APPLICATION OF ANALYTIC HIERARCHY PROCESS (AHP) FOR SELECTING STORMWATER BEST MANAGEMENT PRACTICES

Noor Suraya Romali, Ainon Murshida Isa, Nur Idayu Mohamad

Abstract

Green roof and rain garden are the Best Management Practices (BMPs) that have limited applicability in Malaysia. With the aim to promote their usability, this paper presents the application of the Analytic Hierarchy Process (AHP) to select the best type of these two BMPs. The methodology used is twofold. First, the feedback on factors influencing the selection of the BMPs was collected, while in the second stage, respondents were asked to evaluate the BMP's alternatives using AHP pairwise comparison questionnaire. Construction cost is the most influencing factor in the selection of green roof, with a total priority weight of 0.5013, followed by the lack of awareness and knowledge (0.1152), and maintenance complexity (0.0951). Meanwhile, the selection of rain garden is mainly influenced by the climatic factor (0.2718), followed by the structural criteria (0.1564) and additional cost (0.1547). An intensive green roof and permeable rain garden are selected as the most appropriate type for Malaysian implementation with composite priorities of 0.848 and 0.752, respectively.

Keywords Storm water management, Analytic Hierarchy Process, Best management practices, Green roof, Rain garden.

N.S. Romali, A.M. Isa, N.I. Mohamad

Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia

N. S. Romali (Corresponding Author)
e-mail: suraya@ump.edu.my

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Introduction

Rapid urbanisation and climate change make urban water management very challenging. Various efforts have been done by urban planners and engineers to minimise the negative impact of urbanisation to water bodies. Urban Storm Water Management Manual for Malaysia (MSMA) has been used since 2001 as a guideline to adopt and design BMPs in controlling storm water in terms of quantity and quality. Several other manuals used for storm water management in other countries are Sustainable Urban Drainage System (SUDS) (UK), Low Impact Development (LID) (USA) and Water Sensitive Urban Design (WSUD) (Australia) (Kok et al., 2015). Low-impact development (LID) practices have been used as an alternate and sustainable urban drainage system, which can lower resource runoff, reform groundwater infiltration, and reduce the social and environmental impacts (De Macedo et al., 2018; Paola et al., 2018). The application of LID is relevant to be considered with the purpose of mitigating the appeals of both urbanisation and climate change, because it consolidates environmental friendliness with technical effectiveness.

The BMPs facilities offered in MSMA are infiltration facilities, bioretention systems, gross pollutant traps (GPT), swales and water quality ponds, and wetlands. The main potential benefits of the BMPs are to reduce runoff, litter, debris and pollutant removal. Meanwhile, in other countries, the examples of storm water management practices could be green roofs, infiltration trenches, permeable pavements, wet ponds, and bioretention cells or rain gardens (Rossman, 2017). These interventions together can have a significant impact; allowing water to infiltrate the soil and return to the groundwater can rebuild the natural hydrological cycle (Demuzere et al., 2014).

The selection of BMPs for mitigating the impacts of urbanisation could be a complex process. A wide scope of criteria such as site physical characteristics, pollution control ordinances, stakeholder input, BMP implementation and long-term maintenance costs need a priority of examination when selecting the best BMP for storm water management (Young et al., 2010).

Green roof and rain garden are two BMPs measures that have limited applicability in Malaysia. The implementation of green roofs can be observed in limited buildings such as extensive green roofs at Heriot-Watt University, intensive green roofs at Acappella Residence, Shah Alam, and semi-intensive green roofs at Bandar Rimbayu, Shah Alam (Ismail et al., 2018). Hence, with the aim to assist in the management of storm water, this study aims to identify the factors influencing the implementation of green roofs and rain gardens in Malaysia. Then, the application of the AHP approach as a decision-making tool was utilised for selecting the best type of these two BMPs measures.

The concept of green roofs and rain gardens

The green roof is one of the storm water management techniques, which significantly increases water retention, and thus helps to mitigate the urban flooding (Paithankar and Taji, 2020). The green roof system consists of the vegetation layer, soil layer (substrate), filter layer, drainage layer and waterproofing layer, from top to bottom. The lowest part component of green roof assembly by waterproofing membrane is placed directly over the structural layer, to avoid water from being absorbed by structure. The function of the drainage layer is to allow the water to flow into the irrigation system to reserve the water for vegetation. It also inserts a shield layer amid the drainage layer and the waterproofing membrane. Between the drainage layer and the growth medium, a filter layer is installed to prevent substrate material seepage into the drains and gutters (Roseli et al., 2014). There are two types of green roofs, which are intensive and extensive green roofs. Intensive roofs are usually associated with roof gardens with a substrate depth of more than 15-20 cm, while extensive green roofs have an adequately thin substrate of soil (less than 15 cm) (Cascone, 2019).

A rain garden is a form of BMP that utilises biological absorption and porous media filtering processes while treating storm water runoff. The bio filtration systems assorted by vegetation, such as trees, shrubs and grasses, indirectly enhance the aesthetics of the urban landscape and layer media using soil, sand and mulches. Two types of commonly applied rain gardens are permeable and impermeable systems. The impermeable system drains water from the filtration media through a layer of transition, yet was hampered by pipes or underground channels located in the drainage layer. The types of soil suitable for this system are clayey and poorly drained soils (DID, 2012). The permeable system drains water through the filter media and the sand layer, and finally fills the groundwater. This type of rain garden is without an underdrain, and the Seasonal High-Water Table (SHWT) should be at least 2 feet below the bottom of the system's soil planting bed, referring to the BMPs manual (2009).

Analytic Hierarchy Process (AHP) for decision making

The Analytic Hierarchy Process (AHP) is an algorithm capable of assisting the complex decision-making problems that were first developed by Thomas Saaty (Saaty, 1980). The AHP has been used worldwide in the field of water resources i.e. in the selection of BMPs in Town of Blacksburg, Virginia (Young et al., 2010), to select the landfill site in Kuantan, Malaysia (Romali et al, 2013) and in the identification of influencing factors in the selection of green roof in Italy (Rosasco and Perini, 2019). The technique begins by structuring a problem of decision making as a hierarchy in the form of an upside-down tree, where the main objective is put on top. The second level sets partial objectives that meet the primary target. At the second level, each partial goal can be decomposed into third-level targets and each set at each level meets the aim of the level to which they are subordinated. The alternatives are described at a lower level and then compared pairwise according to their contribution from the lower level to achieve each goal or criterion. The pairwise comparison was performed based on the Saaty's scale of relative importance.

Methodology

Data Collection

The first stage of data collection was conducted to determine the criteria and sub-criteria for the objectives goal, while the second stage data collection aims to obtain related information for the ranking analysis of the alternatives. The respondents are experts in the private sector, government organisations, academia, and who have experiences in policy research, design, and construction that specialises in green roof and rain garden systems, as shown in Table 1.

The first stage data has been collected using an interview form with a 5-point Likert scale, in which respondents specify their level of agreement to a statement typically in five points: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree, regarding the factors that influence the implementation of green roofs or rain gardens in Malaysia. The list of the tested influencing factors was gathered from literature reviews, as shown in Table 2. The respondents have been asked to indicate to what extends they agree or disagree with the listed criteria with regards to the 5-point Likert scale. The results from the analysis were then used to develop the AHP structure diagram as the criteria and sub-criteria components.

Table 1: List of Interviewees.

Green Roofs		Rain Gardens	
Nos of respondents	**Position**	**Nos of respondents**	**Position**
20	Contractors, engineers, academician	22	Architects, engineers, academicians, project managers

Table 2: Available selection criteria/sub-criteria for AHP analysis

Green Roofs	Rain Garden
High initial construction cost	Cost for groundwork
Lack of government support or incentives	Cost for planting
High maintenance cost	Additional cost
Lack of awareness and knowledge	Maintenance cost
Lack of example	Reduce the risk of flood
Lack of local research	Protect biodiversity
Lack of competence	Reduce garden maintenance
Lack of client and interest	Serve as an appliance for conversing water
Lack of policy and standard	Creating featured landscape
Legal and political	Make green areas
Increased structure load	Harmonise the surrounding area
Structural damage	Provide natural elements within an urban setting
Weak under weak load	Maintenance
Maintenance complexities	Type of vegetation
Risk of failure and leakage	Depth of layer filter media
Challenges of installation an existing building	Soil investigation
Lack of rainfall	Site location
Lack of suitable plant	Water quality performance
Increase fire risk	Hydrological performance
	Hydraulic conductivity
	Climate control
	Storm water runoff
	Pollutant removal
	Ecological conservation

The questionnaire for the second stage of data collection was designed based on the AHP hierarchy model. The respondents have been asked to evaluate the criteria/sub-criteria and alternatives using the Saaty's rating scale by Saaty (1980), as shown in Table 3. The second stage data are analysed using the

AHP approach to rank the alternatives.

Table 3: Saaty's relative importance scale.

Intensity of importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance

AHP Hierarchy Structure Model

AHP hierarchy structure model is a three-level diagram consisting of objectives goal (first level), criteria/sub-criteria (second level) and alternatives (third level). The evaluation criteria/sub-criteria were chosen according to the mean statistic result from the first stage data analysis using the Statistical Package for the Social Sciences (SPSS) software. The alternatives were identified from the literatures, interviews with experts, sites observation and secondary information on the implementation of green roofs and rain gardens in Malaysia.

AHP Evaluation

Once the hierarchy model has been established, a pairwise comparison matrix (PCM) of all the criteria is constructed. Then, the weight (W_i) for each level is determined by the solving system of linear simultaneous shown in Equation (1);

$$W_i = 1/\lambda_{max} \sum a_{ij}\, w_i, i = 1,2, \ldots \ldots .. n \quad (1)$$

for uniqueness, we normalise the set of weights such that using Equation (2):

$$\sum_{i=1}^{n} W_i = 1 \quad (2)$$

To determine the consistency of decision and reveal the possible need of revisions to judgments, the consistency ratio (C.R) was calculated using Equation (3):

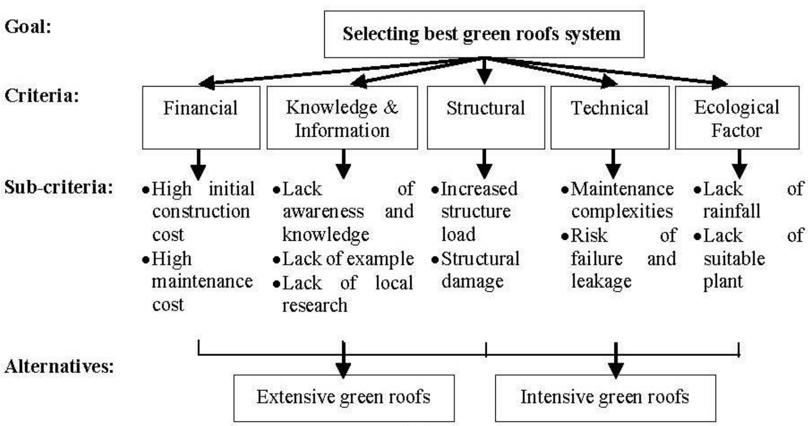
$$C.R = \frac{C.I}{R.I} \text{ where } C.I = \frac{\lambda_{max} - n}{n-1} \quad (3)$$

C.I is the consistency index with n is the element being compared and R.I is the random consistency value according to the size of the matrix. The value of C.R should be around 10% (0.1) or less to be acceptable. In some cases, 20% (0.2) may be tolerated but never more. If the C.R is not within this range, the participants should study the problem and revise their judgment.

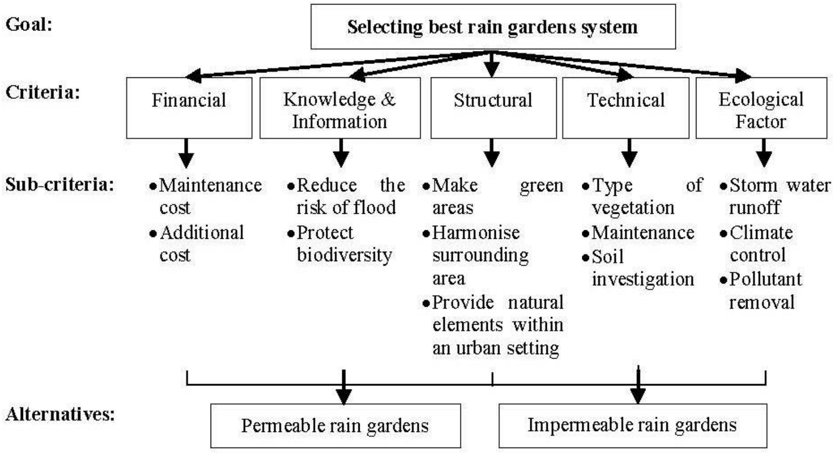
Results and discussion

AHP Hierarchy Structure Model

Figures 1 (a) and (b) show the AHP hierarchy model developed for green roofs and rain gardens, respectively. The selection of the criteria/sub-criteria and alternatives for the model was described in the following sub-sections;



(a)



(b)

Figure 1: AHP Hierarchy Structure Model for BMPs; (a) green roofs and (b) rain gardens

Criteria and sub-criteria

Table 4 shows the factors that affected the implementation of green roofs and rain gardens system in Malaysia. The factors have been grouped into five main criteria; financial, knowledge and information, structural, technical, and ecological factors. As shown in the results, the respondents agreed that the economic factors (initial, maintenance and additional cost) play a key role in the application of the BMPs system, where the mean score is between 3.9 to 4.6 for both green roof and rain garden. Lack of awareness, knowledge, example and local green roof research were also obtained above average mean score value (4.2 to 4.4). Meanwhile, most respondents agreed that the usability of rain gardens to improve the storm water runoff, climate (temperature) and storm water pollutants influenced its preference as a BMP control. Other green roof sub-criteria, i.e. increased structure load, structure damage, maintenance complexities, risk of failure and leakage, lack of rainfall, and lack of plant suitable for local climate conditions, were also selected to support the main criteria. For rain gardens, another eight sub-criteria were selected, namely make a green area, harmonise the surrounding area, provide natural elements within an urban setting, type of vegetation, soil investigation, maintenance, protect biodiversity and reduce risk of flood.

Table 4: Factors influencing the implementation of BMPs; green roofs and rain gardens.

Criteria	Green Roofs		Rain Gardens	
	Sub-criteria	**Mean**	**Sub-criteria**	**Mean**
Financial	High initial construction cost	4.4	Maintenance cost	4.6
	High maintenance cost	3.9	Additional cost	4.2
Knowledge and information	Lack of awareness and knowledge	4.4	Reduce the risk of flood	4.6
	Lack of example	4.3	Protect biodiversity	3.8
	Lack of local research	4.2		
Structural	Increased structure load	3.7	Make green areas	4.8
	Structural damage	3.5	Harmonise the surrounding area	4.5
			Provide natural elements within an urban setting	4.3
Technical	Maintenance complexities	4.3	Type of vegetation	4.7
	Risk of failure and leakage	4.2	Maintenance	4.6
			Soil investigation	4.5

Criteria	Green Roofs		Rain Gardens	
	Sub-criteria	**Mean**	**Sub-criteria**	**Mea n**
Ecological factor	Lack of rainfall	3.5	Storm water runoff	4.6
	Lack of suitable plant	3.4	Climate control	4.3
			Pollutant removal	4.2

Alternatives

Extensive green roofs and intensive green roofs are the two types of green roof systems that have been selected as alternatives for the AHP model. Extensive green roofs have been used worldwide for storm water management (Rincón et al., 2014 Kok et al., 2015; Paithankar and Taji, 2020) due to their low weight, easy handling, and low maintenance costs. Meanwhile, the intensive green roof is also a preferable choice as it encompasses a comparatively better potential than extensive green roofs in storm water management (Cascone, 2019). On the other hand, two alternatives chosen for the rain garden system are permeable rain garden and impermeable rain garden, as these two are the types of bio filtration systems suggested by DID (2012) and BMPs manual (2009).

Selection of best BMPs system

*Green roof*s

Table 5 shows the total weight of alternatives of sub-criteria in the analysis to select the best suitable system for the green roof. The significant criteria factors are identified based on the highest priority weight value (approaching 1). It can be seen that high initial construction cost has the highest weight (0.5013), followed by the lack of awareness and knowledge (0.1152), and maintenance complexity (0.0951). From the result, it can be suggested that the high cost to construct the green roof is the main factor that needs to be considered in the implementation and selection of green roof system. Otherwise, lack of plants suitable for local climate has the lowest weight (0.0082), but it also can affect the implementation of green roof. As a result, the intensive green roof was found to be the best system to be applied in the residential area with the composite priority of 0.848 compared to extensive green roof 0.152. The C.R value obtained is 0.17, which is not within the limit (<0.1), but it can be tolerated if the value is in the range of 20% (0.2).

Table 5: Total weight of pairwise comparison between alternative and sub-criteria for green roofs

Criteria /Sub-criteria	**Total priority weight**	**Alternatives**	
		Intensive green roofs	**Extensive green roofs**
Financial			
High initial construction cost	0.5013	0.846	0.154
High maintenance cost	0.0716	0.857	0.143
Knowledge and information	0.1152	0.862	
Lack of awareness and knowledge			0.138
Lack of example	0.0157	0.833	0.167
Lack of local research	0.0250	0.862	0.138
Structural			
Increased structure load	0.0924	0.875	0.125
Structural damage	0.0185	0.862	0.138
Technical			
Maintenance complexities	0.0951	0.818	0.182
Risk of failure and leakage	0.0158	0.818	0.182
Ecological factor			
Lack of rainfall	0.0411	0.840	0.160
Lack of suitable plant	0.0082	0.800	0.200
COMPOSITE PRIORITY		**0.848**	**0.152**

Rain gardens

The total weight of pairwise comparison between alternatives to sub-criteria for the rain garden is shown in Table 6. From the result, it can be seen that the climate control is the main factor that needs to be considered in the implementation and selection of rain garden system, as it gives the highest priority weight, which is 0.2718; followed by the structural criteria to provide natural element within an urban setting (0.1564) and additional cost (0.1547). The cost factor can also affect the implementation and selection of rain garden, although it is not a critical factor. As a result, the permeable system was chosen as the most preferred type of rain garden in urban area with the highest composite priority of 0.752, followed by the impermeable system (0.249). The C.R obtained is 0.2, hence the judgement is acceptable.

Table 6: Total weight of pairwise comparison between alternative and sub-criteria for rain gardens

Criteria/Sub-criteria	**Total priority weight**	**Alternatives**	
		Permeable rain gardens	**Impermeable rain gardens**
Financial			
Maintenance cost	0.0269	0.810	0.191
Additional cost	0.1547	0.765	0.235
Knowledge and information	0.0430	0.800	0.200
Reduce the risk of flood			
Protect biodiversity	0.0082	0.500	0.167
Structural			
Make green areas	0.0212	0.750	0.250
Harmonize the surrounding area	0.0606	0.733	0.267
Provide natural elements within an urban setting	0.1564	0.790	0.211
Technical			
Type of vegetation	0.0795	0.750	0.250
Maintenance	0.0250	0.765	0.235
Soil investigation	0.0113	0.757	0.485

Criteria/Sub-criteria	Total priority weight	Alternatives	
		Permeable rain gardens	Impermeable rain gardens
Ecological factor			
Storm water runoff	0.0912	0.733	0.267
Climate control	0.2718	0.714	0.286
Pollutant removal	0.0514	0.810	0.191
COMPOSITE PRIORITY		**0.752**	**0.249**

Conclusion

This study has identified the significant factors that affected the implementation and selection of green roof and rain garden in Malaysia. The factors were grouped into five categories, which are financial, knowledge and information, structural, technical, and ecological factors. High initial construction cost has been found to be the most influenced factor in the implementation of green roof systems with a total priority weight of 0.5013, followed by the lack of awareness and knowledge (0.1152), and maintenance complexity (0.0951). Meanwhile, the implementation of the rain garden is mainly influenced by the climatic factor (0.2718), followed by the structural criteria to provide natural elements within an urban setting (0.1564) and additional cost (0.1547). The alternatives ranking result shows that the intensive green roof is the best system to be implemented in Malaysia with the composite priority of 0.848, compared to the extensive green roof (0.152), whereas for the rain garden, the permeable system had been chosen as the most preferred type of rain garden with priority weight of 0.752.

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Author(s) Biodata

Noor Suraya Romali
suraya@ump.edu.my
(22 September 1983)

Noor Suraya Romali obtained her first degree in B.Eng. in Civil Engineering from Universiti Malaysia Sarawak. She received her M.Eng. in Hydrology and Water Resources Engineering, and completed her doctoral study in Civil Engineering from Universiti Teknologi Malaysia. Her primary research interest includes flood damage and risk assessment, urban storm water management, water management, and hydro-environment research.

Ainon Murshida Isa
ainonmurshida4@gmail.com
(21 October 1994)

Ainon Murshida Isa is currently pursuing her final year undergraduate degree in Engineering Technology at Universiti Malaysia Pahang and will graduate in 2021 with Bachelor Degree in Engineering Technology (Infrastructure Management). She obtained her Diploma in Civil Engineering from Polytechnic Tuanku Sultanah Bahiyah, Kulim Kedah. She is a member of Institute Engineer Malaysia and currently undergoing her internship at Bersatu Eramaju Sdn Bhd, Perak.

Nur Idayu Mohamad
idayumhd96@gmail.com
(14 June 1996)

Nur Idayu Mohamad is currently pursuing her final year undergraduate degree in Engineering Technology at Universiti Malaysia Pahang and will graduate in 2021 with Bachelor Degree in Engineering Technology (Infrastructure Management). She obtained her Diploma in Civil Engineering from Universiti Malaysia Pahang. She is currently undergoing her internship at Small Empire Sdn. Bhd., Kuala Terengganu.