluctuations in mean flow at each dam site. It is observed that the different basins of the studied dams share the same hydrological regime; the fluctuations in inflows are practically similar. However, the volume of inflows at each dam site is proportional to the surface area of its watershed. By analyzing the variation in these inflows over time, we can notice a succession of dry and wet periods, highlighting the relevance of the idea of transferring the substantial inflows during rainy years, which are currently lost to the sea, to areas suffering from chronic deficits.

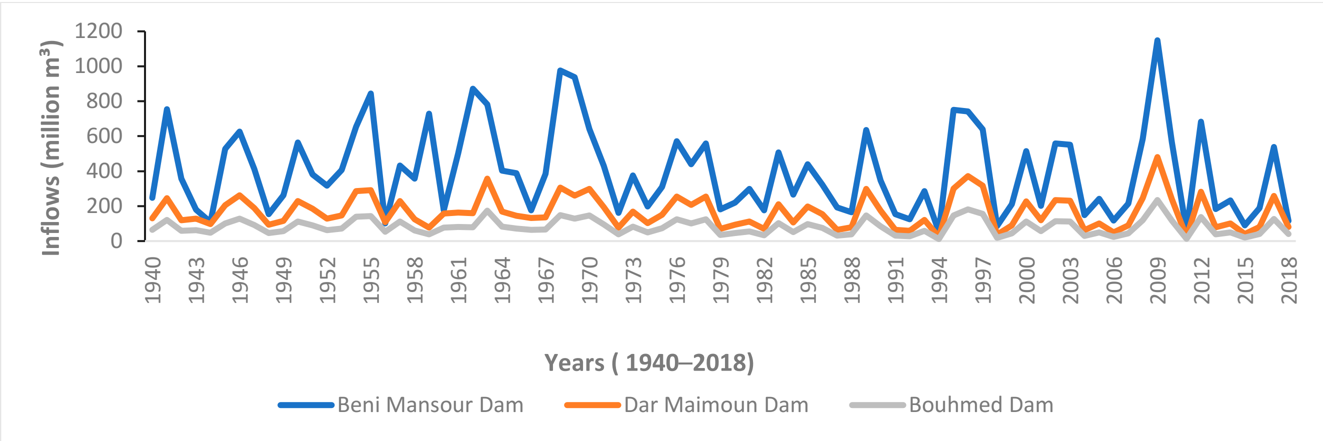


**Figure 3.** Interannual inflows to the donor reservoirs for the period 1940–2018.

The results of the $MWA_{75\,\%\ dep}$ calculation for each projected dam location are shown in Figure 4. It is clear that the most important $MWA_{75\,\%\ dep}$ rates are recorded during the rainy season in Morocco, which extends from November to April. On average, the estimated MWA during February exceeds approximately 160 million m$^3$. This reflects the significance of water surplus in the Laou system.

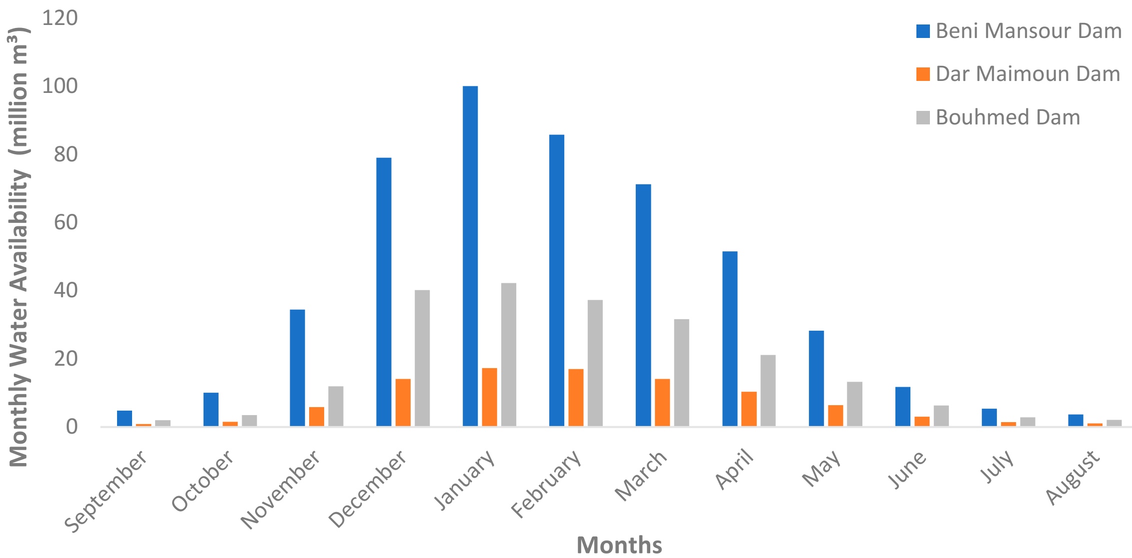


**Figure 4.** Monthly water availability in the Laou basin.

Applying equation (2), the $AWA_{75\%\ dep}$ was calculated for the various donor reservoirs. Then, the overall water surplus in the Laou basin was estimated, without and with climate change consideration, according to the estimates provided by the The Integrated Water Resources Master Plan in Loukkos basin (Table 5). It is observed that the obtained results align with the earlier estimate of water surplus.

**Table 5.** Excess water calculation in the Laou basin.

| Scenario | Dams | Beni Mansour | Dar Maimoun | Bouhmed | Total | Excess water × $10^6$ ($m^3$/year) |
|---|---|---|---|---|---|---|
| Without climate change | $AWA_{75\%\ dep}$ × $10^6$ ($m^3$) | 524.0 | 191.6 | 93.6 | 809.2 | 698 |
| | Ecological flow × $10^6$ ($m^3$) | 28.6 | 11.7 | 5.7 | 46.0 | |
| | Water demand | - | - | - | 40.0 | |
| | Evaporation | 16.9 | 4.0 | 4.7 | 25.6 | |
| With climate change | $AWA_{75\%\ dep}$ × $10^6$ ($m^3$) | 419.2 | 153.3 | 74.9 | 647.3 | 530 |
| | Ecological flow × $10^6$ ($m^3$) | 28.6 | 11.7 | 5.7 | 46.0 | |
| | Water demand | - | - | - | 43.0 | |
| | Evaporation | 18.6 | 4.4 | 5.2 | 28.2 | |

Considering these results, the criterion of real need is justified for the case of the BM-MV WTP.

**Criterion No. 2: Environmental Impacts**

Our review of the environmental impact assessment conducted by the Water Research and Planning Directorate in Morocco revealed both strengths and limitations in the analysis of potential environmental impacts of the BM-MV WTP.

The environmental impact assessment effectively identified significant positive impacts of the project, including the alleviation of water deficit in the Moulouya watershed, enhanced potable water and irrigation supply, hydroelectric energy generation potential, and the creation of wetlands that could foster new ecosystems. These benefits represent important contributions to regional water security and economic development.

The assessment also acknowledged certain negative consequences, notably the inundation of approximately 980 hectares of arable land and alterations to the downstream hydrological regime. The environmental impact assessment recognized that redirecting water from the donor basins could influence the hydrogeological balance and potentially affect aquatic ecosystems downstream from the dams. The recommendation to implement ecological flows downstream of the dams demonstrates awareness of this concern.

Regarding water quality, the environmental impact assessment presented a generally favorable assessment for water transfer operations. It noted the predominantly self-contained local sanitation systems, minimal waste discharge, and a reservoir management strategy involving regular drainage, all contributing to a relatively low risk of eutrophication.

However, our review identified several areas where the environmental assessment could be strengthened. The environmental impact assessment would benefit from a more comprehensive analysis of sediment transport dynamics and their implications for downstream river morphology and estuarine environments. The proposed ecological flow provisions warrant further development, particularly regarding seasonal variability requirements and long-term ecological maintenance.

The assessment did not adequately address the potential risks associated with species transfer between basins, a common concern in water transfer projects. Additionally, the environmental implications of the 242 km water conveyance infrastructure corridor received insufficient attention, particularly regarding terrain stability, wildlife corridor intersections, and construction-phase impacts.

Furthermore, the environmental impact assessment would be enhanced by deeper consideration of cumulative effects when the project is considered alongside existing infrastructure, ongoing land use changes, climate change projections, and other regional development initiatives. The interconnections between ecological and social systems also merit more thorough examination.

**Criterion No. 3: Economic Viability**

*Project cost analysis*

According to the financial study of the BM-MV WTP, the estimated total cost of investment is about 31.3 billion dirhams (approximately 3 billion dollars) [42]. This comprehensive cost includes all essential infrastructure elements: pumping stations (7.2 billion dirhams), pipes and galleries (18.5 billion dirhams), settling structures (3.1 billion dirhams), and other auxiliary facilities (2.5 billion dirhams).

The capital expenditure breakdown reveals that the conveyance infrastructure represents the largest portion of the investment at 59%, followed by pumping facilities at 23%, which highlights the significant energy requirements for moving water across watershed boundaries and elevations. The settlement structures, essential for maintaining water quality during transfer, account for 10% of the project cost, while remaining auxiliary facilities represent 8%.

*Operational costs and unit water cost*

Our economic analysis examined the long-term operational costs of the water transfer project. Annual maintenance expenses were estimated at 470 million dirhams, including routine infrastructure maintenance, equipment replacement, and technical staff salaries. Energy consumption for pumping operations constitutes the most significant operational expense, estimated at 825 million dirhams annually based on current electricity rates and projected pumping requirements.

The calculation of the cost per cubic meter ($m^3$) of transferred water incorporated these capital and operational expenses distributed over the project's expected 50-year lifespan, with an annual transfer capacity of 500 million $m^3$. The resulting estimation settled at 7.6 Moroccan dirhams per $m^3$ (DH/$m^3$). This unit cost breaks down into 3.1 DH/$m^3$ for capital cost amortization, 1.7 DH/$m^3$ for maintenance, and 2.8 DH/$m^3$ for energy requirements.

*Economic comparison with alternative water sources*

This cost stands relatively high in comparison to the general price of locally produced water in Morocco, which typically rests at 4 DH/$m^3$. However, given the widespread water scarcity affecting many regions in the country, water sector administrators are inclining towards relatively more costly alternatives.

For comparative analysis, we examined other water supply options currently implemented in Morocco. The Agadir desalination plant, implemented in 2021, produces water at 8 dirhams per $m^3$. Other recent desalination projects show similar costs: the Laayoune plant (7.9 DH/$m^3$) and the planned Casablanca facility (estimated at 8.4 DH/$m^3$). Traditional groundwater extraction in the recipient region costs approximately 3.5–4.5 DH/$m^3$, but this source faces severe depletion risks and declining quality that makes it unsustainable as a long-term solution.

*Cost-benefit analysis*

Our comprehensive cost-benefit analysis quantified several key economic benefits of the project. The primary benefit derives from agricultural productivity improvements in the recipient Moulouya basin. With 500 million $m^3$ of additional water annually, approximately 75,000 hectares of agricultural land will receive improved irrigation, generating an estimated annual benefit of 1.8 billion dirhams in increased agricultural output based on current crop values and productivity differentials between irrigated and rain-fed agriculture.

Domestic water supply benefits were calculated based on the improved reliability and quality of water supply to approximately 2.3 million residents in the recipient basin. Using willingness-to-pay methodologies, these benefits were valued at 950 million dirhams annually.

Additional quantifiable benefits include reduced flood damage mitigation in the donor basins (estimated at 180 million dirhams annually), hydropower generation at dam sites (providing energy valued at approximately 270 million dirhams annually), and recreational and tourism benefits around the new reservoirs (estimated at 120 million dirhams annually).

*Economic viability indicators*

Based on these costs and benefits, and applying a social discount rate of 6% over the 50-year project lifespan, the calculated Net Present Value (NPV) is 8.2 billion dirhams, indicating positive economic returns. The Internal Rate of Return is estimated at 9.4%, which exceeds the standard threshold (typically 6%–7%) used by the Moroccan government for major infrastructure investments.

Sensitivity analysis revealed that the project maintains positive NPV even with a 20% increase in construction costs or a 15% reduction in benefits. The most sensitive variable is the agricultural productivity increase, where benefits would need to decrease by more than 30% to render the project economically unviable.

Therefore, considering these economic comparisons and analysis, the BM-MV WTP demonstrates economic acceptability and justifiable investment returns, particularly given the critical water scarcity conditions facing the recipient regions and the limited alternatives for large-scale water supply enhancement.

**Criterion No. 4: Social Impacts**

Our systematic assessment of social impacts, following the 11-step methodological framework, revealed substantial effects of the BM-MV WTP project on local communities. The projected reservoirs will directly affect 150 dwellings housing approximately 770 residents across the three dam locations of Beni Mansour, Bouhmed, and Dar Mimoun. These communities will experience significant disruption as the reservoirs will inundate 1760 hectares of land, with 985 hectares (56%) comprising productive agricultural lands that currently serve as the primary livelihood source for most affected households.

Beni Mansour emerges as the most severely impacted area, with the planned reservoir covering 1015 hectares and affecting 83 dwellings with 386 inhabitants. This site also faces the greatest agricultural land loss at 482 hectares, contributing to its high estimated financial impact of 270 million dirhams. Bouhmed follows with 400 hectares of reservoir area affecting 55 dwellings (314 inhabitants) and 253 hectares of agricultural land, with financial losses estimated at 150 million dirhams. The smallest impact occurs at Dar Mimoun, where 345 hectares of reservoir area will affect 12 dwellings (70 inhabitants) and 250 hectares of agricultural land, with projected losses of 130 million dirhams.

Our stakeholder engagement process identified additional affected infrastructure critical to community functioning, including 17 collective wells, 3 fountains, 5 mosques, 2 schools, 20 km of path road, and 3 cemeteries distributed across the impact zones. The total financial estimate for all losses, encompassing dwellings, agricultural lands, and infrastructure, amounts to approximately 550 million dirhams (Table 6).

Through risk assessment and policy review, it is confirmed that the displaced population qualifies for compensation and resettlement arrangements. The community consultations revealed that 84% of respondents prioritize maintaining community cohesion, with strong preferences for resettlement in close proximity to their original lands. This approach would minimize disruptions to their natural surroundings, socio-cultural patterns, and economic activities, addressing a key vulnerability as approximately 65% of affected households depend primarily on agricultural activities.

Our analysis also identified potential positive impacts that could partially offset the disruptions. The affected communities stand to gain from potential tourist attractions that might develop around the future reservoirs, creating alternative revenue streams. Additionally, the construction of the projected dams will enhance drinking water supply to neighboring populations and possibly improve irrigation in downstream areas. The transfer of approximately 500 million $m^3$ per year to the Moulouya basin will provide significant benefits to that region by addressing both drinking water and irrigation needs, potentially contributing to broader socio-economic advancement.

Based on our comprehensive assessment, we recommend implementing additional interventions and mitigation measures beyond basic compensation, including establishing new community infrastructure, developing alternative livelihood programs, and ensuring that water access benefits are shared equitably. We propose quarterly monitoring of resettlement outcomes for at least three years postimplementation to ensure continuous evaluation and adaptation of social impact management strategies.

**Table 6.** Summary of the BM-MV WTP social impact.

| Projected dams | Beni Mansour | Bouhmed | Dar Mimoun | Total |
|---|---|---|---|---|
| Reservoir area (ha) | 1015 | 400 | 345 | 1760 |
| Number of dwellings | 83 | 55 | 12 | 150 |
| Number of inhabitants | 386 | 314 | 70 | 770 |
| Area of agricultural lands (ha) | 482 | 253 | 250 | 985 |
| Financial estimate of losses (million dirhams) | 270 | 150 | 130 | 550 |

**Criterion No. 5: Technical feasibility**

Concerning the studied project scheme, the designers have proposed considering some key factors [42]. Firstly, identify a route corridor that would optimize topographical, geological, and environmental conditions. Additionally, evaluate the choice of structure type (such as pipelines or galleries) based on right-of-way constraints, geological conditions, and operational demands. Also, minimize the cumulative pumping heights for the transfer project. Moreover, for sections using galleries, there was a recommendation to reduce the potential karstic limestone cover to mitigate the influx of high-pressure water, which can be challenging to manage.

According to the project design [42], the hydraulic structures are intended to transfer a flow rate of 20 $m^3$/s. Given the elevation difference between the starting point (53 m) and the destination (230 m), which amounts to 177 m, the use of pumping stations is inevitable. Following the most optimal route variant, four pumping stations are planned, along with 84 km of galleries (36%) and 178 km of pipelines (64%). For a flow rate of 20 $m^3$/s, the transfer can be achieved either through two pipelines with a diameter of 2.5 m each or through a single gallery with a diameter of 4.5 m. As for the pumping stations, the designers have opted for stations equipped with five pumps, each capable of pumping 5 $m^3$/s.

It should be noted that Moroccan water managers have accumulated significant experience in interbasin water transfers. Approximately ten major water transfers have already been commissioned, primarily to supply drinking water to large cities from reservoirs. The latest mega project, with its initial phase inaugurated in August 2023, consists of the interconnection of three dams: Garde Sebou (Sebou Basin), Sidi Mohammed Ben Abdellah (Bouregreg Basin), and Almassira Dam (Oum Rbia Basin), covering a total length of 265 km. In this regard, undertaking projects of this nature in Morocco is not new. Nevertheless, drawing on the lessons learned from these experiences, it is advisable to consider certain recommendations. Firstly, integrate renewable energy solutions, such as solar or wind power, into the pumping infrastructure in order to reduce the environmental footprint of the project. These sustainable energy sources not only reduce electricity consumption but also offer long-term cost savings through reduced reliance on traditional energy grids. Furthermore, adopting smart water management systems equipped with advanced monitoring and control technologies enhances the agility and resilience of the transfer scheme. Real-time data collection and analysis can optimize water distribution, respond to changing demand patterns, and mitigate potential disruptions, thereby ensuring efficient and reliable operation. Also, adopting eco-friendly construction methods for structures and tunneling can significantly reduce the project's environmental impact. This might involve using sustainable building materials, minimizing soil disturbance, and employing tunnel boring machines that produce fewer emissions and have lower ecological footprints. Additionally, to prevent sedimentation within the transfer structures, it is crucial to implement sediment control measures. This can include the use of sediment basins, erosion control practices, and regular maintenance to remove sediment buildup. Moreover, maintaining flexibility in the design and operation of the transfer system is crucial. Anticipating future changes in water demand, climate conditions, and regulatory requirements ensures the scheme's adaptability over time.

**Criterion No. 6: Climate Change Resilience**

Regarding the studied project, climate change presents a substantial challenge for North Africa, impacting and interacting with various environmental and anthropogenic systems in this region. According to Schilling et al. [54], the rainfall in North Africa is expected to decrease by 10% to 20%, and temperatures will experience an increase of 2 to 3℃. These phenomena will be more pronounced as one moves westward, (Especially toward Morocco). Numerous studies and research indicate Morocco has experienced a significant warming trend over the past few decades, accompanied by a notable increase in the frequency and intensity of extreme events such as droughts and floods, has been observed [54–58]. The circulation models predict that this warming trend should persist in this region and may even intensify in the coming decades. In the study area, climate projections anticipate a temperature increase of 1.7 to 2℃ and a decrease in precipitation of 12% to 16% according to the Representative Concentration Pathway (RCP) 4.5 scenario.

According to the The Integrated Water Resources Master Plan in the Moulouya Basin, the assumptions regarding climate change for estimating the evolution of water resources by 2050 consist of a 15% decrease in precipitation, as a result, a 25% reduction in surface water inflow, and a 10% increase in evaporation due to rising temperatures. As for the donor basin (Laou), precipitation is expected to decrease by 10%, groundwater resources will also see a 10% decline. Regarding surface water inflow, the reduction in inflow over the past 44 years (1972–2016) compared to the longer 71-year series (1945–2016) varies from 12% to 15%. The demand for irrigation water is projected to increase by 10% [50]. Overall, the reduction in water resources is attributed to decreased precipitation and rising temperatures.

These factors lead to decreased river flows, reduced recharge of groundwater aquifers, and early snowmelt in mountainous areas.

According to the information mentioned above, studies conducted on the project have taken into account the impact of climate change on water resources, and the increasing water demand. The calculation assumptions regarding this impact align with the aforementioned research estimates. However, it is recommended, in addition to the proposals mentioned above, to develop hydrological models for the various basins involved in this project. These models should be coupled with a water transfer management model, testing various climate scenarios, both optimistic and pessimistic. Additionally, it is important to adopt a flexible and dynamic management mode to enhance the project's adaptability and resilience. Furthermore, the integration of other reservoirs into the transfer scheme (such as the Rhiss and Abdelkrim El Khattabi dams) would be highly desirable. This would maximize the interconnection of dams across different climatic contexts and provide greater flexibility in water transfer management according to the local supply and demand conditions.

**Criterion No. 7: Legal and Regulatory Considerations**

The water transfer project under consideration is not cross-border, which already facilitates its harmonious management and helps prevent discrepancies and overlaps in water sector laws and regulations, as well as potential conflicts with neighboring countries.

Furthermore, Morocco possesses a powerful legal and institutional framework for water resource management. From a legislative perspective, Morocco's water sector is governed by Law 36-15 on water, which is based on fundamental principles including the public domain status of water, the right of all citizens to access clean water and a healthy environment, water management following good governance practices that involve consultation and participation of various stakeholders, integrated and decentralized water resource management while strengthening spatial solidarity, natural environment protection, and the promotion of sustainable development.

Additionally, the main document outlining the country's strategic directions for water management is the National Water Plan. In its current version, this plan recommends the interconnection of surplus and deficit basins, notably Sebou-Bouregreg-Oum Errbia and Loukkos-Moulouya.

On the institutional framework, the Ministry department responsible for water in Morocco is the General Directorate of Hydraulic. This entity is primarily tasked with research, assessment, planning, and water resource management. As water management in Morocco operates at the watershed level, the organizations responsible for this mission are the

Hydraulic Basin Agencies through the preparation and implementation of the The Integrated Water Resources Master Plan for each basin. It is important to note that the latters of the Loukkos and Moulouya provide for the interconnection of certain dams belonging to these two basins, in view of promoting regional solidarity and optimizing the use of water resources.

It's important to note that Water Transfer Systems, whether within the same basin or between two basins, are not a recent development in Morocco. Since the 1960s, several Water Transfer Systems have been implemented to provide drinking water to urban areas and support irrigation in agricultural regions using water from dams. These hydraulic systems involve the use of pipes, tunnels, and canals, covering distances of several tens of kilometers. The volume of water transferred varies based on the scale of the project, ranging from a few cubic meters per second ($m^3/s$) to more than 40 $m^3/s$.

For instance, the water transfer between the Sidi Mohammed Ben Abdellah dam and Casablanca city ensures the provision of drinking water to all towns situated between Rabat and Casablanca, drawing water from the Sidi Mohammed Ben Abdellah dam. This water transfer spans 80 kilometers and operates through three pipes with a transfer rate of 4 to 5 $m^3/s$.

Another example is the water transfer from the Oum Errbia basin to the Tensift basin, aimed at addressing the water demand-supply imbalance in the Tensift basin. This transfer is carried out from the Sidi Driss dam (Oum Er Rabia basin) through the Rocade canal, covering a distance of 120 kilometers. The volume transferred is estimated at 300 million $m^3$/year, supporting irrigation in the Central Haouz area (260 million $m^3$/year) and providing drinking water to Marrakech city (40 million $m^3$/year) at a rate of 20 $m^3/s$.

The third example involves the water transfer between Allal El Fassi and Idriss 1 dams. To manage excess water from the Allal El Fassi dam-reservoir (63 million $m^3$) to the Idriss 1 dam-reservoir (1.130 million $m^3$), the Matmata gallery, connecting the two reservoirs, was constructed, spanning a total length of 16 kilometers. The entrance structure comprises three inlet sluices, followed by a guard valve and a segment valve. The gallery maintains a straight layout up to the compensation basin, featuring a finished internal diameter of 4.50 m, facilitating a maximum flow of 38 $m^3/s$. The annual volume transferred is estimated at 600 million $m^3$ [43].

As mentioned in the previous section, Morocco is currently executing a large-scale project that aims to interconnect three dams situated in different basins. The project's design incorporates the utilization of six pumping stations. In the initial phase, which has already been completed, two pumping stations have become operational. These stations have the capacity to pump water at a rate of 15 $m^3/s$, with the potential for expansion up to 30 $m^3/s$. This underscores the fact that Morocco's legislative and institutional framework not only authorizes but also provides the necessary provisions for the successful implementation and effective management of such projects.

## CONCLUSIONS

Water scarcity and reduced reliability of water resources have become increasingly pronounced worldwide, driven by factors such as population growth, economic development, inefficient water management systems, and the effects of climate change. Morocco is no exception to this trend. The country's water resources are characterized by their scarcity and the irregular distribution of water in both space and time, putting them under growing stress. In a spirit of interregional solidarity, the Moroccan Department of Water has opted for the transfer of surplus water from the Laou Basin to the Moulouya Basin, which is experiencing a growing deficit. This project involves transferring a volume of 500 million $m^3$/year of water from three planned dams in the Laou Basin to the Moulouya Basin, where the Mohammed V dam, currently undergoing elevation, is located. The total distance of the route spans 242 kilometers, with an estimated total cost of 31.3 billion dirhams.

This paper has cited the criteria and approaches proposed by various researchers to assess interbasin transfer projects. A close examination of those criteria reveals some convergence as well as a gradual trend toward the concepts of sustainability, governance, and agility of the transfer system management. In this work we have gathered the seven most significant aspects namely justification of the real need, ecological and social impacts, resilience of the IDRS to climate change, economic viability, legal and regulatory considerations, and technical feasibility. This holistic approach provides a comprehensive framework for assessing and managing water resources, leading to better-informed decision-making and sustainable water management practices.

Initially, this paper proposed a methodology to address each of the proposed criteria. Subsequently, an assessment was conducted to determine the extent to which these criteria were considered in the BM-MV WTP related studies.

The results indicate a genuine need for the implementation of this IDRS in Morocco, and its economic viability is affirmed. The assessments of social and environmental impacts reveal no significant negative repercussions; however, we have recommended measures to enhance social and environmental aspects. Additionally, suggestions were put forth to enhance the completeness of the technical feasibility studies. The project's investigations encompass an examination of the impact of climate change on water availability and the increasing water demand. Nonetheless, it is recommended to develop hydrological models for each of the project's basins. These models should be integrated into a water transfer management model to evaluate various climatic scenarios. Moreover, adopting a flexible and dynamic management approach is crucial to improve the project's adaptability and resilience.

The research outcomes hold substantial significance for interbasin water transfer projects on a global scale. Numerous forthcoming schemes are planned for regions already experiencing water scarcity or in countries with less-established governance systems. Inadequate justifications for these extensive water transfers could result in severe consequences for the affected areas, exacerbating water stress and adversely affecting the livelihoods of countless individuals. The assessment framework devised in this study stands as a valuable resource, promoting transparency and inclusivity in the evaluation of proposed IBWT projects worldwide.

## DATA AVAILABILITY

The dataset of the study is available from the authors upon reasonable request.

## AUTHOR CONTRIBUTIONS

Conceptualization, SS and DL; Methodology, SS, DL and OL; Formal Analysis, SS and DL; Writing—Original Draft Preparation, SS; Writing—Review & Editing, SS, DL and OL; Supervision and Validation, DL.

## CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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