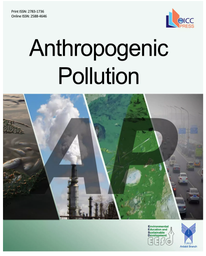

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Evaluation of criteria affecting pollution reduction and sustainable management of water resources using the Flood Hazard Zoning approach (A case study: Goharrood River, Iran)

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Abstract:

The present study aimed to evaluate the criteria affecting sustainable water resources management in the Goharrood River Basin (Rasht City, Gilan Province, Northern Iran) through the Flood Hazard Zoning approach to identify major flood occurrence centers and optimal flood dam location. Criteria and sub-criteria were identified using a Hierarchical Structure and prioritized based on Pairwise Comparison, Analytic Hierarchy Process (AHP) and Expert Opinions. Zoning was also done through Geographic Information System (GIS). The results showed that economic (weight value (WV) = 0.608) and technical (WV = 0.229) criteria were in first and second priority, followed by environmental and social criteria with weight values of 0.112 and 0.051, respectively. Moreover, the sub-criteria of cultivation pattern (WV = 0.539), welfare level (WV = 0.536), demand rate (WV = 0.583) and water conservation (WV = 0.521) were preferred in the management of Goharrood river water resources. Based on the findings, the eastern part of the river basin had a higher potential for flooding. Therefore, three main centers were identified as important locations for the construction of flood barriers. Construction of flood dams can control future floods and prevent environmental pollution and reduction in the quality of surface and groundwater in the study area.

Keywords: Water resources; Sustainable management; Flood Hazard Zoning; Goharrood River

1. Introduction

Today, the main objectives in water resources management include the use, development, protection, management, and control of water resources efficiently and sustainably in order to achieve development priorities equitably (Afzali and Shahidi, 2015). Accurate prediction of basin response to precipitation and knowledge of the water balance of watersheds are essential for effective use of water and soil resources. According to the Organization for Economic Co-operation and Development (OECD, 2012), and also the predictions made, water demand will increase up to 55% by 2050. During this period, consumption in the industrial, electricity generation, and household sectors will have the highest increase rates of 400, 140, and 130%, respectively, while consumption in the agricultural sector will decrease by 14% (Ozlem, 2022). If government policies and investment requirements are not strengthened to support the water sector, the water crisis will lead to worsening water services for millions of people, shrinking agricultural land, reduced food production, rapidly rising food prices, and declining per capita food consumption. Lack of attention to technological development, water resource conservation, and policy reforms may increase water demand for non-agricultural uses even faster than anticipated, which will worsen the situation of water resources and exacerbate the water crisis (Rahimi, 2013). If current trends continue, the share of the world's population facing "extreme water stress" will increase from 26.2% in 2000 to 42.4% in 2050, and the number of people experiencing "extreme water stress" in

2050 will reach about 3.9 billion (Singh and Saravanan, 2020). According to the OECD report, although access to safe drinking water is expected to increase globally in the coming decades, nearly 300 million people will still lack access to safe drinking water by 2050 (Eini et al., 2021). On the other hand, under the influence of population growth exceeding the growth of cultivated land, per capita arable land in various regions of the world will decrease by 2050, from 0.25 hectares per person in 2010 to less than 0.18 hectares in 2050. Under the influence of population explosion, growth in per capita consumption, and the stability of renewable water resources, the annual withdrawal of freshwater resources (surface and groundwater) relative to total renewable water resources will continue to increase by 2050. It is expected that the Middle East and parts of Africa, the Americas, and Southeast Asia will be in a state of high water stress by 2050 (Dutta and Sarma, 2021).

Freshwater resources extracted from rivers, lakes, and groundwater are renewable resources whose renewal process is subject to the water cycle in nature. This amount of water on the surface of the earth is certain and constant regardless of interannual variations. However, the spatial and temporal distribution of renewable water does not correspond to the distribution of population and human water needs. In general, freshwater accounts for only about 2.5% of the total water volume in the world. For example, Asia, with 60% of the world's population, uses only 36% of renewable water resources (Khiabani et al., 2017). On the other hand, drought and the destructive effects of human activities on the environment have presented serious challenges to the use of freshwater resources. Following population growth and increasing levels of prosperity related to water needs, the use of these finite fixed water resources has led to a sharp increase in per capita water consumption, such that global water consumption is rapidly approaching the limit of the amount of water available from the world's renewable water resources (Friesen et al., 2017). Therefore, water consumption and demand management policies in this regard, while ensuring the interests of consumers, should be adjusted towards a consumption pattern that is appropriate to natural, economic, and social conditions with the aim of optimal use of water. Therefore, one of the main pillars of water management and sustainable development is the optimal exploitation of water resources and preventing the waste of renewable resources (Hirji and Davis, 2010).

Sustainable development refers to a movement based on the human-environment axis and considers the development of economic opportunities with regard to environmental considerations and social justice (Ayala and Juízo, 2011). Water resources management is the planning, development, distribution, and management of the optimal use of water resources. This management is a subset of water cycle management. Water resources management planning seeks to allocate water equitably to meet needs. In fact, water resources management makes great efforts to optimize water consumption and reduce its environmental impacts on nature. Optimal management of water resources can increase water quality and quantity and make the region livable (Mou Leong et al., 2017). In the current situation, the proper and efficient management of water resources has in fact become a transdisciplinary issue, and it is impossible to achieve fundamental development goals such as poverty eradication and environmental protection without paying close attention to the issue of water resources management. On the other hand, the drought phenomenon is a threat that is exacerbated by increasing demand for water and imposes many negative effects on human societies and the environment (Faqih Abdulahi and Aufi, 2012).

In this regard, Zheng et al. (2022) examined the need to reform the urban development management system with regard to the quality assessment of the Li River. In this study, some of the most important strategies and solutions for reforming the urban development management system were briefly introduced based on the strategic planning paradigm and data from previous studies. They showed that in addition to various managements including the municipality, urban development, and technical companies including technical and engineering companies involved in urban planning, the potential of urban structure and natural factors such as maintaining the water quality of the Li River had a direct and significant impact on the implementation of sustainable urban development. Ozlem (2022) examined solutions for improving and revitalizing river areas in the city of Ankara, Turkey, and considered the revitalization and renovation of these areas as a spatial strategy to give identity to the residents of these areas and increase the facilities needed by citizens. Saya et al. (2022) examined the sustainability factors in making urban areas livable with the influence of water resources management. The results indicated that livability must be able to change and evolve in order to adapt to different conditions. These densely populated areas needed more attention, and while maintaining the quality of water resources, emphasis should be placed on the sustainable development of the region's ecosystem by creating green design.

Some of the most important challenges related to water resources in the supply sector include a decrease in precipitation compared to the long-term trend, a decrease in the volume of surface water flows compared to the long-term trend, excessive exploitation and depletion of groundwater resources, lack of efficient management of wells, the condition of plains as an indicator of water crisis, asymmetric regional distribution of water resources and precipitation, control of surface water through dam construction, and the release of industrial, agricultural, and urban wastewater. Some of the challenges related to water demand include low water productivity in the agricultural sector, the structure of the ownership system in the agricultural sector and its impact on water productivity, population growth and demand for water resources, drinking water and sanitary water consumption, and industrial use (Mohammadjani and Yazdanian, 2013).

The main problems facing the city of Rasht include the lack of livability of a city on the banks of the Goharrood River, population density without the necessary productivity, the growth and expansion of the compact city without considering the factors driving development, the lack of economic, social, and environmental sustainability, the lack of water resources of the required quality, the lack of proper productivity of water resources, and the failure to maintain the conditions of the Goharrood River ecosystem. Goharrood River is actually one of the important sources of water supply for various uses, including agriculture, drinking, and industry (Komasi and Gudarzi, 2013), and has always been of interest in Gilan Province since ancient times, and therefore large industrial and commercial centers have been established around this river (Izadi et al., 2022). Water consumption has increased significantly in Gilan Province today due to population growth, improved health and public welfare, industrial expansion, and promotion of economic and agricultural activities. Water resource management in Gilan Province has become a very complex and important issue due to the decline in water quality and supply-demand imbalance (Khayami et al., 2019). Therefore, the correct application of water resources engineering and management approaches, along with the equitable water distribution law, will solve many of the issues of Goharrood River engineering and water resources management in the province (Mahmoudi, 2012).

The Goharrood River, which originates from the Lakan Mountains, is one of the main rivers in Rasht. In the past, this river was used as a sightseeing and fishing spots, and also provided water for agriculture and irrigation of fields along its course (Sardarshahraki and Bazrafshan, 2018). The reduction in the water flow of river along its course due to ever-increasing harvests and the discharge of urban, industrial, and agricultural wastewater has jeopardized the condition of the river (Meftah, 2017). Accordingly, the present study was conducted to evaluate the factors affecting sustainable water resources management in the Goharrood River basin in Rasht city. In this study, the zoning technique was used to identify flood hazard areas. The main question of the research was which components could be introduced as influential factors and how were they prioritized based on the sustainable development approach and with the aim of avoiding contamination of the freshwater resources of this basin?

2. Materials and methods

2.1 Study area

Goharrood River is one of the two rivers of the city of Rasht, which originates from the heights upstream of Azizkian village, located 15 km south of Rasht. After entering the city, it joins with another river of the city, the Zarjoob River, forming the Pirbazar River, and exits from the north of Rasht and ultimately flows into the Caspian Sea and Anzali Wetland (Bagherzadeh et al., 2000). Although the construction of dams has been revised and outdated today due to environmental impacts on many countries, especially developed ones, and the dismantling of dams has created a new perspective for preserving the river ecosystem and sustainable development, unfortunately, with the completion of the dam studies in the upstream of the Goharrood River, there is a threat to the river that is completely dried or converted into a sewage canal. Despite the announcement of the Environmental Protection Organization of Iran (2014) opposing the construction of this dam, which will lead to the drying up of this urban river, water resources officials in Gilan province announced that they are still pursuing the construction of this small dam and the destruction of the environmental image of the city of Rasht (Ehteshami and Akrami, 2018). This river was once considered one of the most scenic places in Rasht and was also used for fishing. However, today, this river has been polluted by the entry of wastewater and the transfer of these pollutants to the Anzali Wetland, creating an unpleasant urban appearance and has become a sewage transfer channel. In the summer, hospital wastewater is also visible due to lack of rainfall and has caused dangerous consequences, including skin and infectious diseases, for farmers along the riverbank. This province is one of the high-risk provinces in terms of water pollution (Salehpour et al., 2017). Currently, this situation is not being addressed, the wildlife of this river has been completely destroyed and no action is being taken by the Environmental Organization, and the river flows into the Anzali Wetland on its way, polluting the sea. Among the prominent animal species of this region are the heron, heron, catfish, mink, water snake, carp, whitefish, marsh otter, hedgehog, shrew, and fox. Figure 1 shows the land use map of the study area. Table 1 shows the distribution and percentage of land use in the study area.

2.2 Methodology

This analytical-applied research was conducted in order to reduce pollution and manage water resources with a sustainable development approach. Data were collected through library study and review of research background. This research was conducted between 2023 and 2024. Baseline data were obtained from the Environmental Protection Agency and the Meteorological Department of Guilan Province. Since the approach of this research was based on the principles of sustainable development, the data were categorized based on the four principles of sustainability and in accordance with the World Bank guidelines (2020). Thus, the environmental, economic, social, and technical criteria were used as the basis for decision-making, and then sub-criteria were identified. In-depth survey was used to determine the sub-criteria. The method of data analysis was also the use of expert votes. The main tool of decision-making and prioritization was the Analytic Hierarchy Process (AHP), which identified factors affecting sustainable management of water resources in the Goharrood River Basin. The AHP is a flexible, robust, and simple method used for decision making in situations where conflicting decision criteria make it difficult to choose between alternatives (Bertolini and Braglia, 2006). Table 2 shows the scoring method for the pairwise comparison method.

Figure 2 shows the hierarchical structure of the research and the identified criteria and sub-criteria. The research team consisted of 22 experts in the fields of water resources management, environmental and natural resources management, and engineering, who had a good work background and sufficient knowledge of the study area.

Since achieving a balance between human water needs and environmental water needs is an important step in the sustainability of water resources, in this study, in line with the water resources management based on a sustainable and

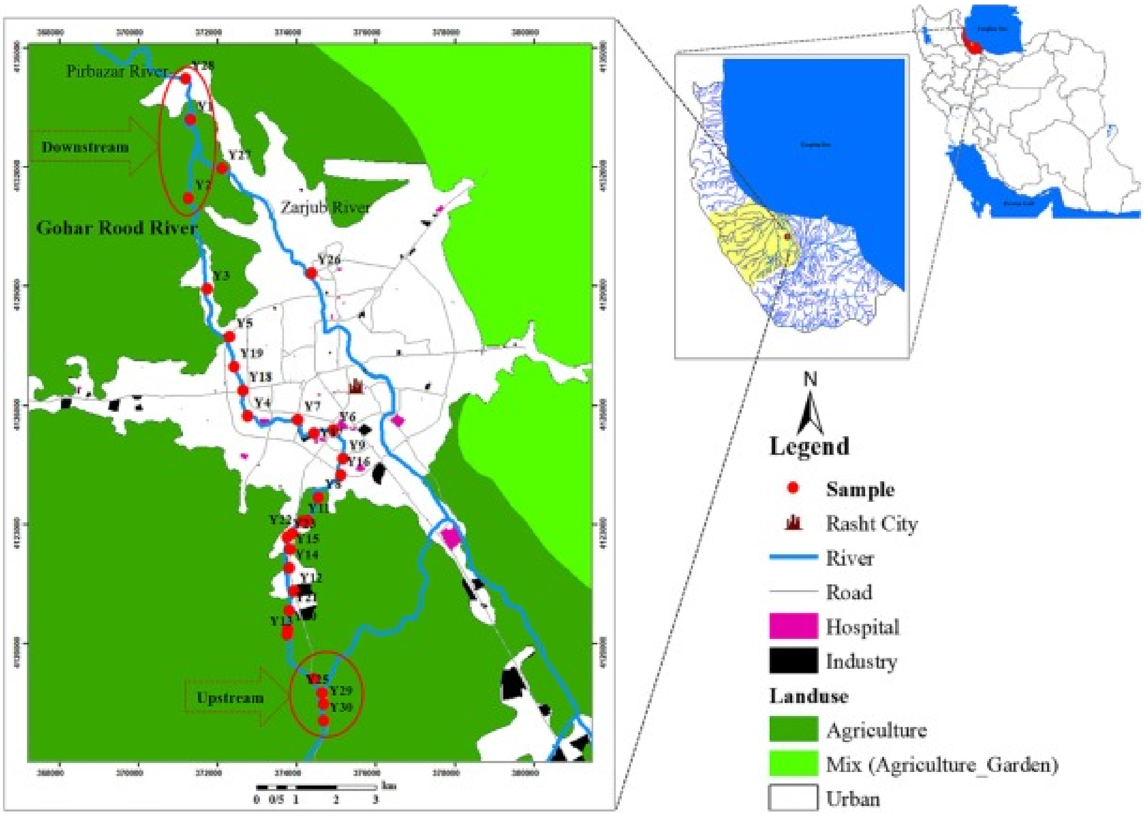


Figure 1. Landuse map of the study area.

livable development approach in the study area, the flood hazard assessment and zoning were used to provide a solution for optimal location for creating flood barriers and controlling surface waters. For this purpose, Geographic Information System (GIS), overlay technique, and ArcGIS 10.3 software were used to minimize the damages caused by floods and surface runoff and take effective steps to control, collect, and conserve this surface runoff in order to increase the quantity of water resources in the province and the study region. Initially, the required geographic layers were prepared in order to locate the optimal site for constructing a flood dam for sustainable water management in the study area. Satellite images were prepared from the Landsat satellite and the responsible organizations and verified with field surveys.

3. Results

Based on the AHP results, by calculating the importance coefficient (priority) of the main criteria relative to the goal, which was the review and prioritization of the Goharrood River water resources management criteria, it was determined that economic (weight value (WV) = 0.608) and technical (WV = 0.229) criteria were in first and second priority, followed by environmental and social criteria with weight values of 0.112 and 0.051, respectively (Table 3 and figure 3).

By calculating the priority of economic sub-criteria, it was determined that the cultivation pattern sub-criteria with a weight value of 0.539 was preferred in the Goharrood River water resources management, and then the profitability and cultivated area sub-criteria with weight values of 0.297 and

Table 1. Type and percentage of land use in the study area.

Type of lands use	Percentage
Reined cultivation	59%
Fish farming	2.6%
Aquaculture	3%
City buffer	8.7%
Poor pasture	3.3%
Medium pasture	21%
Wetland	2.4%

Table 2. Nine-point intensity scale of analytic hierarchy process for pairwise comparison (Beskese et al. (2015) Based on Satty, 1986).

Score (Importance Coefficient)	Definition
1	Equally important
3	Moderately more important
5	Strongly more important
7	Very strongly more important
9	Extremely more important
2, 4, 6, 8	Intermediate values

0.164 were ranked second and third, respectively (figure 4).
By calculating the priority of social sub-criteria, it was determined that the welfare level sub-criteria with a weight value of 0.536 was the most preferred in the Goharrood River water resources management, followed by the job creation and public participation sub-criteria with weight values of 0.286 and 0.178, respectively, in the second and third priority (figure 5).
By calculating the priority of technical sub-criteria, it was determined that the demand rate sub-criteria with a weight value of 0.583 was the most preferred in the Goharrood River water resources management, followed by the meeting needs and uncertainty impact sub-criteria with weight values of 0.308 and 0.109, respectively, in the second and third priority (figure 6).
By calculating the priority of environmental sub-criteria, it was determined that the sub-criteria of water conservation with a weight value of 0.521 was the most preferred in the Goharrood River water resources management, followed by the sub-criteria of downstream ecosystem and fine dust stabilization with weight values of 0.244 and 0.235, respectively, in the second and third priority (figure 7).
In order to locate the optimal site for constructing a flood dam for sustainable water management in the study area, the required geographic layers were initially prepared. In the next step, precipitation zones with return periods of 5, 10, and 15 years were prepared from data related to maximum daily precipitation. This layer was prepared using statistics from six climate stations in the region with a common statistical period of 15 years. After performing the relevant tests regarding homogeneity and data adequacy, precipitation rates for the desired return periods were prepared using a Type-1 Gumbel distribution (figure 8).
According to the maps, the highest precipitation rates were in the northeastern to southeastern parts of the basin, which receive different precipitation for different return periods, and the lowest precipitation rates were in the west and northwest of the basin. The volume of runoff generated in each part of the basin was calculated and zoned based on equation (1); where, P stands for cumulative precipitation in millimeters, S for potential maximum retention in millime-

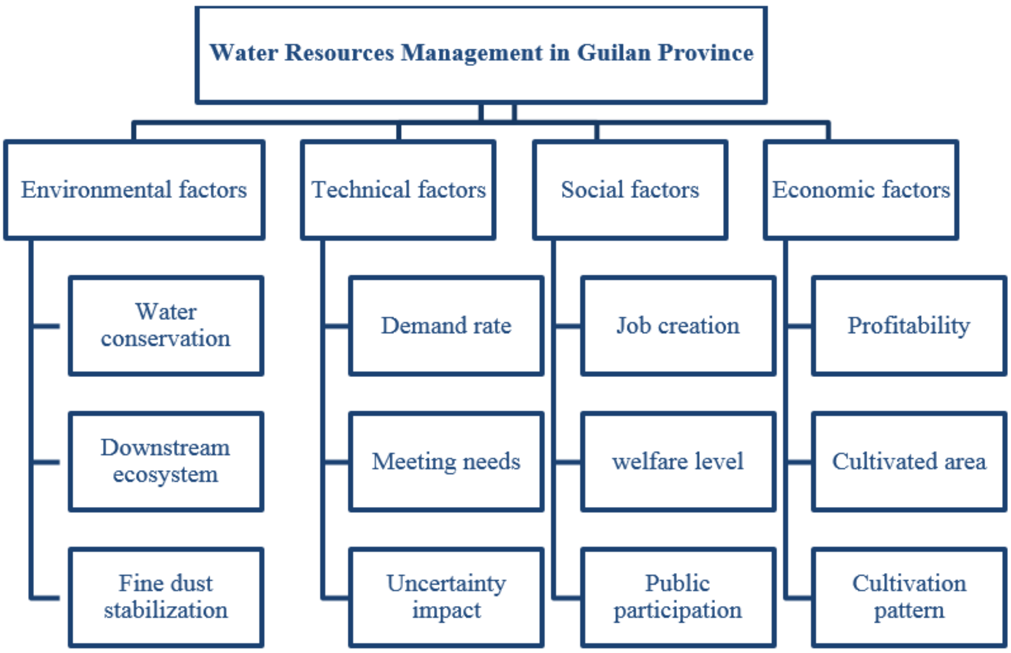


Figure 2. Analytical hierarchy process diagram for water resources management in line with strategic environmental assessment.

Table 3. Priority of main criteria relative to the goal.

Criteria	Geometric mean	Weight value	Rank
Economic	3.637	0.608	1
Technical	1.374	0.229	2
Environmental	0.668	0.112	3
Social	0.299	0.051	4

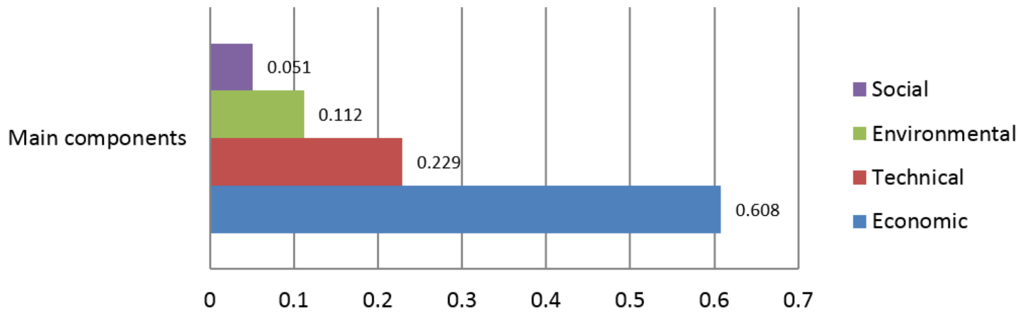


Figure 3. Priority of main components relative to the goal.

ters, and Q for precipitation excess (runoff) in millimeters.

$$Q = \frac{(P - 0.2S)}{P + 0.8S} \tag{1}$$

According to the map, the highest runoff generated in the region was in the eastern areas of the basin, which also received the highest rainfall (figure 9). Finally, a flood hazard map of the Goharrood River basin with different return

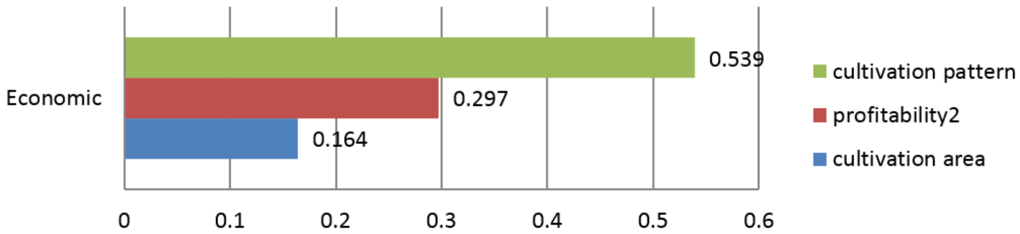


Figure 4. Priority of sub-criteria in the economic criteria.

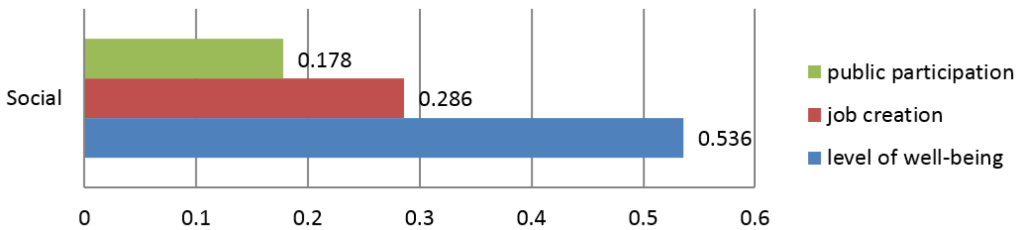


Figure 5. Priority of sub-criteria in the social criteria.

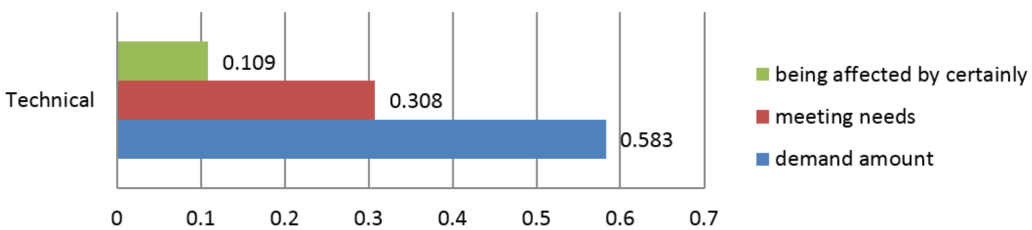


Figure 6. Priority of sub-criteria in the technical criteria.

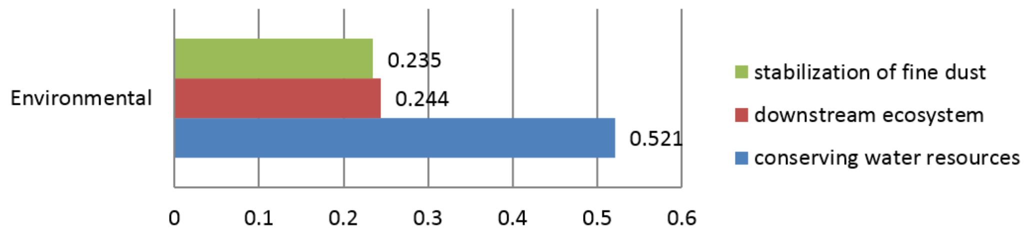


Figure 7. Priority of sub-criteria in the environmental criteria.

periods was prepared (figure 10).
In the next step, the layers were overlapped to obtain suitable locations for the construction of the dam through a zoning approach (figure 11).
As indicated in the map, the eastern half of the watershed had a higher potential for flooding. Therefore, it was necessary to construct a flood barrier in this area. Analysis of the geographical data indicated that three points had suitable conditions for the construction of a flood barrier.

4. Discussion

Based on the results, it was determined that the economic criterion with a weight value of 0.608 and the technical criterion with a weight value of 0.229 were in the first and second priority, and the environmental and social criteria with weight values of 0.112 and 0.051 were in the third and fourth priorities, respectively. This finding showed that adherence to technical aspects in the design and construction of flood dams, as well as watershed management issues, is of great significance. On the other hand, financing the implementation of water resources management plans is also very important. This result was consistent with the findings of Behboudian and Kerachian (2021). In addition, by calculating the priority of economic sub-criteria, it was determined that the cultivation pattern sub-criteria with a weight value of 0.539 was preferred in Goharrood River water management. Also, by calculating the priority of social sub-criteria, it was determined that the welfare level sub-criteria with a weight value of 0.536 was preferred in Goharrood River water management, and the demand rate sub-criteria in economic discussion with a weight value of 0.583 was preferred in Goharrood River water management. By calculating the priority of environmental sub-criteria, it was determined that the water conservation sub-criteria, with a weight value of 0.521, was preferred in the Goharrood River water management. Based on GIS data, the eastern half of the watershed had a higher potential for flooding. Therefore, three points in this area were identified as strategic locations for the construction of flood barriers. Building a flood dam can not only helps control future floods, but also prevents environmental pollution and the reduction in the quality of surface and groundwater resources in the region. According to Heravi et al. (2018), the ranking of comprehensive water management strategies in order of priority were: ensuring sustainable development and management of water resources, creating a profile of the status of raw water management, increasing public awareness using media and social networks, evaluating water resource projects according to the opinions of local people, creating political will to change traditional water resource management, increasing monitoring and assessment mechanisms, enacting comprehensive and dynamic laws, and employing advanced

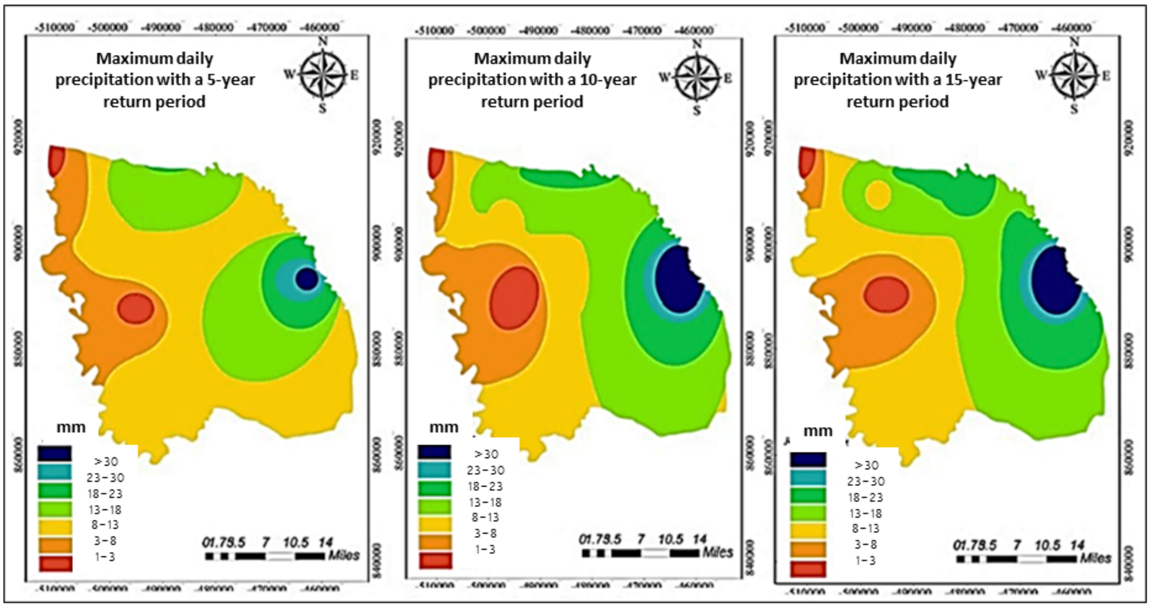


Figure 8. Map of maximum daily precipitation with different return periods.

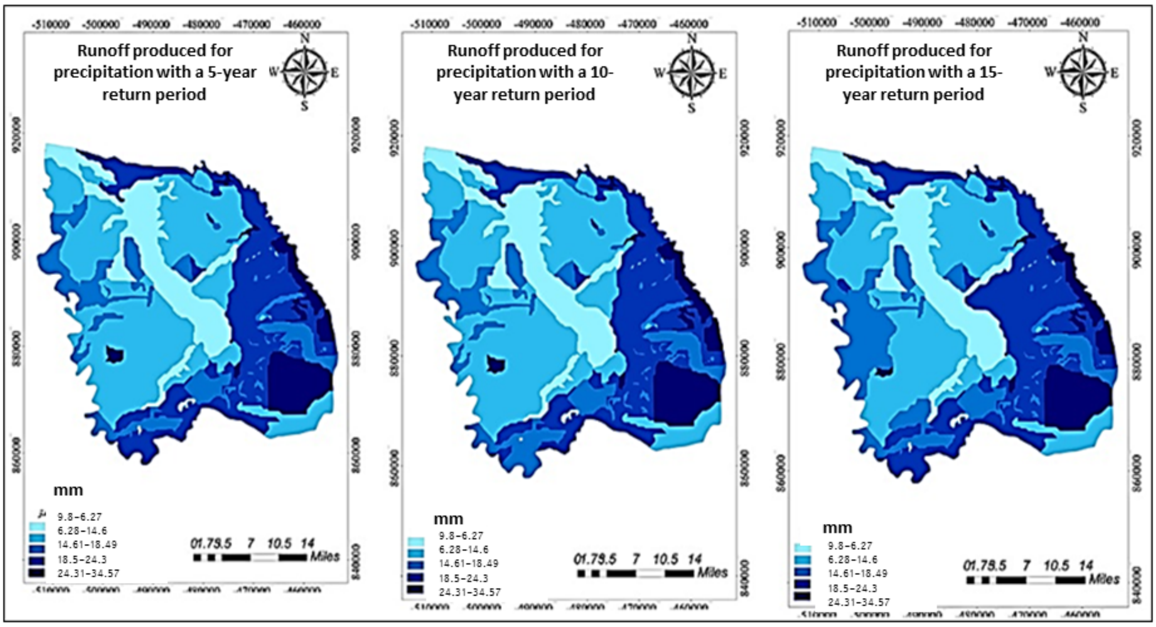


Figure 9. Map of runoff generated for precipitation with different return periods.

technologies, in line with parts of the present study. As Alam Rajabi and Maknoon (2017) pointed out, achieving the conditions of environmental quality sustainability and development sustainability requires macro and strategic decision-making and policy-making within the framework of the Strategic Environmental Assessment (SEA) method in the pre-project stage. The findings of this study were consistent with those of Hung et al. (2022) and Izadi et al. (2022), who examined decision support tools for integrated water management based on GIS, confirming that the use of specialized tools and satellite imagery significantly contributed to decision-making in water management. On the other hand, as Behboudian and Kerachian (2021) pointed out, any type of planning and decision-making for water management must be flexible and selected according to the economic, social, environmental, and technical characteristics of the study area.

Integrated water resources management at the watershed level is a very important issue for designers, planners, managers, and legislators in the field of water resources issues Ahn and Sheng (2021). In general, water resources management at the watershed level is a very complex issue from the point of view of the existence of different aspects. Water resources management can be considered one of the basic principles in any country that is implemented through various techniques Hung et al. (2022). In all these approaches, due to the interdisciplinary nature of water resources issues, there is a need to integrate technical, economic, environ-

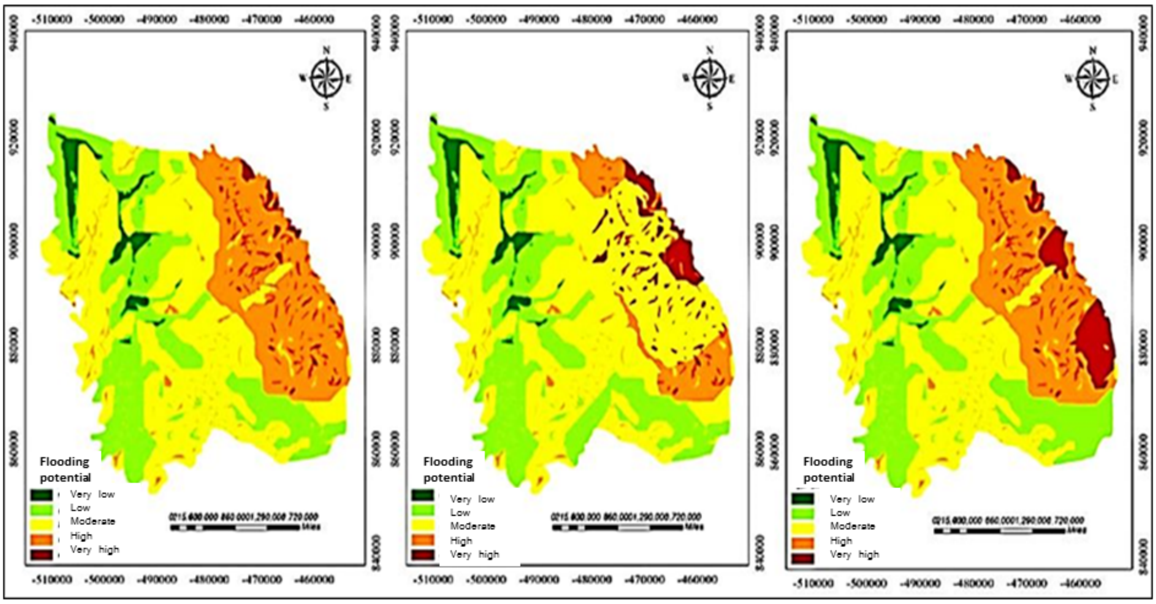
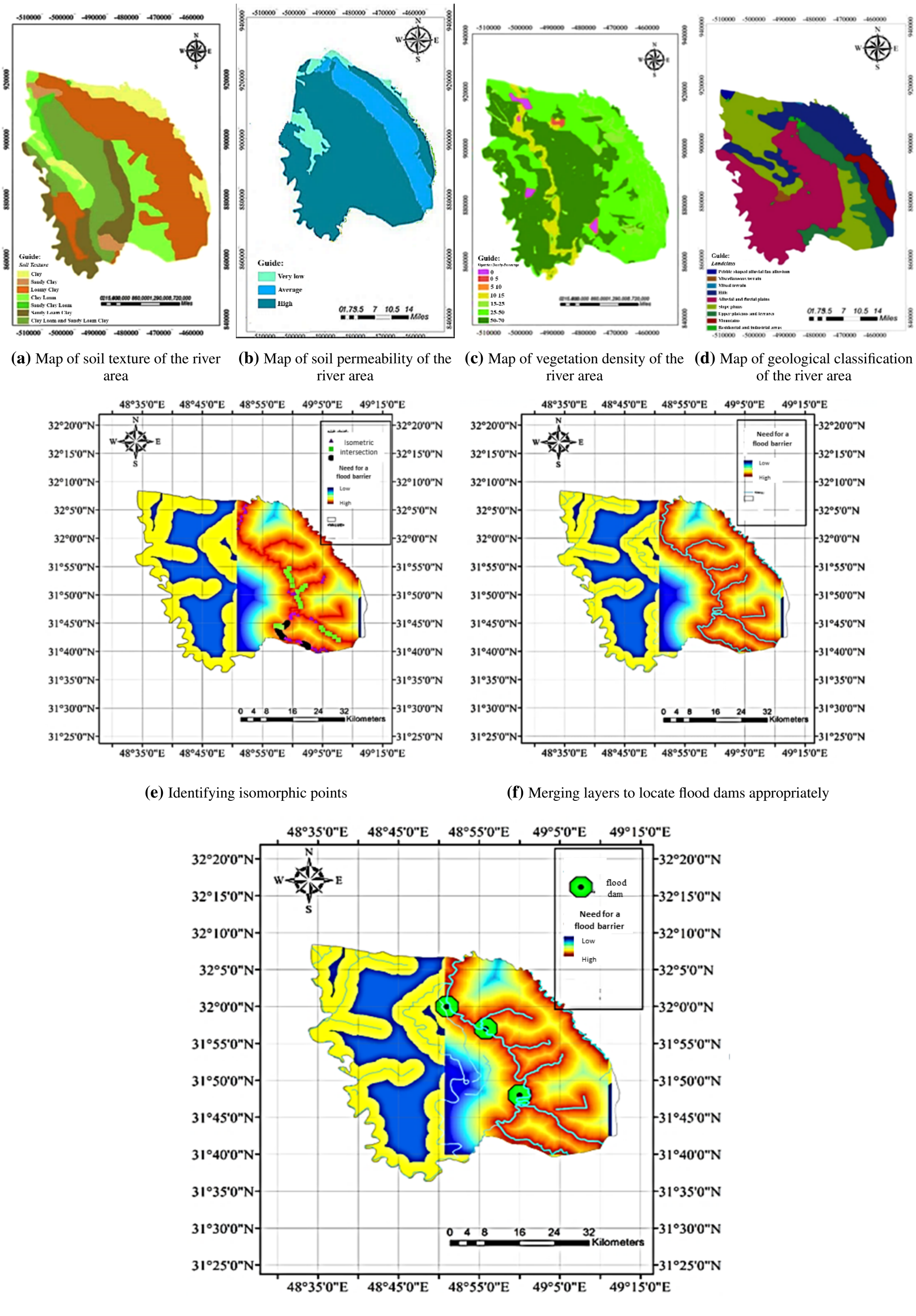


Figure 10. Map of flood hazard in the Goharrood River basin with different return periods.



(a) Map of soil texture of the river area

(b) Map of soil permeability of the river area

(c) Map of vegetation density of the river area

(d) Map of geological classification of the river area

(e) Identifying isomorphic points

(f) Merging layers to locate flood dams appropriately

(g) Proposed locations for the construction of flood dams

Figure 11. Process of zoning and locating a flood dam for water resources management in the study area.

mental, social and legal aspects within a coherent analytical framework for its management. As a result of years of research, researchers have found the river basin to be a suitable natural unit for water resources management and planning (Verma et al., 2022). Water resources management actually refers to the comprehensive and integrated conditions, facilities, and tools for the purpose of assessing and planning water resources, water demand, and rational utilization, and the effective and efficient protection and maintenance of these resources (Shrestha et al., 2021), which is a system in interaction with environmental issues, natural resources, and soil (Guiamel and Lee, 2020).

5. Conclusion

Based on the research findings, it can be concluded that integrated water resources management based on a sustainability approach in the study area requires a focus on planning priorities with an emphasis on technical and economic aspects, followed by environmental and social dimensions.

Among the management and engineering solutions that can be suggested for flood control in the study site, especially in the eastern part, are: Implementation of a watershed management plan upstream; protection and enhancement of the vegetation cover of the study area; livestock grazing avoidance within the site; no use of pesticides in the site; construction of light dams; design and construction of seasonal reservoirs.

Accordingly, the following suggestions were made:

- Studying and evaluating the types of flood dams and selecting the technically superior option for the study site.
- Investigating methods of financing the implementation of sustainable water resources management projects in the study area.

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Authors contributions

Zahra Pourdasht: Conceptualization, funding acquisition, investigation, visualization, writing. Mohammad Ebrahim Ramezani: Methodology, supervision. Fariborz Ahmadzadeh Kaleybar: Project administration, supervision. Omid Rafieiyan: Formal analysis, resources. Arezoo Nejaei: Software, validation.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflict of interests

The author declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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