Multi-Criteria Decision-Making (MCDM) Tools for Hydrological Analysis

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Abstract

Water resource management is an important but difficult undertaking due to the unpredictable nature of hydrological processes. Multi-Criteria Decision-Making (MCDM) tools provide a formal framework for assessing and ranking management solutions based on a variety of criteria. This study examines the role of MCDM tools in hydrological analysis, focusing on their advantages, methodology, and applications. In hydrology, MCDM is used to allocate water resources, manage flood risk, drought, and water quality, while balancing effectiveness, cost, and environmental impact. Data availability, stakeholder engagement, and connection with hydrological models are among the challenges. Future developments in data collection and user-friendly MCDM software will broaden their application. Integrating MCDM with adaptive management and participatory planning will enhance its ability to address complicated hydrological concerns. Finally, MCDM technologies enable educated and balanced decision-making, encouraging long-term water resource management by taking into account a variety of criteria and stakeholders' preferences.

Introduction

Since water resource management affects both human livelihoods and environmental sustainability, it is a major concern in many parts of the world. Understanding hydrological processes is a difficult task since these processes vary spatially and temporally and are affected by numerous factors at a single time. So, for effective management of the water resource and balancing many outcomes of the hydrological process at once, decision-making becomes prerequisite. Herein lies the application of Multi-Criteria Decision-Making (MCDM) tools. These tools offer an organized framework for ranking alternative management options according to different standards. The present paper delves into the function of MCDM tools in hydrological analysis, emphasizing their advantages, approaches, and uses.

The Need for MCDM in Hydrological Analysis

The study of the occurrence, distribution, flow, and quality of water in the environment and its interaction with other environmental parameters is known as hydrological analysis. Planning for water resources, managing flood risk, and protecting the environment are some of the examples where this approach is extensively used. On the other hand, choices in hydrology can entail intricate trade-offs between social, environmental, and economic aspects and decision-making becomes necessary. For example, building a dam could produce hydroelectric power and supply water for irrigation, but it could also uproot residents and disturb ecosystems. So, at a time decision should satisfy all the stakeholders without compromising their concerns, but it is difficult owing to the fact that many factors to be concerned. We use decision-making tools to sort out this problem.

However, due to their tendency to concentrate on single-objective optimization, traditional decision-making techniques might not be effective in these kinds of situations. Multi-Criteria Decision Making (MCDM) tools, on the other hand, enable the simultaneous analysis of many criteria, offering a more thorough assessment of possible solutions. The integration of MCDM into hydrological analysis facilitates a well-rounded approach that is consistent with the objectives of sustainable development.

MCDM Methodologies

Multi-criterion Decision-Making (MCDM) technologies are used to make the best selection from several alternatives with conflicting and incompatible criteria. The technique is often used to solve difficult real-life situations by evaluating alternatives based on numerous decision criteria and selecting the optimal option.

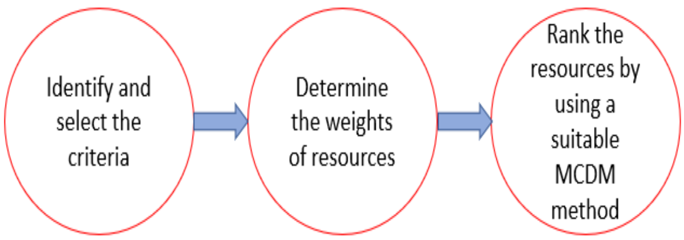

Fig 1. Steps of MCDM

Some of the examples of MCDM tools are Analytic Hierarchy Process (AHP), Weighted Sum Model (WSM), Weighted product model (WPM), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), VIKOR, PROMETHEE, ELECTRE, and Multi-Attribute Utility Analysis (MAUA), Multi-Attribute Utility Theory (MAUT).

Commonly used MCDM methods in hydrological analysis are listed below:

1. Analytic Hierarchy Process (AHP): Analytical hierarchy process (AHP) evaluates numerous factors based on performance and expert opinion (Vahidnia et al. (2009); Rajasekhar et al. (2019)). This strategy divides the choice problem into a hierarchy of criteria and sub-criteria. Decision-makers then use pairwise comparisons to apply weights to each criterion, allowing alternatives to be ranked according to their overall scores.

2. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS): This technique prioritizes the alternative that is farthest from an anti-ideal option and closest to an ideal point (Shih et al. 2007). The alternatives are ranked according to their relative closeness to this ideal solution.

3. Multi-Attribute Utility Theory (MAUT): MAUT/MAVT is an expected utility theory that involves assigning a utility to each conceivable outcome and determining the best possible value. Unlike most MCDM approaches, it has the advantage of accounting for uncertainty by giving a utility value to it (Hester et al. 2013). This method allows for the incorporation of decision-makers' risk preferences.

4. Elimination and Choice Expressing Reality (ELECTRE): ELECTRE is a family of outranking methods that compare alternatives based on pairwise dominance relationships. The non-compensatory multi-attribute decision making (MADM) ELECTRE technique compares alternatives while taking into account specific criteria (Taherdoost et al. 2023). It is particularly useful for dealing with qualitative and imprecise data.

Each of these methods has its strengths and limitations, and the choice of method depends on the specific context and requirements of the decision problem.

Application of MCDM in Hydrological Analysis

MCDM tools have been used to solve a wide variety of hydrological decision-making problems. Some prominent applications are:

1. Water Resource Allocation: In areas with limited water resources, MCDM methods can assist in allocating water among various users (e.g., agriculture, industry, and home usage) in a way that maximizes overall benefits while taking into account social equality and environmental sustainability.

2. Flood Risk Management: MCDM methods can help assess and prioritize flood mitigation measures such as levee construction, floodplain zoning, and early warning systems. These tools allow decision-makers to weigh the costs and advantages of each intervention, accounting for aspects such as effectiveness, cost, and environmental impact.

3. Drought Management: During droughts, MCDM methods can help establish strategies for water conservation, demand management, and emergency response. These techniques contribute to the effectiveness and equity of drought management plans by taking into account numerous parameters.

4. Water Quality Management: Ensuring water quality is critical for both ecosystem health and human well-being. MCDM tools can assess the effectiveness, cost, and environmental impact of various water treatment solutions, pollution control measures, and land-use policies.

Challenges and Future Directions

While MCDM methods have numerous benefits, their use in hydrological analysis is not without obstacles. This includes:

1. Data Availability and Quality: Reliable data is required for accurate MCDM analysis. In many circumstances, data on hydrological and socioeconomic aspects may be sparse or ambiguous, affecting the reliability of the conclusions.

2. Stakeholder involvement: Diverse stakeholders, such as local communities, policymakers, and specialists, must be included in order to make effective decisions. Ensuring meaningful engagement and consensus building can be difficult, but it is critical for decision acceptability and implementation.

3. Integration with Hydrological Models: By combining MCDM techniques with hydrological models, decision-makers can gain a more complete understanding of water systems. However, this integration necessitates considerable technical expertise and interdisciplinary teamwork.

Future developments in data gathering technology, such as remote sensing and geographic information systems (GIS), will improve the quality and availability of data for MCDM research. Furthermore, developing more user-friendly MCDM software and solutions would make them more accessible to a wider range of stakeholders. Integrating MCDM with new approaches such as adaptive management and participatory planning will increase its effectiveness in addressing complex hydrological concerns.

Conclusions

MCDM technologies offer a useful foundation for making educated and balanced hydrological decisions. These tools contribute to the effectiveness and sustainability of water resource management methods by taking into account different criteria and stakeholder preferences. In future, these tools with a better understanding of the hydrological processes and their applicability is going to solve diverse problem in the field of hydrology.

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