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Assessment of constructed wetland projects as a multifunction landscape: a case study in Egypt

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Abstract

This research aims to develop a conceptual framework and assessment tool to assess sustainability of Multifunction Constructed Wetlands Projects (MCWP). First, by literature review to analyze the main points and identify the gaps in existing research to what concerns viewing constructed wetlands as multifunction sustainable landscape projects. To assess the performance of MCWP, urban sustainability indicators are proposed examining interconnections between environmental, economic and social aspects and their effects on each other. 12 environmental, 9 socio-cultural and 7 economic indicators are selected according to their relevance to the United Nations and National Sustainable Development Goals, the impacts of their weights according to a distributed questionnaire showed these percentages: environmental aspects 42%, Socio-cultural aspects 29% and the economic aspects 28%. Also, performance-oriented assessment tools for MCWPs were designed for wastewater treatment. The impacts of proposed indicators are then assessed using the adapted Leopold Matrix method. Hence, this study aims to establish an assessment model to evaluate the sustainability features of MCWPs, by proposing sustainability indicators to be assessed by measurement metrics and respective weights for indicators and sub-indicators.

Keywords Assessment model, Constructed wetlands, Leopold matrix, Multifunction Landscape, Wastewater treatment

1 Introduction

The ongoing urban growth has caused imminent hazards concerning water security and wastewater disposal [1]. In the Middle East region, for example, wastewater generated from industrial and municipal sources is estimated at 23 billion m^3 every year, however, the amount of wastewater reused annually is equivalent to 1.6 billion m^3 only [2]. Furthermore, the escalating impacts of climate change are raising serious concerns about the sustainability of water management processes globally [3], because of the energy consumption of conventional water management systems particularly in regions where non-renewable energy such as fossil fuel is used [4]. That is contributing to higher levels of greenhouse gas emissions [5]. Noting that reducing carbon emissions is a prime concern for all countries according to recommendations

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from the Conference of the Parties 27, 28 [6, 7]. Apart from that, ageing water infrastructure has urged cities worldwide to upgrade and reconsider their water supply and wastewater management processes [8]. This fact has resulted in greater interest in the use of nature-based solutions as infrastructure [9], combined with the growing paradigm shift towards regarding wastewater as a 'resource' when recycled and reused, rather than a 'waste' that is disposed of. Consequently, global Sustainable Development Goals (SDGs) requires developing water management systems to be aligned with the new vision of SDGs [9]. Sustainable landscape projects combine and balance dimensions of environmental, economic, and social sustainability to achieve human well-being and improve the quality of life, while constructed wetlands are artificial urban systems that mimic the various ecological functions of natural wetlands but in a more controlled environment [10]. These systems provide a range of sustainable and resilient urban functions besides being a low-cost, easily operated alternative to conventional urban management systems [11], with wastewater treatment ability of the ecologically rich natural wetlands [12]. mitigating adverse environmental impacts and reduces excessive energy consumption [13]. The performance assessment of Multifunctional Constructed Wetland Projects (MCWPs), among other urban projects necessitates accounting for their contribution to international and national SDGs. Assessing sustainability has vastly grown over the past years including examples like Health Impact Assessment, Social Impact Assessment, Urban Material Flow Analysis and Ecological Footprint. However, such adequacy in assessment approaches indicates that individual projects require their assessment tools [14].This is particularly the case with the MCWPs since assessment must cover environmental as well as social and economic factors. While other metrics essentially focus on specific areas, the proposed assessment tool aims to integrate environmental, economic, social and technical factors into a comprehensive tool designed to assess the performance of constructed wetlands project either throughout their construction phase and their operation phase. For example, Material Flow Analyses assesses landscape projects through their material input, output, and efficiency and sustainability through optimized material selection, minimizing water consumption and waste products, as well as promoting sustainable long-life materials and demolition procedures. Hence this study is focusing on environmental aspects of materials and offering a material inventory that can be further employed in other assessment tools such as the Life Cycle Assessment [14], Another example is the Ecological Footprint Assessment which focuses on the amount of biologically productive land or water areas a certain project requires to cover its resources or sustain its operation, thus also addressing resources' efficiency and their biological impact and ecological footprint on their environment [3]. Hence, the main aim of this study is to: 1) establish an assessment model to objectively evaluate landscape sustainability features of MCWPs; 2) propose a set of sustainability indicators that comprehensively assess their broad spectrum of sustainability criteria, covering environmental as well as social, economic and technical aspects; and 3) propose appropriate measurement metrics and assign respective weights for indicators and sub-indicators.

1.1 Background on MCWPs

The application of MCWPs started experimentally in the 1950s in Germany in The Max Planck Institute, whereas the first systems to be practically constructed were in the 1960s in Europe and the US in the 70s [15]. However, until the late 80s, the technical aspects of constructed wetlands were not widely discussed. During the past 20 years, due to the increase in environmental awareness, there has been a significant increase in applications and research in this regard [13]. However, the utilization of constructed wetlands in urban settlements has not reached its full potential yet [8]. While conventional wastewater treatment plants are usually associated with high energy consumption, elevated construction and operation costs, as well as their unattractive, industrial visual appearance, MCWPs offer an environmentally friendly, cost feasible and aesthetic approach to wastewater treatment processes [16]. They offer visually rich environments that combine water elements and landscape transforming them into constructed wetland parks [17]. These offer a wide range of urban social, economic, educational, recreational benefits besides enhancing biodiversity [12]. Their environmental benefits include treatment of certain pollutant loads, preserving ecosystems and wildlife, climate regulation, and reduced dependence on chemicals [12]. Socially, MCWP parks allow for social interaction with the wastewater treatment process hence increasing social connectivity and awareness of prevailing water management problems. Economic benefits are demonstrated as 1/3 of the construction costs of conventional treatment systems and approximately 1/4 of the operation and maintenance costs, besides being more durable with a minimum of 15 years lifecycle [18]. Moreover, the high construction costs of conventional wastewater treatment systems necessitate their construction as centralized systems with extended sewers. This makes constructing wastewater treatment plants in peri-urban areas an economically unfeasible option. On contrary, MCWPs can be widely implemented onsite as decentralized or centralized treatment systems for domestic, agricultural as well as industrial wastewater.

This is in addition to their ability to mitigate storm-water runoff [12]. Also, they can be implemented on different scales ranging from household to neighborhood and community scale. The only major constriction to the application of MCWPs is concerned with land availability as they require a greater area per person equivalent [16]. The wastewater, treatment property of constructed wetlands employs the interconnections between certain plants and vegetation macrophytes, micro-organisms and the soil in a systematic process. This is reliant on factors such as the natural context, local climate, project design, types of plants, and microbial functions [19]. During the purification process, vegetation macrophytes absorb different pollutants from the wastewater accumulating them in their tissues. Simultaneously, this maintains a suitable environment for the growth of microorganisms which play a significant role in pollutants removal [20]. Moreover, the roots of vegetation macrophytes transfer oxygen through the water enhancing the aerobic conditions required for the purification process [21]. As a result of these combined processes, the wastewater quality is enhanced to meet the standards of water reuse. Constructed wetlands are either categorized according to water levels into surface flow or subsurface flow constructed wetlands, or according to the direction of water flow as horizontal flow, vertical flow or hybrid systems. They are also sometimes classified according to their primary function e.g. habitat preservation, flood control, storm water retention or wastewater treatment [22].

1.2 Environmental sustainability assessment methods

There are several assessment criteria for the environmental performance of buildings established and implemented worldwide like Building Research Establishment Environmental Assessment Methodology of the UK, Japan's Comprehensive Assessment System for Built Environment Efficiency, Australia's Green Star, the US's Leadership in Energy and Environmental Design, as well as Egypt's Green Pyramid Rating System [23, 24]. However, with the increasing awareness of the importance of environmental issues occurring at the city/neighborhood levels, sustainability assessment systems worldwide have established distinct landscape assessment systems such as the "Green Flag Award" originally developed in Britain in 1996 [25]. and Sustainable Sites Initiative developed in the US in 2012. Also, recently in Germany, a research project was concluded by the German Federal Government and the German Research Platform for Landscape in 2015 to evaluate outdoor facilities and develop a certification system [25]. These systems support an integrated design approach, during the development/planning phase of the project site, or throughout the design and management phases [26, 27].

1.3 Leopold matrix

A matrix is an evaluation method designed to assess the impact of different activities on a set of indicators arranged vertically while the different impacts are arranged horizontally. A checkmark is used to mark the impact of any activity on the corresponding indicators. In 1971 Leopold Matrix was developed [28–30]. Later, it was followed by the Component Interaction Matrix in 1974 [31]. Other forms of matrices further developed e.g. Modified Graded Matrix, Loran Matrix, and the Impact Summary Matrix [30]. One of the most prominent advantages of a1 matrix tool is its flexibility and adaptability to several types of projects, especially medium and large-scale projects and its efficiency in presenting data in a simple and easily comprehended form [28]. The Leopold Matrix is a simple analysis of the impacts of a project through many cells representing the magnitude and significance of different actions under several factors [31]. The Leopold Matrix assesses projects through comprehensively managing the project's challenges, impacts as well as the mitigation actions assigned to reduce negative impacts and improve positive impacts, linking various impacts to their respective project phase(s), either preliminary design, final design, construction, or operation phases, which indicates areas and phases of mitigation actions [31]. The construction phase of a project could have a significant impact on the environmental, social, and economic aspects of a project even though these impacts usually end after construction completion, however, in some cases construction extends for a prolonged period. Consequently, evaluating impacts arising during the construction phase should not be overlooked to suggest and discuss alternative construction methods and mitigation procedures [32]. *The operation phase*, on the other hand, contributes most of the project's impacts and is therefore considered the key purpose for the assessment process [31]. In the case of MCWP, the system operation lifetime is dependent on the degree of pollutants contamination of the wetland cells and their removal and storage ability of accumulated wastes [33]. A review of several constructed wetland projects shows that they have been efficiently operating for an extended period of 20 years [34].The monitoring and periodic removal of wetland deposits and the reintroduction of new substrates to the cells are essential procedures to extend their efficient performance [35].

2 Methods

The research process includes the following 5 main steps in order to develop the proposed assessment tool as in Fig. 1 and further explained respectively.

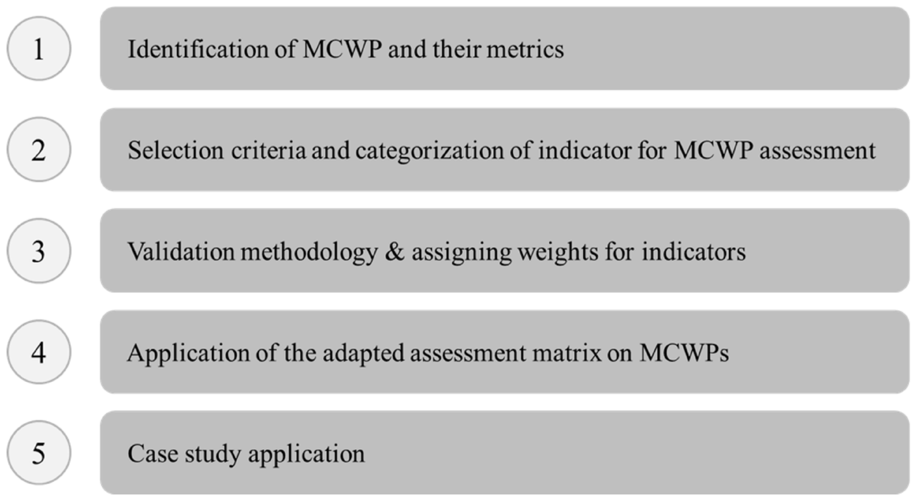

Fig. 1 Research process

2.1 Identification of MCWPs and their metrics in recent scientific research

The identification stage is based on a systemic literature review that was performed using the Scopus database from 2015-to 2021 through peer-reviewed journal papers and conference articles. This discussed MCWPs' background and available assessment methods. The following keywords were used: wetlands, constructed wetlands, and wastewater treatment, and limited to the field of engineering. As a result, a total of 612 publications were extracted, this showed an increasing number of studies throughout the past years as shown in Fig. 2. Also

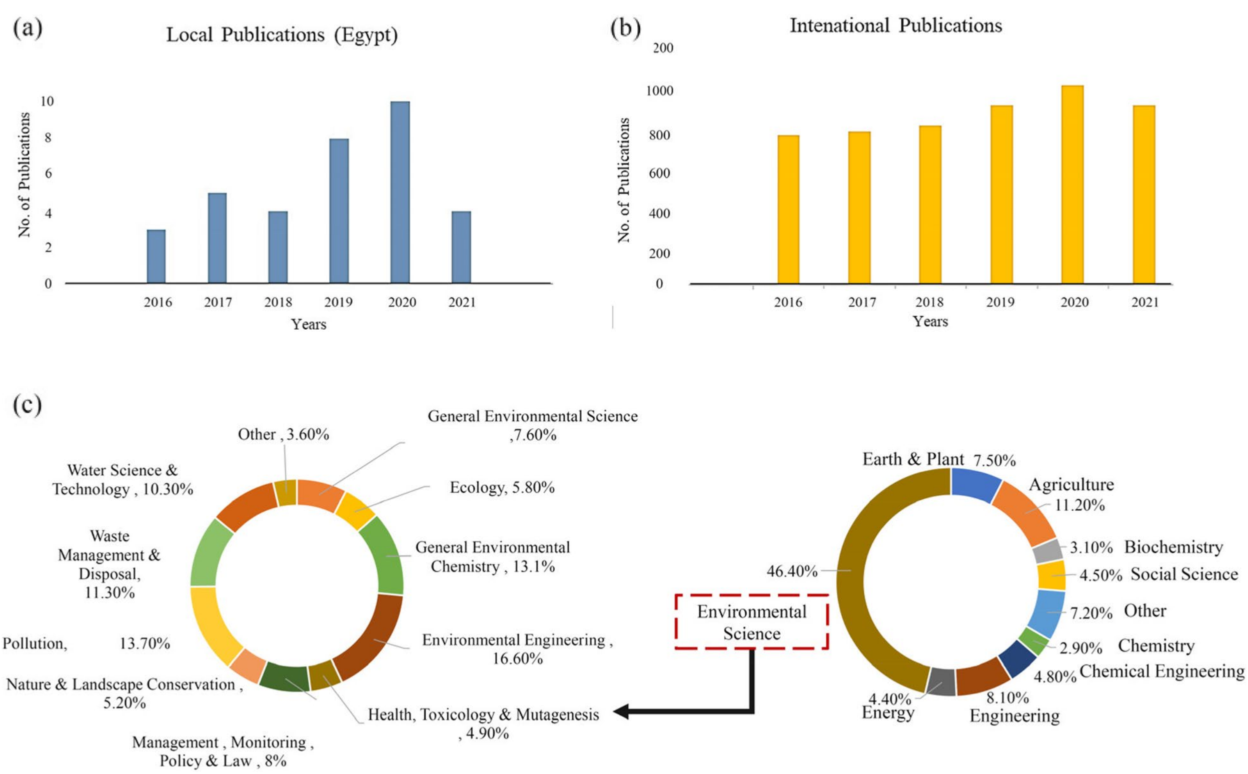

Fig. 2 A systemic review of literature showing an increasing number of publications for constructed wetland projects over the last few years. **a** local Publications (Egypt), **b** International Publications, **c** Publications by Subject Area

a few numbers of local studies discussed their environmental engineering aspects e.g., pollution, environmental chemistry, waste management and disposal, wastewater science and technology, management, monitoring, policy and law, general environmental science, ecology, nature and landscape conservation, health, toxicology and mutagenesis, ecological modelling, and global and planetary change. It was observed that previous studies lacked discussing landscape and the ecological impact of wetland ecosystems and the process of environmental assessment during the design and construction phases which might compromise the sustainability of the entire process. This formulates the justification of this study as an endeavour to attain Egypt's sustainable development goals for 2030 concerning climate change, water and resilient infrastructure.

2.2 Selection criteria and categorization of indicators for MCWPs assessment

The adopted criteria for MCWPs sustainability indicators' selection depend on linking the proposed indicators to the UN global SDGs, the national SDGs, as well as indicators linked to the functional nature of this type of project. Moreover, indicators were selected because they were easily interpreted, measurable, practically applicable, and cost-effective [36]. All were then investigated using a keyword-based analysis of 612 publications to explore their interrelations and establish their hypothetical interrelations in Fig. 3.

A set of specific environmental, social, and economic indicators were selected then sub-categorized and classified into several indicators to quantitatively evaluate the performance of MCWPs as in Fig. 4.

2.3 Validation methodology & assigning weights for indicators

A quantitative analysis was performed to validate the findings of the previous section, such analysis depends on a structured questionnaire designed to test the validity and importance of the selected indicators. Questionnaires were shared online and also during an international conference. The relative importance of indicators was determined by assigning weights that demonstrate their contribution to the sustainable performance of MCWPs. In addition, weights were used to determine whether different indicators substitute or compensate for one another. For this study, the Budget Allocation Method (BAL) was used to identify the weights of the main assessment categories, while the public opinion method was selected for weighting individual indicators. The questionnaire design depended on a combination of open-ended as well as close-ended questions using a 5-point Likert scale. It consisted of 3 hierarchical sections, each of a specific objective. (A) Participants' Profile: this section consisted of 4 questions aiming to identify respondents' backgrounds and areas of expertise. (B) Identifying weights for main categories of MCWP sustainability assessment: for this matter, the BAL method was applied where each participant was given 10 points to divide among the 3 categories of indicators (environmental, socio-cultural, and economical- technical), and then the total results were averaged to obtain a mean value determining the importance of each category. (C) Identifying weights for individual indicators: in this section, participants were asked to rate the importance of each indicator in relation to achieving sustainability using a 5-point Likert scale, a score of 1 indicated the least important and 5 indicated the most important. In order to quantify these relative scores, the Weighted Average Index (WAI) was applied. In this index, values of weighted scores ranging between 0.2 and 1 were multiplied by the number of respective respondents and then the result was divided by the total number of respondents as shown in Eq. (1) [37].

$$\mathrm{WAI} = \frac{\sum \mathrm{fi\ wi}}{\sum \mathrm{fi}} \tag{1}$$

Where fi = frequency of respective respondents, and wi = weight of each score value

The survey questionnaire was distributed through a conference and online platforms among a large number of participants and stakeholders with diverse professional sectors such as urban designers, landscape architects, academic researchers, postgraduate and undergraduate architecture students. The purpose of the questionnaire was to reach out to a variety of experts with different backgrounds and cultures, as well as different areas of interest in built wetland projects, in order to assess the relevance of the various impacts and factors of CW operations from various interest perspectives and to assess their value in attaining landscape sustainability. The number of respondents reached 131 respondents from around 18 different nationalities. Participants' distribution is shown in Fig. 5.

Statistical analysis was performed using IBM SPSS Statistics 22 for survey responses. It indicated retaining the null hypothesis ($P < 0.05$) that assumes a relationship between all variables. Thus, there was a highly significant statistical correlation that supported the research argument. This showed a high certainty ratio. A kurtosis analysis shows a normal distribution among all variables. The Cronbach's alpha of 0.89 shows high reliability of obtained results. Also, Pearson's correlation analysis showed a high statistical correlation of level ($P < 0.001$) of many variables.

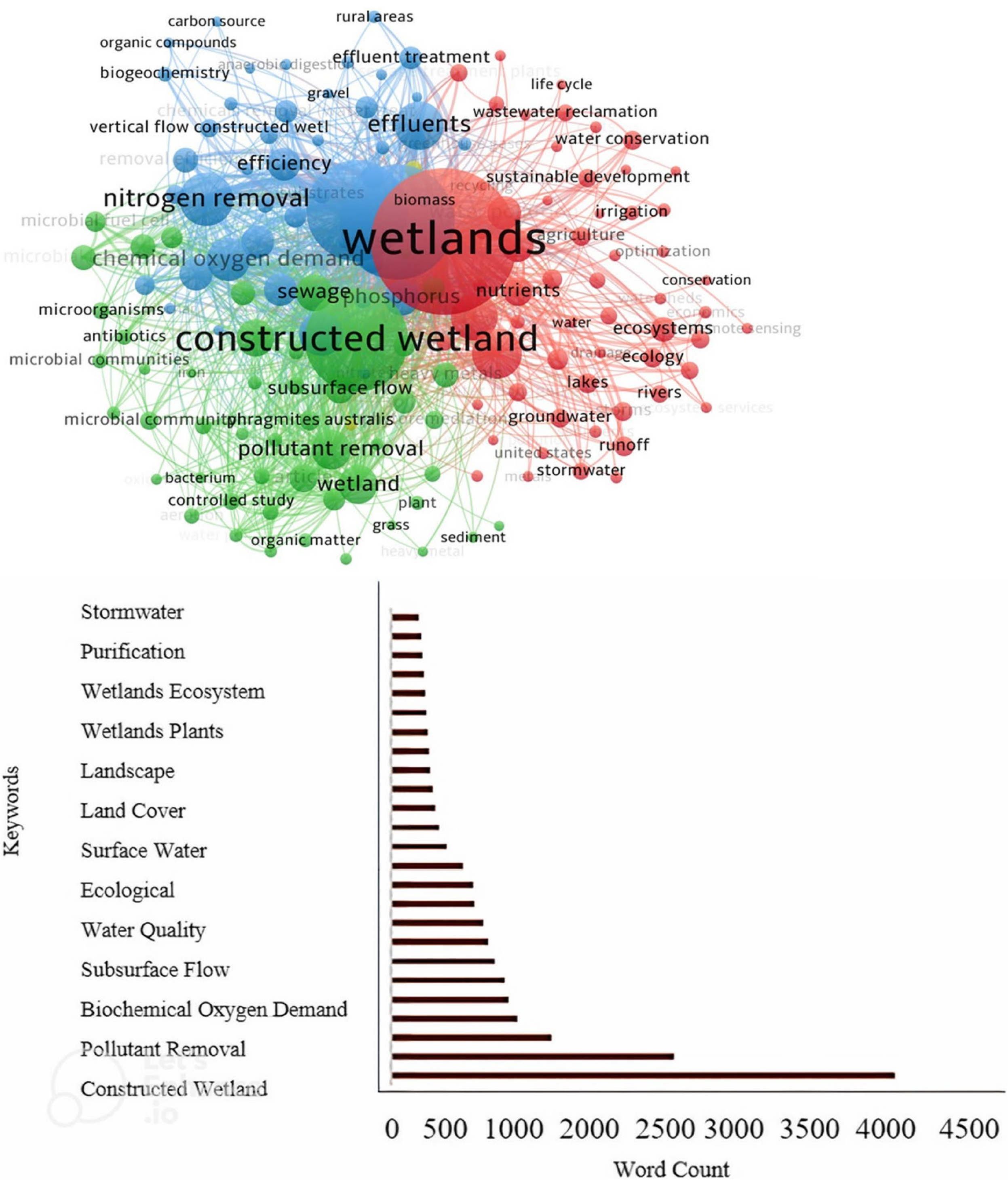

Fig. 3 Keyword-based analysis showing interrelationships of parameters that are related to constructed wetlands, source: Author, generated by: SciVal

2.4 Application of the adapted assessment matrix on MCWPs

An adaptation of the Leopold Matrix was developed to link the two main phases of MCWPs on the horizontal axis and the proposed indicators illustrated vertically as shown in Table 1. For each indicator, the matrix

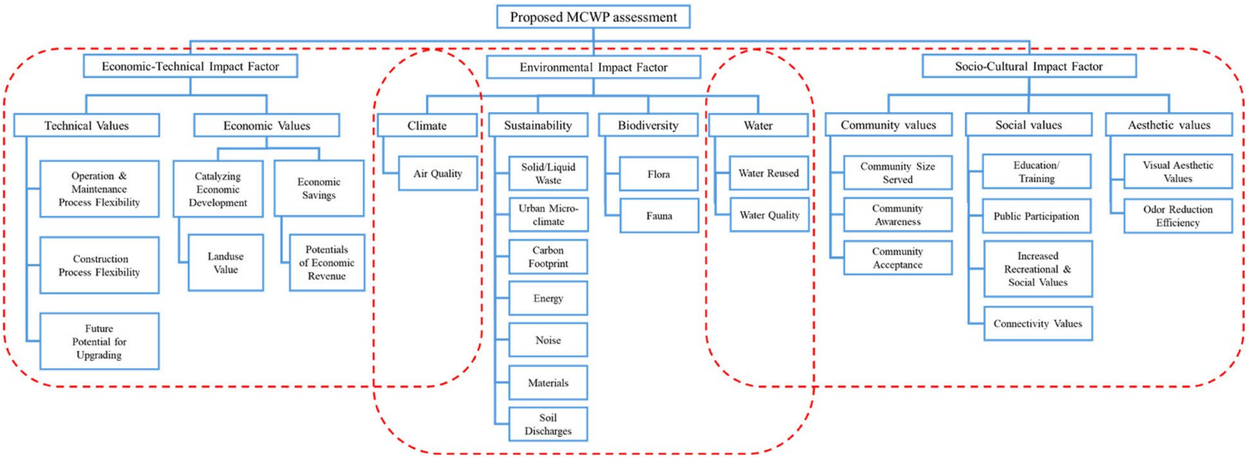

Fig. 4 The selected Indicators Categorized and sub categorized, source: Author

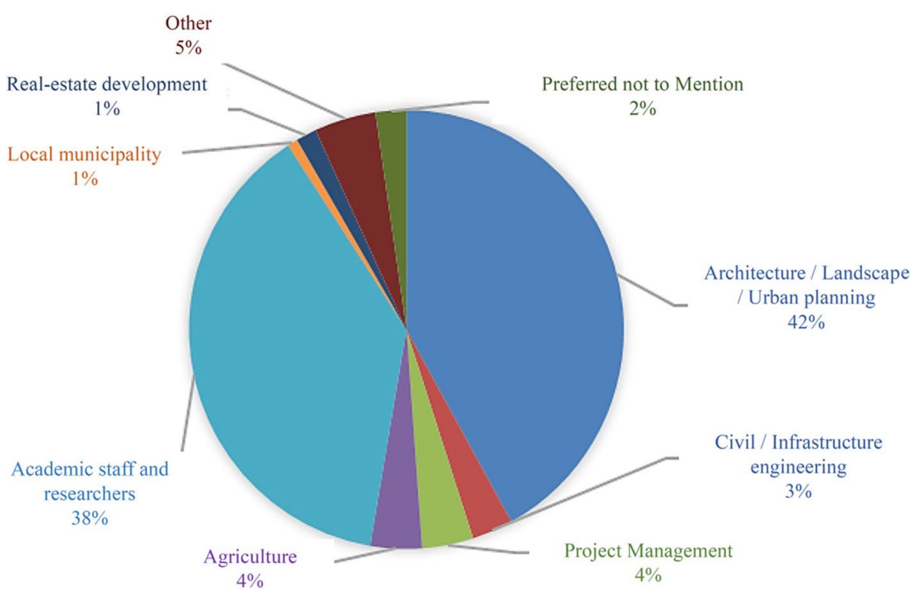

Fig. 5 Survey participants' professional sectors

Table 1 Adapted matrix scoring scheme

Category Score	Magnitude (M)	Significance (S)	Probability (P)	Duration (D)
0	No Effect	No Significance	0–4% Probability	-----
1	Low Effect	Up to 20% Significance	5–24% Probability	Occasional
2	Tolerable Effect	21–40% Significance	25–49% Probability	Temporary
3	Medium–High Effect	41–60% Significance	50–74% Probability	Short Term
4	High Effect	61–80% Significance	75–99% Probability	Long Term
5	Very High Effect	81–100% Significance	100% Certain	Permanent

assesses the Impact Value (IV) through assigning 0–5 scores to evaluate factors of Magnitude (M), Significance (S), Probability (P), and Duration (D), following Eq. (2) [38]. Social, economic and technical factors were added to address the limitation in the original Leopold Matrix which only focusses on environmental factors.

$$IV = M * S * P * D \tag{2}$$

Despite the easy estimation of the magnitude of impacts on facts-basis, the significance depends on the evaluator's value assessment [38]. The significance of each impact must take into account the impacts of a change in a given condition on other factors in the environment [38].The total IV for each dimension is calculated as a summation of IVs of individual indicators according to Eq. (3).

$$\text{Total IV} = \sum\nolimits_{i=1}^{n} Mi * Si * Pi * Di \tag{3}$$

It is worth noting that a matrix score is an effective tool in validating the comprehensive assessment method of MCWPs since it guarantees that each indicator is not only determent on its onsite calculated value, but other factors like; *significance*, *duration* and *probability* are equally considered according to the project phase. The Ratio of the Impact Factor in relation to the total R is calculated using Eq. (4) and the final evaluation of an indicator 'I' is calculated using Eq. (5). Hence, the proposed assessment tool is shown in Table 2.

$$R = \frac{IV}{\text{Total IV}} \tag{4}$$

$$I = R * W \tag{5}$$

where W is the weight of the indicator as deduced from the questionnaire results.

2.5 Case study application

A study among the local community conducted by Zakaria et al. [39] showed that the acceptance of two case studies of MCWPs in rural sites in Egypt scored high value for several reasons, whereas conventional wastewater treatment plants did not receive the same acceptance score in another rural site [39]. A pilot project of a MCWP is currently under construction in the city of 10th of Ramadan as a part of this research fund. The park site is located near a wastewater treatment plant, from which domestic wastewater would be introduced to the constructed wetland after the first treatment stage (removal of solid waste) to be naturally treated throughout the wetland. The project site was selected in a new community to promote civic participation and create a public green space in an industrial

Table 2 The proposed assessment tool

Activities / Category		Code	Impacts / Impact Factors (IF)	Description	TYPE	Project activities: Construction Phase Assessment	W	Project activities: Operation Phase Assessment	W
Environmental Impact Factors	Climatic Aspects	E1	Air Quality	- Air quality: Improved air quality due to increased vegetation	Quantitative	M P D S	0.8	M P D S	0.9
		E2	Urban Micro-Climate	- Heat Island Effect: % Of change in Heat Island Effect due to vegetation and water bodies	Quantitative	M P D S	0.7	M P D S	0.9
		E3	Carbon Footprint	-Carbon Footprint: CO_2 and other GHG emissions associated with the CWPs compared to conventional treatment plant	Quantitative	M P D S	0.7	M P D S	0.8
		E4	Noise	- Noise Level: Reduction in noise pollution through Landscape features, such as berms and walls, natural techniques, and lower vehicles density on site.	Quantitative	M P D S	0.7	M P D S	0.8
	Sustainability	E5	Energy	- Construction Energy Conservation: % of construction energy saved in comparison to the conventional treatment plant - Operation Energy conservation: % of operation energy saved in comparison to operation/maintenance energy in conventional treatment plants measured over a fixed time scale.	Quantitative	M P D S	0.7	M P D S	0.8
		E6	Materials	- Recycled Materials: % of recycled or onsite materials employed - Hazardous Materials: % employed in water treatment process compared to conventional processes	Quantitative	M P D S	0.8	M P D S	0.8
		E7	Solid/ Liquid Wastes	- Quality/ Quantity of wastes: % of waste materials discharged during the treatment process	Quantitative	M P D S	0.8		0.8
		E8	Soil Discharges	- Quality/ Quantity of soil fertility: - Increased soil nutrients. - Reduced harmful soil discharges	Quantitative		0.8		0.8
	Biodiversity	E9	Flora (Vegetation)	- Increased flora species introduced to the habitat	Quantitative	M P D S	0.9	M P D S	0.9
		E10	Fauna	- Increased fauna species introduced to the habitat	Quantitative	M P D S	0.8	M P D S	0.8
	Water	E11	Water Reused	- Water Reused: % of recycled water reintroduced to the irrigation system.	Quantitative	M P D S	0.9	M P D S	0.9
		E12	Water Quality	- Water quality: % of pathogens removal by the CW	Quantitative	M P D S	0.9	M P D S	0.9
Socio-Cultural Impact Factors	Community Values	S1	Community size served	Population size served: No. of visitors during over a fixed time frame	Quantitative	M P D S	0.8	M P D S	0.8
		S2	Community Awareness	Degree of local community awareness of project main targets and goals	Qualitative	M P D S	0.8	M P D S	0.8
		S3	Community Acceptance	Degree of local community acceptance of project	Qualitative	M P D S	0.8	M P D S	0.8
	Social Values	S4	Education / Training	Increased educational and training opportunities	Qualitative	M P D S	0.8	M P D S	0.8
		S5	Public Participation	Local community and stakeholders' active engagement	Qualitative	M P D S	0.8	M P D S	0.8
		S6	Increased recreational & social values	Degree of increased social and recreational activities for visitors	Qualitative	M P D S	0.9	M P D S	0.9
		S7	Added social & connectivity values	Enhanced social connections and sense of belonging / Acceptable visitor experience / special needs requirements fulfilled.	Qualitative	M P D S	0.8	M P D S	0.8
	Aesthetic Values	S8	Visual Aesthetic Value	Scenic/aesthetic/visual acceptance	Qualitative	M P D S	0.9	M P D S	0.9
		S9	Odour Reduction Efficiency	Reduction in unpleasant odours	Qualitative	M P D S	0.8	M P D S	0.8
Economical -Technical Impact Factors	Economic Values	EC 1	Catalyzing economic development	Increase in public/ private investments	Quantitative	M P D S	0.8	M P D S	0.8
		EC 2	Land Use Value	The increased land value of the project site and neighboring properties	Quantitative	M P D S	0.8	M P D S	0.8
		EC 3	Economic Savings	Project economic efficiency during both construction and operation phases	Quantitative	M P D S	0.8	M P D S	0.8
		EC 4	Potentials of economic revenue	Economic revenue of the project and related activities	Quantitative	M P D S	0.8	M P D S	0.8
	Technical Values	EC 5	Construction process Flexibility	The flexibility of the construction process and techniques	Qualitative	M P D S	0.8	M P D S	0.8
		EC 6	Operation & maintenance process flexibility	The flexibility of operation & maintenance processes	Qualitative	M P D S	0.8	M P D S	0.8
		EC 7	Future potential for upgrading	- Project upgrading potential through expansion & technical improvements	Qualitative	M P D S	0.8	M P D S	0.8

city. After site investigation and coordinating with local authorities, A site analysis was conducted by the research team and water samples was taken from the treatment plant to determine the water quality before pumping it into the park. Afterwards, Stockholder meetings and academic workshops were held to discuss conceptual design and the criteria and sustainability indicators of MCWP and answer the questionnaire from stakeholder perspectives. Currently, the water course construction is finished, and the cascaded basins are established. The application of the proposed matrix on the 10th of Ramadan CW project is shown in Table 3.

Table 3 Application of the proposed matrix on the 10th of Ramadan's MCWP[a]

Impacts			**Project Activities**			
Activities			**Construction Phase**		**Operation Phase**	
Category		**Impact Factors (IF)**	**Construction Phase Assessment**	**Percentage Achieved (%)**	**Operation Phase Assessment**	**Percentage Achieved**
Environmental Impact Factors	Climatic Aspects	Air Quality	2 5 2 5	40	5 5 2 5	100.00%
		Urban Micro-Climate	2 4 2 2	12.8	5 5 2 5	100.00%
		Carbon Foot-print	1 3 2 2	4.8	3 4 2 3	28.80%
		Noise	0 0 1 3	0	3 2 2 1	4.80%
	Sustainability	Energy	5 5 2 5	100	5 5 2 5	100.00%
		Materials	5 5 2 5	100	5 5 2 5	100.00%
		Solid/ Liquid Wastes	3 5 2 5	60	5 5 2 5	100.00%
		Soil	2 4 1 2	6.4	3 5 2 4	48.00%
	Biodiversity	Flora (Vegetation)	3 5 2 5	60	5 5 2 5	100.00%
		Fauna	2 4 2 4	25.6	4 5 2 5	80.00%
	Water	Water Reused	0 5 1 3	0	5 5 2 5	100.00%
		Water Quality	0 5 1 3	0	4 5 2 5	80.00%

[a] *MCWP* Multifunctional Constructed Wetlands Project

2.5.1 Project site description

The proposed multifunction park is a long, narrow strip stretching for about 1 km, covering an area of approximately 36 km^2 (1056 m × 35 m). The designated area is a green belt located next to a sewage treatment plant. This green belt buffers the wastewater area from the nearby "Al-Andalus" residential complex. The park site currently has no plantation. The proposed site is nearly flat, requiring minimal preparation for construction. Moreover, the excavation works of the wetland water pathway will be reused in the site to create the required level variations, thus reducing the transportation costs of debris.

2.5.2 Data collection tools

The data used in the analysis and validation of the proposed assessment tool is categorized into primary data and secondary data. Moreover, qualitative as well as quantitative data are mutually employed in the assessment presented in Table 3.

The initial site data is based on the contextual analysis of the project's site including preliminary measurements and reports for air quality, site's urban micro-climate, soil quality, as well as water quality of the wastewater treatment plant that is intended to be filtered through the designed constructed wetlands. Socio-cultural factors are based on user surveys on the proposed design and several workshops that showcase the proposed design of the project and engage targeted stakeholders in the design development process. Hence, implementing participatory design concepts and increasing social engagement and shared values of the project. Economic data values are based on the expected calculations of economic revenues of the project. Performance data of the project are attained through the application of digital software tools such as i-Tree Eco V6 and ENVI met.

3 Results

Scientific contributions of topics concerning constructed wetlands are increasing in recent years on international and national scale respectively resulting in 46% of the screening sample to be of wetlands publications that are related to environmental science category, based on this scientific screening, 12 environmental, 9 socio-cultural and 7 economic indicators were selected, then sub-categorized and classified into several indicators to quantitatively evaluate the performance of MCWPs for the study. The qualitative analysis showed the impact weights of the 3 main sustainability dimensions proposed as follows; Environmental Dimension 0.42, Socio-cultural Dimension 0.29, Economical – Technical Dimension 0. 28. Preformed kurtosis analysis and Pearson's correlation analysis showed high consistency and reliability of the survey outcome results. The final results applied to the case study were presented in an adapted Leopold matrix in project different phases.

4 Discussion

The limited existing research for constructed wetland projects makes it challenging to assess the sustainability of the project and balance the multi-roles it plays. This type of project includes both buildings and landscape areas, hence, existing rating systems fall behind presenting a fair account of their sustainability [40, 41]. This may vary depending on the project types, activities, scale and context or depending on the project phase, whether design or construction. The main aim of this research is the development of a conceptual framework and assessment tool for the sustainability assessment of MCWPs. The study followed a mixed qualitative/quantitative research method. The main steps followed to develop the proposed assessment tool are: 1) identification, 2) selection of indicators, 3) categorization, 4) assigning weights for indicators, and 5) applying the adapted assessment matrix on each phase. In this regard, the study proposes a set of sustainability indicators that comprehensively assess the broad spectrum of sustainability criteria in MCWPs. It also proposes appropriate measurement metrics and assigns respective weights for indicators and sub-indicators. Various studies have proposed several indicators, nevertheless, their suitability for hot arid climates was not discussed. Also, their relative weights indicate the importance of some indicators over others. Hence, surveying a wide range of professionals for the relative weights of indicators provides a robust view of the proposed assessment framework. Also, some responses showed that the relative weight of some indicators may vary depending on the project phase. Hence, the proposed framework enables assessing constructed wetland projects at both the design and construction phases. It accounts for their multi-roles e.g., environmental, social and economic. It presents a set of indicators showing their priorities for local practitioners. Finally, the results are presented in a clear format using an adapted Leopold matrix to enable a better understanding of the project's state and means of improvement. Based on a thorough evaluation of recent literature, research constraints were identified in defining and classifying indicators in addition to the survey responses' inherent subjectivity. Nonetheless, depending on the state of the project, the proposed model can add or remove indicators. The proposed Matrix is tested to be easy applicable, user-friendly assessment tool that can be applied on projects under construction to evaluate expected sustainability outcomes, or during the operation stage to monitor the sustainability performance of the project, and hence determine areas of modifications and improvements`. One of the drawbacks of such tool is its dependence on the assessors' subjective evaluation of the impact score in the matrix [42]. Such subjectivity and perception gaps can be narrowed through the comprehensive understanding of the performance indicators fulfilled by the proposed assessment tools and equations, which would help the assessors to objectively set more accurate scores for indicators.

5 Conclusion

This research aimed to develop a comprehensive assessment framework for evaluating the sustainability of MCWPs acknowledging the limited existing research on assessing these projects, as sustainability assessment methods concerning architectural projects primarily focus on built structures, neglecting the unique aspects of landscape projects. this gap was addressed by a systematic approach of evaluation considering all three pillars of sustainability (environmental, social, and economic) hence, 28 measurable indicators were selected and categorized under these three pillars based on UN SDGs and the project functions. Weights were assigned to indicators using a combination of the BAL and public opinion surveys to reflect their relative importance and priority in achieving sustainability. The impacts of the proposed indicators on sustainability are investigated using an adapted Leopold Matrix method which allows for evaluation during both construction and operation phases, providing a more holistic view of the project's impact. it allows decision-makers to assess the sustainability of their MCWPs along different life cycle stages. It also allows for comparing the significance of different indicators. The ultimate result is a complete approach to decision-making that goes beyond the use of simple tools or models. This results in a full assessment that may be used to prioritize actions and track and measure the sustainability of MCWPs through an integrated assessment approach to deliver their optimal benefits while minimizing negative impacts. The framework can be used by urban planners, landscape architects, and policymakers in order to promote the wider adoption of MCWPs for sustainable wastewater treatment and urban development.

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Authors' contributions

Aya ElMeligy illustrated the Leopold matrix and how to use it in the case study and the equations used to get weights of each factor, Rasha Mahmoud Gaber,researched sustainability indicators for the constructed wetlands project and selected them based on a designed criteria to be applied in the assessment model, Hind Mostafa distributed the online and onsite questionnaire and analysed several case studies of constructed wetlands treatment plants to determine assessment criteria, Ahmed Haron is the principal investigator of the constructed wetland park project and he is advisor and coordinator between all authors and the flow of information and have done editing on the final version of the manuscript, Walaa S.E. Ismaeel ran the statics analysis that resulted on weights of the different indicators and organized research sections,All authors read and approved the final manuscript.

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Data availability

The data will not be shared until the publication of this paper.

Declarations

Competing interests

The authors declare they have no competing interests.

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