Proceedings of Science and Mathematics
Faculty of Science, Universiti Teknologi Malaysia
Vol. 3, 2021, page 121-129

Best Location for Rainwater Harvesting Sites using Analytical Hierarchy Process

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Abstract
Rainwater harvesting can be an alternative source of water to overcome the insufficient water problem as the amount of rainfall in Malaysia is abundant. The objective of this research is to identify the best location for rainwater harvesting sites to maximize the amount of rainwater catchment and minimize the set-up cost. In this study, a method from Multi-Criteria Decision Making is used that is Analytical Hierarchy Process.
Keywords: Rainwater Harvesting Sites; Analytical Hierarchy Process; Location Analysis; Multi-Criteria Decision Making.

1 Introduction

The major factor of water disruption in Malaysia is river contamination. It forces the shutdown of water treatment plant. Moreover, growing of human population is expected to reach 8000 million by 2025 and effect of climate change, only worsen the pressure on water resource supplies [1]. Hence, we need to be prepared before the problem becomes severe. In order to overcome the water disruption problem and to meet the water demand, rainwater harvesting (RWH) is seen to be an alternative source of water. For this, the best location for the system to be built needs to be determined. This is a study under location analysis. Location analysis is used when we want to find location, expand or relocate an operation [2]. Criteria and factor should be determined to choose the best location for rainwater harvesting unit. Decision will be made based on priority given for the factors and criteria. The priority for each criterion can be modeled using analytical hierarchy process (AHP).

The remainder of this article is organized in the following order: Section 2 presents the literature review. The methodology used in this study is discussed in Section 3. In Section 4, numerical simulations of the model are performed, and the results are also presented. Section 5 provides the concluding remark of this study.

2 Literature Review

2.1 Location Analysis

According to ReVelle & Eiselt [3], location analysis relates to the formulation and solution of a group of problems that can be described as placing a facility in a given space. Murray [4] stated that choosing location is a necessary process for private firm and public agencies. The basis to start a project or build a building is to ensure that the location is suitable and strategic so it can be accessible to the society. Hereby, location analysis is the study and development of models, techniques, and tools to provide decision makers with good solutions to realistic locational decision problems. Initially, location problem focused more on minimizing the simple cost-distance of location but as time goes by it is widely used for various purposes. In past twenty years, the number of people with background in academic and business has attracted to facility location decision. Many large corporations even warrant a full-time executive to do site selection [5].

Location analysis helps in solving several location problems including locating and designing airports [6]. It helps in deciding the best area for airport to be built that is close to metropolitan region and also near to industrial areas, residential and commercial that can utilize it services.

Location analysis also helps to determine the suitable location to start a business. Location selection is one of the business decisions that have to be made carefully. There is a research carried out to study the relationship of business location and business success and it is proven that by choosing the best location for a business shows a significant impact for a business to succeed [7].

Some researchers used location theory to identify the gap in agriculture industry [8]. In their conclusion, it was stated that they are a lot of models that are significantly successful, but a new model needs some development to catch up with the demand nowadays. Hence, the location analysis is a comprehensive way to deal with it, which it can completely optimize the warehouse location, the supply chain, capacity of the agriculture production and ship among the suppliers. It covers almost all the aspect in the agriculture industry. However, there are research that only focus on warehouse problem. In determining the optimal location, the warehouse may stay at the same location or be relocated using location analysis in a straightforward way depending on the profit return [9].

Location problems have captivated researchers' attention from various backgrounds such as industrial engineering, economics, and geography [10]. Location analysis has been acknowledged as an important tool in identifying the location in manufacturing. Manufacturing industry nowadays is quite competitive in terms of cost of operation, performance of delivery speed, and flexibility of firm to compete in this marketplace. Thus, it is an advantage to use location analysis method as a strategy to compete in the industry [5].

2.2 Analytical Hierarchy Process

The Analytical Hierarchy Process is a strong and effective tool for dealing with complex decision-making developed by Saaty [11]. AHP generates weight for each considered criterion according to the decision-makers pairwise comparisons of the criteria. The higher the weight shows the priority given to the criteria compared to other criteria. After fixing the weight to the criteria, AHP assigns a score to each option according to the decision maker's pairwise comparisons of the options based on that criterion. Lastly, the AHP combines the criteria option scores and weights to determine the global score and the ranking of the alternatives. The summary of basic AHP is:

(1) Structure a decision problem and select some criteria.
(2) Set the priority criteria by pairwise comparison (weighing).
(3) Pairwise comparison of options on each criterion (scoring).
(4) Calculate an overall relative score for each rank and option.

2.3 Application of Analytical Hierarchy Process

There are some real-world problems that have been dealt using AHP for example to determine the transhipment port location [12]. In the research paper, they compared 20 ports with four main attributes and 12 sub-criteria with the objective to explore the critical criteria where they could focus more on the strategy of transhipments market.

Besides, AHP approach was also applied to a clothing store case study to identify the location that have the highest potential among the alternative selected location [13]. The aim of the study is to fulfill the retailers need and assist the manager to decide on the location of the store. Moreover, AHP is also able to locate the location of logistic center [14]. This study helped to develop and plan the construction or replacement of new logistic center that has complex logistic system connecting the production and consumption.

Another application of AHP is for location of pedestrian zones in Canada [15]. The case study was to find safe environment and a suitable pedestrian zone for area that have a lot of people to visit such as mall and park. The purpose of the study was to reduce traffic and walking distance. The approach that the researchers used was to identify the criteria for pedestrian zone, then identify the alternative zones and finally applied the Multi-Criteria Decision Making (MCDM) method that is AHP for the problem.

2.4 Rainwater Harvesting System

Rainwater harvesting system is the process where the rainwater will be collected directly from the rainfall from the roof or a specific building for the purpose of catching the rainwater. The catchment area may be a natural surface, man-made surface or rock catchment for domestic use such as agriculture and environment use [16]. The RWH can be categorized into three categories that are small, medium and large scale [17] and the size is determined based on the catchment area of the rainwater [18]. Scientifically, rainwater harvesting refers to the collection and storage of rainwater and the pursuit of other activities such as preventing lost water through evaporation and seepage and conducting studies and engineering interventions related to water resources [19].

Rainwater has been used from decades ago when people particularly have no technology during those difficult time [20]. According to [20], the people from the past decade mainly collect the rainwater by using guttering, collect on the surface and water store. Among all the methods, guttering is the cheapest way to collect water however this method is always been neglected. Rooftop is also one of the places that can be considered a surface and infamous way to collect the water [18]. Several countries have begun using rainwater harvesting systems to meet increasing water needs, including the U.S., Japan, China, India, Germany and Australia. By integrating rainwater harvesting systems with existing conventional water supply systems, demand will be met and the supply will be more sustainable.

2.5 Related Works on Analytical Hierarchy Process

One of the related works associated with the study is in identifying location of rainwater harvesting sites for the sustainable management of a semi-arid watershed [21]. They concluded that the key factor to build rainwater harvesting site is by selecting a suitable structure for a specific location and their optimal planning. Since the construction of rainwater catchment structures is expensive, their site selection needs to be precise.

Another related work used AHP to determine the location of dam in Iran [22]. Using AHP helps to choose the suitable place for a dam with multiple choice of criteria. There are many factors in determining the best site for dam such as geology, land use, sediment erosion, slope, groundwater, discharge, soluble sodium percentage, total dissolved solid, potential of hydrogen, and electrical conductivity of water. AHP assists the researcher to rank the criteria and able to check the consistency of the weight that they have been assigned. In addition, a recent research [23] used AHP to identify site suitability for river catchment. This method is used for weighted sum and helps the researchers to rank the location of water conservation from most suitable location, moderately suitable, less suitable and not suitable based on the factors and criteria that have been selected. Other interesting application of AHP in solving location problem is selecting optimum site for rainwater harvesting in the Wadi Horan region of Iraq. [24] used AHP to locate the best location for RWH to overcome the severe water shortage due to lack of water resource management and planning. From the studies, they found that AHP is an effective method to use when making decisions about water resource management.

As seen from the works, location analysis and AHP were used when dealing with problem that takes into consideration some factors or criteria before deciding and choosing the best location.

3 Methodology

3.1 Selection of Criteria

Criteria is a requirement and benchmarks used as a basis for a decision [25]. Constraints and factors are types of criteria. Factor is a criterion that increase the suitability of the distinct alternative for the problem based on the condition, for example amount of rainfall. When the amount of rainfall is high it indicates that it is most suitable otherwise it is considered as least suitable. While constraint acts as a limit to the alternative under consideration. Restriction area can be classified as the constraint for example location that is near to chemical factory and preserve forest. These locations are the place that need to be avoided in this research. Constraints and factors will be decided and chosen by referring to previous studies on site selection done by other researchers for facilities of rainwater management and data availability. This study will focus on the evaporation index, sediment index, hydrology index and economic index. Evaporation index consist of evaporation. While sediment index includes the soil types and land use. Under economic index there are road accessibility and distance to water treatment. Whereas, amount of rainfall and air quality are considered for hydrology index. Figure 1 gives the AHP model of the study.

3.2 Data Collection

The data that are required in this study are amount of rainfall, air quality, evaporation, status of the land, soil type, distance of location to the road and distance of location to water treatment.

In this study, the data are obtained from the Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia and some are taken from open resources such as Google Map and Air Pollutant Index of Malaysia (APIMS). The rainfall data obtained are the average monthly data from year 1980-2012. This research uses the annual data taken from 4 different rainfall stations that are Tadika Kemas Kampung Tanjung Sepat, Sungai Sedu, Rancangan Tanah Belia Bukit Changgang and Ladang West Pulau Carey. Evaporation data consists of daily evaporation rate in millimetre. For this research, only the the annual data from 1997 until 2001 are used. An assumption is made that all the alternative location has the same evaporation rate to avoid bias. The type of soil and status of the land is collected from Open Street Map. The distance of the location from the road and water treatment is calculated in kilometer using Google Map tools.

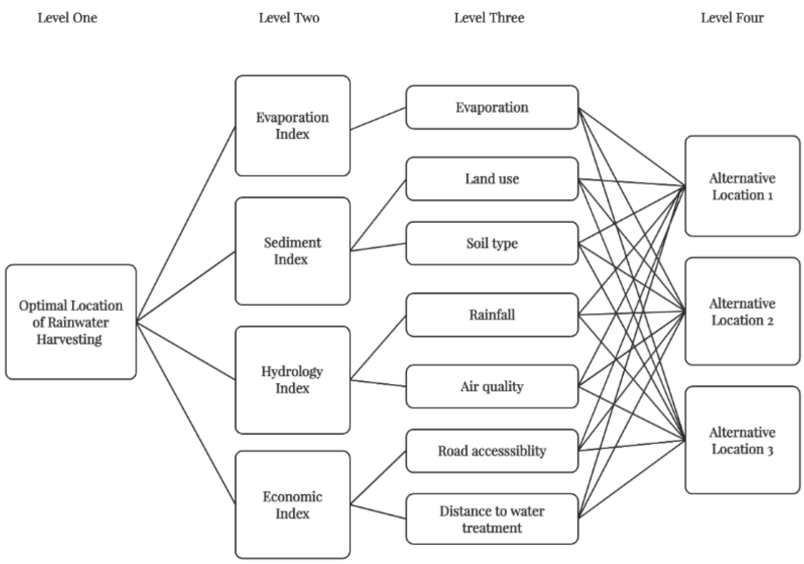

Figure 1: AHP Model

3.3 Standardization of the Criteria

Specified score need to be determined by standardizing the scale. This study classifies the criteria into 9 value of importance scale. The score will be defined as 9 for extremely important and 1 equally important. Table 1 shows the relative score that is used in this study.

Table 1: Table relative score

Value of a_{ij}	Definition of Importance Scale
1	i **and** j **equally important**
2	i equally to moderately important than j
3	i moderately important than j
4	i moderately to strongly important than j
5	i strongly important than j
6	i strongly to very strongly important than j
7	i very strongly important than j
8	i very strongly to extremely important than j
9	i extremely important than j

3.4 Criteria Weighting

Each of the factors is weighted according to level of importance in determining a location. This study will use the pairwise comparison (PC) method in deciding the weight. Table 2 shows example on how to find the pairwise matrix based on the importance scale of each criterion.

Table 2: Pairwise comparison matrix

	Criterion 1	Criterion 2	Criterion 3
Criterion 1	$\frac{\text{Criterion 1}}{\text{Criterion 1}} = 1$	$\frac{\text{Criterion 1}}{\text{Criterion 2}} = \frac{5}{1}$	$\frac{\text{Criterion 1}}{\text{Criterion 3}} = \frac{4}{1}$
Criterion 2	$\frac{\text{Criterion 2}}{\text{Criterion 1}} = \frac{1}{5}$	$\frac{\text{Criterion 2}}{\text{Criterion 2}} = 1$	$\frac{\text{Criterion 2}}{\text{Criterion 3}} = \frac{1}{2}$
Criterion 3	$\frac{\text{Criterion 3}}{\text{Criterion 1}} = \frac{1}{4}$	$\frac{\text{Criterion 3}}{\text{Criterion 2}} = \frac{2}{1}$	$\frac{\text{Criterion 3}}{\text{Criterion 3}} = 1$
Sum	$1 + 0.2 + 0.25 = 1.45$	$5 + 1 + 2 = 8$	$4 + 0.5 + 1 = 5.5$

Then the normalized pairwise matrix is calculated, where all the elements of the column are divided by the sum of the column shown in Table 3.

Table 3: Normalized pairwise matrix

	Criterion 1	Criterion 2	Criterion 3
Criterion 1	$\frac{1}{1.45} = 0.6897$	$\frac{5}{8} = 0.6250$	$\frac{4}{5.5} = 0.7273$
Criterion 2	$\frac{0.2}{1.45} = 0.1379$	$\frac{1}{8} = 0.1250$	$\frac{0.5}{5.5} = 0.0909$
Criterion 3	$\frac{0.25}{1.45} = 0.1724$	$\frac{2}{8} = 0.2500$	$\frac{1}{5.5} = 0.1818$

Then, calculate the criteria weights by finding the average value of each row. Table 4 is the value for criteria weight.

Table 4: Criteria weight

	Criteria weights
Criterion 1	0.6807
Criterion 2	0.1179
Criterion 3	0.2014

3.5 Finalized Score

Weighted Linear Combination (WLC) is used to calculate the total suitability index for all the factors. Equation 1 defines SI as

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

where SI is defined as the suitability index and W_i is the weight that is assigned to factor i and S_i is the standardized suitability for criterion i. Table 5 is the value for the standardized suitability index for this example.

Table 5: Standardized suitability

Alternative / Criteria	Criterion 1	Criterion 2	Criterion 3
Location 1	$\frac{200}{250} = 0.8$	$\frac{16}{32} = 0.5$	$\frac{12}{16} = 0.75$
Location 2	$\frac{200}{200} = \mathbf{1}$	$\frac{16}{32} = 0.5$	$\frac{8}{16} = 0.5$
Location 3	$\frac{200}{300} = 0.6667$	$\frac{32}{32} = 1$	$\frac{16}{16} = 1$

$$\text{Location 1} = (0.8 \times 0.6807) + (0.5 \times 0.1179) + (0.75 \times 0.2014) = 0.7546$$
$$\text{Location 2} = (1 \times 0.6807) + (0.5 \times 0.1179) + (0.5 \times 0.2014) = 0.8404$$
$$\text{Location 3} = (0.6667 \times 0.6807) + (1 \times 0.1179) + (1 \times 0.2014) = 0.7731$$

For this example, Location 2 is the best location since the suitability index is higher than the other locations with the value of 0.8404.

4 Results and Discussion

Table 6 is the data that has been collected during the research also known as the value of criteria for the alternative locations that have been identified suitable for rainwater harvesting. Kuala Langat area is taken as the case study. The numerical simulation is divided into three cases. For the first case, the weight is given equally between the four main criteria as shown in Table 7. The second case gives priority to Hydrology Index as shown in Table 8 while the last case gives priority to Economic Index as shown in Table 9.

Table 6: Value of Criteria

	Bukit Changgang	Tanjung Sepat	Teluk Panglima Garang	Tanah Pertanian Jugra
Rainfall average monthly (mm)	139.5833	177.4167	169.9167	185.25
Air quality (API)	53	70	60	60
Evaporation annually (mm)	118.76	118.76	118.76	118.76
Land use (status)	Palm plantation	Palm plantation	Palm plantation	Palm plantation
Soil type	Clay	Clay	Flat	Flat and sandy

	Bukit Changgang	Tanjung Sepat	Teluk Panglima Garang	Tanah Pertanian Jugra
Distance to road (m)	210.44	391.7	182.36	308.61
Distance to treatment water (km)	5.84	14.83	16.81	19.58

Table 7: Weight of criteria

	Weights
Evaporation	0.25
Sediment	0.25
Hydrology	0.25
Economic	0.25

Table 8: Criteria weight

	Criteria weight
Hydrology	0.5579
Evaporation	0.1219
Sediment	0.2633
Economic	0.0569

Table 9: Criteria weight

	Criteria weight
Economic	0.5579
Sediment	0.1219
Hydrology	0.2633
Evaporation	0.0569

The results from AHP calculation shows that for the equal weight of main criteria and the third case that weightage is heaviest on economic index the best location is at Bukit Changgang. It shows that Bukit Changgang fulfils most of the criteria and compliment with each characteristic of RWH. Furthermore, the location minimizes the cost of RWH as the site has the shortest distance to the main road and water treatment. Then, the results when the priority is given to hydrology index, is at Tanjung sepat where the amount of rainfall is the largest compared to the other alternatives location and that achieve the objective of finding the location that catch a large amount of rainwater. The result comparison is given in Table 10.

Table 10: Ranking

	Rank		
Alternative Location	**Case 1**	**Case 2**	**Case 3**
Bukit Changgang	**1**	**4**	**1**
Tanjung Sepat	**2**	**1**	**3**
Teluk Panglima Garang	**3**	**3**	**2**
Tanah Pertanian Jugra	**4**	**2**	**4**

5 Conclusion

In finding the best location for rainwater harvesting sites, this study utilizes AHP with Hydrology Index, Economic Index, Evaporation Index and Sediment Index as the criteria AHP helps to decide which criteria need to be focused more, and the decision maker can determine and allocate suitable score to the criteria based on the objective.

In this study, three cases involving different weight allocation to the criteria are considered. The weight is given based on the objective that want to be fulfilled. From the result of AHP, it can be seen that the weight given to the criteria plays an important role in determining the best location of the rainwater harvesting sites.

For future study, it is recommended that other factors and criteria to be taken into consideration in determining the best location for rainwater harvesting sites. For example, may consider the slope of the land, the pH value of the water, the soil depth drainage density.

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