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A Multicriteria Decision-Making Approach for Urban Water Features: Ecological Landscape Architecture Evaluation

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Abstract: In recent decades, the issues of ecology and environmental sustainability have become a global concern in contemporary urban design. Among various urban elements, water features play a significant role in improving the ecological characteristics of their surrounding environment, especially in hot and arid areas. The aim of this study is to evaluate the ecological characteristics of urban water features comprehensively and quantitatively, which has been overlooked in previous studies, taking their physical characteristics into account. To this end, a multicriteria decision-making method, an analytic network process, was proposed to quantitatively evaluate the ecological characteristics of water features. In this approach, four ecological criteria—microclimate, biodiversity, greenery, and human wellbeing—and ten physical characteristics of water features were considered. Twenty-one experts were asked to complete a questionnaire for pairwise comparisons of all ecological criteria and the influence of physical characteristics. The results showed that vegetation and scale, with the relative influencing values of 0.255 and 0.188, respectively, were identified as the most decisive features influencing ecological criteria. Conversely, texture, with a value 0.023, had the least impact. Moreover, it was shown that water features have the greatest impact on the microclimate compared with other ecological criteria. The results were used to compare water features at the Koohsangi Transregional Park, located in a hot and arid city of Iran. The results of this study lead to a framework that can help urban designers integrate ecological criteria into water feature planning to enhance urban ecology and sustainability.

Keywords: ecological design; urban ecology; analytic network process; water fountain; water bodies

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1. Introduction

Urban landscape design is moving towards ecological aesthetics, focusing on the integration of natural elements to improve the living environment and support sustainable urban development [1]. In modern sustainable urban development, several strategies have been adopted, using natural elements, such as soil, plants, light, and water, to lead cities to grow and re-establish their relationship with nature [2–4]. These strategies, which are known as nature-based solutions (NBSs) [5], utilize natural processes and structures [6,7] to tackle environmental issues, while offering economic, social, and ecological benefits [8]. They are increasingly implemented to restore natural ecological flows in urban areas and develop a resilient infrastructure [7]. Nature-based solutions focus on managing and providing multiple ecosystem services for both human communities and natural ecosystems. Among all NBSs for sustainable urban development, water-based solutions utilize natural processes to enable, restore, or preserve nature in urban areas [9]. It has also been reported [9] that implementing NBSs requires systemic changes in urban planning and water resource management.

The significance of sustainable water resource management in urban areas has been widely reported in literature. To begin with, it has been widely recognized that water scarcity is one of the main concerns of water resource management in hot and arid areas [10]. It is also imperative that water resources in urban areas are distributed fairly and are accessible to all in order to achieve environmental justice [11]. Therefore, a comprehensive approach to the management of urban water has been emphasized [11]. It is important, too, to analyze the ecological characteristics of urban water bodies to improve water quality, create a better microclimate, and provide ecosystem services for sustainable urban development [12,13].

As one of the main water resources in cities, water bodies have several significant roles in landscape design. They improve the overall beauty and ambience of spaces [14]. They have also been considered as blue–green infrastructures to balance conservation and management for both human and nature needs. Sandeva and Despot discussed the impact of water bodies in landscape design and demonstrated their ability to enrich landscapes and create an attractive development [15]. In addition, their ecological role was demonstrated in a study by Gong et al. [16], the results of which indicated that integrating ecological principles into urban design is important to address environmental challenges and enhance urban livability [16]. In another study by Syafii et al. [17], in addition to ecological characteristics, safety and culture were integrated into the design of water bodies. As a result, studying ecological characteristics, among others, is of paramount importance in urban water bodies' design.

Among all types of water bodies in urban landscapes, water features—namely, water fountains, waterfalls, artificial lakes, and ponds [18]—have attracted significant attention due to their particular properties. Fountains play numerous roles in urban landscapes, including cultural markers and environmental elements [19], improving the microclimate, increasing excitement, and reducing stress [20]. They also add life to public spaces, facilitate urban regeneration, and function as symbolic sites of meaning [21]. Consequently, this study focuses on the ecological characteristics of water features.

Focusing on the ecological characteristics of water features is crucial, because they impact local biodiversity, water conservation, and the sustainability of urban areas [22]. When water features are combined with plant designs, it creates various ecological living spaces and adds movement, light, and sound to the landscape [23,24]. They enhance human wellbeing in terms of thermal comfort, social communication, and livability [12,25,26], as well as improving the microclimate and biodiversity [27]. In view of their importance, the application of water features in urban landscapes, with a focus on their ecological characteristics, has been addressed in the literature [28,29]. According to Xue and et al. [30] and Nishimura and et al. [31], using water fountains in urban landscapes improves local microclimates, which in turn, benefits urban vegetation and biodiversity. This effect is caused by cooling effects and increased humidity levels around the fountains [32,33]. A study by Theeuwes et al. [34] pointed out that, while water bodies can reduce temperature, they may also increase humidity and adversely affect the summertime temperature and thermal comfort. It has also been reported that water fountains and vegetation not only enhance thermal comfort but also significantly reduce particulate matter and carbon dioxide levels [35,36]. Fountains influence urban acoustics and thermal balance, improving the comfort of city residents [37]. In addition, ecological water fountains affect human activities and wellbeing in urban areas. According to Abdulkarim et al. [38,39], water fountains increase livability and recreational activities, especially among children [39]. Recreational activities also lead to increased social interactions, an important element of wellbeing [40]. Therefore, water features have indirect ecological impacts on human wellbeing by changing the thermal comfort and encouraging human activities. In addition, the European Water Framework Directive emphasizes the need to consider human wellbeing alongside other policy objectives in water management [41].

The role of urban park water features goes beyond the regulation of the temperature. The presence of water fountains in urban areas contributes to biodiversity conservation by providing a habitat for a variety of flora and fauna [42]. Tribot et al. [43] also explored the biodiversity impact of water fountains in urban landscapes. Additionally, the presence of aquatic plants in water fountains has a positive impact on ecological preservation, species diversity, and water quality [44]. They improve and stabilize the ecological system by creating a suitable ecological environment [45]. Bao et al. [46] reported that the combination of water and greenery in urban parks creates multifunctional habitats, supporting not only biodiversity but also ecosystem services. This includes providing habitats for various species and improving human wellbeing through enhanced environmental comfort. Based on the findings of the study by Xing et al. [47], it is feasible to use policy and community initiatives to increase the presence of water fountains in urban green spaces, which will facilitate water management and ecosystem services in parallel. In addition, the proper design and management of artificial ponds and lakes can enhance their ecological value and functionality [48,49].

While different experts have discussed the ecological characteristics of water features, the main challenges revolve around the development of accurate concepts and principles, as well as the varying effects of different water body configurations on the microclimate [50] and standards for the ecological design of urban green–blue infrastructure [51]. The other main challenge is to find an effective integration of ecological and aesthetic values in landscape design [52]. To address these issues, landscape ecological knowledge implementation is essential, particularly in urban areas, and can be achieved through the urban ecosystem structural approach and the use of ecosystem services [53]. It has also been reported [51] that the major challenges in evaluating the ecological value of water features in urban landscape design include the lack of a clear and systematic theoretical basis for ecological design. Despite the interest in the field, little research has been conducted into the systematic theoretical aspects of water feature design based on their ecological characteristics.

According to Walczak et al. [54], water fountains should be designed to consider both their physical characteristics and their ecological impact. Langie et al. [20] examined the role of water elements in enhancing urban spaces' attractiveness and identity, with a focus on appropriate location and form. The results of their study showed that designing water elements in public spaces enhances their value, considering both ecological benefits and composition for visual appeal. Additionally, the socio-functional value of water features, such as improving wellbeing, is influenced by their type, size, structure, location, and surroundings. Furthermore, it was proposed by Lin [55] that droplet size and velocity are important factors to consider, as they relate to fountains that are used to improve the thermal environment in urban areas. Scale effects have been considered in the analysis of urban water ecological landscape patterns, their importance being indicated by Wang and Li [56]. Two further studies [33,57] have highlighted the importance of edges in designing water fountains for ecological purposes along with visual aspects and careful consideration of vegetation composition. Moreover, the choice of materials for water features can influence their ecological impact. A recent study by Skovira et al. [58] indicated that permeable pavements can help in the management of runoff and improve water quality. The other essential factor to consider is the thermal properties of materials used around water features. The results of a recent study by Teshnehdel et al. [59] showed that water surfaces are more effective than granite pavements in reducing heat island effects. In summary, several parameters that have been reported in the literature should be considered in the design of ecological water features.

Various methods of examining ecological characteristics, such as temperature, have been reported in the literature. Computational fluid dynamics (CFDs) calculations combined with surface temperature calculations have been used to estimate the cooling influence of water bodies and to simulate different scenarios in urban environments [60]. A simulation approach methodology to measure the reliability of water infrastructures under extreme events was reported in [61]. Although these models offer detailed and accurate simulations, they are expensive and require extensive input data, limiting their practical application [62]. Simulation software, namely, ENVI-met 4.4.1 and 4.4.5, has also been widely used to predict microclimate conditions and thermal comfort under various scenarios involving water features and other landscape types [10,50]. These models, used for vegetation modelling, oversimplify certain parameters to improve computational efficiency, which can lead to inaccuracies, especially in different climate zones [50]. Although several attempts have been made to model temperature profiles, no research has been devoted to the qualitative aspect of ecological characteristics.

The use of single-variable analyses in the context of landscape ecological design is not efficient in solving complex problems of this nature [63]. The analytic hierarchy process (AHP) and the analytic network process (ANP) are decision-making tools used to handle complex decisions by structuring them into a hierarchy of more easily comprehended sub-problems [64]. AHP, introduced originally by Saaty, captures both subjective and objective aspects of a decision and checks the consistency of evaluations [64]. It has been particularly useful for converting qualitative decision-making systems into numerical ones [65]. In view of performing pairwise comparisons in AHP, when the number of either alternatives or criteria increases, the pairwise comparisons become confusing, and a high level of inconsistency is expected [66]. ANP, a generalization of AHP, was designed for decision problems that cannot be structured hierarchically; it involves the interaction and dependence of elements [67]. For all the AHP's merits, ANP is more comprehensive, allowing for the consideration of interdependencies and feedback among decision elements [68,69]. This makes it particularly useful for complex decision-making problems with multiple criteria and subjective inputs [69]. Hence, the ANP method has the potential to be used to evaluate ecological characteristics and extract their parameters for the design of urban water features by architects, landscape architects, urban designers, and planners.

Given the limited water resources in arid climate cities, no research has been conducted on improving the performance of water features from an ecological perspective to the best of the authors' knowledge. In many previous studies, the ecological characteristics of urban water features were not considered comprehensively and quantitatively when addressing water-related sustainability challenges. In addition, a multicriteria decision-making approach to scrutinize water features' ecological impacts has not been addressed. Herein, we aim to evaluate all ecological characteristics of water features quantitatively, taking into account the influential physical characteristics reported in the literature. In this regard, we propose a multicriteria methodology, the ANP method, to evaluate the ecological characteristics of water features in urban parks. The Koohsangi Park of Mashhad, Iran, was used as a case study for the implementation of the methodology. The ANP results will allow urban designers to compare the ecological impacts of water features based on their physical characteristics and integrate these ecological characteristics comprehensively into urban planning and park design.

2. Materials and Methods

The term "ecological characteristics" refers to all ecological aspects of the environment: when it is used, it means we do not address specific aspects. Ecological criteria describe the four main ecological features of the environment, namely, the microclimate, biodiversity, greenery, and human wellbeing. In addition, the term "ecological impact" is used to describe the effect of water features on ecology owing to their physical characteristics. Water features' physical properties are also defined as their physical characteristics in this paper.

2.1. Analytic Network Process

Dual ANP was used in this study. Using ANP allows us to systematically and comprehensively evaluate the relative importance of various physical characteristics affecting the ecological impacts of water features. In this approach, the relevant aspects are considered, and their impacts are accurately quantified, resulting in more informed decisions and better ecological management of water features. ANP is also used to compare water features, classify their physical attributes, and choose the most suitable designs. The ANP method converts qualitative parameters into quantitative ones. Furthermore, the ANP method ranks the unweighted ecological characteristics (as criteria) and the physical characteristics (as alternatives). Both of these parameters were extracted from the literature. The dual ANP method involves two steps. In the first step, the ecological criteria and physical characteristics were evaluated in general and then ranked. Next, the same evaluation was carried out on water features' physical characteristics to compare them based on their impact on ecological criteria.

Figure 1 presents a flowchart of the methodology. According to the literature, evaluations of the index system and influencing factors, physical characteristics, and ecological criteria, respectively, were obtained. In the first step, we use the ANP to weight and rank the ecological criteria and physical characteristics. Following this, the results are applied to compare the water features based on physical characteristics and their impact on ecological criteria. Ultimately, we can use these results to compare water features or choose the best design alternative.

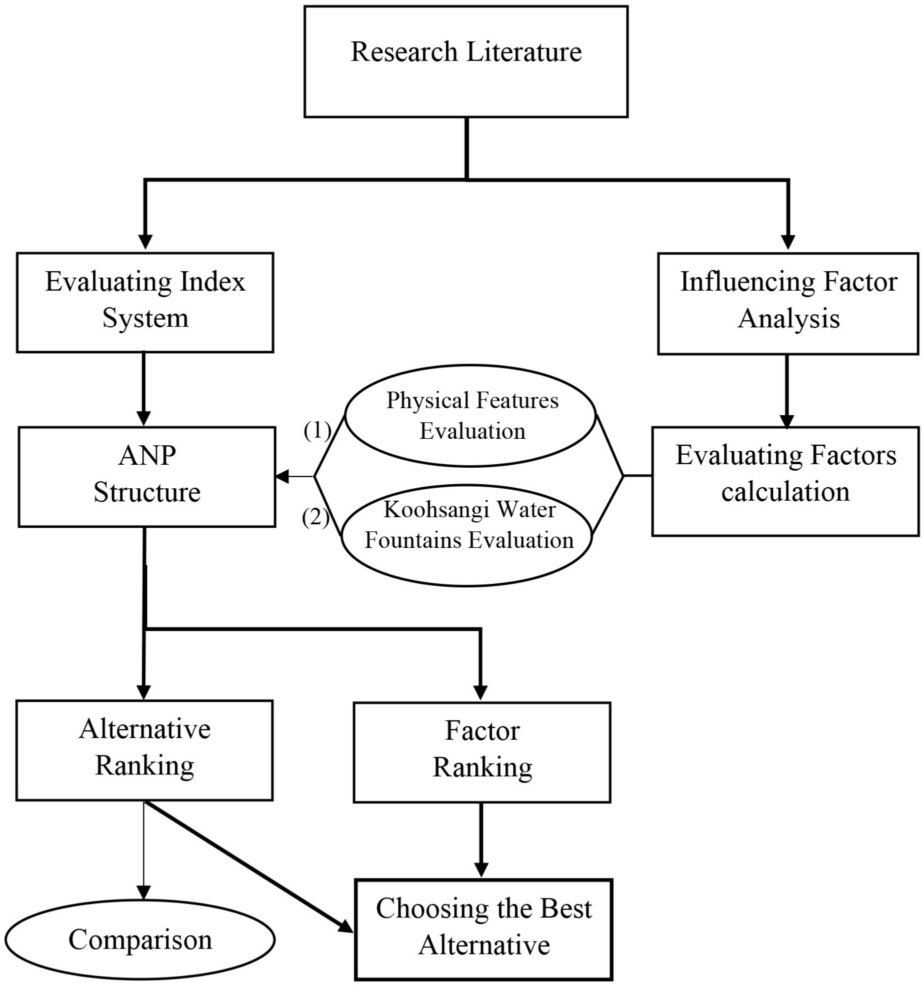

Figure 1. The flowchart of research methodology. Physical characteristics are evaluated first (1) by the ANP method, followed by Koohsangi water features in step (2).

The other main feature of the ANP method is its ability to handle complex interrelationships between factors. These factors, ecological criteria, are interconnected and must be compared effectively. Figure 2 shows the schematic of the ANP method and its interrelationships. As shown, the ANP approach is divided into three layers, namely, the control, network, and alternative layers. The connecting lines illustrate the interrelationships among model components, including internal and external dependencies. The control layer focuses on the system's research target and the criteria influencing decision making to achieve this target, treating each criterion as governed by the target, with their weights determined by a weighted matrix. The network layer comprises factor groups influenced by the control layer, forming an interactive network that illustrates the relationships among criteria. These criteria have subcriteria that affect each other. The inner dependency of a criterion refers to the interrelationship of the subcriteria elements within the criterion. The loops in Figure 2 represent internal dependencies within a cluster of criteria. These loops show how subcriteria within a cluster are interrelated and influence each other. The alternative layer encompasses all the system's alternatives, interacting with the network layer and often functioning as a factor group within it for calculation purposes.

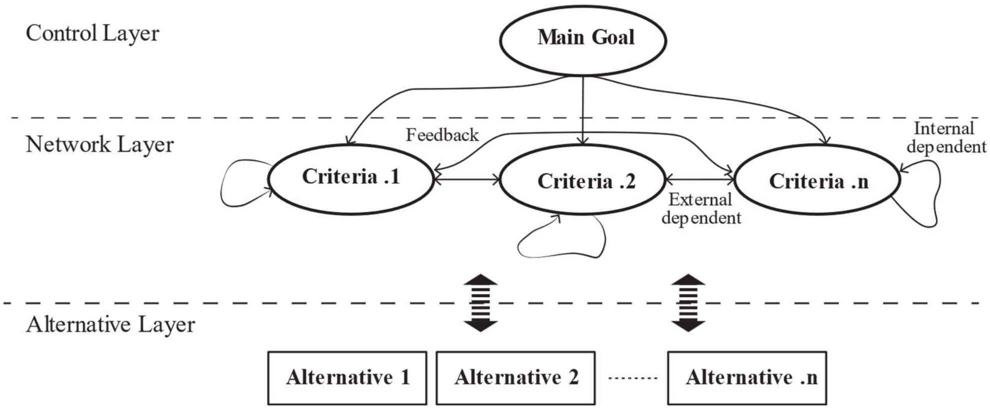

Figure 2. The ANP method showing the relationship among parameters.

Table 1 specifies all physical characteristics and ecological criteria. These features were derived from a comprehensive literature review. In the ANP method, the criteria and alternatives are ecological criteria and physical characteristics, respectively. Physical characteristics of water features include shape and form, line and edge, scale, surface area, material, vegetation, depth, location, static or dynamic, and texture. Ecological criteria for water features are greenery, microclimate, biodiversity, and human wellbeing.

Table 1. Ecological criteria as main criteria and physical characteristics as alternatives in the ANP method.

Physical Characteristics	Ecological Criteria
Shape and form Line and edge Scale Surface area Material Vegetation Depth Location Static or dynamic Texture	Greenery Microclimate Biodiversity Human wellbeing

There is a specific meaning behind every physical characteristic of a water fountain. Shape and form refer to the overall design of the fountain, including circular, rectangular, and others. They refer to water features' design and their visual appearance. Line and edge describe the contour of the water features' borders and edges. Scale refers to the overall size and proportion of the fountain relative to its surrounding environment. The meaning of surface area is the portion of the fountain that comes into contact with water. Material indicates the water feature's construction material, such as stone, metal, glass, concrete, or ceramic. Vegetation is any plants or greenery around water features. The depth of the water in the fountain influences water dynamics, the potential for aquatic life, and safety considerations. A water feature's location refers to where it is located—whether it is in a residential area, foothill, urban area, street, or park. Static or dynamic features refer to whether the water in the water feature remains still (static) or moves (dynamic). Texture refers to the surface quality of water features, such as smooth, rough, or polished. All physical characteristics are independent and have specific meanings.

In Figure 3, the ANP diagram shows the criteria and alternatives for designing ecological water features and their relationships. Four criteria, namely, greenery, microclimate, biodiversity, and human wellbeing, not only correlate with physical characteristics as alternatives, but are also interrelated. Using this structure, the ANP evaluates all relationships among the involved criteria and parameters.

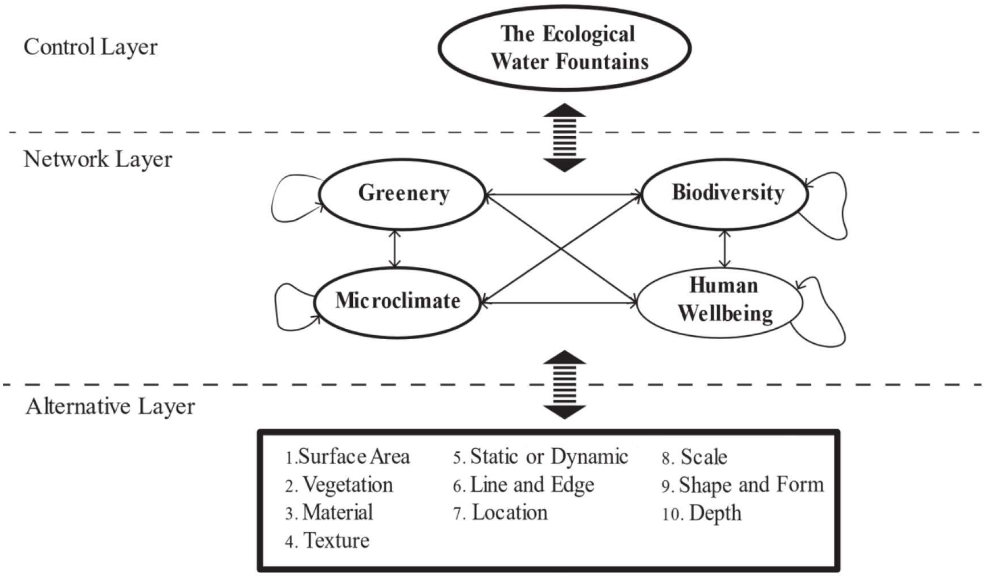

Figure 3. Diagram of the ANP method showing the relationships between the ecological criteria, which are impacted by the physical characteristics of water features.

The comprehensive evaluation index system (CEIS) was used to quantify qualitative parameters. To this end, each qualitative parameter was assigned a number. We made a matrix for all criteria that estimates their weight and ranks them. The interacting evaluation set includes all the influencing factors listed in Table 1. This CEIS was the same as in Saaty [67], which proposed a fundamental scale for pairwise comparisons ranging from 1 to 9, where 1 represents equal importance, 3 indicates moderate importance, 5 signifies strong importance, 7 denotes very strong importance, and 9 represents extreme importance. Intermediate values of 2, 4, 6, and 8 are used for comparisons between two adjacent judgements.

The questionnaires were prepared to rank the importance of ecological criteria and the effects of the physical characteristics of water features on those criteria. From the 30 landscape architecture experts invited to complete these questionnaires, 21 experts answered the questions, and their responses were used. The experts were informed about the academic purpose of this study, and verbal consent was obtained from them before initiating the survey. Ethical approval was waived for this study due to the questionnaire being anonymous and no personal information being collected during the survey. However, internal approval was obtained from project team members.

The experts were drawn from two professional groups, academia and organizations, which may have different viewpoints on a range of academic and practical matters. In total, half of the answer sheets were assigned to academics and half to practitioners. Eleven academics and ten practitioners answered the questionnaires accurately. To perform the survey, academic experts were required to attend the 6th International Conference on Civil Engineering, Architecture, Art, and Urban Design. It was also required that they present a paper on the topic of architectural engineering and sustainable development. It was particularly important to select experts from disciplines, including sustainable architecture, the effect of climate on local and sustainable architecture, the effect of ecological materials on sustainable architecture, and landscaping, ecology, and aesthetics in architecture, etc. As a result, academic experts from various parts of Iran and with diverse expertise in the field were selected, which mitigated both geographical and background bias. Additionally, professionals of the Research Center of Environment and Sustainable Development (RCESD) who have in-depth knowledge of urban ecology and sustainable development were invited to present their practical experiences. Because of the selection process, questionnaire responses are enriched with useful and reliable information.

Firstly, the experts were asked to judge the relative importance of ecological criteria by assigning a number between 1 and 4. Next, they were asked to rank the effect of all physical characteristics (10 parameters) on each ecological criterion by assigning a numerical value between 1 and 10, indicating the extent of their impact. These judgements were then used for the comparative analysis of the matrix construction used in the ANP method. In the ANP method, judgement matrices are built based on pairwise comparisons; however, questionnaires give information about the parameters' ranking. To convert the ranking into a pairwise comparison, the distances between values of parameters' ranks are calculated and used in the CEIS. Therefore, for each expert, five matrices were calculated: one for comparing criteria importance and four for the impact of physical characteristics on each ecological criterion. All these matrices were recorded for further processing.

Following these questionnaires and matrix constructions, eigen vectors were obtained for all matrices. The mathematical procedures for obtaining eigen vectors are presented in Section 2.2. Next, the eigen vectors of all experts were averaged and used in the initial matrix of Super Decisions software (Version 2.10.0, Creative Decisions Foundations, Pittsburgh, PA, USA), performing ANP methods. All mathematical calculations were carried out in Excel (Version 2204, Microsoft), and all judgements and results were produced in an Excel file.

2.2. Mathematical Formula

A normalization process was carried out after all the scores or numbers of the CEIS were obtained and recorded. We used Equation (1) to convert numbers from all ranges to values between 0 and 1. In Equation (1), x_i are qualitative indicators of the CEIS. The normalization process allows for the comparison of all parameters, which is an important step in the weight calculation.

$$x_i' = \frac{x_i - \min(x_i)}{\max(x_i) - \min(x_i)} \quad (1)$$

In the next step, the judgement matrix A_i is defined to find the relative importance of alternative factors within each criterion. The hypermatrix is defined using Equation (2):

$$A_i = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \quad (2)$$

where A_1, A_2, A_3, and A_4 are matrices of all criteria, greenery, biodiversity, microclimate, and human wellbeing, respectively. For each matrix, a_{ij} is the relative importance of alternative i in comparison with alternative j. According to Table 1 and Figure 3, ten alternatives were considered; therefore, n is 10.

Based on the judgement matrices, the relative importance of each alternative was calculated using the geometric mean method. To do this, we used Equation (3), where n is again 10, and W_{ik} is the relative importance of the alternative k in the judgement matrix A_i.

$$W_{ik} = \left(\prod_{j=1}^{n_i} a_{kj}\right)^{1/n} \quad k = 1,\ 2,\ \cdots,\ n \quad i = 1,2,3,4 \quad (3)$$

Next, all relative importances for each matrix are normalized based on Equation (4), as follows:

$$w_{ik} = \frac{W_{ik}}{\sum_{k=1}^{11} W_{ik}} \tag{4}$$

Finally, all normalized relative importances are put into the Super Decisions software to calculate the supermatrix W_{super}. The limit matrix was obtained by multiplying the supermatrix by itself several times:

$$W_{limit} = \lim_{m \longrightarrow \infty} \left(W_{super}\right)^m \tag{5}$$

2.3. The Koohsangi Park Case Study

The urban park water bodies studied are located in Mashhad, a semiarid city in Iran with a population of approximately 3.5 million. The city has 713 different types of parks, classified according to their scale as neighborhood, local, district, regional, and transregional parks. The present research considered 18 regional- and transregional-scale parks because of their high ecological impact in the urban area. Some of these options were removed due to limitations on user accessibility or an insufficient number and variety of water bodies. The Koohsangi, a transregional park, was selected as a case study for evaluation due to its ecological features and its diversity in scale, form, and number of water features. The park covers 2000 hectares and is surrounded by the urban area. It has different natural features, such as varieties of flora, rocky mountain, and natural water sources for irrigating and supplying water features. Using a survey method, the whole area of Koohsangi Park was investigated, and the main water features, including fountains and artificial ponds, were studied, as illustrated in Figure 4.

Figure 4. The water features of Koohsangi Park that are evaluated (A1–A10 are the park water features and detailed description can be seen in the Supplementary Material).

As shown in Figure 4, water features with a variety of physical properties were selected. Water feature A1 consists of two parts and is considered a pond. A2 is a small-scale water feature and is considered a pond with an artificial waterfall. The water feature A3, though it appears similar to A2, is smaller in scale and situated at a lower elevation in Koohsangi Park. The rectangular pool of A4 has approximate dimensions of 110 × 60 m and 2 m depth. A5 is also 15 × 8 m and a rectangular shape. A6 is a circular water fountain with a diameter of 38 m and a low-height water jet in the center. The fountain A7 is designed according to a linear structure, extending through a specific area of the park. The water feature A8 consists of a semicircular form and a linear structure. The square-shaped fountain A9, with approximate length of 20 m, features multiple water jets that spiral outward from the center towards the edges. Fountain A10, approximately 15 meters in size, has a central water jet that is lower in height than fountain A9. These examples demonstrate the use of water features in various shapes and sizes. Pictures of these water features are presented in the Supplementary Material.

The ANP approach was used to compare the physical characteristics of Koohsangi Park's water features. Using this method, the physical characteristics of water features were evaluated and ranked from most valuable to least valuable. On the basis of these results, the water features were compared. In the case study, because physical characteristics do not impact each other, we considered them as criteria and fountains and ponds as alternatives. In addition, their internal relationships were not taken into account.

Based on the literature, ten physical characteristics were used to apply the ANP method. These physical characteristics were used as criteria, and water features were considered as alternatives in the ANP method. Therefore, all alternatives were evaluated according to their physical characteristics, which were used as criteria in step 2 (Figure 5). The numerical weight from step 1 was imported as a criterion for physical characteristics. Then, the fountains and ponds were ranked from 1 to 20. Next, pairwise comparisons were undertaken to construct the initial matrix. The calculated number in pairwise comparisons ranged between 1 and 9, according to the CEIS. Pairwise comparison and ranking of water features was performed using the survey method and our observations. The initial matrix elements were placed, and calculations were carried out, according to the mentioned method of ranking water features based on their physical characteristics. In the subsequent step (step 3), ecological criteria were considered as a separate goal, and physical characteristics and water features were assessed as criteria and alternatives, respectively. Here, we used the results of the previous steps. To determine criteria, each ecological criterion's numerical weight was applied separately from the first step. We then imported the weighted water features' alternatives, which were derived based on their physical characteristics. Finally, the results show the ranking of water features based on their impacts on the ecological criteria of the environment.

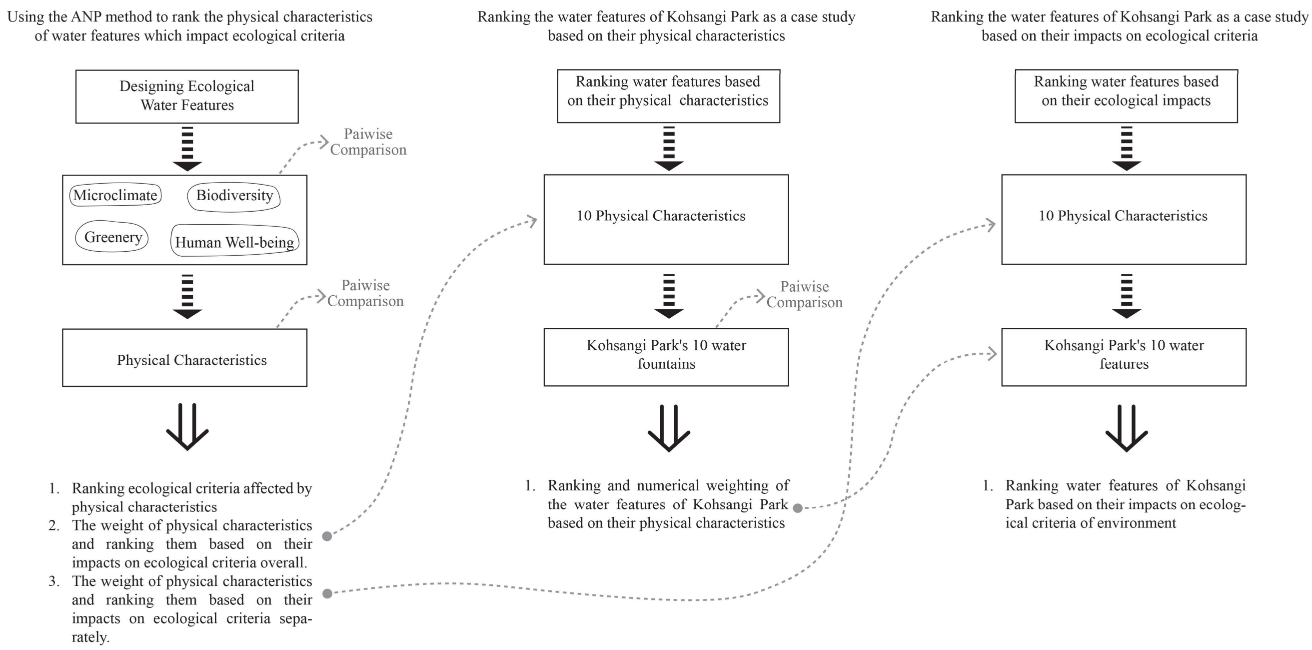

Figure 5. Flowchart of the ANP method to compare Koohsangi Park's water features based on their ecological impact.

3. Results

3.1. Ecological Criteria Comparisons

We compared the ecological criteria of the environment—namely, the microclimate, biodiversity, greenery, and human wellbeing—to determine which is more affected by water features. Figure 6 shows the results of the comparisons. As can be seen, water features have a greater impact on the microclimate than other ecological criteria (0.454), while they have the least impact on biodiversity (0.086). Human wellbeing and greenery are in the second and third positions (0.312 and 0.146, respectively).

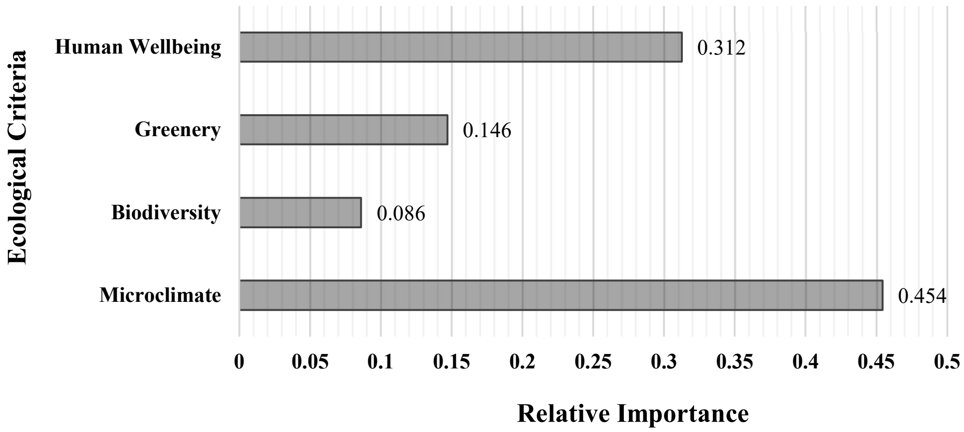

Figure 6. Comparing the relative importance of ecological criteria.

3.2. Impacts of Physical Attributes on Ecological Criteria

The results of comparing the physical characteristics of water features and their impacts on all ecological criteria are shown in Figure 7. A further benefit of this analysis is that it allows us to compare each physical characteristic and its impact on each ecological criterion separately. In order to make a comprehensive decision, it is necessary to examine the impact of these parameters in detail. It is shown that vegetation and scale have significant impacts on ecological criteria, and some parameters, including shape, texture, and material, have moderate impacts.

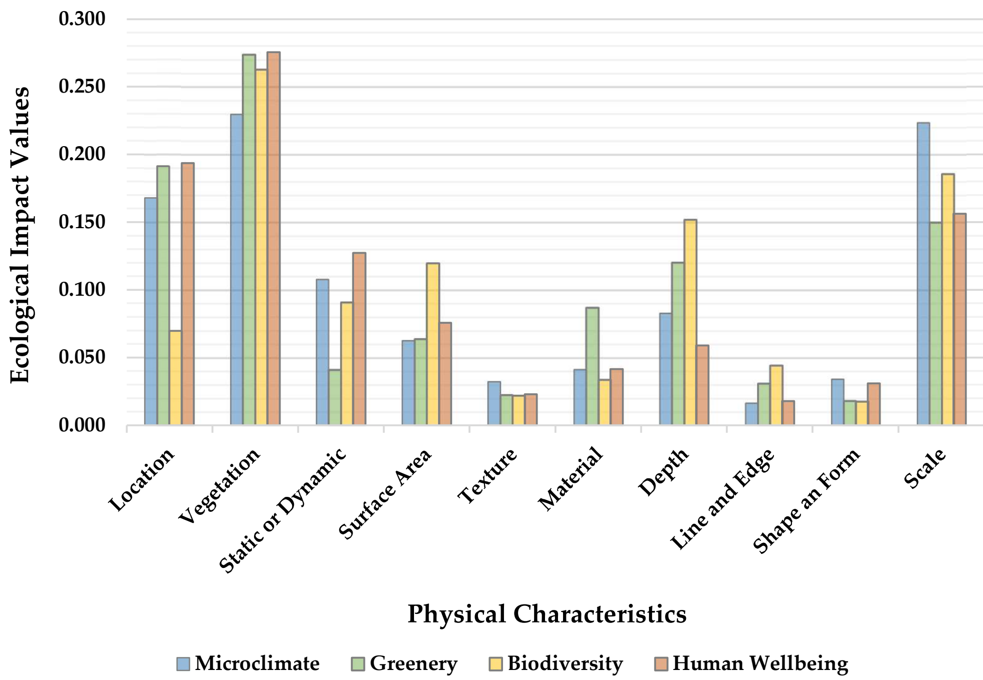

Figure 7. The impacts of physical characteristics on ecological criteria separately.

We calculated the coefficient of inconsistency to analyze the experts' answers. This is a measure of how consistent the expert judgements are when making pairwise comparisons between criteria or alternatives in the ANP. The results indicate that the coefficient of inconsistency is less than 0.1 (10%) in all steps. The figures for physical characteristics' impact on microclimate, biodiversity, greenery, human wellbeing, and ecological criteria are 0.018, 0.051, 0.071, 0.082, and 0.089, respectively. Therefore, all results are reliable enough to support the relative importance of the criteria.

The weighted values of each physical characteristic and their respective impacts on ecological criteria are shown in Table 2. These values have been obtained through ANP calculations. The numbers indicate that the ANP method has transformed the comparison of the impact of each physical characteristic on ecological criteria from qualitative to quantitative evaluations.

Table 2. The weighted values of impacts of physical characteristics on ecological criteria.

	Location	**Vegetation**	**Static or Dynamic**	**Surface Area**	**Texture**	**Material**	**Depth**	**Line and Edge**	**Shape and Form**	**Scale**
Microclimate	0.167	0.229	0.107	0.062	0.032	0.041	0.083	0.016	0.034	0.223
Greenery	0.191	0.273	0.041	0.063	0.022	0.087	0.120	0.031	0.018	0.150
Biodiversity	0.069	0.262	0.091	0.120	0.022	0.033	0.152	0.044	0.017	0.185
Human Wellbeing	0.193	0.275	0.127	0.075	0.022	0.041	0.058	0.017	0.030	0.156

Figure 8 indicates the priority of physical characteristics based on their impact on ecological criteria. The values of the impact are also shown. In contrast to Figure 7, showing impact values in detail in Figure 8, the geometric averages of impacts are reported. The results show that vegetation and scale, with numerical values of 0.255 and 0.188, respectively, have the greatest influence on ecological criteria around the water features; however, texture, shape and form, and line and edge have the least impact.

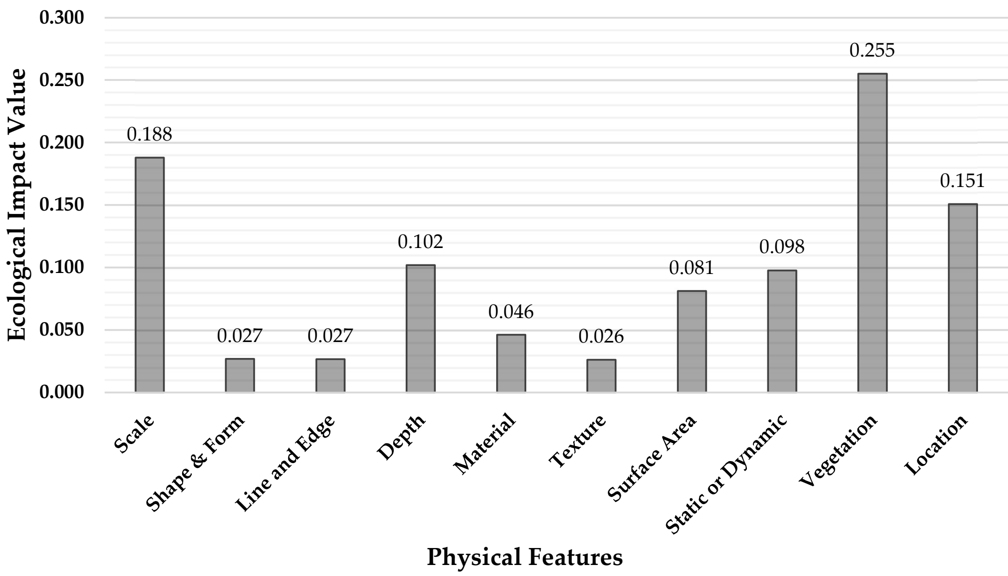

Figure 8. Comparison of the impact of physical characteristics on ecological criteria.

3.3. Results of the Case Study

The water features of Koohsangi Park, shown in Figure 4, were evaluated and ranked in order of importance. Figure 9 provides a visual representation of the weighted scores assigned to different alternatives (A1, A2... and A10), according to their physical characteristics. A1 has the highest score of 0.201. The next closest is A2, with a 0.174 value, and A4 with 0.161, illustrating that both have significant impacts, but lower than A1. In contrast, alternatives A7 and A8 have the lowest values. A closer comparison shows that A2 ranks marginally higher than A4, similar to how A10 and A6 are positioned relative to each other. Overall, alternatives A1, A2, A3, and A4 are notably placed in higher positions within the ranking compared with the others.

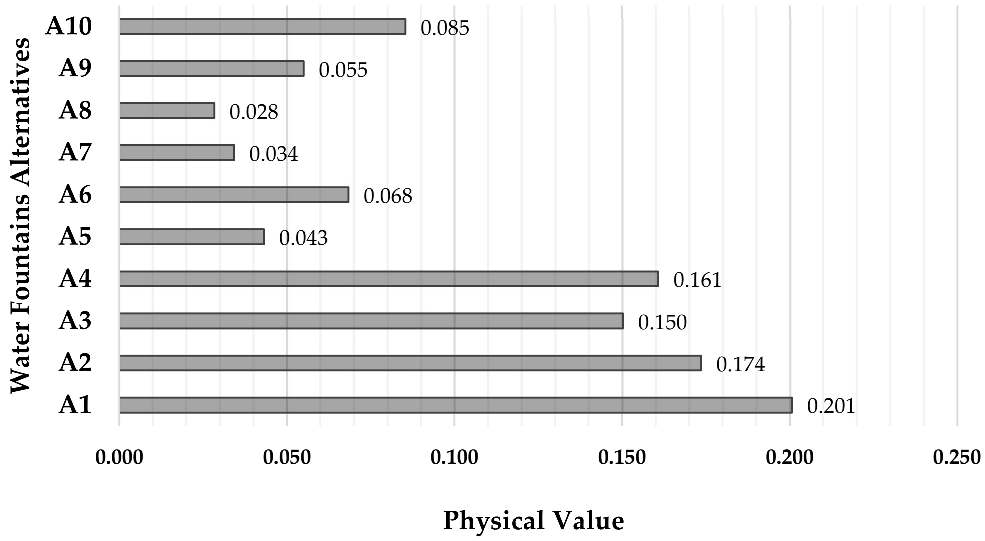

Figure 9. Prioritization of Koohsangi Park's water features based on their physical characteristics.

The study assessed the ecological impacts of the water features in Koohsangi Park by analyzing their physical characteristics and assigning weights to each feature. This re-evaluation by the ANP method aimed to classify the water features based on their ecological impacts. According to the findings shown in Figure 10, alternative A1 emerged as having the most substantial ecological impact, scoring 0.2. Alternatives A2, A4, and A3 followed closely, ranking second, third, and fourth, respectively, with impact scores of 0.175, 0.161, and 0.152. On the other hand, alternatives A7 and A8 were found to have the least ecological impact, with scores of 0.034 and 0.029, respectively, placing them at the bottom of the ranking. This analysis provides a detailed understanding of how the physical characteristics of the water features correlate with their ecological impacts, aiding in prioritizing management and enhancement efforts in the park.

While Figure 9 shows the weighted scores of physical characteristics assigned to all alternatives, Figure 10 shows their relative and quantitative ecological impacts. Despite the numerical values assigned to all alternatives seeming similar between Figures 9 and 10, they have been derived by distinct approaches. The numbers in Figure 9 were calculated through $\sum w_i a_{ij}$, where wi represents weights, reported in Figure 8, and aij are qualitative indicators of the CEIS. On the other hand, the numbers in Figure 10 were calculated through $\sqrt[n]{\prod \sum w'_i a_{ij}}$, where w'i represents the impact of the physical characteristics on the ecological criteria, reported in Figure 7, and aij are again the qualitative indicators of the CEIS. The results in Figures 9 and 10 are, therefore, different.

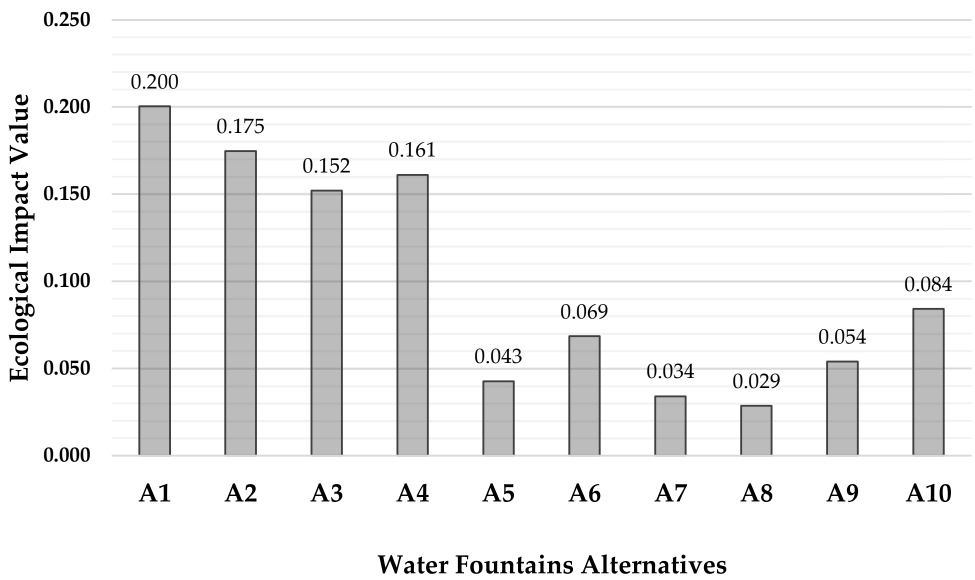

Figure 10. Comparison of Koohsangi Park's water features based on their ecological impacts.

4. Discussion

For the first time, the ecological impacts of water features—namely, microclimate, human wellbeing, greenery, and biodiversity—have been compared in this study. As mentioned in Heymans et al. [70–72] and Ibes [71], there is a lack of comprehensive consideration of all ecological characteristics of water features in the literature. It is essential for urban ecological policies to consider them as integrated factors, because they are intrinsically complicated [72]. Moreover, the need for a multicriteria decision-making approach to scrutinize the ecological impacts of water features has been emphasized in the literature [73,74]. Our study also demonstrated that water features, as small elements in urban parks, improve not only microclimates but also other ecological criteria. Most previous studies, however, focused on urban parks' cooling as an ecological impact [74,75]. As discussed in [76], the urban park studies have a general evaluation of the ecological effects of urban parks on the microclimate, especially temperature, without discussing the additional ecological benefits of the parks in the region. Figure 6 revealed that water features' greatest impacts were on the microclimate and human wellbeing. Water features influence humidity, temperature, and vegetation, which affect thermal comfort and human wellbeing [30]. Urban water bodies reduce air temperature by 0.37–3 °C and increase relative humidity by 4–14% compared with the surrounding areas [77,78]. Nevertheless, during prolonged heatwaves, the temperature of the water bodies might be higher than that of the surrounding area, which will limit the cooling effect. It is important to note that, while the findings of the study [34] have been discussed in the general context of urban design, thermal comfort perception in arid climates depends on people's ability to adapt as well as on wind during hot and humid days [78]. The human body cannot cope with heat buildup when the environment temperature exceeds 32∘C with a humidity value over 75% [79]; however, wind has a significant positive impact on thermal comfort in hot, arid regions when humidity levels rise [77,78,80].

Additionally, Manteghi et al. [81] and Abrahem et al. [10] mentioned that the combination of vegetation and water features can significantly reduce urban air temperature through evaporation and shading. Li et al. [75] indicated that urban green infrastructure in different shapes (such as trees or grass) has positive ecological impacts on the environment and performs better in combination with blue infrastructure. The presence of water bodies can also enhance the microclimate regulation function of vegetation, contributing to seasonal variations in temperature and humidity [75,82]. Although these studies discussed the ecological impacts of water features separately, to the best of our knowledge, no research has compared the impact of water features on these ecological criteria comprehensively.

Based on Figures 7 and 8, the physical characteristics of water features are compared for the first time in this paper. It was revealed that vegetation is the most significant parameter enhancing the effect of water features on the ecological aspects of the environment, particularly microclimate and biodiversity. This is because vegetation helps to reduce temperature and increase humidity. Ballout et al. [83] reported that vegetation, along with water features such as fountains and ponds, can significantly improve thermal comfort in urban spaces by reducing air temperature and increasing humidity. The shade provided by trees and other plants reduces the amount of solar radiation absorbed by surfaces and lowers the temperature in the surrounding area [84,85].

Comparing the relative importance of ecological criteria, water features have the lowest impact on biodiversity, as shown in Figure 6. As can be seen in Figure 7, vegetation and scale play a significant role in improving the biodiversity benefits of water features. Fountains and other large artificial water features are often restricted in size [10] because of their high cost and space requirements. While water features alone may offer limited benefits for supporting biodiversity [86], their ecological impact is significantly enhanced when combined with proper vegetation. This combination can attract various bird species and insects, improving the environmental quality of urban parks [87]. As mentioned in Carbó-Ramírez and Zuria [88], although vegetation is important for attracting birds, water features, when integrated with vegetation, further enhance the biodiversity and ecological value of these green spaces.

Vegetation in and around water bodies improves water quality and provides habitat and food web support [58]. Specifically, aquatic plants are beneficial for improving the habitat of aquatic invertebrates. This is in line with Xie et al. [89], who contended that urban water features, specifically fountains and ponds, act as biodiversity hotspots supporting greater richness of bird species in parks and attracting resident forest birds. Maintaining biodiversity hotspots has also been reported in Jain et al. [87], whose results showed that water features in urban landscapes contribute to the maintenance of bird diversity and provide habitats for various organisms, such as aquatic invertebrates [90]. Therefore, understanding and preserving urban water ecosystems contributes to the overall health and sustainability of urban environments.

According to Figures 7 and 8, after vegetation, the scale of water features has the most noticeable impact on ecological criteria. This is in line with the research of Shu et al. [77], who reported that larger water features have a greater impact. Larger water features can provide a better platform for the growth of aquatic animals, such as invertebrates, frogs, and fish [90]. In our case study, some species of fish, frogs, and invertebrates live and grow in water feature A1, a pond in Koohsangi Park in Mashhad (Figure S1), in contrast to water fountains A7 and A8, which are smaller (Figures S7 and S8). This supports previous findings by Sun [91] that larger ponds provide more heterogeneous environments and dilute pollutants better, supporting greater aquatic biodiversity and purifying water biologically [92]. It was found that larger water features have a greater impact on the microclimate due to their wider surface area and depth, helping to increase environmental humidity and reduce temperature. The same point was made by Xue and Li [93], that larger water features tend to have a more intense impact on the microclimate due to increased evaporation and thermal mass. Additionally, fountains in particular can create a refreshing atmosphere by dispersing water droplets, enhancing the cooling and humidifying effect. The scale of water features is of great importance in designing water features ecologically, because it affects vegetation, the microclimate, and biodiversity.

As shown in Figure 8, the third most important physical characteristic of water features is their location. The proper placement of water features optimizes their ecological benefits by providing habitats for wildlife and significantly improves the microclimate by reducing the temperature and enhancing outdoor comfort through evaporation and shading [10,17,94]. Finally, the lowest impact of water features on ecological criteria was attributed to texture. Soundscapes with textured characteristics improve human wellbeing by conferring visual aesthetics and sensory interactions [95]. Additionally, texture significantly affects human perception and fosters more biophilic interactions with nature [96].

According to the results of this study, planners and designers should integrate ecological criteria into urban planning in order to improve the sustainability of arid cities. Similarly, Ibes [71] demonstrated the importance of urban ecosystem services for both human and environmental health. There is a growing consensus that ecological considerations should be integrated into the policy of planning and designing urban parks. In addition, in arid and warm regions, establishing scientific foundations and using ANP for quantitative indicators is essential in the early stages of urban green–blue infrastructure planning [76]. Moreover, by using the ANP results, urban planners, landscape architects, and designers can choose the most effective alternative with the greatest impact on ecological criteria.

Given the focus of this study on developing a multidecision-making approach for evaluating ecological impacts, there is a possibility that the effect of temperature, humidity, and wind speed are also considered. These key parameters influence and interact dynamically with the microclimate. Fluid mechanics studies these parameters and calculates and models them to quantify their overall effects on the environment. For accurate modeling of these parameters, advanced CFD simulations are typically required. However, conducting such detailed fluid mechanics modeling is beyond the scope of this research. Therefore, detailed fluid mechanics modeling can be studied in future research. In addition, future research should focus on the use of cognitive science to evaluate the impact of water features on human behavior and social interactions. Observational studies can be conducted to determine how people interact around water features compared with other urban green spaces. Additionally, they can be used to evaluate the frequency, duration, and nature of social interactions.

5. Conclusions

This study evaluated the design of urban water features from an ecological perspective using ecological criteria, namely, microclimate, human wellbeing, greenery, and biodiversity. In addition, water features' ecological impacts were evaluated comprehensively and quantitatively using a multicriteria decision-making approach. The ANP was used as a decision-making methodology to assess water features' effects on urban landscape ecology. In this evaluation, landscape architectural parameters and ecological influential criteria were combined.

An innovative framework for comparing the ecological impacts of water features on the microclimate, human wellbeing, greenery, and biodiversity was established, marking the first comprehensive study of its kind. While previous research addressed water features' ecological impacts individually, our study offers the first comprehensive comparison. The findings of this study present a comparative analysis of the physical characteristics and ecological criteria of water features. The indication was that water features have more impact on two ecological criteria, namely, the microclimate and human wellbeing. In addition, it was revealed that vegetation and the scale of water fountains have a greater impact on their ecological benefits. Vegetation significantly enhances water features' ecological benefits, particularly in reducing temperature and increasing humidity. Also, water features have a positive impact on improving the surrounding vegetation and biodiversity, which shows the two-way effect of water features and vegetation. The effect of water features' scale is also remarkable, larger ones having a greater positive impact on the microclimate and other ecological criteria.

This method can be used as a framework to guide landscape architects, designers, urban planners, and policymakers in the design of future water features in urban areas or to evaluate existing plans. This study will pave the way for ecological water features' design and the comparison of design alternatives.

Supplementary Materials: The following supporting information describing the water features of the Koohsangi Park can be downloaded at: https://www.mdpi.com/article/10.3390/land13111799/s1, Figure S1: Water feature A1; Figure S2: Water feature A2; Figure S3: Water feature A3; Figure S4: Water feature A4; Figure S5: Water feature A5; Figure S6: Water feature A6; Figure S7: Water feature A7; Figure S8: Water feature A8; Figure S9: Water feature A9; Figure S10: Water feature A10.

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