Chapter 3
Suitability Mapping for Constructed Wetlands

Alvin Joseph Dolores, Clar Francis Camua, Rey Casas, Angelika Galicia, Perlie Velasco, Angeli Cabaltica, and Joseph Angelo Sabio

Abstract Suitability mapping aims to provide the best locations of systems or infrastructures for their conceptual design, where suitability analysis ranks the locations based on various criteria affecting the performance of the system or infrastructure. This chapter presents the guide for suitability mapping and analysis for constructed wetlands (CWs) with case studies in the Philippines. A geographic information system (GIS) software was used to map the suitable locations, while the suitability analysis used a multicriteria decision-making (MCDM) technique for Bulacan, Laguna, and Negros Oriental, Philippines. The decision criteria analysed were land use, soil type, slope, distance to water bodies, and distance to population centres. Criteria weights were derived from the literature and surveys with experts and then analysed using the Analytical Hierarchy Process (AHP) MCDM technique. A suitability map was generated using the computed weights and normalised maps of each criterion as inputs into ArcGIS Pro. The suitability analysis for the CWs in the case studies was done by taking the top 20% of the suitable locations and further evaluating them based on the actual site conditions using Google Earth.

Keywords Analytic Hierarchy Process · Constructed wetlands · Geographical Information System · Normalised Maps · Suitability analysis · Suitability mapping

A. J. Dolores (✉) · C. F. Camua · R. Casas · A. Galicia · P. Velasco · J. A. Sabio
Department of Civil Engineering, College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños, Los Baños, Laguna, Philippines
e-mail: asdolores@up.edu.ph

A. Cabaltica
School of Civil Engineering & Management, International University - Vietnam National University HCMC, Thu Duc City, Ho Chi Minh City, Vietnam

3.1   Introduction

In the Philippines, the policy on wastewater management for water security is geared towards expanding sewerage and sanitation infrastructures and broadening the scope of the National Sewerage and Septage Management Program (NSSMP) to improve the support from local government units (LGUs) and water districts (WDs) (National Economic and Development Authority 2021). One of the technologies that can be used for wastewater treatment is constructed wetlands (CWs), a type of nature-based solution for water management. CWs are proven to be effective in the treatment and disposal of various types of wastewater. CWs is a cost-effective and sustainable engineered system that uses natural processes involving wetland vegetation and substrate or filter media, promoting the physical, chemical, and biological processes in treating wastewater (Liu et al. 2014; Peñacoba-Antona et al. 2021). Further, CWs have low construction and operational requirements, making them ideal for decentralised wastewater treatment in small rural areas.

As part of the feasibility planning of CWs, it is best to know first which suitable site locations are to construct such facilities. Identifying suitable locations is critical for CWs implementation since these facilities usually require a larger area than conventional wastewater treatment facilities, which is usually challenging to prove CWs feasibility. Available Geographic Information System (GIS) applications can be used to easily map and analyse these suitable locations, depending on the objective and characteristics of the infrastructure being sited. GIS application would be effective in suitability mapping since it allows efficient processing of a large amount of spatial data and provides more accurate and easily accessible information. GIS has multiple functionalities utilising both spatial and attribute data. One of its many capabilities is that it overlays various layers or maps relevant to the same geographical region (Rossi et al. 2023). On the other hand, suitability analysis or ranking of the suitable locations can also be done in the GIS software by incorporating the results from multicriteria decision-making (MCDM) techniques, e.g. Analytic Hierarchy Process (AHP). MCDM methods are popular tools for structuring and evaluating complicated decision problems by evaluating and ranking solutions or options (in this case, the spatial suitable locations). The general steps for MCDM are (i) identifying the factors or criteria affecting the solutions, (ii) assigning the weights for each factor, and (iii) ranking the options (Taherdoost and Madanchian 2023).

Among the MCDM methods, AHP is a frequently employed and popular method for site selection, owing to its simple and direct approach to decision-making. AHP is an analytical problem-solving technique developed by Thomas L. Saaty in the 1970s. The fundamental idea behind AHP is to recognise that not all criteria hold equal importance or weight in a decision-making process. It acknowledges that some criteria are more significant than others and allows decision-makers to assign weights to these criteria when evaluating different alternatives (Asadabadi et al. 2019). The study by Peñacoba-Antona et al. (2021) provided a methodology for the suitability mapping and analysis of CWs in two Spanish provinces, Bizkaia

(oceanic location) and Malaga (Mediterranean location). Similarly, this chapter aims to (i) present a method for suitability mapping of CWs for domestic wastewater treatment in the provinces of Bulacan, Laguna, and Negros Oriental, Philippines, using GIS and AHP, based on the study of Peñacoba-Antona et al. (2021), (ii) present the generated suitability maps for these provinces, and (iii) validate the generated suitability maps by evaluating the most suitable locations found for each province through satellite images and hazard maps.

The generated suitability maps could assist practitioners in identifying suitable locations for CWs. Further, this study could contribute to the scientific research communities to fill the related research gap, locally and globally. Ultimately, suitable maps can be used as part of the guide tool for the easy and successful implementation of CWs, promoting a nature-based approach to manage and preserve water resources.

3.2   Constructed Wetlands (CWs) for Wastewater Treatment

Vymazal (2022) defines wetlands as areas that experience shallow water flooding or prolonged soil saturation, resulting in the development of hydric soils capable of supporting specialised macrophytes adapted to anaerobic conditions. This definition makes wetlands suitable for wastewater treatment purposes. However, wetlands were historically used as disposal sites rather than treatment systems because these were conveniently located closer to discharge points, such as rivers or other waterways (Hoffmann et al. 2011). Unfortunately, this uncontrolled wastewater disposal has led to the degradation and destruction of natural wetlands, with many becoming saturated with nutrients and experiencing severe environmental damage. Despite these issues, the use of natural wetlands persisted. Additional problems arose, including challenges with system maintenance and unpredictable treatment efficiency.

CWs are purpose-built systems that leverage the inherent mechanisms observed in natural wetlands, enabling efficient conversion and elimination of contaminants. These carefully designed systems integrate wetland vegetation, solids, and the accompanying microbial communities to emulate the purification processes found in their natural counterparts. However, they operate within a controlled and optimised environment, offering enhanced effectiveness (Vymazal 2022).

Wallace and Knight (2006) reported that the origins of engineered treatment wetlands could be traced back to 1901 when the first system was patented. This initial system resembled a vertical flow CWs, although there is limited documentation regarding its widespread adoption. On the contrary, Hoffmann et al. (2011) argued that the first known individual to explore the potential of wastewater treatment through CWs was the German scientist Dr. Käthe Seidel in 1952. Utilising studies conducted after that, the first full-scale CWs were built in the Netherlands in 1967 (Tourbier and Pierson 1976). Subsequently, there was a significant increase in CWs installations during the 1980s and 1990s as the application expanded to different

types of wastewater (Vymazal 2022). CWs are continuously being recognised for their use in wastewater management due to their relatively low operational and maintenance requirements and environmentally friendly approach, particularly recommended for developing countries (Rahman et al. 2020).

Omondi and Navalia (2020) identified multiple advantages and disadvantages of CWs, as summarised in Table 3.1, which are important considerations in conceptual designs and implementation of CWs.

The nature-based approach, low operational and maintenance costs, and positive environmental impact make CWs an attractive option for sustainable wastewater management in various settings, ranging from small-scale decentralised systems to large-scale municipal applications. However, properly assessing the site for certain criteria is still essential for maximising treatment efficiency, ensuring site suitability, and complying with regulations. Thoroughly assessing the site based on specific criteria ensures that CWs function optimally, deliver environmental benefits, and provide long-term solutions for wastewater management.

3.3   Methodology for Suitability Mapping of Constructed Wetlands

The case studies for the suitability mapping of CWs for domestic wastewater treatment were conducted in Bulacan, Laguna, and Negros Oriental, following the methodology established by Peñacoba-Antona et al. (2021). The approach incorporated the use of GIS in conjunction with AHP and summarised in the following steps: (i) preparation of spatial data for the site criteria and constraint maps using Aeronautical Reconnaissance Coverage Geographic Information System (ArcGIS), (ii) implementation of AHP to evaluate the suitability criteria for CWs, and (iii) generation of the suitability map that illustrates the varying levels of suitability for CWs across different areas within Bulacan, Laguna, and Negros Oriental. Figure 3.1 presents the methodological framework of the case studies.

Table 3.1 Advantages and disadvantages of CWs (Omondi and Navalia 2020)

| Advantages of CWs	Disadvantages of CWs
• Natural wastewater treatment and environment-friendly solution. • Cost-effectiveness compared to conventional systems, requiring minimal energy input and chemicals, which reduces long-term operational costs. • Enhanced biodiversity conservation and aesthetics by providing habitats for various plants, birds, insects, and wildlife. • Effective removal of nutrients and other pollutants using plants, microorganisms, and natural processes.	• Larger land area requirement than conventional wastewater treatment systems, resulting in land availability and affordability crucial in the design. • Performance efficiency of CWs may vary seasonally or in different locations due to changing environmental conditions. • Toxic chemicals can temporarily reduce effectiveness of treatment. • Requires a minimum amount of water for successful operation.
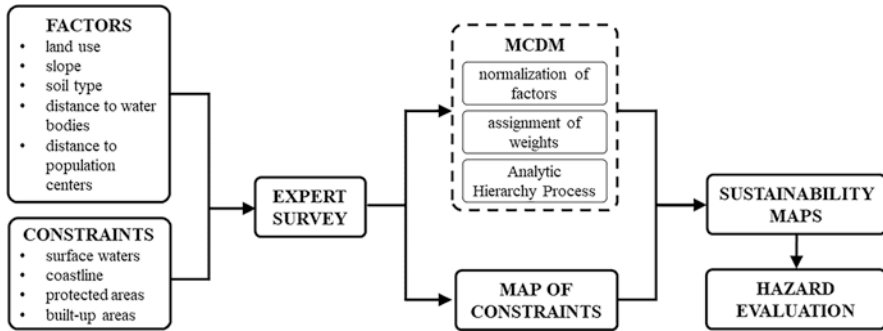
Fig. 3.1 Methodological framework of the study

3.3.1   Determination of Suitability Factors and Constraints

Suitability analysis requires the identification of several criteria that may be geo-physical, environmental, or socioeconomic in nature (El Baroudy 2016; Bato 2018; Mohammed et al. 2019). For this particular study, the following criteria were considered in the suitability analysis: land use, slope, soil type, distance to water bodies, and distance to population centres. Moreover, several constraints were included in the study. These constraints considered are those factors that would be unsuitable for the construction of CWs. A constraint may be dictated by factors such as, but not limited to, protected areas, economic zones, and safety requirements. For the case studies, the following constraints were considered: surface water, coastline, protected areas, and built-up areas. The hazard assessment was considered after the suitability map was created as part of the validation process.

3.3.2   Acquisition of Criteria and Constraint Maps

The border maps specified for Bulacan, Laguna, and Negros Oriental were obtained. These border maps served as the fundamental base maps, providing the spatial framework for conducting the suitability mapping. Subsequently, spatial data for the identified criteria and constraints were acquired from various publicly available databases from various government offices and groups, such as National Mapping and Resource Information Authority (NAMRIA), Provincial Environment and Natural Resources Offices, Humanitarian Exchange Data, and Protected Planet.

3.3.3   Consultation with Experts

If there are no policies set for siting CWs in a location, then it is necessary to consult with experts who have knowledge and expertise in constructed wetlands, as well as the study areas. The consultation aimed to (i) determine the levels of importance of the identified criteria or factors (Fig. 3.2), (ii) obtain the varying degrees of importance of the classifications within each criterion or factor (Fig. 3.3, Part 2), and (iii) set the buffer distances for the identified constraints (Fig. 3.3, Part 3). The complete survey forms were uploaded and discussed on the website: https://doi. org/10.30852/p.18686. This site is the Asia-Pacific Network for Global Change Research (APN-GCR) project for 2021–2023 titled "Integrated Assessment of Existing Practices and Development of Pathways for the Effective Integration of Nature-based Water Treatment in Urban Areas in Sri Lanka, the Philippines and Vietnam", of which this study is part. The following experts were consulted for the case studies:

- Expert A is an Engineer IV in the University Planning and Maintenance Office, Office of the Vice Chancellor for Planning and Development, University of the Philippines Los Baños (UPLB).
- Expert B is an Assistant City Engineer and manager of the Bayawan City, Negros Oriental, Philippines (Waste Management and Ecology Center).
- Expert C is a Water and Environmental Resources Management Specialist at Green STEPS, Inc., and a member of the Society for the Conservation of Philippine Wetlands (SCPW).

A comprehensive assessment was conducted from the input of experts to determine the weights assigned to each criterion. In the survey, as shown in Fig. 3.2, experts were asked to compare two distinct criteria based on their level of importance. The answers provided by the experts were based on the nine-level scale of Saaty (1987) (table shown in Fig. 3.2). These were used to create pairwise comparison matrices, which helped establish the relative importance and priorities of the criteria.

Then, the results from Parts 2 and 3 of the survey (Fig. 3.3) were used to prepare criteria and constraint maps for the suitability mapping of CWs in the study areas using ArcGIS. Suitability analysis requires the quantification of the classifications within each criterion. Thus, the experts were consulted regarding the importance of each classification relative to the other classifications within the identified criterion. The classifications under each criterion are listed in Table 3.2.

Part 1. Site Suitability Criteria for Constructed Wetlands

In this study, the determining factors in siting constructed wetlands are land use, slope, soil type, distance to water bodies, and distance to population centers.

1. **Land Use** – considers the adequacy of particular land use to build a constructed wetland. For instance, burnt areas are classified as very appropriate since it is an open space with no little vegetation while forests are classified as not appropriate due to obstructions and high vegetation.
2. **Slope** – considers the cost of excavation and embankment.
3. **Soil type** – considers the appropriateness of soil in construction and operation. Generally, it is desired to use impermeable (clay) since wastewater is involved.
4. **Distance to water bodies** – considers the distance of transport from the constructed wetlands unit to the water body discharge point.
5. **Distance to population center** – considers the distance of wastewater collection from the source to the constructed wetlands unit.

In this part, you will be asked to compare each factor to one another based on its relative importance. You may refer to Table 1–1 to answer the survey questions.

Table 1–1. Nine-level scale for pairwise comparison.

IMPORTANCE LEVEL	DESCRIPTION	NUMERICAL VALUE
Equally important	Two elements have equal importance	1
Moderately More Important	Experience or judgment slightly favors one element	3
Strongly More Important	Experience or judgment strongly favors one element	5
Very Strong More Important	Dominance of one element proved in practice	7
Extremely More Important	The highest-order dominance of one element over another	9
Intermediate Values	Compromise is needed	2, 4, 6, 8

Source: Saaty, 1987

Part 1. Site Suitability Criteria for Constructed Wetlands

Instruction: Kindly choose the number of your preferred choice based on your opinion on which of the factors is more important.

−9 = being your most preferred choice is on the left side
1 = being the choice of both criteria are of equal importance
9 = being your most preferred choice is on the right side

Note: The negative signs are only used to imply more importance to the criteria on the left side.

1.) Land Cover VS Slope *

| Land Cover | −9 | −8 | −7 | −6 | −5 | −4 | −3 | −2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Slope |

Mark only one oval per row.

	−9	−8	−7	−6	−5	−4	−3	−2	1	2	3	4	5	6	7	8	9
1.)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

2.) Land Cover VS Soil Type *

| Land Cover | −9 | −8 | −7 | −6 | −5 | −4 | −3 | −2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Soil Type |

Mark only one oval per row.

	−9	−8	−7	−6	−5	−4	−3	−2	1	2	3	4	5	6	7	8	9
2.)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

3.) Land Cover VS Distance to Water Bodies *

| Land Cover | −9 | −8 | −7 | −6 | −5 | −4 | −3 | −2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Distance to Water Bodies |

Mark only one oval per row.

	−9	−8	−7	−6	−5	−4	−3	−2	1	2	3	4	5	6	7	8	9
3.)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Fig. 3.2 Sample of the survey questionnaire for the pairwise comparison (Part 1)

Part 2. Site Suitability Criteria for Constructed Wetlands

Instruction: In this part, you will be asked to reclassify the categories based on their appropriateness for constructed wetlands using a scale of 1 to 10, with 1 being not appropriate and 10 being very appropriate.

Land Use *

Mark only one oval per row.

	10	9	8	7	6	5	4	3	2	1
Closed Forest	○	○	○	○	○	○	○	○	○	○
Open Forest	○	○	○	○	○	○	○	○	○	○
Brush/Shrubs	○	○	○	○	○	○	○	○	○	○
Open/Barren	○	○	○	○	○	○	○	○	○	○
Grassland	○	○	○	○	○	○	○	○	○	○
Annual Crop	○	○	○	○	○	○	○	○	○	○
Perennial Crop	○	○	○	○	○	○	○	○	○	○

Part 3. Site Suitability Buffer Zones

Instruction: In this part, you will be asked to provide the minimum distances (approximate) in meters that constructed wetlands must be located from the buffer zones listed below.

18.   Surface Water (m) *

_____

Fig. 3.3 Sample of the survey questionnaire for the experts to provide the weights for each criterion (Part 2) and to set the buffer distances for the identified constraints (Part 3)

Table 3.2 List of classifications considered per criterion

| Criterion	Classifications
Land use	Closed forest, open forest, brush/shrubs, grasslands, annual crop, perennial crop, open barren
Slope	Relatively flat (0–8%), moderate (8–18%), steep (18–30%), very steep (30–50%), extremely steep (>50%)
Soil type	Hydrosol, silty clay loam, fine sandy clay loam, sand clay loam, silt loam, loam, clay loam
Distance to water bodies	Based on numerical value of distance
Distance to population centres	Based on numerical value of distance
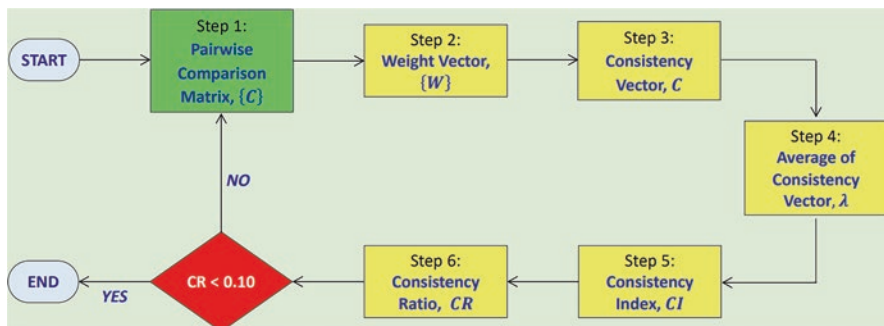
Fig. 3.4 Steps for AHP criteria weighting (Saaty 1987)

3.3.4   Evaluation of Criteria Weighting using AHP

Before using the computed weights in the suitability mapping, a consistency assessment of these weights was carried out using a series of equations to calculate the consistency ratio (CR). These steps are summarised in Fig. 3.4 (Saaty 1987).

The first step involved computing each criterion's consistency vector (C) by multiplying the weighted sum value with the inverse of the criteria weights, as shown in Eq. (3.1).

$$C = \left[\{C\} * \{W\} \right] * \{W\}^{-1} \tag{3.1}$$

where:

C—is the consistency vector

$\{C\}$—is the pairwise comparison matrix

$\{W\}$—is the weight vector

$\{W\}^{-1}$—is the inverse of the weight matrix

The eigenvalue (λ) of the matrix was calculated by taking the average of the consistency vectors. The eigenvalues obtained were then utilised to compute the consistency index (CI) using Eq. (3.2).

$$\text{CI} = \frac{\lambda - m}{m - 1} \tag{3.2}$$

where:

CI—is the consistency index

λ—is the average of consistency vectors

m—is the number of criteria considered

Finally, the consistency ratio was determined by dividing the CI by the random index (RI), as shown in Eq. (3.3). This calculation assessed whether computed weights were appropriate and consistent for application in the suitability mapping.

$$CR = \frac{CI}{RI} \tag{3.3}$$

where:

CR—is the consistency ratio

CI—is the consistency index

RI—is the random index

The RI value was determined based on the number of criteria considered in the study. The specific values for the RI corresponding to different numbers of criteria can be found in Table 3.3. In Eq. (3.3), the RI used is 0.12 (based on Table 3.3) since the matrix size is five, which is also the number of criteria used.

The matrix is consistent if the CR is less than 5% for a 3 × 3 matrix, less than 9% for a 4 × 4 matrix, and less than 10% for larger matrices. In the case studies, there are five factors or criteria evaluated; thus, CR should be less than 10% due to the 5 × 5 matrix. If the resulting consistency ratio exceeds 10%, the criteria weights were re-evaluated with the help of the experts until a CR value less than or equal to 10% was achieved.

3.3.5 Preparation of Criteria and Constraint Maps

The acquired maps of land use, slope, and soil type were clipped to the administrative boundaries of Bulacan, Laguna, and Negros Oriental, reprojected to World Geodetic System (WGS) 1984 Universal Transverse Mercator (UTM) Zone 51 N, and then rasterised to a similar resolution. These three criteria maps were then reclassified based on the survey results using a quantitative appropriateness scale of 1 (not acceptable) to 10 (extremely appropriate) as graded by the experts (Fig. 3.3, Part 2). The average scores based on the experts' decisions were used as the final reclassification values for land use, slope, and soil type. For those maps that were a function of distances (distance to water bodies and distance to population centres), Euclidean distance spatial analyst tool was used to transform the maps into discrete

Table 3.3 RI values based on the number of criteria (Saaty 1987)

Number of criteria	RI values
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.51

rasters and allow for the measurement of the relevant distances. All criteria maps were normalised into the same scale ranging from 0 (least suitable) to 255 (most suitable). Equation (3.4) shows the map algebraic expression used to normalise the reclassified criteria maps based on the Raster Calculator of ArcGIS.

$$\frac{\left(C_R - C_R.\text{min}\right) \times 255}{\left(C_R.\text{max} - C_R.\text{min}\right)} \tag{3.4}$$

where:

    C_R—is the reclassified criteria map

    $C_{R.\text{min}}$—is the minimum value

    $C_{R.\text{max}}$—is the maximum value

Buffers for the five criteria considered in the study were established using the minimum distance provided by the experts (Fig. 3.3, Part 3). Buffer zones were merged and assigned with a suitability value of zero. The final buffer map would render certain areas restricted from the construction of CWs.

3.3.6 Generation of Suitability Map

Suitability mapping of CWs was performed using ArcGIS Pro Version 3.1.2. All the normalised criteria maps and their corresponding weights (computed through AHP) were used to generate suitability maps. In this process, a Python syntax (Eq. 3.5) was employed to multiply the normalised maps by their assigned weights and overlay the individual maps into a unified suitability map. Once a preliminary suitability map for CWs was generated, the buffer zones were subtracted from the preliminary map to generate the final suitability map.

$$C_1 \times W_1 + C_2 \times W_2 + C_3 \times W_3 + C_4 \times W_4 + C_5 \times W_5 \tag{3.5}$$

where:

    C—is the normalised criteria map

    W—is the criteria weight

In addition, the study utilised a classification approach to partition the suitability map into two distinct categories: high suitability and low suitability. Pixels within the top 20% with the highest suitability scores (with suitability values of 204–255) were designated as areas with high suitability, while the remaining 80% were classified as areas with low suitability. This categorisation facilitated the identification of potentially suitable sites for CWs.

The most suitable site was chosen for each of the study areas. These sites were verified, plotted, and measured remotely using Google Earth Pro. The wastewater treatment capacity for the CWs was estimated assuming the following: (i) assuming full utilisation of the areas, (ii) a rated capacity of 180 m³/day, and (iii) a reference value based on the total area of facilities in Bayawan City's CWs, which amounts to 2700 m² (Jegatheesan et al. 2022).

3.3.7   Evaluation of Hazards

An assessment of environmental hazards was conducted to ensure the safety and appropriateness of the identified suitable sites. The assessment specifically focused on evaluating seismic, volcanic, and hydro-meteorological hazards in the chosen sites. The study utilised GeoRisk Philippines' HazardHunterPH, a readily available database developed by the Philippine Institute of Volcanology and Seismology (PHIVOLCS). The application provides comprehensive assessments of seismic, volcanic, and hydro-meteorological hazards.

3.4   Suitability Mapping of Case Studies

3.4.1   Criteria and Constraint Maps

The reclassification of the criteria maps of land use, slope, and soil type can be seen from the reclassification values from Table 3.4, in which closed and open forests are the least priority for the construction of CWs. Meanwhile, open/barren areas were considered the most appropriate land use type for the construction of CWs. Moreover, mangrove forests, marshlands, swamps, fishponds, built-up, and inland waters were deemed to be not suitable for the implementation of CWs under any circumstances and have a reclassification value of 0.

Consistent with the study of Peñacoba-Antona et al. (2021), the site suitability decreases as the slope of the area increases. Lower slope profiles were deemed more appropriate by the experts for the steady flow of wastewater from the entrance to the outflow. As a result, slopes within the 0%–18% range were deemed highly suitable, while slopes greater than 18% were reclassified as less suitable for CWs. For the soil type, clay and clay loam were considered the most appropriate for CWs construction based on the experts' judgments. Conversely, complex and beach sand received the lowest suitability rating for CWs.

Finally, the average minimum distances from the experts' survey served as buffers to the constraints, as summarised in Table 3.5 and shown in Fig. 3.5.

3.4.2   Criteria Weights

After two iterations of consultation with the experts, a list of consolidated criteria weights was computed, as shown in Table 3.6. The consistency ratios from the three experts were determined to be 7.16%, 9.94%, and 8.49%. All consistency ratios were within the acceptable range, which makes the consolidated criteria weights suitable for further use in the suitability mapping of CWs. It is shown that distances to water bodies and population centres obtained the highest weights among the five

Table 3.4 Land use reclassification based on their suitability for CWs

Criteria	Sub-criteria	Value
Land use	Inland water	0
	Built-up	0
	Mangrove forest, marshlands, swamps, and fishponds	0
	Closed forest	1
	Open forest	2
	Brush/shrubs	6
	Grassland	8
	Annual crop	8
	Perennial crop	8
	Open/barren	10
Slope	0%–8%	10
	8%–18%	7
	18%–30%	3
	30%–50%	2
	50% and above	1
Soil type	Complex	1
	Beach sand	1
	Hydrosol	2
	Mountainous land	3
	Silty clay loam	5
	Fine sandy loam	5
	Sandy clay loam	5
	Silt loam	7
	Gravelly loam	7
	Loam	8
	Clay loam	9
	Clay	9

Table 3.5 Constraint minimum distances (in metres)

Constraint	Minimum distance (in m)
Surface water	190
Coastline	213
Protected areas	350
Built-up areas	270

criteria, with 45.2% and 23.2%, respectively. This is consistent with the findings of Peñacoba-Antona et al. (2021), where these two emerged as the highest contributing factors in the determination of site suitability for CWs.

According to the experts, water bodies and population centres cannot be easily altered or modified through engineering interventions, which makes them crucial in assessing the suitability of areas for CWs. Further, water bodies are natural features
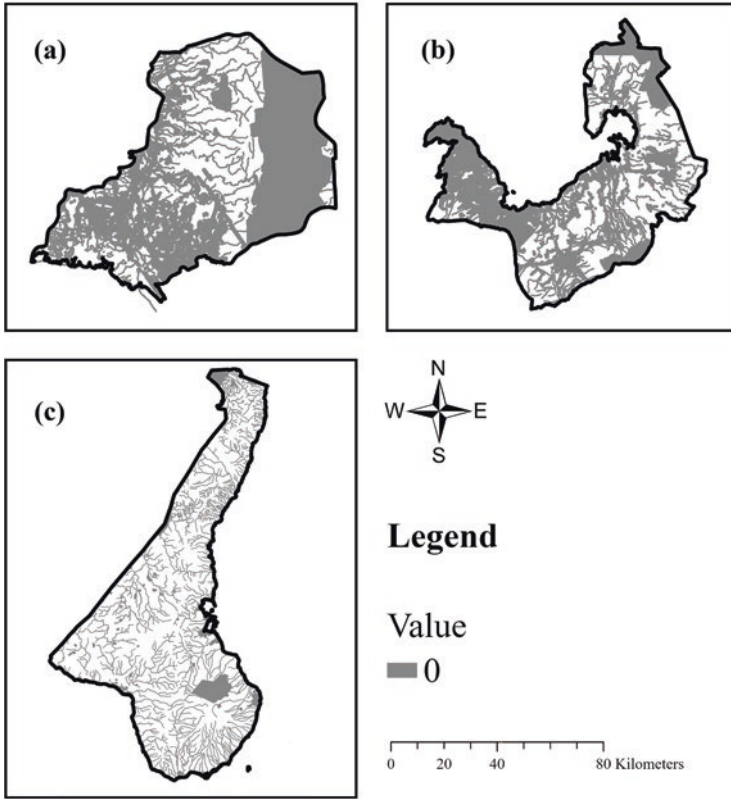
Fig. 3.5 Constraints maps of the study sites: (**a**) Bulacan, (**b**) Laguna, and (**c**) Negros Oriental, with grey colour representing the constraints

Table 3.6 Consolidated criteria weights based on the survey (Part 1) with the experts

Criteria	Criteria weights	Experts' remarks
C1: Land use	0.095	Can be easily changed through policy intervention
C2: Slope	0.149	Can be altered through engineering interventions
C3: Soil type	0.072	Can be altered through engineering interventions
C4: Distance to water bodies	0.452	Natural features that are too costly to divert
C5: Distance to population centers	0.232	Displacement may lead to huge socioeconomic costs

that are costly to alter, difficult to divert, and heavily protected by existing policies. Peñacoba-Antona et al. (2021) stated that water bodies offer multiple economic advantages in the construction of CWs. Thus, the proximity of CWs to water bodies may lead to easier access to water resources, reduced reliance on piping or pumping systems, and lesser land modification costs. Meanwhile, population centres often act as socioeconomic hubs which, aside from also being protected by laws, may make any alterations costly.

On the other hand, the experts perceived soil type, land use, and slope as the lesser impactful factors in the site selection of CWs. Modifying these factors through engineering and policy interventions to suit the needs of CWs is relatively easier. Moreover, CWs may be constructed across a wide range of land use classifications, soil types, and slopes, thus making the infrastructure adaptable to these factors.

3.4.3   Generated Suitability Maps

The constraint maps with zero value were then multiplied by the produced preliminary suitability maps to finalise the mapping. Figure 3.6 shows the final suitability maps of CWs in the provinces of Bulacan, Laguna, and Negros Oriental. The categorisation provides a clear and intuitive representation for local government units and decision-makers to identify and prioritise areas that have high suitability. This enables informed and sustainable planning decisions, ensuring that resources and efforts are directed towards areas with the greatest potential for successful CWs projects in Bulacan, Laguna, and Negros Oriental.

The areas with the highest suitability for CWs were concentrated around water bodies. The coastal provinces (Bulacan and Negros Oriental) have suitable areas near their perimeter. On the other hand, Laguna, as a non-coastal province, has suitable locations near inland water bodies, such as rivers and streams, due to the absence of coastal regions. However, no suitable sites were found near Laguna Lake since it is heavily protected by environmental policies. From the identified high-suitability areas, one site per study area was selected as the most suitable site for the construction of CWs, as summarised in Table 3.7.

The characteristics of the potential sites were also investigated. The investigation of the most potential site in Bulacan revealed that it has annual crops as their primary land use, with slope profiles ranging from 0% to 8%, and clay loam soil type. Likewise, in Laguna, the most potential area for CWs is characterised by perennial crops as their land use, with slopes ranging from 3% to 8%, and loam as the soil type. In Negros Oriental, the most potential site has land use for annual and perennial crops, as well as brushes/shrubs. The soil type was either fine sandy loam or clay, while the slopes range from 0% to 3%.

The summary of the seismic, volcanic, and hydro-meteorological hazard assessments of the most suitable sites in Bulacan, Laguna, and Negros Oriental from the HazardHunterPH app is presented in Table 3.8.
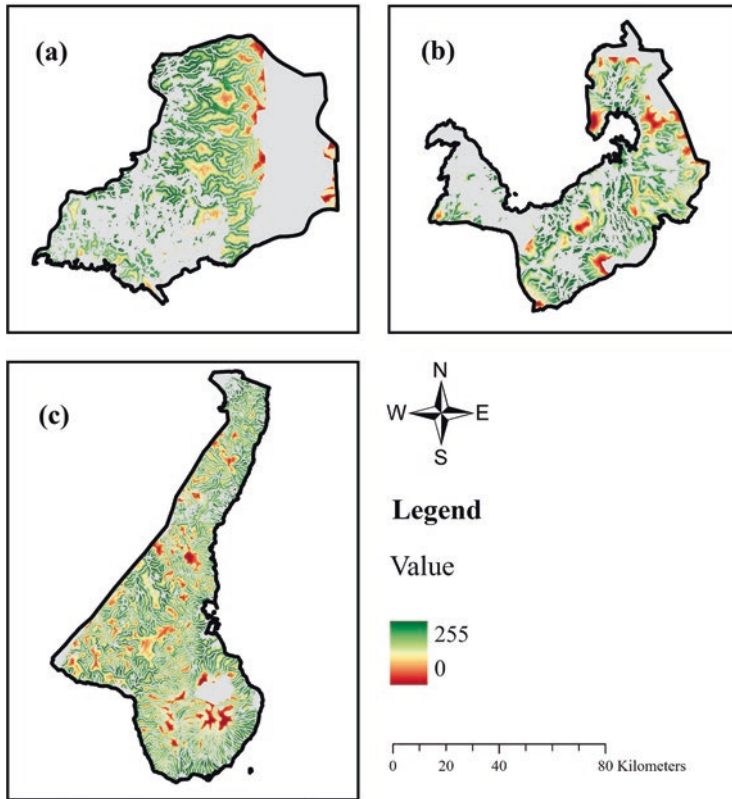
Fig. 3.6 Final suitability maps of the study sites: (a) Bulacan, (b) Laguna, and (c) Negros Oriental, with green colour representing the locations with high suitability for CWs

Table 3.7 Details of the most suitable site per province

Province	Location	Potential Land Area (in km²)
Bulacan	Camias and San Agustin, San Miguel, Bulacan	2.92
Laguna	Buboy, Pagsanjan, Laguna	0.67
Negros Oriental	Cawitan and San Jose, Santa Catalina, Negros Oriental	0.69

3.5   Conclusion

The guide for suitability mapping for CWs is presented in this chapter, with case studies in the three provinces of the Philippines: Bulacan, Laguna, and Negros Oriental. The presented suitability maps were developed based on the study of Peñacoba-Antona et al. (2021). The mapping was performed using ArcGIS, and the analysis with AHP to locate suitable locations for implementing the CWs. The criteria considered in the suitability mapping were identified based on related studies

Table 3.8 Summary of hazards assessment of the most suitable sites in Bulacan, Laguna, and Negros Oriental

Hazard	Bulacan	Laguna	Negros Oriental
Seismic hazards assessment			
Ground rupture	Safe; Approximately 31.7 km northwest of the Valley Fault System: West Valley Fault	Safe; Approximately 28.3 km west of the Unnamed Fault	Safe; Approximately 13.9 km west of the East Negros Fault System; Southern Negros Fault
Ground shaking	Prone; Intensity VIII	Prone; Intensity VIII	Prone; Intensity VIII
Earthquake-induced landslide	Safe	Safe	Prone; low susceptibility
Liquefaction	Moderately susceptible	Safe	Safe
Tsunami	Safe	Safe	Safe
Volcanic hazards assessment			
Nearest active volcano	Approximately 63.6 km east of Pinatubo	Approximately 17.1 km northwest of Banahaw	Approximately 124.5 km south of Kanlaon
Lahar	Safe	Prone; Low	Safe
Pyroclastic flow	NA	Safe	Safe
Ashfall	Prone	Prone	Prone
Hydro-meteorological hazards assessment			
Rain-induced landslide	NA	Low susceptibility; no identified landslides	Low susceptibility; no identified landslides
Severe wind	117.1–220 kph (20-year return period); 117.1–220 kph (500-year return period)	117.1–220 kph (20-year return period and 500-year return period)	88.1–117.1 kph (20-year return period); 117.1–220 kph (500-year return period)
Storm surge	Safe	Safe	Data are being updated

with the addition of other criteria from experts, including land use, slope, soil type, distance to water bodies, and distance to population centres. On the other hand, the constraints considered include surface water, coastline, protected areas, and built-up areas.

From the generation of suitability maps for the case studies, the critical factors are the inputs from the experts surveyed, such as the weights of the criteria to the suitability of the location and buffer distance of the CWs to these criteria. Further, the accuracy of the spatial maps of the criteria used in ArcGIS is equally important. There are cases where the suitable locations in the map had different land use, and the difference could be due to the outdated maps used. Thus, validation through onsite or satellite surveys should be done. Lastly, collaboration with the stakeholders, such as local government units and residents, should be done to verify the identified potential sites for the implementation of CWs.

References

Asadabadi MR, Chang E, Saberi M (2019) Are MCDM methods useful? A critical review of Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP). Cogent Engineering. https://doi.org/10.1080/23311916.2019.1623153

Bato VA (2018) GIS-based suitability mapping of banana in the Philippines. J. ISSAAS 24(1):1–13

El Baroudy AA (2016) Mapping and evaluating land suitability using a GIS-based model. Catena 140:96–104. https://doi.org/10.1016/j.catena.2015.12.010

Hoffmann H, Platzer C, Winker M, von Münch E (2011) Technology review of constructed wetlands: subsurface flow constructed wetlands for greywater and domestic wastewater treatment. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Eschborn, Germany

Jegatheesan V, Pachova N, Velasco P, Mowjood MI, Weragoda SK, Makehelwala M, Trang NT, Dang B, Tran C, Vo T, Trang NT, Pham H, Devanadera MC, Torrens A, Bui X, Nguyen P, Lecciones A, Jinadasa KB (2022) Co-development of an Integrated Assessment Framework to evaluate the effectiveness and impact of selected nature-based water treatment technologies in Sri Lanka, the Philippines, and Vietnam. Environ Qual Manag 32:335–365. https://doi.org/10.1002/tqem.21922

Liu J, Zhang W, Qu P, Wang M (2014) Cadmium tolerance and accumulation in fifteen wetland plant species from cadmium-polluted water in constructed wetlands. Front Environ Sci Eng 10:262–269. https://doi.org/10.1007/s11783-014-0746-x

Mohammed HI, Majid Z, Yamusa YB (2019) GIS based sanitary landfill suitability analysis for Sustainable Solid Waste Disposal. IOP Conference Series: Earth and Environmental Science 220:012056. https://doi.org/10.1088/1755-1315/220/1/012056

National Economic and Development Authority (2021) Philippine Water Supply and Sanitation Master Plan. https://neda.gov.ph/wp-content/uploads/2021/09/120921_PWSSMP_Main-Report.pdf. Accessed 15 Jun 2023

Omondi DO, Navalia AC (2020) Constructed wetlands in wastewater treatment and challenges of emerging resistant genes filtration and reloading. Inland Waters – Dynamics and Ecology. https://doi.org/10.5772/intechopen.93293

Peñacoba-Antona L, Gómez-Delgado M, Esteve-Núñez A (2021) Multi-criteria evaluation and sensitivity analysis for the optimal location of Constructed Wetlands (METland) at Oceanic and Mediterranean areas. Int J Environ Res Public Health 18:5415. https://doi.org/10.3390/ijerph18105415

Rahman ME, Bin Halmi MI, Bin Abd Samad MY, Uddin MK, Mahmud K, Abd Shukor MY, Sheikh Abdullah SR, Shamsuzzaman SM (2020) Design, operation and optimisation of Constructed Wetland for removal of pollutant. Int J Environ Res Public Health 17:8339. https://doi.org/10.3390/ijerph17228339

Rossi M, De Feudis M, Trenti W, Gherardi M, Vianello G, Vittori Antisari L (2023) GIS-based Geopedological approach for assessing land suitability for chestnut (Castanea Sativa Mill.) Groves for Fruit Production. Forests 14:224. https://doi.org/10.3390/f14020224

Saaty RW (1987) The analytic hierarchy process—what it is and how it is used. Math Modell 9:161–176. https://doi.org/10.1016/0270-0255(87)90473-8

Taherdoost H, Madanchian M (2023) Multi-criteria Decision making (MCDM) methods and concepts. Encyclopedia 3:77–87. https://doi.org/10.3390/encyclopedia3010006

Tourbier J, Pierson RW (1976) Biological control of water pollution. https://doi.org/10.9783/9781512807967

Vymazal J (2022) The historical development of constructed wetlands for wastewater treatment. Land 11:174. https://doi.org/10.3390/land11020174

Wallace SD, Knight RL (2006) Small-scale constructed wetland treatment systems: feasibility, design criteria, and O & M Requirements. Water Environmental Research Foundation, Alexandria, Virginia

Alvin Joseph S. Dolores   is a civil engineer, a registered master plumber, and an instructor at the Department of Civil Engineering, University of the Philippines Los Baños, specialising in the fields of water resources management and environmental engineering. He is currently taking his master's degree in environmental science at the UPLB School of Environmental Science and Management, where he researches on the effects of climate and land use changes on watershed management. He was previously involved in research studies related to recycled plastic in construction materials, municipal socioeconomic assessment, water footprint accounting of property developments, and public transport demand assessment.

Clar Francis Doloiras Camua   was born in Baliwag, Bulacan, on 10 January 2001. He attended Mariano Ponce National High School in junior high and Baliuag University in senior high, graduating with High Honours from both institutions. In 2023, he successfully completed his Bachelor of Science degree in Civil Engineering at the University of the Philippines Los Baños (UPLB), where he graduated cum Laude. Additionally, he actively participated as a resident member of the University of the Philippines Civil Engineering Society (UPCES) and the Philippine Institute of Civil Engineers-UPLB Student Chapter (PICE-UPLB SC), enhancing his communication skills and boosting his self-confidence.

Rey Jintalan Casas   was born on 26 January 2001, in San Jose Del Monte, Bulacan. He took his first years of secondary education at Celestino G. Tabuena National High School and transferred to Saint Louise de Marillac College of Sorsogon, where he graduated with honours. He earned his undergraduate degree in civil engineering from the University of the Philippines Los Baños in the year 2023. During his former years in college, he became an active resident member of the Civil Engineering Executive Organization, where he gained valuable experience in academic and social activities focused on promoting excellence and professionalism.

Angelika Natividad Galicia   holds a Bachelor of Science in Civil Engineering from the University of the Philippines Los Baños. Her academic journey was supported by an undergraduate scholarship from the Department of Science and Technology—Science Education Institute. With a keen interest in sanitary and environmental engineering, she pursued an internship at Laguna Water, where she gained valuable experiences in engineering related to wastewater treatment processes. Moreover, her passion for the field led her to pursue her research titled "Suitability Mapping of Constructed Wetlands for Domestic Wastewater Treatment in Laguna, Philippines using Analytical Hierarchy Process and Geographic Information System".

Perlie Velasco   is Associate Professor at the Department of Civil Engineering, University of the Philippines Los Baños (DCE, UPLB). She is the lead faculty in Environmental Engineering at the department with research projects in constructed wetlands and integrated solid waste management. She got her undergraduate degree in Civil Engineering at UPLB (2005), master's degree in Water Resources Engineering at the Katholieke Universiteit Leuven, Belgium (2010), and PhD Degree in Environmental Engineering at the Royal Melbourne Institute of Technology, Australia (2022). Her research works focus on membrane-based recovery of dissolved methane from wastewater effluent and constructed wetlands for wastewater treatment.

Ms. Angeli Cabaltica is a lecturer at the School of Civil Engineering & Management at International University—Vietnam National University HCMC. She is currently handling the courses Fluid Mechanics, Hydrology & Hydraulics, Water Supply & Sewerage, and Surveying. Ms. Cabaltica obtained her master's degree in Environmental Sanitation at the University of Ghent, Belgium, and a second master's degree in Water Resources & Management at the University of Stuttgart, Germany, in 2007 and 2011, respectively. Her research interests are in the fields of habitat modelling of aquatic species, site suitability studies, riverbank erosion risk assessment, hydrological modelling, spatial data analysis and mapping, and other environmental studies.

Joseph Angelo R. Sabio was born on 6 June 1996 in Polangui, Albay. He attended Philippine Science High School—Bicol Region Campus for his secondary education and pursued Bachelor of Science in Civil Engineering in the University of the Philippines Los Baños (UPLB). Eventually, he joined the faculty of the Department of Civil Engineering in UPLB as an instructor in 2022 after gaining experience in the industry. He is also a member of the University of the Philippines Civil Engineering Society (UPCES) and plans to pursue further studies in water resources and environmental engineering in the future.