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RESEARCH ARTICLE

Application of Multi-criteria Decision Analysis in Locating Wastewater Treatment Plants in Sri Lanka

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Abstract: This paper presents GIS integrated with the multi-criteria decision analysis (MCDA) method in selecting suitable sites for locating wastewater treatment plants (WWTPs) for two case studies in Sri Lanka: Unawatuna and Puttalam. The study considered seven different sub-criteria under three main criteria of technical aspects, environmental, and social and cultural aspects. Analytical Hierarchy Process (AHP) was utilized to find corresponding weights. Thereafter, weighted overlay mapping was applied to produce the site suitability maps under three classes, namely, unsuitable, moderately suitable, and suitable. Building/residential areas, other land use types, and groundwater depth were found to be the most influential factors for Unawatuna. High urbanization and its closeness to the coastline might be the reasons for this result. In the case of Puttalam, surface water has gained a higher contribution than groundwater owing to the presence of saltpans. Out of the total area, 6% and 15% were suitable for locating WWTPs in Unawatuna and Puttalam, respectively, indicating a less potential area in Unawatuna. Most suitable sites were selected from the potential candidate sites by considering the WWTP capacity and by field verification. It can be concluded that MCDA integrated with GIS is a promising method for WWTP site selection analysis, especially for highly urbanized cities with fewer probable sites.

Keywords: *Analytical hierarchy process (AHP), Multi-criteria decision analysis (MCDA), Site suitability analysis, Wastewater treatment plant (WWTP).*

Introduction

Industrialization, rapid growth in urban settlements, and lifestyle change have led to an increase in wastewater amount. As a result, improper discharge of untreated wastewater has increased the pollution loads to surface water and groundwater, which severely threatens human life and natural ecosystems. Before being released into the environment, generated wastewater must be treated to fulfil the wastewater effluent standards specified by the authorities in order to safeguard the public's health and water resources. The placement of wastewater management facilities is equally important as other infrastructure facilities such as water, electricity, and transport for maintaining living standards. On-site (non-sewered) and off-site (sewered) disposal are the two basic wastewater management strategies practice in the world (Gunady et al., 2015). Despite the effectiveness of off-site disposal facilities, they need high capital investment, and operational and maintenance costs making them non-affordable for developing countries like Sri Lanka. Thereby, off-site treatment facilities have been limited to city centres while surrounding suburbs rely on on-site wastewater disposal systems. Though off-site treatment facilities are placed, and on-site disposal is practiced, illegal transfer of grey water to storm water drains is also evident in many places. According to the Department of Census and Statistics publication in 2012, 2.5% of the population is served by off-site Wastewater Treatment Plants (WWTPs). 83.2% of the population rely on on-site facilities and 14.3% of the population have no proper sanitation (Karunaweera, 2021). The history of WWTPs in Sri Lanka dates back to 1905 with the construction of Madampitiya and Wellawatta treatment plants. By the time, both were abandoned due to operational problems in the former and community complaints in the latter. Later, Greater Colombo Sewerage System was put in place. Subsequently, several centralized WWTPs were established for housing schemes and for export processing industrial zones. Most recent

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WWTPs include Kandy City, Kurunegala, and Jaffna, and several projects are in the pipeline (Kumararathna, 2012).

Finding a suitable site for an off-site WWTP within city centres involves a wide range of factors dominated by less land availability, which makes the decision-making process complicated. Technical, social, environmental, and economic aspects are the main criteria in WWTP site suitability analysis (Makropoulos et al, 2007). There are many other associated factors under the umbrella of the main criterion such as temperature, wind direction and speed, rainfall, soil type, topography, groundwater depth, type of land use, and the existence of surface waters (Meinzinger, 2003). All these factors are related to the sustainability aspects of the treatment facility: technical efficiency and reliability of the system; system durability and flexibility; cost efficiency; minimization of environmental impacts; minimization of health risks; and public participation and acceptability (Makropoulos et al., 2007). Geographic Information Systems (GISs) have been effectively used to apply for multi-criteria evaluation within the context of site suitability analysis of development plans and in solving many environmental-related problems (Cobos-Mora et al., 2023; Fancek et al., 1999; Gemitzi et al., 2010; Kaya et al., 2020; Kebede & Ayenew, 2023; Xu et al., 2020). The analytic Hierarchy Process (AHP) introduced by Saaty (Saaty, 1980, Saaty, 1997) is the most widely applied Multi-Criteria Decision Analysis (MCDA) method in which pair-wise comparisons are made between factors creating scaled preferences. This method that sees a few worldwide applications to date in the literature of site suitability analysis in wastewater treatment plants (Anagnostopoulos & Vavatsikos, 2012; Hama et al., 2019; Makropoulos at al. 2007; Mansouri et al., 2013) and its applications in Sri Lanka are limited to suitability of waterbodies for culture-based fisheries, water supply need prioritization, flood exposure analysis, and prioritization of the objectives in planning and management of multipurpose reservoirs (Basnayake, 2022; Hewapathirana, 2021; Manikkuwahandi et al., 2019; Wijenayake et al., 2016). Factors that determine the proper site for WWTP facility are distinctive for a geographical area. This research aims to find suitable sites for placing municipal WWTPs in Unawatuna tourist area and Puttalam Municipal Council of Sri Lanka with the application of spatial MCDA.

Methodology

Case Studies

Two coastal towns in Sri Lanka, Unawatuna in the Galle district of Southern Province, and Puttalam in the North-Western Province of Sri Lanka were selected as case studies for locating the WWTPs. Unawatuna is a tourist area that belongs to the wet climatic zone of the country while Puttalam is in the dry zone. Puttalam municipal council area is densely populated with 896 persons per square kilometre while the Unawatuna population density is estimated as 2257 persons per square kilometer (Department of Census and Statistics, 2011). Currently the two towns lack a proper wastewater management system. Studies have proven the presence of E. coli bacteria in the water bodies near these towns hinting toward a potential discharge of sewage into the drains (Kader et al., 2023; Manage et al., 2022). Figure 1 shows the locations of the case study areas in Sri Lanka.

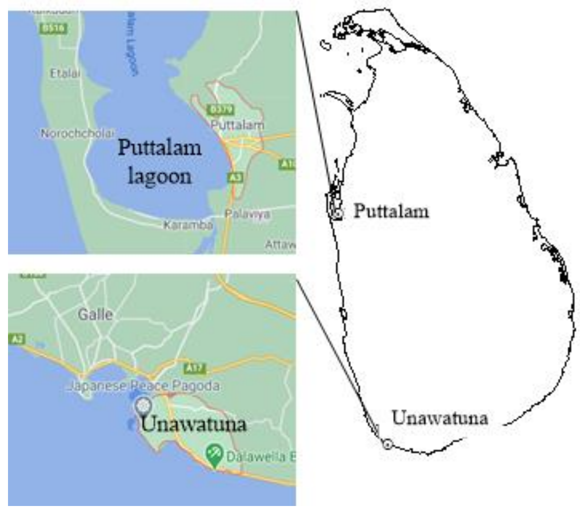

Figure 1: Locations of case studies: (a) Unawatuna and (b) Puttalam in Sri Lanka.

Spatial Multi-criteria Decision Analysis

Multi-criteria decision analysis (MCDA) involves a set of criteria that assign values for different alternatives for a specific purpose. In site suitability analysis for a WWTP, essential criteria may be technical, social, environmental, and economic factors while alternatives become the spatial grids of the study area. Spatial data for each criterion is gathered and processed into a decision in the MCDA approach and thereby referred to as spatial MCDA. It allows the ranking of the alternatives by combining spatial data based on the decision rules (Malczewski, 1999). Every criterion in site suitability analysis can be represented as a raster layer, each cell (or grid) representing a discrete alternative, which can be queried or overlaid with other layers/criteria. ArcGIS is very effective and efficient in handling spatial data. In addition to storing, and displaying spatial data in a map, GIS also provides a platform for applying constraints through creating buffers, overlays, intersections, spatial joins, map algebra, and other analytical operations. In the context of land suitability analysis, GIS-based MCDA helps the decision-maker determine where the most/least suitable sites are located. Figure 2 outlines the flowchart of the methodology. Each step involved in preparing the site suitability map is explained and discussed, presenting the results of this study in subsequent sections.

Development of Site Suitability Criteria

The design, construction, and operation of WWTP facilities depend on climatic, hydrological, land-use, environmental, geological, social, and cultural factors. Site selection for a WWTP facility, therefore, requires due consideration of environmental, social and cultural, and technical constraints (Makropoulos et al., 2007; Qasim 1999). In this research, MCDA is performed using a two-level criteria objectives tree. The criteria structure is organized under three principal objectives: technical aspects; environmental aspects; and social and cultural aspects, with the main goal of finding an optimal site for a WWTP facility as shown in Figure 2-A.

Technical Aspects

Factors that improve and ensure appropriate wastewater treatment as well as safeguard the treatment system were considered under the technical aspects. They mainly include climate, soil, and topography namely the slope. The monthly average temperature in Unawatuna is within the range of 25˚C to 30˚C while it varies between 25˚C to 27˚C in Puttalam (Department of Meteorology, 2021). Therefore, both study areas were in principle temperately suited for placing the facility. Generally, regions with less rainfall and free from flooding are suited for WWTPs. Spatial variation in rainfall is negligible within the study areas (Department of Meteorology, 2021). However, as a flood precaution and to reduce soil erosion, slopes less than 35% were considered. Further, the design process will become more complex when different soil types cover a site. Soil permeability should also be within the permissible level. The bearing capacity of the soil should be adequate to support the facility. There are a number of soil texture types in Sri Lanka, such as reddish-brown earth, red-yellow podzolic, red-yellow latosols, regosols, alluvial soils, etc. The land area of Unawatuna comprises red-yellow podzolic, regosol, bog, and half-bog while Puttalam area is dominated by alluvial, red-yellow latosols, regosols, and reddish-brown earth and low humic gley soils. From the permeability condition and bearing capacity perspectives, red-yellow podzolic is preferable (Table 1). The soil map obtained from the Irrigation Department of Sri Lanka was utilized in creating soil maps for the study areas.

When considering the slope aspect, a low-lying site facilitates the wastewater flow by gravity, minimizing the number of pumping stations. Further, if the slope is too high, surface runoff and soil erosion will be very high. Treated wastewater or effluent is also generally directed to a nearby water body or irrigable land. According to USEPA (USEPA, 1981), slopes <15% are most suitable for slow rate application, slopes of up to 20% are recommended for non-cultivated crops such as pastures, and forests have been successfully irrigated with effluent on slopes of up to 40%. In general, a site with a moderate slope will accommodate all requirements. The regions considered in this research are located in low-lying areas with slopes of less than 60%. Considering the above facts, slopes >30% and <15% were considered unsuitable and moderately suitable, respectively, while slopes in between were preferred for locating the WWTPs. Terrain maps for the study areas were prepared using 1:10,000 raster maps obtained from the Survey Department of Sri Lanka. The terrain maps were first converted to Digital Elevation Model (DEM) using the 'Topo to raster' converter tool in ArcGIS and then DEM was converted to a slope or elevation map using the 'Slope' tool.

Environmental Aspects

The health risks to the environmentally sensitive areas should be considered during the site selection process. Wastewater contains pollutants, which may contaminate the surface water bodies and groundwater by unintended discharges. Therefore, the WWTP should be located at a safe distance away from the surface water bodies, and further, groundwater depth should be considered for possible contamination. According to the Crown Land Ordinance (Chapter 454), there should be a 60 m distance from any public stream or water body to the WWTP. A criteria map for the surface water bodies was created for each study area from the 1:10,000 raster layers obtained from the Survey Department of Sri Lanka. The groundwater table is closer to the ground as the study areas are located closer to the coastline.

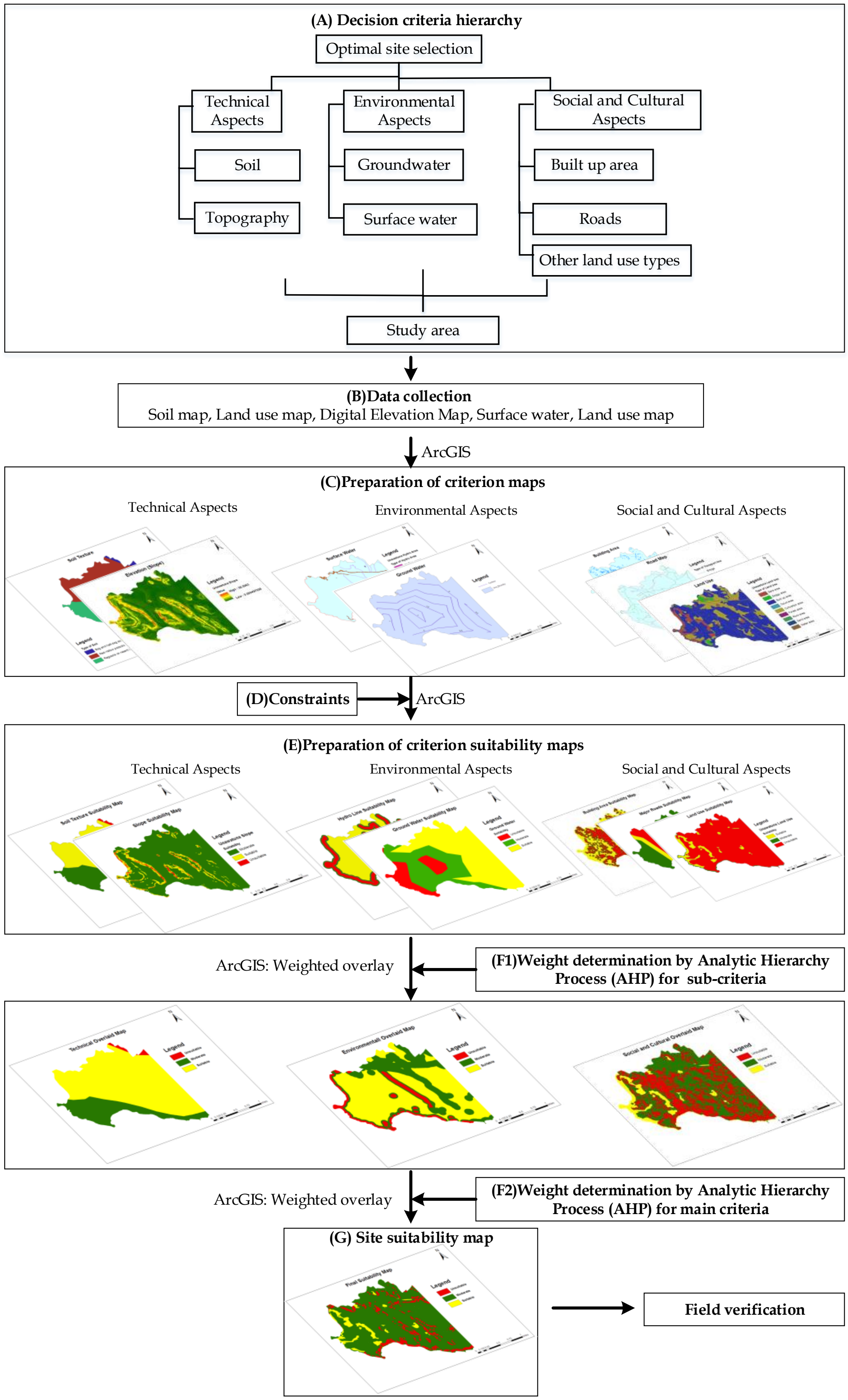

Figure 2: Flow chart of the methodology

Table 1: Constraints analysis outline (Score level: 3-Suitable; 2-Moderate; 1-Unsuitable).

Main Criteria	Sub Criteria		Unawatuna Class	Unawatuna Score	Puttalam Class	Puttalam Score
Technical Aspects	Soil	Soil texture	Bog and half-bog	3	Alluvial	3
			Red-yellow Podzolic	1	Red-yellow Latosols; gently undulating terrain	
			Regosols	2	Regosols	2
					Reddish brown earths and low humic gley soils	1
	Topography	Slope (%)	0 – 15	2	0 - 15	2
			15 – 30	1	15 - 30	1
			>30	3	>30	3
Environmental Aspects	Ground water	Depth (m)	0 – 1.5	1	0 - 1.5	1
			1.5 – 2.0	2	1.5 – 2.0	2
			>2.0	3	>2.0	3
	Surface waters	Buffer (m)	0 – 60	1	0 - 60	1
			60 – 100	2	60 - 100	2
			>100	3	>100	3
Social and Cultural Aspects	Building/ Residential areas	Buffer (m)	0 – 15	1	0 - 50	1
			15 – 30	2	50 - 100	2
			>30	3	>100	3
	Land use	Type	Built-up, Water, Rock, Cultivation, Forest, Boggy	1	Built-up, Water, Rock, Cultivation	1
					Forest, Boggy	2
			Sand	2	Sand	
			Bare	3	Bare	3
	Major roads	Buffer (m)	0 – 400	1	0 – 400	1
			400 – 600	3	400 – 600	3
			>600	2	>600	2
	Minor roads	Buffer (m)	0 – 50	1	0 – 50	1
			50 – 100	3	50 – 100	3
			>100	2	>100	2

Generally, greater depths are preferred. Groundwater depth layers were created from water levels of wells in the study areas and their coordinates. The minimum depth to the groundwater table was kept at 1.5 m (USEPA, 1981).

Social and Cultural Aspects

A thorough assessment of the local socio-cultural aspects is necessary during the site selection process.

Bare lands are more suitable for a site avoiding built-up areas, rock areas, cultivation areas, and forest areas. Further, the sewage must be applied to land that does not cause a nuisance and does not endanger health. Nuisance relates particularly to odour which can be avoided by keeping buffer zones around building/residential areas. Distance from the roads increases the construction and maintenance cost of the facility. On the other hand, the presence of the WWTP close to the roads affects the aesthetic appearance and public health. Mansouri et al., have kept 500m and

50m buffer zones for major roads and minor roads, respectively in siting a WWTP. In this study, a buffer zone of 400m and 50m were considered for major roads and minor roads, respectively.

Constraints Analysis

After the preparation of criterion maps (Figure 2-C), the first step of the analysis involves constraint performance for determining suitable, moderately suitable and non-suitable areas according to exclusionary criteria performance as in Table 1 (Figure 2-D). The raster layer of each criterion was classified into unsuitable, moderate, and suitable and they were scored as 1, 2, and 3 respectively, as this helps to assign weight in the raster overlay process (Figure 2-E).

Development of Site Suitability Criteria

This research applied Analytic Hierarchy Process (AHP), introduced by Saaty (Saaty, 1997), for finding the priorities (weights) for criteria according to their importance. As a procedure, AHP belongs to the family of methods that use pairwise comparisons to estimate relative preferences among decision analysis parameters in semi-structured decision problems. The AHP method involves three steps: the structure of the decision problem a hierarchy; the comparative judgment/pairwise comparison of the elements; and the synthesis of the priorities.

Structuring the Decision Problem

The decision problem is generally broken down into its components by developing decision hierarchies based on the decision maker's experience and awareness of the problem to provide an overall view of the complex relationships. It is composed of a goal at the uppermost level and major criteria at the intermediate level comprising the sub-criteria. For this research, a decision problem is structured as outlined in Figure 2-A.

Priority Setting of the Criteria by Pairwise Comparison (Figure 2-F)

In AHP, pair-wise comparisons are made rather than attempting to prioritize an entire list of elements (Saaty, 1980). Fundamental Saaty's preference scale is a 9-point scale, and in this research preference scale of Pawel (Pawel, 2010) was applied (Table 2). According to Table 2, seven judgments have to be performed when comparing pairs of objectives of the decision model. The pairwise comparison matrix includes the relative importance of different criteria in a preference scale (S) with respect to the main goal of finding an optimal site for a WWTP facility. The general layout of a pairwise comparison matrix is given in Figure 3.

Table 2: Scale of preferences (Pawel, 2010).

Importance	Definition	Explanation
1	Equal importance	Two factors contribute equally
3	Somewhat more important	Experience and judgment slightly favor one over the other
5	Much more important	Experience and judgment strongly favor one over the other
7	Very much more important	Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice
9	Absolutely more important.	The evidence favoring one over the other is of the highest possible validity
2,4,6,8	Intermediate values	When compromise is needed

	Criteria 1	Criteria 2	…..	Criteria n	…..	Criteria k
Criteria 1	S_{11}	S_{12}		S_{1n}		S_{1n}
Criteria 2	S_{21}	S_{22}		S_{2n}		S_{2n}
…..						
Criteria m	S_{m1}	S_{m2}		S_{mn}		S_{mk}
…..						
Criteria k	S_{n1}	S_{n2}		S_{kn}		S_{nn}

Figure 3: Layout of the pairwise comparison matrix

A questionnaire survey was conducted among the experts for assigning the preference scale (S_{mn}; when m>n). Experts in this case were 130 practising Engineers. The reciprocal of this value is assigned to the other criteria pair. Equal importance between each criterion was neglected to obtain an effective multi-criteria weight result (i.e S_{mn} when m=n).

Results and Discussion

Criterion Weights

A normalized pairwise comparison matrix is found by dividing each value by the column sum. Criterion weights are given by the row-averaged values of the normalized row-averaged pairwise comparison matrix. Tables 3 and 4 present the pairwise comparison matrices and weights for each criterion and sub-criterion for Unawatuna and Puttalam, respectively.

Site Suitability Maps

Finally, site suitability maps were prepared by the weighted summation overlay procedure. As all criteria are not equally important in the site selection, they need to be weighted based on their importance.

Table 3: Pairwise comparison judgment results and final weights: Unawatuna.

Decision criteria		Pairwise comparison matrices			Weights
	Goal	T	E	S	
T	Technical	1	5	5	0.09
E	Environmental	-	1	3	0.30
S	Social and Cultural	-	-	1	0.61
T	Technical Aspects	T1	T2	-	
T1	Soil	1	3	-	0.75
T2	Topography	-	1	-	0.25
E	Environmental Aspects	E1	E2	-	
E1	Groundwater	1	3	-	0.75
E2	Surface water	-	1	-	0.25
S	Social and Cultural	S1	S2	S3	
S1	Land use	1	3	5	0.30
S2	Building areas	-	1	5	0.61
S3	Roads	-	-	1	0.09

Table 4: Pairwise comparison judgment results and final weights: Puttalam.

Decision criteria		Pairwise comparison matrices			Weights
	Goal	T	E	S	
T	Technical	1	7	3	0.11
E	Environmental	-	1	3	0.36
S	Social and Cultural	-	-	1	0.53
T	Technical Aspects	T1	T2	-	
T1	Soil	1	-	-	0.75
T2	Topography	-	1	-	0.25
E	Environmental Aspects	E1	E2	-	
E1	Groundwater	1	5	-	0.17
E2	Surface water	-	1	-	0.83
S	Social and Cultural	S1	S2	S3	
S1	Land use	1	3	1	0.39
S2	Building areas	-	1	7	0.51
S3	Roads	-	-	1	0.10

The overlay process was carried out on two levels, one at a sub-criteria level (Figure 2-F1) and the other at the main criteria level (Figure 2-F2) with the use of the Weighted Overlay tool in the spatial analysis toolbox of ArcGIS.

Three maps were produced based on technical aspects, environmental aspects, and social and cultural aspects. However, sub-criteria weightage of technical aspects was found to be similar for both case studies. The surface water layer of Puttalam recorded the highest weightage than the groundwater layer in environmental aspects possibly due to the presence of the lagoon while it is contrariwise for Unawatuna. On the other hand, sub-criteria weights of social and cultural aspects were in the same order.

Figure 4 summarizes the site's suitability at sub-criteria level. Social and cultural aspects were found to be provided with the least percentage of suitable land area. This is expected in the city centres as a high percentage of the land area is occupied by built-up area leaving less for further development plans. Environmental aspects left considerable land area (>60%) for siting the WWTP facility in both cases. In the case of technical aspects, 78% of the total area was suited for placing the facility in Unawatuna while it was only 16% in Puttalam due to the less area offered by the slope constraint.

Despite individually suited area availability in the three aspects, their geographical position should be matched and the relative importance of each aspect towards the final decision should be considered. Therefore, three layers of social and cultural, technical, and environmental aspects were overlaid with the main criteria weightage. The higher the percentage, the more influence a particular dataset had on the suitability model. In both case studies, social and cultural aspects have more contribution to the decision, followed by environmental aspects and technical aspects.

Estimated land space requirement and field verification provided four land parcels which were retained for further consideration. Those land parcels are shown as A, B, C, and D for Unawatuna (Figure 5). Land parcels D and C are located closer to unsuitable zones and B is surrounded by moderately suited areas. A and C are very much closer to the sea than B and D. A is a private land while B, C, and D are state property. D is very much near the railway track. B is moderately near to the main road, which can save transport cost. Therefore, by considering these reasons, the most suitable site for locating the WWTP is selected as B with the extent of 1.6 km^2.

Similarly, 15%, 70%, and 15% of total area found to be suitable, moderately suitable, and not-suitable for Puttalam. Figure 6 shows the selected optimal land parcel having an area of 1.4 km^2 for siting WWTP in Puttalam after field a verification study.

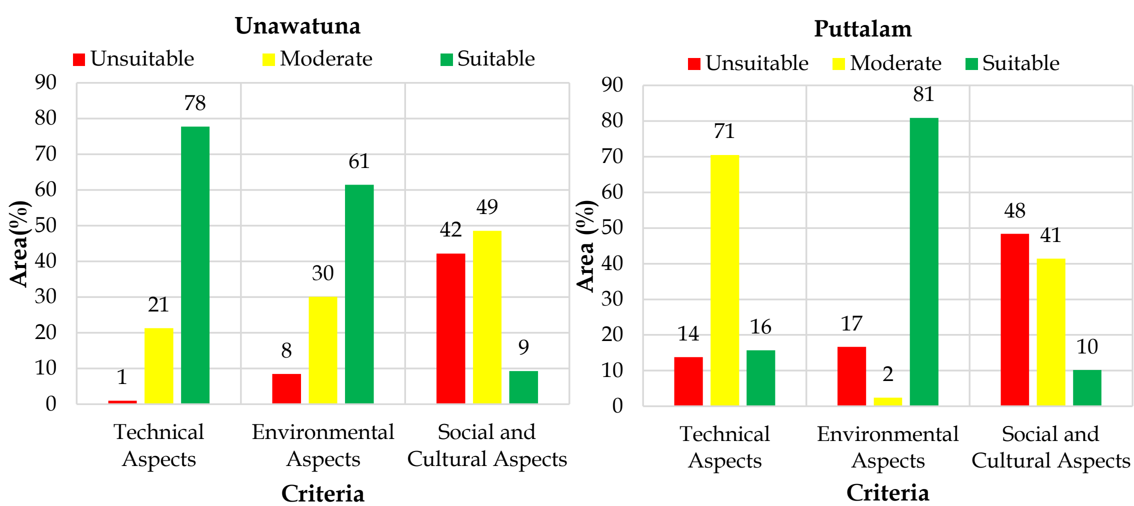

Figure 4: Site suitability level at sub-criteria level.

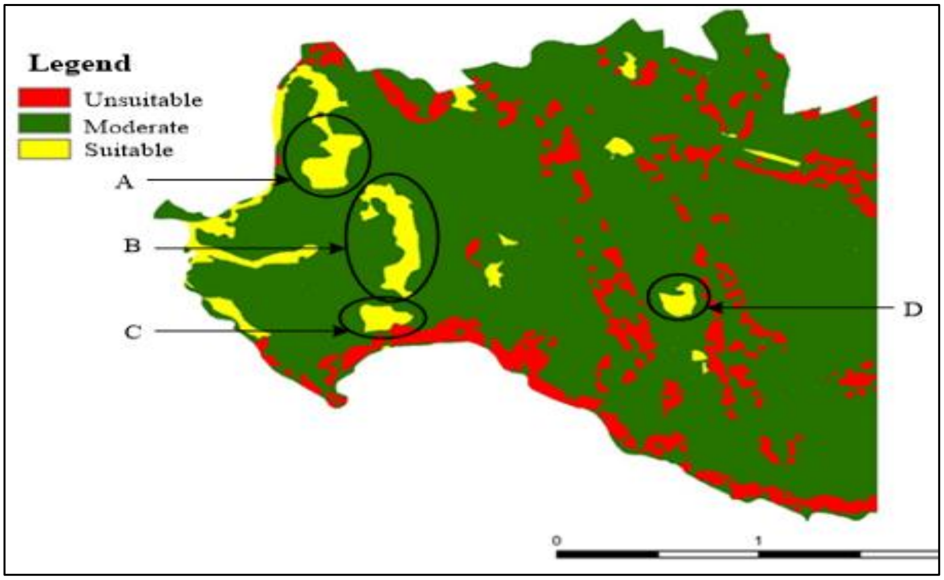

Figure 5: Site suitability index map for Unawatuna area

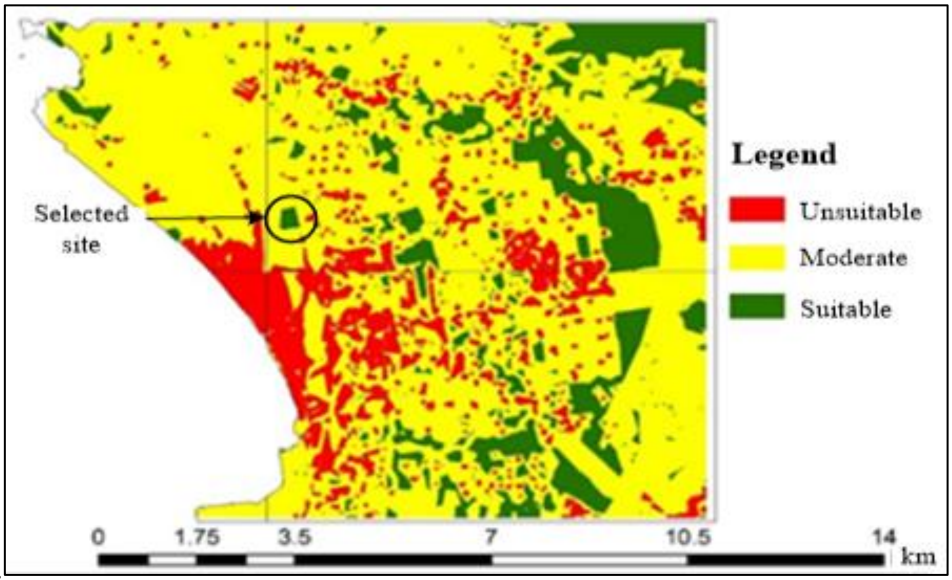

Figure 6: Site Suitability map for Puttalam Municipal Council.

Conclusions

Land allocation for facility development has become problematic due to urbanization. This research considered applying GIS-based multi-criteria decision analysis method based on the analytic hierarchy process for siting WWTPs for two case studies in Sri Lanka. The criteria are structured under the three aspects: Technical aspects, Environmental aspects, and Social and cultural aspects. The presented approach provided a fast way for evaluating possible candidates before field verification. It can be adopted in other parts of Sri Lanka for sustainable future development.

References

Anagnostopoulos, K., & Vavatsikos, A. (2012). Site suitability analysis for natural systems for wastewater treatment with spatial fuzzy analytic hierarchy process. *Journal of Water Resources Planning and Management*, *138*(2), 125-134.

Basnayake, B. M. L. A. (2022). Prioritization of Sub-basins of Nilwala River Basin for Flood Exposure using Multi Criteria Decision Analysis. *ENGINEER*, *55*(01), 23-30.

Cobos-Mora, S. L., Guamán-Aucapiña, J., & Zúñiga-Ruiz, J. (2023). Suitable site selection for transfer stations in a solid waste management system using analytical hierarchy process as a multi-criteria decision analysis: a case study in Azuay-Ecuador. *Environment, Development and Sustainability*, *25*(2), 1944-1977.

Department of Census and Statistics. 2011. *Census of Population and Housing 2011*, Retrieved on January 23, 2022, http://www.statistics.gov.lk/PopHouSat/CPH2011.

Department of Meteorology (2021). Monthly Weather Summary - Weather Synopsis [Review of Monthly Weather Summary - Weather Synopsis]. Department of Meteorology - Sri Lanka. http://www.meteo.gov.lk/

Fancek, M., Klopcic, J., & Klopcic, R. (1999). GIS Helps Return Sewage Sludge to Soils Where Nutrients Can Be Recycled, *GeoWorld*, 12(4), 52-54.

Gemitzi, A., Tsihrintzis, V. A., & Petalas, C. (2010). Use of GIS and Multi-Criteria Evaluation Techniques in Environmental Problems, *In: Tsihrintzis G. A., Jain L. C., Ed., Multimedia Services in Intelligent Environments. Smart Innovation, Systems and Technologies, SST 3, Springer, Berlin*, 5-62.

Gunady, M., Shishkina, N., Tan, H., & Rodriguez, C. (2015). A Review of On-Site Wastewater Treatment Systems in Western Australia from 1997 to 2011, *Journal of En-vironmental and Public Health,* https://doi.org/10.1155/2015/716957

Hama, A. R., Al-Suhili, R. H., & Ghafour, Z. J. (2019). A multi-criteria GIS model for suitability analysis of locations of decentralized wastewater treatment units: case study in Sulaimania, Iraq. *Heliyon*, *5*(3).

Hewapathirana, A. S. (2021). *Using GIS-based multi criteria decision analysis for prioratizing drinking water supply needs: an application to southern region in Sri Lanka* (Doctoral dissertation).

Kader, S., Raimi, M. O., Spalevic, V., Iyingiala, A. A., Bukola, R. W., Jaufer, L., & Butt, T. E. (2023). A concise study on essential parameters for the sustainability of Lagoon waters in terms of scientific literature. *Turkish Journal of Agriculture and Forestry*, *47*(3), 288-307.

Karunaweera, H. (2021). Updates on Domestic Wastewater Management in Sri Lanka, *The 16th Water Environment Partnership in Asia (WEPA) Annual Meeting, 2021.* http://wepa-db.net/pdf/meeting/20210301/11_Sri%20Lanka.pdf, Visited 2021/07/29

Kaya, Ö., Tortum, A., Alemdar, K. D., & Çodur, M. Y. (2020). Site selection for EVCS in Istanbul by GIS and multi-criteria decision-making. Transportation Research Part D: Transport and Environment, 80, 102271.

Kebede, H. A., & Ayenew, W. A. (2023). Solid waste disposal site selection analysis using geospatial technology in Dessie city Ethiopia. *Heliyon*.

Kumararathna, G. A. (2012). Domestic Wastewater Management in Sri Lanka, *A dialogue on water environment, 27th August 2012, Colombo, Sri Lanka.* http://wepa-db.net/activities/2012/20120827_srilanka/pdf/WEPA_DM_SriLanka_Kumararathna.pdf Visited 2021/07/29

Makropoulos, C. K., Argyrou, E., Memon F. A. & Butler, D. (2007). A Suitability Evaluation Tool for Siting Wastewater Treatment Facilities in New Urban Developments, *Urban Water Journal*, 4(2), 61-78.

Malczewski, J. (1999). GIS and Multicriteria Decision Analysis, *John Wiley and Sons, New York*, 392.

Manage, P. M., Liyanage, G. Y., Abinaiyan, I., Madusanka, D. A. T., & Bandara, K. R. V. (2022). Pollution levels in Sri Lanka's west-south coastal waters: Making progress toward a cleaner environment. *Regional Studies in Marine Science*, *51*, 102193.

Manikkuwahandi, T. D. S., Hornberger, G. M., & Baroud, H. (2019). Decision analysis for expansion of Mahaweli multipurpose reservoir system in Sri Lanka. *Journal of water resources planning and management*, *145*(9), 05019013.

Mansouri, Z., Hafezi Moghaddas, N., & Dahrazma, B. (2013). WWTP Site Selection using AHP and

GIS: A Case Study in Falavarjan, *Esfahan. Geopersia*, 3(2), 63–72.

Meinzinger, F. (2003). GIS-Based Site Identification for the Land Application of Wastewater Christchurch City, Mater Thesis, *Lincoln University, New Zealand*, 64.

Pawel, C. (2010). Using the Analytic Hierarchy Process in Evaluating Decision Alternatives', *Journal of Operations Research and Decisions*, 1-23.

Qasim, S. R. (1999). WWTPs, design, and operation (*2nd ed.)*

Saaty, T. L. (1980). The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation.

Saaty, T. L. (1997). A Scaling Method for Priorities in Hierarchical Structures, *J. Math. Psychol.*, 15(3), 234–281.

U.S. Environmental Protection Agency (USEPA), (1981). United States Environmental Protection Agency. Process Design Manual for Land Treatment of Municipal Wastewater.

Wijenayake, W. K., Amarasinghe, U. S., & De Silva, S. S. (2016). Application of a multiple-criteria decision making approach for selecting non-perennial reservoirs for culture-based fishery development: Case study from Sri Lanka. *Aquaculture*, *459*, 26-35.

Xu, Y., Li, Y., Zheng, L., Cui, L., Li, S., Li, W., & Cai, Y. (2020). Site selection of wind farms using GIS and multi-criteria decision making method in Wafangdian, China. *Energy*, *207*, 118222.