COMPOSTING STRATEGY FOR DEVELOPING CITIES: A CASE STUDY OF BEIRA, MOZAMBIQUE

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ABSTRACT

This article aims to provide a contribution to the value and possibility of using composting as a tool for the treatment and management of the organic fraction of urban solid waste in developing contexts – specifically, the city of Beira, Mozambique. The aforementioned process should be intended not as an exhaustive tool but rather as a useful form of treatment to be employed within an Integrated Waste Management Plan. The high and diversified presence of materials suitable for the specific treatment in question is ascertained while also highlighting the diversification of the users that can be involved. Mixing strategies are drawn up in order to provide indications for a correct composition of the matrix that is intended to be started as a process and, according to the quantities considered (according to a modular approach), the production that can derive from it. A technical proposal is then drawn up on the functional areas making up the plant in order to develop the process in question. In addition to promoting the composting process itself, the article aims to valorize its final product, the compost, which in certain specific contexts, such as the one considered, can be useful or even necessary.
Keywords: composting, developing countries, Mozambique, MSW management, organic waste.

1 INTRODUCTION

Waste Management is the second most important problem after water quality in developing countries and worldwide [1]–[8]. According to the United Nations Environment Programme (UNEP) [9] waste disposal is a relevant problem in the less developed countries due to the demographic increase, poverty and high rate of urbanization, all that combined with inefficiency and under-financing by Governments in providing an adequate strategy for the management of municipal solid waste (MSW) [10]–[14].

Factors such as waste composition, technologies and/or lack of infrastructures, have been recognized as basic elements to set up a good and sustainable MSW management in developed and developing countries [15]–[18]. Generally, in the developing countries the only form of final disposal is generally open landfills, which periodically develops uncontrolled combustion with the inevitable production of atmospheric pollution and leachate [19]–[25].

MSW generated in developing countries is characterized by a high density and high content of organic matter, few metals and plastics content [26]–[30]. Big problems refer to the inefficient facilities for MSW collection, low treatment technologies and presence of slums built in a random and unplanned manner with unavoidable problems of accessibility [31]–[35].

At national level, in Mozambique, the Decree No. 13/2006 introduces Waste Management Plans (WMP) and includes relevant rules, provides principles, objectives, tools and guidelines for an Integrated Solid Waste Management (ISWM) [36].

The city of Beira (Conselho Municipal da Beira – CMB), is making concrete efforts in improving provided services to citizens promoting an international partnership coordinated

by Consortium of Associations with Mozambique (CAM). CMB has drafted the "*Postura Municipal para a Gestão de Resíduos Sólidos*", which aims not only to find management tools, but also to improve life conditions of population, in order to establish the sufficient conditions for a sustainable development.

The use of *compost* as a strategy for the management of the organic fraction of municipal solid waste (OFMSW), in Mozambique, it was already used in Maxixe [37]. Also, in Beira, composting has been identified as a possible method of OFMSW treatment, with a view to valorisation and reuse [38]. This article presents the results and proposals for the Beira case.

2 MATERIALS AND METHODS

Beira is the capital of the Sofala Province and the second city of Mozambique with a population of about half million of inhabitants. It represents the second industrial park and the third biggest seaport in Mozambique for the import-export flows. The city's economy is mainly based on trade and port activity and the commercial and transport sectors appear to be the most developed; a sector of equal importance is certainly represented by agriculture.

The MSW management is on the responsibility of the VGUE (*Vereação de Gestão Urbana e Equipamentos*). The current state presents several problems both with regard to the equipment available, their excessive use as well as an incomplete coverage of the service for the areas of the city. A weak link in the chain is precisely the collection service. There are three different systems forms of waste collection: *contendores* (6 m^3), *tambores* (200 L) and direct arrangement on the ground. Container trucks, auto-compacting machines and tractors are the means used for the MSW collection, whose number of units is reduced, and the availability often not guaranteed. The final point of waste delivery, the municipal landfill, is not delimited and presents significant problems with regard to the access especially during the rainy period. The waste disposal is completely uncontrolled, so there are problems of both volumes and run-off; the landfill, as common in other developing contexts, presents the informal collection phenomena.

For the development of the present research, six sectors of different types of waste were considered (domestic, market waste, industrial, commercial, green street sweeping waste). The total daily production being about 523 t/d (190,822 t/y). The domestic sector represents the major contribution, 65%, followed by the market waste sector, 20% [38], [39].

In the context of Beira, different directions were taken that include a direct approach with local institutions, with managers and activities aimed at the quality-quantitative characterization of materials and/or the identification of spaces in order to combine all useful and necessary information to draft the project proposal for MSW management. The field work was divided into: identification of the matrices to be treated and their production points, transfer modes of the selected matrices, treatment plant, composting process and compost, intended destination.

Regarding the market and food wastes, data were collected together with VGUE. The percentage of organic matter (100 m^3/month) produced in these markets was identified through field analysis, direct comparisons with local responsibles and measurements of the apparent density of the waste were carried out in order to extrapolate the weight value of the effective quantity of organic matter produced. The characterization of waste from restaurants activities was conducted through questionnaires. The georeference of the restaurants was made in order to estimate the produced quantities of waste and its percentage of organic fraction (OF).

Thanks to the collaboration with VAPPMA (*Vereação de Agro-Pecuária, Pescas e Meio Ambiente*), and local responsibles, it was possible to retrieve data regarding the maintenance of the urban green waste (number of cropper trees), the pruned roads and the specifications

relating to the operating conditions of the activities themselves (number of means used and their capacity). The average timber productions associated with a tree has been identified and has allowed the extrapolation of the average monthly production and maps have been drawn up to identify the urban areas undergoing maintenance.

Regarding seeping and sludge waste, data were obtained thanks to the collaboration with SASB (*Serviços Autónomos de Saneamento da Beira*) and with ETAR (*Estação de Tratamento de Águas Residuais*). The investigative activity concerning this type of material was possible thanks to a comparison with the treatment plant manager, the direct vision of operations conducted inside the wastewater treatment station and the estimation of the apparent density of the sludge in order to extrapolate quantitative production at monthly scale. Furthermore, chemical analyses have been carried out on the sludge, which has ascertained the suitability for use in the composting process.

The proposed plant, for the above considered materials, is shown in Fig. 1. Compost market opportunities represent a crucial point in order to understand the potential use of the final product. The problem does not consist in identifying the intended use, but in the cost-benefit aspect, in order to make the entire supply chain economically sustainable.

Chemical analyses have been taken on soil samples of some countryside in the outlying areas of the city and investigation in theoretical form have been carried out additionally. As regard the cost-benefit analysis, realities possibly interested in the purchase of compost have been investigated and are worthy of further investigation. The first stage was the identification and selection of the available matrices that it was decided to use in the composting treatment (their quality-quantitative characterization being a nodal point).

In this paper the OFMSW considered to be sent in the composting plant was divided into two components: market and catering waste. Regarding the first one, the production of the two main urban markets of the city, *Maquinino* and *Goto*, have been evaluated.
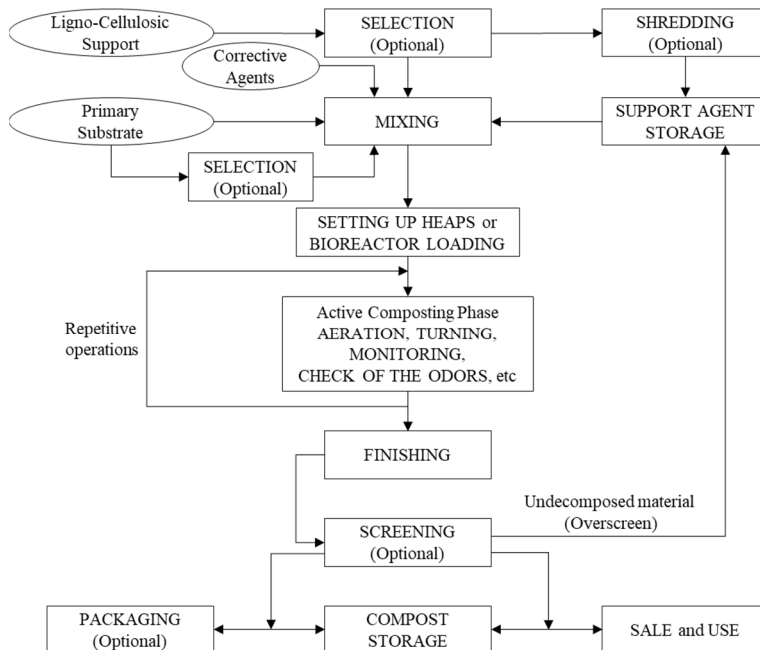

Figure 1: Flow chart of a composting plant.

<div align="center">3 RESULTS</div>

Thanks to the collaboration with local bodies and VGUE, VAPPMA, SASB, ETAR, CAM and CMB, it was possible to obtained the determination of mass quantities, reported in Table 1, useful and necessary to draft the mixing plans.

The values reported have been time scaled, starting from the determination of the OFMSW production on daily basis (day of market) and considering the number of days of market along the year. Half of the containers considered in each market are also improperly used by citizens, so only those for use almost exclusively in the markets were taken into consideration: almost exclusively OFMSW was found with a low percentage of other materials (15%).

Regarding the restaurant activities, a map was created in order to have a graphical representation of their spatial arrangement within the urban fabric. Among those surveyed, 20, only half were taken in consideration. These are the major ones which presented at the same time a greater interest and willingness to collaborate. In Table 2, data regarding the OFMSW for the considered matrices are reported. The OFMSW quantities from these have a contribution of an order of magnitude lower than that of the markets but not less important for this reason. The reported data demonstrate also that it is essential to integrate and involve the users.

Regarding the lignocellulosic material to be used in the composition of the initial matrix, the green waste production was estimated considering the units undergoing maintenance, and the potential of the management service for urban green areas. A production range of 0.4–1.4 t/tree has been assumed, considering the size and variability of the tree type. The average production value of each tree was considered 0,9 t. In Table 3 the production fluctuation during a year is reported.

In order to verify the values, the calculations were performed according to the number of working days (visible in Table 4), the number of means used daily (during maintenance operations) and their capacity.

<div align="center">Table 1: Production of potential organic matter (OM).</div>

Marketplace	Total annual production OM		Total monthly production OM	
	(m^3/y)	(t/y)	(m^3/month)	(t/month)
Maquinino	5,875.2	2,908.2	489.6	242.4
Goto	2,937.6	1,454.1	244.8	121.2
Total	8,812.8	4,362.3	734.4	363.5

<div align="center">Table 2: Quantitative production.</div>

Source	Total monthly production O.M.
	(t/month)
Market waste	364
Restaurants	11

Table 3: Monthly lignocellulosic material production.

Months	Pruned trees	Average production (t/month)
January	0	0
February	145	130.5
March	164	147.6
April	176	158.4
May	275	247.5
June	345	310.5
July	357	321.3
August	294	264.6
September	365	328.5
October	410	369.0
November	204	183.6
December	50	45.0

Table 4: Further estimate of potential quantities of lignocellulosic material.

Period	Days	Working days (Theoretical)	Theoretical production (t)	Assumed production (t)
March to August	184	127	1,587.5	1,587.5
September to February	181	124	1,550	1,162.5*
January to December	365	251	3,137.5	2,750
* Reduced value of 25% due to the climatic conditions characterizing this period (reduced service efficiency)				

Table 5: Amount of produced fresh and dried sludge.

Monthly sludge production 1	Monthly sludge production 2	Sludge average density 2	Monthly sludge production 2	Daily sludge production 2
(m³/month)	(m³/month)	(t/m³)	(t/month)	(t/month)
27	13.5	0.694	9.4	0.310
1 = Fresh sludge leaving the anaerobic reactor; 2 = Dried sludge leaving the drying beds (arranged in cells)				

The sewage sludge (SS) production reported in Table 5, is very low due to the current operating conditions of the whole sanitation infrastructure. Data were given by ETAR. Once the availability of the different materials was known, using a modular approach, and establishing the initial input material as 1,500 t/y (125 t/month), it was possible to draw up a mixing plan on a monthly scale, that is reported in Table 6.

Table 6: Mixing strategy.

Raw material	Weight (t/month)	Weight (%)	A.D. (t/m³)	Vol. (m³)	Vol. (%)	SS (%)	SS (t)	SS (%)	N	C	C/N
OFMSW	78.1	62.5	0.75	104.1	49.3	25	19.5	44.8	1.4	30	21.4
Sludge	9.4	7.5	0.7	13.5	6.4	17	1.6	3.7	2.9	25	8.6
Ligno-cellulosic	37.5	30	0.4	93.8	44.3	60	22.5	51.5	0.7	45	64.3
Total	125	100	0.6	211.4	100	35	43.6	100	1.1	38	34.3

Table 7: Compost quantities produced.

COMPOST	Weight (t/y)	Volume (m³/y)	Weight (t/d)	Volume (m³/d)
Raw[1]	675*	1,269*	3.2	6
Fine[2]	450**	923**	2.1	4.4
1 = downstream of the maturation phase; 2 = downstream of the post-treatments				
* Raw Compost yield: 45% in Weight e 55% in Volume compared to the input quantity;				
** Finished Compost yield: 30% in Weight e 40% in Volume compared to the input				

The *first phase* of the process (accelerated bio-oxidation) is proposed to be carried in 3 cells and will be characterized by 21 days lasting (about 17–18 cycles/y). In each cell, about 29 tons of organic material by cycle can be treated. The aerobic conditions will be guaranteed by an insufflation system consisting of perforated corrugated tubes, a fan for the supply of air and one for suction. The exhausted process air will be sent to a bio-filter for its treatment before release into the atmosphere. This solution (used mainly from the mechanical biological treatment) is the most economic one and have a good pollutants removal efficiency [40]–[42]. Downstream of the accelerated bio-oxidation, a reduction in weight and in volume of 30% and 25% respectively, is was foreseen. In this way the quantity for the second phase is equal to 1,050 t/y (1,730.8 m³/y).

The second phase is carried out by placing the material on a stave along the linear-shaped piles. This area will represent the largest area inside the station. The maturation stage will be characterized by a duration of about 60 days for a total number of 6 cycles/year, about 173 tons/cycle will be treated. It has been hypothesized 4 piles, with a base and length of 3 m and 32 m respectively (384 m² in plan covered with material in the secondary stabilization phase).

The piles are not aerated but they are subjected to turning operations thanks to a revolving machine, actuated and driven by the tractor, which plays a multifunctional role within the whole process. The wetting operations will be carried out by means of a rotary sprinkler located above the revolving machine. The overlapping of the two operations allows the optimization of the time-management aspect. In Table 7 the expected quantities of compost are reported.

For the OFMSW, a manual selection was considered for the removal of the bulkiest materials. For the brushwood, a bio-shredder was proposed. For the materials handling operations (mixing, heaps preparation and loading/unloading) a tractor with front blade can

be used. At the end, a final screening trough a cylindrical roll was proposed. In this way, a homogenization of the material can be made but also will allow the recovery of any material not intercepted in the initial phases.

In Table 8 the surfaces needed for the proposed composting plant, considering the quantity of organic material that will be treated, are reported.

Given the above, the initial matrix value to be subjected to the treatment that was chosen to be considered is equal to 1,500 t/y. This assumption, following the natural reductions that occur during the proposed process, would allow a production of about 450–675 t/y, depending on whether the compost is considered refined or raw, or downstream or upstream of the post-treatments (dimensional screening), which allow a higher final quality.

Regarding the possible use of compost, the first and simplified land analysis has highlighted that its application can be suitable with the existing land and will improve its physical, chemical and biological characteristics. Its use in the agricultural field can be made only after the development of a proper campaign of dissemination, promotion and demonstration, in order that compost will be considered a product of value.

4 CONCLUSIONS AND PERSPECTIVES

The study carried out, has allowed highlighting how the considered city, Beira, presents a high and diversified potential of suitable available materials for the biodegradation process such as composting. The main contribution in the organic material productions is certainly due to market utilities; also, the catering activities represents an important contribution in terms of quality and diversification of the commercial activities involved.

With regard to the wood-cellulosic material, used as the bulking agent, there is a significant quantity, as the city has numerous tree-lined avenues. It must be considered that in Mozambique, wood is widely used in domestic combustion for cooking purposes. The sewage sludge, is taken in consideration with a view to an integrated approach of the utilities and materials involved. Its involvement covers the additive function, however if SS characteristics become unsuitable, it is possible to implement a mixing plan without this element.

Table 8: Internal surfaces of composting plant.

Areas		Surfaces (m^2)
Receiving and pre-treatments materials area	Green waste storage and shredding area	200
	Waste storage box	25
	Mixing box	25
Active composting area	3 Cells	75
	Biofilter	5
Maturation area	Heaps/windrow surface	390
	Lanes surface	260
	Operations surface	200
Post-treatments and storage compost area	Screening and storage compost area	240
Services area	Services local (/room)	40
Total		~1,500

Regarding the composting plant design, the choice to use a modular approach, i.e. to align the sizing to the quantity of input material established rather than the potentially available one, is configured as an evaluation tool for a successful project outcome. This, in fact, allows an analysis step by step of the real potential of using composting as an alternative to disposal in landfill, allowing a better understanding of the possible management limits and process difficulties on a small scale, minimizing the failure risk on a larger scale.

From a managerial point of view, for the success of the composting process, the logistic component must be taken into consideration by the personnel in charge. In this regard, the transmission and acquisition of adequate professional and managerial skills through a completed and iterated training is absolutely vital.

The composting process is capable of presenting its maximum effectiveness only within an ISWM. Composting is not and does not pretend to present itself as an absolute and exhaustive solution, but rather as an effective form of management of a given component of MSW, the biodegradable one.

In additional to the function of composting as a treatment form, the promotion of the "compost" use is important. This means that parallel projects that encourage the use of the product must be implemented. An example is the urban agriculture programs (agro-economy), which may prove capable of combining agricultural production activities for food purposes with the creation of useful spaces for the application of the obtained product, the compost (the country is currently undergoing strong timber exports).

Regarding the plant location, a crucial phase in the design of composting station, this remains a question not completely resolved within this study. Although some possible, suitable sites of the plant installation have been assessed, the selection of one rather than another must follows a careful and in-depth context analysis, also making use of geotechnical instruments. The choice, in addition to the various known criteria necessary to carry it out, should not be dictated by purely economic-financial issues in the short term. On the other hand, it cannot be exempt from careful assessments regarding medium/long-term, technical complications and burdens.

For the project implementation, at whatever scale it is carried out, a wide-ranging evaluation is absolutely necessary, which is capable of taking into consideration social, economic and environmental elements. It is essential, to not underestimate absolutely all those socio-educational and informative paths; that even if they seem apparently marginal, are fundamental ingredients for the success of the project, both from an acceptance and development point of view.

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