Developing a Sustainable Solid Waste Management System Using Analytical Hierarchy Process (AHP) Method at Pondok Institutions in Kelantan

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Abstract. This study focuses on developing a sustainable solid waste management system at Pondok institution using the Analytical Hierarchy Process (AHP) method. Besides that, the types of solid waste generated were determined. Three alternatives were underlined, which are composting, recycling, and both composting and recycling. This research utilised the convenience sampling method, where a constructive questionnaire was used as a research instrument. An online questionnaire with detailed descriptions was distributed to two (2) Pondok institutions in Kelantan. After that, empirical research using the AHP method was carried out to find the priority weights of alternatives to develop a sustainable solid waste management system in Pondok institution. There are two significant findings in this research. This research revealed the types of solid waste generated by Pondok institutions that are food waste/ farm waste, plastics, papers, metal and aluminium tin, and glass. The highest types of solid waste generated are organic waste, and the least is glass. Besides that, this research discovered the most appropriate sustainable solid waste management system alternative to be implemented in Pondok institutions, which is composting and recycling. Developing a sustainable solid waste management system will reduce excessive solid waste generation, reduce space for dumping sites, and overcome environmental problems.

1. Introduction

Human has been generating wastes since ancient time. Initially, the waste produced was just organic-based wastes which did not cause substantial environmental problems. However, with civilization's progress, humans began to produce more non-environmentally friendly and toxic wastes, contributing to environmental impacts. Abd Ghafar [1] reported that Malaysia's overall waste composition was delegated into 64% of municipal solid waste (MSW), 25% of industrial waste, 8% of commercial waste, and 3% of construction waste. Most of the wastes produced are biodegradable, such as food and paper [2, 3]. Furthermore, approximately 80% of the MSW is recyclables and disposed of in the landfill without any pre-treatment [1].

In 2006, the amount of municipal solid waste generated in the Kota Bharu, Kelantan were approximately 146 tonnes/day [4]. Meanwhile, in 2009, Kelantan has generated approximately 1423...
tonnes/day of wastes, increasing by more than 90% every ten years. This waste was produced from various sources, namely, domestic, commercial, and private or public institutions. Moh and Manaf [4] stated that primary sources of MSW are household, followed by the institutions and commercial area. The education institutions (EI), including the Islamic education institutions known as the Pondok institution (PI), are part of the MSW contributors. In the last few decades, education institutions have faced challenges in executing sustainable solid waste management (SSWM) practices, demanding environmentally friendly systems and practices [5]. Implementing the SSWM practice is a daunting task because it encompasses all stakeholders, including students, staff, and surrounding people [6, 7].

Various studies worldwide reported the implementation of the SSWM in EI. However, most of them were focusing on the execution of recycling and reducing resources programs. In addition, most of the studies conducted were focusing on the institution of higher education. Hence, the Pondok institutions have been focused on this research. This research is designed (i) to determine the types of solid waste generated by the community of Pondok institutions, and (ii) to develop a Sustainable Solid Waste Management System (SSWMS) in Pondok institutions in Kelantan using the Analytical Hierarchy Process method.

2. Materials and Methods

2.1. Research Area
The research area chosen for this research is Kelantan, which located in the northeast of Peninsular Malaysia. Kelantan is bordered by Terengganu, Pahang, and Perak. The geographical coordinates for the research area are latitudes 4° 30' - 6° 5' North and longitude 101° - 102°45' East. Kelantan is managed by ten administrative jurisdictions that are Kota Bharu, Pasir Mas, Tumpat, Pasir Puteh, Bachok, Kuala Krai, Machang, Tanah Merah, Jeli, and Gua Musang. Each district has at least one Pondok institution. However, 2 Pondok institutions were involved in this study.

2.2. Research Instrument
This research adopted a self-administered questionnaire as a research tool. It utilised the simple Malay language to help the respondents understand the question easily because some respondents do not have a basis in English. Most of the questions were close-ended questions, and some were open-ended questions. The questionnaire form was adapted and adopted from a few studies by Samah et al. [8]. The questionnaire consists of four sections, that is Section A; Socio-economic profile of respondent and types of wastes generated daily, Section B; Pairwise Comparison between Criteria and Goal, and Section C; Pairwise Comparison between Criteria and Sub criteria, and lastly is Section D; Pairwise Comparison between Alternatives and Criteria. Three alternatives were considered in this study, which is composting, recycling, and recycling and composting. The scale ranges used for pairwise comparison values were referred to the Saaty’s ratio scale [9].

2.3. Validity Test
In order to ensure the questionnaire is representative and appropriate to use, a validity test was designed and conducted. The validity analysis was conducted using the content validity analysis [10]. Referring to Yusoff [11], six necessary steps were used to conduct this test, and the rating scale of relevance applied in this research was referred to as the scale. The acceptable CVI values for the two experts are at least 0.80. The CVI values obtained in this research are 0.89, which is greater than 0.80. Thus, the CVI values obtained are in an acceptable value, and the questionnaire is valid to be used for the survey.

2.4. Data Collection

2.4.1. Sampling Technique. The data used in this research are the primary data collected from the survey in the Pondok institutions. The data were collected utilizing a non-probability or convenience sampling method [12]. An online questionnaire was created using Google form (online survey tools). After the
questionnaire was validated, the Google form link was distributed to the sample population thru online platforms such as email and other social media like Facebook and Telegram.

2.4.2. Sample Size Determination. The respondents of this research are the community of Pondok institutions. Abidin et al. [13] stated that the population of Pondok institution is approximately 200 persons. In this research, 2 Pondok institutions were involved, resulting in the estimated population become approximately 3000 persons. According to Krejcie and Morgan [14], the sample size for a 3000-population size is 341. Nevertheless, throughout the research, the number of respondents obtained is only 105, which is less than the targeted amount. In proportion to the thumb rule, the minimum sample size to ensure that the sample is representative is at least sample size; \( n = 30 \) [15]. Therefore, since 30 persons exceed the number of respondents obtained, it is considered as under acceptable values.

2.5. Data Analysis
The Analytical Hierarchy Process (AHP) method has been adopted as a technique for data analysis. Samah et al. [8] stated that AHP is a suitable technique to select the most appropriate and efficient solid waste management system. It is designed to solve a multi-criterion in several application domains. The AHP methodology has divided into four significant steps that are; (i) structure the decision into objectives and alternatives by developed a General Hierarchy Structural Model (GHSM); (ii) measure the objectives and alternatives utilizing pairwise comparison; (iii) synthesize priority; also, (iv) exploit subjective inputs to reach a prioritised list alternative [16]. Figure 1 shows the GHSM for this research. The development of the GHSM has been done by revisions and references from various secondary sources, such as journals, and articles on waste management.

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![Figure 1. The general hierarchy structural model](image)

In data analysis, a synthesis of priority involved the ranking process of the alternatives based on the criteria and sub-criteria of relatives to the goal. The respondent’s weights and scores were computed using Microsoft Excel. Initially, the data from the pairwise comparisons sections were inserted into the
Pairwise Comparison Matrix. The matrix was filled in to present the relative importance of one element to another.

A vector of composite weights is indicated as rankings to attain the decision problem’s main goal. Therefore, the priority weights were calculated by averaging all the elements in the row and divided with the number of the criteria. Then, consistency of the elements was calculated by multiply each value in the column with priority weights. Subsequently, the Eigenvector's value, consistency index (CI), and consistency ratio (CR) was calculated utilizing Eq. (1) to (3).

Eigenvector principle ($\lambda_{\text{max}}$) = \frac{1}{n} \sum_{i=1}^{n} \left( \sum_{j=1}^{n} a_{ij} \times w_j \right)  

(1)

Where, $\lambda_{\text{max}}$ is the maximal or Eigenvector principle, $n$ is matrix size, $a_{ij}$ is pairwise comparison matrix, $w_j$ and $w_i$ is the j and i elements for values of eigenvector.

Consistency Index (CI) = \frac{\lambda_{\text{max}} - n}{n-1}  

(2)

Consistency Ratio (CR) = \frac{CI}{RI}  

(3)

For the CR, the index random consistency (RI) value was referred to RI table by Saaty [17]. According to the rule of thumb, a CR value must not exceed 0.10 or 10% to obtain a consistent matrix and be considered as an acceptable value. After the CR was calculated, each criterion, sub criteria, and alternatives have been ranked according to the priority weights. Finally, the alternative score was calculated to determine which alternative are the most appropriate to be used.

3. Results and Discussions

3.1. Respondent’s Demographic

From the survey, the total number of respondents is 105, from two Pondok institutions in Kelantan, namely Pondok Pasir Tumboh Kubang Kerian and Pondok Ar-Rahmaniah Tumpat. The parameters used to determine the demographic data is gender, age group, residency area, position, and educational level. Table 1 shows the respondents’ demographic by all the Pondok institutions. Besides that, 39 respondents (37.1%) stayed in hostels, whereas five respondents (4.8%) and 61 respondents (58.1%) of the total respondents stayed in the warden’s hostel and their home. The majority of the respondents stayed in their home due to the spread of infectious coronavirus disease (COVID-19) situation, which caused many of the Pondok institutions to close. It has resulted in the inaccuracy of the information on the actual residency areas of the Pondok institutions population. However, approximately 37.1% of the respondents stayed in hostels, and 4.8% of them stayed in the wardens’ hostel. Thus, it can be concluded that 41.8% of 105 respondents are known as contributors to the solid waste generation in the Pondok institutions.

Table 1. The respondent’s demographic

| Demographic Features | Frequency (N) | Percentage (%) |
|----------------------|--------------|----------------|
| Gender               |              |                |
| 1) Male              | 46           | 43.80          |
| 2) Female            | 59           | 56.20          |
| Marital status       |              |                |
| 1) Single            | 89           | 84.80          |
| 2) Married           | 14           | 13.30          |
| 3) Divorce           | 2            | 1.90           |
| Age group (years old)|              |                |
| 1) < 18              | 45           | 42.86          |
Demographic Features | Frequency (N) | Percentage (%)  
--- | --- | ---  
2) 19-25 | 40 | 38.10  
3) 26-30 | 6 | 5.71  
4) 31-35 | 4 | 3.81  
5) >36 | 10 | 9.52  
Residency area  
1) Hostel | 39 | 37.10  
2) Warden house | 5 | 4.80  
3) Home | 61 | 58.10  
Position  
1) Student | 80 | 76.20  
2) Teacher | 12 | 11.40  
3) Staff | 10 | 9.50  
4) Others | 3 | 2.90  
Education level  
1) Primary school | 2 | 1.90  
2) Secondary school | 53 | 50.50  
3) Foundation/Matriculation | 2 | 1.90  
4) Diploma | 16 | 15.20  
5) Bachelor’s Degree | 30 | 28.60  
6) Others | 2 | 1.90  

3.2. Types of Solid Waste Generated by Pondok Institutions  
This research managed to determine the frequency and percentage of waste disposals, the types of solid waste generated by the respondents and the types of solid waste generated by Pondok institutions, and the waste management alternatives practised by the Pondok institutions been stated in Table 2. This information is essential to know the estimation of the amount of solid waste generated by the institutions.

As stated in Table 2, the types of solid waste generated by Pondok institutions are consists of food waste/farm waste (33.20%), plastics (26.17%), papers (24.61%), metal/steel/aluminium tin (9.38%), also glass (6.64%). The result indicates that organic compositions dominated waste generated in Pondok institutions: food and kitchen waste, farm waste, and other organic wastes.

Table 2. The types of solid waste generated by Pondok institutions.

| Types of Solid Waste Generated by Pondok Institutions | Frequency (N) | Percentage (%)  
--- | --- | ---  
Waste disposed per day  
1) 1 time | 23 | 21.90  
2) 2 to 4 times | 56 | 53.30  
3) 5 to 8 times | 18 | 17.10  
4) More than 10 times | 8 | 7.60  
Types of wastes generated  
1) Paper | 63 | 24.61  
2) Plastic | 67 | 26.17  
3) Glass | 17 | 6.64  
4) Metal / steel / aluminium tin | 24 | 9.38  
5) Food waste / farm waste | 85 | 33.20  

3.3. First Level Pairwise Comparison between Criteria and Goal  
The first level of the pairwise comparison indicates the criteria that are significant in developing a sustainable solid waste management system. There are five criteria involved in this research such as Environmental Aspects (EAS), Social Aspects (SA), Technical Aspects (TA), Economic Aspects (EA), and Administrative Aspects (AA). Based on the result obtained, the rank of priority weights for the
criteria is as follows: AA (0.30), EA (0.24), TA (0.19), SA (0.15), and EAS (0.12). The AA (0.30) is the most crucial aspect since throughout developing an SSWMS, effective and efficient management are vital to ensure the development, program complementation, and implementation of rules and laws are going smoothly as planned [18, 19]. Samsudin and Don [20] reported in their research, the development of SWM requires the existence of policies and regulations that contributed to the critical purpose of growth being accomplished, resulting in effective management as the foundations of SWM.

3.4. Second Level Pairwise Comparison between Sub criteria and Criteria
The sub-criteria of the system were consisting of eleven elements, that is Emissions and residuals (ER), Resource conservation (RC), Socially inclusive and acceptance (SIA), Stakeholder’s involvement (SI), Health (H), Technical expertise (TE), Appropriate technologies and facilities (ATF), Total cost (TC), Efficient and effective management (EE), Institutional and legislative support (ILS), also Location (L). The significant impacts of this stage are that all of the listed criteria will play essential roles and might affect the criteria above. Based on the results, the highest sub-criteria elements based on the priority weight fall to L with the 0.15 priority weights, whereas the least essential fall to ER with the priority weights of 0.04.

3.5. Third Level Pairwise Comparison between Alternative and Sub criteria
The third level of the pairwise comparison indicates the alternatives required to develop a sustainable solid waste management system. The alternatives that have been considered in this research were composting (A1), recycling (A2), and composting and recycling (A3). Based on the result, the highest priority weights of the alternatives fall to A3 with 0.49 priority weight. Both composting and recycling aim to minimize the flow of waste to landfills or dumpsites. Besides that, recycling and composting will help conserve natural resources, where recycling processes will reduce the consumption of natural resources, and composting will reduce the waste of natural resources [21]. Moreover, using recycled materials require less energy than new raw materials. Meanwhile, composting may generate energy by release methane gas during the decomposition process, which can be burned to produce energy [22].

3.6. Development of Sustainable Solid Waste Management System at Pondok Institutions
The alternative score was calculated to analyse the best alternatives that will be used to develop a sustainable solid waste management system at Pondok institutions. Based on the graph of the alternatives score in Figure 2, the order of rank for alternatives practices that can be adopted based on survey which is A3 (0.50), A2 (0.30), and A1 (0.21). The development of sustainable solid waste management system is crucial for Islamic educational institutions. The system developed is the important guideline for managing their solid waste properly. This system will ensure the smooth functioning of the organization and the system and enhance the use of appropriate techniques to manage the waste without contributing to other environmental issues.

![Graph showing the alternatives score of the SSWMS.](image)
4. Conclusion
This research has successfully determined the types of waste generated by Pondok institutions which is food waste and farm waste is the most waste generated. Besides, this research also discovered the most appropriate sustainable SWM system to be implemented in Pondok institutions. The first priority that need to be highlighted is the administrative aspect followed by economic, technical, social and environmental aspects. After that, the SWM system developed need to consider the location of the system first as compared to the other factors. This study also revealed that the integrated of composting and recycling could enhance the SWM system at Pondok institution. The findings of this study could be used as a guideline to Pondok institution to manage their waste generated properly. The development of the sustainable SWM system in Pondok institutions will reduce the excessive solid waste production and overcome the inefficient solid waste management system in that area. It will also help to reduce pollution generation and other environmental problems caused by the feeble and weak solid waste management system.

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