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Defining Optimal Location of Constructed Wetlands in Vojvodina, Serbia

Sanja Antić *, Pavel Benka, Boško Blagojević, Nikola Santrač, Andrea Salvai, Milica Stajić, Radoš Zemunac and Jovana Bezdan

Department of Water Management, Faculty of Agriculture, University of Novi Sad, Trg D. Obradovica 8, 21000 Novi Sad, Serbia; pavel.benka@polj.uns.ac.rs (P.B.); bosko.blagojevic@polj.edu.rs (B.B.); nikola.santrac@polj.uns.ac.rs (N.S.); andrea.salvai@polj.uns.ac.rs (A.S.); milica.stajic@polj.uns.ac.rs (M.S.); zemunac.rados@polj.uns.ac.rs (R.Z.); jovana.bezdan@polj.edu.rs (J.B.)

* Correspondence: sanja.antic@polj.uns.ac.rs

Abstract: With the continuous trend of urbanization, increase in industrial capacities, and expansion of agricultural areas, there is also a rise in the amount of wastewater. One of the effective and economical solutions for wastewater treatment has proven to be Constructed Wetlands (CWs). Defining the locations where CWs can be built is not an easy task and there are several criteria that need to be considered. The Geographical Information Systems (GIS) and Multi-Criteria Decision Analysis—Analytic Hierarchy Process (AHP) are combined to select CW locations. AHP is one of the most commonly used methods in many environmental decision making problems, involving various conflicting criteria. In this case, conflicts arise between the evaluation of criteria that influence the selection of CW locations. The evaluation of selected criteria and sub-criteria resulted in a suitability map indicating that the first class represents 44%, the second class 37%, and the third class 16% of the total area. The fourth and fifth classes represent 3% of the total area. The criteria with the highest significance are land use, floodplains and distance of the location from populated places. This study has important implications for sustainable wastewater management in Serbia and provides guidelines for selecting locations for CWs.

Keywords: wastewater treatment; constructed wetland; geographical information system; analytic hierarchy process

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1. Introduction

Anthropogenic and industrial activities are negatively affecting the quality of water bodies, leading to the gradual loss of their ecological value [1,2]. Therefore, the prevention of pollution and effective treatment of wastewater is a crucial issue that must be addressed. Polluted water is often discharged into the influent without prior treatment, which represents a direct cause of environmental degradation to surface and groundwater, which affects various economic sectors, water management, as well as agriculture. The study region of Vojvodina (Serbia) has a high potential for Constructed Wetlands (CWs) because of the predominance of numerous decentralized rural settlements. The implementation of CWs in the area can contribute to addressing significant water and agricultural management challenges, as well as improve public health and environmental conditions. Considering that water is necessary for successful agricultural production, it is important to prevent contamination and ensure that the surface water used for irrigation is of appropriate quality [3–5]. Discharging untreated wastewater is a direct contributor to groundwater pollution in sources of water that supply for settlements, which can have detrimental effects on human health.

In Serbia, the majority of wastewater is not treated. According to a report from the Serbian Environmental Protection Agency [6], it was found that the percentage of untreated wastewater in relation to the total volume of discharged wastewater for 2019 amounts to

88.6%. Although it is evident that constant efforts are being made to address this problem, the rate of untreated wastewater is still high. The problem also lies in the need to allocate significant financial resources to construct large-capacity wastewater treatment plants. One solution is the construction of CWs, which have significantly lower capacity but also require lower financial resources.

Considering that CWs are an efficient and environmentally sustainable approach for wastewater treatment, there is a noticeable increase in interest in this system. They can be applied in various geographical areas with different climatic characteristics, as documented in relevant references [7–10].

CWs are engineered systems that mimic the biological, chemical, and physical processes that occur in natural wetlands to treat polluted effluent [11]. Given that CWs are ecological systems, there are no negative indications if they are located near settlements. They are made to benefit from many of the same processes that occur in natural wetlands, but they do so in a more controlled system [12]. CWs systems are mostly composed of vegetation, substrates, soils, microorganisms, and water, and use various processes including physical, chemical, and biological mechanisms to eliminate contaminants and improve the quality of the water [13–15]. According to Vymazal [12], CWs can be classified based on vegetation type, hydrology, and direction of flow. Vegetation can be emergent, submerged, floating left, or free-floating. In terms of hydrology, they can be divided into free water surface, sub-surface flow, and hybrid. Sub-surface CWs can be in the vertical or horizontal flow direction.

CWs can be used to treat municipal wastewater, wastewater from various industries and farms, runoff from agricultural, urban, and traffic areas, as well as landfill leachates, in the primary, secondary, and tertiary stages of water treatment [16]. They are used to eliminate a variety of contaminants including organic compounds, suspended particles, pathogens, and heavy metals [17,18].

In small rural settlements with a decentralized location, it is necessary to promote a low-cost system based on natural processes for treating wastewater as it should be treated as close to the source as possible [19]. Especially for small towns and isolated areas, CWs provide an energy-efficient and less operational demanding alternative to traditional treatment systems [13,20]. Because CW uses natural processes to remove pollutants from water, they are seen as a sustainable and economical method of managing water resources [21]. CWs technology has been extensively embraced as a green solution for the treatment of environmental contamination due to its low energy consumption, simplicity of use, and maintenance [22–24]. They offer a natural filtering system where microorganisms and plants decompose and remove contaminants including nutrients, heavy metals, and organic matter.

Selecting suitable areas for constructing CWs is a complex task that requires careful analysis of several key factors. CWs locations should be close to pollution sources and recipients were treated wastewater will be discharged. Compatibility with existing land use should also be considered to avoid conflicts and utilize the selection of the most economical and suitable location. Integrating CWs harmoniously into the landscape not only preserves valuable land resources but also enhances overall sustainability. The elevation of CWs locations plays an important role in their economic suitability. Choosing sites with lower or equal elevation to the settlements contributes to the reduction of the need for additional pumping, resulting in cost savings and long-term sustainability. The presence of embankments should be avoided as an economically less adequate solution because of the necessity for pumping processed wastewater to the recipient. Avoiding flood prone areas is important to ensure the efficient functioning of CWs, as situating them in flood prone regions could diminish their ability to manage wastewater effectively.

For site selection, we propose combining Geographic Information Systems (GIS) with one of the multicriteria decision analysis methods, such as the Analytic Hierarchy Process (AHP). GIS can assist in collecting and analyzing spatial data regarding the criteria. These data can be integrated into the AHP methodology, which will help us quantify and rank the importance of each criterion and sub-criterion in the decision-making process. The AHP is a method of multi-criteria decision-making (MCDM) in which the components are ordered in a hierarchy [25]. The technique can be effectively applied in selecting a suitable location for constructing wetlands [19], choosing the best technology and design [26–28], substrate selection [29], and evaluating the performance of constructed wetlands [30].

A study by Peñacoba-Antona's et al. [19] bears resemblance to the present study in terms of employing multicriteria decision analysis methods. In this study, the authors examined seven criteria across two distinct locations to ascertain the applicability of CWs in diverse geographic areas with varying climatic conditions. Research by Oral and Alagöz [31] delved into identifying the optimal criteria for wetland site selection based on nature utilizing multiple decision-making methods. Anagnostopoulos and Vavatsikos [32] conducted a study centered around multicriteria analysis, aiding the assessment of site suitability for CWs.

This study aims to identify optimal locations for constructing CWs in small settlements with fewer than 5000 residents in the central Balkan region. Through the integration of Geographic Information Systems (GIS) and the Analytic Hierarchy Process (AHP), the research seeks to provide a decision-making framework for selecting suitable areas to establish CWs facilities. The analysis will encompass the following criteria: distance of the location from populated places, distance of the location from the recipient, land use, elevation, and the presence of embankments and floodplains. By quantifying and ranking the significance of each criterion and sub-criterion, this study will provide valuable insights to relevant institutions for effectively determining the most suitable locations for CWs implementation. The goal is to achieve maximum efficiency and cost-effectiveness in wastewater treatment processes, contributing to the preservation of water resources and environmental protection in the region.

2. Materials and Methods

2.1. Study Area

Potential locations for CWs were considered in settlements with up to 5000 inhabitants [33] in the Vojvodina region. Based on the total population of the analyzed rural settlements, the production of 85,471 m^3 of wastewater per day is estimated, assuming an equivalent of 150 L per day per inhabitant [34]. The need and conditions for the application of natural wastewater treatment systems, primarily CWs, exist in Vojvodina. According to Josimov-Dunđerski et al. [35], it would require 0.14% of the territory of Vojvodina to build CWs for such settlements, assuming a need of 5 m^2 per inhabitant. The selection of locations for the implementation of CWs is determined by conditions at specific sites. One of the tasks is to decide suitability, which can be a complex task.

The study area covers 21,506 km^2, located between 44°37′ and 46°11′ north latitude and between 18°49′ and 21°34′ east longitude (Figure 1). The area experiences a temperate continental climate. Vojvodina is characterized by a rich hydrographic network, with large watercourses flowing through it, as well as a dense network of canals and the Danube-Tisza-Danube (DTD) hydro system, which serves as a recipient for purified wastewater of various origins. Situated in the northern part of Serbia, the Vojvodina region holds utmost importance as an agricultural area, with cultivated land accounting for approximately 75% [36]. Due to the uneven distribution of precipitation throughout the year in the studied area, there is a necessity for irrigating agricultural crops. The main water source for irrigation is the aforementioned hydrographic network. Consequently, it is essential to monitor the water quality in watercourses and implement wastewater treatment measures, to prevent endangering agricultural crops and thereby causing damage to this crucial economic sector in the region.

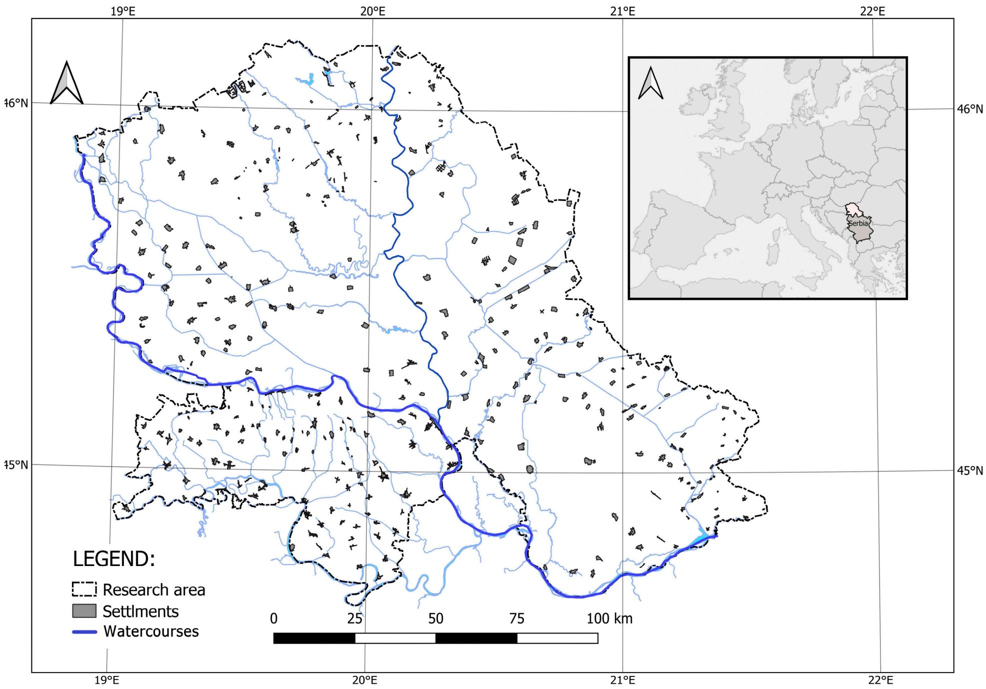

Figure 1. Location of investigated area.

2.2. Data Collection and Analysis

After collecting data in vector format (population, land cover, maps of flooded areas, embankments, and waterways), data were also collected in raster format—Shuttle Radar Topography Mission (SRTM) 30 [37]. SRTM is a digital terrain model that resulted from the Shuttle Radar Topography Mission Global 3 arc second. This model provides detailed information about the elevation and topography of the Earth's surface. Additionally, the CORINE Land Cover (CLC) [38] database provides information on land cover and classifies surfaces based on their use and vegetation type. Based on the analyzed surveys, weights for evaluated criteria were obtained using the AHP method, assessed by experts in the field. The collected data was processed using QGIS software (3.16.3) in combination with AHP. The advantage of QGIS compared to other software is the precise definition of the exact location on the Earth's surface to which the data relates.

2.3. Criteria for Site Selection

In a study by the authors Anagnostopoulos and Vavatsikos [32], the following criteria and sub-criteria were employed: land availability (slopes, distance from faults, and lithology), natural resource protection (distance from Natura 2000 areas, aquifers vulnerability), socioeconomic status (distance from primary road network, distance from railway network, and land use), and design principles (temperature, distance from secondary road network, distance from settlements, and distance from receivers). The authors Oral and Alagöz [31], used the following criteria in their study: land use type, land slope or topography, vegetation type, whether the appropriate area is located on the floodplain, the archeological developments or sites proximity to the area, the absence of any endangered and protected plant or animal species in the area, the population density per square meter near the area, the distance from human settlements and to other existing wastewater treatment units, and the climatic features, logistics. The criteria and sub-criteria used in the study by Peñacoba-Antona et al. [19] are as follows: environmental factors (temperature, precipitation, and solar orientation), and socioeconomic factors (land use, distance to riverbeds, distance to population centers, and slopes).

Although many researchers are investigating CWs, there are only a few relevant articles focusing on a similar research subject to this study. The initial information on the selection of influential factors is presented in the extended report of the Environmental Protection Agency (EPA) [39], but criteria have not been proposed and defined. In this study, criteria similar to those used in the previous studies were applied. However, the criterion of terrain slope was not considered in this research, as the terrain in the Vojvodina region is predominantly flat.

By reviewing the literature and considering the characteristics of the studied area, the following six criteria have been selected to evaluate locations: distance of the location from populated places, distance of the location from recipient, land use, elevation, presence of embankments, and floodplains. In addition, sub-criteria have been defined, which will be discussed further in the text. It is important to analyze these criteria and sub-criteria and, if possible, involve a wide range of decision-makers to integrate their knowledge into the modeling process.

For practical reasons, primarily cost-saving, the CWs must be located close to settlements, with a buffer zone of 1000 m around each settlement. Within this criterion, two sub-criteria are defined. The first sub-criterion represents a buffer zone from 0–500 m, and the second sub-criterion is a buffer zone from 500–1000 m.

For similar reasons, it is important for CWs to be located near water bodies where the treated wastewater will be discharged. The sub-criteria are defined as in the previous case.

When analyzing the land cover using CLC [38] as favorable areas for CW implementation, the following surface areas were taken into account, which also represent the sub-criteria, agricultural areas, forest and semi-natural areas, wetlands, and water bodies, while other surface areas were not included in the analysis, such as urban areas.

The location of the CWs facilities should be at a lower elevation than the settlements, enabling the gravitational discharge of wastewater. In cases where the elevation of the site is higher than the elevation of the settlement, the installation of a pump is necessary, which increases the costs of construction and operation. Due to this, the following two sub-criteria have been defined: the first sub-criterion is when the elevation of the area is lower or equal to the elevation of the settlement, and the second sub-criterion is when the elevation of the area is higher than the elevation of the settlement.

The presence of embankments criterion refers to situations where there is no levee between the settlement and the watercourse, and water can flow by gravity. On the contrary, when there is a levee between the settlement and the watercourse, pumps are required to evacuate wastewater, which increases the construction and operation costs. Within this criterion, two sub-criteria are defined: the first sub-criterion is Without embankment and the second sub-criterion is the presence of an embankment.

Finally, the criterion Floodplains can create conditions for higher flow rates and water velocity through CWs. This reduces the time that water spends in the CWs, which reduces its purification efficiency. Based on this, the mentioned criterion has two sub-criteria as follows: the first sub-criterion is areas that are not flooded, and the second sub-criterion is floodplains.

2.4. *Defining Weights of Criteria*

Multi-Criteria Decision Making (MCDA) involves formally structuring and resolving decision problems, typically by explicitly weighing criteria and balancing their trade-offs. This approach captures the preferences of decision-makers (DMs) and aims to provide consistent, transparent, and reliable support for making informed decisions [40].

The most common way to define the weights assigned to criteria is to elicit preference values (subjective judgments) from experts or decision makers (DMs). Usually, this is performed in a group (participatory) context in order to include different opinions and to minimize the risk of poor individual and subjective judgments [41]. In this paper, six experts, i.e., decision makers (DMs), participated in the process of defining the weights of criteria. Incorporating diverse viewpoints will reduce the potential for biased individual judgments.

An alternative to these explicit techniques involves using implicit quantitative (statistical) approaches for assigning criteria weights. Examples of quantitative methods are the entropy method [42] and the Criteria Importance Through the Inter-Criteria Correlation (CRITIC) method [43]. Quantitative methods are less commonly used than preference-based weighting methods because they are blind to problem reality, i.e., the weights are allocated based on the observed level of variation within each criterion rather than on problem-related values [40,44].

Numerous explicit methods exist for deriving weights from preference statements [45,46]. Among these, the Analytic Hierarchy Process (AHP) [47] stands out as the most widely used and cited in the literature related to environmental decision making [48–50]. Prominent institutions and companies like the US Nuclear Regulatory Commission (NRC), the US Department of Defense, British Airways, the US Congressional committee, Xerox Corporation, Ford Motor Company, and IBM have utilized AHP [51].

AHP's popularity rests on the following two key features: the method of pairwise comparisons [52] and the decomposition of complex problems into hierarchies. The hierarchical structure aids DMs in organizing copious information into manageable components, enhancing comprehension [53]. The essence of pairwise comparison can be boiled down to a simple rule, handle two options at a time if managing more becomes overwhelming [54,55]. Thus, AHP is less cognitively demanding for DM than other methods, and this is the main reason why is used for defining weights of criteria relevant for defining optimal location of constructed wetlands.

2.5. Analytic Hierarchy Process (AHP)

The AHP method uses hierarchical structures to represent a problem and then develop priorities for the alternatives based on the judgment of the decision maker. AHP is carried out through the following steps: defining the unstructured problem, developing AHP hierarchy, pair-wise comparison, computation of relative weights, consistency check, and obtaining parameter weights [56]. The methodology uses pairwise comparison matrices to compare all possible pairs of criteria and determine which criterion has the highest priority. For representing the relative importance of one criterion over another, Saaty's nine-point scale for pairwise comparisons was used (Table 1). Criteria are scaled from 1 to 9, where 1 indicates equal importance and 9 indicates the highest priority. It is also possible to use reciprocal values (e.g., 1/5) which indicate a reciprocal comparison.

Table 1. Saaty's rating scale [47].

Intensity of Importance	Definition	Explanation
1	Equal importance of *i* and *j*	Two activities contribute equally to the objective
3	Weak importance of *i* over *j*	Experience and judgment slightly favor one activity over another
5	Strong importance of *i* over *j*	Experience and judgment strongly favor one activity over another
7	Demonstrated importance of *i* over *j*	An activity is strongly favored, and its dominance is demonstrated in practice
9	Absolute importance of *i* over *j*	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values the two adjacent judgments	When compromise is needed

If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*.

The process begins by constructing a pairwise comparison matrix A, which is filled with values from Saaty's scale. The components a_{ij} of the matrix A are numerical entries which express the relative importance of the element i over the element j with respect to the corresponding element in the next higher level. In matrix A, for all i and j, it is necessary that and a_{ii} = 1 and $a_{ij} = 1/a_{ji}$. The additive method is used to calculate relative priorities among the n elements of matrix A (1), mathematically, it can be represented by relations (2) and (3).

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \dots & \vdots \\ \vdots & \vdots & \dots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nm} \end{bmatrix} \quad (1)$$

$$a'_{ij} = a_{ij} \, [\sum_{i=1}^{n} a_{ij}]^{-1} \quad (2)$$

$$w_i = (1/n)\sum_{j=1}^{n} a'_{ij} = (1/n)\sum_{j=1}^{n} a_{ij}[\sum_{i=1}^{n} a_{ij}]^{-1} \quad (3)$$

The consistency index (CI) is used to check the consistency of the priority ratio:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (4)$$

where n is the number of elements being compared in the matrix, λ_{max} is the largest or principal eigenvalue of the matrix. If this consistency index failed to reach a threshold level, then the answers to comparisons were re-examined. In order to ensure that the pairwise comparison matrix is consistent, the consistency ratio (CR) is calculated as follows:

$$CR = \frac{CI}{RI} \quad (5)$$

where RI is the random consistency index given by Saaty [46]. A lower CR value means that the consistency of the participant's assessment is at a high level, while a high CR indicates that the consistency of the participant's assessment is at a low level. In environmental and engineering problems, it is expected that the consistency ratio should not exceed 0.20 [57].

The survey created for this study was forwarded to a group of 6 experts from the related research area and competent institutions. Six criteria were evaluated, which were recognized as important in determining the suitability of the location for the construction of CWs (Table 2). Subsequently, the sub-criteria were evaluated. The hierarchy of problems is shown in Figure 2.

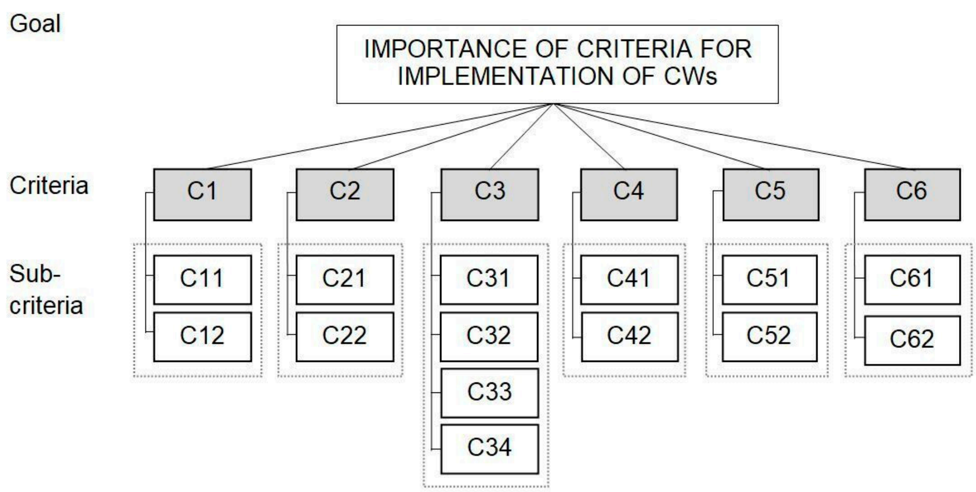

Figure 2. Hierarchy of decision problems for determining the suitability of a site for constructing Constructed Wetlands (CWs).

Table 2. Criteria and sub-criteria for determining the suitability of a site for constructing Constructed Wetlands (CWs).

Criteria		Sub-Criteria	
C1	Distance of the location from populated places	C11 C12	0–500 m 500–1000 m
C2	Distance of the location from recipient	C21 C22	0–500 m 500–1000 m
C3	Land use	C31 C32 C33 C34	Agricultural areas Forest and semi natural areas Wetlands Water bodies
C4	Elevation	C41 C42	Elevation $\leq$ settlements elevation Elevation > settlements elevation
C5	Presence of embankments	C51 C52	Without embankment The presence of an embankment
C6	Floodplains	C61 C62	Areas are not flooded Floodplains

3. Results and Discussion

The AHP method was applied after processing the vector and raster data, as well as the analysis of surveys evaluated by experts in the field. The AHP method was used to obtain weights for the evaluated criteria and sub-criteria. Figures 3–8 show the defined criteria and sub-criteria in QGIS, from which a map of suitable locations for the implementation of CWs was obtained.

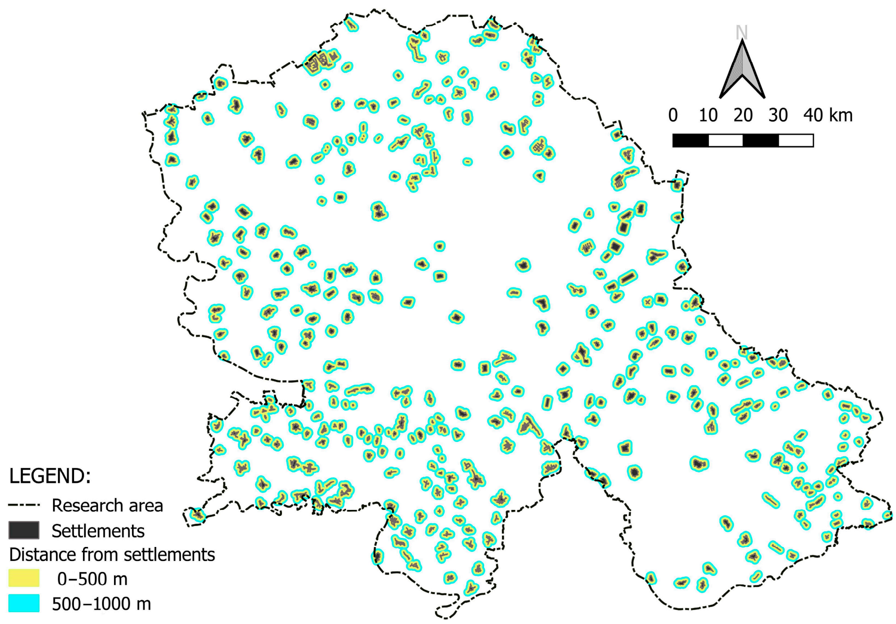

Figure 3. Criteria for determining the suitability of a site for constructing CWs. Distance of the location from populated places with sub-criteria: 0–500 m and 500–1000 m.

Figure 3 shows the distance of the location from populated places, and a buffer of 0–500 and 500–1000 m was formed around each settlement for this purpose. For practical reasons, primarily cost savings, CWs must be in proximity to settlements. Figure 4 shows the distance of the location from the recipient by forming a buffer of 0–500 and 500–1000 m distance from the watercourses, for similar reasons as in the previous case. Figure 5 shows land use as possible locations for implementing CWs, while detailed data in CORINE code is shown in Table 3.

Figure 6 shows locations with an elevation lower than or equal to the settlement elevation and locations with an elevation higher than the settlement elevation. In Figure 7, the presence of embankments indicated by the red color, while areas without embankments are marked in green. Figure 8 shows areas that are not prone to flooding, indicated by the white color, and areas prone to flooding, floodplains, indicated by the blue color.

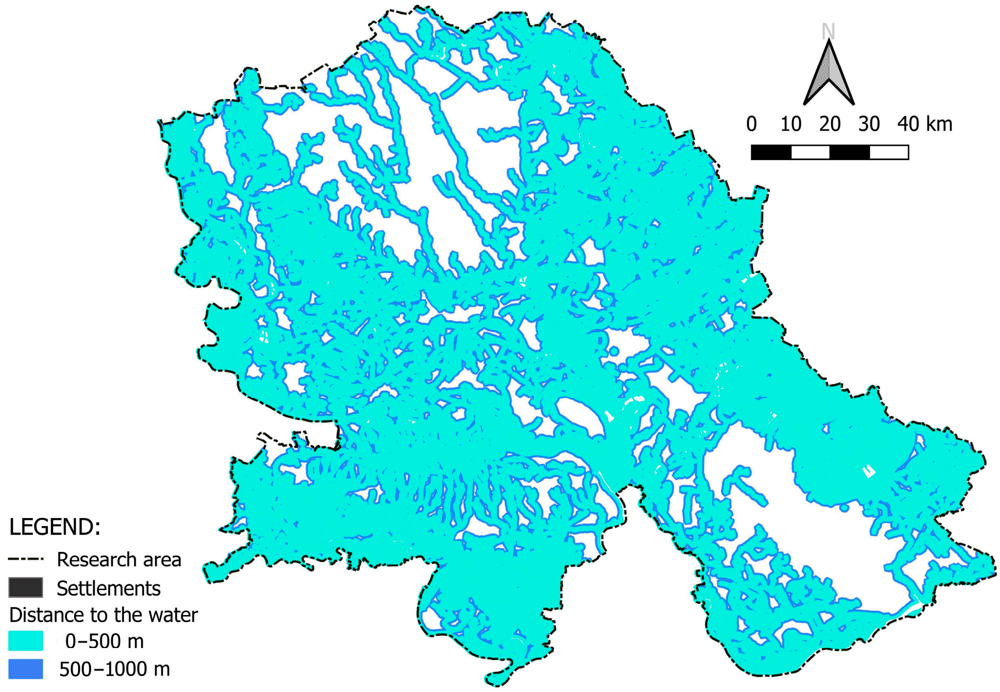

Figure 4. Criteria for determining the suitability of a site for constructing CWs. Distance of the location from recipient with sub-criteria: 0–500 m and 500–1000 m.

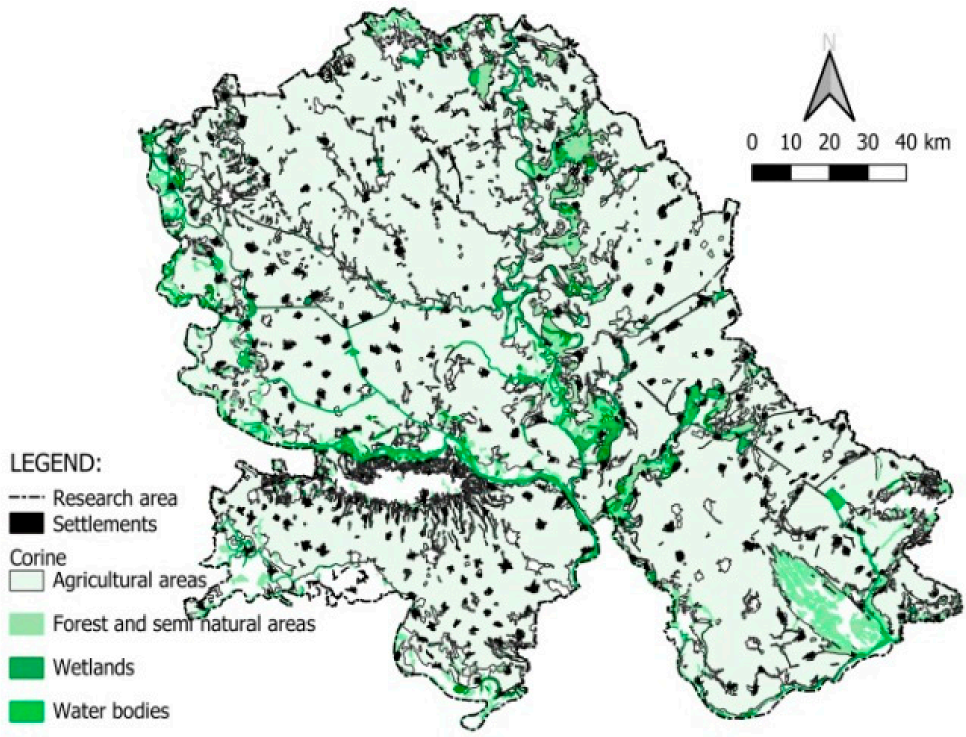

Figure 5. Criteria for determining the suitability of a site for constructing CWs. Land use with the following sub-criteria: agricultural areas, forest and semi natural areas, wetlands and water bodies.

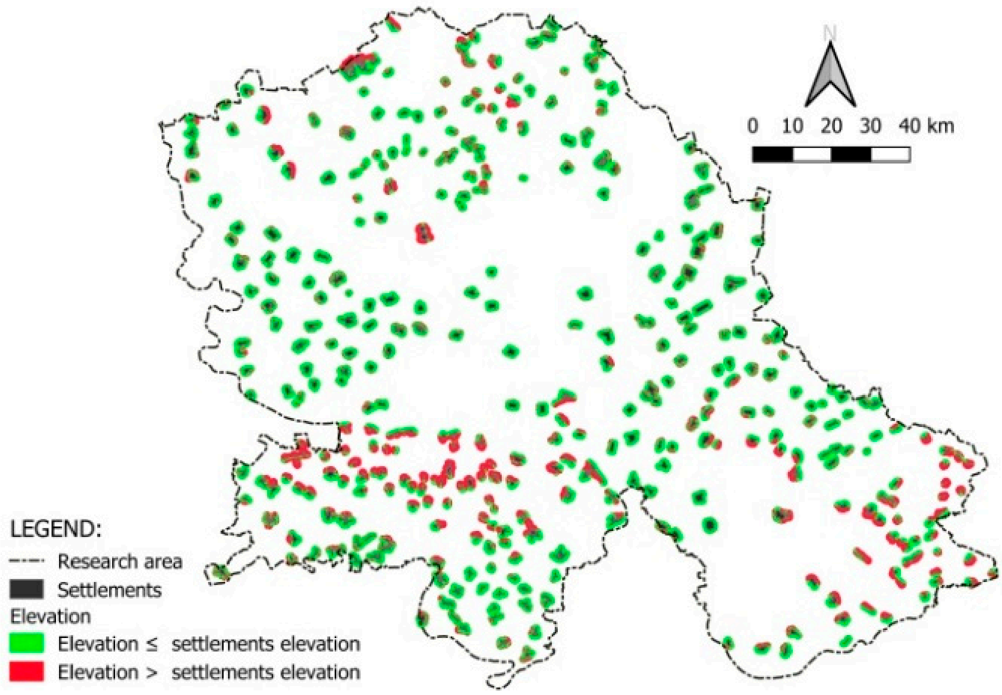

Figure 6. Criteria for determining the suitability of a site for constructing CWs. Elevation with sub-criteria: elevation ≤ settlements elevation and elevation > settlements elevation.

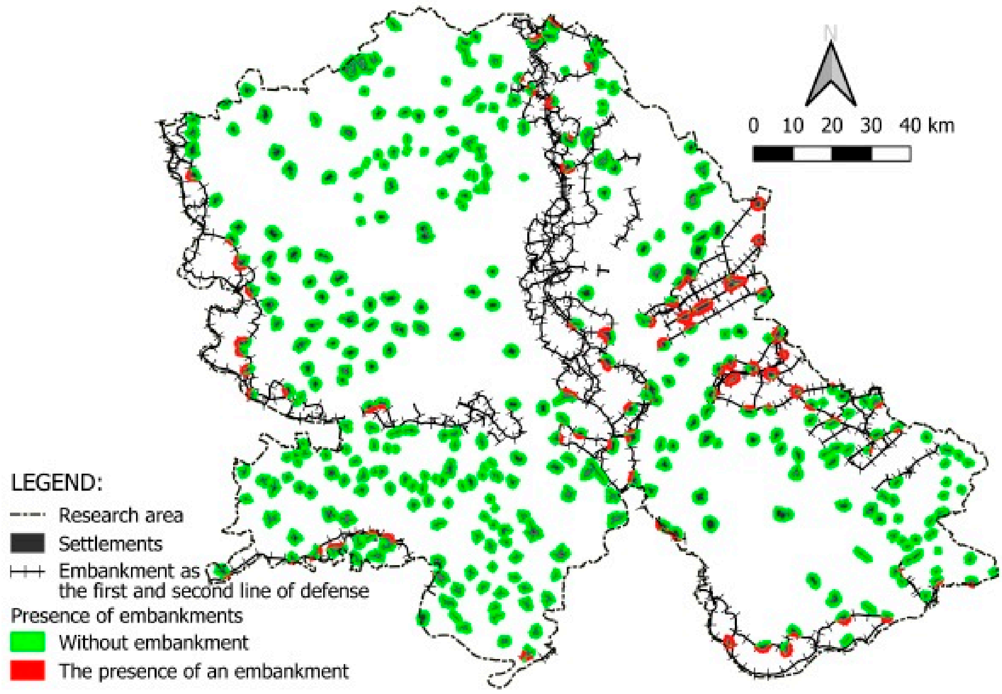

Figure 7. Criteria for determining the suitability of a site for constructing CWs. Presence of embankments with sub-criteria: without embankment and the presence of an embankment.

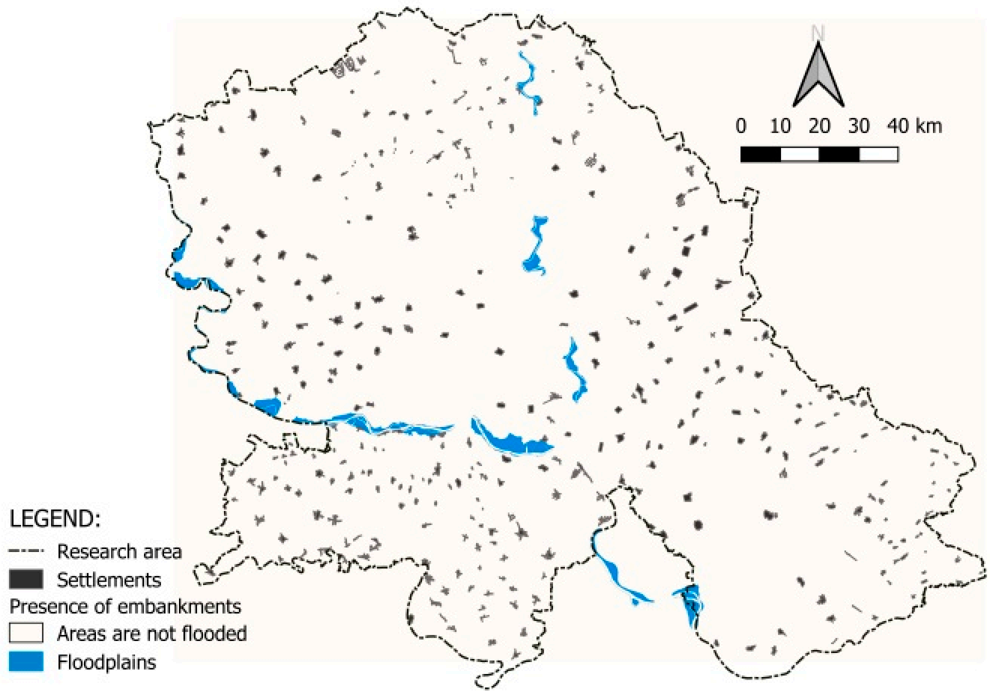

Figure 8. Criteria for determining the suitability of a site for constructing CWs. Floodplains with sub-criteria: areas are not flooded and floodplains.

Table 3. Reclassification of Land use according to their suitability for CWs, [38].

Land Use	CORINE Code
Agricultural areas	211, 221, 222, 231, 242, 243
Forest and semi natural areas	311, 312, 313, 321, 324
Wetlands	411
Water bodies	511, 512

Analytic Hierarchy Process (AHP) and Weight Assignment

In this study, AHP was applied in the following steps. experts evaluated the defined criteria using Saaty's scale, as shown in Table 1. Then, weights were assigned to each criterion matrix, as shown in Table 4. Finally, the consistency of the criteria evaluation was determined by each decision maker. The consistency ratio (*CR*) values for all matrices are shown in Table 5 and do not exceed the acceptable value of 0.20 [57].

Table 4. Criteria weights.

W_i	DM_1	DM_2	DM_3	DM_4	DM_5	DM_6
C1	0.084	0.239	0.249	0.056	0.066	0.321
C2	0.086	0.109	0.187	0.057	0.104	0.135
C3	0.259	0.254	0.302	0.229	0.257	0.257
C4	0.200	0.031	0.056	0.121	0.167	0.092
C5	0.121	0.059	0.036	0.113	0.120	0.144
C6	0.249	0.307	0.170	0.425	0.306	0.052

Table 5. Consistency Ratio CR.

W_i	DM_1	DM_2	DM_3	DM_4	DM_5	DM_6
CR	0.15	0.10	0.13	0.09	0.12	0.13

The final weights of the criteria in relation to the objective, as well as their ranks, were obtained by using the weighted geometric mean, as shown in Table 6. The criterion with the highest weight is C3—land use with a weight of 0.293, indicating that this criterion is the most important and influential in the multicriteria sense when choosing the location of CWs in the Vojvodina region, according to the evaluation of experts in the field. The second most important criterion is floodplains with a weight of 0.241, followed by distance of the location from populated places with a weight of 0.151. The remaining criteria had significantly lower weights.

Table 6. Final weights and ranks criteria.

Criteria	W_i	Ranks
C1	0.151	3
C2	0.111	4
C3	0.293	1
C4	0.103	5
C5	0.102	6
C6	0.241	2

After evaluating the criteria, the sub-criteria were assessed. The assigned weights of the sub-criteria are presented in Table 7.

After applying AHP to the analyzed area, surface areas for each class (Figure 9), and a suitability map for the implementation of CWs (Figure 10) were obtained. Only settlements with up to 5000 inhabitants were analyzed, while settlements that are already connected to a centralized wastewater treatment system or have an existing wastewater treatment plant were excluded from the analysis. The suitability map (Figure 10) consists of five classes, with the first class (dark green, most favorable) occupying the largest area of 1421 km^2, while the second class (green, favorable) covers 1191 km^2. The third class (yellow, moderately favorable) occupies an area of approximately 82 km^2. These areas can be presented in percentages, where the first class accounts for 44% of the total area, the second class 37%, and the third class 16%. The first three classes together account for 97% of the analyzed area, while the fourth and fifth classes occupy 3% (orange and red—less favorable and least favorable), which is approximately 82.35 km^2. These results indicate great potential for the implementation of CWs areas in Vojvodina.

Table 7. Weights sub-criteria.

Criteria	Sub-Criteria	W_i
C1	C11	0.8
	C12	0.2
C2	C21	0.8
	C22	0.2
C3	C31	0.5
	C32	0.1
	C33	0.2
	C34	0.2
C4	C41	0.9
	C42	0.1
C5	C51	0.9
	C52	0.1
C6	C61	0.6
	C62	0.4

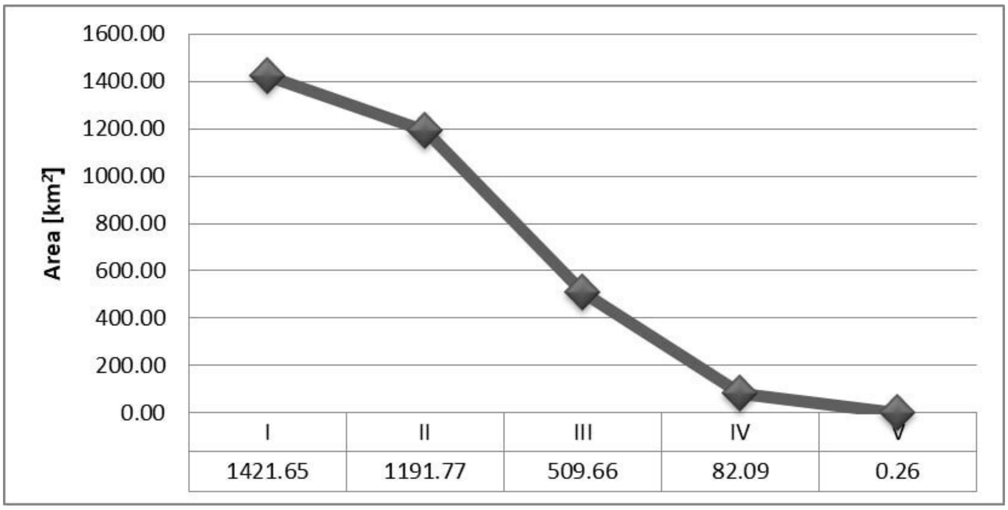

Figure 9. Classes of the suitable locations for the implementation of CWs.

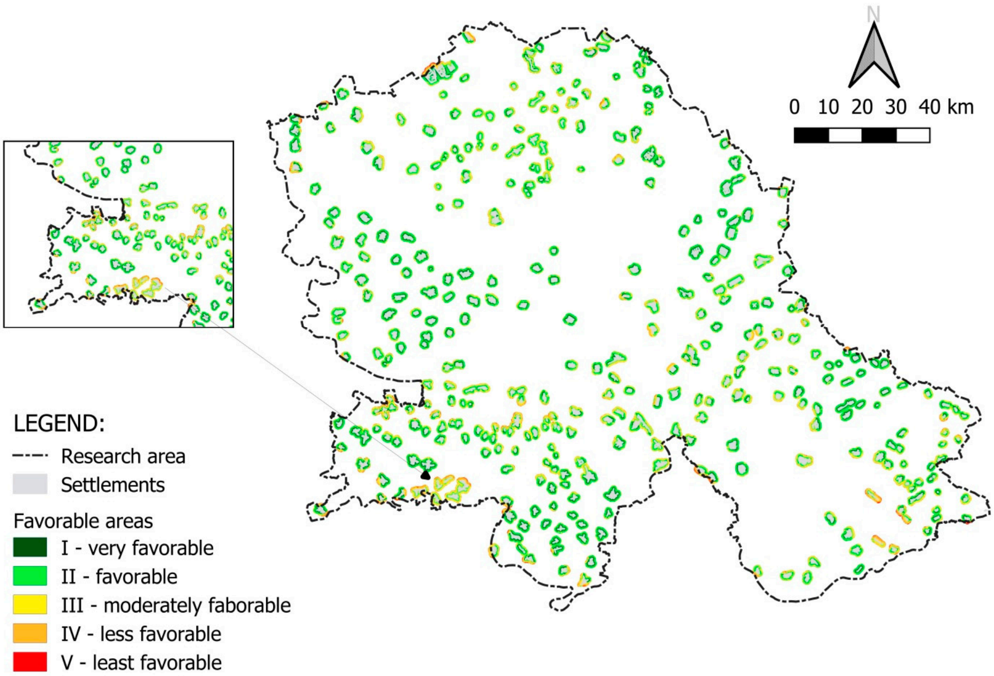

Figure 10. Map of suitable locations for the implementation of CWs.

4. Conclusions

The expansion of industries and modern agricultural practices has led to an increasing demand for the treatment of large volumes of wastewater. In order to safeguard the natural environment and prevent the contamination of surface and groundwater, it is imperative to prioritize adequate purification of wastewater. Among the efficient and economically viable approaches to wastewater treatment, constructed wetlands (CWs) have emerged as a promising solution, especially for small communities. These CW facilities offer an effective means of wastewater treatment, providing an environmentally friendly and cost-effective alternative. Vojvodina has great potential for the implementation of CWs due to numerous decentralized rural settlements, geographical, and other characteristics. The combination of GIS and AHP methods represents a powerful tool for solving planning problems in the field of wastewater treatment, providing decision-makers with information regarding the favorable of location selection. Using these tools, favorable locations for constructing CWs systems have been successfully identified.

The results of the study indicate that the implementation of CWs in rural settlements in Vojvodina is a feasible option for solving the problem of untreated wastewater. The evaluation of the selected criteria and sub-criteria resulted in a suitability map indicating that the first class constitutes 44% of the total area, the second class 37%, and the third class 16%. The fourth and fifth classes represent 3% of the total area. The criterion with the highest significance was land use, indicating its considerable impact in the decision-making process. Following closely was the criterion of floodplains, which also carried substantial weight in the evaluation. Another essential consideration was the distance of the location from populated places. On the other hand, the remaining criteria had relatively lower importance, collectively accounting for a smaller portion of the overall decision. The reliability of the obtained suitability weights is underscored by the fact that the current CW in Gložan settlement [16] is situated within the favorable region, as clearly depicted on the suitability map. This alignment between the existing CW and the suitability map reinforces confidence in the accuracy and reliability of the weights used in the analysis. The results of this research can be used by the institutions responsible for assessing the economic aspects and for determining the priority locations for the construction of wetlands.

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