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Statistical Approach to the Problem of Selecting the Most Appropriate Model for Managing Stormwater in Newly Designed Multi-Family Housing Estates

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Abstract: Stormwater is a valuable resource, whose management in harmony with nature is one of the main challenges of modern water management. The problems encountered are additionally exacerbated by the lack of space for the development of sustainable drainage systems. For that reason, new housing estates should be designed considering efficient stormwater management. This paper assesses five stormwater management models to determine the statistically most appropriate model for managing stormwater in newly designed multi-family housing estates using multi-criteria analysis. Various options were assessed by means of the scoring method based on six groups of criteria (political, economic, social, technological, legal, and environmental). The research considered the different views and priorities of the experts involved in stormwater management in Poland. A survey conducted among them showed that the statistically most suitable way of managing stormwater is its infiltration into the ground with the use of infiltration basins or tanks. Only if the possibility of their application is excluded, should the application of other models of stormwater management, especially its retention, be considered. It is expected that the research results presented in this paper will be a guide for investors and developers, and their use will allow people who are not experts in the field of stormwater management to make appropriate decisions.

Keywords: drainage system; multi-criteria decision-making; multi-family buildings; scoring method; stormwater management

1. Introduction

Stormwater management in harmony with nature should be one of the main goals of sustainable water management [1,2]. Therefore, it is necessary to take measures aimed at increasing the efficiency of underground infrastructure management and at reducing the risk associated with its malfunctioning [3]. In addition to typical procedures aimed at maintaining or improving the good technical condition of networks and facilities [4], and at ensuring channel self-cleaning [5], a number of measures should be considered. These include the following: reduction of the stormwater runoff to the receiving surface water bodies [6], delay of stormwater runoff from the catchment area [7], reduction of stormwater pollution [8], prevention of the adverse effects occurring in stormwater receivers [9], restoration of ecosystems to their pristine state [10], and protection against floods and drought [11], as well as ensuring the economic efficiency of drainage investments [12].

The implementation of the tasks presented above is possible through an application of systems supporting the functioning of a conventional drainage system or enabling its complete elimination [13]. This can be, for instance, low-impact development (LID) facilities [14]. The idea of "sponge cities" is also getting more and more popular [15]. However, a problem is the lack of space available for the development of surface facilities, which is particularly noticeable in city centers [16]. For this reason, new housing estates on the outskirts of cities should be planned considering the need for efficient stormwater management. The lack of the application of individual drainage system solutions at the development planning stage in a given area may prevent their implementation in the future. As a consequence, significant amounts of stormwater will be discharged beyond the drained catchment area, increasing the risk of flooding [17,18] and preventing the use of this valuable resource [19].

Multi-criteria decision-making methods may support rational investment decisions, considering both the individual stages of the project implementation and its operation. Their application facilitates a systemic and interdisciplinary approach to a given problem and makes it possible to consider all criteria that determine the selection of a specific design solution. A number of studies on the use of multi-criteria decision-making methods in stormwater management have been conducted around the world [20,21]. These studies, however, included systems dedicated to stormwater management at the point where the runoff occurs and concerned specific locations of the system, examples of which were presented by Li et al. [22] and Jia et al. [23]. As a consequence, their results cannot be directly applied to catchments with different characteristics. In addition, the examples of using multi-criteria decision-making methods presented in the literature are usually limited to environmental, technical, economic, and social criteria [24]. However, a comprehensive analysis of the rationality of the application of various design options of the drainage system also requires consideration of political and legal criteria. Earlier studies showed that they could have a significant impact on the implementation process of sustainable drainage systems and the selection of specific solutions [25]. It should be also noted that in Polish conditions the drainage of stormwater through underground canal systems and its quick discharge to the receiver is the dominant method of stormwater management [26]. Therefore, one should not expect a sudden change in the approach to stormwater management within urban catchments, which will enable the replacement of conventional drainage systems with LID facilities. For this reason, the presented research focused on the assessment of sustainable systems that can be used within conventional drainage systems.

In a situation where an analysis concerns a strictly defined location of the system, it is reasonable to make an initial pre-selection of the decision options and limit their set to those whose implementation under given conditions will be technically and economically justified [27]. This selection may be carried out, for example, on the basis of the ground and water conditions prevailing in a given area [28], and the size of the area available for system development [29]. The size and the way of managing the drained catchment are also important [30]. In many cases, it may be necessary to divide it and consider the issue of stormwater drainage in each of the distinguished parts as a separate decision problem. However, this requires the entire process of assessing individual design options to be repeated at least several times. In such a situation, the hydrodynamic model of the catchment in question is also often developed, and the obtained results of the hydrodynamic simulations are considered when assessing individual decision options. The application of such an approach is time-consuming and generates high costs, which discourages potential investors. Additionally, consideration of all potential solutions is difficult due to a wide range of available methods of stormwater management, including a number of systems dedicated to stormwater harvesting [31,32], as well as its retention and infiltration into the ground [33,34]. The complexity of the decision problem is also important [35]. For this reason, it is reasonable to combine devices with similar requirements and the range of application into groups in order to limit the required scope of the analysis.

Considering the above, the aim of the study was to assess a range of stormwater management models for the purpose of determining the statistically most appropriate model for managing stormwater in newly designed multi-family housing estates. The choice of the catchment type was dictated by the relatively predictable characteristics of stormwater from the residential catchments and the significant independence of the application of the solutions from the good will of individual system users. The analysis covers five models of stormwater management, including the conventional model and four sustainable models. Six groups of criteria were considered as decision criteria: political, economic, social, technological, legal, and environmental. The scoring method, which is one of the multi-criteria decision-making methods, was applied as a tool.

2. Materials and Methods

2.1. The Decision Model

Decision making is a process whose effect is to select one of the feasible solutions of the decision problem [36], which can be defined as a situation in which the decision-maker has to make a choice. This process includes the following steps: definition of the problem and the resulting purpose of the analysis, identification of decision options, indication of the most beneficial one in light of the adopted decision criteria, as well as its implementation, and assessment of the effects of the actions taken [37]. This paper focuses on the first three steps of the decision-making process related to the choice of stormwater management model (Figure 1). As noted in the Introduction, the main purpose of the analysis is to determine the statistically most appropriate model for managing stormwater in newly designed multi-family housing estates. In order to achieve this purpose, it was necessary to determine the remaining elements of the decision model, i.e., the theoretical representation of the part of reality that describes the decision problem [38]. These elements include possible decision options and decision criteria that can be organized into clusters [39].

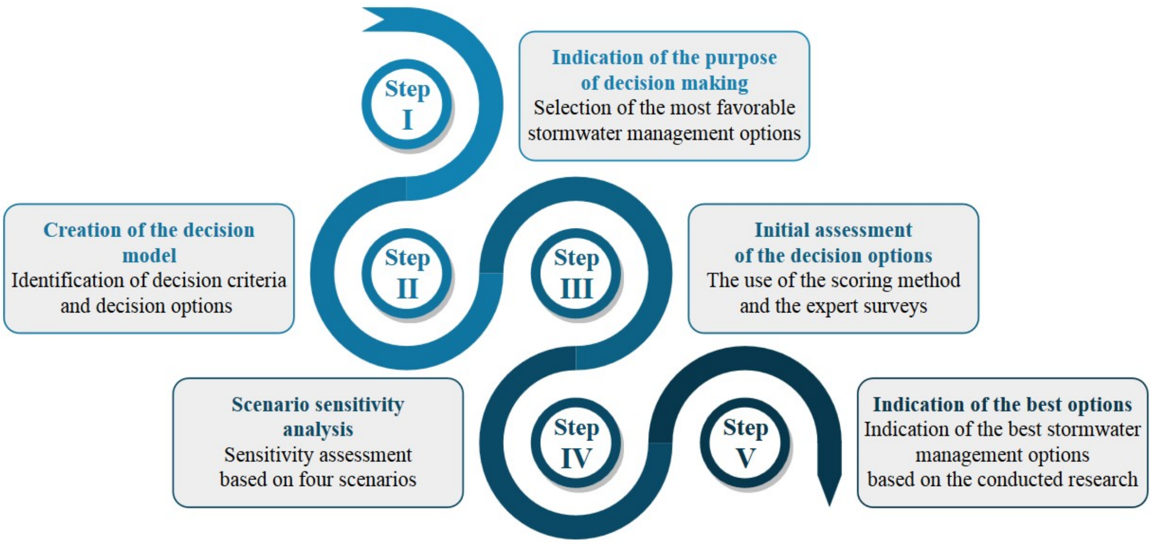

Figure 1. The procedure for selecting the most advantageous method of stormwater management discharged from the area of newly designed multi-family housing estates.

Based on a detailed analysis and synthesis of the state of knowledge about stormwater management in Poland, it was found that the decision criteria (C_j) determining the choice of a specific stormwater management model, can be classified into six groups, including political, economic, social, technological, legal, and environmental criteria. The identified groups of criteria turned out to be identical to those indicated in the previous stage of the research as part of the political, economic, social, technological, legal, and environmental (PESTLE) analysis [25]. For this reason, it was assumed that the individual decision criteria were also the same as the factors determining the implementation of sustainable drainage systems, which were identified in the PESTLE analysis. These factors are summarized in Figure 2. Due to the clear definition of criteria and the assessment of individual options based on the same criteria, each result was determined objectively and uniformly, and the results did not depend on personal experience and interpretations.

C_{P1}: The level of administrative obstacles associated with the implementation of stormwater management system
C_{P2}: The promotion of sustainable solution applications for the drainage infrastructure by local governments
C_{P3}: The strategy for implementing EU legislation in the field of stormwater management
C_{P4}: The strategy for the implementation of sustainable development principles
C_{P5}: The strategy of supporting sustainable drainage systems

C_P: Political criteria

C_{Ec1}: The level of benefits associated with the application of drainage infrastructure facilities
C_{Ec2}: The level of operational costs of stormwater systems
C_{Ec3}: The level of investment expenditure incurred for the construction of drainage systems
C_{Ec4}: The level of subsidies for the construction of drainage systems
C_{Ec5}: The manner in which drainage infrastructure is managed

C_{Ec}: Economic criteria

C_{S1}: The readiness for cooperation between groups of different participants in the decision-making process associated with investing in a drainage system model
C_{S2}: The level of awareness concerning the use of sustainable drainage systems
C_{S3}: The residents' safety level, which can be ensured thanks to the use of drainage infrastructure
C_{S4}: The level of social losses
C_{S5}: The susceptibility of the society to use innovative water management solutions

C_S: Social criteria

C_{T1}: The availability of the footprint area for the construction of individual systems
C_{T2}: The supply of sustainable stormwater management systems
C_{T3}: The reliability of used drainage systems and the required maintenance frequency
C_{T4}: The level of experience in the operation of sustainable stormwater management systems
C_{T5}: The level of hydraulic overload of existing drainage systems

C_T: Technological criteria

C_{L1}: The preferences concerning the use of sustainable technologies in the field of public procurement
C_{L2}: The scope of regulations in the field of cooperation between local governments, industrial and scientific centers
C_{L3}: The cohesion and stability of legal provisions concerning stormwater management
C_{L4}: The range of requirements in applicable land development plans
C_{L5}: The scope of requirements in the field of drainage impact on the environment

C_L: Legal criteria

C_{En1}: The level of legal protection of the environment and natural resources
C_{En2}: The possibility of reducing stormwater run-off to the receiver
C_{En3}: The level of capacity of drainage systems to supply underground water resources and an increase of biodiversity in urban areas
C_{En4}: The scale of how the drainage infrastructure impacts the environment
C_{En5}: The quality of stormwater, the water of the receiver and the drained area

C_{En}: Environmental criteria

Figure 2. Decision criteria included in the analysis (developed on the basis of [25]).

Considering the indicated decision criteria made it possible to identify devices whose application in a given type of catchment will bring the greatest benefits for people and the surrounding environment. As part of the research, five decision options were considered. They are presented in Figure 3. Option 1 (O_1) includes the use of conventional drainage systems. The other four decision options are sustainable stormwater management models.

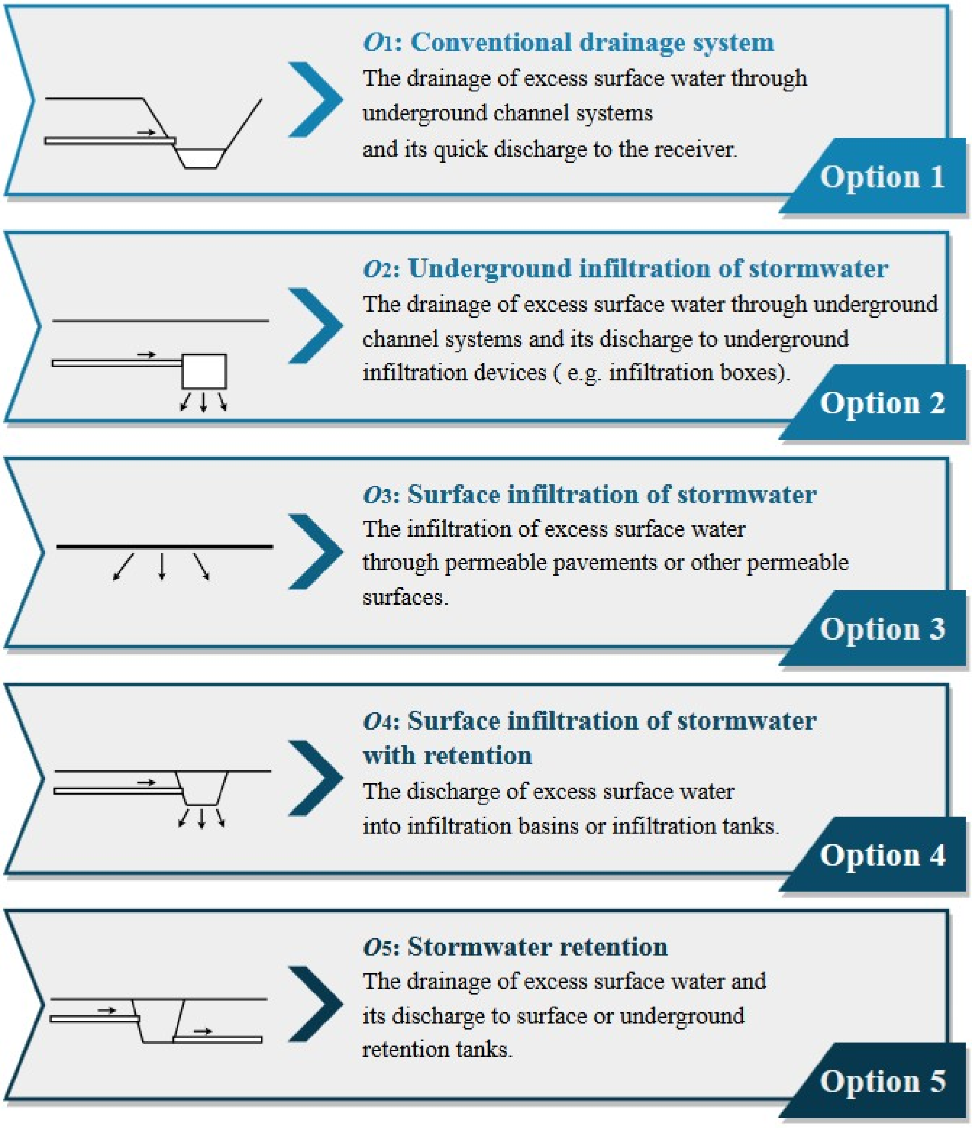

Figure 3. Decision options included in the analysis.

2.2. The Scoring Method

The assessment of the stormwater management models for the purpose of determining the statistically most appropriate model for managing stormwater in newly designed multi-family housing estates was made using the scoring method. Its application made it possible to visually represent the results based on a set of criteria. This research method was used as early as the eighteenth century, and its essence is based on summing up direct assessments of individual decision options in relation to subsequent detailed decision criteria [40]. The task of the decision-maker in this case is only to assign specific numerical values to the considered decision options. Their permissible range may differ depending on the importance of the criterion against which the options are assessed [41]. Due to the ease of application, the scoring method is one of the most frequently used multi-criteria decision-making methods. It is also applied when it is necessary to assess environmental problems [42], including those relating to water and sewage management [43].

Over the years, the technique described has undergone numerous modifications, as a result of which several varieties have been created, differing mainly in the method of assigning assessments [44]. As part of the research, the version of the method whose assumption was to evaluate individual decision options on the basis of the obtained sum of the products of the assessments assigned to them, and the weights assigned to the individual decision criteria, was used. The maximum number of points that the decision-maker can assign to the assessed decision options is in this case the same for each criterion, and the significance of the decision criteria is expressed by weights whose sum is equal to 1.0.

Global assessment (v_i) of the considered options for the drainage system (O_i) in light of the adopted criteria (C_j) can then be determined on the basis of Equation (1) [44].

$$v_i = \sum_{j=1}^{s} \left[w_j \cdot C_j(O_i) \right], \tag{1}$$

where: v_i—global assessment of the analyzed decision option (O_i), w_j—weight assigned to a given decision criterion (C_j), s—total number of decision criteria included in the research, and $C_j(O_i)$—number of points assigned to the analyzed option (O_i) in relation to the decision criterion (C_j).

The assessment of the considered decision options of the drainage system was made on the basis of a survey conducted among a group of 16 experts, consisting of representatives of the scientific community and industry, drainage system operators, and representatives of local governments. Among the representatives of the scientific community, there are people conducting research on stormwater management with outstanding scientific achievements in this field. The industry representatives are the employees of the companies producing pipes and other systems for land drainage purposes. The drainage system operators are people who have to solve problems of the functioning of the existing drainage infrastructure on a daily basis. The last group are employees of departments related to environmental protection. All members of the expert team have been involved in stormwater management for at least five years. Their required number was based on [45]. The involvement of professionals in the field of stormwater management in the decision-making process allowed an objective assessment of individual options in relation to the considered type of catchment.

As part of the research, the experts assigned assessments to both individual options and the analyzed decision criteria. The research used a seven-point Likert scale, according to which, the value "1" corresponded to the lowest mark, while the value "7" was the highest mark. The undertaken research method required transforming the obtained criteria assessments to a form in which their sum would be equal to 1.0, and they themselves would take values from 0 to 1. The normalization of the results was carried out in accordance with Equation (2).

$$w_j = \frac{P(C_j)}{\sum_{j=1}^{s} \left[P(C_j) \right]}, \tag{2}$$

where: $P(C_j)$—the number of points assigned to a given decision criterion (C_j) in light of the established purpose of the analysis (P).

Based on the calculated values of the weights (w_j) and the number of points ($C_j(O_i)$) assigned to decision options, their global assessments (v_i) were determined, for which Equation (1) was used. Due to the fact that the expert team was a group of independent people, it was assumed that individual global assessments of the experts would be aggregated [46]. For this purpose, the arithmetic mean was applied. For comparison, the medians of assessments obtained by the considered options were also determined.

2.3. Sensitivity Analysis

Next, the impact of changes in individual assessments on the final ranking of the considered options was examined. The purpose of this analysis was to minimize the subjectivity associated with the decision-making process. To this end, the following scenarios were analyzed:

- Scenario 1—the decision is made on the assumption that all criteria have the same influence on the subject of the analysis,
- Scenario 2—the decision is made based on only one group of criteria that has the greatest impact on the subject of the analysis,
- Scenario 3—the decision is made on the basis of three groups of criteria with the greatest impact on the subject of the analysis,
- Scenario 4—the decision is made on the basis of criteria not included in Scenario 2.

On the basis of the research, the most favorable models of stormwater management in newly designed multi-family housing estates were then indicated.

3. Results and Discussion

3.1. Initial Assessment of the Decision Options

The results of the survey conducted among experts indicate a significant potential of sustainable stormwater management systems. This confirms the previous findings, according to which, these systems can be successfully used in different catchments [23,47]. In the case of aggregation of assessments using the arithmetic mean, only the option assuming the use of conventional drainage systems (O_1) obtained the mean global score below 4.0 (Table 1). The highest assessments, exceeding 4.5, were given to the options assuming surface infiltration of stormwater with retention (O_4) and stormwater retention only (O_5).

Table 1. Global assessments (v_i) obtained by the decision options (Oi) (designations as in Figure 3).

Option	Average Global Assessment (v_i)	Position in Ranking	Median of Global Assessments	Position in Ranking
O_1	3.879	5	3.964	4
O_2	4.254	3	4.194	3
O_3	4.070	4	3.946	5
O_4	4.525	1	4.522	2
O_5	4.503	2	4.593	1

Due to relatively small differences between the assessments assigned to individual decision options, replacing the arithmetic mean with the median resulted in a slight change in the final ranking. In this situation, the option O_5 obtained a slightly higher score than O_4, however, both of these decision options still had a clear advantage over the other considered methods of stormwater management. The positions taken by the conventional drainage system (O_1) and the option assuming surface infiltration of stormwater into the ground (O_3) were also changed. This leads to the conclusion that the use of sustainable drainage systems that do not have the capacity to store stormwater is not, in the opinion of experts, an effective method of stormwater drainage. This is despite the promotion of such systems in other parts of the world [48].

As part of the research, the presence of outliers of global assessments for individual decision options was also checked. For this purpose, Statistica 13.3 software was used. However, the analysis performed in relation to the median with a coefficient for outlier observations of 1.5 showed no such values (Figure 4).

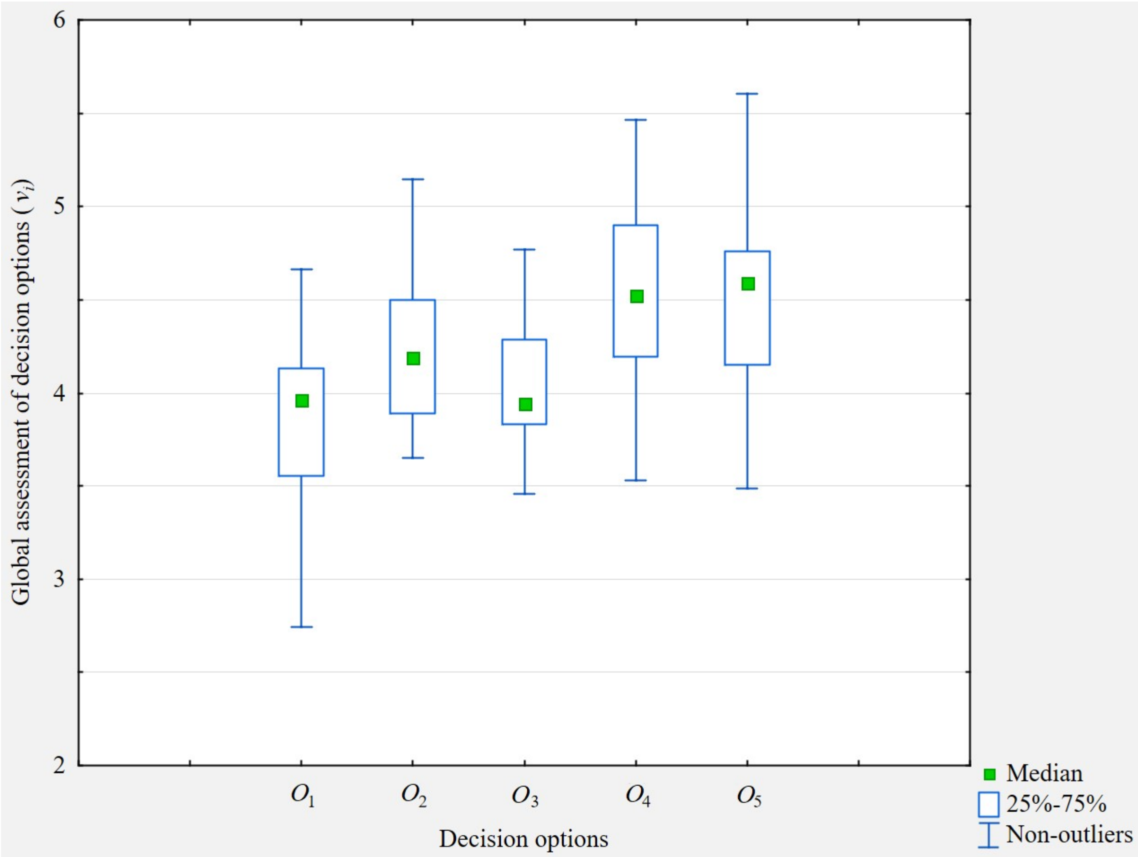

Figure 4. The obtained values of global assessments (v_i) of the decision options (O_i) (designations as in Figure 3).

The largest differences between the assessments assigned by individual experts ($\Delta v_{i\text{max-min}}$) were noted for the option assuming stormwater retention ($\Delta v_{5\text{max-min}}$ = 2.12). However, it is worth noting that despite such a wide range of results, it only twice obtained a global score exceeding 5.0 (Figure 5). The results of 11 surveys were assessments in the range of 4.0 to 5.0, of which as many as eight obtained results at the level of 4.5–5.0. In the opinion of most experts, this option is therefore characterized by significant application possibilities in urban catchments. However, it should be emphasized that three experts rated the option O_5 below 4.0, and the lowest global score obtained was, in this case, almost 38% lower than the highest. This leads to the conclusion that, according to some specialists, the enormity of the advantages of stormwater retention systems is not able to compensate for their weaknesses, especially those related to the discharge of stormwater runoff outside the catchment area. The analysis of the option consisting in surface infiltration of stormwater with retention ($\Delta v_{4\text{max-min}}$ = 1.94) and the option assuming the use of conventional drainage systems ($\Delta v_{1\text{max-min}}$ = 1.92) also showed a significant diversity of the obtained assessments. The option O_4 was given an assessment above 5.0 three times, and in the case of 10 surveys, the results were at the level of 4.0–5.0, half of which were in the range of 4.5–5.0. Three experts, as was the case with option O_5, assigned option O_4 scores below 4.0. The configuration of the global assessments obtained by options O_4 and O_5 is therefore similar, which proves the significant potential of both of these solutions. This also suggests the need to carry out a detailed analysis of the ground and water conditions in the catchment each time in order to determine the legitimacy of their application in a given location. These conditions play a significant role in the application of systems that can be used in flood protection [49].

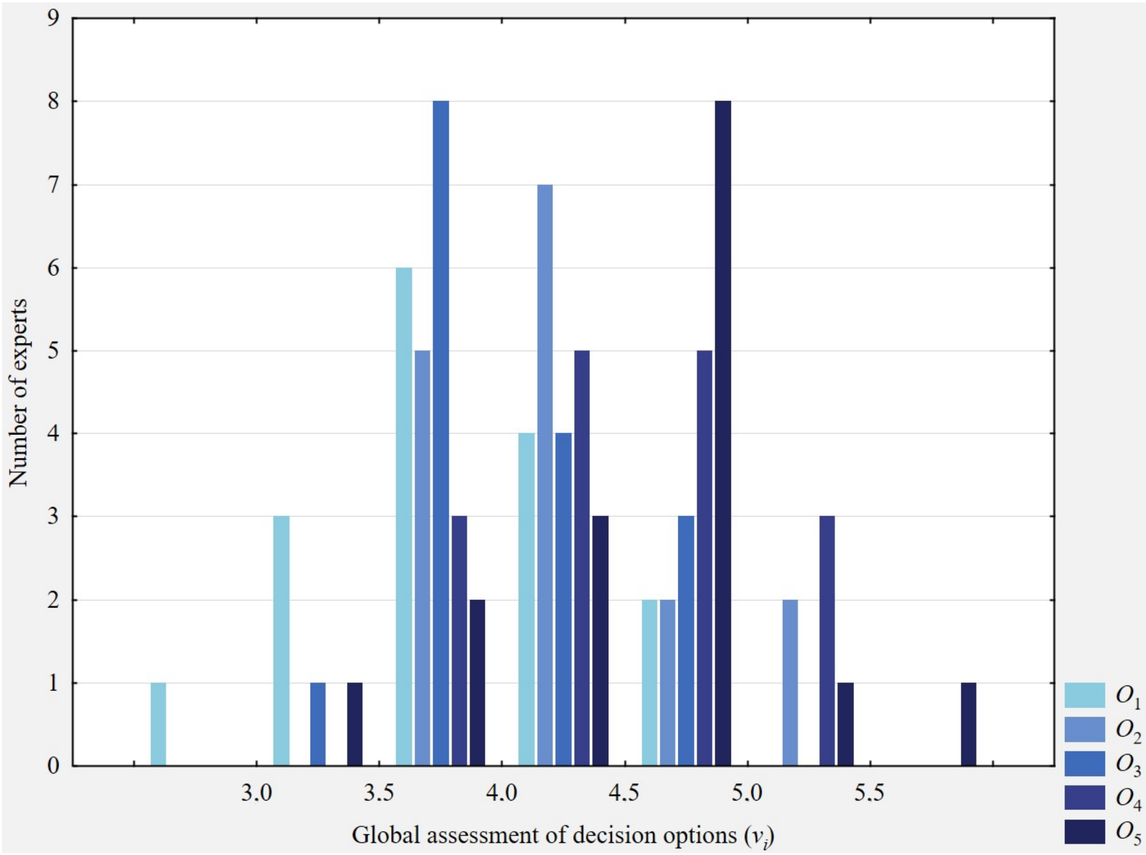

Figure 5. Distribution of the obtained values of global assessments (v_i) of the decision options (O_i) (designations as in Figure 3).

On the other hand, the conventional drainage system (O_1) was the only one to receive a global assessment below 3.0 from one of the experts. Nine consultants assessed it as 3.0–4.0, and as many as six scored it above 4.0. In the opinion of most specialists, it is the option that has the least advantages compared to its weaknesses. However, there is still a group of professionals in Poland who do not allow for the possibility of a wider application of sustainable drainage systems. These preferences may result both from the fear of operational requirements posed by sustainable drainage systems and from significant administrative obstacles related to their implementation. The obtained results also confirm the conclusions drawn by Kaplowitz and Lupi [50], according to which, each stakeholder has its own priorities, and therefore clearly prefers some solutions over others.

Underground infiltration systems, on the other hand, are characterized by a clearly smaller scope of the obtained global assessments ($\Delta v_{2\text{max-min}} = 1.49$). Option O_2 was rated above 5.0 twice. The highest score awarded to it was 8% and 6% lower than in the case of options O_5 and O_4, respectively. Nine experts awarded it a score of 4.0–5.0, of which only two above 4.5, and as many as five scored it below 4.0. Therefore, it can be concluded that the option assuming underground infiltration of stormwater is a relatively advantageous solution when other models of sustainable stormwater management cannot be used. Such a situation may occur, for example, in the case of insufficient availability of land for the development of other systems and favorable soil and water conditions that allow stormwater infiltration into the ground. In other cases, retention facilities (O_5) and surface infiltration systems with retention (O_4) should be used.

The most similar results were obtained in the case of surface infiltration systems ($\Delta v_{3\text{max-min}} = 1.32$). None of the experts gave option O_3 a score above 5.0, seven of them rated it at the level of 4.0–5.0, and most (nine) scored it below 4.0. This confirms the relatively low application possibilities of these systems, especially in the case of the drainage of catchments characterized by a large area. However, this solution can be successfully used as a replacement for impermeable surfaces, for example in parking lots, access roads, or pavements. Such an approach will reduce the amount of stormwater discharged to other systems, thus reducing their required volume and/or infiltration area, and will additionally constitute an attractive diversification of the local landscape.

Global assessments (v_i), which were obtained for the considered decision options, were determined, inter alia, by weights assigned to individual decision criteria (w_j). The results obtained from individual surveys were interpreted separately, which resulted from the adopted method of their aggregation. However, in order to present the general tendency of the influence of individual elements on the obtained results, it was decided to present the average values of the weights of the criteria (Table 2).

Table 2. Average weights of decision criteria assigned to individual groups (designations as in Figure 2).

Group of Decision Criteria	Total Weight of Criteria
Political criteria (C_P)	0.156
Economic criteria (C_{Ec})	0.184
Social criteria (C_S)	0.153
Technological criteria (C_T)	0.172
Legal criteria (C_L)	0.161
Environmental criteria (C_{En})	0.174

The research showed that economic criteria (C_{Ec}) have the greatest impact on the subject of the analysis. The level of investment expenditure incurred for the implementation of a given project (C_{Ec3}), and the scale of economic benefits that can be achieved through the use of drainage infrastructure (C_{Ec1}) were considered the most important by the experts. It is worth noting that as many as four elements from the group of economic criteria had average weights in the range of 0.035 to 0.041, which allows one to believe that financial aspects are of key importance for the selection of stormwater management in newly designed multi-family housing estates in Poland. Therefore, it is important to strive to minimize the amount of investment expenditure necessary to implement stormwater retention and infiltration systems, which may be enabled by their widespread use, especially since in other European countries the economic criteria have long been relegated to the background [51]. In the case of economic criteria, weight at a level of 0.030 was obtained only by the factor related to the method of managing the drainage infrastructure (C_{Ec5}). This confirms that this element is characterized not only by a low impact on the implementation of sustainable drainage systems [25], but also by negligible importance in terms of the choice of stormwater management in urban catchments.

Environmental criteria (C_{En}) were in the second most important place. In the conducted PESTLE analysis [25], they were not considered important for the implementation of sustainable drainage systems. However, experts admitted that elements such as the possibility of reducing the amount of stormwater directed to the receiving water bodies (C_{En2}) or the quality of stormwater and the surrounding environment (C_{En5}) have a significant impact on the effectiveness of stormwater management in a given area. As a result, these criteria were given weights averaging 0.039 and 0.037. On the other hand, the remaining environmental criteria received assessments at levels of 0.032–0.033, which places them slightly below the global average of weights of all detailed decision criteria.

The experts also included technological criteria (C_T) among the factors with a significant impact on the choice of stormwater management model. The significant importance of these criteria is conditioned mainly by the high significance of the criteria related to the availability of land for the development of individual systems (C_{T1}) and the level of overload of the existing drainage systems (C_{T5}). It is worth noting that criterion C_{T1} received the highest assessment among all the considered decision criteria (w_{T1} = 0.043). The other technological criteria (C_{T2}, C_{T3}, C_{T4}) were assigned weights below the global average.

On the other hand, the legal criteria (C_L) were assigned slightly less importance, despite the fact that they were considered to be of key importance for the implementation of sustainable drainage systems [25]. Although the significance of the element related to the requirements of the applicable land development plans (C_{L4}), was appreciated, the other criteria assigned to this group did not gain much recognition in the eyes of the experts. This applies in particular to regulations regarding cooperation between academic centers and other units (C_{L2}). This criterion was weighted at a level of 0.026, which puts it in last place in the hierarchy of importance of the considered criteria of the decision-making process.

In the case of political factors (C_P), attention was paid to the criterion of the level of administrative obstacles that can be encountered in implementing the considered stormwater management options (C_{P1}). The other political criteria were assigned weights below the global average. On the other hand, two elements were distinguished among the social criteria, i.e., the level of residents' safety (C_{S3}) and the scale of social losses resulting from improperly conducted stormwater management (C_{S4}). The significance of the remaining elements assigned to this group was assessed so low that, in general, social criteria were considered to be the least important in terms of the selection of the stormwater management model in newly designed multi-family housing estates. This fact is worth emphasizing because the research concerned residential catchments. It is within such catchments that a clear impact of social acceptance and the susceptibility of residents to particular solutions should be expected. The experts concluded, however, that in the case of multi-family buildings, the decision to use a central stormwater management system is made regardless of the will of the residents, which confirms the legitimacy of adopting this type of housing estate as the subject of the research.

The conducted analysis of the rationality of the application of the stormwater management models in newly designed multi-family housing estates also showed that the weights assigned to individual criteria were not the only parameter determining their impact on the v_i value. Of great importance were also the assessments of decision options, which in the case of the applied research method, were not subject to the standardization process. As each individual expert judgment was considered correct, this analysis was not based on individual judgments, but on the overall results obtained within individual thematic groups. The charts (Figure 6) present the sums of products of the criteria weights and the decision option assessments. As can be seen from the presented data, in the case of several questionnaires, values clearly different from the others were observed. However, their rejection does not significantly affect the final analysis results (Table 3).

In addition, in order to ensure the possibility of comparing the option assessments obtained in relation to different groups of criteria, the average results from all surveys (obtained after rejecting the surveys generating outliers and extreme values of product sums) are also presented (Figure 7).

When analyzing the presented results, it can be noticed that the environmental criteria have the greatest impact on the global assessments (v_i) of the decision options (O_i). It is worth noting that these criteria also had a significant impact on the selection of the stormwater management system in the case of stormwater drainage from the roof of a single-family residential building [27]. In the case of environmental criteria, the average result obtained by the option assuming surface infiltration of stormwater with retention (O_4) is almost 135% higher than the assessment of the conventional drainage system (O_1). This is over 20% of its final score (v_4). Additionally, the sums of products obtained by the remaining sustainable options of stormwater management, especially those assuming stormwater infiltration into the ground, clearly exceed the score assigned to option O_1. Therefore, experts' opinions confirm that the use of conventional drainage systems within residential catchments causes significant damage to the surrounding environment. The only decision criterion in light of which option O_1 was highly assessed is the criterion of the quality of stormwater, the water of the receiver and the drained area (C_{En5}). This probably results from the fact that residential catchments have predictable characteristics, and stormwater discharges from such catchments are characterized by relatively low concentrations of pollutants compared to other types of catchment area [52,53].

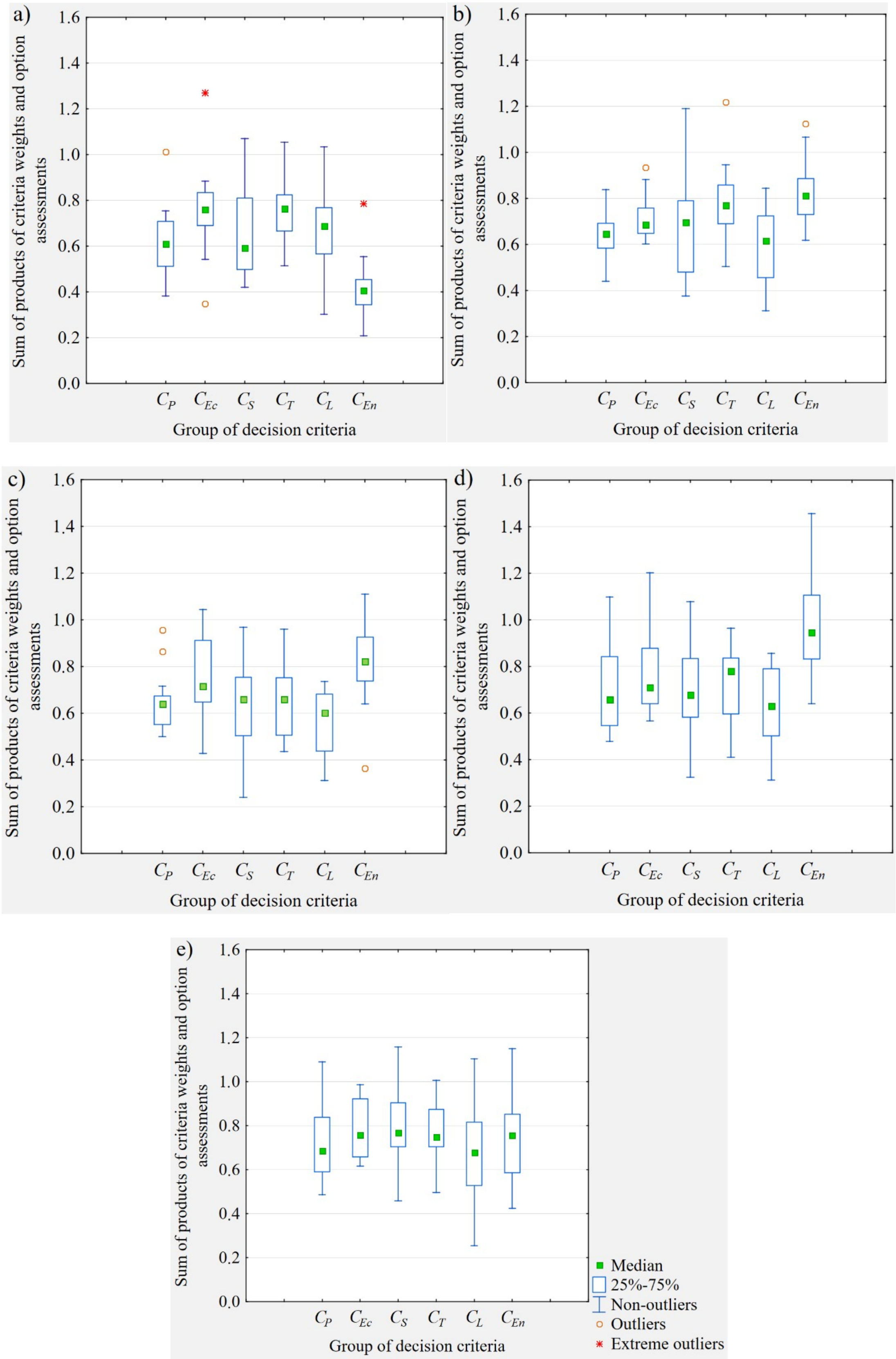

Figure 6. The sums of products of the criteria weights (w_j) and the decision option assessments ($C_j(O_i)$) obtained within the considered criteria groups: (**a**) option O_1, (**b**) option O_2, (**c**) option O_3, (**d**) option O_4, (**e**) option O_5 (designations as in Figures 2 and 3).

Table 3. Global assessments (v_i) obtained by the considered decision options (O_i) in the case of the rejection of questionnaires generating outliers and extreme values of the sums of products (designations as in Figure 3).

Option	Average Global Assessment (v_i)	Position in Ranking	Median of Global Assessments	Position in Ranking
O_1	3.737	5	3.827	5
O_2	4.213	3	4.240	3
O_3	4.011	4	3.949	4
O_4	4.429	1	4.483	2
O_5	4.397	2	4.543	1

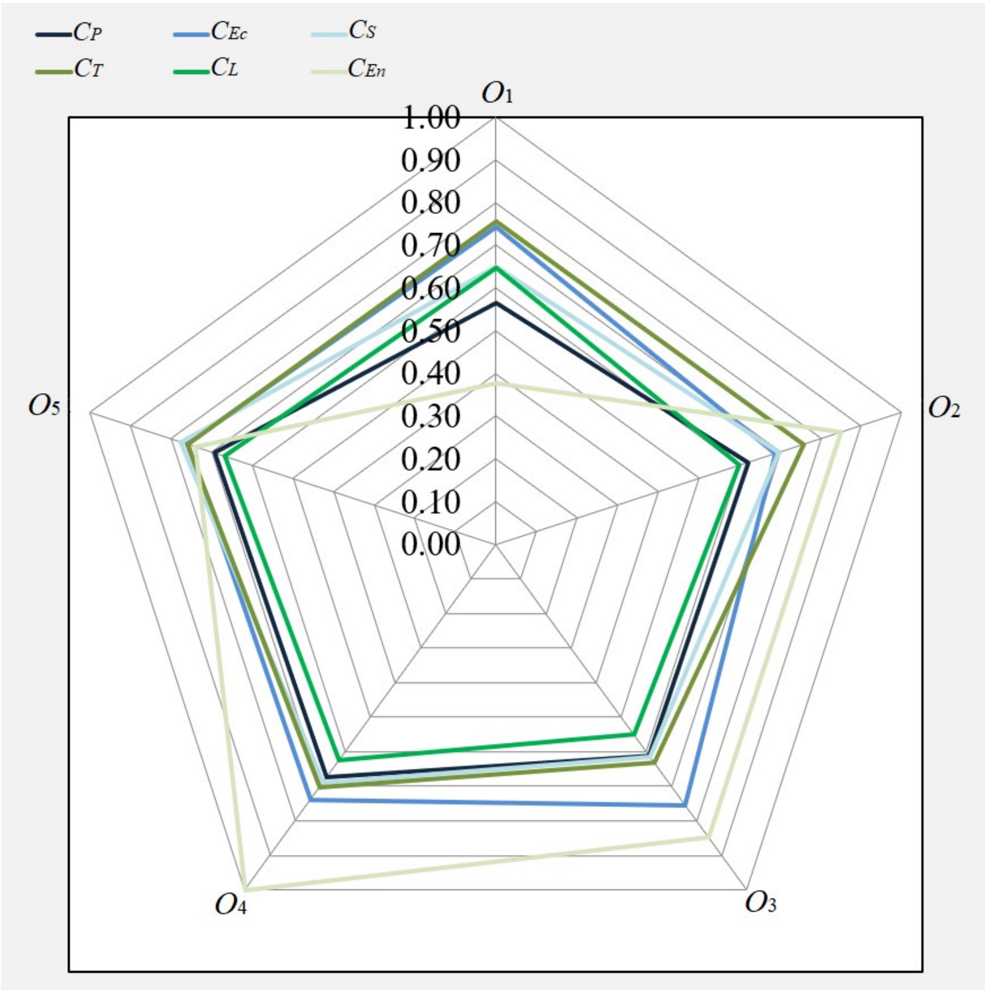

Figure 7. The average values of the sums of products of the criteria weights (w_j) and the assessments of options ($C_j(O_i)$) obtained within the considered groups of criteria (designations as in Figures 2 and 3).

Significantly smaller differences between the ratings obtained by individual options (O_i) were noted for the remaining groups of criteria. With regard to the legal criteria, options O_5 and O_1 were rated the highest. This is mainly due to the scores assigned to them in relation to the criteria regarding preferences in the area of public procurement (C_{L1}) the cohesion of the legal provisions (C_{L3}), and in the case of the stormwater retention systems (O_5), as well as the requirements regarding the impact of drainage infrastructure on the environment (C_{L5}). In light of the latter criterion, other sustainable stormwater managements models, especially O_4, were also highly assessed. However, the low scores assigned to them in relation to criteria C_{L2}–C_{L4} meant that they obtained slightly lower values of the sum of products. It is also worth noting that it is in the group of legal factors that the greatest differentiation of option O_5 assessments is noticeable, which is undoubtedly the result of the instability of the applicable legal regulations in Poland.

In terms of technological criteria, option O_3 was rated the lowest, and the sum of products obtained by it was mainly determined by insufficient availability of land for the development of such facilities (C_{T1}). In addition, this problem is exacerbated by the lack of retention capacity of systems intended for surface infiltration of stormwater into the ground (O_3), as a result of which they were rated much lower than other options for stormwater management, the implementation of which requires the reservation of significant areas (O_4 and O_5). It should also be emphasized that the option assuming stormwater retention (O_5), although its application is not always possible, obtained in this case one of the highest values of the sum of products. This results from a relatively high score assigned to it in relation to the criterion concerning the supply of innovative stormwater management systems (C_{T2}). This confirms that the use of retention systems is an effective way of managing stormwater within urban catchments, as already indicated by Ngamalieu-Nengoue et al. [54].

High values of the sums of products of the technological criteria weights and the option assessments were also noted in the case of options O_2, O_4, and O_1. The level of overload of the existing drainage systems (C_{T5}) was the most important for options O_2 and O_4. Option O_1 received the highest score in relation to criterion C_{T4} concerning the level of experience in the operation of drainage systems.

In turn, the social criteria are met, in the opinion of experts, primarily by options O_4 and O_5. Their high rating in relation to the criteria concerning the safety of residents (C_{S3}) and potential social losses (C_{S4}), which were assigned the highest weights (w_j), is noteworthy. Option O_5 was also given relatively high assessments in relation to other social criteria, however, in their case, option O_1 was rated higher. Its low rating in relation to criteria C_{S3} and C_{S4} prevented option O_1 from achieving a high position in the ranking. Option O_3 had the lowest average value of the sum of products of the social criteria weights and the option ratings. Both in its case and in the other considered options for stormwater management, the obtained ratings are very diverse. Therefore, it can be assumed that, in the opinion of some experts, this option also deserves recognition. It is also worth emphasizing that the rejection of questionnaires generating outliers of the sums of products of the other criteria weights and the ratings of the options in relation to these criteria slightly changes the ranking of decision options obtained in relation to social criteria. It is true that the highest value of the obtained sum of products still characterizes option O_5, however, reducing the rating of option O_4 by less than 3% results in its shifting to the third position in the classification.

The most even results were obtained for the group of economic criteria. This may be due to the fact that the costs of building and operating the same system may differ depending on local conditions, as indicated by Song and Chung [55] for the example of South Korea. For this reason, it may be beneficial to perform a detailed cost (C) and benefit (B) analysis as part of the ongoing investment process and to determine the B/C ratio [56]. The obtained values of this ratio can be the basis for comparing different devices representing the same stormwater management model and for choosing the one for which the B/C ratio is the highest.

As the most expensive (C_{Ec3}), the experts considered the systems for the underground infiltration of stormwater (O_2). As a result, option O_2 obtained the lowest sum of products of the economic criteria weights and the option assessments in relation these criteria. According to the experts, relatively high investment expenditure could also be incurred in the case of implementing options O_1, O_4 and O_5. However, these options received higher assessments in relation to other economic criteria. For example, options O_1 and O_5 were rated the highest in terms of the manner in which drainage infrastructure is managed, which is probably due to the large scale of implementations of these types of systems. Option O_4, on the other hand, owes its assessment to the high level of economic benefits associated with its use (C_{Ec1}). Additionally, in this case, the rejection of questionnaires generating outliers and extreme sums of products results in a change of the obtained ranking, but option O_2 remains the lowest assessed decision option.

Options O_4 and O_5, which have the highest global assessments (v_i), were also rated the highest in light of the political criteria. Both options were given particularly high assessments in relation to the criteria concerning the strategy for implementing EU regulations (C_{P3}) and the principles of sustainable development (C_{P4}), but in light of other political criteria, they were also assessed quite well. The lowest sum of products of the criteria weights and the system ratings was obtained in this case by the option assuming the use of conventional drainage systems (O_1). This is so despite the fact that their implementation generates the smallest administrative obstacles (C_{P1}), and a relatively high rating of this option in relation to criterion C_{P2} suggests a lack of sufficient promotion of sustainable drainage systems at the level of local government. It should also be emphasized that the rejection of the questionnaires generating outliers and extreme sums of products did not change the ranking of the considered options in relation to the political criteria. It is important because it is within this group of criteria that the greatest number of such values was determined.

When analyzing the results of the surveys, it can also be noticed that in the case of all options assuming infiltration of stormwater into the ground (O_2, O_3, O_4), the sums of products of the environmental criteria weights and the option assessments in relation to these criteria have the largest share in the global assessments (v_i). On the other hand, the least important role is played by legal criteria, despite the fact that the weights assigned to them by the experts are not the lowest that were obtained in the analysis. The latter have a minimal impact on the assessment of stormwater retention systems (O_5), where the most important are social criteria with the lowest values of assigned weights. The sums of products obtained in relation to technological criteria have the largest share in the assessment of conventional drainage systems (O_1), while the presence of environmental criteria results in their shifting to another position in the final ranking. Therefore, it is clear from the presented results that in the scoring method, both the weight of the criteria (w_j) and the assessment of individual options in relation to these criteria ($C_j(O_i)$) have an impact on the global assessments of the options (v_i).

3.2. Sensitivity Analysis

The sensitivity analysis confirmed that options O_4 and O_5 are the most advantageous ways of managing stormwater drained from the area of newly designed multi-family housing estates (Table 4). Their position in the final ranking of the options results from the scenario.

In the case of Scenario 1, where each decision criterion was assigned equal weights (w_j = 1/30), retention (O_5) turned out to be the most favorable method of stormwater management. This is mainly due to a significant increase in the impact of social criteria (C_P). Because of this, option O_5 was rated the highest among all the decision options. The systems dedicated to the infiltration of stormwater into the ground, O_4, O_2 and O_3, respectively, ranked further down in the assessment. Their high assessments, as was the case with the basic analysis, are primarily determined by the positive impact of such systems on the surrounding environment (C_{En}). In turn, the lowest global assessment (v_i) was obtained in this situation by option O_1, which confirms that it was the least favorable method of stormwater management. The sums of products obtained by this option in relation to technological (C_T) and social (C_S) criteria are indeed higher than in the case of infiltration systems. However, the extremely low assessment of this option in light of other criteria of the decision-making process is the reason for its shift to the last position in the ranking.

Option O_5 remains the most advantageous way to manage stormwater also when the average global assessments (v_i) determined solely on the basis of economic criteria (C_{En}) are considered (Scenario 2). When analyzing the medians of the global assessments (v_i), it can be noticed that the final ranking of the options (O_i) is completely different than in the case of using the arithmetic mean. The highest median assessments were observed for the conventional drainage system (O_1), while option O_5 moved to the penultimate position in the ranking. Changes in the positions taken by these options probably result from small differences between the sums of products of the criteria weights and the option assessments in relation to these criteria. However, it should be emphasized that in the case of two options, the results turned out to be so stable that replacing the arithmetic mean with the median did not change their positions. This applies to option O_2, whose extremely low assessment was mainly determined by the necessity to incur the largest investment expenditure for its implementation, and option O_4, which owed its high position to the significant economic benefits that could be achieved through its implementation.

Table 4. The results of the sensitivity analysis (designations as in Figure 3).

Option	Average Global Assessment (v_i)	Position in Ranking	Median of Global Assessments	Position in Ranking
Scenario 1				
O_1	3.940	5	3.967	5
O_2	4.248	3	4.217	3
O_3	4.079	4	4.067	4
O_4	4.517	2	4.483	2
O_5	4.527	1	4.617	1
Scenario 2				
O_1	4.131	3	4.296	1
O_2	3.954	5	3.792	5
O_3	4.122	4	4.094	3
O_4	4.177	2	4.114	2
O_5	4.303	1	4.003	4
Scenario 3				
O_1	3.647	5	3.668	5
O_2	4.400	2	4.372	2
O_3	4.218	4	4.143	4
O_4	4.632	1	4.743	1
O_5	4.343	3	4.277	3
Scenario 4				
O_1	3.823	5	3.872	5
O_2	4.338	3	4.189	3
O_3	4.056	4	3.970	4
O_4	4.612	1	4.501	2
O_5	4.556	2	4.608	1

The application of Scenario 3, whose assumption is to consider only the economic (C_{Ec}), environmental (C_{En}), and technological (C_T) criteria, results in a clear dominance of the option assuming surface infiltration of stormwater with retention (O_4). As in the case of the basic analysis, it is conditioned by its high assessment in relation to the second most important group of criteria. The second place in the ranking was taken by option O_2. Its shift to a higher position results from the fact that the research did not consider the political (C_P), legal (C_L), or social (C_S) criteria, in relation to which it was assessed significantly lower than the option assuming stormwater retention (O_5). For the same reason, option O_5 obtained a slightly lower global score (v_i). The last positions in the ranking were taken by options O_3 and O_1, which confirm that they do not meet the requirements of key importance for the subject of the analysis.

The analysis of the results determined under Scenario 4 showed that the economic criteria (C_{Ec}) were not the main determinants of the global assessments (v_i) of the considered decision options, despite the fact that the experts assigned them higher weights than the other groups of criteria. The final ranking of individual drainage systems is similar to the one obtained directly from the surveys. As in Scenario 2, this is due to the fact that the decision options (O_i) were assigned even sums of products of the economic criteria weights and the option assessments in relation to these criteria. The only difference is noted in the last two positions in the ranking based on the median of global assessments (v_i). In this case, the order of options O_3 and O_1 did not change compared to the ranking obtained on the basis of the arithmetic mean, which suggests that the rejection of the economic criteria results in an increase in the stability of the results.

4. Conclusions

The assessment of a range of stormwater management models, which was carried out using the scoring method, showed that the statistically most appropriate way to manage stormwater in newly designed multi-family housing estates is its surface infiltration with retention. This can be realized by implementing infiltration basins or tanks. However, it should be emphasized that the research described in this paper was focused on a specific type of catchment area. In the event that stormwater is drained from catchments showing different characteristics, for example, industrial areas, it may not be possible to use such facilities. In addition, the effectiveness of the use of the described devices is determined by the permeability of the ground and the location of the groundwater table, as well as the availability of land for their development, which means that even within residential catchments they cannot be used indiscriminately. For this reason, it is important to carry out successive research aimed at determining the hydrological conditions of the ground. As a result, it will be possible to create maps of potential locations of stormwater infiltration systems and to carry out a series of hydrodynamic simulations allowing for the assessment of the functioning of the designed system when the catchment is loaded with rainfall of different characteristics. It will also be useful to identify possible threats that may affect the effectiveness of stormwater infiltration, e.g., excessive pollution of stormwater and soil, and in some cases also the control of the quality and quantity of groundwater. Based on the specific characteristics of individual devices representing the given stormwater management model, it will also be possible to calculate the B/C ratio for each of them. The values of this ratio may be the basis for the selection of a specific device due to the fact that economic criteria have the greatest impact on the subject of the analysis. However, it must not be forgotten that each decision-maker has its own priorities that affect the final choice of a specific model for managing stormwater.

If the use of infiltration basins and tanks is excluded, the application of other models of stormwater management should be considered. This applies in particular to the retention facilities, as the option of the periodic storage of stormwater before its discharge into the receiving water body was assessed to be only slightly lower than the option assuming surface infiltration of stormwater with retention. In addition, the use of retention systems is independent of the ground and water conditions prevailing in a given area, which significantly increases the possibilities of their implementation.

Despite the limitations resulting from the failure to consider the position of people living in drained areas, the results of the analysis may provide a clear indication for investors and developers. Thanks to the knowledge of experts in the field of stormwater management, even people who are not specialists in this field will be able to make the right decisions regarding the choice of a stormwater management model in newly designed multi-family housing estates.

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