Research Article

Advance in Environmental Waste Management & Recycling

Selection of the Best Solid waste Management Yaounde using an Analytical Hierarchy Process

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Abstract
Municipal solid waste (MSW) management is one of the global challenges facing the world today in order to achieve development goals. This paper aims to structure MSW management problems into hierarchy to assist in decision making process in order to select the most appropriate MSW management strategy in Yaounde. The tool used is the Analytical Hierarchy Process (AHP), one of the multi criteria decision making techniques. From the synthesis of the decision/policy makers' judgements, the criteria "sustainable development" and "waste service quality" are the priority objectives that must be applied to MSW management system in Yaounde; and the alternatives "pre-collection" and "selective collection" are the suitable actions to integrate into the current MSW management system in Yaounde.

Keywords: Municipal solid waste, Analytical hierarchy process, Decision/policy makers, Multicriteria decision model JEL. Q53, Q58, D78, N57

Introduction
As the world hurtles toward its urban future, the amount of municipal solid waste (MSW) produced in municipalities is growing even faster than the rate of urbanization [1]. MSW generate today it is about 1.2 kg per person per day (1.3 billion tonnes per year). By 2025 this will likely increase to 4.3 billion urban residents generating about 1.42 kg/capita/day of solid waste (2.2 billion tonnes per year). MSW Management is defined as the discipline associated with control of generation, storage, collection, transport or transfer, processing and disposal of all materials (such as package, bottles, leftovers, newspapers, equipment, devices, batteries and dyes etc.) produced as a result of our daily activities in a way that best addresses the range of public health, conservation, economics, aesthetic, engineering and other environmental considerations. MSW management has been identified as one of the global challenges facing the world in order to achieve development goals [2].

Cameroon also faces a challenge of MSW management. Located at the central African country on the Gulf of Guinea, the country's surface area is 475,650 km². In 2016, its population was estimated to be 23,924,000. According to the World Bank (2012), the average waste generation in Cameroon is estimated to 0.77kg/capita/day [1]. The total daily production of MSW in Cameroon is currently estimated at around 6.5 million tons per year. Waste composition in Cameroon is 48% organics, 5% plastics, 4% papers and paperboards, 5% metal, 4% glass and 34% other wastes (textiles, inert, combustibles). According to Shekdar (2009), waste composition is influenced by economic status [3]. Composition impacts waste collection and disposal.

Yaounde, the capital city of Cameroon is divided into seven subdivisions and cover an area of 300 km² with a population estimated at 3,000,000 in 2016 (Fig. 1). In this city, MSW generation varies between 0.50 and 0.80 kg/capita/day depending on the seasons, with a mean of about 0.62 kg/capita/day [4]. The current total daily production of MSW in Yaounde is estimated at 2,000 tons. According to Ngambi (2015), waste composition in Yaounde is 70% organics, 8% plastics, 8% papers and paperboards, 4% glass, 2% textiles, 2% inert, 2% combustibles and 4% other miscellaneous wastes [5].

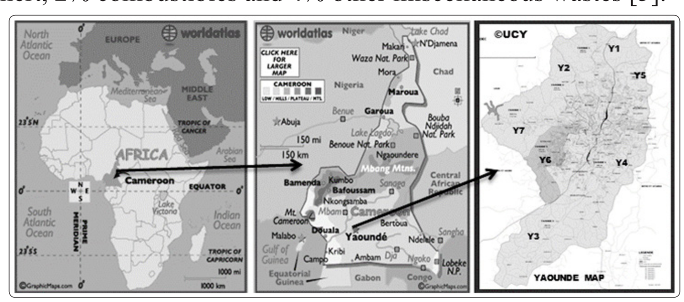

Figure 1: The Yaounde city, Cameroon

MSW management policy in Cameroon is based on a public-private partnership (PPP); and HYSACAM (Hygièneetsalubrité du Cameroun) is the private MSW management operator in 16 cities. Based in Yaounde and Douala, HYSACAM operates across the entire MSW management chain, from collection through to processing. It has 5,000 employees and a fleet of 500 vehicles. In Yaounde, HYSACAM operates an official landfill at Nkolfoulou, located 10 km away from Yaounde city centre. The landfill covers a 56 ha area. Since 1990 it has been used for disposal of more than 03 million tons MSW collected in the city [6].

MSW management practices in the Yaounde city include: collection and transportation with trucks (door-to-door collection) and communal waste containers (fixed-point collection), landfilling in Nkolfoulou, treatment of leachate and the capture and destruction of biogas. Recycling activities are informal and carried out by some NGOs and CBOs in swampy areas. Unfortunately, pre-collection(waste transfer form slums and swamp areas to fixed collection points using rudimentary tools), sorting and composting activities which are essential in the African context due to the high amount of organic waste, are not included formally in the current MSW management system in Yaounde; these are poorly practiced, but in the informal economy [7]. According to Mbue et al. (2015) and Sotamenou (2012) the MSW collection rate in the principal towns of Cameroon, Yaounde and Douala is between 47% and 53% [8,9]. Due to an inefficient collection, disposal and management system, MSW generated in Yaounde pile up continuously provoking a dirty, unaesthetic environment, water pollution, bad odours that cause air pollution and multiplication of flies that are carriers of diseases like malaria, typhoid, diarrhea and cholera [10]. May be these poor score (low rate of collection, lack of pre-collection, sorting and composting) are due to the current management system who have to be revised or improved.

The main objective of this paper is to structure MSW management problems into hierarchy to assist in decision making process in order to select the most appropriate MSW management strategy in Yaounde. In terms of priorities, it is first of all the vision for MSW management in the city, the major directions to be implemented by decision/policy makers, and then strategies to turn this vision into reality on the field.

This paper is organised into four sections, including this introduction. Section 2 presents the materials and details. Section 3 presents the results and finally, conclusions are presented in Section 4.

Materials and Methods

The selection of the best and appropriate MSW management strategy is based on a MCDM. In this study, we use AHP decision support tool based on an exponential scale to calculate the weight of each element. Compared to another MCDM tools, AHP decision support tool is the most widely applied method in the field of MSW management. The advantages of this method are the possibility to use qualitative and quantitative criteria, the ordered fashion of the decision making which allows a good traceability of the decision and the quality assurance given by the consistency indices.

Conceptual Framework: A Multicriteria Decision Model

MCDM refers to making decisions in the presence of multiple, usually conflicting, criteria [11]. According to Khalili and Duecker (2013), most decision analysis methodologies share similar steps of organizing data into a decision matrix, but they differ in synthesizing matrix information and ranking of the alternatives [12]. To deal with decision problems that involve both quantitative and qualitative considerations, MCDM can be used because it provides a systematic procedure to help decision makers identify desirable alternatives under uncertainty [13]. The procedure of applying MCDM consists to 4 major steps: identify the main goal of the process and the nature of the decision, identify a set of alternative solutions, and specify the criteria for evaluating the alternatives. After the alternatives and criteria are identified, the next step is to collect data from stakeholders, who can provide either quantitative or qualitative data on the problem.

In a public context, in order to select the most appropriate MSW management strategy, MCDM can be applied. In fact, decision/policy makers can decide to base their strategies on several criteria. For example, the priorities concerning MSW management in Cameroon are mentioned into a report entitled: "Waste Management Strategy Document of Cameroon (WMSD)". The WMSD, the official strategy on MSW management in Cameroon was elaborated in December 2007 with the participation of the public authorities, decentralized local council, economic operators and non-governmental associations (NGOs) and organizations (CBOs). According to the Ministry in charge of Environment, Nature Protection and Sustainable Development (MINEPDED) in Cameroon, the WMSD will help to improve access to pre-collection and waste collection services in the cities, improve waste management through the promotion of appropriate waste treatment, promote recycling and recovery methods, establish a sustainable system for the management of hazardous wastes produced by households, businesses and health institutions, promote incentives to encourage the voluntary commitment of stakeholders to the efficient management of waste, and finally to promote and strengthen international cooperation in the management of trans boundary movements of hazardous wastes. The WMSD is structured around three priorities: the guiding principles of the strategy, the institutional and legal framework and the strategic orientations.

Most of these guiding principles derived from the Law N° 96/12 of 05/08 1996 relating to Environmental Management in Cameroon. The guiding principles include in the WMSD are: principle of sustainable development, polluter pays principle, principle of waste management hierarchy, principle of waste service quality, principle of information and awareness, principle of the most practical environmental options, principle of proximity, principle of coherence and coordination, and principle of equity.

The WMSD presents also the institutional and legal framework for MSW in Cameroon. Manga (2008) summarizes the key statutory orders related to waste management in Cameroon [14].

The third priority of the WMSD presents the strategic orientations. These orientations concern in addition to household solid waste, industrial wastes, hospital wastes and inert waste. But for this study we just present strategic orientations on MSW management. The main orientations of the Cameroonian government about the MSW management include the following treatment options: prevention, valorisation and disposal. Prevention involves the following aspects: promotion of individual composting at local and national level, reducing the use of plastic packaging by citizen's behaviour, promoting the creation of dumpsite by decentralized local authorities, incentives for the creation of waste treatment companies. Valorisation includes composting and biogas valorisation. Transfer stations for waste will be created in collaboration with the decentralized local council and the administrations in charge of the environment and urban development. They should be environmentally friendly. As regards the waste disposal, it is a process involving collection, transport and land filling. Selective sorting or collection, pre-collection should be applied. Recycling and waste collection with trucks and containers also. Legal dumpsite will be built in all towns with more than 100,000 inhabitants. In resume many alternatives can be choose to achieve the goal mentioned in WMSD. We can cite: composting, pre-collection, waste collection by garbage container and trucks, selective selection, plastics prohibition, decentralised dumpsite.

All the problems which are considered above shared the following common characteristics: multiple alternatives (a Cameroonian government must generate relevant alternatives for each problem setting), conflict among alternatives (multiple alternatives usually conflict with each other), incommensurable units (each alternatives may have different unit of measurement), and design or selection (solutions to these problems are either to design the best alternative or to select the one among previously specified finite alternatives). The MCDM is therefore a suitable framework for this research.

AHP method

AHP is an effective tool for dealing with complex decision making, and may aid the decision maker to set priorities and make the best decision [15]. AHP can be considered as a theory of relative measurement with absolute scales of both tangible and intangible criteria based on the judgment of knowledgeable and expert people. Let us mention that AHP method is based on expert judgement. How to measure intangibles is the main concern of the AHP. According to Ramanathan (2001), Bertolini et al. (2006) and Saaty (2008), application of AHP to a decision problem involves four steps [16, 17, 18].

Step 1: Structure the Decision Problem into Objectives and Alternatives

The first step consist to structure the decision problem into a hierarchical model includes decomposition problem into elements according to their common characteristics. The formation of a hierarchical model has different levels. Each level in the hierarchy corresponds to the common characteristic of the elements in that level. The topmost level is the "focus" or "goal" of the problem. The intermediate levels correspond to criteria and/or sub-criteria, while the lowest level contains the "decision alternatives". For example, Figure 2 gives an illustration for a simple decision problem of choosing the most appropriate solid waste management strategy. The top-most level is the ultimate goal. The goal is characterized by several criteria and the second level indicates the alternatives. The criteria can be seen for example as the guiding principle or the priority objective; and the alternative represents the action to be taken to ensure that the adopted criterion is achieved. The criteria considered in figure 1 are C_1, C_2, C_3 and C_4. We can subdivide the criteria further if necessary. For example, C_1 may be subdivided into C_{11}, C_{12}, etc. The last level in figure 1 represents the alternatives. In the presence of more decision-makers (i.e. the persons from whom the judgements are elicited), we can introduce a level of decision-makers just below the goal.

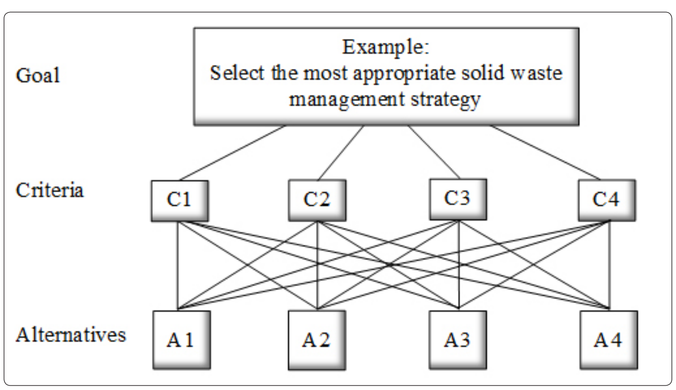

Figure 2: A sample of AHP model with four criteria and five alternatives
Source: The author

Step 2: Making Pair-Wise Comparisons and Obtaining the Judgmental Matrix

In the second step, the elements of a particular level are compared pair wise, with respect to a specific element in the immediate upper level. The comparison of any two criteria C_i and C_j with respect to the goal is made using questions type: "of the two criteria C_i and C_j, which is more important, relevant or preferred with respect to the ultimate goal?

In order to calculate the relative weight of the considered criteria, each criterion has to be compared to the others by the expert team; the expert judgement is displayed in a matrix. The method uses a scale with values ranging from 1 to 9. The possible values are presented in table 1.

Table 1: Saaty's ratio scale

Evaluation	Scale / Judgement
1	Equal importance of both elements
3	Moderate importance of one element over another
5	Strong importance of one element over another
7	Very strong importance of one element over another
9	Extreme importance of one element over another
2, 4, 6, 8	Compromises between the previous judgements
1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i

Source: Saaty (1977, 1980)

A judgmental matrix is formed and used for computing the priorities of the corresponding elements [15,19]. First, criteria are compared pair-wise with respect to the goal. A judgmental matrix, denoted as A, will be formed using the comparisons. Each entry a_{ij} of the judgmental matrix is formed comparing the row element A_i with the column element A_j :

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix}$$

a_{ij} represents the pair wise comparison rating between the element *i* and element *j* of a level with respect to the upper level. The entries a_{ij} are governed by the following rules:

$$a_{ij} > 0 \,;\ a_{ij} = \frac{1}{a_{ji}} \,;\ a_{ii} = 1 \ \forall i \,.$$

Because of the above rules, the judgmental matrix A is a positive reciprocal pair wise comparison matrix.

Step 3: local priorities and consistency of comparisons

Once the judgemental matrix of comparisons of criteria with respect to the goal is available, the local priorities of criteria are obtained and the consistency of the judgements is determined. The following performance calculation (λ_{max}) was used as a governance equation to find the maximum value of Eigenvector, consistency ratio CR, consistency index CI and normalized value for each criteria or alternative as follow:

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\left\{\frac{\sum_{j=1}^{n} a_{ij} \times w_j}{w_i}\right\} \quad (2)$$

Where λ_{max} is the maximal or principal Eigenvector, n the matrix size, a_{ij} is an element of pair wise comparison matrix, w_j and w_i, is the j and i elements of value of Eigenvector, respectively.

Following Saaty (1980, 2000), the priorities of the elements can be estimated by finding the principal eigenvector w of the matrix A, that is:

$$AW = \lambda_{max} W \quad (3)$$

When the vector W is normalized, it becomes the vector of priorities of elements of one level with respect to the upper level [15, 20]. λ_{max} is the largest Eigen value of the matrix A. In cases where the pair wise comparison matrix satisfies transitivity for all pair wise comparisons it is said to be consistent and it verifies the following relation:

$$a_{ij} = a_{ik} a_{kj} \qquad \forall i,j,k \quad (4)$$

Saaty (1977) has shown that to maintain reasonable consistency when deriving priorities from paired comparisons, the number of factors being considered must be less or equal to nine [19]. AHP allows inconsistency, but provides a measure of the inconsistency in each set of judgments. The consistency of the judgmental matrix can be determined by a measure called the consistency ratio (CR), defined as:

$$CR = \frac{CI}{RI} \quad (5)$$

Where CI is the consistency index and RI is the Random Index. CI for a matrix of order n is defined as:

$$CI = \frac{(\lambda_{\max} - n)}{(n-1)} \quad (6)$$

Furthermore, Saaty (1980, 2000) provided average consistencies (RI values) of randomly generated matrices (table 2) [15,20].

Table 2: The average consistencies of random matrices (RI values)

N	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Source: Saaty (1980, 2000)

In general, components of a pair wise comparison matrix would be acceptable to be applied in evaluations, if its CR value is less than 0.1 (CR≤0.1).If the value is higher, the judgments may not be reliable and should be elicited again [15, 20, 21].

Step 4: Aggregation of Local Priorities

The last stage is to calculate the global priority (regarding the main goal) of the respective element, multiplying its local average priority by the local average priorities of the hierarchically superior nodes. The priorities are aggregated as follows:

$$S(a_i) = \sum_k w_k * S_k(a_i) \quad (7)$$

Where w_k is the local priority of the element k and $S_k(a_i)$ is the priority of alternative a_i with respect to element k of the upper level.

Empirical Model

The final goal (level 0) of this research is to select the most appropriate MSW management strategy in Yaounde. The first level represents the criteria or guidelines on the basis of which this research is to be evaluated and the second level presents the alternatives or policy options. It would have been possible to choose all the criteria and alternatives mentioned in the WMSD and presented in the first sub-section of this section, but such a choice had to lead us to design a complex and long questionnaire for the decision/policy makers and to handle large matrices. Finally, for the case study, among all the guiding principle included in the WMSD, we opt to choose the first four criteria and four alternatives. The criterion here is seen here as the guiding principle or the priority objective that must be applied to MSW management strategy in Yaounde.

They include:

- Sustainable development (criterion 1): to manage MSW so that present and future generations' well-being is ensured by a sustainable investment in waste-related equipment and facilities;
- Polluter pays principle (criterion 2): each households should pay a tax for MSW management;
- Waste management hierarchy (criterion 3): MSW management system must be based on priorities actions like prevention (use of eco-friendly products), valorization (reuse of waste materials) and disposal (best technology of treatment);
- Waste service quality (criterion 4): the concept of quality must take place at all stages of MSW management from production to disposal.

Alternatives, on the other hand, represent the action to be taken to ensure that the chosen criterion is achieved (level 2).Compliance with the above-mentioned criteria implies the implementation of one or more alternatives.

Alternatives retained are:

- Pre-collection (alternative 1): pre-collection is waste collection in slums and swampy areas, using rudimentary tools, and transfer to waste container, transfer station for waste or waste trucks. Pre-collection helps to increase the rate of MSW collection and avoid pollution;
- Composting (alternative 2): Composting is MSW transformation into an organic amendment (compost); not at the landfill but in the slums or swampy areas. Composting helps to reduce the quantity of waste to collect and treat;
- Current collection (alternative 3): current collection is the current MSW management system in Yaounde. It consists to collect waste by waste containers disposed along the roadsides and waste trucks in some quarters of the city;
- Selective collection (alternative 4): selective collection is the separation of materials intended for recycling. It means that recyclable materials should not be discarded together with other garbage. It is not yet applies in MSW management system in Yaounde. Selective collection will help to reduce the cost of waste treatment and to reuse some materials.

After the specification of the three-level (level 0, 1 and 2) decision tree, figure 3 presents the general hierarchy structure model.

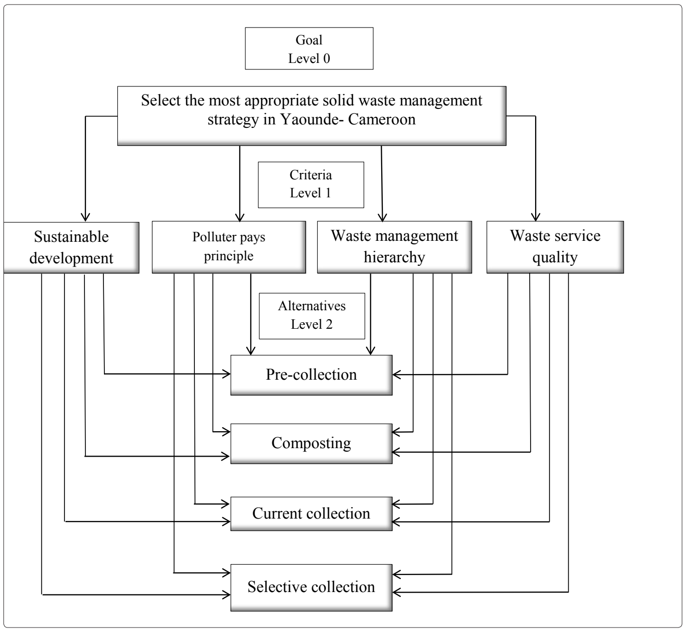

Figure 3: General hierarchy structure model

Source: The author

After the structuration of the decision problem into a hierarchical model, decision/policy makers were asked to compare pair-wise the relative importance of the elements for each level on the basis of the Saaty scale. From the pair-wise comparisons, a judgmental matrix was formed for each decision/policy makers. This matrix was used for computing the priorities and the consistency index was carried out.

There are several methods employed in AHP for aggregating group opinions, one of which is the geometrical mean (*Gm*) method. In this paper, priorities or opinions expressed by decision/policy makers have been combined using the *Gm* method following the equation (8):

$$Gm = \left(\prod_{i=1}^{n} a_i \right)^{1/n} \qquad (8)$$

Where n is the number of experts who whose one criterion or alternative and a_i the judgement score of the decision/policy makers i. The symbol "Π" is mathematical notation for "product" [22, 20].

Results

In order to achieve our objective, 26 decision/policy makers have been consulted in an individual way. These decision/policy makers are from the ministry in charge of environment, the city council and the sub-division councils. Initially, we submitted a questionnaire to some fifty decision/policy makers, but we selected those decision/policy makers who were consistent in their judgments. A consistent judgement is when pair wise comparison satisfies transitivity for all pair wise comparisons. For example, if criterion 1 is preferred to criterion 2, and criterion 2 to criterion 3, then criterion 1 is preferred to criterion 3.

According to the AHP procedure, after the structuration of the decision problem into a hierarchical model (figure 3), the second step consists to make pair-wise comparisons and obtain the judgmental matrix for the level 1 and level 2 of the hierarchy. After the calculation of the maximum value of Eigenvector, the consistency index and the Random Index to validate the judgements of the experts surveyed, the priorities will be aggregate in order to identify the most appropriate solid waste management strategy in Yaounde.

For level 1, comparisons between criteria are summarised and presented on table 3.

Table 3: Summary of comparisons between criteria

Comparisons	More important criterion	Correspondent Criterion	Evaluation	Scale of Judgement
Criterion 1-Criterion 2	C1	Sustainable development	5	Strong importance of one element over another
Criterion 1-Criterion 3	C1	Sustainable development	3	Moderate importance of one element over another
Criterion 1-Criterion 4	C1	Sustainable development	2	Equal to moderate importance
Criterion 2-Criterion 3	C2	Polluters pays principle	2	Equal to moderate importance
Criterion 2-Criterion 4	C4	waste service quality	5	Strong importance of one element over another
Criterion 3-Criterion 4	C4	waste service quality	5	Strong importance of one element over another

In order to establish the priorities of the different elements, let us make a pair wise comparison; which is the comparison of elements two by two with respect to an element found in the given superior hierarchy level. The binary comparison procedure begins on the top of the hierarchy by selecting the element that will be used for the first comparison. After, we consider the elements of the immediate lower level (table 4).

Table 4: First level pair wise comparison matrix: criteria to Goal

Criteria	C1	C4	C2	C3
C1	1	2	5	3
C4	½	1	5	5
C2	1/5	1/5	1	2
C3	1/3	1/5	½	1
Colon Sum	2.033	3.400	11.500	11.000

And the pair wise comparison matrix A associated to table 4 is:

$$A = \begin{bmatrix} 1 & 2 & 5 & 3 \\ 1/2 & 1 & 5 & 5 \\ 1/5 & 1/5 & 1 & 2 \\ 1/3 & 1/5 & 1/2 & 1 \end{bmatrix}$$

Next step consist to divide each element of the matrix by the colon summation and calculate the average elements of each row of the matrix (table 5).

Table 5: Priority establishment

Criteria	C1	C4	C2	C3	Priorities
C1	0.492	0.588	0.435	0.273	0.447
C4	0.246	0.294	0.435	0.455	0.357
C2	0.098	0.059	0.087	0.182	0.106
C3	0.164	0.059	0.043	0.091	0.089

Table 5 helps to calculate the principal Eigenvector λ_{max} that will help to find the maximum value of Eigenvector.

λ_{max} is obtained by multiplying the matrix A by the vector elements of priority (x), x is the Eigen value of the vector (n) of priority, the average of the values found is calculated.
We obtained:

$$0.447\begin{pmatrix}1\\1/2\\1/5\\1/3\end{pmatrix}+0.357\begin{pmatrix}2\\1\\1/2\\1/2\end{pmatrix}+0.106\begin{pmatrix}5\\5\\1\\1/2\end{pmatrix}+0.089\begin{pmatrix}3\\5\\2\\1\end{pmatrix}=\begin{pmatrix}1.962\\1.560\\0.446\\0.363\end{pmatrix}$$

Let us divide the elements of the sum of vector by the priority corresponding to each criterion (table 6).

Table 6: Calculation of the principal Eigenvector

Criteria	Priority	Values
C1	0.447	4.390
C4	0.357	4.365
C2	0.106	4.187
C3	0.089	4.065
λ_{max} = (4.390 + 4.365 + 4.187 + 4.065)/4 = 4.252		

According to table 2, for n=4, the random index RI=0.90. From equation (5) and (6),

$$CI=\frac{(\lambda_{max}-n)}{(n-1)}=\frac{(4.252-4)}{(4-1)}=0.084 \text{ and } CR=\frac{CI}{RI}=\frac{0.084}{0.9}=0.093<0.1$$

The value of the consistency ratio CR means that components of a pair wise comparison matrix are acceptable. Table 7 resumes the results obtained.

Table 7: Pair wise comparison matrix of the criteria with regards to the goal

Criteria	Sustainable development	Waste service quality	Polluter pays principle	Waste management hierarchy	Priority vector	Ranking
Sustainable development	1	2	5	1	0.447	1
Waste service quality	½	1	5	½	0.357	2
Polluter pays principle	1/5	1/5	1	1/5	0.106	3
Waste management hierarchy	1/3	1/5	½	1/3	0.089	4
Note: λ_{max}=4.252 CI=0.084 CR=9.3% < 1						

For level 2, by applying the procedure previously outlined for level 1, we obtain tables 8, 9, 10 and 11 which present the pair wise comparison matrix for the alternatives with regards to each criterion.

Table 8: Pair wise comparison matrix for the alternatives with regards to criteria "sustainable development"

Alternatives	Pre-collection	Selective collection	Composting	Current collection	Priority vector	Ranking
Pre-collection	1.000	3.000	6.000	6.000	0.532	1
Selective collection	0.333	1.000	5.000	8.000	0.325	2
Composting	0.167	0.200	1.000	2.000	0.086	3
Current collection	0.167	0.125	0.500	1.000	0.057	4
Note: λ_{max}=4.213 CI=0.071 CR=7.9% < 1						

Table 9: Pair wise comparison matrix for the alternatives with regards to criteria "polluter pays principle"

Alternatives	Pre-collection	Selective collection	Composting	Current collection	Priority vector	Ranking
Pre-collection	1.000	2.000	9.000	8.000	0.527	1
Selective collection	0.500	1.000	7.000	8.000	0.349	2
Composting	0.111	0.143	1.000	3.000	0.079	3
Current collection	0.125	0.125	0.333	1.000	0.045	4
Note: λ_{max}=4.206 CI=0.069 CR=7.6% < 1						

Table 10: Pair wise comparison matrix for the alternatives with regards to criteria "waste management hierarchy"

Alternatives	Pre-collection	Selective collection	Composting	Current collection	Priority vector	Ranking
Pre-collection	1.000	2.000	9.000	6.000	0.517	1
Selective collection	½	1.000	5.000	9.000	0.346	2
Composting	1/9	1/5	1.000	3.000	0.087	3
Current collection	1/6	1/9	1/3	1.000	0.050	4
Note: λ_{max}=4.249 CI=0.083 CR=9.2% < 1						

Table 11: Pair wise comparison matrix for the alternatives with regards to criteria "waste service quality"

Alternatives	Pre-collection	Selective collection	Composting	Current collection	Priority vector	Ranking
Pre-collection	1.000	3.000	9.000	9.000	0.596	1
Selective collection	1/3	1.000	4.000	7.000	0.264	2
Composting	1/9	¼	1.000	4.000	0.097	3
Current collection	1/9	1/7	¼	1.000	0.042	4
Note: λ_{max}=4.229 CI=0.076 CR=8.5% < 1						

CR values are also found to be less than 10% for all the pair wise comparisons matrix for the alternatives with regards to the four criteria adopted in our hierarchical model.

Table 12 resumes the priority of alternatives according to tables 8, 9, 10 and 11 and help us to present the relative priorities weights according to the hierarchical structure (figure 4).

Table 12: Priority of alternatives according to criteria

Alternatives	Sustainable development	Polluter pays principle	Waste management hierarchy	Waste service quality
Pre-collection	0.532	0.527	0.517	0.596
Composting	0.086	0.079	0.087	0.097
Current collection	0.057	0.045	0.050	0.042
Selective collection	0.325	0.349	0.346	0.264

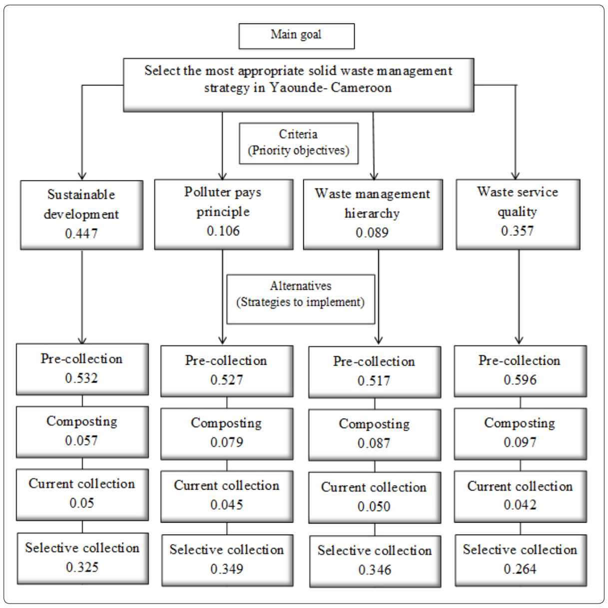

Figure 4: Relative priority of criteria and alternatives weights according to the hierarchical structure

According to the equation 7, global priority for the alternatives A1, A2, A3 and A4 is calculated and resumed in table 13.

Table 13: Global priority for the alternatives

Alternatives	Calculation method	Total weight	Total weight (%)
Pre-collection	0.447*0.532 + 0.106*0.527 + 0.089*0.517+ 0.357*0.596	0.5525	55.25%
Composting	0.447*0.086 + 0.106*0.079 + 0.089*0.087 + 0.357*0.097	0.0891	08.91%
Current collection	0.447*0.057 + 0.106*0.045 + 0.089*0.050 + 0.357*0.042	0.0497	04.97%
Selective collection	0.447*0.325 + 0.106*0.349 + 0.089*0.346 + 0.357*0.264	0.3073	30.73%

The aggregate judgement of 26 experts (decision/policy makers) show that the criterion "sustainable development" is the major principle that support the general policy on MSW management in Yaounde with a weight of 44.7% followed by the criterion "waste service quality" with a weight of 35.7%. "Polluter pays principle" and "waste management hierarchy" with a respective score of 10.6% and 8.9% are the less priority objectives (see table 7). The value of the consistency ratio (CR) is found to be 9.3%, so it is less than 10%, hence the judgements of experts is acceptable as earlier highlighted in section 4.1.

The criteria "sustainable development" and "waste service quality" focus on the necessity to implement a MSW management system that takes into account the socio-economic and environmental concerns of present and future generation. In addition more emphasis should be placed on the construction of high quality dumpsite complying with environmental standards. These criteria also recommend regular investments in solid waste-related equipment and facilities such as waste containers and transfer stations in the slums and swampy areas. The low score of criteria "polluter pays principle" (10.6%) is due to the fact that it is not easy to implement such tax at the household level. The main tax for the waste industry in Yaounde is the waste removal collection tax (TEOM). This tax ranges from FCFA 30,000 to 50,000 (US$50 to $90) for private and public sector companies. It is also deducted at the source according to the monthly wage. TEOM is less than 1% of the total waste budget in Yaounde because it does not take into account per capita quantities of waste generated and does not include all households and workers. The predominance of the informal sector explains the difficulty of implementing such a tax, because around 91% of the working population does not have an employment contract. According to the decision/policy makers, the criterion "waste management strategy" ranks last in Yaounde's priority in term of waste policy with a score of 8.9%. Let remind that in the "waste management hierarchy" actions like the use of eco-friendly products, the reuse of waste materials and the selection of the best waste disposal are recommended. Actually it is not easy to base the MSW policy in Yaounde on this criterion because of the low standard of living of households. It is estimated that more than 40% of households in Yaounde lives below the poverty line and therefore consumption of eco-friendly goods cannot be a priority for them. By cons, under certain conditions, household's waste materials can be recycled and reused.

Global priority for the alternatives show that with a respective score of 55.25% and 30.73%, the alternatives "pre-collection" and "selective collection" are the suitable actions to apply in Yaounde in order to obtain a best MSW management strategy. "Composting" with a score of 8.91% and "Current collection" with a score of 4.97%are respectively the third and the last priority actions that can be implement in Yaounde.

This result match with the recommendation of Sotamenou (2012), Sotamenou et al. (2010) and Parrot et al. (2009) who mention that pre-collection is an essential component for efficient MSW management in African cities in general and Yaounde in particular [7,9,23]. The main reason who justifies the institutionalization of pre-collection in Yaounde is the existence of slums (a manifestation of mismanaged urban planning) and swampy areas (the town is built on 12 hills at altitudes ranging from 750 to 1200 meter). In these conditions, pre-collection can help to transfer solid waste from the slums and swampy areas to transfer stations, waste containers or waste trucks generally accessible in paved roads. According to Sotamenou et al. (2018) in Yaounde, 25% of MSW generated daily are disposed into open (illegal) dumpsite around houses in the quarters; 58% are collected by Drop-off container and 17% by collection trucks [24]. Only 20% of households have access to pre-collection that can help to collect the uncollected waste (principally in slums and swampy areas). 81% of household's head are ready to pay monthly a lump sum to support pre-collection and 82% of household's heads are willing to sort their wastes. Pre-collection and selective collection of MSW will help reduce floods, promote recycling of materials that would have become garbage and as well create jobs such as the collection and sale of recyclables.The low score of alternatives "composting" and "current collection" can be explained by the fact that in the 1990s a few composting projects were implemented in Yaounde without much success. Indeed these projects stopped with the termination of the funding [25]. The factors contributing to the non-sustainability of these projects were short-term investment outlooks, insufficient crop areas in Yaounde, high transport costs, and the lack of support from the city councils. High production costs also contributed to the failure of the project. However, efficient recycling and composting could save 18.6% in MSW costs and 57.7% in landfill cost [26].The current low rate of waste collection (47 - 53%) in Yaounde explains the last rank of alternative "current collection". Only 26% of the 565 households surveyed by Sotamenou et al. (2018) are satisfied with the current MSW management in Yaounde [24].

Conclusion

Following our results, the most appropriate MSW management strategy in Yaounde consists to promote pre-collection and selective collection. Such activities need more financial support and much sensitization. In order to improve MSW management in Yaounde, 35% of household's head suggest more containers and trucks for waste, 14% of them are favourable for direct contribution of households for pre-collection and for 13% of them suggest more sensitization. Daily MSW generation in Yaounde is about 2000 tons and the average rate of collection is 50%. For Hebette (1996) a collection rate range from a low of 75% is harmful for the environment and the human health [27]. Pre-collection would help to transfer at least 25% of these MSW (500 tonnes) from slums and swampy areas to waste containers and trucks. According to Sotamenou (2012), the cost of pre-collection in Yaounde is FCFA 9,448 (US$ 16) per ton of solid waste [9]. This means that FCFA 4,724,000 (US$ 8,000) per day is necessary to increase the current collection rate to 75%; FCFA 141,720,000 (US$ 236,200) per month. According to the National institute of statistics (NIS, 2015), Yaounde has an average of 500,000 households. If each household pay FCFA 300 (US$ 0.5) per month for pre-collection tax, FCFA 150,000,000 (US$ 250,000) will be collected every month. 83% of household's head surveyed in Yaounde are ready to pay for this monthly amount [28-42].

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