

A Multi-criteria Decision-making Framework for Selecting the Best Low Impact Development Techniques (LIDs)

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Research Article

Keywords: Low Impact Development, MCDA, Green roof, Bioretention, Stormwater, Runoff

Posted Date: February 10th, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1344103/v1>

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Version of Record: A version of this preprint was published at Environmental Protection Research on May 27th, 2022. See the published version at <https://doi.org/10.37256/epr.2220221367>.

Abstract

Low impact Development (LID) techniques are known as a novel stormwater management approach designed to mitigate the adverse effects of stormwater runoff and nonpoint source pollution. This study proposes a methodology for selecting the best LIDs based on the multi-criteria decision analysis (MCDA) while incorporating different stakeholder priorities. First, we characterize all main stakeholders so that their influences can be assessed. Second, relevant main criteria and sub-criteria are selected. Third, a stakeholder analysis is carried out to obtain social performance values and criteria priorities. Finally, two MCDA methods are applied to obtain the final LID rankings. The results show that the performance of infiltration practices and vegetated filter strips are reasonably good in stakeholders' opinion. Subsequently, the performance of the soil restoration has a number of positive effects on stormwater quality and quantity function. Most of the ten LID techniques received ratings more than 3 from the Weighted Average Method (WAM) method (performing well) other than green roofs and constructed filters, and no techniques averaged lower than 2.29 out of 5. There is a general consensus on how vegetated filter strip and infiltration practices would perform, while there is little consensus on the bioretention, level spreaders, and porous pavements. The ratings show that the majority of stakeholders thought most LIDs would perform well (score of more than 3). While further investigations into the opinions held by main stakeholders of stormwater management of LID will be required, the results of this study provide an initial insight into how these results can be applied to support effective widespread LID implementation.

1. Introduction

The urban infrastructure management needs to be integrated, beginning with a definition of land-use that aims to preserve the natural functions like infiltration and the natural drainage system [1–3]. This approach of development has been termed Low Impact Development (LID) in the United States or Water-Sensitive Urban Design (WSUD) in Australia [4]. The LID approach is based on managing stormwater at the source by the use of planning techniques, known as non-structural LID BMPs, and microscale controls, known as structural LID BMPs, that are distributed throughout the site in order to maintain the pre-project hydrologic function of the site [5, 6].

LID has the potential to mitigate some negative impacts of urban development that conventional stormwater management techniques have not been able to address adequately [7]. LIDs vary significantly in performance across different criteria. Appropriate LID techniques can be selected according to the project objectives, capabilities, and limitations of the study area [7]. Reduction in the peak and volume of runoff, improvement of stormwater quality, and water conservation are the main goals of the LIDs implementation. Besides, basin slope, climate, groundwater depth, operation and maintenance of existing facilities and cost are some influential factors that should be considered in the selection of proper LID techniques [6].

Additionally, the stakeholders can have different views and priorities, adding to the complexity of the situation [8]. Conflicting views from the stakeholders may lead to a complicated selection procedure [9, 10]. It is important to note that the effective LID implementation will not occur without the support of all affected stakeholders [10].

Therefore, this study aims to propose a methodology for selecting the best LIDs for urban areas by comparing applying multi-criteria decision analysis (MCDA) under different stakeholder scenarios. The proposed methodology considers every stakeholder separately and to carry out a single evaluation of the LID alternatives. Note that while these kinds of problems are not new in water resource management, and the use of MCDA method, itself, has been investigated in different studies, the direct application of MCDA for selecting best LIDs has been rarely investigated. The proposed methodology comprises analysis of alternatives, stakeholder analysis, application of the MCDA methods.

2. Materials And Methods

We applied the Weighted Average Method (WAM) and the Preference Ranking Organization

We applied the Weighted Average Method (WAM) and the Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE) methods as two common scoring mechanism of the MCDA tool. Each the selected MCDA methods was evaluated based on their ability to match the desired criteria. The procedure for evaluating the differing methods of MCDA followed a step-by-step technique as explained in the following sections.

2.1 Stakeholder Identification

The successful LID implementation requires the involvement of a wide groups of stakeholders such as local government, the local water authority, stormwater practitioners, elected officials, landscape architects and representatives from the community [8,9]. In this study, the main stakeholder groups within the watershed are considered as below:

- Municipal governments
- Building and Land Developers
- Planner (i.e. architect, urban planner)
- Private homeowner
- Local Business Owner (i.e., restaurant, supermarket, etc)
- Organizations (NGOs)

2.2 Criteria

In this study, we selected a list of sub-criteria based on the requirement that the criteria can be quantified according to the literature. The most significant factors that influence the low impact development techniques are listed below [6,9,11].

- Stormwater quantity function

- Volume
- Groundwater Recharge
- Peak Rate

- Stormwater quality function

- TSS
- TP
- TN
- Temperature

- Cost

- Maintenance

- Winter Performance

2.3 LID Alternatives

The next step is to develop the various LID alternatives for consideration. In this study, we selected the following ten LID techniques [6].

- Bioretention
- Vegetated Swale
- Vegetated Filter Strip
- Permeable Pavement
- Rainwater Harvesting
- Green Roof
- Infiltration Practices
- Level Spreaders
- Constructed Filter

- Soil Restoration

For more detailed investigation, effective quality parameters are quantified according to Table 1. Each LID technique was scored for the main criteria according to the Army LID Technical User Guide manual [6]. Tables S1 to S10 provides the scores of criteria for each LID alternatives according to their importance and impact.

Table 1
Rating of alternative function

Function	Rating	Rating for Maintenance and cost
Low	1	5
Low/Medium	2	4
Medium	3	3
Medium/High	4	2
High	5	1

2.4. Criteria Weighting

The stakeholders' interests or priorities were analyzed in this section to obtain separate LID rankings [8]. We consider every stakeholder separately to obtain a single evaluation of the LID techniques [4].

2.4.1. Stormwater quantity function

Volume reduction is the most important factor from the engineers' perspective. After that, planners and citizens are equally concerned about volume reduction [9, 10]. Most stormwater systems are on city property or within city setbacks; therefore, municipal governments are the main responsible to control the runoff. Volume reduction is also considered a concern for NGOs. However, NGOs are less concerned about the volume reduction in comparison with planner and municipal governments. For municipal governments, increasing the groundwater recharge can be important factor. This factor is also important for NGOs. LID reduces demand on water supply and encourages natural groundwater recharge [4, 12]. Nevertheless, compared to NGOs and governments, groundwater recharge does not have importance for building and land developers, private homeowner and local business owner. Planners are located somewhere between the two aforementioned groups. Peak flow reduction has the same priority for planners, citizens and developers and municipal governments [9, 10]. However, NGOs are less concerned about this factor.

Table 2
Stormwater quantity function

Stakeholders	Score
Municipal governments	4
Building and Land Developers	3
Planner	3
Private homeowner	2
Local Business Owner	1
Organizations (NGOs)	2

2.4.2. Stormwater quantity function

For private homeowner and NGOs, LIDs protect site and regional water quality by reducing sediment, nutrient, and toxic loads to water bodies [9, 10, 13, 14]. TSS removal is an incentive factor for citizens, engineers and municipal governments. Planners are also concerned about this factor, but it is less than three aforementioned groups [9]. As it is mentioned in previous section, stormwater quality improvement is the most important factor for NGOs. Therefore, for all stormwater quality sub criteria, NGOs have the highest score. Planner usually do not care about TP removal. However, citizens are usually more sensitive in this case. Engineers, municipal governments and developers are somewhere between two these groups [9]. Stakeholders' opinion about TP removal is very similar to TN removal [9]. Stormwater temperature reduction is another benefit of LID techniques. As it is mentioned in previous sections, for NGOs, stormwater quality has more importance than other stakeholders. Furthermore, we assumed that temperature of stormwater has the least importance for planner and land developers among all stakeholders [8].

Table 3
Stormwater quality function

Stakeholders	Score
Municipal governments	3
Building and Land Developers	1
Planner	1
Private homeowner	2
Local Business Owner	2
Organizations (NGOs)	4

2.4.3. Cost

Quantifying the economic benefits of LIDs implementation is not a simple task because some benefits such as aesthetics, recreational opportunities, and environmental impacts are not monetary or cannot be obtained directly [9]. LIDs reduce land clearing, grading, infrastructure costs (streets, curbs, gutters, sidewalks) and stormwater management costs for developers. For municipal governments, it reduces system-wide operations and maintenance costs of infrastructure and costs of combined sewer overflows. For private homeowner, LID provides shading for homes, which decreases monthly energy bills for cooling. It also saves money through water conservation [2, 14–16]. Economic NPV has more importance respectively for developers, citizens and planners [10]. For NGOs, cost has the least score.

Table 4
Cost

Stakeholders	Score
Municipal governments	4
Building and Land Developers	4
Planner	2
Private homeowner	3
Local Business Owner	3
Organizations (NGOs)	1

2.4.4. Maintenance

LID techniques should be maintained to retain its effectiveness. The costs associated with maintenance of a LID technique can easily be returned in reduced flooding, reduced home energy heating and cooling costs, increased amenity values, and improvements to water quality [5, 13, 17, 18]. Most property owners would prefer and are looking for their municipal government to take on their stormwater drainage systems maintenance and repairs for obvious reasons [19].

Table 5
Maintenance

Stakeholders	Score
Municipal governments	2
Building and Land Developers	2
Planner	4
Private homeowner	1
Local Business Owner	1
Organizations (NGOs)	2

2.4.5. Winter Performance

Stakeholders' opinion about winter performance is considered to be similar to maintenance considerations [6, 9, 14, 20, 21].

Table 6
Winter performance

Stakeholders	Score
Municipal governments	1
Building and Land Developers	2
Planner	4
Private homeowner	1
Local Business Owner	1
Organizations (NGOs)	2

2.5. MCDA Method

We considered the WAM approach and PROMETHEE analysis in this study as a scoring mechanism to the MCDA tool [4, 19]. The Weighted Average Method (WAM) of MCDA is a value-based method where the score assigned to each criterion is a value along a discrete pre-determine range. The overall scores for criteria are determined by following equation [4, 19]:

$$S_j = \sum W_i * R_j(1)$$

where S_j is overall score for technology, W_i is weight, and R_j is the relative importance of criteria.

3. Results

Values of 1-5 are assigned by the user for importance of each main criteria with 1 representing little to no importance of a criteria of 5 representing very important criteria [4, 9, 10, 19]. The scale of 1-5 was chosen for the criteria importance since there are five technologies considered in each analysis and this scale is considered simple for users to understand.

Table 7 summarizes the rating for each technology for each criterion in the absence of weighting. As we can see, for stormwater quantity function, infiltration practices have the best score. Bioretention, vegetated filter strip, rainwater harvesting, and soil restoration are the best LID techniques in terms of stormwater quality function. As a result, environmentally, they should be the best alternatives. In addition, vegetated filter strip, permeable pavement, level spreader and soil restoration require less maintenance. According to the below Table, vegetated filter strip, permeable pavement, level spreader and soil restoration have the highest scores for winter performance. In terms of cost, vegetated filter strip, permeable pavement, level spreader are the best LID practices. As a result, they can be acceptable for municipal organizations. However, varying levels of performance across a wide range of criteria and conflicting stakeholder views could complicate the selection process of these practices.

Table 7
Summary of rating for each technology for each criterion

Resource Criteria	Bioretention	Vegetated Swale	Vegetated Filter Strip	Permeable Pavement	Rainwater Harvesting
Stormwater quantity function	3.7	2.0	1.0	1.0	2.3
Stormwater quality function	4.0	3.3	4.0	1.0	4.0
Cost	3.0	4.0	5.0	5.0	4.0
Maintenance	3.0	4.0	5.0	5.0	3.0
Winter Performance	3.0	3.0	5.0	5.0	3.0
Resource Criteria	Green Roofs	Infiltration Practices	Level Spreaders	Constructed Filter	Soil Restoration
Stormwater quantity function	2.7	4.0	1.0	3.0	2.3
Stormwater quality function	3.5	3.8	1.0	3.0	4.0
Cost	1.0	4.0	5.0	2.0	3.0
Maintenance	3.0	4.0	5.0	1.0	5.0
Winter Performance	3.0	4.0	5.0	3.0	5.0

The results of this study provide a greater insight into the opinions and concerns of stakeholders of stormwater management.

3.1. Weighted Average Method (WAM)

As we can see in the Table 8 and Figures 1 and 2, for municipal governments, infiltration practices and constructed filter are respectively the best and worst techniques. It seems logical because infiltration practices have some distinct advantages mainly around the stormwater quantity function and cost, and it is exactly what is more important for municipal governments. For building and land developers in addition to infiltration practices, vegetated filter strips have also the high score due to the same reasons. In fact, stormwater quality function has less importance for these groups. For planner, vegetated filter strip and constructed filter have respectively the highest and lowest score. Planners are more sensitive about maintenance and winter performance, and as it is mentioned in previous sections vegetated filter strip needs the less maintenance and better winter performance among LIDs. For private homeowner, infiltration practices are the best techniques. However, vegetated filter strips have importance for NGOs as much as infiltration practices. That is because these techniques have high stormwater quality function, and it is the most important factor for environmental organizations.

Table 8
Scores of alternatives for selected stakeholders (WAM method)

Stakeholders	Bioretention	Vegetated Swale	Vegetated Filter Strip	Permeable Pavement	Rainwater Harvesting
Municipal governments	3.40	3.20	3.64	3.00	3.31
Building and Land Developers	3.25	3.27	3.92	3.67	3.25
Planner	3.21	3.23	4.07	3.86	3.07
Private homeowner	3.37	3.28	3.89	3.22	3.41
Local Business Owner	3.30	3.39	4.33	3.67	3.48
Organizations (NGOs)	3.48	3.18	3.91	2.82	3.33
Stakeholders	Green Roofs	Infiltration Practices	Level Spreaders	Constructed Filter	Soil Restoration
Municipal governments	2.44	3.95	3.00	2.43	3.45
Building and Land Developers	2.29	3.98	3.67	2.33	3.58
Planner	2.68	3.98	3.86	2.29	4.07
Private homeowner	2.37	3.94	3.22	2.44	3.52
Local Business Owner	2.41	3.94	3.67	2.44	3.81
Organizations (NGOs)	2.94	3.91	2.82	2.55	3.97

Finally, the summary of this project for WAM method can be shown in the Table 9 and Figure 3. For these groups of stakeholders, using WAM method, infiltration practices and vegetated filter strip can be chosen as the best techniques. Also, according to stakeholders' preferences and main criteria, green roof and constructed filters are not recommended here. Selection of permeable pavement, level spreaders and bioretention heavily depend on stakeholders' preferences.

Table 9
Rating of alternatives (WAM method)

	Bioretention	Vegetated Swale	Vegetated Filter Strip	Permeable Pavement	Rainwater Harvesting
Worst	8	7	2	8	8
Best	4	6	1	3	4
Average	5.83	6.17	1.67	5.50	5.83
	Green Roofs	Infiltration Practices	Level Spreaders	Constructed Filter	Soil Restoration
Worst	10	3	8	10	5
Best	7	1	3	9	1
Average	9.17	1.67	5.50	9.5	2.67

3.2. Preference Ranking Organization Method (PROM)

As we can see in the Table 10 and Figures 4 and 5, infiltration practice is still the best technique for municipal government. However, from PROM method, green roofs have the lowest score. Vegetated filter strip and infiltration practices have the highest score among LIDs for the most of stakeholders. In other side, green roofs and constructed filters have the lowest score for different group of stakeholders, respectively.

Table 10
Scores of alternatives for selected stakeholders (PROM method)

Stakeholders	Bioretention	Vegetated Swale	Vegetated Filter Strip	Permeable Pavement	Rainwater Harvesting
Municipal governments	-0.04	-0.21	0.27	-0.05	0.04
Building and Land Developers	-0.25	-0.21	0.35	0.23	-0.13
Planner	-0.25	-0.21	0.41	0.30	-0.25
Private homeowner	-0.14	-0.25	0.36	0.03	0.00
Local Business Owner	-0.31	-0.31	0.53	0.19	-0.11
Organizations (NGOs)	0.05	-0.30	0.39	-0.16	0.02
Stakeholders	Green Roofs	Infiltration Practices	Level Spreaders	Constructed Filter	Soil Restoration
Municipal governments	-0.41	0.54	-0.05	-0.30	0.23
Building and Land Developers	-0.54	0.46	0.25	-0.38	0.21
Planner	-0.50	0.32	0.29	-0.50	0.39
Private homeowner	-0.47	0.50	0.06	-0.36	0.28
Local Business Owner	-0.56	0.39	0.25	-0.50	0.42
Organizations (NGOs)	-0.32	0.41	-0.18	-0.45	0.55

Finally, the summary of this project for PROM method can be shown in the Table 11 and Figure 6. For these groups of stakeholders, using PROM method, vegetated filter strip and infiltration practices can be chosen as the best techniques. Using PROM method, rank of vegetated filter strip is more variable compared to WAM method. Also, according to stakeholders' preferences and main criteria, green roof is not recommended here. The installation of the green roofs has very little impact on the overall watershed response.

Table 11
Scores of alternatives for selected stakeholders (PROM method)

	Bioretention	Vegetated Swale	Vegetated Filter Strip	Permeable Pavement	Rainwater Harvesting
Worst	8	8	3	6	7
Best	4	6	1	4	4
Average	6.33	7.33	1.83	5.00	5.67
	Green Roofs	Infiltration Practices	Level Spreaders	Constructed Filter	Soil Restoration
Worst	10	3	7	10	5
Best	9	1	3	9	1
Average	9.67	1.83	4.83	9.17	2.67

4. Summary And Conclusions

As stated previously, the purpose of this project was to investigate the concerns held by each stakeholder group for implementing LID practices. Characteristics and project objectives should be considered as the main influential factors in the planning, design, and construction of LID techniques. Averaged across the group, infiltration practices and vegetated filter strip received the best ratings, while green/living roofs and constructed filters came in last. However, other techniques received ratings more than 3 out of 5 from WAM method (performing well), and no techniques averaged lower than a 2.29. It is also important to note how the stakeholders rated each technique. For example, it appears that there is a general consensus on how vegetated filter strip and infiltration practices would perform here, while there is little consensus on bioretention, level spreaders and porous pavements. The ratings showed that the majority of stakeholders thought most of LIDs would perform well (score of more than 3). Generally, many agreed that all techniques are feasible if used in the intended climate and in proper functions [7]. Overall, there are some concerns and recommendations which should be considered. First, including LID combinations in the analysis can be highly relevant. Second, note that the land-use cover and construction constraints can play an important role as some LIDs are only suited for some specific urban context [9]. Third, the watershed modeling should be done to calculate the performance of each LID alternative. Finally, several sub-criteria were considered but eliminated due to the inability to find proper data on the corresponding metrics. The improved understanding of key elements of LIDs provides a background for planners, designers, engineers and stormwater managers to begin the site planning process to achieve stormwater management requirements.

5. Declarations

Acknowledgments

The author thanks Dr. Sybil Sharvelle for her helpful ideas during the preparation of this study.

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Figures

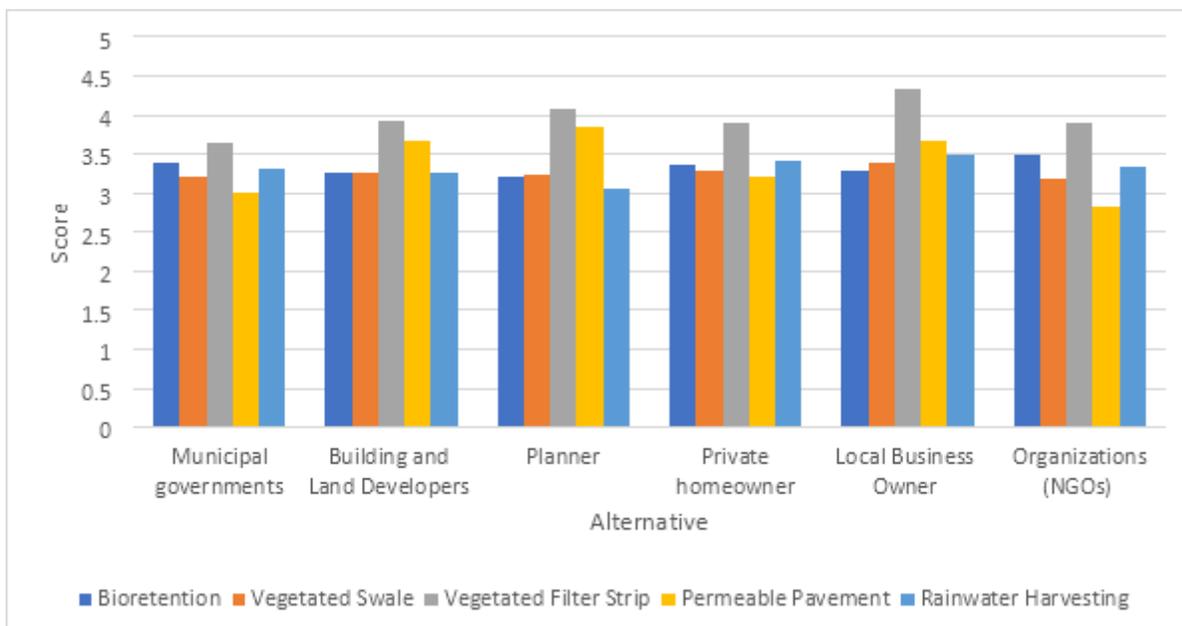


Figure 1

Scores of first five alternatives for selected stakeholders (WAM method)

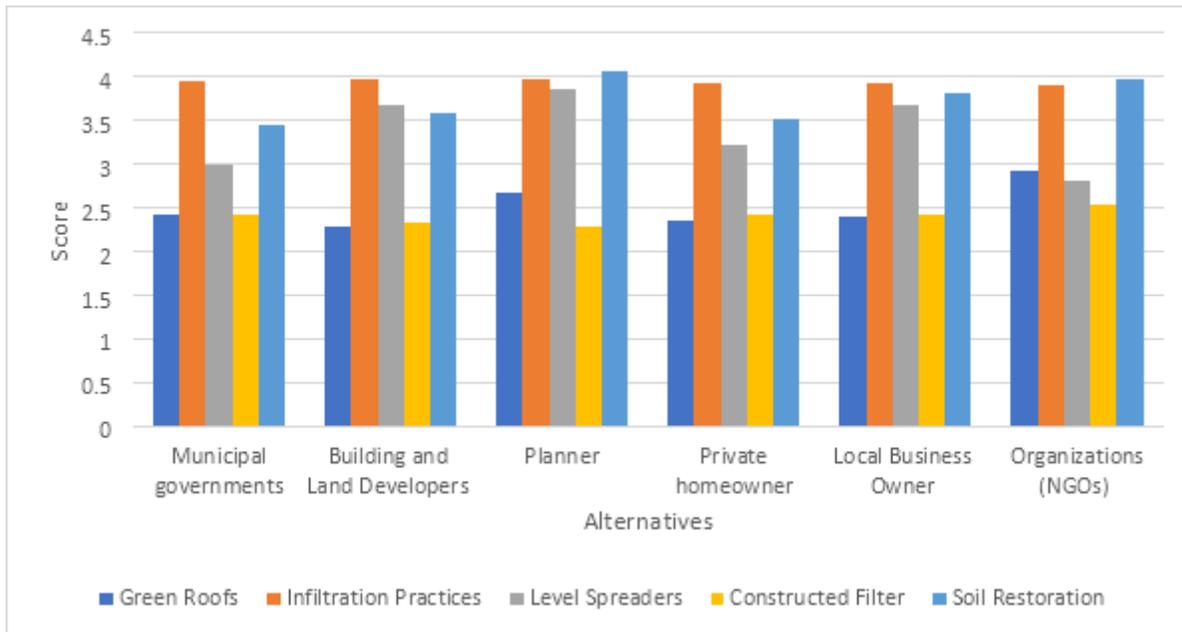


Figure 2

Scores of second five alternatives for selected stakeholders (WAM method)

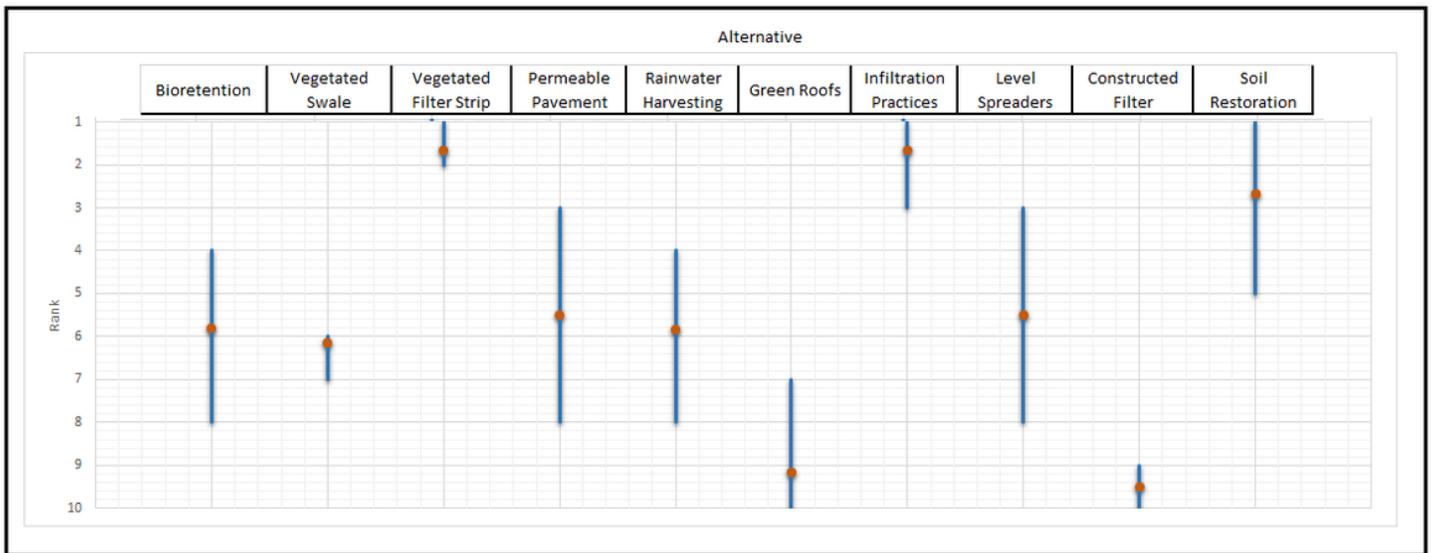


Figure 3

Rating of alternatives (WAM method)

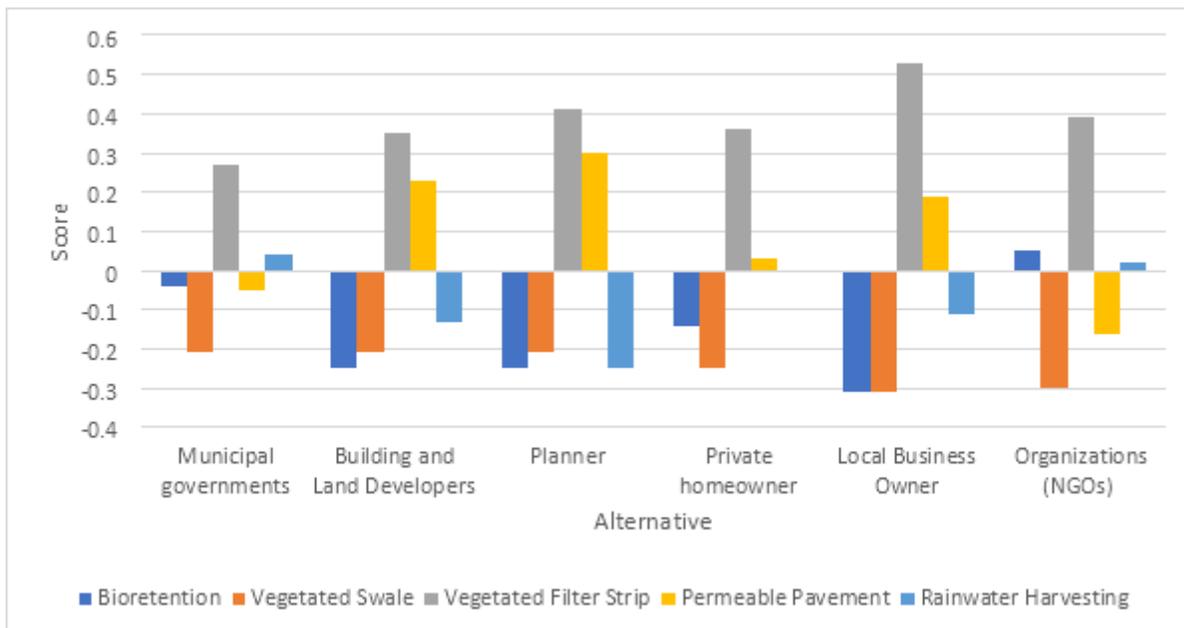


Figure 4

Scores of first five alternatives for selected stakeholders (PROM method)

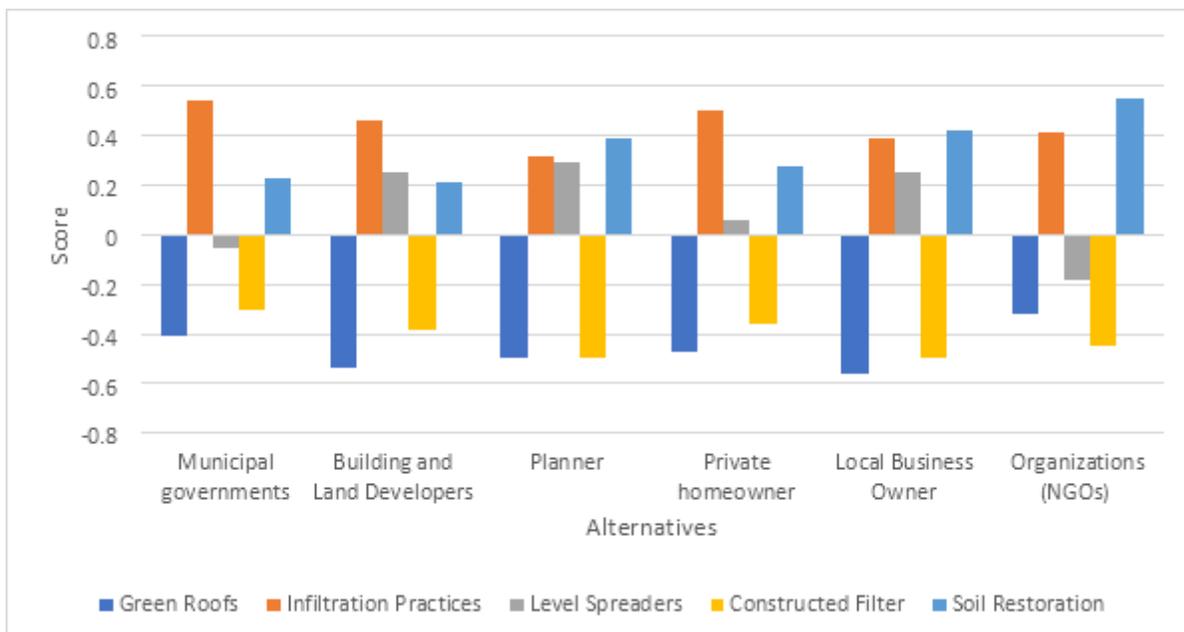


Figure 5

Scores of second five alternatives for selected stakeholders (PROM method)

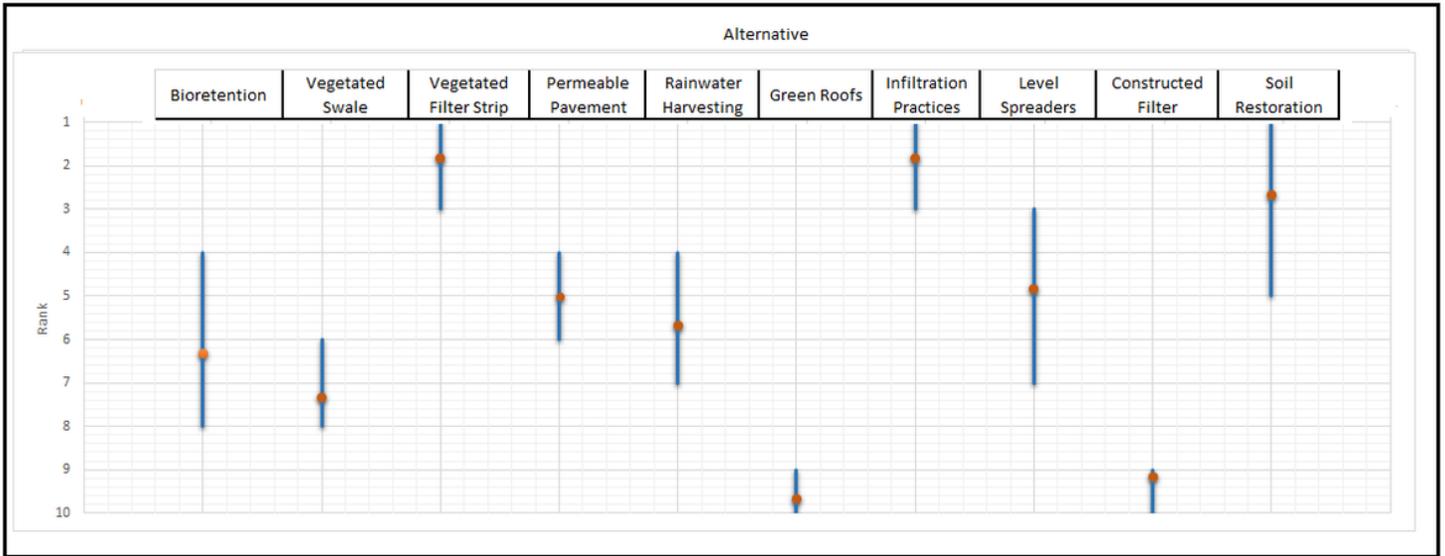


Figure 6

Rating of alternatives (PROM method)

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