Toward a Sustainable Municipal Solid Waste Management: Gaps and Challenges in Africa

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Abstract: This paper comprehensively evaluates the status of municipal solid waste (MSW) management in 54 African countries, with particular attention on MSW generation, collection, disposal, and related legislations from economical and geographical perspectives. By non-spatial data analysis model, the controlling factors that affect the daily MSW generation per capita are determined. The results show the heterogeneity of daily per capita MSW generation across African countries, ranging from 0.1 kg to 1.49 kg in 2016, largely affected by income level, national laws, geographical location and frequency of collection, particularly by GDP per capita and legislation system. The higher MSW generation, collection rates and disposal rate often occurred in economically developed maritime countries. In addition, the wide gap of MSW collection rate not only existed between African countries, but also existed within a country, even in a city, especially for low-income and middle-income countries. Moreover, there was a lack of solid waste regulations in majority Africa countries, and they are poorly implemented while where there are regulations. Based on MSW generation prediction model, the total MSW generation in Africa is expected to triple in 2050, making the future of solid waste management in Africa more challenging.

1. Introduction

With rapid economic development and urbanization and change in peoples' consumption behaviors, municipal solid waste (MSW) generation is growing vigorously. Africa, the second largest continent, covering about one-fifth of the total land surface of Earth, has nourished more than one-eighth of the total population of the world. World Bank and United Nations Population Division reported that during the period of 2012-2016 the GDP and population of Africa grew by -5% and 11% but the MSW generation increased by 55% (United Nations 2019, World Bank 2018), suggesting that the MSW management system of Africa worthy of investigation.

Published literatures have summarized the status of MSW management in Asia (Khajuria et al. 2008), Europe (Bing et al. 2016), even at a global (Karak et al. 2013). However, the research on MSW management throughout Africa is still lacking, only few works focused on some countries or cities in Africa are available. On a national scale, many African countries, such as Uganda (Okot-Okumu &Nyenje 2011), Kenya (Tukahirwa et al. 2013) and Nigeria (Abila 2014, Ezeah &Roberts 2012) have shown significant shortcomings of solid waste management. For example, in Lake Nakuru, Kenya , as many as 40,000 birds died in 1993 due to the heavy metal pollution brought by the improper management of MSW, and the number of deaths increased following years , causing multiple environmental and financial problems to the city (Raini 2009). At a city level, the MSW disposal system in Accra, Ghana (Oteng-Ababio et al. 2013) and Johannesburg and South Africa (Serge Kubanza &Simatele 2019) have been also reported. There were limited research references dealing with the generation, composition, disposal, and management system of MSW in Africa. Therefore, a

76   comprehensive study addressing these issues is crucial.

77   Africa is bounded on the west by the Atlantic Ocean, on the north by the Mediterranean

78   Sea, on the east by the Red Sea and the Indian Ocean, and on the south by the mingling

79   waters of the Atlantic and Indian oceans. As a result, Africa appears to be geographically

80   isolated, facing the Europe across the Mediterranean Sea and the Strait of Gibraltar in the

81   north, separating from Asia by the narrow Red Sea and the Suez Canal. However, due to the

82   600 years' colonial history of Africa and growing foreign aid initiated by the vision of

83   community with shared future for mankind, the generation and disposal of MSW in Africa is

84   undergoing huge transformation, with the policy and technology transfer from developed

85   countries. In this pretext, this paper attempts to review the overall situation of MSW

86   management in Africa. Specific objectives are to: (I) identify the MSW generation and

87   composition in African countries, and forecast the future MSW generation;(II) examine the

88   differences of MSW collection and disposal methods between African countries and

89   neighboring regions; (III) investigate the MSW legal and regulatory systems in African

90   countries; (IV) identify the determining factors of MSW generation with multiple regression

91   model; and (V) recommend potential solutions for MSW management in future.

92

93   **2. Data collection and analysis methods**

94   **2.1 Date collection**

95   Most data used in this article including the African MSW generation, compositions,

96   collection rates, disposal and treatment information mainly comes from the World Bank

97   database (World Bank 2018). The population growth data comes from the United Nations'

98 World Population Outlook 2019, and the economic growth data comes from Africa

99 Development Bank (United Nations 2019). Additionally, the specific laws and regulations

100 involved in environmental laws and solid waste management in various countries are from

101 their respective national environmental websites(NUNIGU 2020).

102 **2.2 MSW generation prediction**

103 　　In order to evaluate the increasing tendency of MSW generation in the future, the global

104 MSW generation forecast model eq. (1) proposed in the World Bank report (Silpa Kaza 2018)

105 was adopted. It assumes that MSW generation is mainly based on two factors: the growth of

106 gross domestic product (GDP) and population growth. In the model, the natural logarithm of

107 GDP per capita is the independent variable and waste generation per capita is the dependent

108 variable. GDP per capita (PPP) is also introduced to adjust the differences in prices in

109 different countries. In that case, predication of $MSW\ generation$ can be easily determined

110 from historic data including PPP, population, economic and population growth rates.

111 $$MSW\ generation\left(\frac{kg/person}{day}\right) = \beta_0 - \beta_1 Ln(GDP\ per\ capita) + \beta_2 Ln^2(GDP\ per\ capita) \quad (1)$$

112 　　Where:β_i: Coefficient of independent variables, β_0: Constant term

113 **2.3 Degree Estimation of the impact factors affecting the MSW generation**

114 　　The daily MSW generation per capita is related to local economic growth (per capita

115 GDP), collection rate, solid waste management legislation, geographical location and other

116 factors. Taking daily MSW generation per capita as a dependent variable, and taking

117 economic growth (per capita GDP), collection rate, solid waste management legislation and

118 geographic location as independent variables, the controlling factors that affect the daily

119 MSW generation per capita can be determined by historical data modeling and fitting

120 analysis.

121   Keser et al. (2012) proposed an impact analysis model for non-spatial data analysis as

122   the eq. (2). The Ordinary Least Square (OLS) method was used to estimate the parameters in

123   multiple regression models. Per capita GDP and collection rate are quantitative variables, and

124   solid waste management legislation and geographic location are qualitative variables.

125                                $$Y = \beta_0 + \beta_i X_i + \varepsilon \qquad\qquad (2)$$

126   Where: Y= Amount of daily per capita MSW generation,

127   X_i: Independent variables,

128   β_i: Coefficient of independent variables,

129   β_0: Constant term, ε: Disturbance term

130   In order to test the effectiveness of the OLS model, for non-spatial and spatial variables,

131   the significance is tested at the 95% confidence level ($P<0.05$), so that independent variables

132   can effectively predict the variation of dependent variables. The standardized correlation

133   coefficient (Beta) is often used to compare the importance of various variables, and its

134   absolute value can be directly used to determine the ranking order among independent

135   variables.

136

137   **3. Results and discussion**

138   **3.1. Municipal solid waste generation**

139   **3.1 1 MSW Generation Vs GDP**

140   According to the World Bank(World Bank 2018), in 2016, the world and Africa

141   generated 2.01 billion tons and 194 million tons of MSW, respectively. The average MSW

142   generation per capita in Africa (0.49 kg per day), Middle East averages (0.89 kg), Latin

143   America and the Caribbean averages (0.99 kg), and Europe (1.2 kg) varies substantially (Kaza

144   et al. 2018).

145   The daily per capita MSW generation in African countries varied from 0.1 kg to 1.49 kg

146   in 2016 (as shown in Fig.1), with 21 countries had higher than African averages (0.49

147   kg)—such as Seychelles (1.49 kg), Rwanda (1 kg), South Africa (0.98 kg), Libya (0.95

148   kg)—while Ethiopia, Lesotho, Sudan and Guinea had less than 0.2 kg.

149   Fig.1 depicts that the relationship between daily per capita MSW generation and GDP

150   per capita cannot be expressed by the linear model. For 37 African countries where GDP per

151   capita were less than \$5000, the daily per capita MSW generation ranged from 0.1 kg

152   (Lesotho) to 1.0 kg (Rwanda), and most countries (accounting for 73%) generated in the

153   range of 0.3 kg~ 0.6 kg. For the remaining 17 countries where GDP per capita were higher

154   than \$5000, MSW generation per capita varied from 0.29 kg (Botswana) to 1.49 kg

155   (Seychelles). In 11 countries' daily MSW generation rates were higher than African averages
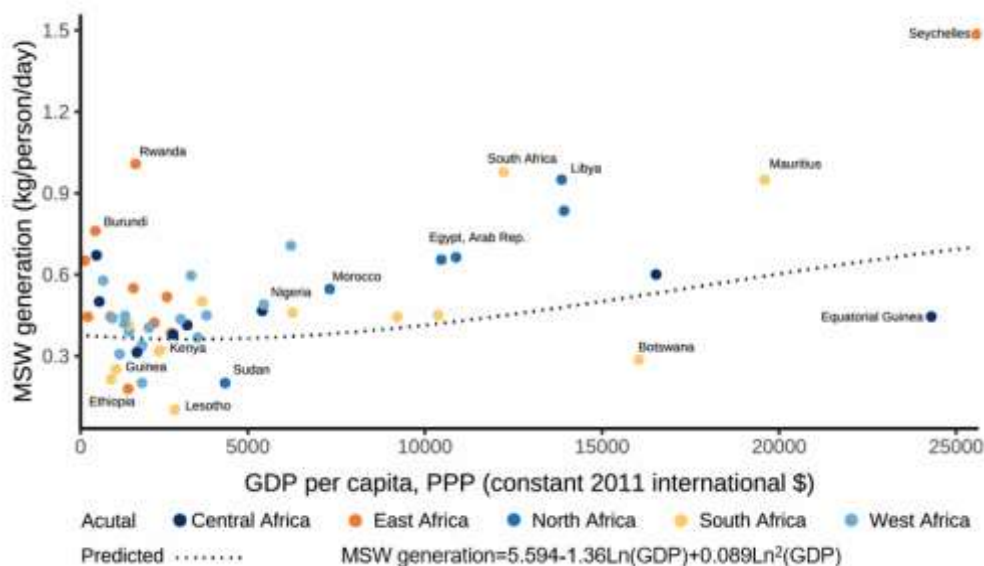
156   (0.49 kg).

157

158   **Fig.1.** The per capita GDP and daily per capita MSW generation in African countries.

159   There was no significant difference in daily per capita MSW generation between North

160   Africa and Sub-Saharan Africa (Central Africa, East Africa, Southern Africa and West Africa).

161   In North Africa, per capita MSW generation ranged from 0.2 kg (Sudan) to 0.95 kg (Libya)

162   with the average of 0.6 kg, whereas in Sub-Saharan Africa it ranged from 0.1 kg (Lesotho) to

163   1.49 kg (Seychelles) with the average of 0.46 kg.

164   **3.1.2. MSW Generation Vs Geographical location**

165   Fig.2 presents the total and daily MSW generation and population size across the five

166   regions of Africa. West Africa has the highest population followed by East Africa, North

167   Africa, Southern Africa and Central Africa, whereas the total MSW generation was highest in

168   West Africa followed by North Africa, East Africa, Southern Africa and Central Africa, and

169   daily per capita MSW generation was highest in North Africa followed by Southern Africa,

170   Central Africa, West Africa and East Africa.

171   According to Fig.2, population and total MSW generation in Central Africa was the

172   lowest, while the lowest daily per capita MSW generation occurred in East Africa.

173   Surprisingly, Seychelles, located in the East Africa region, produced the highest amount of

174   daily per capita MSW generation at 1.49 kg in Africa, which was even higher than European

175   countries, such as France (1.37 kg) and Britain (1.33 kg). This was mainly due to market

176   liberalization and economic development fueled particularly by tourism, which resulted in a

177   dramatic increase of net imports of consumer goods and durables (Meylan et al. 2018,

178   Ragazzi et al. 2014). Similarly, Mauritius (0.95 kg per day) and South Africa (0.98 kg per

179   day), as coastal tourism-oriented countries, also generated relatively higher amount of MSW

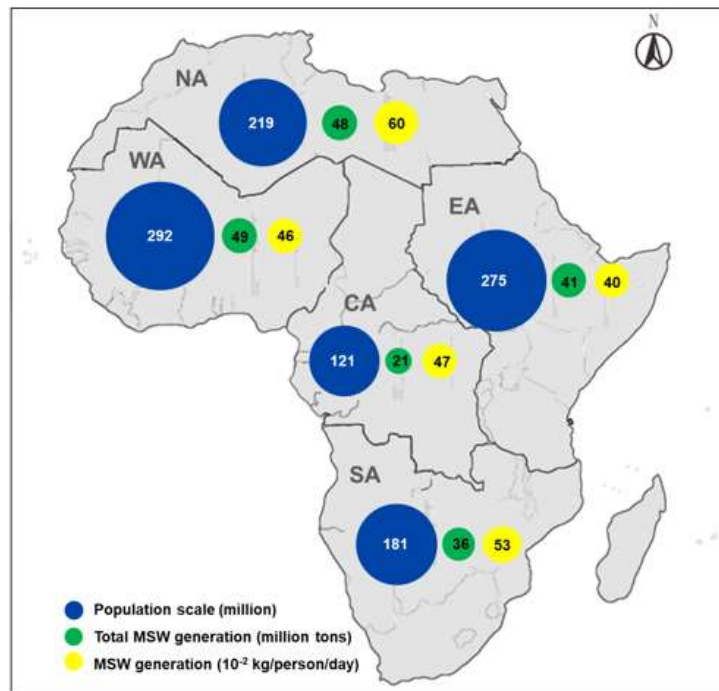180   per capita than other countries in Africa.

181

Fig.2. Population and MSW generation in Africa.

The coastal tropical scenery has promoted the rapid development of tourism, and becomes the main driving force of economic development in Seychelles, Mauritius and South Africa. Moreover, the advancement of economic development has inevitably led to changes in lifestyle, production and consumption patterns, which further promoted the increase in the number of MSW per capita (Foolmaun et al. 2011).

3.1.3 Prediction of MSW generation in 2050

MSW generations are generally correlated with income levels, population, urbanization and consumption behaviors (Couth &Trois 2011, Scarlat et al. 2015). The effect of changing consumption behaviors on MSW generation is difficult to be quantified. Urbanization and income levels are closely related with the economic growth of countries (Chen et al. 2014).

The best fitted-curve for Africa MSW generation is shown in Fig 1. The GDP per capita of $2100 seems an important inflection point in some countries. When GDP per capita is below $2100, MSW generation is negatively correlated with GDP per capita but when it is

197 greater than about $2100, MSW generation is positively correlated with GDP per capita. This

198 findings is in concurrent with the results of *Global Waste Management Outlook* (UNEP 2015).

199   In 2016, the national GDP per capita of 32 African countries all exceeded $2100. Thus, it

200 is possible to well predict the increase tendency of MSW generation in Africa on the basis of

201 PPP and population data. Based on above model method in 2.2, the regression model of MSW

202 generation per capita can be expressed as (1):

203 $$MSW\ generation\left(\frac{kg}{person}\Big/day\right) = 5.594 - 1.361Ln(GDP\ per\ capit) + 0.089Ln^2(GDP\ per\ capit) \quad (1)$$

204   The R square of the model is 0.37, and the p-value is 0, which is less than the inspection

205 standard of p<0.05.

206   The International Monetary Fund (IMF, 2019) reported that the economic recovery in

207 sub-Saharan Africa continues, and the growth is projected to rise to 3.6% in 2020. According

208 to African development bank (AFDB, 2011), GDP growth rate will be 3.9% and 3.8% in 2030

209 and 2050, respectively and GDP per capita will be $7999 in 2030 and $15080 in 2050.

210 Meanwhile, (United Nations 2019) predicted that the Africa's population will be 1.7 billion in

211 2030 and 2.5 billion in 2050. Therefore, according to the MSW generation prediction model,

212 the total MSW generation in Africa will be 342 million tons in 2030 and 673 million tons in

213 2050 (triple than that in 2016).

214 **3.2 Municipal solid waste Composition**

215   Food organic waste is the foremost contributor to the total MSW stream with a high

216 proportion of 49%, followed by dry recyclables, including plastic, paper and cardboard, metal

217 and glass, which collectively accounts for 28%(World Bank 2018). However, the

218   compositions of MSW in Africa countries were very uneven, varies significantly by cities,

219   industrialization，income levels and consumption behaviors (Kumar et al. 2009, Ozcan et al.

220   2016). Globally, the largest proportion of MSW was food organic waste (44%) followed by

221   dry recyclables (38%). Compared with the world averages, the higher ratio of food organic

222   waste and lower ratio of dry recyclables in Africa are partly attributable to the less

223   industrialization (Zhang et al. 2010).

224   As discussed in previous section, the compositions of MSW in African countries were

225   dominated by food organic waste and dry recyclables, but the proportion in different income

226   levels presented a certain discrepancy. According to 2015 GNI per capita (World Bank, 2020),

227   the income level was classified into four categories, high-income (HIC): $12,476 or more,

228   upper-middle-income (UMIC): $4,036-$12,475, lower-middle-income (LMIC):

229    $1,026-$4,035, low-income (LIC): $1,025 or less. Fig.3(a) illustrates the MSW composition

230   in 31 African countries at different income levels. From high to low, the ratio of food organic

231   waste in MSW was LIC (58%), LMC (52%), HIC (48%) and UMIC (34%), the ratio of dry

232   recyclables was UMIC (34%), LMC (31%) HIC (25%), and LIC (16%). In general, income

233   level was negatively related to daily per capita generation of food organic waste, and

234   positively related to daily per capita generation of dry recyclable, which is consistent with

235   previous studies (Qu et al. 2009). Seychelles was the only countries classified as high-income

236   country, therefore the MSW composition in HIC was not representative enough to meet the
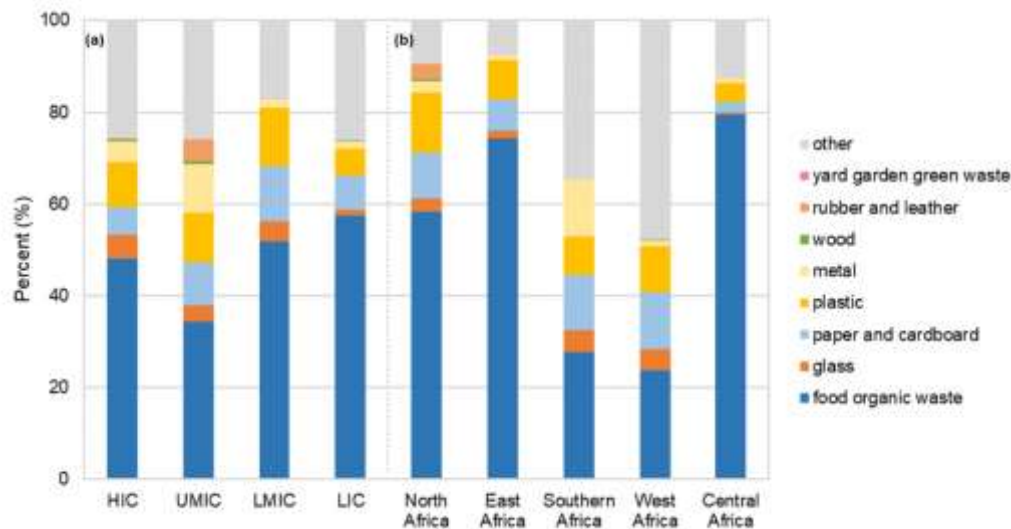
237   inference proposed above.

238

Fig.3. Compositions of municipal solid waste by income levels (a) and by regions (b).

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The differences of MSW compositions between cities with different income levels were

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even greater than that of between countries. Durban in Southern Africa and Windhoek in

241

Namibia, which were classified as high-income countries, the proportion of dry recyclables

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was roughly similar (50%) to that in Western Europe. However, the proportion of dry

243

recyclables in cities belong to low-income countries, such as the Debre Tabor in Ethiopia and

244

Niamey in Niger, were less than 5%.

245

According to Fig.3 (b), the difference of MSW compositions by regions were even more

246

noticeable. The ratio of food organic waste in MSW was highest in Central Africa (79%)

247

followed by East Africa (74%), North Africa (58%), Southern Africa (28%) and West Africa

248

(24%). Similarly, the ratio of dry recyclables in MSW was highest in Southern Africa (38%)

249

followed by North Africa (28%), West Africa (28%), East Africa (18%) and Central Africa

250

(8%). The ratio of dry recyclables in Southern Africa (38%) was close to the world averages,

251

whereas the dry recyclables in Central Africa was only a fifth of the world averages.

252

253

254 **3.3 Municipal solid waste collection**

255   Fig.4 depicts the income levels and collection rates of MSW in African countries, using

256 the collection rate data from Scarlat (Scarlat et al. 2015). The average collection rate of MSW

257 of Africa countries is 48%, with the range from 18% to 98%. Mauritius accounts for the

258 highest collection rate (98%) in Africa, followed by Seychelles (96%), Algeria (92%) and

259 Morocco (86%). As shown in the Fig.4(a), the countries with higher collection rates are

260 mostly located in coastal economically developed areas. The MSW collection rate in

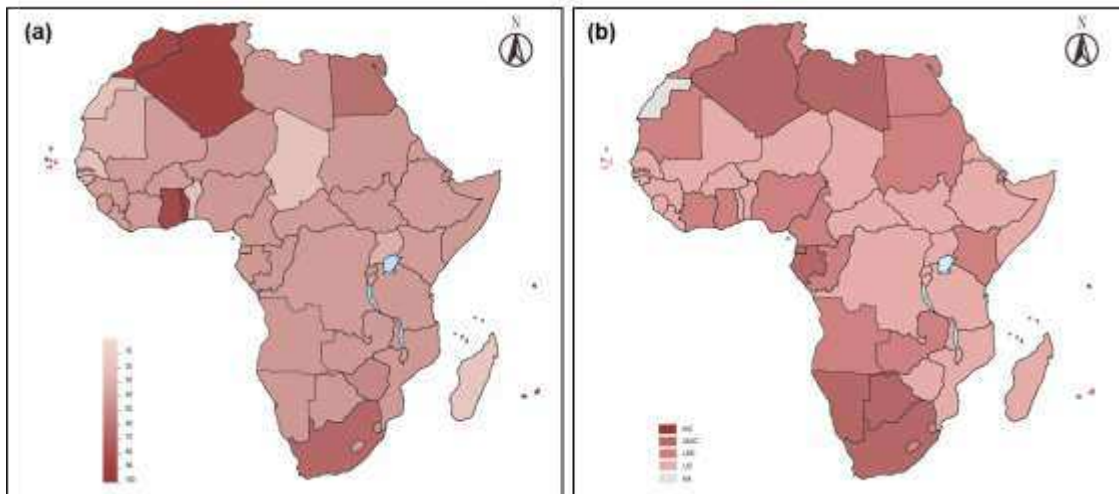261 landlocked African countries were less than 50%, with the average collection rate of 40%.

262

263   **Fig.4.** Collection rates of MSW (a) and income levels classification (b) in African countries.

264   The average collection rates of MSW in African countries by income levels were as

265 follows: HIC (96%), UMIC (57%), LMC (54%) and LIC (39%), excluding for Western

266 Sahara, as a disputed territory lacking of income level data. The average collection rate of

267 MSW in high-income countries was 2.46 times greater than low-income countries. Hence, we

268 suggest that the higher the income level was, the better the MSW collection rate.

269   The collection rate of MSW in African countries was unbalanced and had a wide

270 variation even if within a country. For example, in Morocco, the collection rates differed

271   greatly between Tangier (31%) and Rabat (90%), partly due to the variation of community

272   structure. In addition, MSW collection rates even varied within a city. Collection rate was

273   higher in urban areas (43%) than in sub-urban areas (9%). In low-income and middle-income

274   countries, collection rate of MSW can be as high as 90% in urban centers, yet as low as 10%

275   in the sub-urban areas (UN-Habitat 2010).

276   Mixed collection was another problem of MSW management in Africa, and the source

277   separation was yet to emerge (Oteng-Ababio et al. 2013). The main limitations of MSW

278   source-separation collection are the disorganization of MSW classification and the mixed

279   transportation and disposal (Taweesan et al. 2016, Zhang et al. 2012). Although Africa was

280   not enthusiastic about the MSW source separation , the residents had potential and strong

281   appetite for formal recycling at the household level, and nearly 80% of residents are willing to

282   separate at source in Eastern and Southern African cities (Mbiba 2014). If this willingness

283   was encouraged and supported by city policies and intervention activities, as much as 40% of

284   MSW currently landfilled could be diverted (Mbiba 2014) .

285   **3.4 Municipal solid waste disposal**

286   **3.4.1 Municipal solid waste disposal**

287   Due to the lack of regular waste collection and disposal services in most African cities,

288   MSW management and disposal operations was very difficult (Mmereki 2018, Teshome

289   2020). Poor financial resources, limited technical capabilities and poor infrastructure was

290   major obstacles in planning and managing solid waste (Gutiérrez Galicia et al. 2019, Henry et

291   al. 2006). At present, governments are increasingly focusing on SWM and taking proactive

292   actions to reduce waste generation but is mostly targeted at urban areas.

293   Open dumping and landfills was the main disposal method of MSW in Africa, sharing

294   approximately 31% and 28% of MSW were disposed, respectively(World Bank 2018). With

295   the absence of MSW disposal data in some Sub-Saharan African countries, we speculate that

296   the actual amount of MSW disposed by open dumping might be higher than the current

297   statistics presented in this paper.

298   Fig.5 presents the disposal methods of MSW by income levels in 28 African countries.

299   Since the lack of disposal data in high-income country such as Seychelles, the income levels

300   in this section were only divided into three levels: UMIC, LMC and LIC. The open dumping

301   rate of MSW was highest in LIC (51%) followed by LMC (28%) and UMIC (0%). The open

302   dumping rate of MSW in LIC was nearly twice of LMC. Therefore, we conclude that the

303   lower the income level was, the higher the open dump rate would be. The recycling rate of

304   MSW was highest in UMIC (8%) followed by LMC (7%) and LIC (6%). The lower the

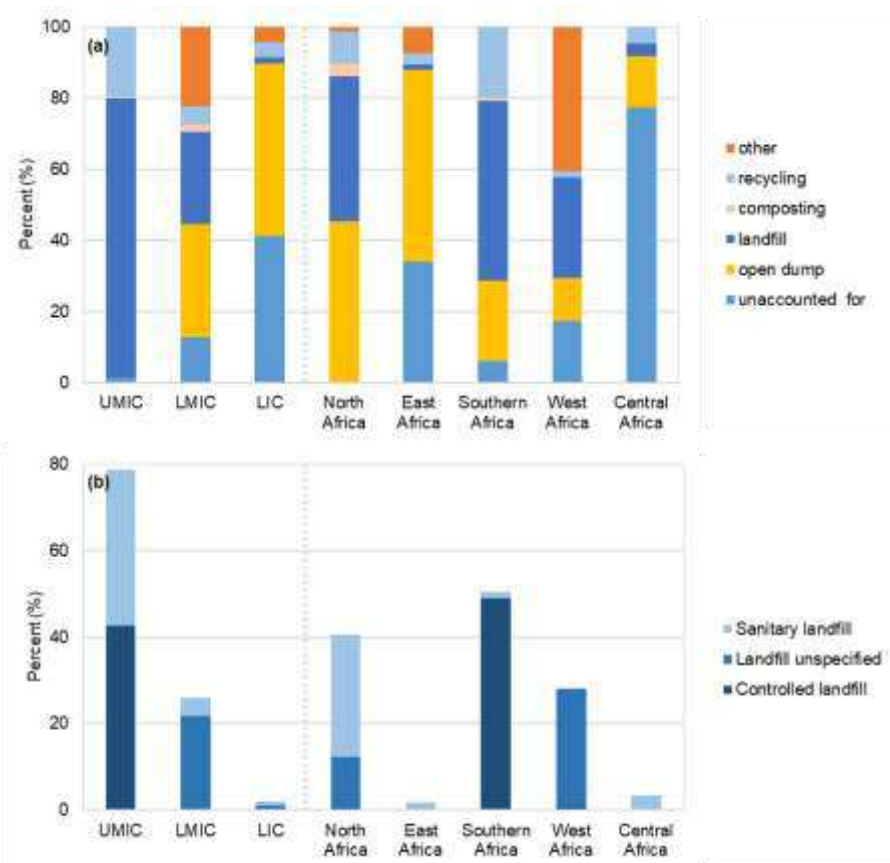305   income level was, the lower the recycling rate would be.

Fig.5. Disposal methods (a) and landfill types (b) of MSW in Africa.

As a whole, being a cheaper options, open dumping and unaccounted-for were the most common disposal methods in Africa, but the difference between African regions still was evident. The open dumping rate was highest in East Africa (54%) followed by North Africa (45%), Southern Africa (23%), Central Africa (15%), and West Africa (12%). The unaccounted-for disposal in Central Africa was grim, accounting for as much as 77%, while 0% in North Africa, 6% in South Africa, 17% in West Africa and 34% in East Africa, respectively.

The landfill rate of MSW varied widely by income levels or regions, with highest rate in UMIC (79%) followed by LMC (26%) and LIC (2%). By regions, the landfill rate was the highest in Southern Africa (51%) followed by North Africa (41%), West Africa (28%), East Africa (3%) and Central Africa (2%). It is noteworthy that the open dump in East Africa and Central Africa were still the mainstream disposal method, indicating that planning and

319   constructing landfill facilities may be the most important way to improve the current status of

320   solid waste management in these regions. Furthermore, there still existed a large gap in the

321   delicacy landfilling in Africa, as a uniform landfill management framework has not yet been

322   developed. In UMIC, the landfill is classified into sanitary landfill and controlled landfill,

323   while in LMIC, unspecified landfill was the main landfill disposal method. Sanitary landfill in

324   the main type of landfill in North Africa, East Africa and Central Africa while controlled

325   landfill in Southern Africa and unspecified landfill for West Africa. The areas where

326   unspecified landfill still exist were West Africa and North Africa.

327   Recycling, as an important way to promote the reduction of MSW, which is also an

328   important indicator of MSW management and technological advancement levels. Recycling

329   rate was highest in Southern Africa (20%) followed by North Africa (9%), Central Africa

330   (5%), East Africa (3%) and West Africa (2%). However, the gap of recycling levels between

331   low-income and lower-middle-income countries in Africa was not significant. The average

332   recovery rate of UMIC was 19%, while that in LMIC and LIC was 5% and 4%, respectively.

333   It should be noted that, since local authorities paid little attention to it, the vast majority of

334   recyclable MSW are collected by human scavengers without risk aversion (Mohammed et al.

335   2013), and only 1.5% of Africa's MSW were formally recycled (Mbiba 2014), making

336   recycling in Africa more challenging.

337   At present, every African country is gradually improving their waste management

338   systems and trying to replace open dumping with sanitary landfill or other disposal methods.

339   However, even if a compliant landfill is built, there are many operational challenges (Iyamu et

340   al. 2020).

341   **3.4.2 Comparison of MSW disposal method of Africa with adjacent area**

342   Compared with adjacent areas like Latin America and the Caribbean, Middle East and

343   Europe, the unaccounted-for rate of MSW in Africa was highest (20%), which is an obvious

344   shortcoming of MSW management in Africa (See Fig.6). Open dumping was common in both

345   Africa and neighboring regions, but the situation in the Middle East was even severe, with the

346   open dumping rate accounts for nearly 51%, about 1.6 times of Africa. The proportion of

347   unaccounted-for and open dumping in Africa and Latin America reached 51.1% and 53.9%

348   respectively, both higher than twice that of Europe (20.41%) (World Bank 2018).
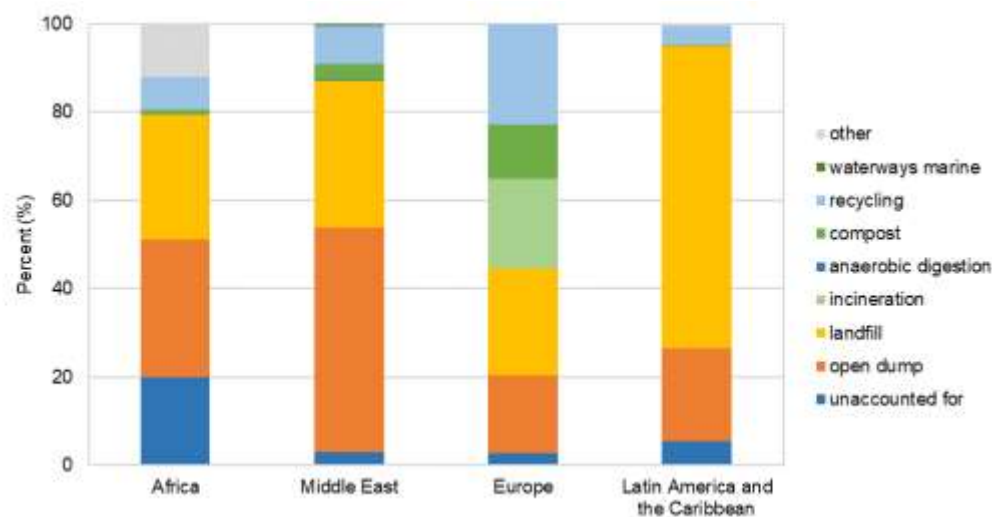
349

350   **Fig.6.** Disposal methods of MSW in Africa and adjacent regions.

351   As an important disposal way for MSW reduction, incineration accounts for more than

352   20% in Europe, while in Africa, Middle East, Latin America and the Caribbean it was less

353   than 1%. Nowadays, the European advanced disposal method has a subtle influence on Africa,

354   and Africa is actively planning to construct the MSW incineration facilities. A landfill site

355   located on the outskirts of the Ethiopian capital, Koshe dump site, caused 114 deaths due to

356   collapse mountain of waste. To improve the situation, the government and a consortium of

357   international companies have collaborated to establish a new waste-to-energy plant in

358   Ethiopia, first of its kind in Africa, and it is expected to incinerate 1400 tons of waste per day,

359   approximately 80% of the city's rubbish. At the same time, it fulfils Addis Ababa with 30% of

360   its household electricity needs and meets European standards on air emissions (Africa

361   Renewal).

362   Under the overall framework of the EU's "Zero Waste" strategy, the ideal hierarchy of

363   MSW management is: rethink/redesign, reduce, reuse, recycle/compost, recovery, residual

364   management and unacceptable (Zero Waste International Alliance 2018). Recycling is an

365   important way to realize zero waste but recycling rate in Africa is about 7%, less than one

366   third of Europe (23%).

367   Owing to the rapid development of incineration and resource recovery technology, the

368   landfill rate in Europe has dropped to 24%. The landfill rate in Africa and the Middle East

369   was similar, about 30%, which may be caused by the uncontrolled open dumping, rather than

370   the rapid development of incineration, recycling and other advanced disposal methods.

371   There was still an obvious gap between Africa and Europe in terms of advanced MSW

372   disposal structure and disposal capability, and the situation in the Middle East was even worse

373   than that in Africa. Therefore, unlike developed countries and regions such as Europe, the

374   short-term goal of MSW management in Africa should be to achieve zero open dumping.

375   **3. 5 Municipal solid waste legislation**

376   Law is an important tool for implementing MSW management strategies (Daskal et al.

377   2018). Almost half of African countries had followed all or part of the French legal tradition

378   due to long-term colonial aggression. In the post-independence period, African countries have

379   failed to maintain the normal operation of the environmental management system during the

380   colonial period, leading to the backwardness of the SWM system. In 1990s, African countries

381   have gradually established solid waste management legal systems, with main goal of

382   preventing environmental damage, but they failed to form a coordinated and effective legal

383   system similar to that of Europe.

384   Table S1 summarizes the solid waste management legislation of 32 African countries,

385   including 3 countries in North Africa, 4 countries in East Africa, 8 countries in Southern

386   Africa, 13 countries in West Africa and 4 countries in Central Africa. Among them, only 7

387   African countries have established special law on solid waste management, while other 25

388   countries established national environment laws covering solid waste management in a

389   section. In 2001, Algeria passed 'Municipal Solid Waste Law (Law No. 01-19)', which was

390   the first solid waste law in Africa countries.

391   As Fig.7 (a) portrayed, countries that have established legislation were mostly located in

392   coastal areas in which people was easily close to overseas tourists. However, the absence of

393   environmental legislation including solid waste management was common, with 22 countries

394   in Africa including five upper-middle-income level countries have no national environment

395   legislation. These five countries account for 63% of total UMIC in Africa, while the

396   proportion of not having SWM legislation in LMIC and LIC was 33% and 40%, respectively.

397   This information indicated that there was no obvious correlation between legislation and

398   economic level in Africa.

399   Fig.7 (b) compares the collection rate and MSW generation per capita in African

400   countries in consideration of their legislations in 2016. Prevalence of MSW related legislation

401   significantly improved the MSW collection rate while the daily per capita MSW generation

seemed unaffected by the existence of legislation. In addition, it is worth noting that there

were still some African countries without special law on solid waste management, but their

collection rates were well above 80%, like Togo (95%) and Cabo Verde (95%). It means that

just enacting laws is not enough, the powerful institution and regular supervision from

authorized body is necessary. However, in 2016, only 14 African countries had set up national
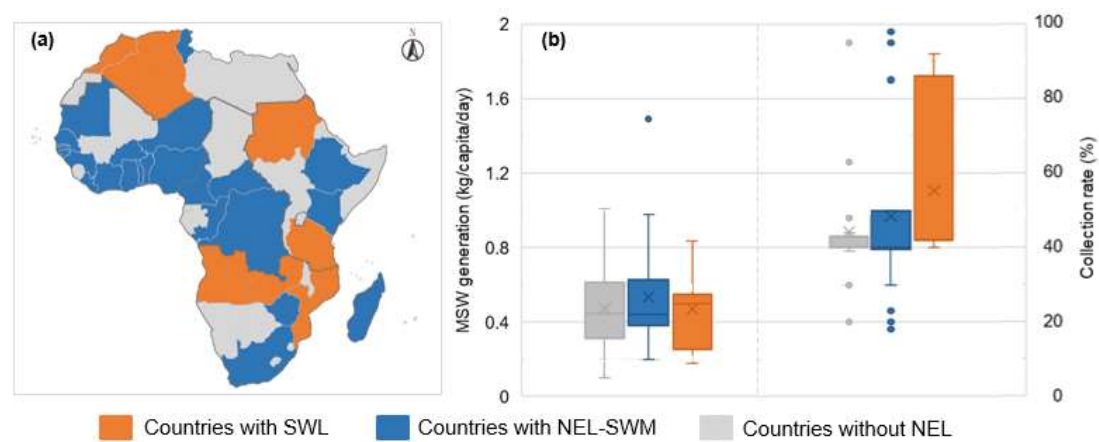
agency to enforce solid waste laws.

Fig.7. Solid waste legislation map (a) and corresponding collection rates and daily per capita

MSW (b) in Africa.

The laws enforcement on solid waste management in Africa seemed to be short of

coordinated actions among the authorities. Even where the legislation was strong,

implementation was often weak. For example, South Africa Environmental Management Law

of 1989 provided an environmental management framework to control waste emissions to a

minimum level and promote their recycling. They signed the Polokwane Declaration in 2001

to reduce waste generation and waste disposal to 50% and 25% respectively by 2020.

However, no city of South Africa has achieved this goal. Nigeria has also formulated 33 waste

disposal rules, but these rules have not been implemented yet which resulting in uncontrolled

dumping, and the MSW disposed through landfill unspecified was 40% in 2016.

420   Generally speaking, the situation of solid waste management in Africa was still poor, and

421 the legal enforcement was not effective and efficient. Moreover, there was a big gap between

422 what was written in the legislation and what was practiced on the ground. A powerful

423 institution and coordinated actions between all the local stakeholders, including private sector,

424 is necessary for effective and efficient SWM system.

425 **3. 6 Challenge of MSW management in Africa**

426   The current status and level of MSW in African countries were not balanced, and there

427 were big differences between regions and cities. As noted, this paper developed a multiple

428 regression model with the eq. (2) to determine major factors of daily per capita MSW

429 generation in 54 African countries.

430   The correlation coefficients of daily MSW generation per capita with four factors were

431 illustrated in Table 1. The regression model had statistical significance, $P<0.001$, R square

432 was 0.46. Since the Durbin-Watson test value was 2.201, the independent variables above

433 were independent to each other, and there was no multicollinearity.

434 **Table 1.**

435 Correlation coefficients of daily per capita MSW generation and influence factors.

Generation rate	Coef.	Std.Err.	Beta	t	P>|t|	[95% Conf. Interval]	
LnGDP	8.581×10^{-2}	.0323	.366	2.66	0.011	.0207	.1509
*LnC*ollection rate	1.710×10^{-1}	.0767	.273	2.23	0.031	.0166	.3254
Legislation							
Legislation =2	reference variable						
Legislation =0	6.984×10^{-2}	.0890	.141	0.78	0.437	-.1094	.2491
Legislation =1	2.186×10^{-1}	.0958	.499	2.28	0.027	.0257	.4115
Geographical location							
EA	reference variable						
CA	-2.709×10^{-1}	.0961	-.396	-2.82	0.007	-.4645	-.0773
NA	-1.651×10^{-1}	.1131	-.214	-1.46	0.151	-.3929	.0627
SA	-2.908×10^{-1}	.0880	-.512	-3.30	0.002	-.4681	-.1135
WA	-3.239×10^{-1}	.0863	-.609	-3.75	0.000	-.4977	-.1501

436   On the basis of the magnitude of standardized correlation coefficient (Beta), for

437   quantitative variables, economic growth (GDP per capita) presented the highest correlation

438   with daily per capita MSW generation, followed by collection rate. While for quantitative

439   variables, legal factor took precedence over geographical location. The results of model

440   analysis indicated that the improvement economy and collection rate would promote the daily

441   per capita MSW generation. Legislation and the establishment of standards are also crucial for

442   promoting MSW collection to increase daily MSW generation per capita. In terms of

443   geographical location, with the exception of North Africa, the rest regions are significant at

444   the 1% confident level.

445   It has been expected that MSW generation in Africa will increase rapidly, getting to 342

446   million tons in 2030 and 673 million tons in 2050, posing huge challenge to MSW

447   management in Africa.   The major concerns of MSW management in Africa are related to

448   the low MSW collection rate, excessive open dumping and poor national and specific

449   legislations, as well as their poor financial situation and geographical disadvantages.

450   Therefore, developing legislation and regulatory framework, conducting separate collection

451   and transport system and maintaining adequate disposal facilities should be the top priorities.

452   Currently, preventing dumping MSW without mandatory punishment is almost impossible.

453   Countries like Japan and Australia have instituted management system to reduce dumping. In

454   Japan, Waste Management and Public Cleansing Law can effectively prevent waste from

455   dumping if other options are available, even if they are expensive ones (Environment Agency

456   1970). In Australia, Protection of the Environment Operations Act 1997 made a provision of

457   range of fines and penalties for dumping offences. As per the Act, duping offenders must pay

458   a fine, $7500 for individuals and $15000 for corporations, and the repeat offenders can

459   receive prison sentences of up to 2 years (NSWEPA 2017). A MSW specific legislation and

460   regulatory framework should be established and strictly implemented in Africa. Furthermore,

461   to meet the increasing disposal demand of MSW in Africa, reasonable recycle and disposal

462   facilities should be constructed, reuse of metals, glasses and plastics should be promoted, the

463   biomass should be used for bioenergy, the inert household waste should move from dumping

464   to sanitary landfill. Additionally, building a separate collection and transport system of MSW

465   generated by all households and commercial activities could be instrumental (Yang et al.

466   2018).

467

468   **4. Conclusion**

469   Based on MSW management data of 54 African countries, the recent status of MSW

470   management in African including MSW generation, compositions, collection, disposal and

471   legislation is evaluated from their economical and geographical perspectives. The results

472   showed that daily MSW generation per capita in African countries ranged from 0.1 kg to 1.49

473   kg, which was largely affected by economic growth, national laws, geographical location and

474   waste collection rate. The waste collection rates in Africa countries also presented spatial and

475   income level heterogeneities. In addition, there is huge variation in MSW collection within a

476   country, even in a city, especially for low-income and middle-income countries. The

477   non-spatial data analysis model shows that the GDP per capita and legislation system are

478   considering as major controlling factors in affecting daily MSW generation.

479   Sustainable disposal of MSW is still a distant dream in Africa as the proportion of

480 unaccounted-for and open dumping still accounted for 51%. Moreover, the municipal SWM

481 legislation in Africa was still inadequate and premature as majority of countries do not have

482 special law on SWM.

483   Altogether, the study indicated that the higher generations, collection rates and disposal

484 rates often occurred in economically developed maritime countries compared to that of

485 developed landlocked countries. Therefore, development and strict implementation of

486 legislation and regulatory framework, conductance of separate collection and transport

487 systems and creation of adequate disposal facilities should be the top priorities of African

488 countries.

489   This study also forecasted that the total MSW generation in Africa is expected to triple in

490 2050, making the future of solid waste management in Africa more challenging. The

491 challenges of MSW management in Africa and their potential solutions highlighted in this

492 study could help African countries to manage their MSW more effectively and efficiently. The

493 findings are also useful for many MSW Aid Programs in Africa for using and prioritizing their

494 scarce resources in developing infrastructure, legislations, institutions and capacity of

495 government and non-governmental organizations.

496 **Availability of data and materials**

497   All supporting data were obtained from previously published articles in journals and

498 published reports by World Bank. All references are cited in the text and are listed below.

499 **Funding**

502 **Authors Contributions**

503   All authors contributed to the study conception and design. Data collection, Method

504 implementation and optimization, data evaluation were performed by Yu Shi, Yao Wang. The

505 impact analysis model was improved by Yue Yang, Jun Zhao. The first draft of the manuscript

506 was written by Yao Wang, Yu Shi, and manuscript was reviewed by Tek Maraseni and

507 Guangren Qian. All authors commented on previous versions of the manuscript. All authors

508 read and approved the final submitted.

509 **Compliance with ethical standards**

510 **Competing interest**

511   The authors declare that they have no conflict of interest.

512 **Ethical Approval**

513   Not applicable.

514 **Consent to Participate**

515   Not applicable.

516 **Consent to Publish**

517   Not applicable.

518 **Abbreviation**

519 GDP: Gross Domestic Product

520 UNEP: United Nations Environment Program

521 IMF: International Monetary Fund

522 AFDB: African Development Bank

523 PPP: Purchasing Power Parity

524   MSW: Municipal Solid Waste

525   HIC: High-income Country

526   UMIC: Upper-middle-income Country

527   LMIC: Low-income Country

528   LIC: Lower-middle-income Country

529   NA: North Africa

530   EA: East Africa

531   SA: Southern Africa

532   WA: West Africa

533   CA: Central Africa

534   NEL: National Environmental Legislation

535   NEL-SWM: National Environment Law Covering Solid Waste Management

536   SWL: Solid Waste Legislation

537   SWM: Solid Waste Management

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Figures
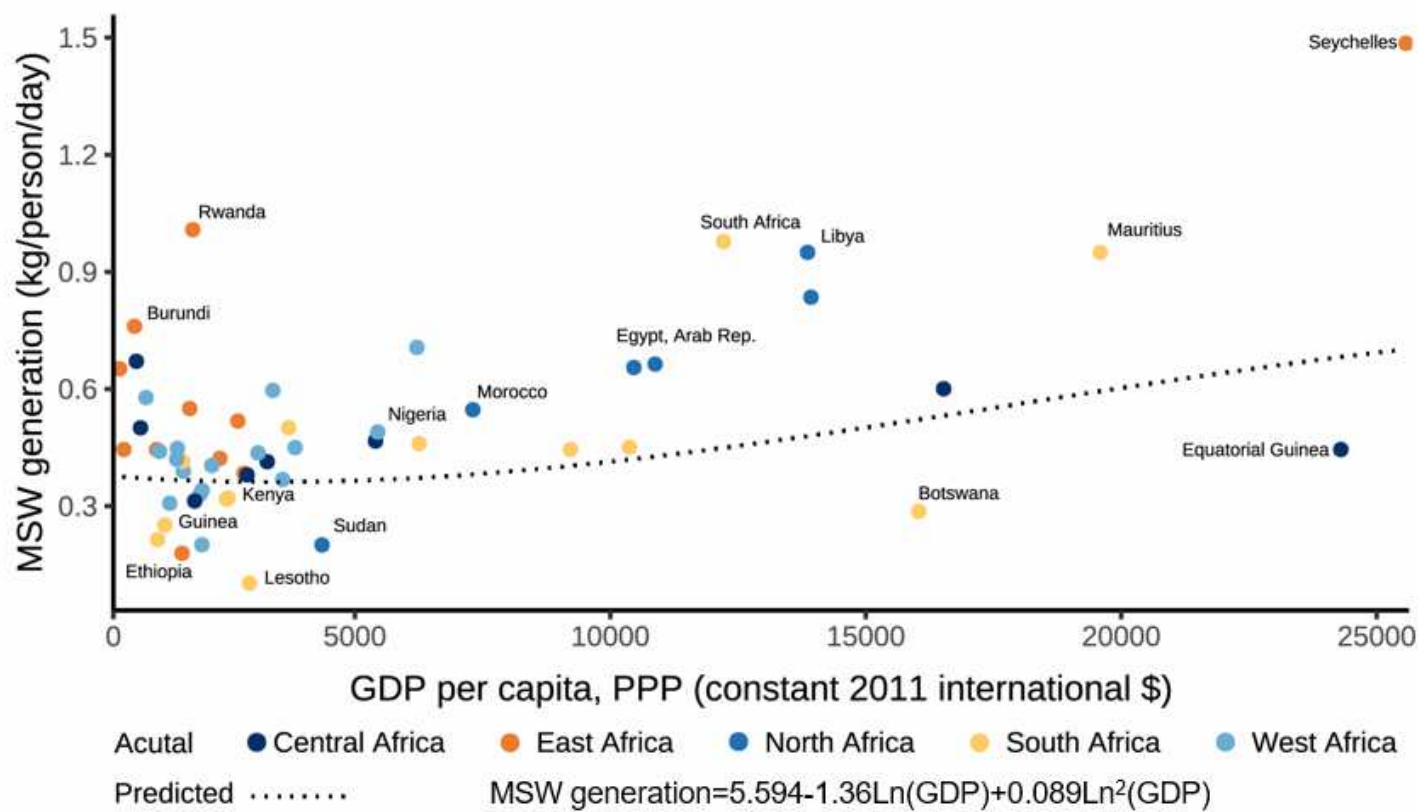
Figure 1

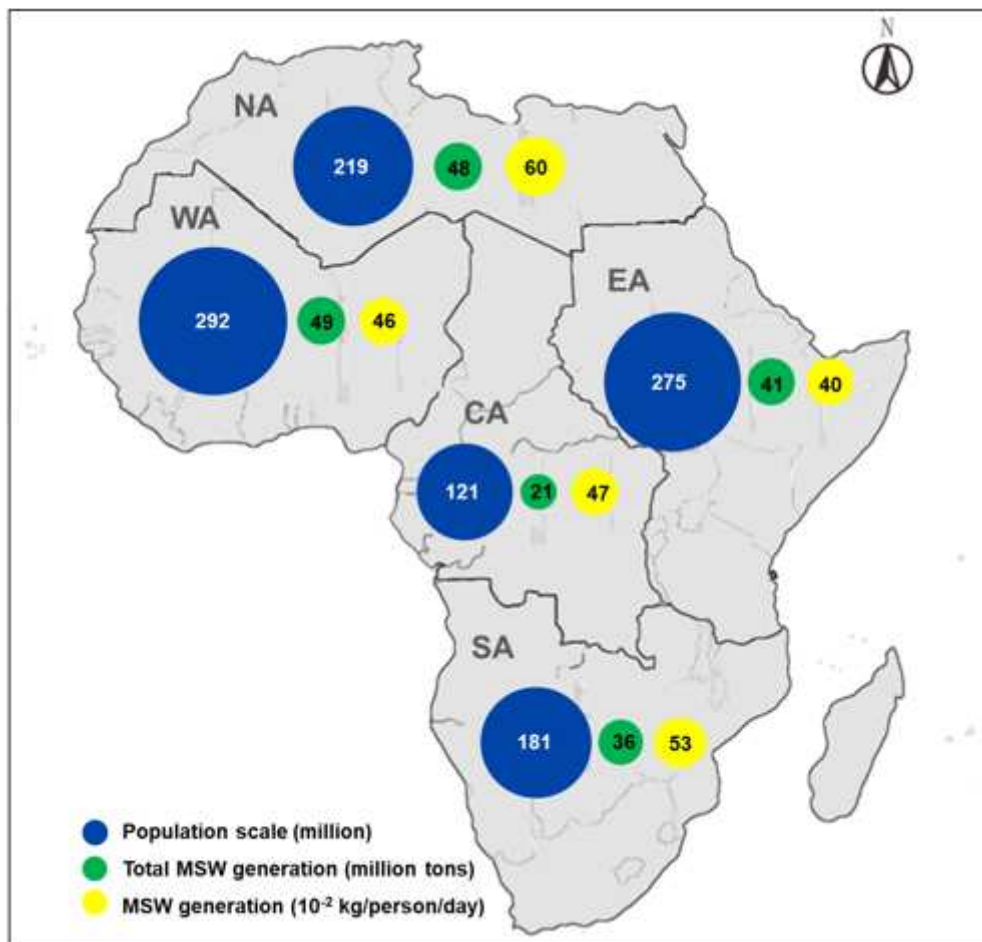The per capita GDP and daily per capita MSW generation in African countries.

Figure 2

Population and MSW generation in Africa. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.
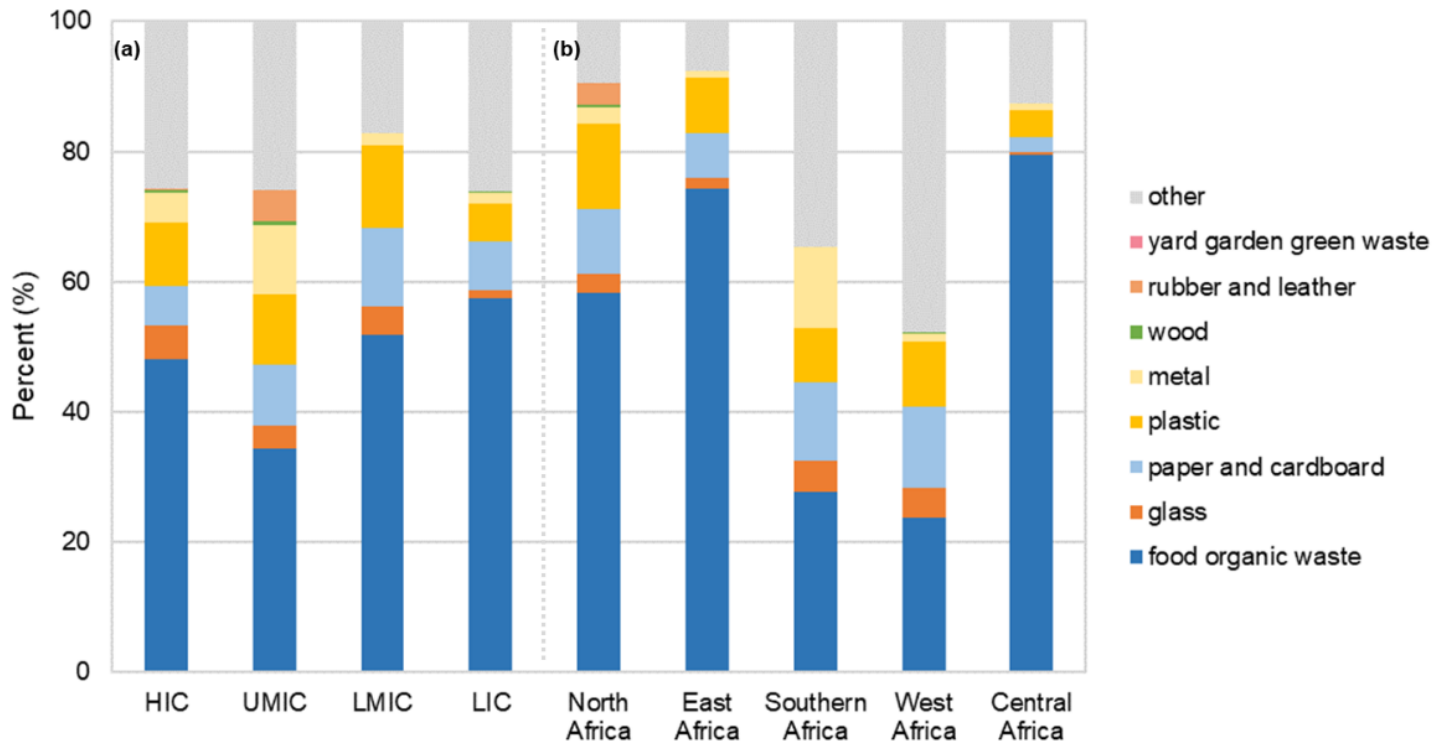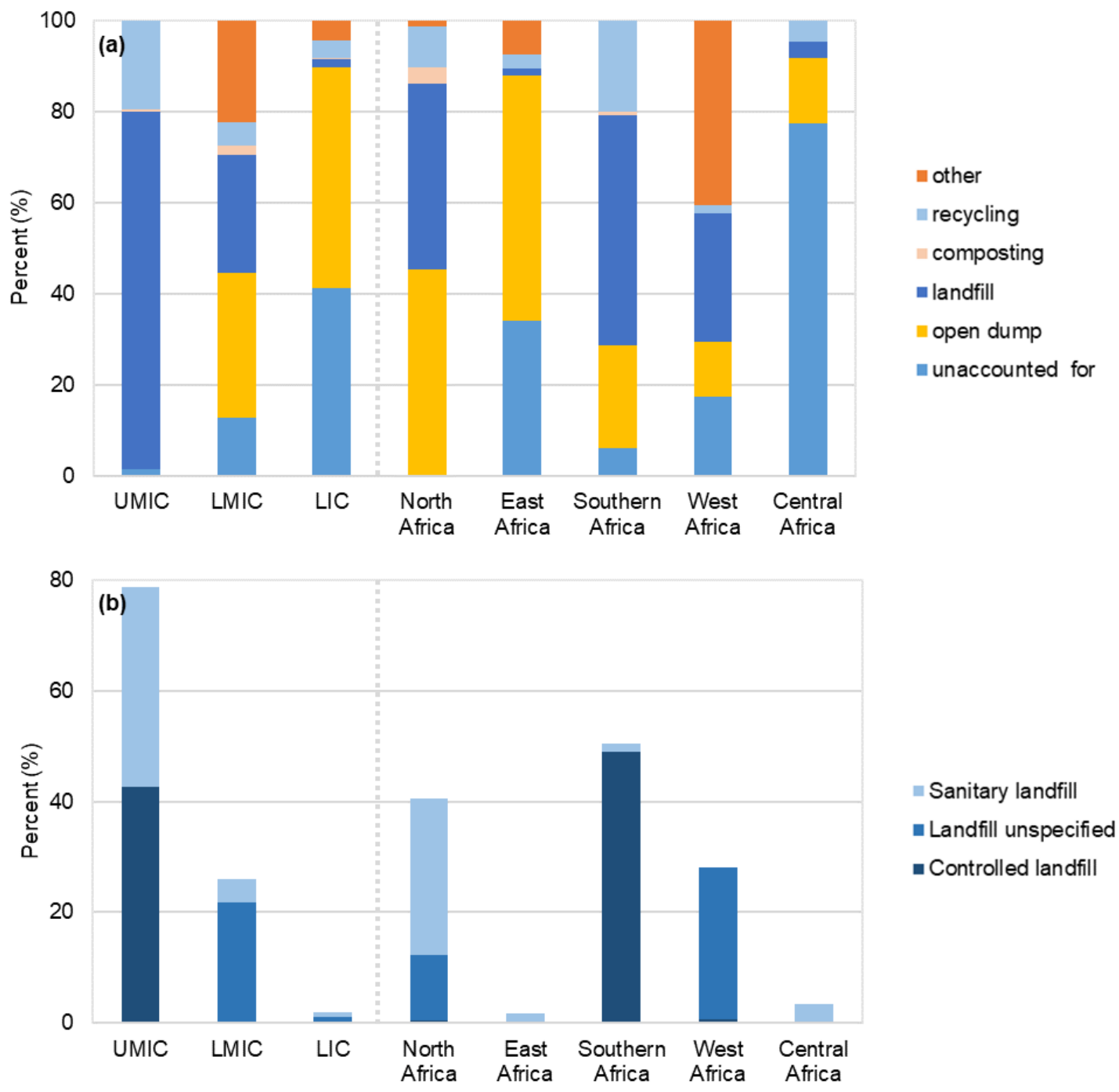
Figure 3

Compositions of municipal solid waste by income levels (a) and by regions (b).
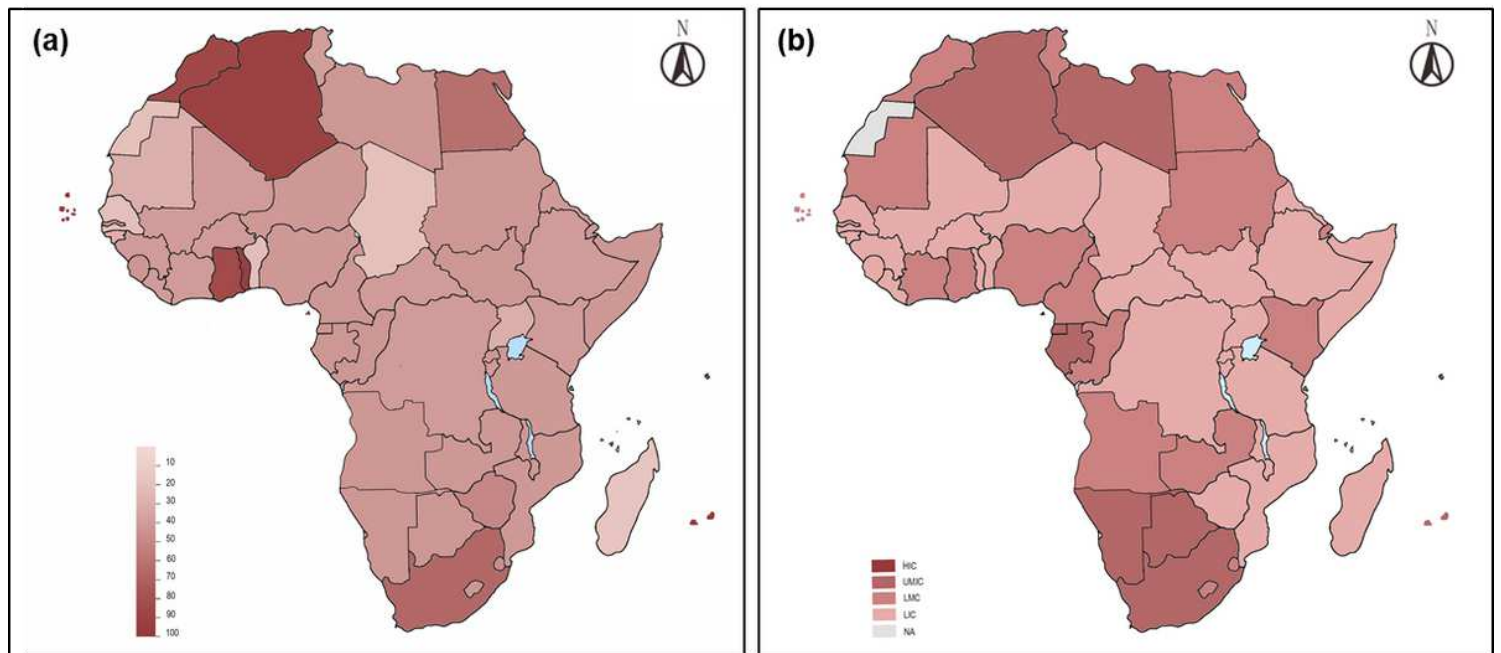
Figure 4

Collection rates of MSW (a) and income levels classification (b) in African countries. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country,

territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 5

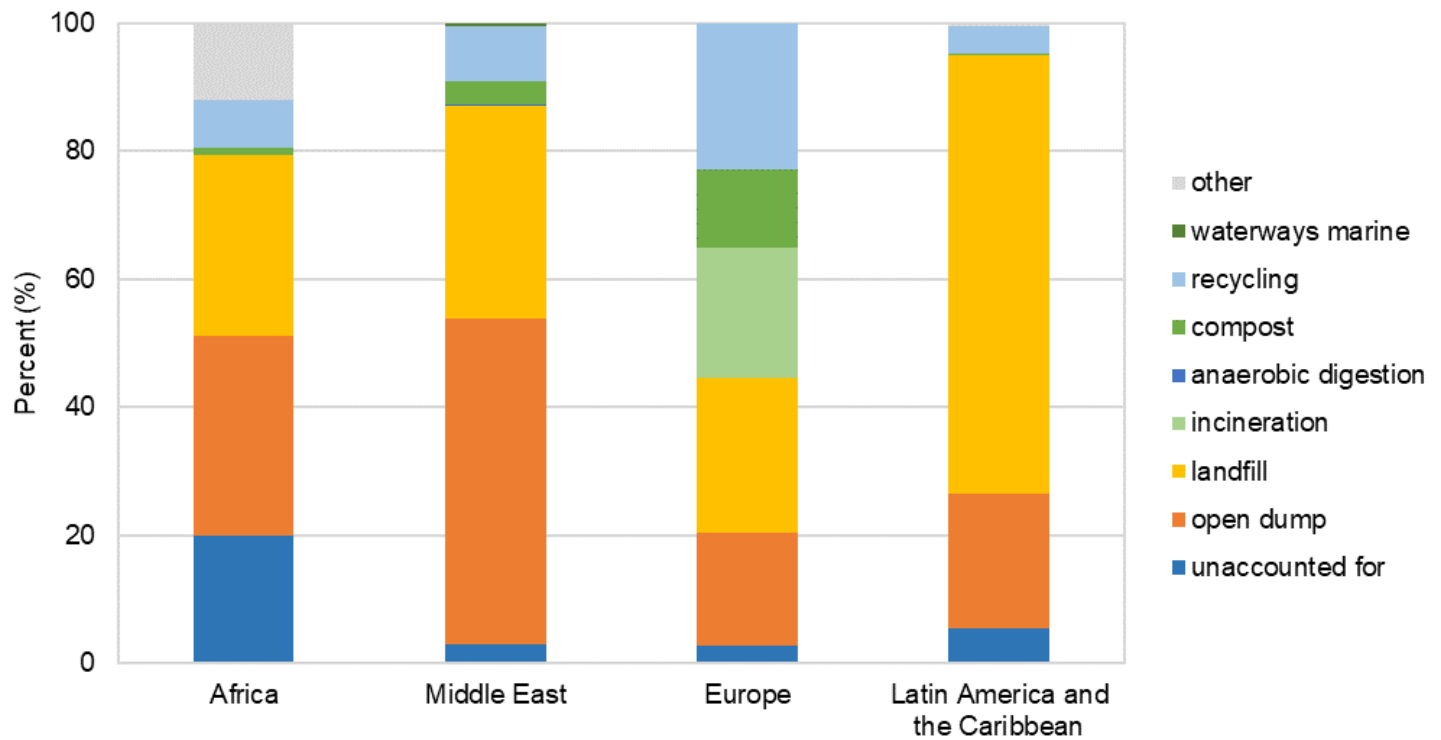Disposal methods (a) and landfill types (b) of MSW in Africa.

Figure 6

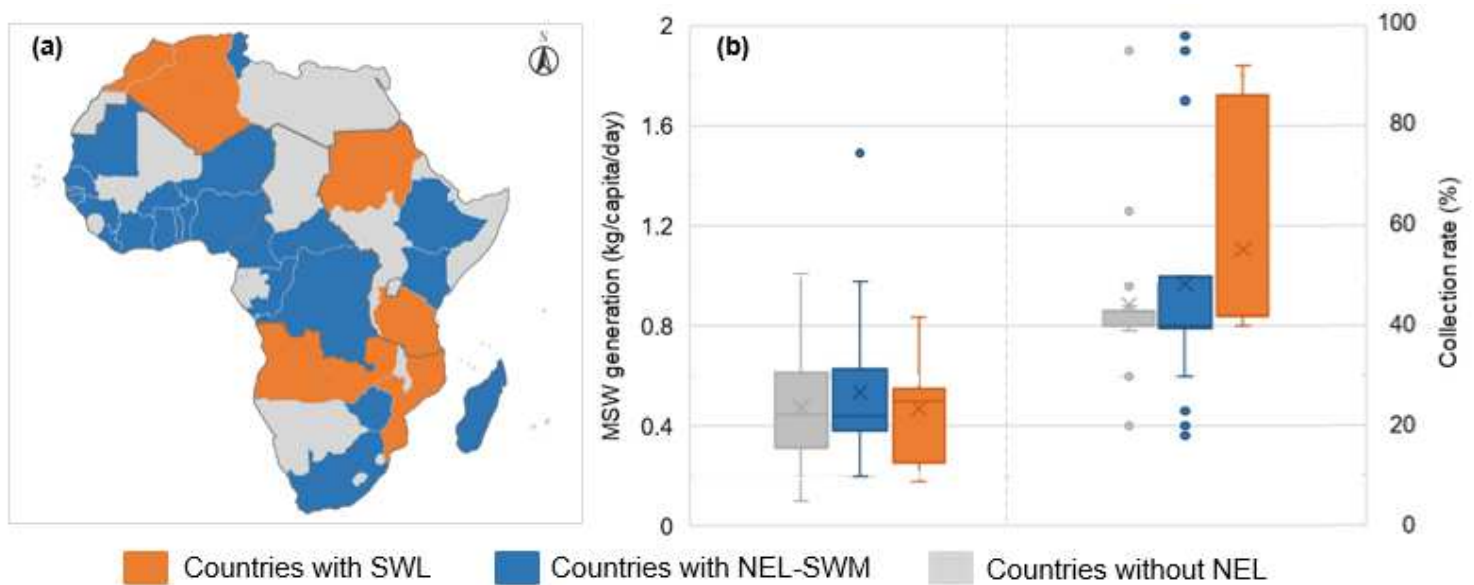Disposal methods of MSW in Africa and adjacent regions.

Figure 7

Solid waste legislation map (a) and corresponding collection rates and daily per capita MSW (b) in Africa. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

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