Article

Evaluation of the Methane (CH$_4$) Generation Rate Constant ($k$ Value) of Municipal Solid Waste (MSW) in Mogadishu City, Somalia

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Abstract: Landfills are the third largest source of the greenhouse gas methane, contributing to 25% of global warming. Therefore, the characterization of national municipal solid waste (MSW) and estimation of methane generation rate are very important for the solid waste management (SWM) toward sustainable development goal no. 13, climate action. This study presents (a) an assessment of daily MSW generation, (b) the characterization of MSW, and (c) an evaluation of the methane generation rate constant ($k$ value) in Mogadishu, Somalia. The MSW samples were collected from three (3) sampling zones (Zones 1, 2, and 3; 204 households) and weighted (kg). Next, the waste generation per person per day was estimated. The MSW characterization includes sorting (based on plastic/polythene, food wastes, wood, metals, yard waste, paper/cardboard, textile, glass/ceramic and miscellaneous components, %), the determination of bulk density (kg/L), and measuring moisture content (%). The $k$ values were evaluated from the percentages of different components in MSW based on first-order decay models. Mogadishu city generated 1671.03 kg MSW per week (maximum on Friday: 348.72 kg, and minimum on Monday: 152.04 kg). The total mean MSW generation rate observed in this study was 0.2 kg/person/day. The solid waste generation found was in the decreasing order of food waste > plastic/polythene > yard waste > miscellaneous > papers/cardboard > wood > glass/ceramic > textiles > metals by weight. The average bulk density was found to be 0.269 kg/L. The average moisture content was ranged from 61.6 to 73%. The total $k$ values were categorized as fast (Zone 1: 0.216053 yr$^{-1}$, Zone 2: 0.228739 yr$^{-1}$, and Zone 3: 0.244595 yr$^{-1}$) and moderate (Zone 3: 0.244595 yr$^{-1}$) degradation. This research serves as Somalian MSW baseline data and projected the methane generation rate from the MSW production in the country. The MSW sorting may reduce the impact of global warming and is highly recommended for better SWM in the future.

Keywords: municipal solid waste; waste generation; characterization; global warming; methane generation rate constant; Mogadishu

1. Introduction

Landfills generate the mass production of greenhouse gases (GHS) contributing to global warming. First implemented in the 1940s, the landfill is the oldest conventional SWM system without the segregation or characterization of different MSW components [1]. Therefore, physical, biological, and chemical reactions occur in one large, designated site for rubbish dumping: namely, landfills. It becomes a super-emitter of various hazardous
GHGs [2]. One of the GHGs produced from landfill is methane (CH$_4$, molecular weight: 16.04 g/mol). Although CH$_4$ is a natural hydrocarbon gas, it becomes anthropogenic (human-caused) due to mass production accumulation in landfills, causing a surge in world temperature up to 0.5 °C. The gas traps photons from the sun (or solar energy) per molecule, and light cannot pass through (it has blocked the sun) to the earth, causing heat to accumulate in the atmosphere. It is the second most abundant GHG and 80 times more potent than carbon dioxide (CO$_2$) [1]. It takes 12 years for CH$_4$ to be degraded into hydroxyl radicals (•OH). Other anthropogenic sources of CH$_4$ include oil and natural gas systems, agricultural activities, coal mining, combustion, wastewater treatment, rice farming, and industries [3].

The methane generation rate constant (represents in $k$ value, unit: yr$^{-1}$) describes the methane decay rate from waste placed in a landfill [4]. At higher values of $k$, the methane generation in a landfill increases more rapidly (active landfill) and then declines more quickly after the landfill closes. The value of $k$ is proportionate to (a) the waste moisture content, (b) the availability of nutrients for methane-generating bacteria, (c) pH, and (d) temperature. Moisture conditions within a landfill strongly influence $k$ values and waste decay rates. Waste decay rates and $k$ values are very low at desert sites, and they tend to be higher at sites in wetter climates. Annual precipitation is often used as a surrogate for waste moisture because of the lack of information on moisture conditions within a landfill [5]. Due to the difficulties in the monitoring of methane emissions at landfill sites, modelling approaches using first-order decay have been used [6,7].

MSW is the solid waste associated to a city that has its own local government. It is estimated that 2.01 billion tons of MSW is generated annually worldwide. Globally, waste governance is becoming conventionally managed on a regional basis. SWM is an official task at the municipal or regional scale. According to the standard method established by ASTM International (ASTM D5231-92), MSW can be categorized into (a) organics, (b) paper, (c) plastics, (d) metals (scraps, cans/tins), (e) glass (colored, plain), (f) rubber and leather, (g) textiles, (h) inert (sand, fine organics, ash), and (i) miscellaneous. The organics waste includes food, yard waste, wood, and animal manure. Paper consists of cardboards, newsprints, office papers, and tissue papers. Plastics are plastic products such as polyethylene terephthalate (PET), high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-density polyethylene (LDPE), polypropylene (PP), polystyrene (PS), and others. Miscellaneous waste includes construction waste, batteries, paints, and/or any other waste fraction that does not fit in the categories. These MSW categories can be weighted and differentiated based on their composition percentage [2].

Somalia has been torn apart by internal conflicts for many years [8]. Solid waste is generated daily in all districts of Mogadishu city at an approximately known rate where only a small portion of waste is collected and deposited in landfills, none of the waste is managed in Somalia properly, and no sanitary landfills are planned or organized [9]. Thus, SWM is a significant problem in Mogadishu districts, Somalia [10]. Like other developing cities in Africa, Mogadishu is facing rapid urbanization and population growth, which is responsible for the increasing generation of solid waste per day. Households living in the city have long struggled with environmental issues, especially in the urban areas, where waste disposal is a serious concern. The problem that this research addressed is the ineffectiveness calculation of total daily generation and collection and composition rate using zero basic research papers and project reports and moreover, due to lack of motivation, awareness in Mogadishu city, Somalia. There is yet to be a report on the data on solid waste generation per capita (kg person$^{-1}$ day$^{-1}$) in the past thirty years in Somalia [11]. This study discloses that [12] the SWM performance of the city is a very poor due to a lack of properly designed collection systems services. The research also demonstrates that no training on separation and collection exists, there are also inadequate time schedules for collection, and there is an insufficient or lack of malfunctioning operation equipment. However, MSW data in Mogadishu, Somalia are yet to be reported, making the SWM a big challenge for the researchers, engineers, and policymakers in the country.
Characterizing solid waste management and estimating solid waste generation rates are essential components of statistics when looking for alternatives to conventional methods of disposing of waste due to rising dumping expenses, growing popular objection to dumping sites, and developing involvement in recycling during the coming years [13]. Africa is also struggling with an increasing challenge in solid waste management when compared to industrialized nations, but the quantity of solid waste generated in Africa is comparatively low nevertheless. In fact, the volume of increase in waste creation in Africa, particularly Sub-Saharan Africa, is estimated to be so huge that any decline in waste generation anticipated in other regions across the world will be dominated by Africa. In African countries, problems with SWM have taken on a frightening new dimension [14]. The lack of training in modern solid waste management procedures, combined with the high population growth rate and increase in economic activity in developing countries’ metropolitan areas, complicates the efforts to improve solid waste management services [3]. The amount of household solid waste quantification, characterization via direct measurement and sampling techniques were reported from Mthatha City, South Africa [15], Dilla Town, southern Ethiopia [16], Kigali City Nduba Dumpsite [17], Paynesville City, Liberia [18], new municipalities of Nepal [19], Homs City, Syria [20], Gulberg Town, Lahore, Pakistan [21], Tehran and Alborz, Iran [22], Palapye, Botswana [23], class II city of India [24], Bahir Dar City, Ethiopia [25], Laga Tafo Laga Dadi Town, Oromia, Ethiopia [26], Debre Berhan Town, Ethiopia [27], Tripoli city, Libya [28], Thika District of Kiambu County, Kenya [29], Aksum and Shire-Endaslasse Towns, northern Ethiopia [30], and Hosanna Town, Ethiopia [31] are shown in Table 1. Studies on MSW and methane generation rate from the MSW are yet to be reported in African countries, including Mogadishu city.

Therefore, this study aims to (a) assess MSW daily generation, (b) characterize MSW, and (c) evaluate methane generation rate constant (k value) in Mogadishu, Somalia. This scientific knowledge sets out to present the fundamentals of SWM in Mogadishu, Somalia.
Table 1. Previous studies on solid waste quantification and characterization from the literature in comparison to the current study.

<table>
<thead>
<tr>
<th>Research Focus</th>
<th>Methodology</th>
<th>Sample Size</th>
<th>Country/City/Study Area</th>
<th>Findings</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWM practice, MSW characterization and generation</td>
<td>Direct measurement technique (Miezah et al., 2015).</td>
<td>250 households from the two settlements</td>
<td>Mthatha City, South Africa</td>
<td>Solution for WM strategy</td>
<td>[15]</td>
</tr>
<tr>
<td>SWM practice, MSW characterization and generation</td>
<td>Waste source sorting and separation</td>
<td>152 households</td>
<td>Dilla Town, Southern Ethiopia</td>
<td>Important for legislators and town municipals</td>
<td>[16]</td>
</tr>
<tr>
<td>The composition and quantification of solid waste</td>
<td>Random sampling methodology</td>
<td>60 households</td>
<td>Kigali</td>
<td>Establish solution faced by Kigali city in terms of SW</td>
<td>[17]</td>
</tr>
<tr>
<td>SWM practice, MSW characterization and generation</td>
<td>Multistage sampling technique (Bobek, 2010; EPA, 2002).</td>
<td>Total of 60 households of four zones (A, B, C and D)</td>
<td>Paynesville City, Liberia</td>
<td>Findings show an alarming state</td>
<td>[18]</td>
</tr>
<tr>
<td>To set up a new reference line for municipal solid waste quantification and characterization</td>
<td>Questionnaire and waste quantification and characterization.</td>
<td>60 municipalities</td>
<td>Nepal</td>
<td>Encouraged the local governments to think about tactical collaborators,</td>
<td>[19]</td>
</tr>
<tr>
<td>MSW characterization and generation</td>
<td>Stratified random sampling method</td>
<td>300 families</td>
<td>Homs City, Syria</td>
<td>Results to serve as a reliable database for SWM</td>
<td>[20]</td>
</tr>
<tr>
<td>MSW characterization and generation</td>
<td>Stratified sampling method</td>
<td>250 households</td>
<td>Ibadan metropolis, Nigeria</td>
<td>Reveals stench associated with HW</td>
<td>[21]</td>
</tr>
<tr>
<td>MSW characterization and generation in rural communities</td>
<td>ASTM D5231-92</td>
<td>70 households were randomly selected</td>
<td>Tehran and Alborz (Iran)</td>
<td>Source segregation of waste for separation</td>
<td>[22]</td>
</tr>
<tr>
<td>MSW characterization and generation</td>
<td>Botswana Waste Management Strategy (BWMS)</td>
<td>Samples ranged from 3 to 5 persons per household</td>
<td>Palapye, Botswana</td>
<td>WM planning by the Administrative Board of the region</td>
<td>[23]</td>
</tr>
<tr>
<td>The key issues in SWM in the city</td>
<td>Sample collection was carried out</td>
<td>329 solid waste samples from 47 households</td>
<td>Sunder Nagar, Himachal Pradesh, India</td>
<td>Solid waste management is very inadequate</td>
<td>[24]</td>
</tr>
<tr>
<td>Factors that might influence MSW generation and SWM behavior of households</td>
<td>Stratified and systematic random sampling techniques</td>
<td>196 samples</td>
<td>Bahir Dar City, Ethiopia</td>
<td>Very low environmental awareness among the residents</td>
<td>[25]</td>
</tr>
<tr>
<td>The MSW composition and generation</td>
<td>Formal survey using structured questionnaire was conducted</td>
<td>157 samples</td>
<td>Laga Tafo Laga Dadi Town, Oromia, Ethiopia</td>
<td>Convert the waste to organic fertilizer complete composting</td>
<td>[26]</td>
</tr>
</tbody>
</table>
Table 1. Cont.

<table>
<thead>
<tr>
<th>Research Focus</th>
<th>Methodology</th>
<th>Sample Size</th>
<th>Country/City/Study Area</th>
<th>Findings</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSW generation rate and onsite handling practices</td>
<td>Cross-sectional study, face-to-face interview</td>
<td>211 households</td>
<td>Debre Berhan Town, Ethiopia</td>
<td>90% household store waste a one container</td>
<td>[27]</td>
</tr>
<tr>
<td>MSW characterization and generation within Thika municipality</td>
<td>Site-specific study methodology was used</td>
<td>Different sources which are coded from C1 up to C8</td>
<td>Thika District of Kiambu County, Kenya</td>
<td>SW by converting it to energy</td>
<td>[29]</td>
</tr>
<tr>
<td>Technical and regulatory arrangements and characterization of MSW</td>
<td>Measurement, direct observation</td>
<td>140 samples</td>
<td>Aksum and Shire-Endaslassie, North Ethiopia</td>
<td>SW is under stress</td>
<td>[30]</td>
</tr>
<tr>
<td>The MSW generation in Hosanna town</td>
<td>Sampling method, door to door data collection</td>
<td>Representative samples were selected</td>
<td>Hosanna Town, Ethiopia</td>
<td>Landfill of ten year is compulsory for the dumping</td>
<td>[31]</td>
</tr>
<tr>
<td>MSW characterization, generation and evaluation on k values</td>
<td>Waste source sorting, separation and sampling method</td>
<td>300 households randomly selected</td>
<td>Mogadishu-Somalia</td>
<td>Presented in this paper</td>
<td>Current Research</td>
</tr>
</tbody>
</table>
2. Methodology

2.1. Research Location and Sampling Procedure

With a total area of 637,540 square kilometers, Somalia is located at the Horn of Africa’s tip. Its 3025 km of coastline, the longest in Africa, stretching from the Indian Ocean in the east and south to the Gulf of Aden in the north (1000 km). The actual size of Somalia is 1550 km north to south and 1090 km east to west. Apart from the southern and central sections close to the Ethiopian border, which rise to a few hundred meters above sea level, most of the country is flat. Somalia experiences persistent droughts and erratic precipitation patterns. The daily temperature ranges between 85 to 105 °F with the distinction of places at higher elevations and along the ocean. The daily minimum temperature range is 60 to 85 °F in this location. May through October are the southwest monsoon season months. From December to February is the northeast monsoon season. Based on the Holdridge regional bioclimatic scheme, Mogadishu is situated in or adjacent to the tropical thorn woodland biome. The average temperature of Mogadishu city is 27 °C (81 °F) with average highs of 30 °C (86 °F) and lows of 24 °C (75 °F).

This study was carried out in Mogadishu: the city located in the most populous administrative zones in Somalia. Mogadishu is certainly the largest populous administrative territory in Somalia and comprises 17 administrative districts in the capital city with a current population of 2,388,000 [32]. Mogadishu is administratively divided into seventeen districts, as depicted in Figure 1.

\[
n = \frac{N \cdot Z^2 \cdot P \cdot Q}{d^2 (N-1)} + \frac{Z^2 \cdot P \cdot Q}{d^2} \]

where
- \(n\) = Sample size of housing units
- \(N\) = Total number of housing units for each district
- \(P\) = Housing unit variable (residential houses)
- \(Q\) = 1 - \(P\)
- \(Z\) = Standardized normal variable (1.96)
- \(d\) = Allowable error (0.05)

In conclusion, the researcher chose to apply the proportionate methodology and select sample households from specified zones. However, to improve the quality of the data in this survey, an additional eight residential households were added, and a total of 204 samples were considered in this study.

Figure 1. Sampling locations.

The weather in Mogadishu is described as moderate and semi-arid, with a high yearly humidity of about 79%. The yearly averages for temperatures and precipitation are about 27 °C and 400 mm, accordingly. There is a distinct dry and wet season, although there are no season-to-season temperature fluctuations. The direction of the southerly airflow causes rain to be created from the moist air coming from the Indian Ocean. Little to no
considerable rainfall occurs in this area because of the northeasterly winds that originate in Asia and Arabia. The four seasons of the area’s annual weather pattern are as follows:

- **Jilaal**: December to March—Warm, sunny, and dry.
- **Gu**: March to June—Heavy rains.
- **Haggai**: July to September—Cool, and cloudy with rain showers.
- **Deyr**: September—December—Short rains.

Sampling of wastes from households in every district was collected by marking selected households from in Zones 1, 2 and 3, as shown in Table 2. Samples of 12 houses from each district group were randomly chosen in the survey to ensure that the findings were representative: 12 households × 17 districts × 7 days = 1428. In terms of population, the average household size in Zones 1, 2, and 3 was 5.7, 6.1, and 5.0, respectively. Over the course of the time period, 1428 samples were taken from three distinct zone sampling locations. Collection of sampling was carried out in September, October, November, December (2022), January, February, and March (2023); solid waste samples were collected for a total of seven continuous days. The sampled bags were collected Saturday to Friday, and the wastes were sorted to determine composition of the wastes.

**Table 2. Sampling distribution.**

<table>
<thead>
<tr>
<th>Zones</th>
<th>Study Districts</th>
<th>Sampling Coordinates</th>
<th>Population in the Study Districts</th>
<th>Selected Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>Abdulaziz</td>
<td>2.042995 45.355955</td>
<td>56,800</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Bondere</td>
<td>2.043950 45.344310</td>
<td>156,720</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Shangani</td>
<td>2.037263 45.345502</td>
<td>62,479</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Karan</td>
<td>2.050990 45.363817</td>
<td>315,810</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Shibis</td>
<td>2.045693 45.353688</td>
<td>204,481</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Hamar Weyne</td>
<td>2.035612 45.338810</td>
<td>111,010</td>
<td>12</td>
</tr>
<tr>
<td>Zone 2</td>
<td>Hamar Jijab</td>
<td>2.031226 45.331399</td>
<td>93,152</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Waber</td>
<td>2.030347 45.317108</td>
<td>130,400</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Heliwaa</td>
<td>2.075538 45.371455</td>
<td>111,328</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Hodan</td>
<td>2.041902 45.312415</td>
<td>183,556</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Wardigley</td>
<td>2.043398 45.340840</td>
<td>137,479</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Hal-Wadaag</td>
<td>2.048143 45.326343</td>
<td>100,246</td>
<td>12</td>
</tr>
<tr>
<td>Zone 3</td>
<td>Yaqshid.</td>
<td>2.065382 45.350973</td>
<td>329,400</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Dayniile</td>
<td>2.062808 45.294690</td>
<td>84,019</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Wadajir</td>
<td>2.024782 45.282862</td>
<td>128,420</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Dharkenley</td>
<td>2.031838 45.271925</td>
<td>105,000</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Kahda</td>
<td>2.045252 45.243363</td>
<td>77,700</td>
<td>12</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>2,388,000</td>
<td>204</td>
</tr>
</tbody>
</table>

The selection of the sample size is a crucial stage in any sampling survey. The cost-to-benefit ratio determines the quantity of sampling most significantly. More samples will be used if the statistical accuracy and confidence level are higher and the number of samples at each level of confidence can be calculated statistically. Typically, the confidence level for solid waste statistics is set at 80% to 95%. Therefore, a 95% confidence level is considered into account for this assessment. In addition, the acceptable error was set at 0.05, and statistically principal sampling techniques were employed and calculated. The entire population of Mogadishu city under 18 administrative districts has been designated as the target population [33] to gather primary data. The sampling formula described by Cochran (1977) for measurements of continuous variables has been frequently used by various researchers [34] and was employed to calculate the typical waste sample that would...
be used for analysis. Equation (1), which is illustrated below, is used to determine the total sample sizes for the investigation.

\[
n = \frac{NZ^2PQ}{d(N - 1) + Z^2PQ}
\]  

(1)

where
\( n = \) Sample size of housing units.
\( N = \) Total number of housing units for each district.
\( P = \) Housing unit variable (residential houses).
\( Q = 1 - P. \)
\( Z = \) Standardized normal variable (1.96).
\( d = \) Allowable error (0.05).

The sample of households was designated randomly (simple and stratified) from the three zones, as mentioned in Table 2. Zone 1 contains the districts of Abdiaziz, Bondere, Shangani, Karaan, Shibis and Hamar-Weyne, Zone 2 contains the districts of Hamar-Jijab, Waberi, Hodan, Hal-Wadaag, and Wardigley and Huriwa, and Zone 3 contains the districts of Yaqshid, Daynile, Wadajir, Dharkenley, and Kahda.

\[
n = 2,388,000 \times (1.96)^2 \times 0.85 \times 0.15 \times (0.05)^2 (2,388,000 - 1) + (1.96)^2 (0.85)(0.15) = \frac{1,169,651.952}{5970.4873} \approx 196
\]

In conclusion, the researcher chose to apply the proportionate methodology and select sample households from specified zones. However, to improve the quality of the data in this survey, an additional eight residential households were added, and a total of 204 samples were considered in this study.

2.2. MSW Daily Generation Assessment

According to [35], the per capita household waste generation is determined by dividing the total amount of waste produced by the number of households and the number of days the waste was generated.

\[
\text{Generation rate formula } \left( \frac{\text{KG Capita.day}}{\text{kg}} \right) = \frac{\text{Mass of solid waste (kg)}}{\text{number of people} \times \text{Number of days}}
\]

(2)

The total mass of waste produced by each selected sample household in the three zones in Mogadishu city was weighed using a weighing balance. The weighing scales used in this study had capacities of 10 kg, 30 kg, 50 kg, and 150 kg with an accuracy of up to 100 g, which is the weight of the lightest waste that could be measured prior to sorting. Furthermore, the materials utilized to separate organic waste from inorganic waste for the survey also include white sacks and blue sacks, placing organic waste in the white sack and inorganic waste in the blue sack, while also identifying the other forms of municipal waste. According to the numbers of assigned households, the weight of each sack was measured and recorded. Over the course of the data collection and sorting, the same method will be repeated on every data of solid waste collection. In addition to that, nose masks and rubber gloves were both utilized to protect the hands and the lungs. Survey papers and pens were used for the collecting and recording of the outcome.

2.3. Characterization of MSW

2.3.1. Waste Sorting

After door-to-door solid waste collection from the sampled households, the waste was manually sorted. The wastes were placed on clean plastic sheet stretched on the floor and separated out for sorting purposes based on its content. The sample preparation procedures and sampling techniques were adjusted from ASTM D5231-92 and [22] for the chemical and physical examination of waste. Sorting involved separating the waste into groups
according to different categories depending on their characteristics, and each category was classified separately, as shown below:

- Putrescible materials (Food remnants, leaves, grasses etc.);
- Plastics;
- Paper (cartons and other paper to be separated);
- Metals (ferrous and non-ferrous to be separated);
- Glass;
- Textiles;
- Fines (Ash, dust etc.);
- Miscellaneous (wood, discarded hardware, discarded shoes, and other footwear, dry cells, batteries etc.).

\[
\text{Component of each waste (\%) = } \frac{\text{Weight of waste Sorted}}{\text{Total of waste sampled}} \times 100 \tag{3}
\]

The separated wastes were then weighed accordingly. Weighing the sorted wastes led us to determine their weight and volume. The weight and the volume of waste were recorded in a tabular form at the relevant household number manually. The volume of the samples was measured using a bucket with a known volume and mass. Knowing the weight and volume of each waste component, it was possible to compute the percentages of each waste component in the given sample. After sorting and weighing was completed, all wastes were then collected and sent to the landfill site.

2.3.2. Bulk Density

After measuring the volume and weight of each group of solid waste, the bulk density was calculated by filling the waste into a plastic bucket with a known weight; then, the bulk density of waste was determined by dividing the weight of the waste by its volume [30].

\[
\text{Bulk density} = \frac{M_1 - M_0}{V} \tag{4}
\]

2.3.3. Moisture Content

The weight of the waste sample, which reflected its wet weight, was calculated in order to determine the moisture content of solid waste. These samples were then dried for 24 h at 75 °C in an oven before being measured and recorded once more. The moisture content was then represented by the weight decrease as a percentage. The following technique was used to determine the moisture content.

\[
\text{Moisture Content} = \left[ \frac{\text{Initial Weight} - \text{Final Weight}}{\text{Initial Weight}} \right] \times 100 \tag{5}
\]

2.3.4. Statistical Analysis

This section focuses on the presentation, analysis, and interpretation of data collected from households. The statistical skewness and kurtosis are used to evaluate the normality of datasets’ model distribution [36]. In this study, skewness and kurtosis were used to evaluate the normality of MSW datasets in Mogadishu, Somalia. The equations are presented below (Equations (6) and (7)).

\[
\text{Skewness} = \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^3 \left( \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2 \right)^{\frac{3}{2}} \tag{6}
\]

\[
\text{Kurtosis} = \frac{1}{n} \sum_{i=1}^{n} i(x_i - \bar{x})^4 \left( \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2 \right)^{2} - 3 \tag{7}
\]

\( \bar{x} = \text{sample mean} \)
Pearson’s correlation coefficient (r), was used to measure the linear association between two variables (Equation (8)) with an inference that both variables are normally distributed. The correlation coefficient between variables can range from −1 (shows negative linear correlation) to 0 (shows no linear relationship) to +1 (shows positive linear correlation) [37,38].

\[
r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2}}
\]  

(8)

2.4. Evaluation of Methane Generation Rate Constant (k Value)

The methane generation rate constant, k (expressed in 1/year, or yr\(^{-1}\)), describes the rate at which waste placed in a landfill decays and produces landfill gas (LFG). At higher values of k, the methane generation at a landfill increases more rapidly (as long as the landfill is still receiving waste) and then declines more quickly after the landfill closes. The value of k is a function of waste moisture content, the availability of nutrients for methane-generating bacteria, pH, and temperature [1]. Table 3 shows the k values from first-order decay models in the literature [39]. The k value in this research is based on an IPCC model. The equation is as follows (Equation (1)):

\[
k = (FW \times 0.4) + (GW \times 0.17) + (PW \times 0.07) + (TW \times 0.07) + (DN \times 0.17) + (WS \times 0.035)
\]

(9)

where

- FW = Percentages of food waste;
- GW = Percentages of garden waste;
- PW = Percentages of paper waste;
- TW = Percentages of textile waste;
- DN = Percentages of dispositional nappies;
- WS = Percentages of wood and straw.

Table 3. The k values from first-order decay models in the literature [39].

<table>
<thead>
<tr>
<th>Country</th>
<th>Model</th>
<th>k Value (yr(^{-1}))</th>
<th>Waste Degradation/Landfill (LF)</th>
<th>t(_1)</th>
<th>t(_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>E-PRTR</td>
<td>0.5</td>
<td>Fast</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.1</td>
<td>Moderate</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.04</td>
<td>Slow</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>LandGEM</td>
<td>0.7</td>
<td>Wet area LF</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.04–0.05</td>
<td>Conventional LF</td>
<td>14–17</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.02</td>
<td>Arid area LF</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>International</td>
<td>IPCC</td>
<td>0.185</td>
<td>Food, sludge</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.10</td>
<td>Garden, disposable nappies</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.09</td>
<td>Industrial waste</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.06</td>
<td>Textile, paper</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.03</td>
<td>Wood, straw</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>GasSim</td>
<td>0.116</td>
<td>Fast</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.076</td>
<td>Moderate</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.046</td>
<td>Slow</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Holland</td>
<td>Afvalzorg</td>
<td>0.187</td>
<td>Fast</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.099</td>
<td>Moderate</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.030</td>
<td>Slow</td>
<td>23</td>
<td></td>
</tr>
</tbody>
</table>

*t\(_1\)^2 is referred to the time taken for the mass of degradable organic carbon (DOCm) in waste to decay to half of its initial mass.
3. Results and Discussion

3.1. MSW Daily Generation Assessment

The amount of MSW generated in Mogadishu city was estimated using a sample of MSW collected from each week. Figure 2 below demonstrates the results of various data collection from three zones of Mogadishu city. Most of the waste created in the study area arrived from Hodan district in Zone 1, totaling 121.2 kg. Hamarweyne district in Zone 1 took second place, generating 118.08 kg of the total waste weight for the week. Howlwadag district in Zone 2 came in the third position for generating a total 115.85 kg, whereas Waberi districts ranked fourth, weighing 115.75 kg of waste for the week. Following these were Wardhigley, 115.02 kg; Hewliwaa, 111.7 kg; Hamarjajab, 104.4 kg; and Wadjir, 90.46 kg. Dharkanley of Zone 3 and Shibis of Zone 1 scored the same rank, each weighing 89.75 kg, these were followed by Karan, 89.19 kg; Kahda, 87.89 kg; Deynile, 86.31 kg; and Yaqshid, 85.74 kg; while Shangani, Bondhere and Abdulaziz generated totals of 83.46, 83.23 and 83.15 kg, respectively. In this case, the sampled households in the three zones generated solid waste with a total amount of 1671.03 kg in one week of collection. The quantity of waste generated varies depending on the total weekday. Friday had the maximum amount of waste generation with a total of 348.72 kg throughout the research area. This shows that the generation of waste increased as households tend to stay at home on the weekends. It could be the explanation that in this study, the households are in Muslim communities, which results in a high amount of waste being generated on Friday, as it is the weekend. Also, this was noted by [35], who observed households visiting shopping centers on weekends to buy products and foods for their homes before spending that weekend in their homes. Thursday followed second, with a total of 305.44 kg, while the least amount of waste was produced on Monday: 152.04 kg.

Solid waste generation rates from all the districts of Mogadishu city were recorded during the study. It was observed that waste generation rate of districts such as Hamar Jijab, Wardigley, Waberi, Heliwaa, Hal-Wadaag, and Shangani recorded the highest amounts at 0.24, 0.23, 0.22, 0.22 and 0.22 kg/person/day, respectively, with an average value of 0.225 kg/person/day. The districts that took the second place in waste generation rate included Hodan, Bondere, Hamarweyne, Yaqshid and Dayniile. which recorded the medium amounts at 0.21, 0.21, 0.21 and 0.2 kg/person/day, respectively, with the mean per capita waste generation rate of 0.208 kg/person/day. The least quantity of waste generated came from districts such as Abdulaziz, Shibis, Wadjir, Kahda, and Dharkanley at 0.18, 0.18, 0.17, 0.17 and 0.16 kg/person/day, respectively. The total mean generation rate observed in this study was 0.2 kg/person/day. A comparable investigation conducted by [25] in Bahir Dar City, Amhara National Regional State, Ethiopia, showed that the average waste generation by households is 0.22 kg/capita/day. Therefore, the generation rate of this study differs from that of a study by [35], which found that households in Palapye, a district in central Botswana, had the lowest generation rate of 0.038 kg/capita/day and the greatest generation rate of 0.364 kg/capita/day. This study has revealed that Zone 2 households generated the highest quantities of solid wastes followed by Zone 1 and lastly Zone 3. This study is comparable to the study conducted by [40]. The results are also close to the outcome of a study conducted by [24] in Rishikesh, a town of Dehradun city of Uttarakhand and a class II city of India.

3.2. Characterization of MSW

3.2.1. Bulk Density

The bulk density of the waste from different areas in Mogadishu city was also calculated. The total bulk density of the households in Zones 1, 2, and 3 was calculated to be 0.262, 0.270 and 0.275 kg/L, respectively. The average bulk density was found to be 0.269 kg/L, as shown in Figure 3. Bulk density is important for engineers to estimate the shear strength of MSW as well as determine the MSW slope stability analysis and landfill liner system [41].
Figure 2. Daily generation of total solid waste (kg) in Zones 1, 2, and 3 (results are presented as mean ± standard deviation).
3.2.2. Moisture Content

The rapid determination of moisture content plays an important role in guiding the recycling, treatment, and disposal of solid waste, as the moisture content of solid waste directly affects the leachate generation, microbial activities, pollutants leaching and energy consumption during thermal treatment [42]. Moisture content also has an environmental impact by producing greenhouse gas emissions (e.g., methane, nitrous oxide, and carbon dioxide) [43].

Figure 4. In the present investigation, food waste has the greatest percentage of moisture content of 55.27%, which is followed by yard waste (26.83%), paper (8.75%), wood (5.17%), plastic (2.34%) and miscellaneous (1.12%). The lowest moisture contents of the waste component came from textiles (0.21%), glass (0%) and metal (0%). The results are equivalent to those found by [44]. Organic wastes containing high moisture content were obtained in every sample from households. On weekdays, the overall moisture content of the household sample waste from Zone 1, Zone 2 and Zone 3 was observed to be just 66, 61.6, and 72%, respectively. In comparison to weekends, the overall moisture content was found to be 70, 68.6, and 73% respectively.

The results were comparable to a study conducted by [35]. Since the percentage of food waste was predominant in comparison to the collected wastes, it is expected that the overall moisture content of the food wastes from the three study zones would be significant solid wastes in general. Due to a significant percentage of food wastes being identified in the present study, it is likely that the overall moisture content of the solid wastes will be significant.

3.2.3. Statistical Analysis

The descriptive statistics on the weight (Weight_Z1, Weight_Z2, and Weight_Z3) and moisture contents (MC_Z1, MC_Z2, and MC_Z3) of the generated solid waste in Zones 1, 2 and 3 are presented in Table 4 below. It consists of minimum, maximum, mean, standard deviation, variance, skewness, and kurtosis.
Figure 4. Moisture content of SW in three zones of Mogadishu districts (results are presented in mean ± standard deviation).

Table 4. Descriptive statistics in weight and moisture content of generated solid waste in Zones 1, 2, and 3.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Variance</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight_Z1</td>
<td>9</td>
<td>0.29</td>
<td>47.45</td>
<td>11.1111</td>
<td>14.61028</td>
<td>213.460</td>
<td>2.307</td>
<td>5.873</td>
</tr>
<tr>
<td>Weight_Z2</td>
<td>9</td>
<td>0.21</td>
<td>51.46</td>
<td>11.1111</td>
<td>15.96583</td>
<td>254.908</td>
<td>2.455</td>
<td>6.502</td>
</tr>
<tr>
<td>Weight_Z3</td>
<td>9</td>
<td>0.16</td>
<td>56.94</td>
<td>11.1111</td>
<td>17.95015</td>
<td>322.208</td>
<td>2.565</td>
<td>6.916</td>
</tr>
<tr>
<td>MC_Z1</td>
<td>9</td>
<td>0.00</td>
<td>55.39</td>
<td>11.1111</td>
<td>18.67171</td>
<td>348.633</td>
<td>2.093</td>
<td>4.170</td>
</tr>
<tr>
<td>MC_Z2</td>
<td>9</td>
<td>0.00</td>
<td>55.48</td>
<td>11.1111</td>
<td>18.18332</td>
<td>330.633</td>
<td>2.252</td>
<td>5.112</td>
</tr>
<tr>
<td>MC_Z3</td>
<td>9</td>
<td>0.00</td>
<td>49.88</td>
<td>11.1111</td>
<td>17.43537</td>
<td>303.992</td>
<td>1.815</td>
<td>2.553</td>
</tr>
</tbody>
</table>

Skewness and kurtosis are used to describe the spread and height of the data normal distribution [38]. Skewness is used to measure the asymmetry of data distribution. The data distribution can be symmetrical (−0.5 to 0.5), negatively (−1 to −0.5) or positively (>1) skewed. If the skewness is lower than −1 (negatively skewed) or greater than 1 (positively skewed), the data are highly skewed. The skewness values obtained for the generated daily weight of solid waste were 2.307 ± 0.717 (Zone 1), 2.455 ± 0.717 (Zone 2), and 2.565 ± 0.717 (Zone 3). Meanwhile, the skewness values for moisture content were
2.093 ± 0.717 (Zone 1), 2.252 ± 0.717 (Zone 2), and 1.815 ± 0.717 (Zone 3). Overall, all the data were positively skewed.

Kurtosis is used to find outliers in the analyzed data. Kurtosis values can be classified as mesokurtic (kurtosis = 3), leptokurtic (kurtosis > 3), and platykurtic (kurtosis < 3). The greater the value of kurtosis, the higher the peak. The kurtosis values obtained for the generated daily weight of solid waste were 5.873 ± 1.40 (Zone 1), 6.502 ± 1.40 (Zone 2), and 6.916 ± 1.40 (Zone 3). They were classified as leptokurtic. The kurtosis values for moisture content were 4.170 ± 1.40 (Zone 1), 5.112 ± 1.40 (Zone 2), 2.553 ± 1.40 (Zone 3). Zones 1 and 2 were classified as leptokurtic, while Zone 3 was classified as platykurtic.

Table 5 shows the Pearson correlation (r) and p-value for (a) the weights and (b) the weights and moisture content of generated solid waste in Zones 1, 2 and 3. The Pearson correlation (r) measures the linear relationship between two variables: two data points, X and Y [45]. Pearson correlation can be categorized into negative linear (r ≤ −1), positive linear (r ≥ 1), and no linear (r = 0) relationship. Data points that have no linear relationship can be considered to have the potential to be quadratic or any other higher degree relationship between the data points. The r values for data points between weights in all zones were 0.978 (Z1 vs. Z2), 0.999 (Z1 vs. Z3), and 0.976 (Z2 vs. Z3). As for the data points between weight and moisture contents, the r values were 0.891 (weight_Z1 vs. MC_Z1), 0.917 (weight_Z2 vs. MC_Z2), and 0.817 (weight_Z3 vs. MC_Z3). Overall, the r values were close to 1 (0.817 ≤ r ≤ 0.999).

**. Correlation is significant at the 0.01 level (2-tailed).

The p-value (also quoted as Sig. (2-tailed)) stands for probability value of measured variables to be under the assumption of no effect or no difference) between variables [46]. It is called 2-tailed because the areas under both sides of tails of a normal distribution are tested (two critical regions, mean > p-value and mean < p-value). Moreover, there are two hypotheses to be tested for this purpose. They are null (H₀) and alternative (Hₐ) hypotheses. H₀ represents no difference between variables (p-value > 0.05). Hₐ represents significant difference between variables (p-value < 0.05). A significant difference implies that the tested variables affect each other. The Sig. (2-tailed) values were 0.000 (Z1 vs. Z2), 0.000 (Z1 vs. Z3), 0.000 (Z2 vs. Z3), 0.001 (weight_Z1 vs. MC_Z1), 0.001 (weight_Z2 vs. MC_Z2), and 0.007 (weight_Z3 vs. MC_Z3). Overall, the sig. (2-tailed) values for (a) the weights and (b) the weights and moisture content of generated solid waste in all zones were all less
than 0.05 and significant at the 0.01 level. It showed that $H_a$ is acceptable, since there is a significant difference between the measured variables, and therefore, $H_0$ is rejected.

3.3. Evaluation of Methane Generation Rate Constant ($k$ Value)

The waste components that accounted for the $k$ value estimation in this study were food wastes, wood, yard waste, paper/cardboard, and textiles. Figure 5 shows the methane generation rate constant ($k$ value) for all the waste components in this study. The $k$ values established by E-PRTR, GasSim and Afvalzorg [39] were found to be matched with the values obtained in this study.

Figure 5. The methane generation rate constant ($k$ value) for all waste components in this study (1 E-PRTR, 2 GasSim, 3 Afvalzorg, results are presented in mean ± $p \leq 0.05$).

The $k$ values for food wastes were 0.1898 yr$^{-1}$ (Zone 1), 0.20584 yr$^{-1}$ (Zone 2), and 0.22776 yr$^{-1}$ (Zone 3). These values can be categorized as fast degradation. As mentioned earlier in the introduction, the value of $k$ is proportionate to (a) the waste moisture content, (b) the availability of nutrients for methane-generating bacteria, (c) pH, and (d) temperature [2–4]. Moisture conditions within a landfill strongly influence $k$ values and waste decay rates. Restaurant wastewater contained high chemical oxygen demand (COD) values, showing high nutrients present in the wastewater [47]. Therefore, food waste may contain the same nutrients required for methane-generating bacteria and archaea (also known as anaerobic methanogens). The average moisture contents for food waste in all zones were observed to be more than 50%, indicating the presence of water needed for all microbes to survive and degrade the food waste.
The $k$ values for wood were 0.001246 yr$^{-1}$ (Zone 1), 0.000938 yr$^{-1}$ (Zone 2), and 0.000518 yr$^{-1}$ (Zone 3). These values can be categorized as slow degradation. Yard wastes comprised shrubs, grasses, and bushes. The $k$ values for yard waste were 0.018343 yr$^{-1}$ (Zone 1), 0.016235 yr$^{-1}$ (Zone 2), and 0.011305 yr$^{-1}$ (Zone 3). These values can be categorized as slow degradation. The $k$ values for paper/cardboard were 0.005432 (Zone 1), 0.004788 (Zone 2), and 0.004053 (Zone 3). These values can be categorized as slow degradation. Wood, yard wastes, and paper/cardboard are high cellulose content organic materials, similar to polymeric materials like plastics. At normal temperature, they took a longer time to degrade. The degradation can be induced with high temperature [48].

The $k$ values for textiles were 0.001232 yr$^{-1}$ (Zone 1), 0.000938 yr$^{-1}$ (Zone 2), and 0.000959 yr$^{-1}$ (Zone 3). These values can be categorized as slow degradation. Textiles can be made from organics (animal, plants, minerals) or synthetic materials (nylon, polyester, acrylic) [49]. Textiles may contain harmful chemical dyes that posed environmental threats during the degradation process.

The total $k$ values were 0.216053 yr$^{-1}$ (Zone 1), 0.228739 yr$^{-1}$ (Zone 2), and 0.244595 yr$^{-1}$ (Zone 3). Overall, the $k$ values from Zones 1, 2, and 3 can be categorized as moderate and fast degradation. Other $k$ values were also reported from Thailand (0.33 yr$^{-1}$), Malaysia (Jeram Sanitary landfill, wet season: 0.136 yr$^{-1}$, dry season: 0.072 yr$^{-1}$) [50], the USA (14 landfills, 0.04 yr$^{-1}$) [51], and Panama (Central America, wet climate, 0.23 yr$^{-1}$) [52]. The $k$ values in Mogadishu, Somalia were similar to those in Central America, Panama, which has a wet climate.

The waste that is of great concern is emerging miscellaneous waste such as e-waste (electronics, electrical appliances, batteries, etc.). As compared to the rest of the world, the SWM in Mogadishu is foreseen to be improved in the future starting from this research.

4. Conclusions

The current study is a pioneering effort to investigate the generation, collection, and composition rates of household solid waste during the past three decades in Mogadishu city, Somalia. Mogadishu city is experiencing an increase in the quantity of waste generated from households, similar to other developing cities in Africa, yet there is a shortage of important data to create a successful waste management system. Therefore, this study establishes the quantification and characterization of household solid wastes, which are essential in determining the sources of generation of solid waste management system.

The weekends experienced the largest amounts of waste generated. The waste generated by the three zones differed significantly from one another. Zone 2 created the highest quantities of waste, with a total weekly significant difference of 137.16 kg from Zone 1. The food waste in Zone 1 and Zone 2 increased by 6.21% and 3.86% from weekday to weekend, respectively. It has also been found that there was a reduction in food waste in Zone 3 by 5.03%.

The study indicates that food waste is the largest component of solid wastes in the study area. The food waste composition collected from weekdays and weekends is found to be 47.45% and 53.66% for Zone 1, whereas it is 51.46% and 55.32% for Zone 2, and 56.94% and 51.93% for Zone 3, respectively. On weekdays, the solid waste generation was found in the following decreasing order: food waste > Plastic/Polythene > yard waste > miscellaneous > papers/cardboard > wood > glass/ceramic > textiles > metals by weight.

The high moisture content in household samples may have been caused by the high percentage of food wastes. The overall moisture content of food waste from household sample waste from Zones 1, 2 and 3 was observed to be just 55.39%, 55.48%, and 49.88%, respectively. The bulk density of collected waste samples from the households in the three Zones 1, 2, and 3 was found to be 0.622, 0.670 and 0.275 kg/L, respectively. For Zones 1, 2, and 3, the methane generation rate constant ($k$ value) values of food wastes, wood, yard waste, paper/cardboard, and textiles were determined. These values can be categorized into three categories: slow degradation, moderate degradation, and fast degradation. Other
than the first collection of MSW data toward MSW management in the country, the added value of this research is the methane generation rate constant indicated a dispersion of landfill gas to the atmosphere per year from Mogadishu city.

The beginning and the progress of this research over time are always challenging. The type of challenge being faced is the involvement of the local people in practicing safe disposal. It all starts with education. The government is new but always has given full support for this research. The authors worked hard to sustain the progress of this research in order to have a fully operational MSW management and planning in the country in the future. The study strongly suggests that the city needs comprehensive planning to overcome the major problems with SW management. The local government should implement waste reduction strategies including reducing, reusing, and recycling at every household level in every district, and daily waste audits should be performed in the city to maintain the collection system of solid waste from households. The city needs an incineration process to be adapted in the city, since the percentage weight of paper and cardboard ranges from 5 to 12%. The following are further recommendations aimed at improving the current SWM system in Mogadishu city: it should contain contributions from the community and the participation of non-governmental organizations. To promote a scientific way of collecting waste from the place of generation, dust bins should be used at and around the streets to reduce the risk of the spread of diseases. All districts should demonstrate, promote and implement waste management into educational programs under local government administration.


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References


42. Victoire, A.; Martin, N.V.; Abias, M.; Pacifique, U.; Claude, M.J. Solid Waste Management Challenges and Its Impacts on People’s Livelihood, Case of Kinyinya in Kigali City. J. Geosci. Environ. Prot. 2020, 8, 82–96. [CrossRef]


46. Erdal, N.B.; Hakkarainen, M. Degradation of Cellulose Derivatives in Laboratory, Man-Made, and Natural Environments. Biomacromolecules. 2022, 23, 2713. [CrossRef]


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