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# Detailed Municipal Solid Waste Composition Analysis for Nur-Sultan City, Kazakhstan with Implications for Sustainable Waste Management in Central Asia

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# Detailed Municipal Solid Waste Composition Analysis for Nur-Sultan City, Kazakhstan with Implications for Sustainable Waste Management in Central Asia


## Abstract

A detailed characterization of municipal solid waste (MSW) beyond a standard compositional analysis may offer insights useful for improving waste management systems. The present paper contributes to the scarce literature in the field by presenting new data from a rapidly developing Central Asian city, the capital of Kazakhstan, Nur-Sultan. Three sampling campaigns (each one week-long) have been conducted at the city landfill over a one-year period (2018-2019) and a detailed characterization for selected waste components and sub-components has been performed. The major fractions of MSW were organics (46.3%), plastics (15.2%), paper (12.8%), and diapers (5.9%). The detailed composition analysis showed high LDPE (low-density polyethylene) content (5.5%) mostly comprised of plastic bags (4.5%), transparent glass (3.2%), pharmaceuticals (0.4%), and fine (i.e. <12 mm) organic fraction content (29%). The MSW generation rate of Nur-Sultan City was estimated as 1.47 kg.capita$^{-1}$.d$^{-1}$ based on the field collection as well as literature composition data. Among sustainable waste management recommendations addressed for Nur-Sultan and applicable to other cities in Central Asia, composting is promptly recommended due to high organics fraction in MSW since it has a great potential to reduce the landfilled waste volume and help valorizing the waste.



**Key words:** composting; landfill; urban sustainability; waste characterization; waste generation rate

## List of acronyms

C&DW: construction and demolition waste
HDPE: high density polyethylene
HHW: household hazardous waste
GDP: gross domestic product
IWM: integrated waste management
LDPE: low density polyethylene
MBT: mechanical-biological treatment
MSW: municipal solid waste
NGO: non-governmental organization
PCBT: plastic carriage bag tax
PET: polyethylene terephthalate
RSD: relative standard deviation
SW: solid waste
WEEE: waste electrical & electronic equipment

## 1. Introduction

The land disposal (landfilling) of solid waste (SW) is a widely applied practice of discarding municipal solid waste (MSW) worldwide owing to its economic advantages compared to other waste disposal practices (Renou et al. 2008). Nowadays, almost 70% of the municipal solid waste generated globally is disposed in landfills (including sanitary or unsanitary landfills as well as dumpsites), and the level of waste recycling and composting could be considered low as only 19% of total waste is recovered (Kaza et al. 2018). However, landfilling has several environmental drawbacks such as the generation of leachates and gaseous emissions requiring the employment of effective control technologies and the requirement of large areas. There are methods providing an alternative to or reducing the need for landfilling such as waste-to-energy technologies, mechanical and biological treatment (MBT) including composting, and recycling. Nevertheless, there is no single best way of resolving waste management issues as the constituents of MSW vary in shape and composition leading to different optimal treatment processes for each MSW fraction (Tehrani et al. 2009). As a systematic approach, integrated waste management (IWM) is preferred since it offers flexibility in treating different MSW fractions; and consequently, it has been commonly practiced in the majority of the developed countries (Zaman 2010). IWM could be strongly advised as a tool to address MSW issues of developing countries; however, it requires initial robust data including a detailed composition of MSW for effectively establishing waste management and treatment systems.

The country of Kazakhstan is situated in Central Asia which contains five former Soviet republics: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan; being one of the rapidly developing areas of the world. Kazakhstan is also the political and economic leader of Central Asia and has access to vast mineral, oil, and gas reserves. In the country, landfilling is still a predominant waste management practice (Inglezakis et al. 2017). In the capital city (Nur-Sultan City, formerly named as Astana), the fraction of SW landfilled is slightly lower than in other cities and the MSW disposal facility contains a sorting plant situated next to the city landfill (Inglezakis et al. 2018). The received waste enters the sorting plant to remove some of the recyclable waste after which the rest is landfilled. According to Abylkhani et al. (2018), between 2017 and 2018, the recyclable fraction of MSW was around 32%; however, only 13% of the received MSW was collected as recyclables whereas the rest was disposed in the city landfill (Urcha 2018). To meet the requirements of the country's Green Economy Concept which states that the recycling rate in Kazakhstan should reach 40% by 2030 and to 50% by 2050, the country's waste management system requires more strict legal norms along with proper enforcement (Strategy2050.kz (n.d.)). In order to facilitate local authorities to take well-aimed actions as well as to attract on-target support from non-governmental organizations (NGOs) towards the realization of the potential for SW recycling, it is important to first obtain the detailed characterization of MSW constituents spread over the period of a year.

There exists some limited literature on the detailed/advanced characterization of MSW. Selected studies with details are presented in Table 1 and are discussed below, along with additional studies that are not presented in the table. Detailed MSW characterization studies mainly focus on components and sub-components suitable for processing (e.g. recyclables and organics); however, there is no consensus on the exact items to characterize. Detailed compositional analyses of MSW streams reported in these studies have led to valuable conclusions which would substantially aid developing waste management frameworks by resolving associated issues. For instance, a study by Bernache-Pérez et al. (2001) identified the amount of SW that can be valorized by using a market-oriented approach which could be expected to assist local municipality to develop treatment techniques for extraction of goods for commercialization. Another study by Pan and Voulvoulis (2007) determined a large difference in methane production from different waste categories and therefore calls for recycling/reusing putrescible fractions which are normally landfilled. Miezah et al. (2015) showed how the content of MSW may vary across a country (case: Ghana) along with characteristic consumption habits of locals as well as waste sorting and separation efficiency. Conversely, a research from Denmark indicated that the household MSW composition is not significantly affected by household size or by season, but its generation rate is impacted by household size; therefore, the authors recommended its careful consideration for estimating MSW generation rates (Edjabou et al. 2018). Zorpas et al. (2015) claimed that most of the household waste could be separated at source for recycling, proposed to raise public awareness and involve government and NGOs to reach zero waste in the future. Poon et al. (2001) and Yeheyis et al. (2013) conducted a detailed characterization of construction and demolition waste (C&DW) at construction sites. It was recommended that C&DW should be separated at the source which would be achieved by increasing taxes for its disposal. Dehghani et al. (2019), Komilis et al. (2017), Korkut (2018), and Taghipour and Mosaferi (2009) performed samplings of medical waste stream. They indicated a potential benefit in separation and reduction of the disposed medical waste via collection fees as well as the need for ensuring the infectious waste is not mixed and then co-disposed with household MSW. These studies serve as important steps to foster the development and improvement of SW management practices both at local and global scale.

A detailed characterization of MSW components and sub-components may serve as an important tool in improving waste management systems. More specifically, the Central Asian region and particularly Kazakhstan highly needs to improve its underdeveloped MSW management systems to cope with ever increasing waste generation rates due to the rapid development in the region. However, a detailed MSW characterization study representative of Central Asian cities has not yet been conducted. The present study aims to (1) perform a detailed characterization of MSW as received by the landfill of Nur-Sultan City via three sampling campaigns, and to (2) estimate the city's SW generation rate based on field collection and literature data. It is expected that these data on detailed composition and generation rate of MSW would substantially aid the strategic planning of the waste management practices and policies in Kazakhstan and in Central Asia. Based on the findings, implications for more sustainable waste management are also addressed, which are not only valid for Central Asia but may also be applicable to other similar rapidly developing regions in the world.

## 2. Materials and Methods

### 2.1 Study area, sampling methodology

With its population surpassing 1 million by 2017 (Stat.gov.kz (n.d.)), Nur-Sultan is one of the wealthiest and fastest-growing cities of Central Asia. Its surrounding region has extreme continental climate accompanied by long winters that affects consumer patterns such as variations in year-long consumption of fruits and vegetables. The waste management company "Clean City" collects MSW from the city's three districts (once a week) delivered directly to the city's only waste processing facility. There is no legally enforced or publicly promoted system for waste separation or collection at source, and thus, the collected waste is commingled. The operations of the mechanical sorting plant, which is a part of the waste processing and disposal facility (Figure 1) aid to a small extent in diversion of the collected waste from landfilling. The MBT plant was originally designed to process annually over 300,000 t of waste and to recover 20%. Due to low demand for recovered materials from commingled waste (exhibiting poor quality compared to materials recovered from waste separated at source) leading to small profits and a lack of storage area at the facility, the actual estimated recovery rate is around 6% (Inglezakis et al. 2018).

Sampling for MSW characterization has been performed according to ASTM D5231-92 (ASTM International 2016). In summary, the mean MSW composition has been determined based on the sorting of collected waste which has been performed manually. Sorting was done in sampling campaigns, each taking five days with daily sampling. In sampling days, a waste collection truck (randomly selected) brought MSW samples from one of the three districts of Nur-Sultan City, which helped to ensure the reliability and representativity of the MSW composition. The number of sorting samples was found as explained in ASTM D5231-92 according to equation:

$$n = [t\ \mathrm{s}\ (e\ x)^{-1}]^2 \qquad (1)$$

where $n$ is the number of sorting samples to be taken, $s$ is the estimated standard deviation, $x$ is the estimated mean, $t$ is the desired confidence, and $e$ is the precision level.

The weight of samples ranged from 91 to 136 kg whereas the estimated values of standard deviation and mean depended on the component on which the daily campaigns were based. Plastics fraction was selected as the most representative MSW fraction because it is lightweight, present in various fractions that are recyclable or combustible, and relatively abundant in MSW collected from urban zones. This fraction was used for further calculations according to Eq. 1 where s = 0.03 and x

= 0.09 (Tables 3 and 4 of ASTM D5231-92). The chosen desired confidence level was 90%, the precision level was 20%, and the number of samples was selected as 10. To decrease the sampling duration to five days, the number of samples was doubled by doubling the daily mass of MSW samples (range: 182 to 272 kg). In total, three sampling campaigns have been conducted over the period of one year: in summer 2018 (starting on 30 July 2018), winter 2019 (starting on 30 January 2019), and summer 2019 (starting on 24 July 2019); each consisting of five days of sampling over one week (total of 15 days of sampling activities).

## 2.2. Sorting procedure

After discharge of MSW from the collection vehicle, the MSW was placed on a cemented surface, then mixed by a loader from four sides of the waste pile. Then the waste was reallocated onto a 36 $m^2$ tarpaulin in a closed space to protect collected MSW from weather elements (e.g. wind, rainfall, or snowfall) during sorting operations. The sorting process was performed by the project team members and by the MSW sorting plant employees. For the present study, the MSW has been sorted to: fractions – 12 in total (Tables 2 and 3), then to the components of selected four fractions – paper, plastics, glass, metals (Tables 2 and 4), and to the sub-components for selected five components – all organics, LDPE, paper, separable glass, all miscellaneous (Tables 2 and 4).

The sorting has been completed in three stages:

1. The first step sorting consisted of separating larger pieces (i.e. constituents >20 cm) into the following categories: cardboard, C&DW, ferrous metals, glass, HDPE, LDPE, non-ferrous metals, other plastics, paper, PET, Tetra Pak, textile and leather, WEEE, and wood. This procedure continued until all recyclable materials have been separated.
2. The second step aimed to classify the remaining but smaller-sized waste constituents (>12.7 mm, by ASTM D5231-92) as either combustible (mixed paper, mixed plastics, textile and

leather, wood) or non-combustible material (C&DW, diapers, ferrous metals, glass, non-ferrous metals, organics, WEEE, and miscellaneous). It was performed until the remaining waste had particle size <12.7 mm. Next, sieving via a 12 mm screen was done to separate fine fraction. The remaining fraction that predominately consisted of residual food waste and green waste was added to the organics fraction. Each fraction was weighed and recorded, a separate sample from the combustibles fraction was taken for future analyses. A coning/quartering procedure was employed to receive a well-mixed sample.

3. A detailed sorting was conducted after first and second steps for selected components: all organics, LDPE, paper, separable glass, all miscellaneous have been sorted into their selected sub-components. In detail, the paper fraction was further classified into newspaper/ magazine/ advertisement (including journals), packaging paper (for packaging of food and other goods), office paper (blank or printed A4 and A3 papers), and other paper (remaining paper such as toilet paper and tampons). The LDPE fraction was further divided into bags (for carrying goods) and other LDPE (used for food/clothing wrapping). The glass fraction was further classified by color: transparent, green, and dark. The miscellaneous fraction was further categorized as either pharmaceuticals (drugs with their wrappings) or other miscellaneous (waste constituents such as ceramics and rubber).

After the second step sorting, the organic fraction was further separated into cooking waste (processed items consisting of kitchen waste and food leftovers), large compostables (all remaining biodegradable waste such as raw vegetables and fruits, flesh and bones, and green waste), and other organics (fraction of organic waste <12 mm).

## 2.3. Estimation of MSW generation

The monthly data on different waste constituents entering the mechanical sorting plant at the city landfill of Nur-Sultan for the year of 2017 was obtained from the Municipality of Nur-Sultan.

The mechanical sorting plant is where all collected SW from city streets and back alleys is first processed, hence includes residential and commercial SW, bulky items, and waste from municipal services (while excluding certain MSW constituents such as some C&DW and treatment sludge). Thereafter, the quantity of SW entering the mechanical sorting plant in 2017 provided as monthly data was summed up, extrapolated to 100% to represent the total quantity of MSW (i.e. all constituents). It was divided by the population of Nur-Sultan City in 2017 (1,001,124 according to Stat.gov.kz (n.d.)) and then by 365, resulting in the MSW generation in kg.capita$^{-1}$.d$^{-1}$.

## 3. Results and Discussion

### 3.1. MSW generation rate

MSW has been defined as the waste that "covers household waste and waste similar in nature and composition to household waste" (EC 2017). According to Tchobanoglous et al. (1993), MSW consists of the following waste categories: (1) residential and commercial goods (typical value: 62% of the entire MSW), (2) special items such as bulky items and white goods (5%), (3) HHW (0.1%), (4) institutional waste (3.4%), (5) C&DW (14%), (6) municipal services (9.5%), and (7) treatment plant sludges (6%), where reported typical estimated values naturally exclude industrial and agricultural wastes. The fractions related to household waste from the records of the Municipality of Nur-Sultan (i.e. MSW accepted in mechanical sorting plant) were "mixed MSW" (corresponding to waste category: 1 as reported above) , "extracted goods and bigger items" (waste category: 2), "street sweeping" (waste category: 6), and "litter pick" (waste category: 6); with a combined estimated typical value of 76.5% of all MSW stream while excluding waste categories 3, 4, 5, and 7.

The waste quantities and categories delivered to the Nur-Sultan mechanical sorting plant in 2017 reported by the Municipality of Nur-Sultan (Table 5) show that the annual total waste entering the mechanical sorting plant was 411,674 tons. Residential and commercial SW constituted 67.3% of the total, municipal services accounted for 25.6% of the total, and the special wastes were 7.04%. The quantities of residential and commercial SW as well as special wastes were rather uniform throughout the year as indicated by monthly minimum, maximum, and standard deviation values. On the contrary, the waste from municipal services was not uniformly generated i.e. peaking in April, May, and June which marks the period from the end of long winter to the beginning of summer and contains major street cleaning activities and collection of year-long yard residues which is mainly done in the country after winter.

As discussed above, the annual total of 411,674 tons of SW processed at the mechanical sorting plant did include an estimated 76.5% of the total MSW stream. Based on this, it can be also estimated that the 100% of the MSW stream for Nur-Sultan City for 2017 is 538,136 tons. According to the Stat.gov.kz, the population of Nur-Sultan was 1,001,124 in 2017. Therefore, the MSW generation in Nur-Sultan in 2017 could be calculated as 538 $kg.capita^{-1}.y^{-1}$ or 1.47 $kg.capita^{-1}.d^{-1}$. The most recent data on MSW generation per capita in Nur-Sultan City has been reported by Inglezakis et al. (2017) as 1.39 $kg.capita^{-1}.day^{-1}$ , with five major constituents being organics: 0.384 $kg.capita^{-1}.day^{-1}$ (27.6%), other glass: 0.145 $kg.capita^{-1}.day^{-1}$ (10.4%), other plastics: 0.121 $kg.capita^{-1}.day^{-1}$ (8.7%), packaging paper/cardboard: 0.095 $kg.capita^{-1}.day^{-1}$ (6.8%), packaging plastic: 0.095 $kg.capita^{-1}.day^{-1}$ (6.8%)).

The MSW generation rate is expected to be mainly a function of the level of socio-economic development in a country (Tchobanoglous et al. 1993), where high-income countries account for 16% of the world's population but generate about 34% (World Bank (n.d.)). The estimated value in the present study (538 $kg.capita^{-1}.y^{-1}$ or 1.47 $kg.capita^{-1}.d^{-1}$) is not high; and parallel to the SW composition, it is in between of the generation characteristics of developing economies and developed countries. It is comparable to the range in Europe, such as in Germany it is 633 $kg.capita^{-1}.y^{-1}$ whereas in Romania it is 272 $kg.capita^{-1}.y^{-1}$ (Eurostat (n.d.)), and is below the current average rate in the U.S. (USEPA, 2015) which is 2.03 $kg.capita^{-1}.d^{-1}$. Finally, the estimated value in the present study is at the lower end of the worldwide values, where waste generation averages at 0.74 $kg.capita^{-1}.d^{-1}$ but ranges widely, from 0.11 to 4.54 kilograms (World Bank (n.d.)). It should be noted that the estimated rate accounts for a 14% C&DW fraction in MSW, however in reality, this fraction could be higher as the rapid growth in the last decade due to an economic boom in Central Asia mainly including Kazakhstan has led to high C&DW generation rates (Turkyilmaz et al. 2019).

### 3.2. Composition of solid waste

The compositional analysis of MSW from Nur-Sultan City (Table 3) showed that the major constituents of SW stream were organics (46.3%), plastics (15.2%), and paper (12.8%). The overall characteristic for SW generation indicates a similarity to middle-income countries in terms of typical distribution of its components: food waste being the predominant waste fraction whereas other waste fractions indicating more affluent consumption characteristics (e.g. paper, glass, and textiles) are more pronounced compared to lower-income countries. This is in parallel to Kazakhstan's economic status that has shown a rapid GDP growth from 18.3 billion US$ to 163 billion US$ between 2000 and 2017 (Turkyilmaz et al. 2019).

The share of major recyclables (paper, plastics, glass, and metals) in the SW stream was 34.8%, indicating a good potential for recycling. As only 13% of incoming MSW is currently collected as recyclables in Nur-Sultan (Urcha 2018) which corresponds to a 37% recovery rate for recyclables, the requirements of the country's Green Economy Concept state (that the recycling rates in Kazakhstan should reach 40% by 2030 and 50% by 2050 (Strategy2050.kz (n.d.)) would need additional effort. Assuming that the composition of MSW from other cities in Kazakhstan would be similar to that of Nur-Sultan, meeting these national recycling requirements would require a rapid establishment of mechanical sorting plants in major cities as currently no city except Nur-Sultan has any waste processing facility. Finally, it should be noted that the effective utilization of this good potential for recycling necessitates the implementation of a separate collection system for recyclables, which is not currently in place in any of the cities of Kazakhstan. Currently, there is a pilot project operating for separate collection system for recyclables in Nur-Sultan. However, the efficiency of this pilot project is still very low, resulting in all the recycling activities performed on commingled waste that is processed at the mechanical sorting plant at the landfill. This negatively affects both the quantity as well as the quality of the material that is recovered.

In the present study, diapers are categorized separately as they contain a mixture of materials such as cotton, paper, plastics, and hydrogel. Diapers are relatively easy to identify and separate from the waste stream, have relatively good energy content (lower heating value of 2,850 $kcal.kg^{-1}$, which is comparable to that of paper and cardboard (2,748 $kcal.kg^{-1}$) (Rada and Cioca 2017)) and, thus, sometimes are classified under the waste category "combustibles" or "other combustibles" (Ozcan et al. 2016). They could also be efficiently processed via waste transformation techniques such as composting (Colon et al. 2013) and hydrogel recovery (Al-Jabari et al. 2019). The percentage of diapers in the SW stream of Nur-Sultan is significant (5.9%), which means that depending on the future availability of technologies, they could be valorized via options such as substrate in composting operations or as refuse derived fuel in heat recovery systems.

MSW is a heterogenous material showing high variation in terms of its contents, characteristics, and physio-chemical properties based on sampling time, frequency, and location. As expected, the waste composition data resulting from several field campaigns showed some differences between the campaigns (Table 3). Among the waste components with a fraction of 5% or more in the total SW stream, the relative standard deviation (RSD) values between summer 2018, winter 2019, and summer 2019 sampling campaigns were low for plastics, glass, and organics fractions (i.e. 4-5%), indicating similar generation characteristics within the city largely independent of season or location. However, they were higher for diapers (21%) and paper (25%). The RSD values were also higher for the waste components with a fraction <5% in the total SW stream, which may be expected due to their lower quantities. Among these, C&DW particularly had very high RSD (119%). As the SW is received from a collection vehicle during sampling operations, the contents of the truck impact directly the percentages of each fraction. While some waste constituents are expected to come at similar proportions from each household (e.g. food waste, plastic bags), others may not be generated at all at one household while being generated in high quantities at another one (e.g. C&DW, pharmaceuticals). Also, the income status of neighborhoods within the same city, where the waste is collected from, has some impact on the composition data (Ozcan et al. 2016), which may explain to an extent the variation in the present study as the contents of waste collection vehicles were from different districts in Nur-Sultan.

The waste composition identified in the present study shows some differences compared to limited literature on SW in Kazakhstan. To start, it is somehow inconsistent with the composition data for Kazakhstan reported by Vermenicheva et al. (1999), who reported a higher paper and cardboard (22.9-40.0%) and lower organic fraction (reported as food wastes, 24.0-40.0%) and plastics (1.0-2.0%). A similarly low organics content and high paper and cardboard content was reported in more recent government studies on MSW composition (MEWR 2014, MRD 2012) whereas the plastics fraction indicated in these works was more consistent with the current findings. Since sampling and estimation methods used as well as the representativeness of the waste profile sampled by these studies (MEWR 2014, MRD 2012, Vermenicheva et al. 1999) either have not been clarified or are outdated, the confidence in these studies could be deemed relatively low. That being said, the waste composition data reported in the present study was quite similar to previous four field campaigns performed by Abylkhani et al. (2019) from summer 2017 to spring 2018 (Table 6).

### 3.3. Detailed characterization of solid waste

A detailed sampling and subsequent advanced characterization have been conducted during the sampling campaigns after the first and second sorting steps for selected waste components and sub-components (Table 4). These components and sub-components have been selected mainly based on their potential for undergoing further waste transformation processes (e.g. composting, recycling, energy recovery) as well as their abundance or availability (%) in the SW stream.

For the paper fraction (including all types of paper and comprising 12.8% of the total SW stream), the components investigated were classified as paper (2.6%), cardboard (5.7%), Tetra Pak (0.7%), and mixed paper (3.8%). Among these, the paper component (2.6%) was further sorted for its sub-components as this is a component with good potential for high quality recycling once a separate collection system is to be established. Three sub-components (newspaper/magazine/advertisement including journals, packaging paper for packaging of food and other goods, and office paper blank or printed A4 and A3 papers) comprised the majority of the paper component which is also the 2.2% of the entire MSW, whereas other paper (remaining paper such as toilet paper and tampons) was the remaining (approx.15% of all paper) and is more suitable for other processing methods such as composting or energy recovery.

Regarding the plastics fraction (15.2%), the components investigated were LDPE (5.5%), HDPE (0.5%), PET (2.4%), other plastics (1.9%), and mixed plastics (4.9%). The share of other plastics and mixed plastics which normally proves impractical for recycling operations was high (a combined 45% of all plastics), so, energy recovery may be a more suitable option for them due to high energy content of plastics if implemented in the future. Among components analyzed, LDPE (5.5%) was further sorted for its sub-components: bags (for carrying goods), and other LDPE (used for food/clothing wrapping). LDPE in the SW stream has a particularly bad image among public and NGOs, as it has been strongly associated with the environmental pollution. Its investigated sub-component (bags) is also relatively easy to target for reduction via public awareness campaigns and tax levies. This sub-component comprised the majority of LDPE and 4.5% of the total SW stream.

This percentage could be considered high compared to the overall plastic content (15.2%), and it is in fact greater than the percentages of several SW fractions of MSW of Nur-Sultan such as metals, wood, glass, and C&DW. The results indicate a significant use of disposable plastic bags by the residents of Nur-Sultan. A study by Martinho et al. (2017) reported that after implementation of the Portuguese plastic carrier bag tax (PCBT) in two cities of Portugal, the consumption of plastic bags has been reduced by 74%. It was also reported that an adoption of PCBT or levy substantially decreased plastic bag consumption (by 50-90%) in countries such as Denmark, Ireland, Luxemburg, Belgium, Spain, and UK (Martinho et al. 2017). Thus, an implementation of levy or tax on plastic bags by the local municipality is highly recommended as it would significantly help reducing the consumption of plastic bags, and thus, their fraction in the SW stream.

The glass fraction (4.9%) consisted of almost exclusively separable glass (4.8%) which can be recovered and recycled effectively if a separate collection system for recyclables is implemented. The separable glass component has been further sorted to its sub-components; transparent glass (3.2%), green glass (0.9%), and dark glass (0.7%). The transparent glass, which is the most economically valuable sub-fraction of glass comprised the majority of the glass (65%). Similar results were found in Rome, Italy, where the amount of transparent glass reported to be 2.5% of total MSW and 50% of glass fractions (Lombardi et al. 2010). The results on the detailed characterization of glass fraction further supports the establishment of a separate waste collection system that will enable the un-commingled collection and separation of recyclables in the SW stream of Nur-Sultan.

The organics fraction (the fraction with the highest percentage of SW fractions in the SW stream of Nur-Sultan, 46.3%) was further sorted into the following sub-components: cooking waste (defined in the present study processed items consisting of kitchen waste and food leftovers, 4.0%), large compostables (all remaining biodegradable waste such as raw vegetables and fruits, flesh and bones, and green waste, 13.3%), and other organics (fraction of organic waste smaller than 12 mm, 29.0%). First of all, the organics fraction of the SW stream of Nur-Sultan is very high, which validates the need for a municipal composting plant (scheduled to be constructed in the near future). The mechanical sorting plant that processes the SW already separates the organics but currently sends them to the city landfill as there are no other existing means to valorize this fraction. Also, the other organics (organics fine fraction <12 mm) comprises the majority of the organics (63%), which may be preferable for composting, for use as refuse derived fuel, or for digestion systems. The installation and operation of alternative waste transformation approaches such as composting, heat recovery, or biogasification will significantly reduce the landfilling requirements while allowing the valorization of this fraction. It has been recently proposed that composting can be a valuable resource recovery option e.g. in the case of Saudi Arabia, composting food waste can cover the country's annual demand for fertilizers (500,000 tons) and save over 70 million USD each year (Waqas et al. 2018).

The miscellaneous fraction (1.0%) of the SW stream has been further sorted into its sub-components to quantify the pharmaceuticals in the stream. It was found that pharmaceuticals comprised 0.4% of the total SW. This is also a part of the HHW which is typically less than 1% of the total MSW (Inglezakis and Moustakas 2015). This specific waste must be separately collected and handled from the existing MSW stream. These results imply that HHW and/or medical waste collection and management in Nur-Sultan is not effective. Another example which faces the issue of mismanagement of medical wastes is Iran with an ineffective policy system of handling this type of waste leading to majority of medical wastes being landfilled with MSW. Lack of resources, labor, awareness, and strict enforcement of the regulation result in a poor policy performance (Rupani et al. 2019).

Finally, the metals fraction (1.9%) has been sorted into two components: ferrous metals (1.3%) and non-ferrous metals (0.6%). Non-ferrous metals, which comprise 32% of all metals in the SW stream of Nur-Sultan could be assumed to contain mainly aluminum, which has higher economic value than ferrous metals. The extraction of aluminum and subsequent production of aluminum cans are also energy intensive processes. The previously suggested implementation of a separate collection system for recyclables would also reduce the percentages of both non-ferrous and ferrous metals in the SW stream, thus reducing energy needs and providing economic benefit.

The percentages of sub-components analyzed in the present study (Figure 2) showed variation between field campaigns conducted at different times over one year (statistical significance not investigated). Most of the variation between sampling campaigns was relatively small and could be associated with the changes in the composition of waste received from collection vehicles. Some waste constituents could be expected to come at similar proportions from each household (e.g. organics such as food waste) whereas others may not be generated at all at one household while being generated at high quantities at another, which may explain the change of the percentage of pharmaceuticals in summer 2019 campaign. Furthermore, some notable changes have been observed between quantities of transparent glass in winter and summer as well as of large compostables. More specifically, large compostables (all biodegradable waste such as raw vegetables and fruits, flesh and bones, and green waste) as well as transparent glass have been found in higher percentages in summer than winter. This may be attributed to the fact that more vegetables and fruits are available to locals in summer than in winter, and also to the fact that more drinks in transparent bottles (water, juice, soda, etc.) are consumed in summer months than in winter.

## 4. Conclusion

Three field campaigns for municipal solid waste (MSW) sampling were conducted at the Nur-Sultan City's landfill during a one-year period, and results showed that the major waste fractions were organics (46.3%), plastics (15.2%), and paper (12.8%). The MSW generation rate of Nur-Sultan City was estimated based on field collection and literature composition data. The estimated MSW generation rate (1.47 $kg.capita^{-1}.d^{-1}$) was at the lower-middle range of worldwide values and, along with the waste composition data, was typically characteristic of middle-income countries. The detailed composition analysis showed ample opportunity for the implementation of various waste management/transformation techniques for a more sustainable waste management that is not only applicable to Nur-Sultan but also to major cities in Kazakhstan as well as in Central Asian countries which share similar economic status, culture, and rapid development characteristics. Specifically, the following actions (in order of priority) would be recommended for implementation:

(1) establishment and operation of a composting plant (due to high organic fraction (46.3%) mainly comprised of organics fine fraction <12 mm (29.0%), currently being disposed to the city landfill) as this will drastically reduce the volume of the waste going to landfill and help valorize the waste;

(2) imposing a tax levy on plastic bags (due to high LDPE (low-density polyethylene) content (5.5%) mostly comprised of disposable bags (4.5%)) as a rapid and effective action item; and,

(3) an implementation of separate collection system for recyclable fractions (where current quality and quantity recovered from commingled waste is low) due to high potential of recovery and economic benefit.

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Table 1. Summary of selected studies reporting detailed/advanced characterization of municipal solid waste (MSW)

| # | Study | Fraction | Component | Sub-component |
|---|---|---|---|---|
| 1 | Bernache-Perez et al. (2001) | Paper | Cardboard | Packaging, non-packaging, laminated with aluminum, laminated without aluminum |
| | | | Paper | Packaging, non-packaging, toilet paper, feminine pads |
| | | Plastic | Rigid plastic | PET, HDPE, PVC, non-packaging, others |
| | | | Plastic film | Snack bags, LDPE, laminated |
| | | | Other plastic | PP, PS, foam packaging, foam non-packaging, PU |
| | | Glass | Stained glass | Packaging, non-packaging |
| | | | Clear glass | Packaging, non-packaging |
| 2 | Miezah et al. (2015) | Paper | Paper and cardboard | Newspaper, office print, tissue paper, cardboard/packaging |
| | | Plastic | | Plastic Film/LDPE, HDPE, PP rigid, PS, PVC, other plastics |
| | | Glass | | Colored, plain |
| 3 | Pan and Voulvoulis (2007) | Paper | Paper | Newspaper, magazine, other paper |
| | | | Card | Liquid cartons, card, other card |
| | | Miscellaneous | | Disposable, other miscellaneous |
| | | Putrescible | | Garden waste, other |
| 4 | Aja and Al-Kayiem (2013) | Paper | | Mixed paper, newsprint, high-grade paper, corrugated paper |
| | | Plastic | | Rigid, foam, film |
| | | Glass | | Clear, colored |
| 5 | Lombardi et al. (2010) | Paper | Paper | Wrapping paper, newspaper/magazines, photographic paper, other paper |
| | | | Cardboard | Cardboard packaging, stiff cardboard, other |
| | | Glass | | Transparent, colored, other glass |
| | | Plastic | | Packaging, garbage bags, PVC, PET, HDPE, PS, plastic films, other packaging material, other plastic |
| | | Hazardous materials | | Medicines, batteries, accumulators, other hazardous materials |
| 6 | Zorpas et al. (2015) | Packaging | | Plastic bottles, ferrous packages, tetra pack |
| | | Paper | Other paper | Toilets and kitchens paper |
| | | | Paper | Packages, newspapers, magazines, office stationery, advertisements |
| | | Plastic | | Plastic film, plastic-non recyclable |
| | | Organics | Food waste A | Bakery, confectionery, dairy products, meat, fish, cooked food |
| | | | Food waste B | Yogurt, wine, oils (cooking), olives, eggs, bananas, apples, pears, peaches, pomegranates, grapes, watermelon, oranges, passionfruit, mandarins, potatoes, girasol, tomatoes, lemons, cucumber, carrots, onions, bread, pasta |

| | | | | |
|---|---|---|---|---|
| | | | Compostable | Vegetables, skin fruits, green waste, dust, soil |
| 7 | Sahimaa et al. (2015) | Biowaste | Kitchen waste | |
| | | | Garden waste | Stick and branches, other garden waste |
| | | | Other waste | |
| | | Paper | Packaging, non-packaging | Aluminum layered and other |
| | | | Paperboard and cardboard | |
| | | Plastic | Packaging, non-packaging | Dense plastic, plastic film |
| | | Glass | | Packaging, non-packaging |
| 8 | Edjabou et al. (2018) | Paper | Paper | Advertisements, books and booklets, magazines and journals, newspaper, office paper, phonebooks, paper (miscellaneous) |
| | | | Board | Beverage cartons, corrugated boxes, folding boxes, board (miscellaneous) |
| | | Plastic | Packaging | Packaging, HDPE, LDPE, LLDPE, PET/PETE, PP, PS, PVC/V, resin |
| | | | Film | Pure plastic film, composite plastics |
| | | Organics | Food waste | Bread, cereals, coffee grounds, fresh fruit, fresh carrots and potatoes, residues (fruits, vegetables), rest of the food that contains meat |
| | | | Gardening waste | Flowers |

Table 2. Fractions, components, and sub-components investigated in detailed characterization of MSW of Nur-Sultan City

| MSW fraction | Component of selected MSW fraction | Sub-component of selected component |
| --- | --- | --- |
| Organics | All organics | Cooking waste |
| | | Large compostables |
| | | Other organics (organics fine fraction <12 mm) |
| Plastics | LDPE | Bags |
| | | Other LDPE |
| | HDPE | - * |
| | PET | - |
| | Other plastics | - |
| | Mixed plastics | - |
| Paper (all) | Paper | Newspaper/ magazine/ advertisement |
| | | Packaging |
| | | Office paper |
| | | Other paper |
| | Cardboard | - |
| | Tetra Pak | - |
| | Mixed paper | - |
| Diapers | - | - |
| Glass | Separable glass | Transparent |
| | | Green |
| | | Dark |
| | Mixed glass | - |
| Textile and leather | - | - |
| Other fine fraction (<12 mm) | - | - |
| Construction & demolition waste | - | - |
| Metals | Ferrous | - |
| | Non-ferrous | - |
| Miscellaneous | All miscellaneous | Pharmaceuticals |
| | | Other misc. |
| Wood | - | - |
| Waste electrical & electronic equipment | - | - |

* -: not investigated

Table 3. Average composition of MSW (%, w/w) for Nur-Sultan City based on year-long sampling from three campaigns (total: 15 days of sampling)

| MSW Fraction | Summer 2018 | Winter 2019 | Summer 2019 | Average | Relative St. Dev. |
|---|---|---|---|---|---|
| **Organics** | 48.1% | 44.5% | 46.3% | **46.3%** | 4 |
| **Plastics** | 15.5% | 15.7% | 14.3% | **15.2%** | 5 |
| **Paper (all)** | 14.1% | 15.1% | 9.1% | **12.8%** | 25 |
| **Diapers** | 5.8% | 7.2% | 4.7% | **5.9%** | 21 |
| **Glass** | 5.1% | 5.0% | 4.6% | **4.9%** | 5 |
| **Textile & leather** | 2.7% | 3.5% | 5.0% | **3.7%** | 33 |
| **Other fine fraction (<12 mm)** | 3.0% | 5.2% | 2.3% | **3.5%** | 43 |
| **Construction & demolition waste** | 1.4% | 0.6% | 7.6% | **3.2%** | 119 |
| **Metals** | 1.8% | 1.3% | 2.7% | **1.9%** | 37 |
| **Miscellaneous** | 0.8% | 0.4% | 1.8% | **1.0%** | 72 |
| **Wood** | 1.0% | 0.6% | 0.8% | **0.8%** | 21 |
| **Waste electrical & electronic equipment** | 0.6% | 0.8% | 0.6% | **0.7%** | 15 |

Table 4. Advanced characterization and detailed composition of MSW from Nur-Sultan City (%, w/w)

| Selected MSW fraction | Average % total | Sorting | Component | % | Detailed sampling done? | Sub-component | % |
|---|---|---|---|---|---|---|---|
| Paper (all) | 12.8 | 1st step | Paper | 2.6 | Yes | Newspaper/magazine/advertisement | 0.8 |
| | | | | | | Packaging | 0.6 |
| | | | | | | Office paper | 0.8 |
| | | | | | | Other paper | 0.4 |
| | | | Cardboard | 5.7 | No | | |
| | | | Tetra Pak | 0.7 | No | | |
| | | 2nd step | Mixed paper | 3.8 | No | | |
| Plastics | 15.2 | 1st step | LDPE | 5.5 | Yes | Bags | 4.5 |
| | | | | | | Other LDPE | 1.0 |
| | | | HDPE | 0.5 | No | | |
| | | | PET | 2.4 | No | | |
| | | | Other plastics | 1.9 | No | | |
| | | 2nd step | Mixed plastics | 4.9 | No | | |
| Glass | 4.9 | 1st step | Separable glass | 4.8 | Yes | Transparent | 3.2 |
| | | | | | | Green | 0.9 |
| | | | | | | Dark | 0.7 |
| | | 2nd step | Mixed glass | 0.1 | No | | |
| Organics | 46.3 | 2nd step | All organics | 46.3 | Yes | Cooking waste | 4.0 |
| | | | | | | Large compostables | 13.3 |
| | | | | | | Other organics (organics fine fraction <12 mm) | 29.0 |
| Miscellaneous | 1.0 | 2nd step | All misc. | 1.0 | Yes | Pharmaceuticals | 0.4 |
| | | | | | | Other misc. | 0.6 |
| Metals | 1.9 | 1st step | Ferrous | 1.3 | No | | |
| | | | Non-ferrous | 0.6 | No | | |

Table 5. Quantities of solid waste entering mechanical sorting plant in Nur-Sultan City landfill as reported by the Municipality of Nur-Sultan

| | ***Residential and commercial solid waste (reported as mixed solid waste)*** | ***Municipal services (reported as street sweeping and litter pick)*** | ***Special waste such as bulky items and white goods (reported as extracted goods and bigger items)*** | **Total waste entering mechanical sorting plant** |
|---|---|---|---|---|
| ***Monthly average*** | 23,103 | 8,788 | 2,416 | 34,306 |
| ***St. Dev.*** | 3,060 | 10,485 | 844 | 14,389 |
| *Monthly minimum* | 17,448 | 1,690 | 1,470 | 20,608 |
| *25th percentile* | 21,540 | 3,725 | 1,944 | 27,209 |
| *Median* | 23,103 | 4,892 | 2,289 | 30,283 |
| *75th percentile* | 24,336 | 10,394 | 2,434 | 37,164 |
| *Monthly maximum* | 28,289 | 38,799 | 4,575 | 71,663 |
| ***Annual total*** | **277,233** | **105,451** | **28,990** | **411,674** |

Table 6. MSW composition of Nur-Sultan City based on data from 2017 to 2018 (Abylkhani et al. 2019) and from 2018 to 2019 (the present study)

| **MSW Fraction** | **% (± St. Dev.), Abylkhani et al.** | **% (± St. Dev.) the present study** |
|---|---|---|
| Organics | 47.2 ± 1.6 | 46.3 ± 1.9 |
| Plastics | 15.4 ± 1.4 | 15.2 ± 0.8 |
| Paper (all) | 12.5 ± 1.1 | 12.8 ± 3.2 |
| Diapers | 6.2 ± 0.4 | 5.9 ± 1.2 |
| Glass | 6.2 ± 1.2 | 4.9 ± 0.2 |
| Textile & leather | 3.4 ± 0.6 | 3.7 ± 1.2 |
| Other fine fraction (<12 mm) | 3.5 ± 0.8 | 3.5 ± 1.5 |
| Construction & demolition waste | 0.9 ± 0.4 | 3.2 ± 3.8 |
| Metals | 2.7 ± 0.5 | 1.9 ± 0.7 |
| Miscellaneous | 0.8 ± 0.1 | 1.0 ± 0.7 |
| Wood | 0.8 ± 0.4 | 0.8 ± 0.2 |
| Waste electrical & electronic equipment | 0.6 ± 0.2 | 0.7 ± 0.1 |

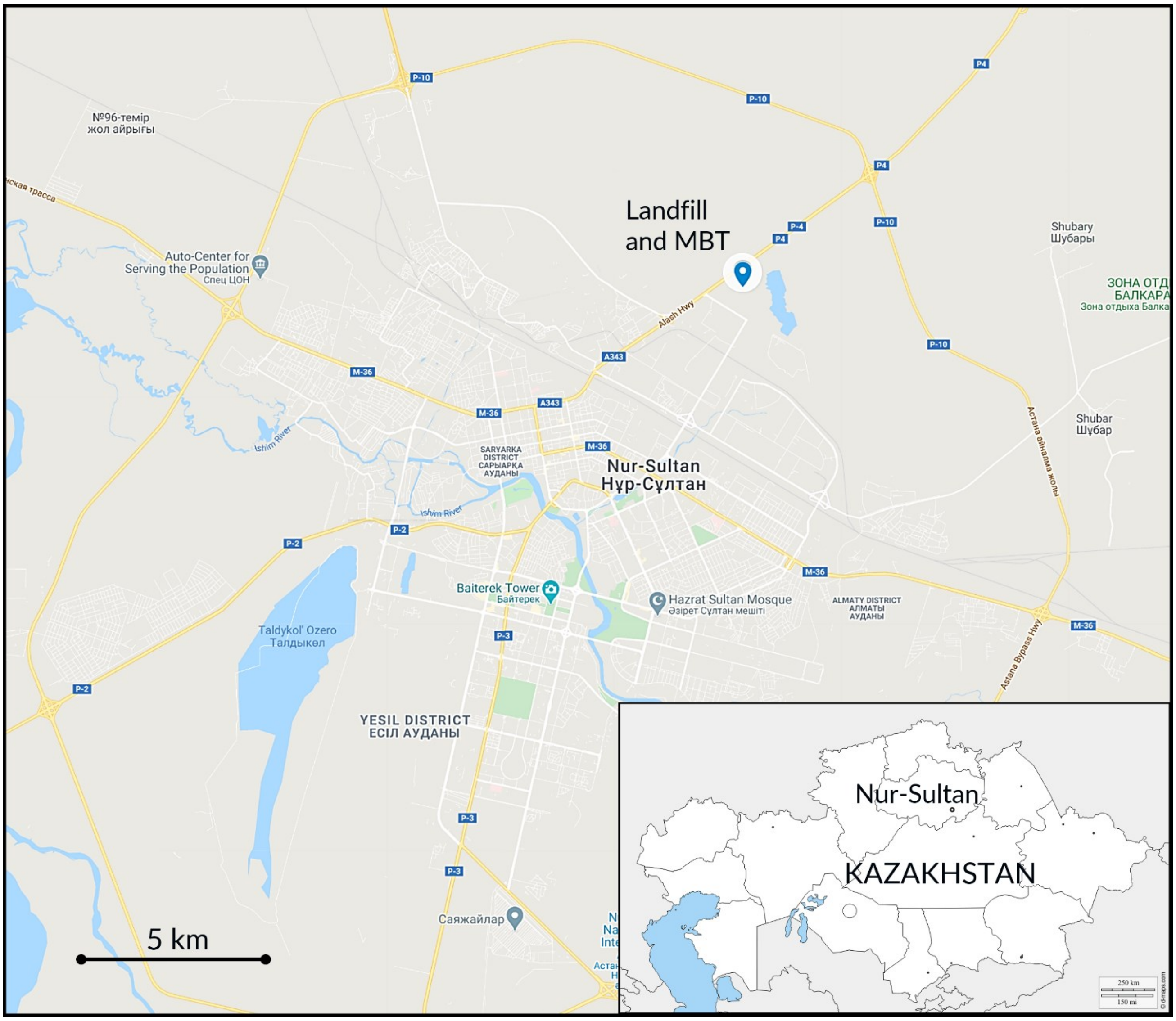


Figure 1. Map of Nur-Sultan City, Kazakhstan along with the location of the city's mechanical treatment plant at the city landfill

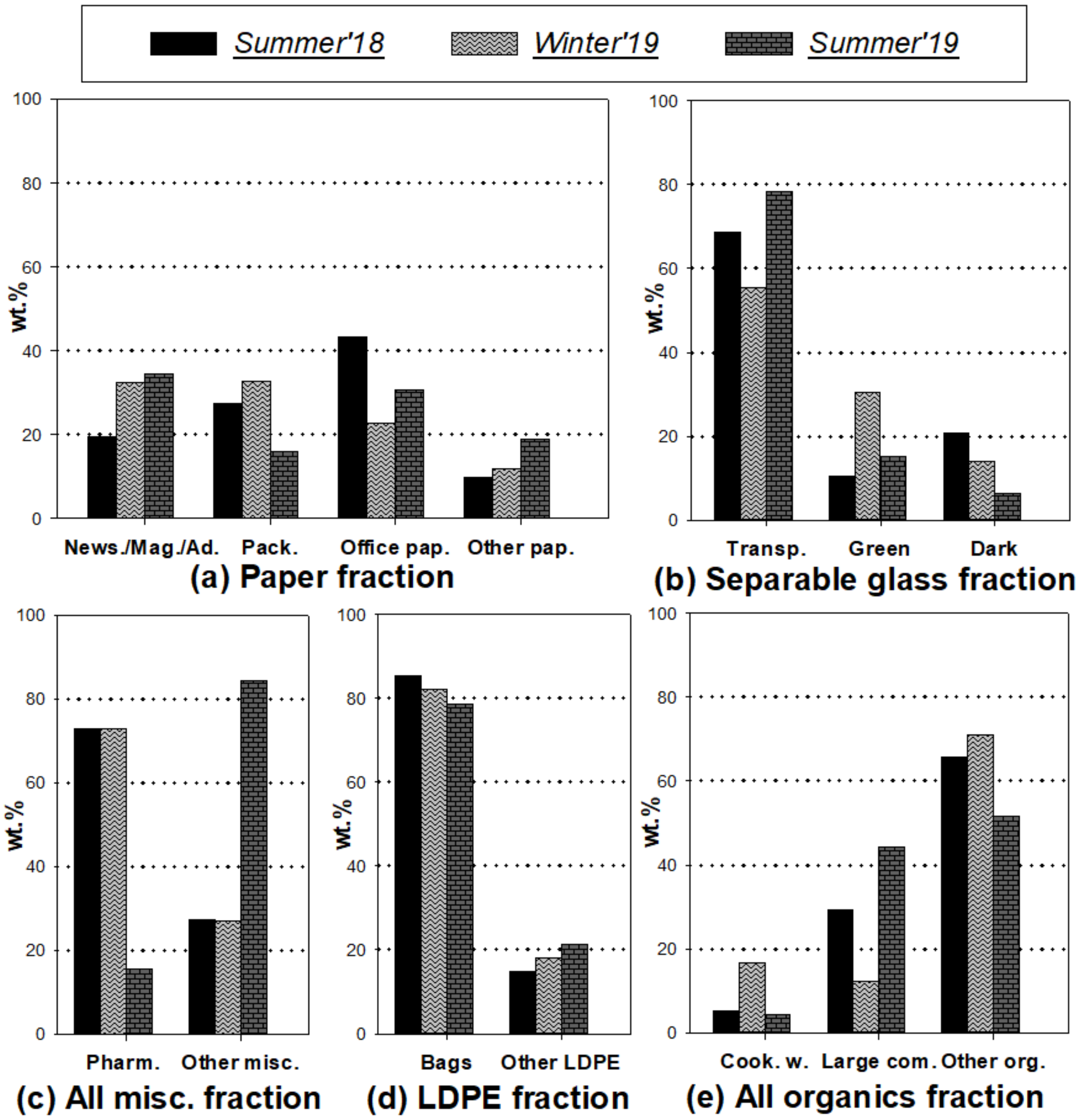


Figure 2 (a-e). The results of detailed characterization for municipal solid waste from Nur-Sultan City for components and sub-components (a) Paper fraction, (b) Separable glass fraction, (c) All miscellaneous fraction, (d) LDPE fraction, and (e) All organics fraction.