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SUPPLEMENTARY MATERIAL

Text SI- 1: Detailed description of wastewater system configurations and planning considerations

Centralized systems—characterized by extensive sewer networks conveying wastewater to large-scale facilities for centralized discharge—have historically been the dominant model in industrialized countries and large communities due to their perceived efficiency, reliability, and economies of scale [1-5]. This dominance reflects the broader Modern Infrastructural Ideal, within which large-scale, capital-intensive infrastructure was prioritized to ensure sanitary performance and regulatory compliance [1]. However, traditional centralized systems present notable limitations related to high land and energy requirements, elevated capital and operating costs, and constrained opportunities for resources recovery and sustainability [6-8].

In contrast, decentralized wastewater systems offer an alternative configuration by operating closer to wastewater sources and handling comparatively smaller volumes at the scale of individual building or small clusters [9]. Such systems span a broad range of configurations, from septic tanks and leach fields to compact treatment units, constructed wetlands, membrane-based package plants, and other modular or nature-based technologies [9, 10]. Decentralized solutions can reduce conveyance requirements and enable phased implementation, offering greater flexibility and adaptability, often with lower upfront infrastructure investments [7, 11, 12]. These characteristics make decentralization particularly attractive in low-density or rapidly expanding settlements and in areas where sewers extension is financially or technically challenging [13]. However, decentralized options are not determined solely by cost-efficiency considerations; their adoption and design are also influenced by local actors, institutional arrangements, land availability, and regulatory constraints, which can lead to heterogeneous solutions across jurisdictions [4]. Their long-term performance additionally hinges on local management capacity, operation, and maintenance, and can be sensitive to hydrogeological, demographic, and regulatory contexts [7, 11].

Between these two poles, hybrid systems have emerged as an intermediate strategy that integrates centralized and decentralized components by deploying satellite or cluster-scale treatment units that serve small groups of buildings, typically between four and twelve households, without relying on full sewer network extensions. Such configurations enable localized treatment while still benefiting from shared infrastructure and coordinated operational oversight, often reducing capital and maintenance costs compared to stand-alone or fully individualized solutions [14, 15]. Satellite treatment facilities, co-located with advanced treatment technologies, can facilitate water reuse or nutrient recovery in semi-urban and peri-urban areas, while easing pressure on aging centralized infrastructures [14, 15].

Soleimani [16] illustrates a range of possible configurations through six alternatives spanning fully centralized to fully decentralized systems, including several hybrid options in between. These include flexible systems with urine and graywater separation for nutrient recovery, collaborative arrangement that share treatment functions between on-site and centralized facilities, and environment-friendly systems that route graywater to centralized plants and blackwater to satellite units to reduce emissions and support recover resources.

Urban wastewater system selection is constrained by demographic growth, climate pressures, and resource limitations[17, 18]. These challenges are particularly acute in small and medium-sized cities, where limited technical and financial capacity, ageing infrastructure, and stringent environmental requirements narrow the range of feasible options. Under such conditions, selecting wastewater treatment systems is far from a purely technical exercise. It involves navigating multi-objective decision spaces that combine environmental performance, lifecycle costs, operational reliability, land availability, technological maturity, institutional capacity, and compliance with regulatory frameworks[14, 17, 19, 20]. The decision landscape is further complicated by heterogeneous stakeholder priorities—from utilities and regulators to community actors and property developers—as well as spatial constraints such as proximity to water bodies, hydrogeological vulnerability, and compatibility with existing infrastructure[21-23]. As a result, solution pathways vary widely across jurisdictions, reflecting localized socio-technical, environmental, and institutional contexts rather than any universal optimum. These complexities highlight the need for structured decision-support approaches capable of systematically comparing alternatives, integrating stakeholder preferences, and managing planning uncertainties, and addressing trade-off[22]. In the context of wastewater management, such methodologies provide a formal basis for evaluating, ranking, and selecting infrastructure configurations[7].

Text SI- 2: Detailed explanation of the development and structuring of decision objectives

A master list of objectives was first developed to support systematic elicitation and reduce omission bias. It compiles a broad set of objectives derived from literature and case experiences, helping stakeholders articulate concerns that might otherwise be overlooked. This approach has been shown to increase both the diversity and completeness of objectives' elicitation in complex public planning contexts, including wastewater infrastructure [24].

The list was compiled through a review of academic and grey literature on wastewater decision-making, with emphasis on criteria used in previous MCDA applications. Existing decision frameworks were examined to identify commonly applied evaluation dimensions [16, 19]. Regulatory standards and guidelines from Quebec and North America [25, 26] were also incorporated to ensure alignment with policy and technical requirements.

Literature highlights that spatial decision-making for wastewater planning has typically focused on technical and physical constraints, including topography, land use, hydrology, and proximity to infrastructure, with the primary objective of minimizing costs and maximizing efficiency [27, 28]. Thus, GIS-MCDA applications emphasize technical feasibility, while environmental and social dimensions remain weakly integrated. To our knowledge, no GIS-MCDA framework for centralized systems explicitly evaluates the feasibility of connecting unsewered areas to existing collection and treatment networks, revealing a gap in current planning approaches. Similarly, spatial selection of decentralized infiltration systems is mainly driven by soil permeability/thickness, groundwater vulnerability, and terrain constraints, with limited consideration of equity, governance, and sustainability [29, 30].

In contrast, non-spatial MCDA studies place greater emphasis on environmental performance, pollutant removal, resource recovery, and stakeholder and social acceptance [14, 19]—dimension largely absent from spatial frameworks. This divergence highlights the need to extend GIS-MCDA to multidimensional objectives beyond technical constraints. Table SI-1 summarizes the dominant drivers and constraints for surface water discharge system (SDS) and onsite wastewater treatment facility with infiltration (OWTF) systems reported in the literature, with detailed sources and criteria description.

Objectives were then formulated following three principles: defining the decision context, specifying the object of concern, and clarifying the preferred direction of the objective. Here, the context is the strategic selection of wastewater management solutions. For example, "maximize water infiltration into the soil" identifies water infiltration as the object, with greater infiltration representing the preferred direction. All objectives were expressed in clear, measurable terms to ensure consistent evaluation and maintain preferential independence among criteria [31].

16 decision objectives were identified and structured to meet the case study requirement. These objectives span technical feasibility, spatial constraints, economic considerations, environmental protection, and public health, ensuring alignment with established decision-making frameworks and planning priorities.

Objectives were organized into two perspectives: locations where systems can be implemented most effectively (opportunities) and area where intervention is most needed (needs). This structure enables the joint assessment of feasibility and benefits within the GIS-MCDA framework.

Two system-specific hierarchies were developed to distinguish infiltration-based systems (A) from surface discharge and centralized systems (B). Systems (A) prioritize objectives such as maximizing infiltration potential, reducing groundwater resurgence, and integrating with planned developments, whereas systems (B) emphasize minimizing infrastructure conflicts, reducing sewer network overuse, and limiting excavation and pumping costs.

Each objective was linked to a measurable spatial attribute to ensure operationalization within the GIS-MCDA analysis. For instance, soil permeability/thickness and groundwater depth assess infiltration feasibility, while sewer network proximity and bedrock depth capture infrastructure and cost constraints. This hierarchical structure enables a transparent translation of planning goals into spatial decision rules. The complete list of objectives and attributes for perspectives is provided in Tables SI-2 and SI-3.

Table SI- 1: Common spatial decision criteria used in spatial and non-spatial MCDA approaches for wastewater systems planning.

Criteria	**Interpretation**	SDS	OWTF	**Sources**
Topography	The slope and elevation of the land must be considered to ensure the feasibility of construction and effective wastewater flow.	✓		[28, 32-38]
Land Use	The existing and planned land use must be assessed to avoid conflicts with residential areas or other sensitive uses.	✓		[28, 39]
Depth to groundwater table	The groundwater table should be sufficiently low to avoid waterlogging of underground structures and minimize the risk of tank flotation.	✓		[23, 32, 36, 38]
Hydrology	The proximity to surface water bodies must be considered to minimize environmental risks and to comply with regulations.	✓		[34, 35, 40, 41]
Distance to receiving water body	The treatment system should be located close to the receiving water body to reduce transportation and pumping costs.	✓		[23, 33, 35, 42]
Distance from settlement	The system should be placed away from residential and potentially developing areas to minimize visual, odor, and noise disturbances.	✓		[23, 28, 34-36, 38, 42]
Proximity to infrastructure	The distance to existing sewer networks and transportation routes must be minimized to optimize construction and operational costs.	✓		[27, 43]
Distance to access roads/railroad	The site should be accessible by major roads or railways to facilitate the transportation of equipment and materials.	✓		[23, 28, 32-35, 38, 42]
Slope	The slope of the terrain should ideally range between 0% and 8%, as slopes greater than 15% create challenges for the installation of drainage fields.		✓	[23, 30, 44-47]
Soil Permeability	The soil's infiltration capacity must be sufficient to allow for decentralized wastewater treatment systems.		✓	[23, 29, 30, 45, 47, 48]

Depth to groundwater table	On-site wastewater systems require at least 1 m of separation between the drainage field and the groundwater table to maintain effective pollutant filtration and pathogen removal.		✓	[23, 29, 45, 46, 49]
Groundwater Vulnerability	The vulnerability of groundwater to contamination must be assessed based on the depth and permeability of the soil.	✓	✓	[14, 29, 30, 32, 37, 42, 50, 51]
Social Acceptance	The concerns of stakeholders and the potential for public opposition must be considered.	✓	✓	[14, 19]
Environmental Impact	The impacts on biodiversity, greenhouse gas emissions, and overall sustainability must be considered.	✓	✓	[14, 19]

Note: SDS = surface water discharge system; OWTF = onsite wastewater treatment facility with infiltration;

Table SI- 2: Master list of objectives of the opportunities' perspective developed based on literature, existing frameworks and guidelines.

<u>Opportunities perspective:</u> Prioritizing sites offering the best opportunities for setting up a wastewater system	
Objectives (example of attribute or indicator)	WWT type
Avoid exposure to recurrent flooding (presence of a flood plain, presence of bodies of water)	OWTS, hybrid OWTS, SDS, hybrid SDS
Prioritize integration into future real estate developments *(planned real estate development)*	SDS, hybrid SDS
Promote integration into future road works *(planned road works)*	hybrid SDS
Maximize wastewater system adaptability to development density *(projected volume of wastewater [m^3])*	OWTS, hybrid OWTS, SDS, hybrid SDS
Maximize placements on sites with enough space *(percentage of available area per site [%])*	OWTS, hybrid OWTS
Avoid interfering with public easements *(type of public easement)*	OWTS, hybrid OWTS, SDS, hybrid SDS
Maximize water infiltration into the soil *(soil type)*	OWTS, hybrid OWTS
Avoid interfering with existing buildings *(distance from building footprint [m])*	OWTS, hybrid OWTS, SDS, hybrid SDS
Minimize groundwater-induced flooding *(water table height [m]))*	OWTS, hybrid OWTS, hybrid SDS
Avoid interfering with existing underground and overhead infrastructure (distance from underground infrastructure [m])	OWTS, hybrid OWTS, SDS, hybrid SDS
Minimize overload in sewer networks and treatment plants (percentage of use of the sewer network [%] or percentage of use of the treatment plant [%])	SDS
Avoid potential contamination (distance to landfill or contaminated sites [m])	OWTS, hybrid OWTS, SDS, hybrid SDS

Minimize pumping costs (distance between site and the nearest sewer line [m])	OWTS, hybrid OWTS, SDS, hybrid SDS
Minimize excavation costs related to rock depth *(rock depth [m])*	OWTS, hybrid OWTS, SDS, hybrid SDS
Prioritize sites with suitable slopes *(slope [%])*	OWTS, hybrid OWTS, SDS, hybrid SDS
Minimize connection costs (distance between site and the nearest sewer line [m])	OWTS, hybrid OWTS, SDS, hybrid SDS
Minimize the distance between the WWT and the receiving waterbody *(distance to bodies of water [m])*	Hybrid OWTS

Note OWTS: Onsite Wastewater Treatment System (septic tank with drain field for individual household); Hybrid OWTS: Moving Bed Biofilm Reactor (MBBR) with drain field (cluster of approximately 10 houses); SDS: Surface Discharge System (connection to centralized wastewater treatment facility); Hybrid SDS: MBBR with surface discharge (cluster of approximately 10 houses).

The OWTS include (A1) individual septic tanks connected to individual drain fields, and (A2) cluster-scale moving bed biofilm reactors (MBBR) connected to a polishing bed serving approximately ten households.

The SDS include (B1) cluster-scale MBBR with surface discharge, and (B2) connection to the centralized WWTF.

Table SI- 3: Master list of objectives of the needs' perspective developed based on literature, existing frameworks and guidelines.

<u>Needs' perspective:</u> Prioritize sites with the greatest need for wastewater system implantation

Objectives (example of attribute or indicator)	WWT type
Reduce surface water vulnerability (bacteriological and physicochemical quality index and surface water availability indicator - horizon 2011-2040)	OWTS, hybrid OWTS, SDS, hybrid SDS
Reduce groundwater vulnerability *(DRASTIC index)*	OWTS, hybrid OWTS, SDS, hybrid SDS
Minimize the number of days beaches are closed (Number of days exceeding bathing water quality standards per urban drainage basin [days])	OWTS, hybrid OWTS, SDS, hybrid SDS
Minimize noise and odor levels *(Distance to settlement [m])*	hybrid SDS
Minimize reliance on electricity for system operation *(Presence of aerial power grid)*	OWTS, hybrid OWTS, SDS, hybrid SDS
Maximize the distance between the treatment facility and drinking water supply wells *(Distance to wells [m])*	OWTS, hybrid OWTS, SDS, hybrid SDS
Maximize the distance between the treatment facility and bodies of water *(Distance to bodies of water [m])*	OWTS, hybrid OWTS, SDS
Minimize overflows (Overflows intensity index per urban drainage basin)	OWTS, hybrid OWTS, SDS, hybrid SDS
Maximize access to green spaces *(Distance to a green space [m])*	hybrid OWTS
Maximize the reuse of biosolids (Distance to sludge treatment facilities [m])	OWTS, hybrid OWTS
Minimize the effect of heat islands *(Temperature class)*	hybrid OWTS

Note OWTS: Onsite Wastewater Treatment System (septic tank with drain field for individual household); Hybrid OWTS: Moving Bed Biofilm Reactor (MBBR) with drain field (cluster of approximately 10 houses); SDS: Surface Discharge System (connection to centralized wastewater treatment facility); Hybrid SDS: MBBR with surface discharge (cluster of approximately 10 houses).

The OWTS include (A1) individual septic tanks connected to individual drain fields, and (A2) cluster-scale moving bed biofilm reactors (MBBR) connected to a polishing bed serving approximately ten households.

The SDS include (B1) cluster-scale MBBR with surface discharge, and (B2) connection to the centralized WWTF.

Text SI- 3: Detailed swing weighting procedure, hierarchical weight calculation, and weighted linear combination (WLC) aggregation method

Stakeholder preferences were elicited using the swing weighting method to quantify the relative importance of decision objectives. This method evaluates the relative importance of improving each objective from its worst to its best level while all other objectives remain at their worst level [31].

The weighting process was applied hierarchically. At the first level, high-level objectives were scored and normalized to derive their weights:

$$w_I = \frac{S_I}{\sum_{b=1}^{n} S_b} \qquad Eq. (1)$$

Where W_I: the weight of high-level objective I, S_I its score, n: the number of high-level objectives, and b: the index of high-level objectives.

t the second level, sub-objectives under each high-level objective were scored independently and normalized. Their final weights were computed as:

$$w_i = \frac{S_i}{\sum_{a=1}^{m} S_a} \times w_I \qquad Eq. (2)$$

Where W_I: the weight of sub-objective i, S_I: its score, m: the number of sub-objectives under high-level objective I, and a: the index of sub-objectives

Spatial criteria were aggregated using a weighted linear combination (WLC) method, a commonly used approach in GIS-based multi-criteria decision analysis[52].

The overall suitability score for each alternative $A_i$is calculated as:

$$V(A_i) = \sum_{k=1}^{n} w_k \times v(a_{ik}) \text{ Eq. } (3)$$

Where $V(A_i)$: Overall value of the alternative i, w_k: Weight of the criterion k, $v(a_{ik})$: Value of the alternative I on criterion k, n: number of criteria, i: Alternatives index (spatial unit), and k: the criterion index.

This aggregation produces a composite suitability score reflecting both criterion performance and stakeholder-defined weights. Higher values indicate better alignment with decision objectives.

Table SI- 4: Value scales of the objectives related to opportunities for systems with infiltration (A1 and A2) in the final hierarchy.

Higher objective	Lower objective	Attributes	Classes	Suitability score	Weight (%)
1. Maximize system performance	1.1 Maximize water infiltration into the soil	Soil type (categories)	Impervious	0	0.12
			Low permeability	0.25	
			Moderate Permeability	0.5	
			Permeability	0.75	
			High permeability	1	
	1.2 Minimize groundwater-induced flooding	Thickness of the unsaturated layer [m]	0	0	0.1
			3	0.25	
			3.5	0.5	
			4	0.75	
			5	1	
2. Maximize integration into urban planning	2.1 Prioritize integration into future real estate developments	Areas planning real estate development (boolean)	Absence	0	0.13
			Presence	1	
	2.2 Maximize wastewater system adaptability to development density	Projected volume of wastewater (m^3)	20	0	0.11
			15	0.2	
			12	0.3	
			6	0.5	
			5	0.7	
			4	0.8	
			3.24	1	
	2.2 Maximize wastewater system adaptability to development density*	Projected volume of wastewater (m^3)	3.24	0	0.11
			4	0.2	
			5	0.3	
			6	0.5	
			12	0.7	
			15	0.8	
			20	1	
3. Minimize conflicts with urban infrastructure	3.1 Maximize placements on sites with sufficient space	Percentage of available area per site (%)	100	0	0.12
			75	0.25	
			65	0.5	
			55	0.75	
			50	1	
			40	0	0.16
			50	0.25	

	3.2 Minimize overload in sewer networks and treatment plants	Percentage of use of the sewer network (%)	60	0.5	
			75	0.75	
			80	1	
		Percentage of use of the treatment plant (%)	40	0	
			50	0.25	
			60	0.5	
			75	0.75	
			80	1	
4. Limit costs	4.1 Limit connection costs	Distance between site and the nearest sewer line (m)	100	0	0.11
			150	0.25	
			300	0.5	
			450	0.75	
			1000	1	
	4.2 Limit pumping costs	Distance between site and the nearest sewer line (m)	100	0	0.08
			1000	0.25	
			2500	0.5	
			5000	0.75	
			10000	1	
	4.3 Limit excavation costs linked to rock depth	Rock depth (m)	0	0	0.07
			1	0.25	
			2	0.5	
			3	0.75	
			4	1	

Table SI- 5: Value scales of the objectives related to needs for systems with infiltration (A1 and A2) in the final hierarchy and elicited weight.

Higher objective	Lower objective	Attributes	Classes	Suitability score	Weight (%)
5. Maximize sustainable protection of water resources	5.1 Reduce surface water vulnerability	Bacteriological and physicochemical quality index (categories)	Good (80-100)	0	0.1
			Satisfactory (60-79)	0.25	
			Doubtful (40-59)	0.5	
			Bad (20-39)	0.75	
			Very bad (0-19)	1	
		Surface water availability indicator - horizon 2011-2040 (categories)	high	0	
			moderate to high	0.5	
			moderate	0.75	
			low	1	
	5.2 Reduce groundwater vulnerability	DRASTIC index (categories)	180	0	0.15
			170	0.25	
			160	0.5	
			150	0.75	
			100	1	
6. Maximize the well-being of the population	6.1 Minimize the number of days beaches are closed	Number of days exceeding bathing water quality standards (days)	0	0	0.1
			10	0.25	
			15	0.5	
			20	0.75	
			30	1	
	6.2 Maximize access to green spaces*	Distance to a green space (m)	0	0	0.07
			300	0	
			525	0.25	
			750	0.5	
			975	0.75	

			1200	1	
7. Maximize public health protection	7.1 Minimize reliance on electricity for system operation	Presence of aerial power grid (boolean)	Absence	0	0.09
			Presence	1	
	7.2 Maximize the distance between the treatment facility and drinking water supply wells	Distance to wells (m)	30	0	0.17
			45	0.25	
			50	0.5	
			100	0.9	
			200	1	
	7.3 Maximize the distance between the treatment facility and bodies of water	Distance to bodies of water (m)	300	0	0.13
			320	0.25	
			340	0.5	
			360	0.75	
			400	1	
8. Maximize adaptation to climate change	8.1 Minimize overflows	Overflows intensity index per urban drainage basin (categories)	Nil or not applicable	0	0.06
			Very low	0.2	
			Low	1	
			Medium	1	
			High	1	
			Very high	1	
	8.2 Maximize the reuse of biosolids*	Distance to sludge treatment facilities (m)	100000	0	0.09
			70000	0.25	
			60000	0.5	
			50000	0.75	
			25000	1	
	8.3 Minimize the effect of heat islands*	Temperature class (categories)	1	0	0.04
			3	0.25	
			5	0.5	
			7	0.75	
			10	1	

Table SI- 6: Value scales of the objectives related to opportunities for systems with surface discharge (B1 and B2) in the final hierarchy and elicited weight.

Higher objective	Lower objective	Attributes	Classes	Suitability score	Weight (%)
1. Maximize system performance	1.1 Minimize the distance between the WWTF and the receiving waterbody*	Distance to bodies of water (m)	300	0	0.09
			320	0.25	
			340	0.5	
			360	0.75	
			400	1	
	1.2 Minimize groundwater-induced flooding	Water table height (m)	0	0	0.08
			3	0.25	
			3.5	0.5	
			4	0.75	
			5	1	
2. Maximize integration into urban planning	2.1 Prioritize integration into future real estate developments	Areas planning real estate development (boolean)	Absence	0	0.12
			Presence	1	
	2.2 Prioritize integration into upcoming roadworks	Planned infrastructure projects (boolean)	Absence	0	0.07
			Presence	1	
	2.3 Maximize wastewater system adaptability to development density	Projected volume of wastewater (m^3)	3.24	0	0.16
			4	0.2	
			5	0.3	
			6	0.5	
			12	0.7	
			15	0.8	
			20	1	
3. Minimize conflicts with existing urban infrastructure	3.1 Minimize conflicts with infrastructure	Presence of public utility (boolean)	Presence	0	0.09
			Absence	1	
	3.2 Minimize overload in		80	0	0.15
			75	0.25	

	sewer networks and treatment plants	Percentage of use of the sewer network (%)	60	0.5	
			50	0.75	
			40	1	
		Percentage of use of the treatment plant (%)	80	0	
			75	0.25	
			60	0.5	
			50	0.75	
			40	1	
4. Limit costs	4.1 Limit connection costs	Distance between site and the nearest sewer line (m)	1000	0	0,09
			450	0,25	
			300	0,5	
			150	0,75	
			100	1	
	4.1 Limit connection costs*	Distance between site and the nearest sewer line (m)	100	0	
			150	0,25	
			300	0,5	
			450	0,75	
			1000	1	
	4.2 Limit pumping costs	Distance between site and the nearest sewer line (m)	10000	0	0,06
			5000	0,25	
			2500	0,5	
			1000	0,75	
			100	1	
	4.2 Limit pumping costs*	Distance between site and the nearest sewer line (m)	100	0	
			1000	0,25	
			2500	0,5	
			5000	0,75	
			10000	1	
	4.3 Limit excavation costs linked to rock depth	Rock depth (m)	0	0	0,09
			1	0,25	
			2	0,5	
			3	0,75	

	4	1	

Table SI- 7: Value scales of the objectives related to needs for systems with surface discharge (B1 and B2) in the final hierarchy and elicited weight.

Higher objective	Lower objective	Attributes	Classes	Suitability score	Weight (%)
5. Maximize sustainable protection of water resources	5.1 Reduce surface water vulnerability	Bacteriological and physicochemical quality index (categories)	Very bad (0-19)	0	0.15
			Bad (20-39)	0.25	
			Doubtful (40-59)	0.5	
			Satisfactory (60-79)	0.75	
			Good (80-100)	1	
		Surface water availability indicator - horizon 2011-2040 (categories)	low	0	
			moderate	0.5	
			moderate to high	0.75	
			high	1	
	5.1 Reduce surface water vulnerability*	Bacteriological and physicochemical quality index (categories)	Good (80-100)	0	
			Satisfactory (60-79)	0.25	
			Doubtful (40-59)	0.5	
			Bad (20-39)	0.75	
			Very bad (0-19)	1	
		Surface water availability indicator - horizon 2011-2040 (categories)	high	0	
			moderate to high	0.5	
			moderate	0.75	
			low	1	
	5.2 Reduce groundwater vulnerability	DRASTIC index (categories)	180	0	0.14
			170	0.25	
			160	0.5	
			150	0.75	
			100	1	
6. Maximize the well-being of the population	6.1 Minimize the number of days beaches are closed	Number of days exceeding bathing water quality standards (days)	30	0	0.11
			20	0.25	
			15	0.5	
			10	0.75	

Higher objective	Lower objective	Attributes	Classes	Suitability score	Weight (%)
			0	1	
	6.1 Minimize the number of days beaches are closed*	Number of days exceeding bathing water quality standards (days)	0	0	
			10	0.25	
			15	0.5	
			20	0.75	
			30	1	
	6.2 Minimize noise and odor levels*	Distance to settlement (m)	100	0	0.09
			150	0.25	
			300	0.5	
			450	0.75	
			1000	1	
7. Maximize public health protection	7.1 Minimize reliance on electricity for system operation*	Presence of aerial power grid (boolean)	Absence	0	0,11
			Presence	1	
	7.2 Maximize the distance between the treatment facility and drinking water supply wells	Distance to wells (m)	30	0	0,18
			45	0,25	
			50	0,5	
			100	0,9	
			200	1	
8. Maximize adaptation to climate change	8.1 Minimize overflows	Overflows intensity index per urban drainage basin (categories)	Very high	0	0,16
			High	0	
			Medium	0	
			Low	0	
			Very low	0,2	
			Nil or not applicable	1	
	8.1 Minimize overflows*	Overflows intensity index per urban drainage basin (categories)	Nil or not applicable	0	
			Very low	0,2	
			Low	1	
			Medium	1	

Higher objective	Lower objective	Attributes	Classes	Suitability score	Weight (%)
			High	1	
			Very high	1	
	8.2 Maximize the reuse of treated wastewater*	Distance to golf course (m)	30	0	0,06
			45	0,25	
			50	0,5	
			100	0,9	
			200	1	

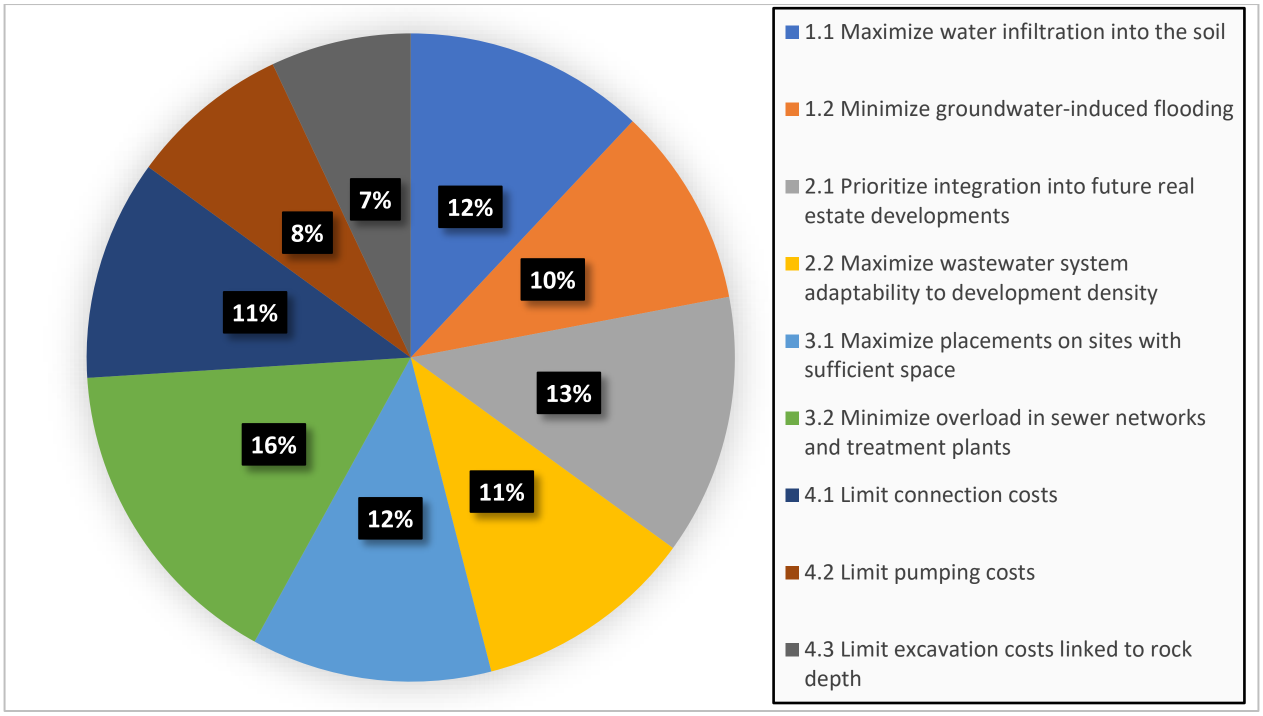

Figure SI- 1: Weighting of sub-objectives related to opportunities for systems with infiltration (A1 and A2).

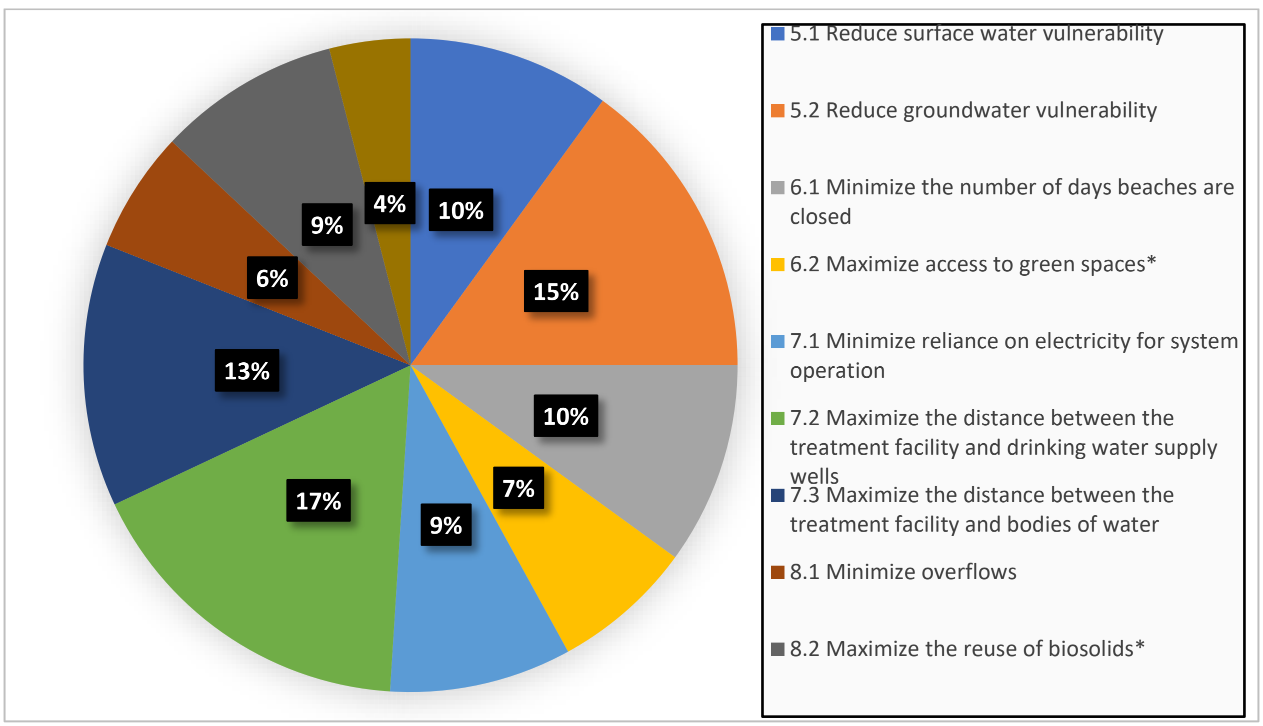

Figure SI- 2 : Weighting of sub-objectives related to needs for systems with infiltration (A1 and A2). Values represent the mean weight obtained from *n* respondents (n=6).

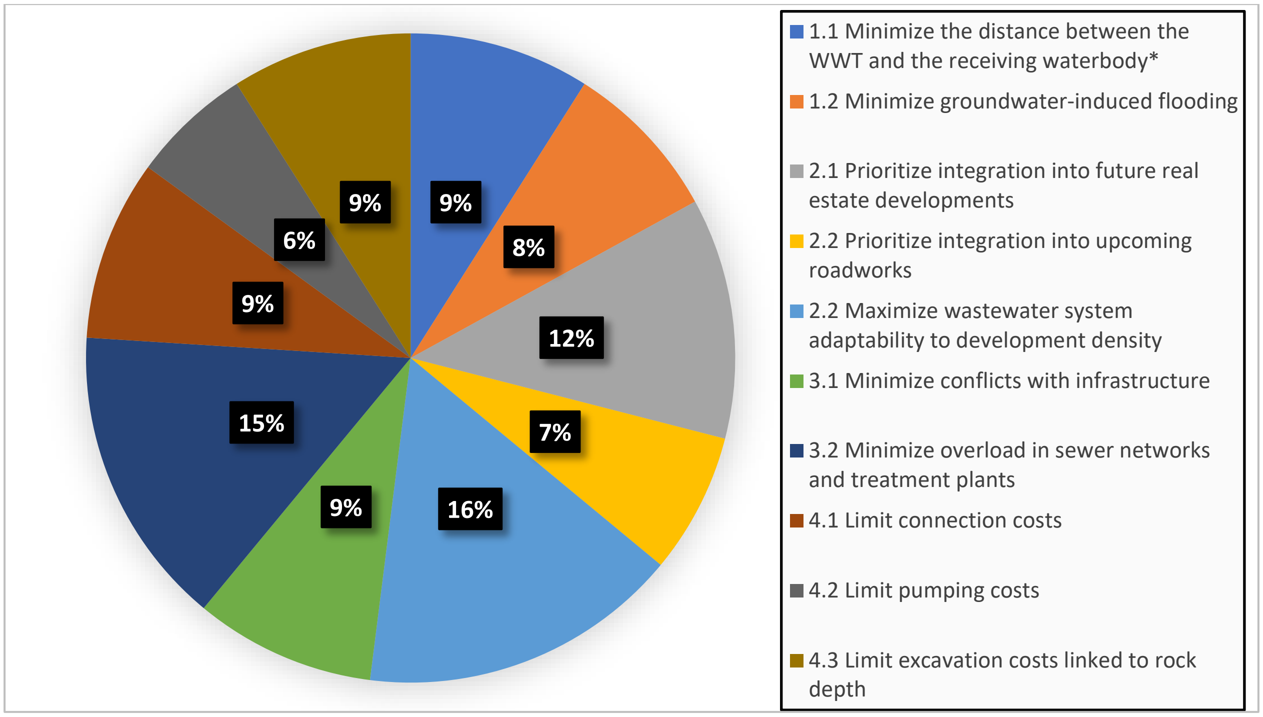

Figure SI- 3 : Weighting of sub-objectives related to opportunities for systems with surface discharge (B1 and B2). Values represent the mean weight obtained from *n* respondents (n=6).

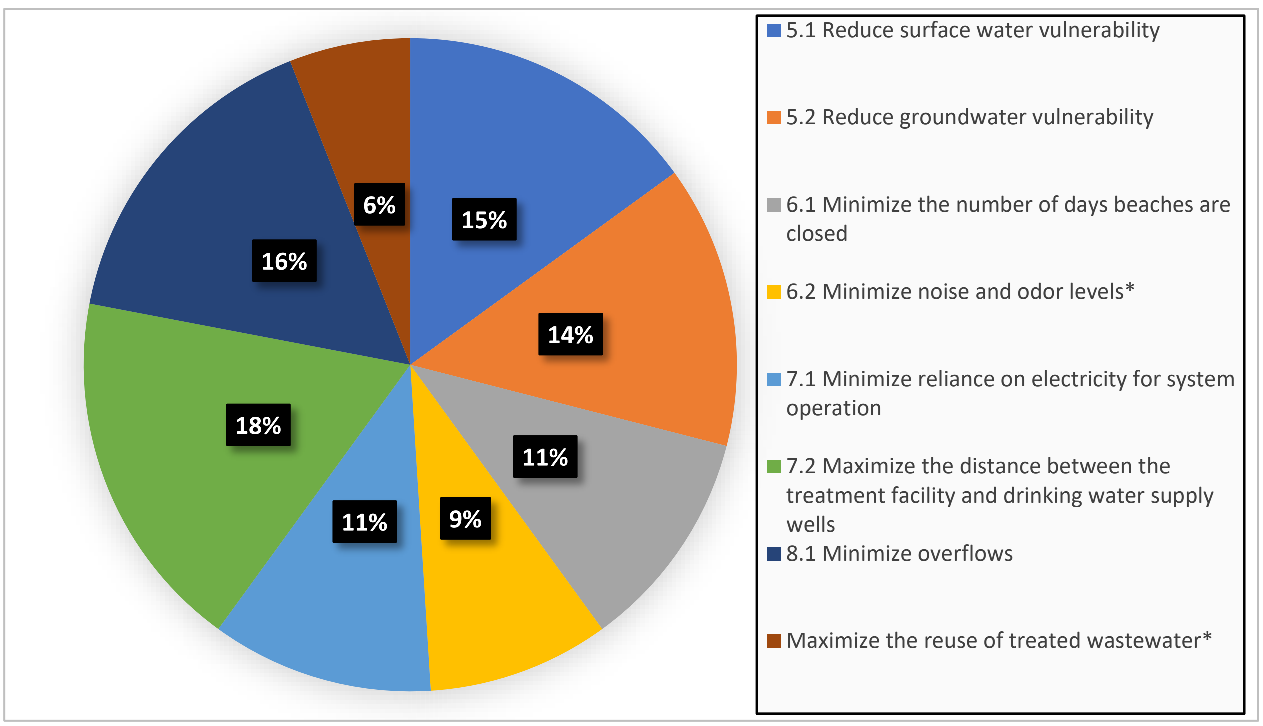

Figure SI- 4 : Weighting of sub-objectives related to needs for systems with surface discharge (B1 and B2). Values represent the mean weight obtained from *n* respondents (n=6).

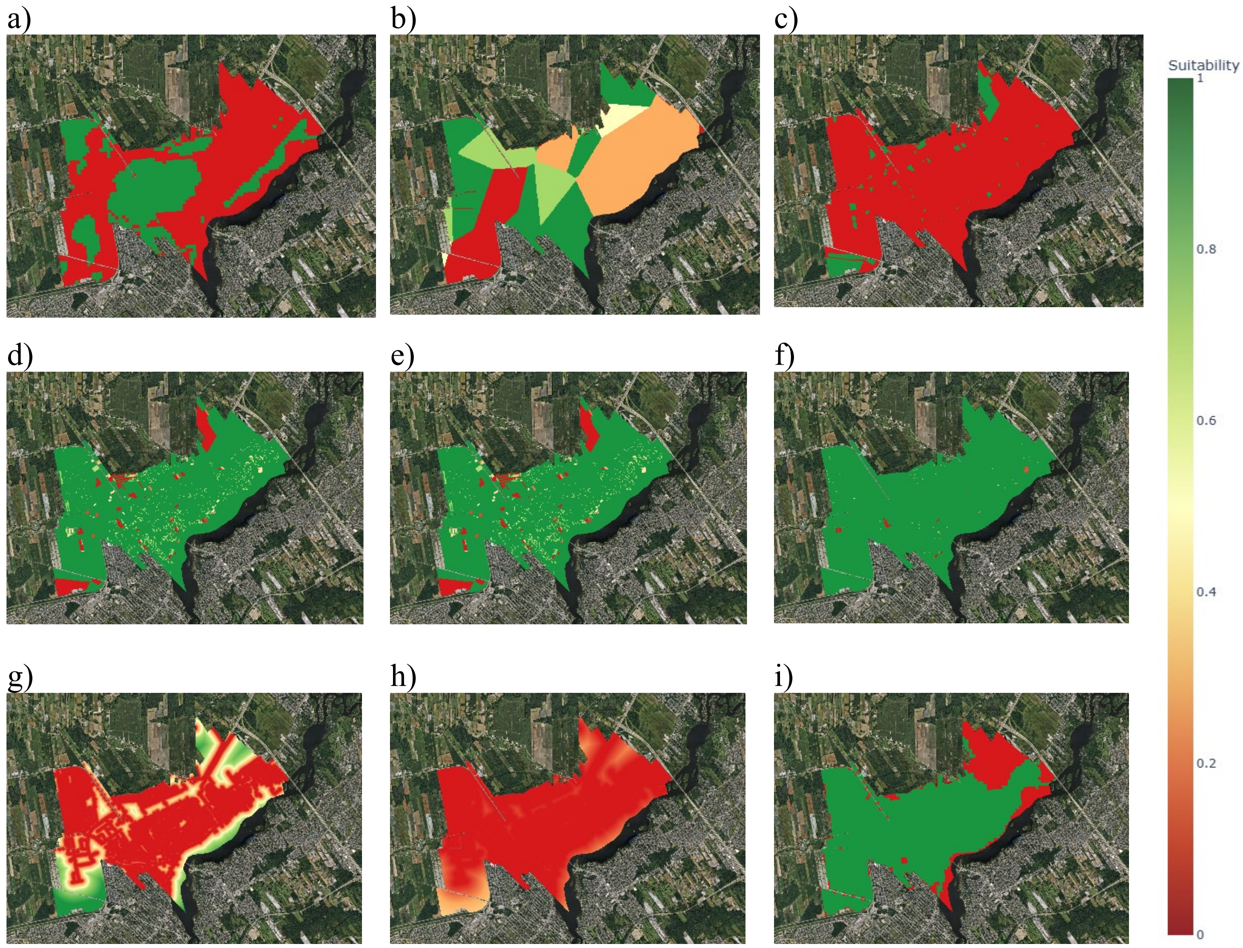

Figure SI- 5: Suitability maps of system with infiltration (A1 and A2) attributes related to opportunity objectives in the final hierarchy: a) soil type; b) water table height; c) areas planning real estate development; d) projected volume of wastewater; e) projected volume of wastewater*; f) percentage of available area per site; g) percentage of available area per site*; h) percentage of use of the sewer network; i) distance between site and the sewers; j) distance between site and the sewers; k) rock depth.

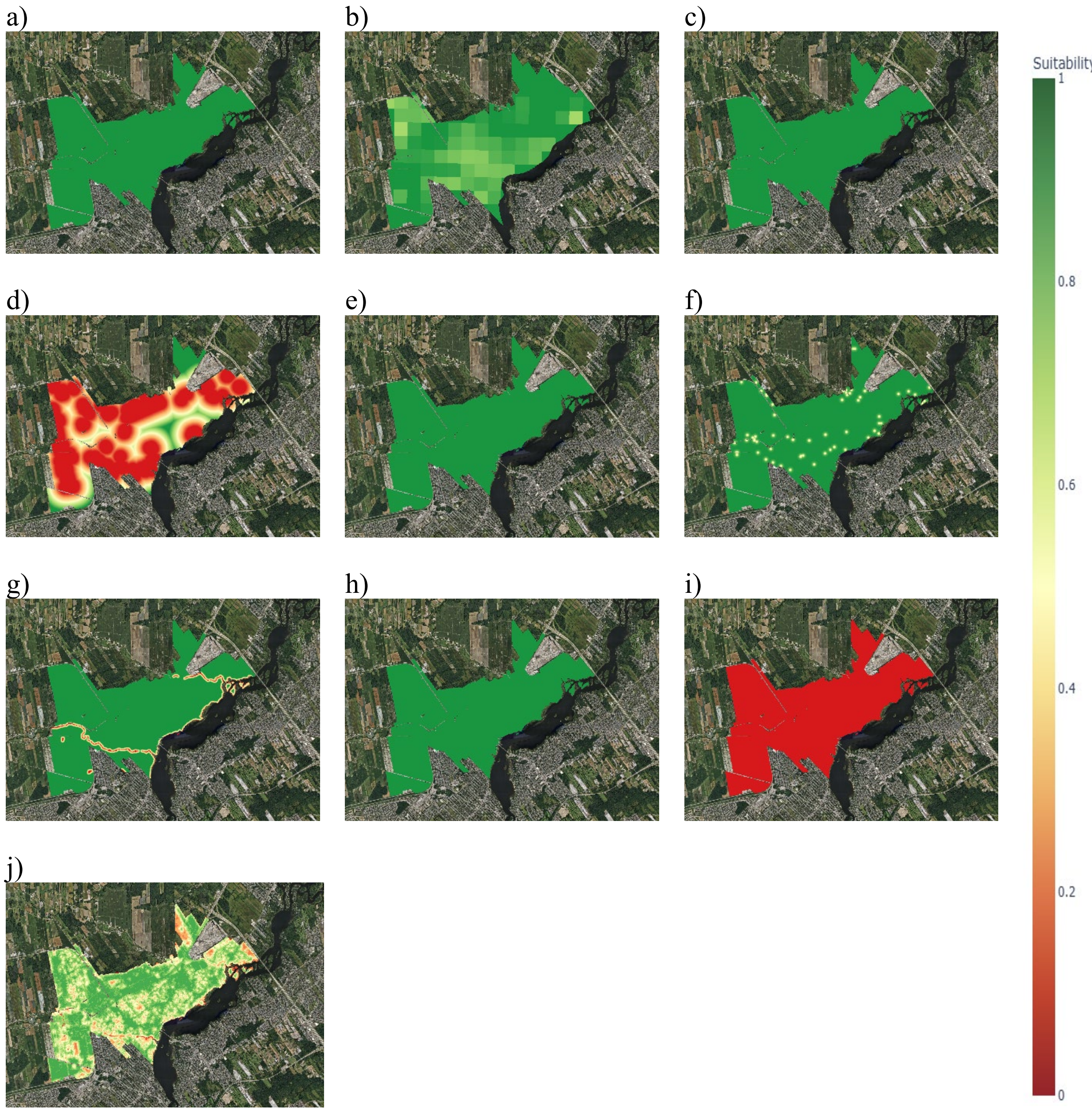

Figure SI- 6: Suitability maps of system with infiltration (A1 and A2) attributes related to need objectives in the final hierarchy: a) bacteriological and physicochemical quality index; b) DRASTIC index; c) number of days exceeding bathing water quality standards; d) distance to a green space; e) presence of aerial power grid; f) distance to wells; g) distance to bodies of water; h) overflows intensity index per urban drainage basin; i) distance to sludge treatment facilities; j) temperature class.

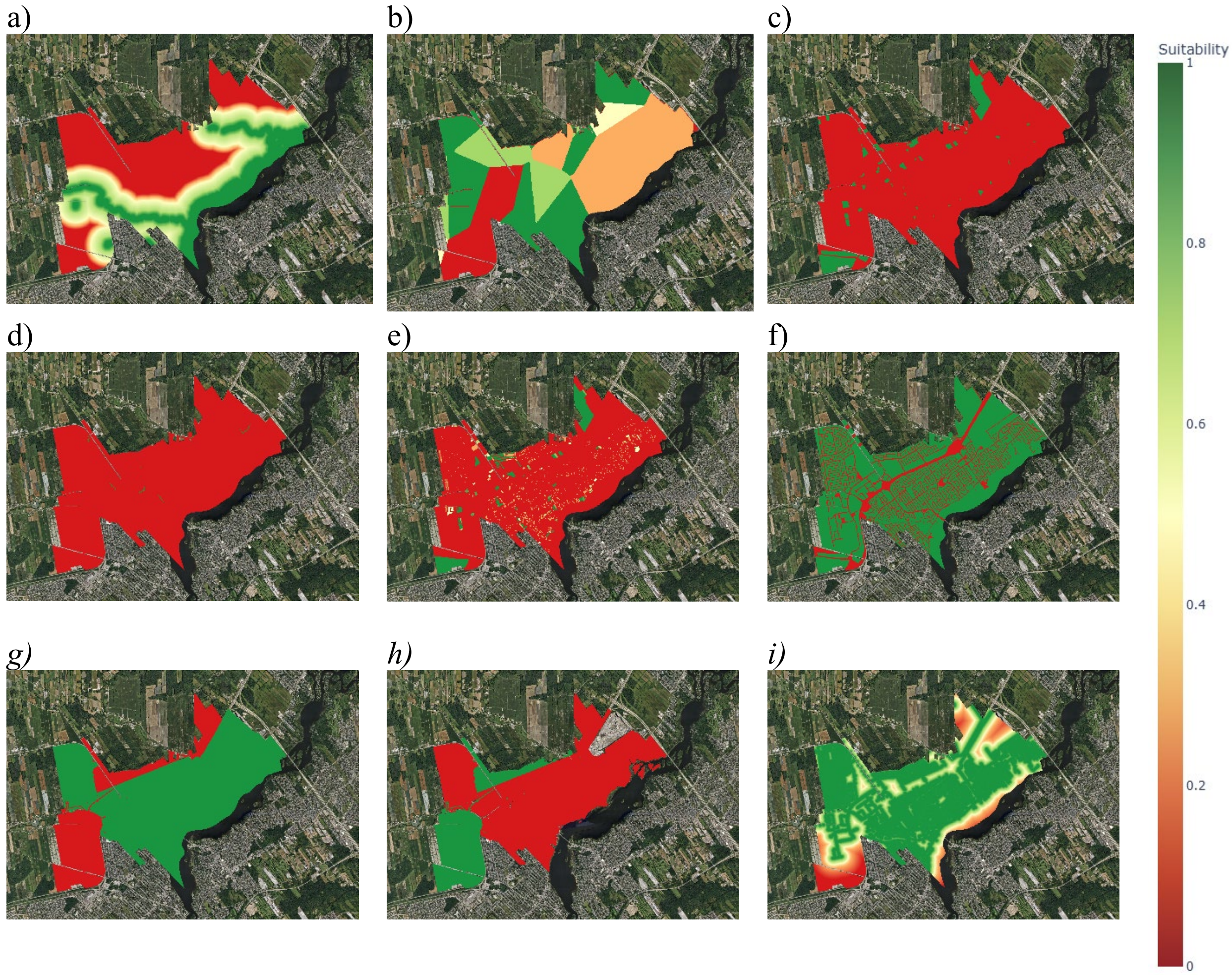

Figure SI- 7: Suitability maps of system with surface discharge (B1 and B2) attributes related to opportunity objectives in the final hierarchy: a) distance to bodies of water*; b) water table height*; c) areas planning real estate development; d) planned infrastructure projects; e) projected volume of wastewater; f) presence of public utility; g) percentage of use of the sewer network; h) percentage of use of the sewer network*; i) distance between site and the sewers.

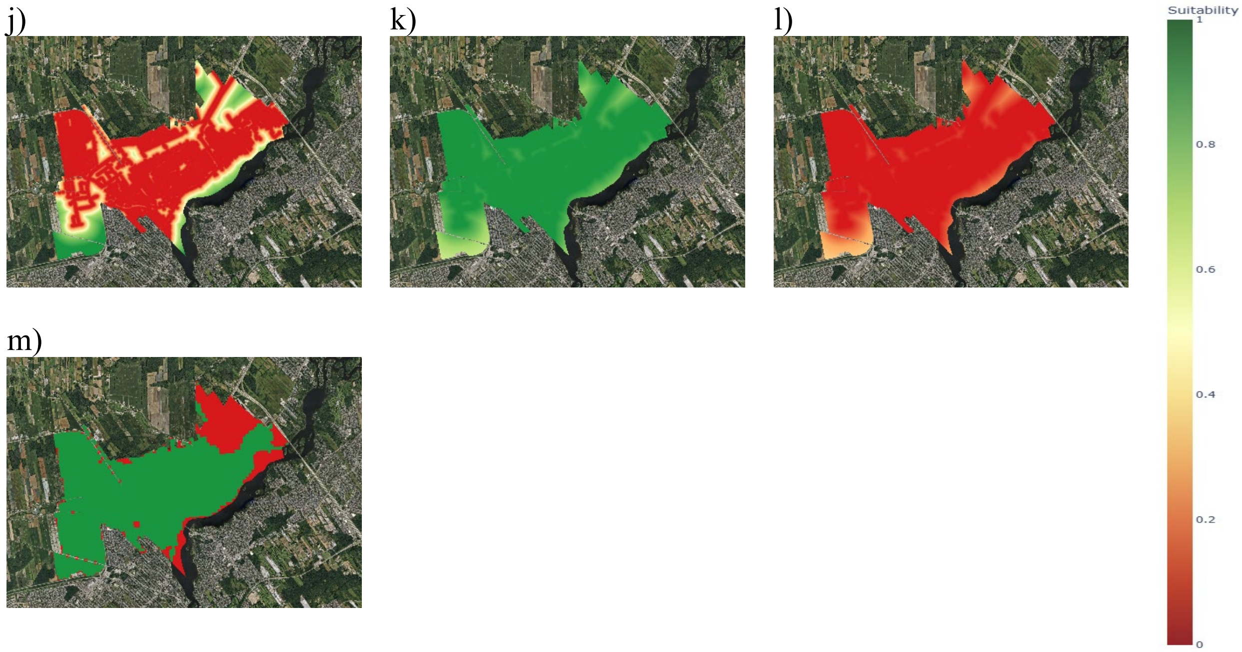

Figure SI- 8: Suitability maps of system with surface discharge (B1 and B2) attributes related to opportunity objectives in the final hierarchy (continued) : j) distance between site and the sewers*; k) distance between site and the sewers; l) distance between site and the sewers* m) rock depth.

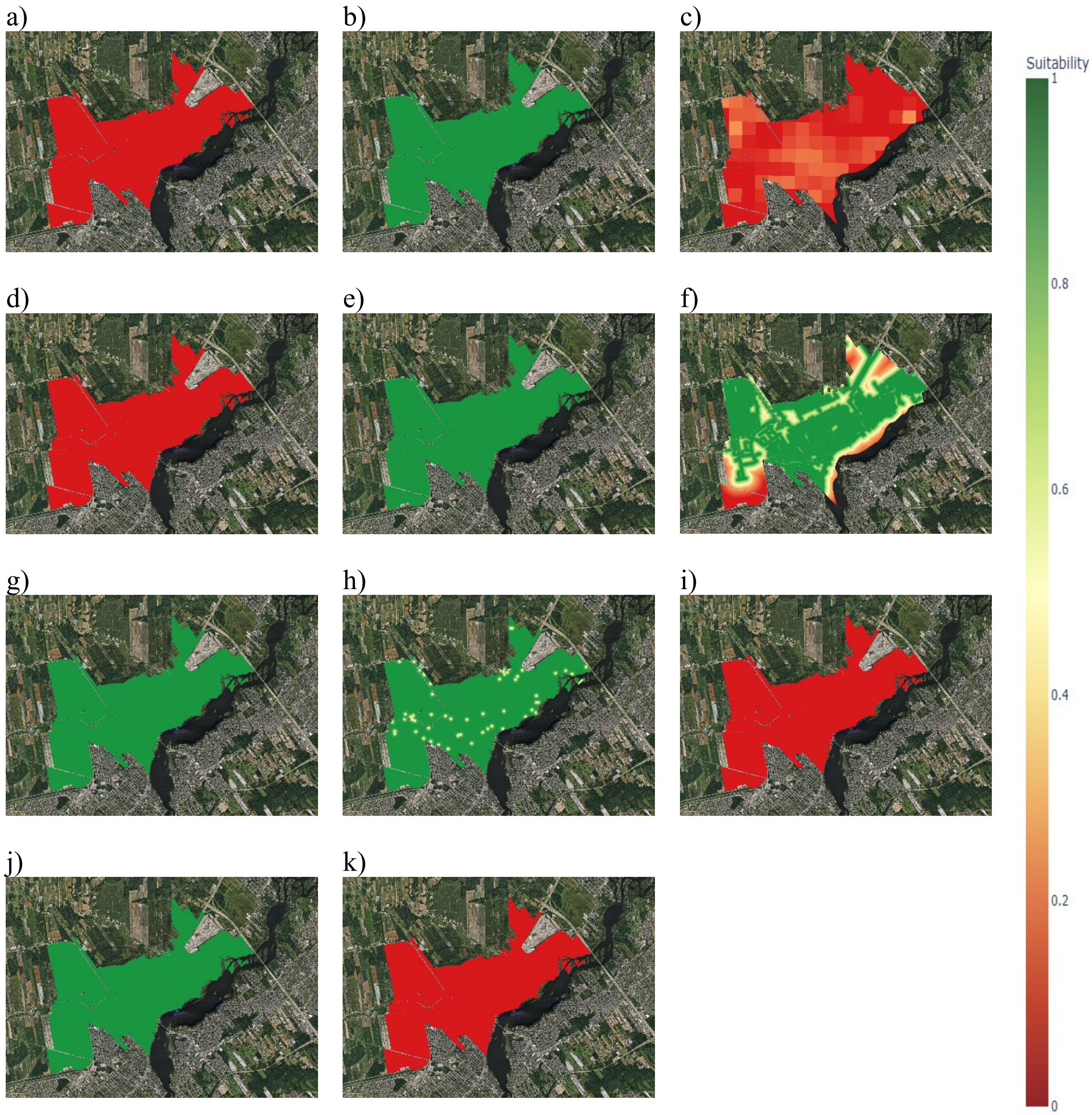

Figure SI- 9: Suitability maps of system with surface discharge (B1 and B2) attributes related to need objectives in the final hierarchy: a) bacteriological and physicochemical quality index; b) bacteriological and physicochemical quality index*; c) DRASTIC index; d) number of days exceeding bathing water quality standards; e) number of days exceeding bathing water quality standards*; f) distance to settlement; g) presence of aerial power grid; h) distance to wells; i) overflows intensity index per urban drainage basin; j) overflows intensity index per urban drainage basin*; k) distance to golf course*.

REFERENCES

[1] F. Bichai, A. Cabrera Flamini, The water-sensitive city: implications of an urban water management paradigm and its globalization, WIREs Water 5 (2018). https://doi.org/10.1002/wat2.1276.

[2] S. De Gisi, R. Pica, P. Casella, M. Notarnicola, Dealing with a cluster of large centralized municipal wastewater treatment plants: a case study, Process Saf. Environ. Prot. 118 (2018) 268–278. https://doi.org/10.1016/j.psep.2018.07.002.

[3] S. Eggimann, B. Truffer, M. Maurer, To connect or not to connect? Modelling the optimal degree of centralisation for wastewater infrastructures, Water Res. 84 (2015) 218–231. https://doi.org/10.1016/j.watres.2015.07.004.

[4] Y.T. Jung, N.C. Narayanan, Y.L. Cheng, Cost comparison of centralized and decentralized wastewater management systems using optimization model, J. Environ. Manage. 213 (2018) 90–97. https://doi.org/10.1016/j.jenvman.2018.01.081.

[5] M. Maurer, A. Scheidegger, A. Herlyn, Quantifying costs and lengths of urban drainage systems with a simple static sewer infrastructure model, Urban Water J. 10 (2013) 268–280. https://doi.org/10.1080/1573062X.2012.731072.

[6] P.P. Kalbar, S. Lokhande, Need to adopt scaled decentralized systems in the water infrastructure to achieve sustainability and build resilience, Water Policy 25 (2023) 359–378. https://doi.org/10.2166/wp.2023.267.

[7] F. Pasciucco, I. Pecorini, R. Iannelli, Planning the centralization level in wastewater collection and treatment: a review of assessment methods, J. Clean. Prod. 375 (2022) 134092. https://doi.org/10.1016/j.jclepro.2022.134092.

[8] F. Saadatinavaz, M.A. Alomari, M. Ali, P.E. Saikaly, Striking a balance: decentralized and centralized wastewater treatment systems for advancing Sustainable Development Goal 6, Adv. Energy Sustain. Res. 5 (2024). https://doi.org/10.1002/aesr.202400097.

[9] C. Lüthi, P. Reymond, S. Renggli, Towards sustainable sanitation in an urbanising world, in: M. Ergen (Ed.), Sustainable Urbanization, 2016, London.

[10] S.M. Oakley, A.J. Gold, A.J. Oczkowski, Nitrogen control through decentralized wastewater treatment: process performance and alternative management strategies, Ecol. Eng. 36 (2010) 1520–1531. https://doi.org/10.1016/j.ecoleng.2010.04.030.

[11] S. Eggimann, B. Truffer, M. Maurer, Economies of density for on-site wastewater treatment, Water Res. 101 (2016) 476–489. https://doi.org/10.1016/j.watres.2016.06.011.

[12] S. Eggimann, B. Truffer, M. Maurer, The cost of hybrid wastewater systems: a systematic framework for specifying minimum cost-connection rates, Water Res. 103 (2016) 472–484. https://doi.org/10.1016/j.watres.2016.07.062.

[13] N. Rezaei, A decision-making framework for hybrid resource recovery oriented wastewater systems, University of South Florida, Florida, 2019, 210 pp.

[14] P. Beutler, T.A. Larsen, M. Maurer, P. Staufer, A. Vervoort, A. Truffer, A participatory multi-criteria decision analysis framework reveals transition potential towards non-grid wastewater management, J. Environ. Manage. 367 (2024) 121962. https://doi.org/10.1016/j.jenvman.2024.121962.

[15] G. Tchobanoglous, Integrated wastewater management: the future of water reuse in large metropolitan areas, Integr. Environ. Assess. Manag. 15 (2019) 160–163. https://doi.org/10.1002/ieam.4103.
[16] P. Soleimani, A new multicriteria decision support framework on hybrid wastewater systems: application to a municipality in Quebec, Canada, Polytechnique Montréal, 2023, 136 pp.
[17] M. Spiller, J.H. Vreeburg, I. Leusbrock, G. Zeeman, Flexible design in water and wastewater engineering – definitions, literature and decision guide, J. Environ. Manage. 149 (2015) 271–281. https://doi.org/10.1016/j.jenvman.2014.09.031.
[18] E.S. Solomon, O.A. Peter, D.I. Nnamso, Sustainable urban water management: reuse, recycling and climate-resilient strategies, J. Sci. Res. Sci. Eng. Technol. 12 (2025) 122–135. https://doi.org/10.32628/ijsrset251217.
[19] J. Zheng, C. Egger, J. Lienert, A scenario-based MCDA framework for wastewater infrastructure planning under uncertainty, J. Environ. Manage. 183 (2016) 895–908. https://doi.org/10.1016/j.jenvman.2016.09.027.
[20] S. Hoffmann, U. Feldmann, P.M. Bach, C. Binz, H. Farrelly, L. Frantzeskaki, R. Brown, A research agenda for the future of urban water management: exploring the potential of nongrid, small-grid, and hybrid solutions, Environ. Sci. Technol. 54 (2020) 5312–5322. https://doi.org/10.1021/acs.est.9b05222.
[21] S. French, J. Geldermann, The varied contexts of environmental decision problems and their implications for decision support, Environ. Sci. Policy 8 (2005) 378–391. https://doi.org/10.1016/j.envsci.2005.04.008.
[22] D. Ko, J.W. Norton Jr., G.T. Daigger, Wastewater management decision-making: a literature review and synthesis, Water Environ. Res. 96 (2024) e11024. https://doi.org/10.1002/wer.11024.
[23] C.K. Makropoulos, E. Argyrou, F.A. Memon, D. Butler, A suitability evaluation tool for siting wastewater treatment facilities in new urban developments, Urban Water J. 4 (2007) 61–78. https://doi.org/10.1080/15730620701336729.
[24] F. Haag, S. Zürcher, J. Lienert, Enhancing the elicitation of diverse decision objectives for public planning, Eur. J. Oper. Res. 279 (2019) 912–928. https://doi.org/10.1016/j.ejor.2019.06.002.
[25] MDDELCC, Guide technique – traitement des eaux usées des résidences isolées, édition de janvier 2009, version révisée en mars 2015, Gouvernement du Québec, 2015, 208 pp.
[26] USEPA, Guidelines for water reuse, EPA/600/R-12/004, USEPA Office of Wastewater Management, 2012.
[27] A. Hamlat, M. Errih, A. Guidoum, Simulation of water resources management scenarios in western Algeria watersheds using WEAP model, Arab. J. Geosci. 6 (2013) 2225–2236. https://doi.org/10.1007/s12517-012-0539-0.
[28] M. Awawdeh, Z. Al-Rousan, K. Alkaraki, Wastewater treatment plant site selection using GIS and multicriteria decision analysis, Arab Gulf J. Sci. Res. 42 (2023) 1504–1517. https://doi.org/10.1108/agjsr-09-2023-0412.
[29] D. Dubber, F. Pilla, D. Smyth, N. Qazi, M. McCarthy, M. Gill, Development of a geographic information system-based decision support toolset to assess the feasibility of on-site

wastewater treatment and disposal options in low permeability subsoils, Water Sci. Technol. 70 (2014) 464–471. https://doi.org/10.2166/wst.2014.244.
[30] M.A. Jordan, A.S. Ojeda, E.A. Larson, S.R. Rogers, Investigating the relationship between surface water pollution and onsite wastewater treatment systems, Environ. Sci. Technol. 57 (2023) 17042–17050. https://doi.org/10.1021/acs.est.2c09590.
[31] F. Eisenführ, M. Weber, T. Langer, Rational Decision Making, Springer, Berlin, 2010.
[32] M.M. Ahmadi, H. Mahdavirad, B. Bakhtiari, Multi-criteria analysis of site selection for groundwater recharge with treated municipal wastewater, Water Sci. Technol. 76 (2017) 909–919. https://doi.org/10.2166/wst.2017.273.
[33] N. Al Nasiri, A. Al Fazari, W. Ali, B. Agyekum, E. Ramadan, Multi-criteria decision-making approach for siting sewer treatment plants in Muscat, Oman, Urban Sci. 7 (2023) 82. https://doi.org/10.3390/urbansci7030082.
[34] A. Elkadri, H. Sahnoun, S. Elfkih, M. Abichou, Assessing the sustainability of olive mill wastewater storage tank locations in Tunisia, Euro-Mediterr. J. Environ. Integr. 8 (2023) 255–273. https://doi.org/10.1007/s41207-023-00364-4.
[35] A. Hamlat, C.B. Kadri, M. Sekkoum, A. Guidoum, A. Remada, Multi-criteria decision-making approach for selecting an alternative wastewater treatment plant site in urban areas of Laghouat (North-Central Algeria), Euro-Mediterr. J. Environ. Integr. 7 (2022) 511–530. https://doi.org/10.1007/s41207-022-00333-3.
[36] H. Kallali, M. Anane, S. Jellali, J. Tarhouni, GIS-based multi-criteria analysis for potential wastewater aquifer recharge sites, Desalination 215 (2007) 111–119. https://doi.org/10.1016/j.desal.2006.11.016.
[37] G. Massei, L. Rocchi, L. Paolotti, S. Greco, A. Bubic, L. Bianchini, Decision Support Systems for environmental management: a case study on wastewater from agriculture, J. Environ. Manage. 146 (2014) 491–504. https://doi.org/10.1016/j.jenvman.2014.08.012.
[38] T.T. Wondim, B. Dzwairo, A scenario-based multiple attribute decision-making approach for site selection of a wastewater treatment plant: Bahir Dar City (Ethiopia) case study, Water SA 44 (2018). https://doi.org/10.4314/wsa.v44i4.26.
[39] S.A.S.A.F. da, V.H.R. Coelho, B.B. Tsuyuguchi, O.G.C. de, et al., Spatial multicriteria approach to support water resources management with multiple sources in semi-arid areas in Brazil, J. Environ. Manage. 297 (2021) 113399. https://doi.org/10.1016/j.jenvman.2021.113399.
[40] B. Asefa, W. Mindahun, Geospatial based optimum site selection for wastewater treatment plant: the case of Debre Berhan Town, Amhara Regional State, Ethiopia, J. Geosci. Geomatics 7 (2019) 97–104. https://doi.org/10.12691/jgg-7-3-1.
[41] V. Singh, S.R. Samadder, A novel approach for identification of environmentally and economically suitable locations for establishment of wastewater treatment plants, Water Sci. Technol. 90 (2024) 413–431. https://doi.org/10.2166/wst.2024.215.
[42] O.E. Demesouka, A.P. Vavatsikos, K.P. Anagnostopoulos, Spatial UTA (S-UTA) – a new approach for raster-based GIS multicriteria suitability analysis and its use in implementing natural systems for wastewater treatment, J. Environ. Manage. 125 (2013) 41–54. https://doi.org/10.1016/j.jenvman.2013.03.035.

[43] A.G. Nigusse, U.G. Adhaneom, G.H. Kahsay, A.M. Abrha, D.N. Gebre, A.G. Weldearegay, GIS application for urban domestic wastewater treatment site selection in the Northern Ethiopia, Tigray Regional State: a case study in Mekelle City, Arab. J. Geosci. 13 (2020) 311. https://doi.org/10.1007/s12517-020-5257-4.
[44] K.A. Capps, J.M. Bateman McDonald, N. Gaur, R. Parsons, Assessing the socio-environmental risk of onsite wastewater treatment systems to inform management decisions, Environ. Sci. Technol. 54 (2020) 14843–14853. https://doi.org/10.1021/acs.est.0c03909.
[45] J. He, M. Dougherty, R. Zellmer, G. Martin, Assessing the status of onsite wastewater treatment systems in the Alabama Black Belt soil area, Environ. Eng. Sci. 28 (2011) 693–699. https://doi.org/10.1089/ees.2011.0047.
[46] S. Kanwal, M. Sajjad, H.F. Gabriel, E. Hussain, Towards sustainable wastewater management: a spatial multi-criteria framework to site the Land-FILTER system in a complex urban environment, J. Clean. Prod. 266 (2020) 121987. https://doi.org/10.1016/j.jclepro.2020.121987.
[47] L. Wang, M. Ye, J. Fernando Rios, R. Fernandes, R. Hornung, P. Bloom, Estimation of nitrate load from septic systems to surface water bodies using an ArcGIS-based software, Environ. Earth Sci. 70 (2013) 1911–1926. https://doi.org/10.1007/s12665-013-2283-5.
[48] Z. Mansouri, N.H. Moghaddas, B. Dahrazma, Wastewater treatment plant site selection using AHP and GIS: a case study in Falavarjan, Esfahan, Geopersia 3 (2013) 63–72. https://doi.org/10.22059/jgeope.2013.36015.
[49] C. Cui, W. Zhou, M. Geza, GIS-based nitrogen removal model for assessing Florida's surficial aquifer vulnerability, Environ. Earth Sci. 75 (2016) 526. https://doi.org/10.1007/s12665-015-5213-x.
[50] W.M.K.R.T.W. Bandara, B.M.L.A. Basnayake, T.M. Rengarasu, N.A. Nusky, Application of multi-criteria decision analysis in locating wastewater treatment plants in Sri Lanka, J. Univ. Ruhuna 10 (2022) 51–61. https://doi.org/10.4038/jur.v10i2.7993.
[51] P. Zolfaghary, M. Zakerinia, H. Kazemi, A model for the use of urban treated wastewater in agriculture using multiple criteria decision making (MCDM) and geographic information system (GIS), Agric. Water Manag. 243 (2021) 106490. https://doi.org/10.1016/j.agwat.2020.106490.
[52] J. Malczewski, C. Rinner, Multicriteria Decision Analysis in Geographic Information Science, 2015.