The present work was submitted to the Faculty of Engineering

Plastic in the environment of Nalaikh

Bachelor Thesis

by

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Statutory Declaration

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I hereby affirm in lieu of an oath that I provided the submitted bachelor thesis

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Ulaanbaatar/Nalaikh, 11th of March, 2020
Place, Date

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Abstract

Plastic is one of the most produced material in the world due to its flexibility and cheap cost to produce and plastic production has been growing since 1950 and expected to keep on growing. Once plastic product is used and becomes waste plastic becomes problem to the environment. First of all, shear amount of the plastic and plastic accumulation due to slow degradation of plastic and additionally plastic waste causes problems such as entanglement, ingestion, leaching. On top of negative environmental impacts plastic waste is a health hazard as well.

This thesis assesses impact of the plastic waste in Nalaikh by evaluating amount of landfilled plastic waste, recycled plastic waste, plastic waste directly disposed to the environment and impact of different methods to deal with plastic waste trough material flow analysis based on literatures and assumptions. Currently Nalaikh has population of 37608, where majority of the population is living in Ger area. Waste generation pattern is different by a season and during winter majority of the plastic waste is generated by households and during summer majority of the plastic waste is from households and illegal dumping, especially illegal dumping in Terelj national park. Currently it is estimated 610.29 tons of plastic waste is directly disposed to the environment.

Population of Nalaikh is expected to keep on growing and as the population grows amount of plastic waste generated is expected to keep on growing and amount of plastic waste disposed to the environment is expected to grow from 1.72tons/day to 2.55tons/day in 2050. To deal with this problem one measure by itself would not have enough impact and combination of multiple methods is required. If multiple methods are used together including recycling plant in Nalaikh amount of plastic waste disposed to the environment is expected to reduce from 1.72tons/day to 0.54tons/day in 2050 and there is potential to supply plastic recycling plant for next 60 years. With current limited knowledge on plastic waste of Nalaikh further research are highly recommended as Nalaikh is currently under a threat of plastic pollution.

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1. Introduction

1.1. Introduction to plastics

Plastic is a man-made polymer material that can be molded or shaped by using heat and pressure. This property of plastic is often referred as plasticity and additional properties such as low density, low electrical conductivity, toughness, and transparency makes plastics useful in many different applications starting from polyethylene terephthalate (PET) which is used for beverage bottles, polystyrene which is used for food containers, and polyvinyl chloride polyvinyl chloride which is used for various building materials.

Plastics can be categorized by their application as commodity resins and specialty resins, where commodity resins are plastics that are produced at high volume and low cost for common disposable items and durable goods. Polyethylene, polypropylene, polyvinyl chloride, and polystyrene are common type of commodity resins. On the other hand, specialty resins are as the name suggests plastics whose properties are tailored for specific application which includes plastics used for automotive applications, hardware, engineering, etc. Examples of specialty resins are polyacetal, polyamide (commonly called nylon), polycarbonate.

Additionally, plastics can be categorized by their chemical composition. First category is plastics that are made of polymers having only linear carbon atoms in their chains and polypropylene is an example of plastic with linear carbon atoms in its chain. Second category is plastics that are made of heterochain polymers. This type of plastic commonly contains oxygen, nitrogen, and sulfur in their chains and majority of engineering plastics are in this category.

Another very important categories for plastic are thermoplastic and thermoset. Thermoplastics are plastics that are capable of being molded and remolded into different shapes multiple times without change to its mechanical and chemical properties, thus thermoplastics can be recycled. On the other hand, thermosets are plastics that cannot be reshaped through application of heat.

Mass production of plastic began during World War II due to excessive use of other materials for warfare leading to shortage of materials [40]. Data availability for global plastic production starts with 1950 [41] [43] and also 1950 is suggested start of Anthropocene and plastic is proposed as an indicator for this era [42]. In 2017 polyethylene was majority of plastic production with 29% where 16% was for low-density and linear low-density polyethylene and 13% was for high density polyethylene and second most produced plastic type was polypropylene with 17% and other plastic types such as polyvinyl chloride, polyethylene triphosphate, polystyrene, polyurethane having less than 10% respectively. Globally half of the plastic resins are produced by Asian countries where China produces 29% and other Asian countries produces 21% and next biggest producer region is Europe with 19% [41] and in terms on plastic fiber production is dominated by Asian region with china producing 64% and other Asian countries are producing 22% of total plastic fiber products [44].

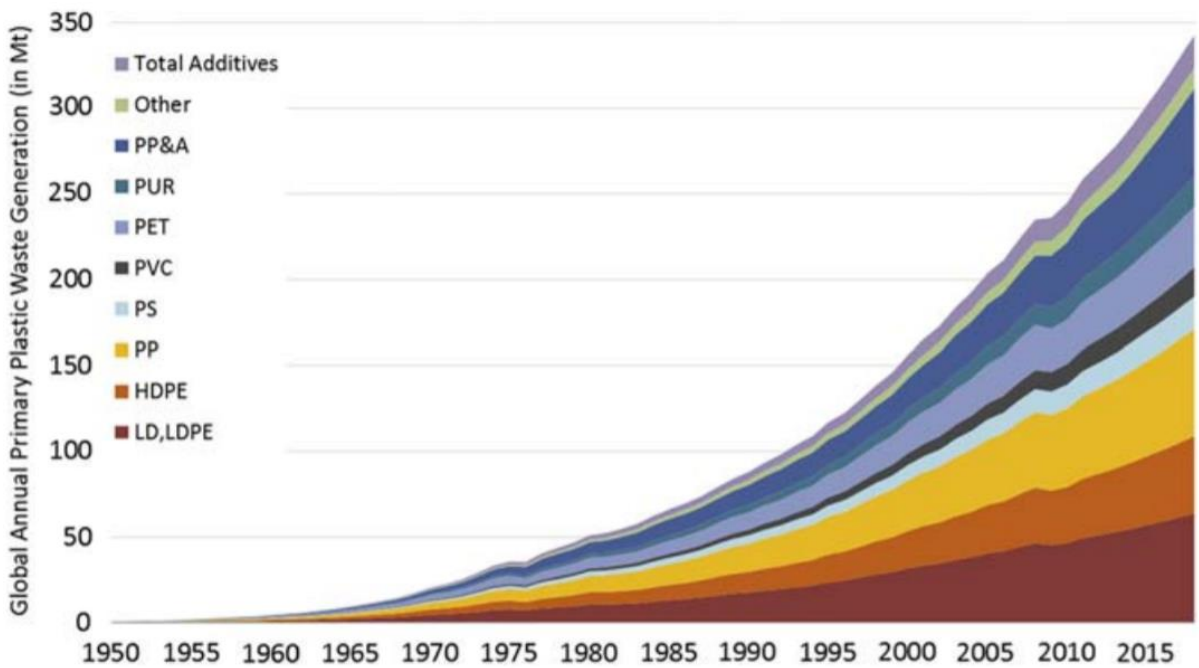


Figure 1. Global plastic production in Mt by material type from 1950 to 2017 [41]

Packaging sector takes 42% of total plastic consumption and packaging industry and polyethylene, polypropylene, and polyethylene triphosphate are most common types of plastic resins used for packaging. Building sector takes 16% of total plastic consumption and majority of plastic products in building sector is polyvinyl chloride products (69%). Application of plastic highly impacts lifetime of plastic products where plastics used for packaging has lifetime from few months to few years while lifetime of plastics used for industrial machinery is expected to be 15-30 years and plastics used for transportation sector is expected to have lifetime of 20-50 years.

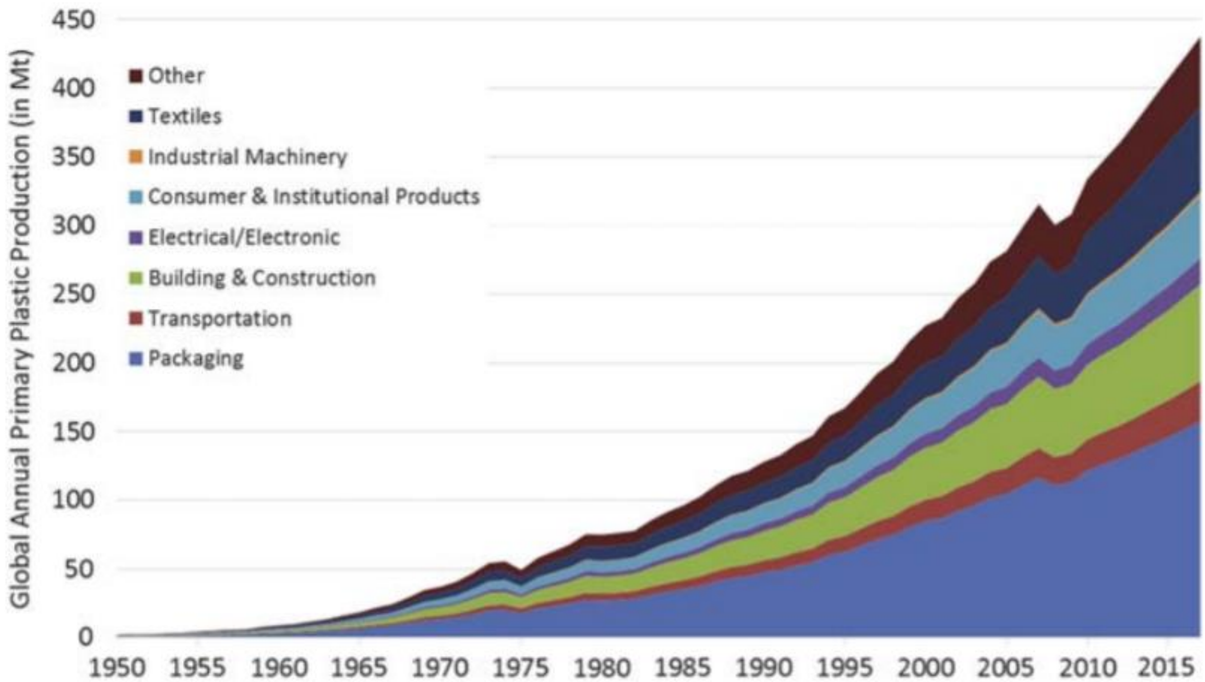


Figure 2. Global primary plastics production in Mt by consuming sector from 1950 to 2017 [41]

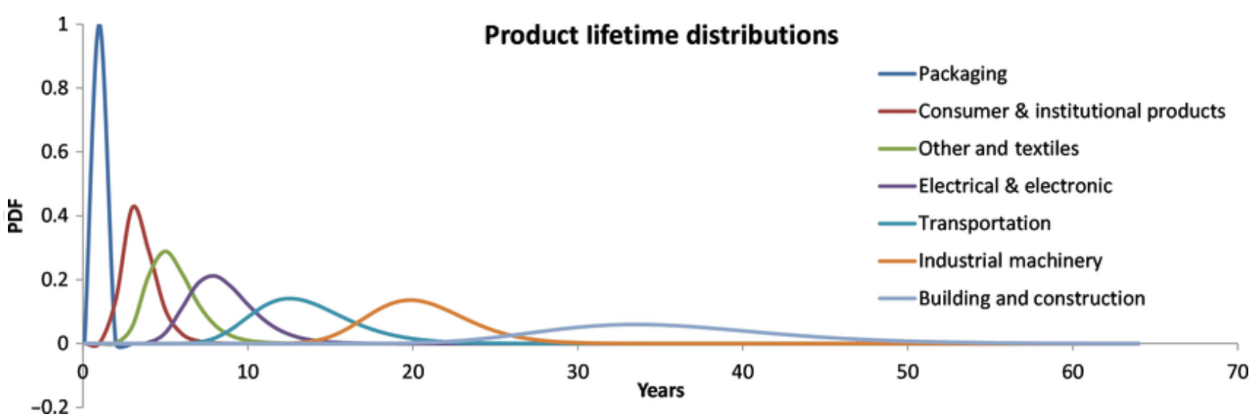


Figure 3. product lifetime distribution for industrial use sectors plotted as log-normal probability distribution function [45]

After finished using plastic waste is dealt with in three main ways which are discarding in landfill, energy recovery through incineration and recycling. Exact amount on how much waste is discarded, incinerated and recycled is not clear, by [41] estimated 29.3% if all plastic produced is currently in use, 7.6% of the all plastic is recycled, and 54.3% of all plastic produced is discarded in landfill and remaining is incinerated while [45] estimated 30.1% of all plastic produced is currently in use, 7.2% of all produced plastics is recycled, and 59.0% of all plastic produced is discarded. From 1950 to 1980 most of the plastic waste was directly discarded and starting from 1980 amount of recycled and incinerated waste is slowly increasing and even though from 2007 to 2012 amount of recycled waste was more than incinerated waste, since 2013 amount of incinerated waste exceeded amount of recycled waste. As for 2017 approximately 53% of waste is directly discarded and the percentage of directly discarded waste is trending downwards while percentage of incinerated and recycled waste is trending upwards. [41]

Plastics are generally produced from natural carbon materials such as petroleum, natural gas, and coal and during plastic production molecules of those materials are restructured to polymers. Many plastic products contain additives which helps plastic product to have specific properties depending on its application. Additives are plasticizers, colorants, reinforcements, and stabilizers. Plasticizer are additives used to change glass transition temperature of plastic product (glass transition temperature is the temperature region where polymer transition from hard material to soft material). For instance, polyvinyl chloride used for home should be rigid with glass transition temperature of 90 degree Celsius, but polyvinyl chloride used for hose should be flexible at common ambient temperatures. In terms of colorants, they can be soluble, organic or inorganic pigments and examples would be titanium dioxide and zinc oxide are used to make white colored plastics, carbon is used to make black colored plastics and additionally various organic compounds are used as pigments. Reinforcements are used to improve mechanical properties of plastic products. Stabilizers are additive that helps improve durability of plastic products. Plastics are carbon-based polymer and carbon-based polymers are vulnerable to oxidation, thus antioxidants are one common type of stabilizer. Additionally, filler materials are used to reduce plastic materials cost. Commonly used fillers are cheap materials such as mica, talc, or calcium carbonate and fillers can make up to 50% of final plastic [46].

1.1.1. Common plastic types

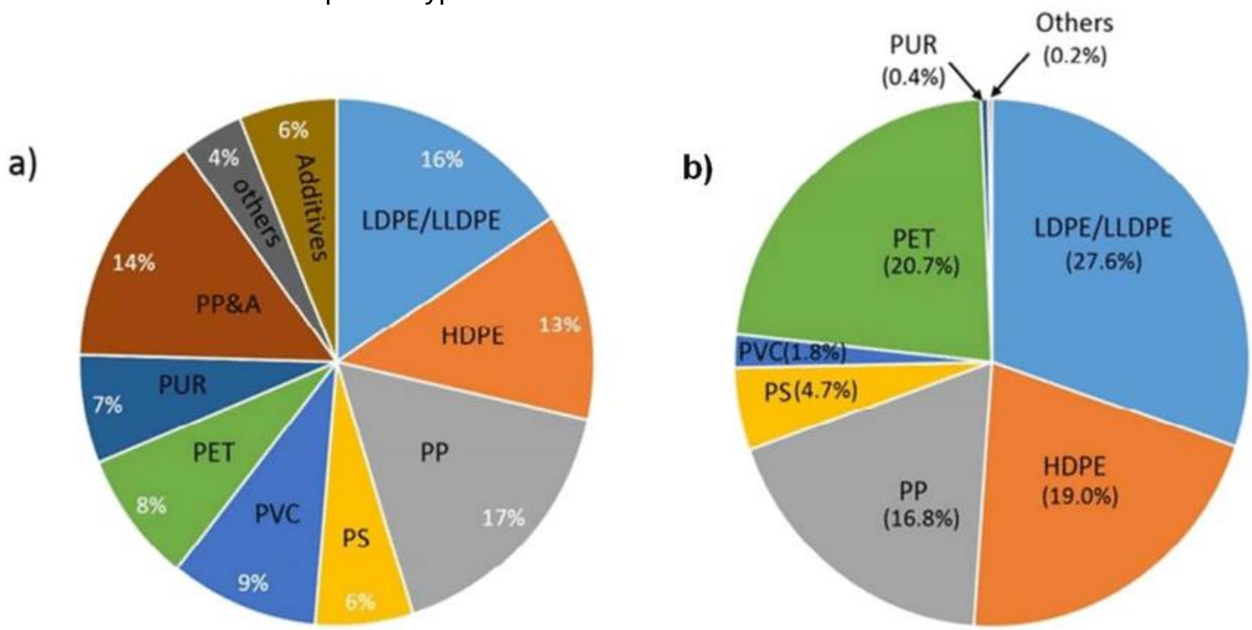


Figure 4.(a) Types of plastic produced worldwide (b) Plastic use in packaging industry in 2015 [2]

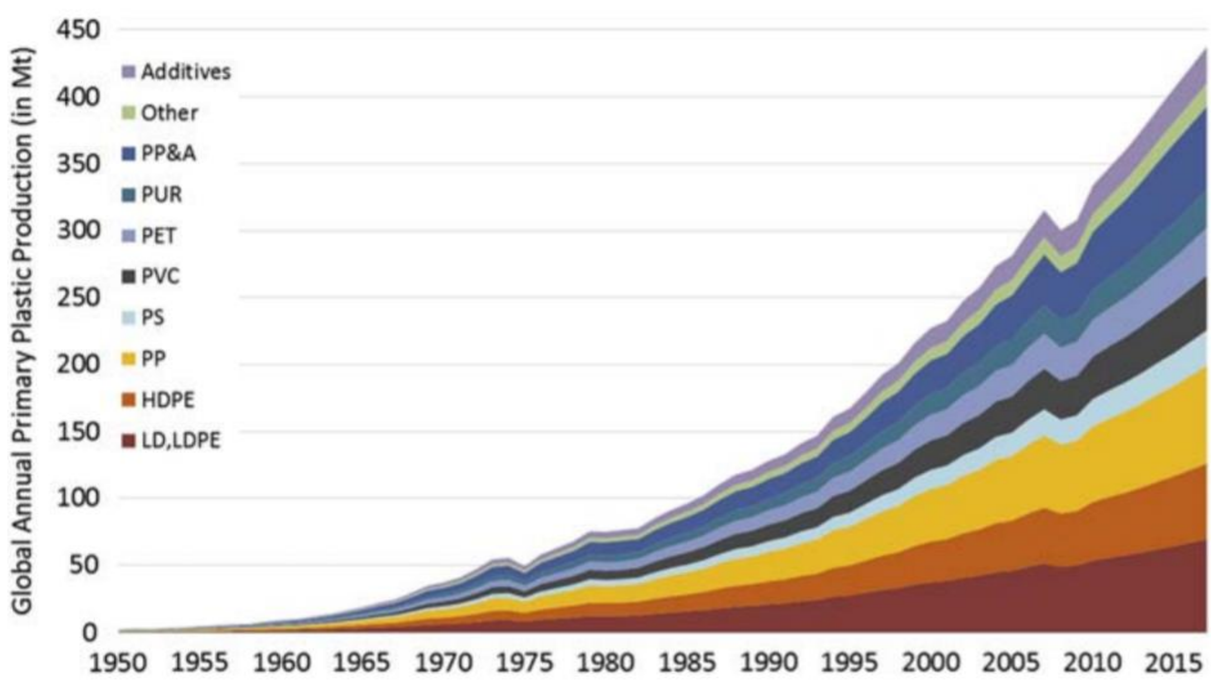


Figure 5. Global primary plastic production in Mt by material type from 1950 to 2017 [41]

1.1.1.1. Polyethylene

History of Polyethylene goes back as far as 1933 where it was first discovered by Reginald Gibson and Eric Fawcett. It is produced at high pressures and temperature in a presence of multiple catalysts, where choice of catalyst depends on desired properties of the application [1].

Polyethylene is classified according to the density of the polyethylene. Low-density polyethylene and high-density polyethylene are significant portion of global plastic production and very commonly used in packaging industry (figure 1) and there are less commonly used polyethylene types such as ultra-low-density polyethylene, very-low-density polyethylene, medium-density polyethylene (figure 2).

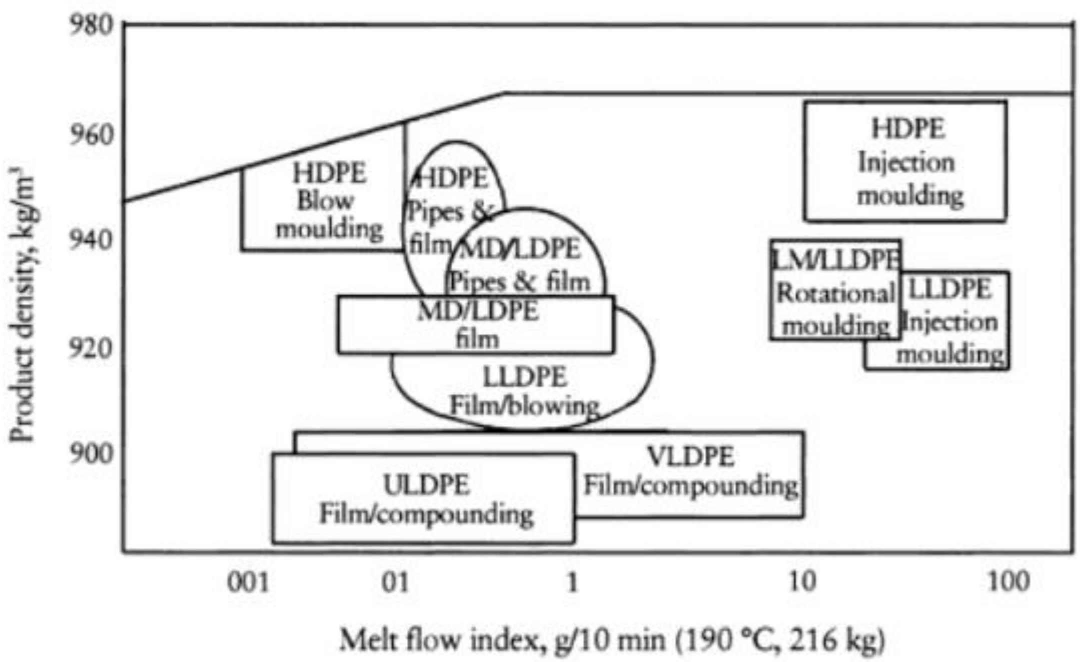


Figure 6. Classification of PE grades [1] (Melt flow index is ability of a material to flow in limited interval of time [4])

Due to ease of processing and properties such as printability, strength, tear resistance, resistance to chemicals and elasticity low-density polyethylene has wide range of applications such as food packaging, shopping bags, liners, overwraps, consumer bags, heavy-duty sacks, clarity shrink, lamination films, agricultural films, extrusion coatings, caps, closures, power cables, and toys [1] [3]. There are two main types of low-density polyethylene where low density polyethylene is lightweight, formable, has good resistance to impact and weldable with low melding point, on the other hand another type is linear low-density has poor physical properties regarding tensile strength, puncture, tear resistance, and elongation but has higher melting point and lower clarity compared to low-density polyethylene. Linear low-density polyethylene is ideal to be used as industrial containers, rubbish bins, automotive parts, and closures and low-density polyethylene is not used for such applications due to having poor UV resistance, lower operating temperature, high gas permeability and being susceptible to environmental stress cracking.

High-density polyethylene is easy to process and cheap material with important properties such as being weatherproof, high impact strength, self-lubricating, chemical resistance to corrosives making it suitable to be used as pipe and pipe fitting especially for water pipes, but also it is used for multiple different applications such as petroleum tank, toys, bowls, buckets, milk container, crate, film for packaging, food cutting board, pipe flanges, radiation shielding, chemical drums, general household and kitchenware, cable insulation, and food wrapping material. Blow-moulding is one of the common methods used for producing high-density polyethylene products and this method is used for producing bottles, packaging containers, car fuel tanks, and household goods. Significant disadvantages for high-density polyethylene would include poor UV resistance, high mould shrinkage and additionally if it is strongly heated it can produce dangerous fumes [1] [6].

Outside of high-density polyethylene and low-density polyethylene other types of polyethylene are used for more niche applications. For instance, ultra-high-molecular-weight polyethylene is used in niche applications such as lead-acid battery separator, fishing lines, nets, hopper, and snowmobile wheels. Additionally, polyethylene can be mixed with other material to be used for specific applications and one big example of it is ethylene-vinyl acetate where weight percent of vinyl acetate varies between 10% to 40% which is used as deep-freeze bag, agricultural file, handle grip [7] and another example would be chlorinated polyethylene where it contains 33% to 44% chlorine which improves toughness and it is specifically used for agricultural applications. [8]

1.1.1.2. Polyvinyl chloride (PVC)

Polyvinyl chloride is similar to polyethylene, can be used for various applications as variety of additives can be added to get properties required for the specific application [9]. Composition of polyvinyl chloride consists of 56.8% of chlorine, 38.4% carbon and 4.8% of hydrogen [10]. Pure polyvinyl chloride is a bright white brittle solid material, but with additional chemical it can be changed into multiple colors and flexibilities depending on its application. It is a thermoplastic meaning it can withstand heat and temperature without significant degradation. There are two main type of polyvinyl chloride products one being rigid and another is flexible. Normally it is not a flexible material but with additional plasticizers it can become more flexible and examples of it are cable coating and plastic wraps. Flexible polyvinyl chloride can contain up 10 to 60 percent additives [30].

Polyvinyl chloride is very flexible plastic and over 50% of polyvinyl chloride manufactured are used as building material, specifically used as pipe, window profile, and house siding and it has been replacing traditional building material such as wood and concrete due to its cheap price and ease to assemble. Additionally, it is used as food wrap, gloves, cable coating, flooring. Important properties of polyvinyl chloride are it is flame resistant, compatibility with additives, flexibility, resistance to fat and oil, and chemically stable [3] [11]. On top of that various applications such as waterproof coil [12], modified atmosphere packaging [13] and using polyvinyl chloride in orthopedic devices for biomedical engineering application [14] due to its properties transparent, flexible, chemical stability, and ease of fabrication, good temperature resistance (40 to 90°C in both cold and hot regions [12]), long service life and specifically sterilization performance in a case of biomedical application and high breaking elongation in a case of waterproof coil application where explored.

Polyvinyl chloride contains chloride in its structure and it tends to be toxic and because it is compatible with additives polyvinyl chloride products contains many different additives making recycling those products very complicated and when incinerated polyvinyl chloride products releases dioxins, which is highly toxic when entered food chain [3] and release of large amount of additive chemicals to the environment in fire scenarios in landfill is big concern as polyvinyl chloride can burn easily if ignited [32]. If burned carbon monoxide, carbon dioxide, hydrogen chloride and water is released and additionally products of incomplete combustion including dioxins can be released but monomer is not produced from incomplete combustion and hydrogen chloride gas is major health concern. Therefore, if polyvinyl products are landfilled fire safety is very important consideration and if it is incinerated it is important to control emissions of it.

Polyvinyl chloride degrades at low temperature and especially susceptible to photooxidative degradation [15] [16] where in a presence of a sunlight it degrades and releases hydrogen chloride [15]. But heat stabilizers are added to prevent degradation. It is found that rigid polyvinyl chloride is more susceptible to releasing stabilizer materials compared to flexible polyvinyl chloride [33] and it is a concern to environment as metal stabilizers are very commonly used [31]. In a landfill conditions polyvinyl chloride waste does not release vinyl chloride and vinyl chloride in landfill is rather from breakdown of volatile chlorinated organic compounds in landfill [29]. As mentioned before plasticizers are used to produce flexible polyvinyl chloride and release of plasticizers to the environment is another concern. Release of plasticizer can firstly depend on plasticizer type where plasticizer such as di-isodecyl phthalate and di 2-ethylhexyl phthalate shows minimal release, while release of butylbenzyl phthalate is varied up to 30 percent. [29]

1.1.1.3. Polyethylene terephthalate

Polyethylene terephthalate is a thermostatic plastic that is commonly used as a fiber and often referred as polyster. It has properties such as resistance to mechanical, thermal, and chemical stress, flexible, lightweight, electrical insulating, good fracture resistance making it suitable for multiple applications. Depending on the specific choice of additives polyethylene terephthalate can either be semirigid and rigid and has operating temperature from -60°C to 130°C [110].

it is mostly used for bottles, and also increasingly for clamshell containers [41] but application of polyethylene terephthalate is not limited to the bottle and containers especially in medical field. Multiple biomedical and medical devices are made of polyethylene terephthalate [108] and polyethylene terephthalate is used in multiple cardiovascular applications such as vascular prostheses, heart valves, surgical meshes [109]. Other applications would include roasting bags, video tapes, mechanical components and polyethylene terephthalate fibers blended with fabrics is commonly used in clothing.

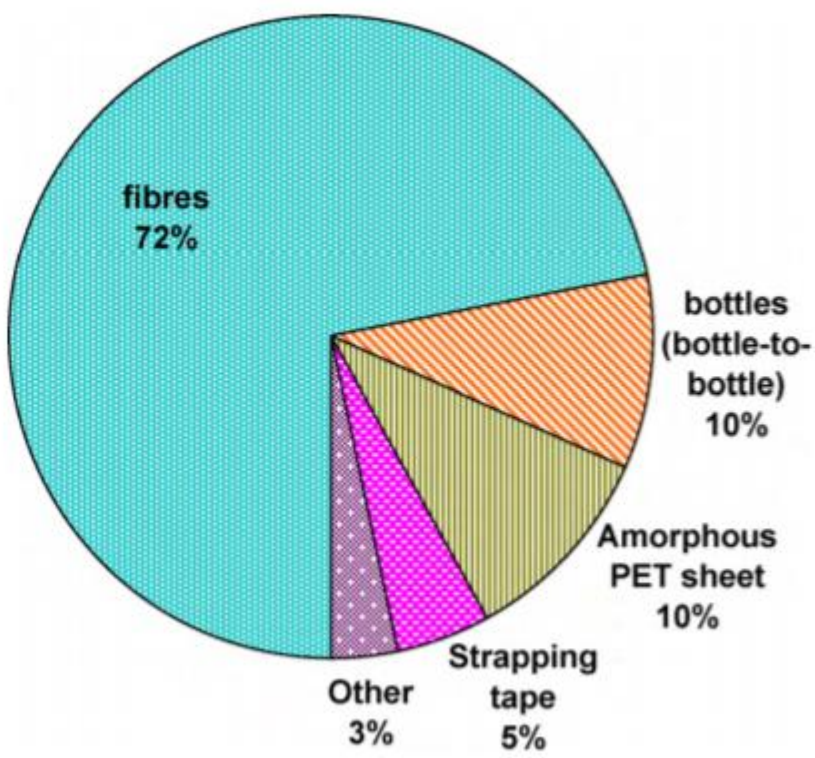


Figure 7. Apllication of PET flakes worldwide, 2007

1.2. Objectives of the study

Current knowledge on plastic waste in environment of Nalaikh very limited. Initial objectives of this study were to:

- Identify plastic materials in the environment of the Nalaikh
- Access plastic degradation process in Nalaikh
- Analyze potential countermeasures

Unfortunately, due to corona virus situation university was off limits, therefore objectives of this study were changed to:

- Analyze potential countermeasures
- Calculate material flow analysis of plastic in Nalaikh
- Access potential impacts of plastic in Nalaikh

Scope of the thesis:

This study was done to provide background information for the further studies related to plastic waste management, impact of plastic to the environment, microplastics, plastic recycling especially in Nalaikh.

Hypothesis of study:

- Recycling is potentially suitable countermeasure in Nalaikh.
- Material flow of the plastic would be highly influenced by season due to waste ash.
- Plastic pollution can have very big impact to the environment and health of the population of Nalaikh.

2. Study area

Study area of this work is Nalaikh, which is one of the smaller districts of Mongolian capital city Ulaanbaatar. In a past Nalaikh was well known for its coal mine which is currently not operating. Nalaikh district has population of 37608, 8772 of them lives in apartment area and remaining 28836 lives in ger area or homeless (last updated in December of 2019). Very important place in Nalaikh is Terelj national park which is one of the biggest national parks in Mongolia and very importantly Tuul river, which is main water supply for Mongolian capital city Ulaanbaatar where 46% of Mongolian current population lives originates from Terelj national park.

In terms of climate of the area, temperature during winter and summer are vastly different. Average temperature during summer varies between 13°C to 18°C with July typically being the warmest, and average temperature during winter varies between -17°C to -23°C with January being coldest month.

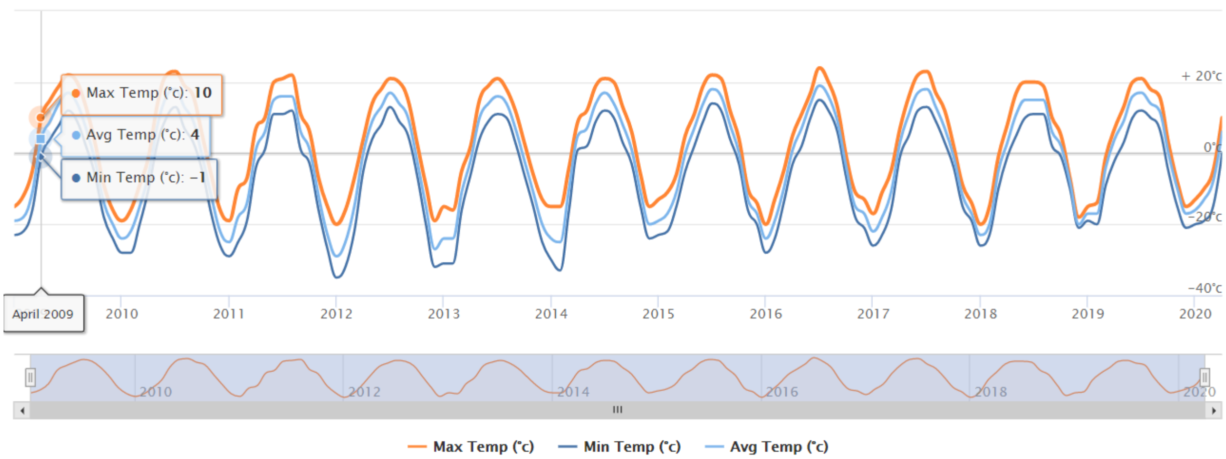


Figure 8. Average, minimum and maximum temperature from 2009 to 2020 [59]

Nalaikh is low income area where average monthly income is 983’298 MNT (350 USD) for ger areas and 1’357’034 MNT (482 USD) for apartment areas. [101]

In a case of waste generation there is no direct source on how much waste is generated in Nalaikh area or what type of wastes are generated. Thus, we are assuming waste generation trends for Nalaikh is same as Ulaanbaatar and using [60] [61] [63] as source for waste generation amount. According to [60] 650grams of waste is generated per person from apartment area regardless of season. However, waste generation amount is different for winter and summer for ger area due to ash generated from burning coal in ger areas. During summer 800grams of waste is generated per person from ger area and during winter 1200grams of waste is generated per person from ger area [60]. According to [61] 216grams of waste was produced per person from apartment and 590grams of waste was produced per person during summer per person and 640grams in a case of winter which is significantly less compared to [60]. However, [61] is a source from 2006 and [62] states that waste generation of the Ulaanbaatar has significantly increased per person from 2010 to 2015 which can be an explanation for difference between two sources. [63] states 414grams of waste is generated per person from apartment area per day during summer while 427grams of waste is generated per person from apartment area per day during winter and in a case of ger area 609grams of waste is generated per person from during summer and 149grams of it is ash, and during winter 1530grams of waste is produced per person where 1108grams of it is ash, even though [63] contains very detailed data it is important to note that study was done by taking samples from household waste from chosen households from 6 different districts of Ulaanbaatar not including Nalaikh therefore results might not be accurate for entirety of Ulaanbaatar.

Figure 9. waste generation per person per day from apartment and ger areas [60]

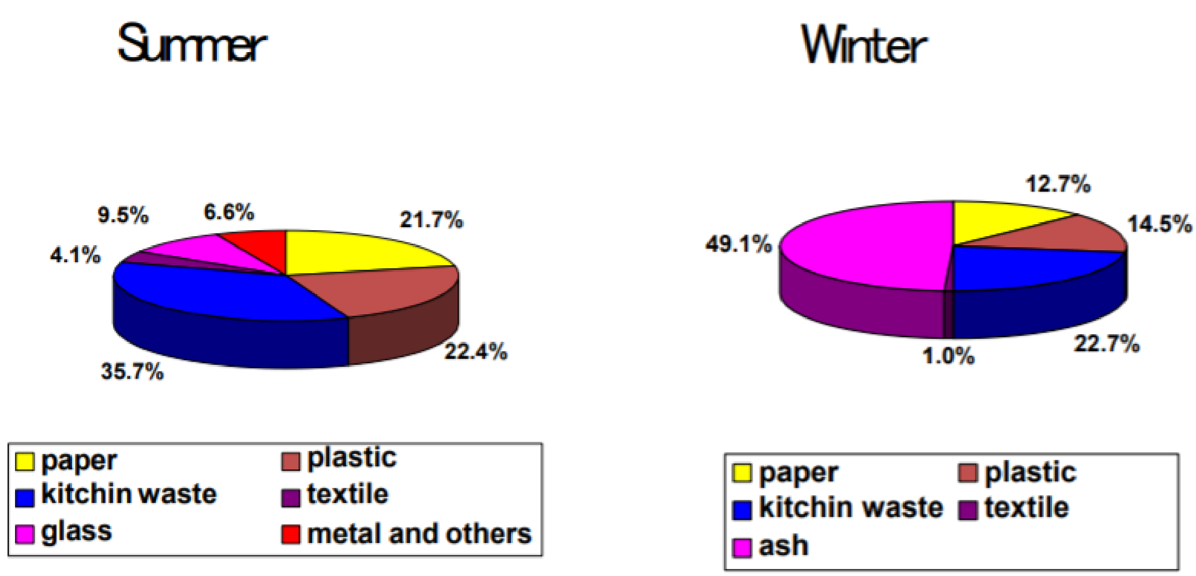


Figure 9. waste composition of Mongolia during winter and summer [60]

Table 1. waste generation and composition in 2006 [61]

Items		Planned (Apartment) Area	Unplanned (Ger) Area
Technical System	1. Waste generation and composition in 2006	**Waste generation** • The generation rate of household waste and other MSW in winter is 590 g/person/day and 640 respectively and it is more or less the same as other economically comparable countries. • The rate in summer (if ash is excluded), however, is only 216 g/person/day and 286 respectively, which are small by international standards.	
		• The generation rate of household waste (256 g/person/day in winter and 228 in summer respectively) is lower than other economically comparable countries.	• The generation rate of household waste (951g/person/day) in winter is almost four times more than planned area due to high percentage of ash (788 g/person/day). • However the generation rates of wastes other than ash are only 163 g/person/day in winter and 202 in summer, much less than the generation rate of household waste in the planned area, 256 g/person/day in winter and 228 in summer respectively.
		Waste composition • The proportion of ash both in household waste and MSW is overwhelming in winter; 64.1% and 60.2 % respectively.	
		• The proportion of kitchen waste is low (32.7% in winter and 35.7% in summer). The proportion of recyclable matters such as metals, papers, plastics, metals and bottles is very high 51.5% in winter and 47.5% in summer all together. Of that, the proportion of plastic is 22.4% and 14.5%, which is strikingly high. Plastic bottles have become popular and the use of plastic bags has drastically increased; their consumption rate is equal to that of developed countries.	• As ash comprises 82.9 % by weight in winter, the other components' shares are small. The proportion of kitchen waste and recyclable matters is only 4.9% and 8.2 % respectively in winter while they are 30.4% and 49.5% in summer. Consequently, collection of recyclables in this area is not promising.

in terms of waste composition according to [60] ash is very big portion of waste in Ulaanbaatar especially during winter and our subject of interest plastic waste is 21.7% of the total waste during summer and 14.5% of the total waste during winter which is expected decrease due to significant increase in burning coal during winter in Mongolia.

Despite being such a high portion of total waste in Mongolia separating plastic and recycling plastic is rarely considered. There are companies that buys plastic waste and sells it to either plastic industries in Mongolia, or industries abroad especially to the China and at the time of this article approximately 20000 tons of plastic waste (100 million plastic items) was exported to the China each year but in 2018 export of plastics to the China stopped and many companies stopped buying plastic waste [61]. In first of March of 2020 there was a ban on single-use plastic bags across Mongolia, and before that according to Mongolian Ministry of Environment and Tourism approximately 2 million tons of waste is produced across Mongolia each year and 500000 tons of it is a plastic waste which is approximately 25% of all the waste and less than 10% of it is recycling meaning remaining is either landfilled or incinerated [62]. In a case of Ulaanbaatar city as for 2018 1.4 million tons of waste is produced each year and estimate of 300000 tons of waste is plastic waste which is 21.4% of the total waste [61].

Table 2. Ulaanbaatar's waste type by household type (used data from [63] and rigid plastic is referring to polyethylene and rigid polyvinyl chloride waste)

Household type		Season	Number of samples	Paper	PET bottles	Rigid plastic	Tetrapack	Plastic bag	Glass	Metal	Food waste	Electric waste	Battery	Cloth	Ash	Other
Ger area	Ger	winter	174	3%	2.00%	1.00%	0.00%	2.00%	5.00%	0.00%	7.00%	0.00%	0.00%	1.00%	71.00%	11.00%
		summer	169	5%	7.00%	2.00%	1.00%	5.00%	9.00%	1.00%	11.00%	1.00%	0.00%	2.00%	39.00%	22.00%
	House	winter	287	2%	2.00%	1.00%	0.00%	1.00%	5.00%	1.00%	7.00%	0.00%	0.00%	1.00%	77.00%	5.00%
		summer	280	6%	7.00%	3.00%	1.00%	4.00%	19.00%	1.00%	19.00%	0.00%	0.00%	3.00%	20.00%	23.00%
	Average	winter	461	2%	2.00%	1.00%	0.00%	1.00%	5.00%	1.00%	7.00%	0.00%	0.00%	1.00%	75.00%	7.00%
		summer	449	5%	7.00%	3.00%	1.00%	4.00%	16.00%	1.00%	16.00%	0.00%	0.00%	3.00%	27.00%	22.00%
		average	910	3%	3.00%	1.00%	1.00%	2.00%	8.00%	1.00%	10.00%	0.00%	0.00%	1.00%	61.00%	12.00%
Apartement	Public apartement	winter	263	14%	5.00%	4.00%	2.00%	7.00%	18.00%	1.00%	36.00%	0.00%	0.00%	1.00%	0.00%	26.00%
		summer	286	14%	5.00%	4.00%	1.00%	4.00%	14.00%	2.00%	41.00%	0.00%	0.00%	1.00%	0.00%	28.00%
	Private apartement	winter	24	16%	7.00%	3.00%	4.00%	3.00%	19.00%	3.00%	35.00%	0.00%	0.00%	1.00%	0.00%	25.00%
		summer	4	16%	6.00%	7.00%	1.00%	5.00%	3.00%	1.00%	48.00%	0.00%	0.00%	0.00%	0.00%	29.00%
	Average	winter	287	14%	5.00%	4.00%	2.00%	6.00%	18.00%	2.00%	36.00%	0.00%	0.00%	1.00%	0.00%	26.00%
		summer	290	14%	5.00%	4.00%	1.00%	4.00%	13.00%	2.00%	41.00%	0.00%	0.00%	1.00%	0.00%	29.00%
		average	557	14%	5.00%	4.00%	2.00%	5.00%	16.00%	2.00%	38.00%	0.00%	0.00%	1.00%	0.00%	27.00%

According to [63] if we exclude Tetrapak from plastic waste 3.6% of all the waste in terms of mass is polyethylene terephthalate bottles and 1.7% is combination of polyethylene and rigid polyvinyl chloride and 3% is plastic bags where what type of plastic bag it is was not specified and other types of plastic wastes was included in other types of waste which was 4% of total waste which suggests 8.3% to 12.3% of total household waste is plastic waste which depends on what portion of total waste is plastic waste. Compared to total waste which had 21.4% (for Ulaanbaatar [61]) of total waste was plastic waste it is way lower percentage, suggesting big portion of industrial waste contains plastic. When it comes to non-household waste latest documentation that can be found was from 2013 [64] and documentation related to plastic waste from non-household waste was not available. According to [64] illegal dumping makes up for big part of waste in Ulaanbaatar during summer 24.4% of all the waste is illegally dumped, and during winter 19.9% of waste is illegally dumped. In a case of illegal dumping in Nalaikh those percentages might be even higher as illegal dumping in Terelj national park is big problem [65] [66] especially during summer as Terelj national park is attractive place for tourists as in 2018, 430000 tourists visited Terelj national park [66] and vacation in general during summer and according to interview with governor of Nalaikh approximately 80 tons of waste is collected from Terelj national park each year [66] in 2018 total of 10 waste collection points were built in Terelj national park [66] and result of this is yet to be shown. Trace of microplastics amounting to 358 items/kilogram of sediment were detected from sediment near direct downstream from Terelj national park of Tuul river [67] which is possibly a result of illegal dumping in this area. Currently there are no data or studies publicly available regarding composition of the illegal dumped waste in Terelj national park area and it is important to find out composition of it to address its potential impact to the environment.

Table 3. Waste amount from different sectors in Ulaanbaatar, 2012 units are in tons/day [64]

Season	Illigal dumping	Industrial waste	Building waste	Medical waste	Public waste	AAN	Apartment	Ger area	Disposed	Not managed	Recycled
winter	246.1	109.7	98	20.9	12.3	160	145.7	690.8	1140.5	73.8	22.9
summer	215	109.7	198.9	20.9	20.8	241	161.9	127.3	787.3	64.5	28.3

With exception of medical waste and hazardous waste, all the other types of wastes are treated in a same way where solid waste is usually delivered to disposal area without any separation and sent to landfill [68] and law on waste of Mongolia does not require specific waste separation except hazardous waste and medical waste [69]. Majority of the recycled plastic waste is collected by homeless or people with little to no income [61] and recyclable waste bin in the streets. In a case of Nalaikh there are two places that buys plastic waste and price for plastic bags is 400tugrug (0.142USD) per kilogram, price for plastic bottles is 300tugrug (0.107USD) per kilogram, and 200tugrug (0.071USD) for soft plastic (exact definition of soft plastic was not clear in this source) [70]. Information on composition of collected plastic waste such as what type of plastics bags are collected, what type of plastic bottles are collected, what trace elements those wastes contain and how much plastic waste is collected are not available to the public at the moment.

"Налайх-Тохижилт үйлчилгээ ОНӨААТҮГ" is a company responsible for disposal of household solid waste and cleaning and disposing public roads and nearby areas. Waste from apartment area is collected once in two weeks and as for the ger area waste is collected once in 14 days or 28 days depending on the type of household. There are 40 waste bins where people bring their waste and it is collected by the company and waste is not separated but directly disposed into disposal site. Additionally, the company deals with illegal dumping in the Nalaikh area.

Figure 10. collection of household waste in Nalaikh

Nalaikh's disposal area is located 2.48kilometers to the southeast from Nalaikh's center and all of the combined wastes are disposed there. Exact method used for landfill is not known but from the visit to Nalaikh's disposal site firstly waste is disposed directly without any covering afterwards multiple waste pickers are collecting waste with their bare hands in the disposal site without proper equipment. Additionally surrounding fence has height of less than two meters making it vulnerable to wind erosion and transportation of waste and under high risk of fire hazard due to presence of combustible materials and waste pickers burning waste in non-safe manner to keep themselves warm during cold seasons and there was a big scale fire in August of 2019 in disposal site [99].
Not only there are waste pickers, livestock such as cows and sheep sometimes stay inside the disposal area and even ingest plastic waste, which is potential to start bioaccumulation of plastic waste. It is common for old apartments in Nalaikh to have waste storage room at the ground floor or next to the entrance of the apartment. Waste pickers also picks up plastic waste from waste storages and waste bins and causes waste scatter which results in waste getting exposed to the environment. In general waste pickers are causing problems to the environment as they are one of the main causes of the waste scattering but also under in health risk to stay under that condition can contain dangerous gases and it is generally very unsanitary.

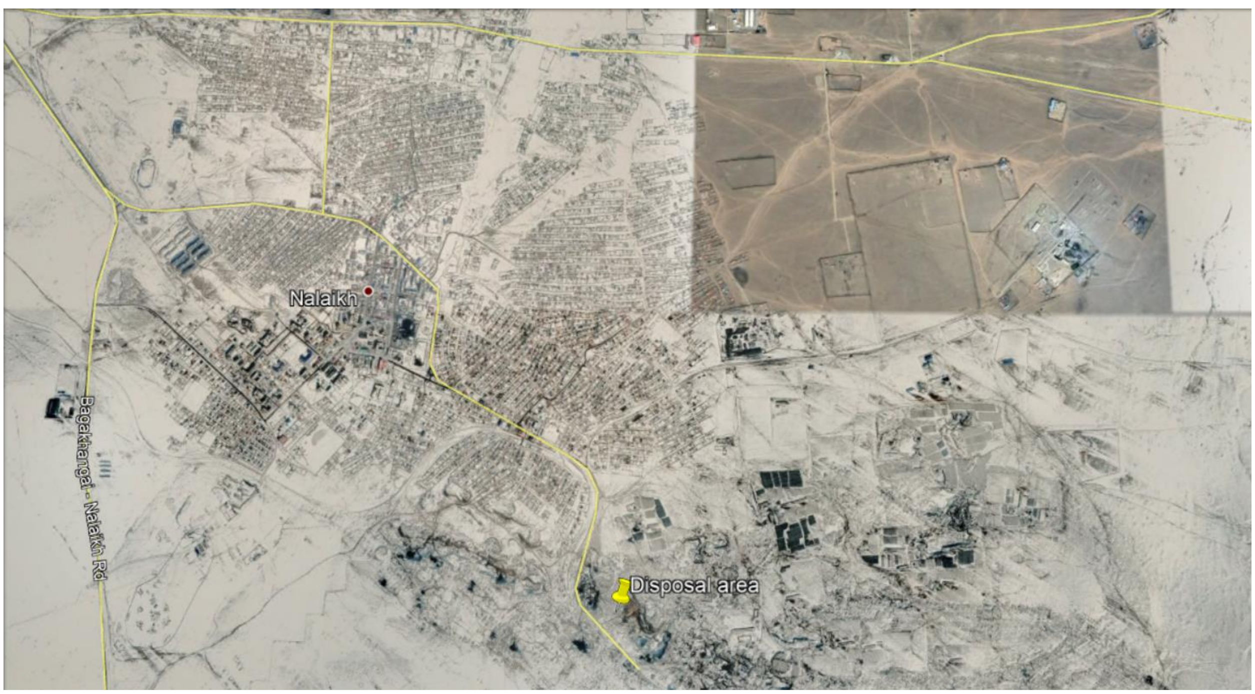


Figure 11. Location of Nalaikh's disposal area (sourced from google Earth)

Figure 12. Waste scattered by waste pickers

Figure 13. Waste pickers [71]

3. State of art

3.1. Impact of plastic on the environment

Plastics are insoluble in water [41][42] and resistant to biological decay and chemical attack, over decades to centuries at least [42] and generally highly resistant to biodegradation and good chemical resistance [41] making them similar to quartz and silica containing minerals but lighter and easier to transport through wind and water.

Impact of plastics on the environment would include health hazards and plastic pollution.

3.1.1. Health hazard of plastic

As mentioned before plastic contains multiple additive materials and more than 50% of those materials are hazardous [72]. Primary ways for plastic to enter human body and other mammals are through ingestion, inhalation, and dermal absorption (absorption through skin) and deposition of plastic occurs in liver, kidney and gut [41]. Main exposures of plastic to human body are food, food packaging leachate, clothing, household equipment, and other environmental exposures such as microplastics in the air, personal care products, plastic toys in terms of children.

Airborne microplastics which are mainly primary microplastics (for information in primary microplastic please check microplastics section of this chapter) from sources such as erosion of synthetic rubber tires, plastic cloth fragments, fragments of plastic household items but mainly synthetic clothing results in inhalation of plastics [73]. Inhalation of plastics mainly causes raspatory system illnesses as once plastic is inhaled it can cause dust overload, oxidative stress cytotoxicity, translocation. Dust overload is when high surface particles such as inhaled plastic preventing macrophage migration and can result in breathlessness, cough, acute respiratory failure, oxidative stress is induction of cell injury and release of inflammatory mediators caused by plastic, cytotoxicity is plastics damaging cellular structures, and lastly translocation is injury of vascular occlusion by particles. Illnesses caused by plastic inhalation can be observed very commonly amongst workers in plastic industry, for instance workers in synthetic textile industries are vulnerable to interstitial fibrosis (asthma-like syndrome), severe dyspnea, large bowel cancer, chronic bronchitis [73] [74] just to name a few and additionally non raspatory system illness such as stomach cancer can be resulted from long time exposure to synthetic fiber dust [75] and it is important to note that mortality due to lung cancer was observed higher than exposure to the dust [76]. Similar to other raspatory system illnesses factors such as size of particle, exposure time, exposure amount, toxicity of the material dictates how much impact inhalation of plastic can results in therefore people who are at most risk are people who are in close contact with airborne plastics especially ones near plastics with more hazardous additives such as polyvinyl chloride, for instance workers at plastic industry, car maintenance, waste collection but on top of it almost everyone is at a smaller or comparable risk due to potential of airborne primary microplastic produced from tires, plastic household equipment, plastic clothing which are present in nearly everyone's lives. For instance, average annual uptake of microplastic particles in outdoor was estimated at 3223 for children and 1063 for adults [81].

Table 4. estimated intake of microplastics in normal and acute exposure scenarios [81]

Sample number	Organic matter (%)	MPs abundance (particles/30 g street dust)	Number of ingested MPs							
			Adults				Childs			
			Normal exposure (100 mg day^{-1})[a]		Acute exposure (330 mg day^{-1})[a]		Normal exposure (200 mg day^{-1})[a]		Acute exposure (1000 mg day^{-1})[a]	
			Per day	Per year	Per day	Per year	Per day	Per year	Per day	Per year
1	12.8	605	2.0	736	6.7	2429	4.0	1472	20	7361
2	12.4	271	0.9	329	3.0	1088	1.8	659	9	3297
3	12.3	387	1.3	470	4.3	1553	2.6	941	13	4709
4	11.6	148	0.5	180	1.6	594	1.0	360	5	1801
5	14.2	153	0.5	186	1.7	614	1.0	372	5	1862
6	9.8	88	0.3	107	1.0	353	0.6	214	3	1071
7	11.8	95	0.3	115	1.0	381	0.6	231	3	1156
8	9.2	112	0.4	136	1.2	449	0.7	272	4	1363
9	9.8	577	1.9	702	6.3	2316	3.8	1404	19	7020
10	10.6	213	0.7	259	2.3	855	1.4	518	7	2592

Potential ingestion of plastic is from food packaging, contaminated food, plastic clothing. Food products can contain plastics due to bioaccumulation. For instance [77] found 55% of the species in fish markets of Makassar, Indonesia were contaminated with microplastics and 67% of the species in fish markets of California, USA were contaminated with microplastics.

Plastic leaching

One of the concerns with ingestion of plastic is the hazardous additives in the plastic. One such example is bisphenol A (BPA), which was commonly used for production of many plastic resins, namely polycarbonate water bottle and food packaging, and even used in beverage cans. Negative effects such as decrease in performance of immunological system was found among US population [78], metabolic disease was found in children in United States [79], endocrine disruption was acknowledged by European chemical agency [80] and package leaching of BPA is a common due to thermal degradation of plastic package and plastic bottles and microwaving plastic container is one of the common example of package leaching due to thermal degradation. Reducing impact of plastics to the human health has to be done by reducing exposure to plastics. Therefore, avoiding usage of plastic food containers, avoid using plastics containing highly hazardous additives or avoid using hazardous additives in plastic materials, avoiding usage of food products with high levels of plastic contamination are important considerations.

Leaching of additives, especially toxic additives is an important health concert, especially plastic materials used daily such as plastic bottles for soft drink, food container. For instance, polyethylene terephthalate plastic bottles commonly contain antinomy. Antinomy leaching from polyethylene terephthalate to the water has been observed especially at the higher temperature and longer exposure time [112] therefore storing soft drink or drinking water for a long time in high temperature creates risk of ingestion of antinomy. At the 65^{o}C leaching of BPA from plastic bottle to the water has been observed [113]. Polyvinyl chloride water bottles have shown to have leaching of di(2-ethylhexyl) phthalate which is plasticizer material. Since polyvinyl chloride is commonly used as pipes, leaching from polyvinyl chloride pipe to the water is a concern as well. Parameters such as turbulence, salinity, and UV irradiance have important role in leaching behavior and it was shown leaching of additives such as bisphenol A, phthalates, citrates and phosphate has been observed [115]. Leaching of less dangerous materials such as nutrients [116], nucleic acids and proteins [117] dissolved organic compound [119].

Not only plastics used in packaging and food containers created leaching problem, leaching of plastics used in agriculture poses a threat as well. For instance, nitrate in the plastic mulch can be leached into potato crops [114] and peanut [118] and the leached nitrate can lead into emission of N_2O [120] which is potentially harmful to the environment.

3.1.2. Plastic pollution

Most plastics are considered highly resistant to degradation and life span of plastics can range from several hundred years to several thousand years. Currently amount of plastic waste in the environment is increasing each year and it is estimated that by 2050 amount of plastic on the environment is going to reach 1200 million tonnes [45]. As for 2015 only 30% of the all the produced plastics are currently in use and remaining 70% has become plastic waste which amounts to 5800 million tons of plastic waste. Plastic pollution is present in marine environment, freshwater, and terrestrial environment. Plastic pollution in the marine environment has been widely studied. Plastic pollution in the marine environment can be divided into floating debris, seafloor plastics, and shoreline plastics.

Plastics waste can be divided into macroplastic, mesoplastic, nanoplastic and microplastic with regards to their size [41]. Macroplastics are plastics that are more than 5mm in size and visible to human eyes. Microplastics are plastics that are less than 5mm in size and typically hard to recognize through human eyes [5] [47].

Macroplastic waste includes commonly used plastics such as plastic bags, plastic bottles, food packaging, agricultural waste and typically results from mishandling plastic waste such as spills and spread from landfills, or direct littering from people and other sources would include wind dispersal, spills and illegal discharges. Environmental fragmentation is one of the big concerns with plastic wastes in the environment. Fragmentation is a generation of smaller sized particles from bigger sized particles. Impact of macroplastic waste would include entanglement and digestion of plastic, but as the size of the plastic decreases negative impact of plastic waste and health hazard of plastic waste increases. For instance, as mentioned before (health hazard section) macroplastic cannot enter raspatory system of mammals while smaller sized plastics especially microplastic can enter raspatory system and cause raspatory system illnesses, and nanoplastics, which are even smaller than microplastics can enter raspatory system and cause damage at cellular level [73]. Smaller sized plastics can be ingested by wider range of organisms [41] which results in bioaccumulation of plastic.

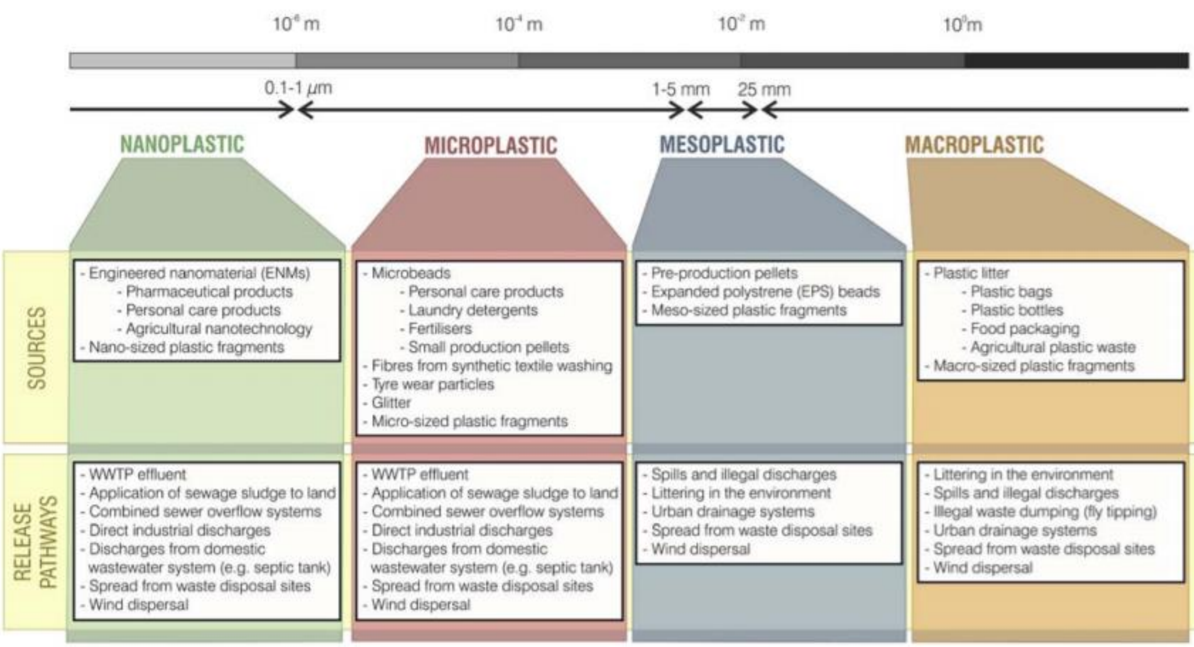


Figure 14. Size spectrum of plastic waste items and associated sources and release pathways to terrestrial environment [41]

Fragmentation of plastic waste can result from multiple different processes including oxidation, biodegradation and hydrolysis of plastic which are resulted from exposure to sunlight, various types of oxidants, various types of stress in the environment [82]. Two major types of oxidation are photodegradation (photooxidation) and termooxidation which are resulted from exposure to sunlight and temperature changes. Plastics with carbon-carbon backbone, which includes polyethylene, polypropylene, polystyrene, and polyvinyl chlorine one of the very common types of macroplastic are susceptible to photodegradation [82]. Photodegradation has three main steps:

initiation, propagation and termination [82][83]. During initiation step chemical bonds in plastic is broken by light or heat in a case of termooxidation and produces free radical. Initiation by light occurs when polymer contains unsaturated groups that can absorb light. Despite not containing unsaturated bonds polyethylene and polypropylene can be susceptible to initiation if there is impurity or abnormalities in the structure of it [82][83][84]. UV-light breaks C-H bonds in this step and formed free radicals are further reacted with oxygen thus oxidizing which is called propagation step [82]. Oxidation forms peroxy radicals (hydroperoxides) and lastly the final stage of the photodegradation takes place where radicals reacts and inert products are formed by combination of two radicals. Final inert product from photodegradation is not susceptible to the photodegradation, however during this process even though polymer is formed, overall molecular weight is decreased and makes the polymer susceptible to biodegradation as they contain unsaturated double bonds, and overall plastic becomes more brittle and more susceptible to other fragmentation processes [85]. Photodegradation on polyethylene produces degradation products such as propane, propene, ethane, ethene, butene, hexene and becomes brittle, however degradation tie highly depends on additives in the polyethylene and degradation through microorganisms can be faster that photodegradation for polyethylene with small molecular weight. In aquatic conditions abiotic and biodegradation of polyethylene significantly degreases [82]. Polypropylene degradation process is similar to polyethylene, but compared to polyethylene polypropylene has lower stability and additionally impurities in polypropylene can result in formation of radicals that reacts with oxygen. Difference in photodegradation of polypropylene compared to polyethylene is after degradation new functional groups such as hydroperoxides and carbonyls are formed and those functional groups are biodegradable but resistant to aerobic biodegradation [82][86] therefore further degradation of polypropylene in aerobic conditions is significantly slower. In a case of polystyrene, it is susceptible to both photodegradation and thermooxidation process but polystyrene is considered to be most durable thermoplastic polymer towards biodegradation [82] and addition of additives such as anti-oxidants and UV-stabilizers are very common in polystyrene which further slows down degradation process. Among plastics with carbon-carbon backbone polyvinyl chloride is considered to be most sensitive towards UV-radiation, however because polyvinyl chloride does not contain unsaturated chemical bonds impurities are required for photodegradation. During photodegradation process dichlorination process takes place and forms double bonds between hydrochloric acid and polyene along with other products. This dichlorination process is enhanced in aerobic conditions and in general humidity, mechanical stress, high temperature and presence to other chemicals increases degradation rate of polyvinyl chloride. Further degradation is however very slow for polyvinyl chloride as polymers formed during photodegradation are resistant towards biodegradation especially aerobic biodegradation and similar to polystyrene additives of thermal and UV-stabilizers are very common in polyvinyl chloride which further decreases speed of degradation [82]. Fragments of plastic can also be created from plastic that is currently in use and big example of it is plastic fragment generated from car tires which is one of the big sources of primary microplastics [52].

Accumulations of plastic waste be commonly seen on terrestrial environment as majority of the plastics are manufactured and used and finally discarded on land. Accumulations of such waste is more commonly found in regions with higher population density or places with high amount of human activity and areas near waste processing plants or sites. But it does not mean more rural areas do not have accumulation of plastic waste as plastic has important role in agriculture starting from use of plastic films in agriculture, wrapping for hay bales, plastic mulching but also plastic is commonly used for packaging agricultural products [41]. And lastly, illegal dumping of waste is one of the big causes of accumulation of plastic waste. Once plastic is accumulated in environment plastics can be easily transported by wind depending on the particle size and morphology and precipitation events and has high possibility to enter surface water sources and in urban environments if sewage system of that area is combined sewer system plastic waste can end up entering wastewater treatment plants and discharged into water sources in a case of smaller plastic particles [41]. If plastic waste enters subsurface movement of plastic would highly depend on properties of the soil and transfer of plastic waste both laterally and vertically occurs commonly due to ingestion of plastic particles by organisms [50] [87] or through leaching of plastic particles through pores of the soil depending on the soil type and especially for smaller plastic particles [88]. Plastics that are in subsoil and has low potential to have movement would be stored over time and as mentioned before plastics are highly resistant to biodegradation most of the time [41][82], unless there is photodegradation thus plastic waste has potential to stay in that subsoil and as it accumulates more over time biodegradation process slows down even more and has potential to lead to incorporation of plastics into rocks and soil of that are [89].

In a case of plastics in freshwater systems, especially in river, river flow can lead into fast transport of plastic items in short amount of time. Transport of plastic and where it ends up once it enters river system highly depends on shape and density of the plastic particle. In a case of thinner low-density plastics are highly mobile and more likely to be trapped by vegetation in river while higher density particles are less mobile and more likely to be buried in sediments of the river. Additionally, flow speed of the river has important influence as higher the flow speed more likely for plastics to be transported to the downstream while at lower flow speed it is more likely for plastic particles to be less mobile [41]. Potential health hazard of the plastic in the atmosphere has been discussed in previous section. On top of being health hazard for the local in the local environment small plastic particles can transport over long distances as microplastic transport through the atmosphere can reach distance of up to 95 kilometers [90], therefore small plastic particles in atmosphere can affect wide range of areas.

Biggest threat of presence of plastic waste in terrestrial environment is potential impacts to the ecosystem. In a case of macroplastics, macroplastics causes entanglement of birds and mammals in terrestrial environment [72][91] and ingestion of macroplastic is prevalent issue as first of all it can potentially cause bioaccumulation, but also it leads to digestive system problems for that organism similar to human, for instance 27.5% of sheep and 24.3% goats in Birjand of Iran had plastic in their gastrointestinal tract and most common plastic type was plastic bags while the study are has been highly polluted by heavy metals no trace of metals was found [92] suggesting plastic pollution can be even more harmful than metals in the environment and effects such as reduced nutrition intake, reduced body mass, damage to digestive tract was observed on birds ingested plastic [93]. On top of plastics being pollutant by itself, potential hazards of additive materials in the plastics is another important consideration. Even though in short term additives in plastics are not a big concern in a long term due to degradation additives in plastic leaches out of plastic the environment [94] and because of wide range of additives in the plastic it is hard to access exact risk of additives in plastic.

3.1.3. Microplastics

When plastic is in soil, it essentially becomes geological material and has a potential to interact with organic matter and minerals in the soil.

Microplastics are divided into two types by source: primary microplastics refers to plastics that are produced in small scale and secondary plastics refers to plastics that undergo degradation and reduce in size in the natural environment. Main examples of primary microplastics would include microbeads, which are produced to be used in cosmetics, fibers, which are released during washing of synthetic clothing, and lastly granules.

Secondary microplastics can be generated in-use and post-use of plastic product. Examples of in-use secondary microplastics would include formation of microfibres during washing clothes, wear of plastic fishing gears. Post use secondary microplastics are generated from breakdown of discarded plastics. Exposure to wind, sunlight, and cold temperature can cause plastic items to become brittle and additionally microplastics can be produced through ingestion [57]. For instance, polyvinyl chloride at ambient temperatures below its critical value goes through glassification process where polyvinyl chlorine material becomes brittle with little to no potential for diffusion of chemical [29].

Potential microplastic sources includes sewage [48] [49], agricultural soils [55], freshwater beaches [51], cities and roads [52], landfills [53], dams [54] and it was found that microplastic leaching to groundwater through soil was possible [56].

Microbeads cannot be degraded and originates from cosmetic products specifically various types of scrubs [49] and are highly present in wastewater and it is released to the environment through wastewater treatment plants [48] [49]. For instance [48] found microbeads found in coastal waters of Hong Kong has similar characteristics with microbeads found in facial scrub products in local markets and [49] found approximately 15.2mg of microbead per person is released sewage systems and in was estimated that 112500000 particles per day is released to local river which is resulting in 21particles per cubic meter. On top of that [49] confirmed presence of smaller microbeads in sludge (60 to 70 micro meters) and bigger microbeads in effluent of wastewater treatment plant. [56] found that during wastewater treatment over 90% of the microplastics are retained in sewage sludge and additionally microplastics with density greater than water are mostly retained to sludge during primary and secondary treatment processes and during tertiary treatment lager floating particles are removed but lighter particles are released with wastewater effluents.

Table 5.Concentration, specific surface area, particle size distribution, 10th and 90th percentile of particle size distribution and mean number of particles per mg of microbeads in scrubs [49]

Parameter	Product				
	A	B	C	D	E
	Facial scrub	Body scrub	Facia scrub	Body scrub	Body scrub
Concentration of microbeads g per 100 mL of the product	0.42	2.47	1.06	0.87	11.12
Specific surface area $S_{single\ point}$ (cm^2/g)	<1	10	33	295	189
Mean number particle size distribution (μm) (mean ± SD, n = 3)	37.66 ± 16.79	71.30 ± 34.29	55.76 ± 28.88	95.95 ± 68.99	74.95 ± 36.25
10th percentile of particle size distribution (μm)	16.88	31.04	24.38	37.76	32.86
90th percentile of particle size distribution (μm)	68.99	128.40	104.40	202.30	132.70
Mean number of particles per mg of microbeads[a]	3108	853	2185	625	1186

[a] Calculated values.

[50] developed method to evaluate amount of microplastic in soil using Lterrestris (earth worm) and L.terrestris transporting microplastics can cause leaching of microplastics to groundwater bodies.

[55] found using wastewater treatment plant sludge as fertilizer is becoming source for microplastic pollution in agricultural soils. Additionally, microplastics in such fertilizers shown to remain in the soil for long period of time, for instance microplastic fibers have been reported in agricultural field 15 years after fertilizer was used while still maintaining original properties of itself [58].

Microplastics were found present in sediments near Etobicoke Creek which is freshwater beach where maximum concentration of particles reached 28000 particles per kilograms of dry sediment [51].

[54] observed presence of microplastic near dam area including surface water near dam (55000 to 3420000 items per square kilometer), sediment (80 to 864 items per square meter) and digestion tracts of fish sample (27% of fish samples contained microplastics). Even though in this study no correlations between water quality and microplastics was found but very importantly in this work correlation between water level and microplastics was found which indicates potential impact of dam to the concentration of microplastics in water.

Microplastics generated from thermoplastic road surface marking paints were found site near road in River Thames basin [52] it is important to note in this study only microplastics with size over 1mm was considered.

Ingestion of microplastics is very common and has been observed on multiple species including different bird species such as chicken [95], buzzard, black kite and other 15 bird species [96] and macroinvertebrates such as earthworm [95], freshwater tubifex worm [97], mayfly [98]. Gizzards of chicken that are eating crops contained high amount of microplastics despite the crop containing little to no microplastics [95]. High amount of microplastics were found from gastrointestinal tracts of 16 out of 17 different bird species where more than half of it was plastic fibers, but no direct relationship between plastic load and body condition was found [96]. Similar to [96] microplastics were present in macroinvertebrates but no direct link between microplastic and health of the species in [97] and [98].

Ingestion of microplastics results in different impacts on different species ranging from increase in mortality rate, decrease in growth, decrease in reproductive capacity, early settlement, weight loss, reduction in energy reserves and even changes in tissue level such as gut inflammation, damage to intestines, alteration of gut microbiota, development of granular structures or for some species no significant change is observed. In some cases, behavioral changes such as feeding capacity, speed, travel distance. Not only changes in reproductive capacity was observed additionally change in larval health, embryo number, brood size, egg production was observed. Human can uptake microplastics through various sources including seafood, air, bottled water, honey, beer, salt. However, evidence of negative impact of microplastic uptake of human is currently limited. [41]

Determining microplastic

Currently there are no defined methodology for determining microplastics. For instance [51] used Raman spectroscopy to count microplastics [50] used earth worm to determine microplastic amount [52] determined microplastics in a range of 1mm to 4mm through visual extraction, flotation, Raman spectroscopy while [105] proposed pressurized fluid extraction method. In general method has to:

- Separate materials in 1 to 5mm range
- Separate plastic from organic and inorganic materials
- Separate plastics with different shapes (fragment, film, foam, fiber, line, pellet)
- Determine amount of plastic in the sample

Separating materials in 1 to 5mm size through using mesh net [104], trawl [106], glass filters [107] can be used in a case of water sample and in a case of soil sample sieve with different sizes can be used [103].

For the separation of organic and inorganic materials density separation is very commonly used method [107] and density separation is typically done by either NaCl solution or ZnCl2 solution as majority of the plastics have low density and specifically solution with 1.2kg/l is used [52] [107] and problem with this method is firstly high density plastics are not separated by this method, and secondly separation efficiency is poor for smaller particles [107] and flotation can be used to improve efficiency [52]. Separation of high- density plastics is not a concern for water samples as water samples are taken from water surface where low-density plastics would float, thus high density plastics are rarely found in water samples but it is a concern for soil samples, therefore method such as pressurized fluid extraction [105] can be more suitable for soil samples.

Type of plastic	Density (g cm^{-3})
LDPE	0.91−0.93
HDPE	0.94−0.97
PP	0.90−0.91
PS	1.04−1.07
PVC	1.35−1.45
ABS	0.99−1.10
Polyester	1.38−1.39

Figure 15. Densities of different plastic types [41]

Density separation helps to separate inorganic materials from plastic. However, additional separation from organic materials is required. Chemical degradation is used to separate organic materials from plastic and [105] compared degradation efficiency of different materials including

KClO, NaOH, HNO_3, H_2O_2 and HNO_3 was found to be best chemical to use for chemical degradation.

Lastly, after plastic is separated from other materials amount of plastic is quantified. According to [107] currently known methods are microscopic counting where number of plastic particles are counted directly, FTIR where sample is subjected to infrared radiation, Raman spectroscopy where sample is irradiated by laser light and atoms of the sample result in different frequency and Raman shift occurs, Processing sample image with electron spectroscopy, liquid chromatography and tagging methods are available and method can be chosen accordingly to the characteristics of the sample.

3.2. Recycling plastic waste

Recycled plastic materials are applied in different applications compared to raw plastic materials. Important first consideration of recycling plastic is to identify if there is a demand for recycled materials.

Recycled polyethylene terephthalate fibers are used for fabrics (clothing), food packaging, automotive parts, and several different construction materials and in general clothing is biggest market for recycled polyethylene terephthalate. Recycled high-density polyethylene is used for plastic lumber, nonfood bottles, brush arms. In general demand for recycled high-density polyethylene is limited. Polyvinyl chloride is hard to recycle and recycled polyvinyl chlorine has niche applications such as flooring, pipes, window profile, traffic cone. Recycled low-density polyethylene is used for nonfood plastic bags, trash cans, plastic lumber. Recycled polypropylene is used as car parts, plastic trays and bins. Currently demand for polystyrene is very low.

One of the biggest problems with plastic is sorting. Sorting is essential part of recycling as plastic type can result in various different properties and additive materials makes recycling process even more complicated. Currently sorting of the plastic mainly focuses on high-value and high-density plastics and low-density plastics such as polystyrene is not sorted [102]. Plastic recycling is a process that typically requires proper legal framework that promotes recycling and reutilization of plastic waste as plastic recycling is comparatively low value process.[41]

Plastic recycling process consist of three enrichment steps as directly recycling municipal solid waste is not profitable, where first enrichment is collecting plastic waste effectively, meaning collecting plastic waste with as little amount of other materials. One big example of first enrichment is separate collection of household waste which significantly decreases cost of the recycling process. Secondary enrichment is a sorting process where different plastic types are separated from each other which is mainly done manually and lastly third enrichment is a refinement process which is done differently depending on the plastic type. [41] Even though separate collection has its benefits one concern with separate collection is requirement of huge space as in general plastic products have low bulk density.

If waste is not separately collected waste has to go through 3 step process. Liberation is a first step which is used to increase bulk density of plastic waste. Countercomb shredders are main type of comminution tool used for plastic recycling. Rotary diameter of this shredders can be up to 1050mm and rotor of it can be up to 3000mm long with electric drive power up to 400kW [41].

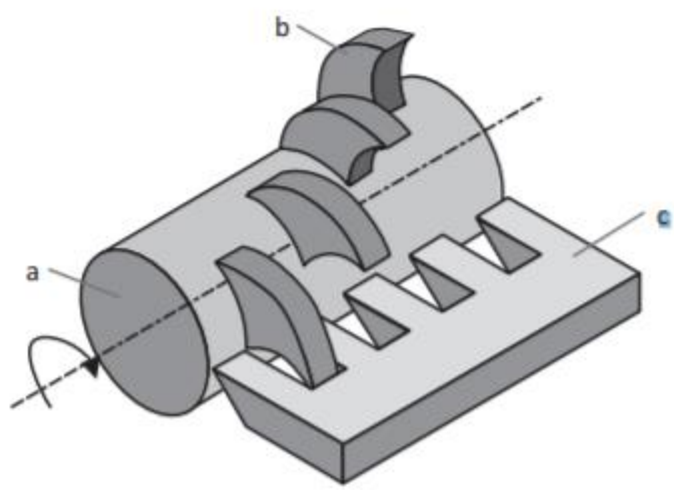


Figure 16. Countercomb shredder design [41]

Second step is conditioning, and this step makes sorting process easier. Following conditions has to be met for separation process:

- Ejection of coarse and disturbing fractions
- Differentiation according to shape characteristics
- Allocation of material flows in narrow particle size distribution

and conditioning process varies depending on which conditions has to be met. Equipment used varied according to conditions as well and commonly used equipment are drum screens, waste screen, ballistic separators, air separators, drum separators.

Final step is sorting where ferrous and non-ferrous fractions are separated. Ferrous fractions are separated by their magnetic property and non-ferrous fractions are separated by their electric conductivity. In this step magnetic separator, eddy current separators, or sensor-based sorting methods are commonly used as well as manual sorting is used as well.

After sorting plastic waste goes through secondary enrichment where manual separation is most commonly used.

Finally, after secondary enrichment final enrichment (refinement) starts. Even after being sorted twice plastic waste would contain impurities such as remaining liquid in plastic bottles, surface dirt, labels, caps which affect quality of the recycled material and has to be removed and impurities highly depend on plastic type as for instance acetaldehyde is a huge problem for polyethylene recycling, but not as big of a problem for other recycling processes. Depending on the application of the recycled plastic refinement process varies heavily varies.

3.2.1. Recycling polyethylene

Main problems for recycling polyethylene are contamination and choosing proper method. Contaminations can be classified as acid producing contaminants, water, coloring contaminants, acetaldehyde, and others and contaminants affects recycling process especially during melt extrusion process [17]. One of the most harmful acid for PET recycling is acetic acid which negatively affect recycling process thus and polyvinyl chloride is considered as one of the acid producing contaminants [17] and small concentration of polyvinyl chloride would increase chain scission during recycling process [18], therefore proper separation between polyethylene and polyvinyl chloride is essential. Water content is another important consideration as it is common for waste polyethylene to contain water and moisture content reduces molecular weight during recycling through hydrolysis and water content below 0.02% is required [19] thus drying is required for polyethylene recycling processes. Fragments of colored bottles and ink labels are examples of coloring contaminants and can be commonly found in waste polyethylene and can cause undesirable color during recycling process and proper soring process is required to reduce amount of coloring contaminants [17]. Acetaldehyde is produced from degradation process of Polyethylene and stabilizer materials are used to reduce amount of acetaldehyde produced [17]. Recycling process can be classified in 4 different categories [17]:

1. Primary recycling: use of pre consumer industrial scrap
2. Secondary recycling: physical processing
3. Tertiary recycling: chemical treatment
4. Quaternary recycling: incineration

And as for using waste plastic material primary recycling is not an important consideration.

Secondary recycling (physical processing)

Secondary recycling process has three main steps. Firstly, it starts off with removing contaminants where first it is sorted from other plastics as it is common for different types are plastics to be separated as same category. Then polyethylene is ground in order to process them easily and ground polyethylene is washed by either aqueous washing which consist of two steps; a hot wash with 2% NaOH solution and detergent at 80°C followed by cold water wash or solvent washing where tetracholoroethylene (TCE) is suitable for washing. After washing process flakes are dried as mentioned before water content has to be low. Then finally, flakes are reprocessed by melt extrusion.

Advantages of using secondary recycling methods are it is simple process that requires low investment and uses established equipment and can be flexible in terms of feedstock which is very big advantage as feedstock of the process always changes.

Disadvantages of using such method would be contaminants generate acidic compounds which catalyze hydrolysis of polyethylene during melt extrusion, polymer has yellow color due to oxidation reactions during recycling process, final product properties such as printability or dyeability can be affected. [17]

Tertiary recycling (chemical processing)

Tertiary recycling is also referred as chemical recycling is process of breaking polymer chains of polyethylene into monomers. Two main processes used for chemical recycling are solvolysis and pyrolysis, where solvolysis is degradation by solvents and pyrolysis is degradation by heat and it is anaerobic process. Monomers, petroleum liquids and gases are final products of chemical recycling.

Solvolysis process is divided into hydrolysis, aminolysis, ammonolysis, metanalysis, glycolysis.

Hydrolysis is a process of hydrolyzing polyethylene into TPA and this method removes methanol from the technological cycle. Process operates at high temperature (200°C to 250°C) and high pressure (1.4MPa to 2MPa) and requires long time. Hydrolysis can be carried out with alkaline, acid, or under neutral conditions and for acidic hydrolysis terephthalic acid has best depolymerization [20] and additionally acids such as sulfuric acid and nitric acid can be used. As for alkaline hydrolysis sodium hydroxide and kalium hydroxide are commonly used and lastly for neutral hydrolysis is carried out with water or hot water steam with PET to water ratio from 1:2 to 1:12. Due to its high cost it is not a widely used method for recycling.

Aminolysis is process of producing diamides of TPA and it is not a commonly used method for polyethylene recycling. Process is carried out primarily with amine solutions which includes methylamine, ethylamine, and ethanolamine and operates in the temperature range of 20°C to 100°C. This process is not suitable for big scale recycling as even with catalysts process can take long time up to 8 hours and requires additional catalysts such as acetic acid, sodium acetate and potassium sulfate with concentration from 0.3% to 1.5%.

Ammonolysis is process of producing terephthalamide from reaction of polyethylene with ammonia and process is carried out under high pressure of 2MPa and in a high temperature (120°C to 180°C) for long time (1-7hours) and after the complete reaction produced terephthalamide is filtered, rinsed with water and dried. Final product has purity of not less than 99% with above 90% yield. Same process can be done at lower temperature (70°C) with a help of zinc acetate as catalyzer with yield of about 87% [21].

Methanolysis is a process of producing dimethyl terephthalate and ethylene glycol by degrading of polyethylene with methanol at high temperate (180°C to 280°C) and high pressure (2MPa to 4MPa) and method was applied successfully to scrap bottles, fiber waste, used films and plant waste and the process does not require catalyst and complete depolymerization can take 30minutes at above 300°C and 11MPa. This process requires separation of reaction products which makes it expensive process.

Glycolysis is a process of degrading polyethylene with glycols which includes ethylene glycol, diethylene glycol, propylene glycol and ethylene glycol. Process is slow and complete depolymerization is not achieved without using catalysts. There are four different glycolysis processes and those are solvent assisted glycolysis, supercritical glycolysis, microwave assisted glycolysis, and catalyzed glycolysis. Solvent assisted glycolysis uses ethylene glycol and reaction medium, zinc acetate is commonly used as catalyst and addition of xylene has shown higher product yield. Supercritical glycolysis also uses ethylene glycol, but reaction takes place at temperature and pressure above the critical point (446.7°C and 7.7MPa) of ethylene glycol which eliminates need of catalyst and yield can reach 93.5% in 30 minute and main disadvantages of this method would be high operating temperature and high operating pressure. Microwave assisted glycolysis uses microwave radiations as heat source to reduce reaction speed and it can reduce reaction time from 8 hour to 35 minutes and additional use of catalyst can result in increase of yield as well as further reducing reaction time and alkali catalysts and zinc acetate catalyst can be options and radiation time is important factor as it affects system temperature. Catalyzed glycolysis uses trans-esterification catalysts and metal acetates such as zinc acetate, manganese acetate, cobalt acetate and lead acetate are commonly used as catalyst [23] and in terms of effectiveness zinc acetate was most effective. Even though lead and zinc catalysts are very effective they are heavy metals with negative impact on the environment, therefore even though using catalyst such as sodium carbonate or sodium bicarbonate are not the most effective it can be less harmful to the environment. [17]

As mentioned before another way to chemically process polyethylene is through pyrolysis where fuel is produced. Pyrolysis is generally operated at high temperature [24] [25] [26] (300°C to 600°C) and purity and conversion of final product depends on the operating temperature [25] and additionally cracking temperature is important parameter for pyrolysis as higher the cracking temperature oil yield of process improves but a reaction time become longer and pyrolysis is process that can also be used for polypropylene [26].

Other possibilities

Recycling high density polyethylene waste such as bottles, packages and food crates as plastic cement is a one possibility. Plastic cement is produced by mixing grinded polyethylene waste with water and cement it was found 25% to 35% of polyethylene mixed with 75% to 65% of cement had a best result [16]. As mentioned before water content is important consideration for recycling but in this method, it is not significant as water is required to be added to produce plastic cement but having too much water content can lead to problems as final product should have water content of 3.6% to 3.79%. Here important thing to note is fact that polyethylene waste used for this experiment contained insignificant amount of impurities and it is important to consider impact of impurities to the quality of cement.

Another possibility is to using secondary recycled polyethylene for polyethylene production and it is important to find optimum point for amount of recycled polyethylene to use as using excessive amount of recycled polyethylene can affect quality of the product as recycled polyethylene has worse quality in terms of mechanical properties [27].

One of the approaches to dealing with polyethylene waste can be improving biodegradability of polyethylene. Blending in biodegradable masterbatch specifically thermoplastic starch with polyethylene has shown to have its impact of biodegradability but can impact plastic recycling stream [28].

3.2.2. Recycling polyvinyl chloride

Despite being completely recyclable, recycling polyvinyl chloride runs into multiple problems where some problems are general problem with recycling industry and some problems are specific problems for polyvinyl chloride. Specific problems would include shortage of material for rigid and chemical additives especially in flexible polyvinyl chloride. Supply of shortage is due to long life of the rigid polyvinyl chloride products as they are most commonly used for building applications where life time of those products can last from several years to few decades. As for chemical additives it is near impossible to remove them with normal physical processes and can significantly affect chemical recycling processes. Additionally, heterogeneity of polyvinyl chloride products is big concern it is very common for those products to compose of large portion of other materials especially in building products it is common to contain large portion of wood, metals or other building materials. Therefore, if possible separating flexible polyvinyl chloride and rigid polyvinyl chloride would be optimal for recycling. In a case of rigid polyvinyl chloride both physical recycling process and chemical recycling process are possibility, on the other hand in a case of flexible polyvinyl chloride chemical recycling process is only option.

One of the possible chemical recycling processes is extraction. Extraction process have multiple different approaches and extraction process such as dissolution precipitation were applied in recycling industry [34] [35] [36]. There are other extraction processes that are not proven for plastic but can be suitable for polyethylene recycling would include ultrasonic extraction with thermolabile additives as it can operate under low temperatures [37] which was used for extraction of caffeine and microwave assisted extraction (MAE) method with thermolabile additives, or highly polar additives can be suitable as well as with thermolabile additives extraction time is short and require short exposure time to microwave and in a case of highly polar additives they require very low amount of solvents due to pressure [35] [38] but it is method currently applied in agriculture sector and not explored well enough for plastics. Additionally supercritical fluid extraction and accelerated solvent extraction methods with thermolabile additives has shown promise as extraction time is short thus exposure time to high temperature is significantly less but supercritical fluid extraction is explored for food industry and accelerated solvent extraction method is explored for food and agricultural industry and not proven for plastics [38].

Producing carbon materials is one possibility and the process is called polyvinyl chloride carbonization. It is a high temperature process with proper catalysts and process time highly depends on catalyst choice. One possible catalyst option is catalytic CuAl layered double hydroxide as not only it decreases optimal operating temperature but also it can decrease carbonization time down to 90 minute and operation requires 20°C/min of heating rate [39].

4. Materials and methods

4.1. Material flow analysis

Material flow analysis of plastic was mainly done based on literatures. Exact literatures on the Nalaikh is very limited and due to it data and literatures based on Ulaanbaatar city was used as Nalaikh is a part of Ulaanbaatar and there are multiple similarities. Material flow was calculated for a summer and winter separately as there is significant seasonal difference in waste flow [60-64].

4.2. General waste

General waste was categorized into household waste, waste from cleaning public roads, hospital waste, industrial waste, building waste, illegally dumped waste, microplastic waste in wastewater and others. Others would include waste from offices, schools, universities, markets, etc.

General household waste amount was calculated using [63] as [62] mentions waste consumption is increasing each year and [63] is the latest available source based on amount of household waste produced while other sources are mainly based on amount of waste collected [60-62]. Additionally, population data of 2018 from Nalaikh’s government was used.

Waste from cleaning public roads were calculated using data from [64] with assumption of there is direct correlation between amount of waste generated from cleaning public roads and area of the road.

Hospital waste was calculated using data from [64] and with assumption of there is direct correlation between population and hospital waste amount.

Industrial waste was calculated 2 different ways using data from [64] and [61] with assumptions of there is direct correlation between population and number of industries, which can lead into very bad estimates as this assumption is very likely to be incorrect, however data for number of industries was not publicly available for Nalaikh but this number was available for Ulaanbaatar, therefore this assumption had to be used to estimate number of industries in Nalaikh.

Building waste was calculated using data from [64] with assumption of there is direct correlation between population and building waste.

Illegal dumping was calculated with using data from [64] and with assumption of there is direct correlation between ger area population and illegal dumping additionally waste from tourists and people having vacation in Terelj national park was considered with using [66] as source with assumption of significant amount of waste is not collected, and illegal dumping from industries were considered. Additionally, it was assumed that during winter illegal dumping at Terelj national park is none, as typically tourist and people visit Terelj national park during summer.

Even though there are multiple different microplastic sources exact amount is not clear most of the time and microplastic in the wastewater was calculated based on [54].

Other wastes are calculated with 2 different ways using data from [64][61] with assumption of there is direct correlation between other wastes and population.

4.3. Waste collection

Following assumptions were made regarding waste collection:

- 10% of household waste is lost due to waste scattering by waste pickers.
- All of the hospital waste is collected properly except 5% lost due to environmental factors
- All of industrial waste is collected properly with exception of illegally dumped waste and 5% lost due to environmental factors
- All of building waste is collected properly except 5% lost due to environmental factors
- Only 40% Illegal dumped waste is collected and remaining is left in the environment
- All of the microplastic in the wastewater is disposed directly to the environment either through using sludge in agriculture or directly disposed to surface water after treatment processes.
- All of the other wastes are collected properly except 5% lost due to environmental factors

4.4. Amount of plastic in the waste

Following assumptions were made regarding amount of plastics in the waste:

- Household waste has same composition as survey results of [63]
- 40% of hospital solid waste is plastic. (Due to prevalence of plastic equipment, containers in medical industry.)
- 30% of industrial waste and building waste is plastic (this is purely guessed number, information on plastic usage in industry and building was not available.)
- Waste illegally dumped by people from Nalaikh has similar composition with household waste, 70% of illegal dumped waste by tourists and people on vacation is plastic. (multiple

news articles mentioned majority of the illegal dumped waste consists of food packaging, plastic bottles and food waste 62-66)

- 20% of waste dump is lost due to environmental factors such as wind, rainfall and among these lost waste majority are low density waste that can easily get carried by wind and water.
- Composition of other waste are similar to household waste with exception of food waste where percentage of food waste was assumed to be 3 times less percentage wise while proportion between other wastes remain same as household waste.
- 60% of waste from cleaning public road is plastic (this is purely guessed number, considering majority of the waste are plastic bottles, plastic wraps, and dust)

4.5. Future situations

Future situation was calculated with assumptions of Nalaikh's population is going to keep on growing with linear growth as population data of Nalaikh from 1995 to 2018 shows linear growth trend.

Future situations in 2050 are considered where:

Situation 1: No measure has been taken with regards of dealing with plastic waste, waste generation and management trend is same as 2020. Other assumptions are same. Additionally, it is assumed area of public road grew correlated with population.

Situation 2: waste generation amount is reduced by 1% each year. Other assumptions are same.

Situation 3: recycling plant with capacity of 5tons/day during winter and 2.5tons/day during summer started to be built in 2020 and started operating at 2025 and operating without problem since then and waste pickers are working at recycling plant for manual separation. Other assumptions are same.

Situation 4: usage of plastic in households are reduced by 1.5% each year through replacing plastic products with other alternatives. Other assumptions are same.

Situation 5: landfill conditions are improved and loss of waste through wind and runoff reduced from 5% to 1% and improvement of landfill started in 2020 and finished in 2023. Other assumptions are same

Situation 6: microplastic in wastewater is reduced by 1.5% each year by reducing usage of cosmetic products with microplastics and reducing usage of synthetic clothing. Other assumptions are same.

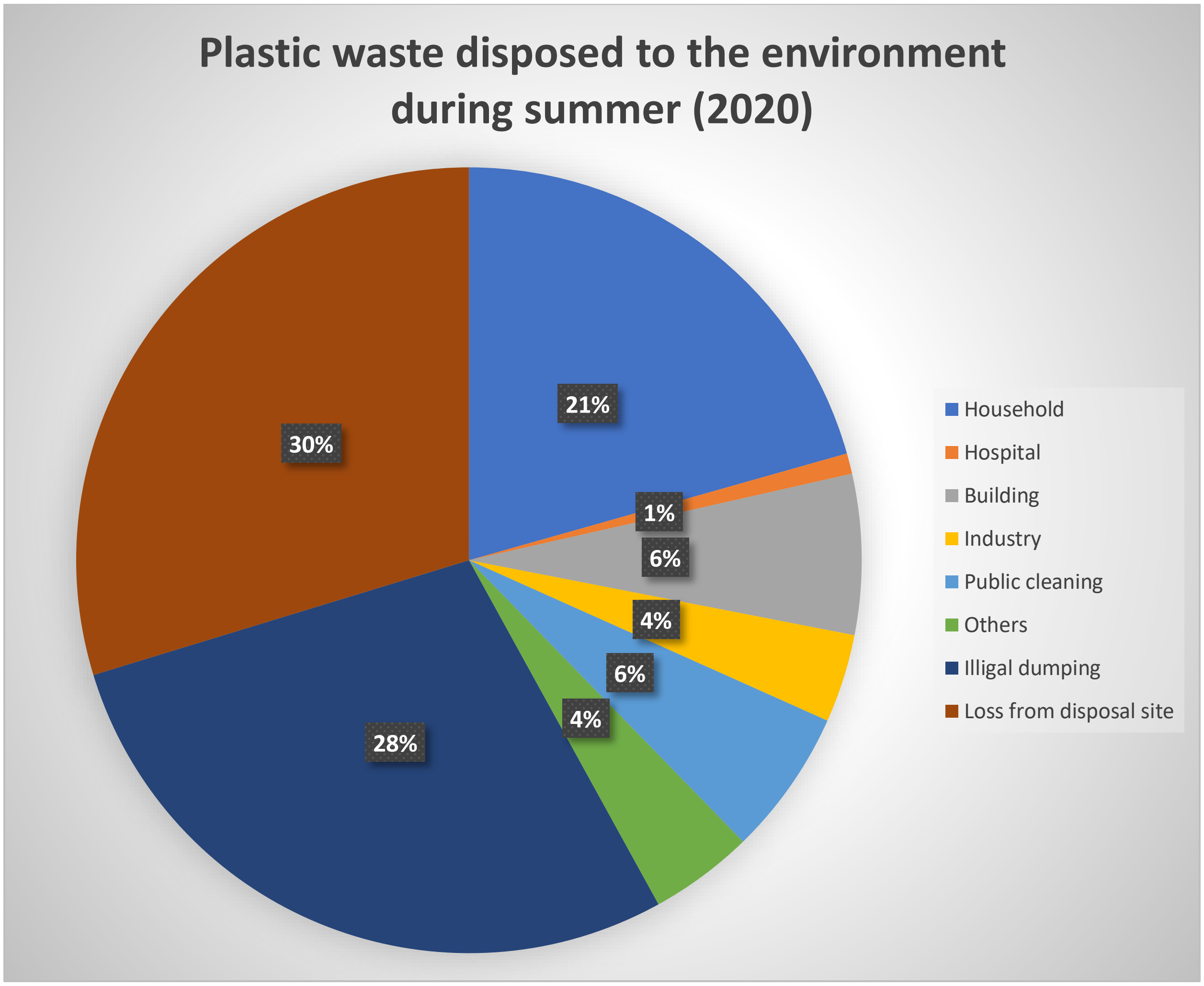
Situation 7: plastic usage in building, industries and other sectors are reduced by 2% each year. Other assumptions are same.

Situation 8: collection of illegal dumped waste is improved from 40% to 60%. Other assumptions are same.

Situation 9: collection of illegal dumped waste is improved from 40% to 60%. Other assumptions are same.

5. Results and discussions

5.1. Material flow of plastic in 2020



Currently with this calculation during winter total of 1.72tons of plastic waste is deposited directly to the environment each day without getting dealt with properly and big portion of it is due to household waste scattering and loss of waste from disposal site. 11.69 tons of plastic waste is deposited at Nalaikh's disposal site each day and 0.13kilograms of microplastic is deposited to environment each day through either wastewater treatment or using sludge of wastewater treatment.

Figure 17. plastic waste disposed to the environment during winter (2020)

During summer this amount decreases to 1.63 tons/day due to significant reduce of household waste (according to results of the calculations household waste amount decreases to 21.2

tons/day compared to 47.9 tons/day during winter) due to change in amount of ash from burning coal in the household waste from ger areas. In terms of other waste types differences are quite similar with exceptions of plastic waste from building waste which is expected as majority of the buildings are built during summer due to climate of the area and illegally dumped plastic waste amount in summer is 3.46 times more than amount of illegally dumped plastic waste during winter. In general, 611.4 tons of plastic waste would be directly deposited to the environment where 314 tons of it is during winter and 296.9 tons of it is accumulated during summer.

On the other hand, it is important to consider plastic waste in the disposal site as it is essentially disposed to the environment in a way. Nalaikh's disposal site is under high risk of contamination of ground water, and potentially one of the sources for airborne microplastics. Direct impact of landfill on the environment is however currently not well known and only speculations can be made at the time of this study. There is very high amount of plastic waste gathered in the disposal site and handling it properly is required.

With these results we can conclude under current circumstances there will be accumulation of plastic waste as 611.4 tons of plastic waste is disposed to the environment each year and it poses threat of plastic pollution in the environment and health hazard. If we threat plastic as a waste according to [100] we have several ways to deal with it.

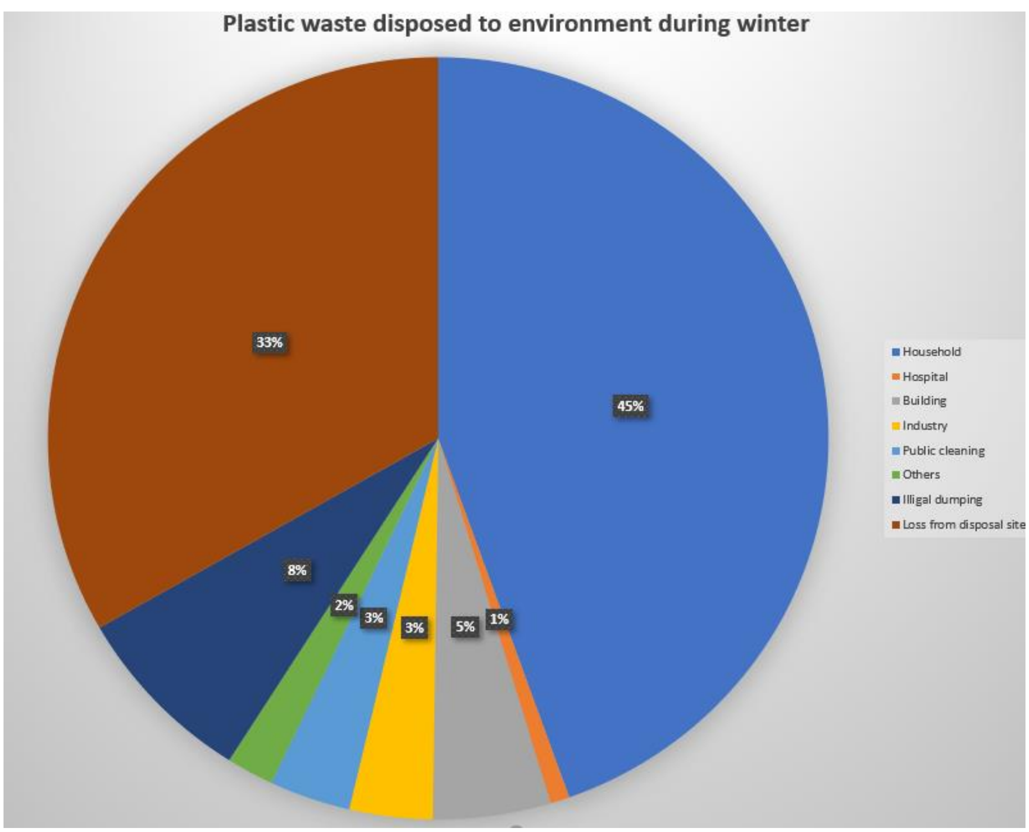


Figure 18. Plastic waste disposed to the environment during summer (2020)

Figure 19. waste hierarchy [100]

First consideration must be a prevention of the plastic waste. In other words, prevent using plastic by replacing it with other materials or reduce usage of plastic. In a case of Nalaikh, it is hard to convince prevention of the plastic usage to the plastic due to low income of the region and poor economic incentive to replace plastic due to its low price. Therefore, it is expected for prevention method to have poor impact and impact of if was accessed in "situation 1" where plastic in household waste is reduced by 1% each year by reducing waste generation and in "situation 4" where plastic waste from households is reduced due to replacing plastic with other material and in "situation 7" where plastic usage is reduced through replacing plastic with other materials in other sectors and in "situation 6" considered reducing amount of microplastics in the personal care products.

Next consideration re-use of plastic, however in general plastic is already re used very effectively in Mongolia, especially in the ger area or in households with lower income to save money. Examples would be collecting used plastic bags to use it again, collecting and re using old polyvinyl chloride pipes from waste disposal sites, buying used clothes from others, using used plastic bags as a wrapping, etc (this section was written based on my own experience living in Nalaikh). But in general re-use of plastic is not a good way to deal with plastic waste due to potential release of additives and generation of microplastic which poses potential health threats as re-used plastics are expected to be more brittle and more vulnerable to degradation.

After re-use next consideration is to recycle plastic. Exact economic incentive of plastic recycling was not considered as calculating exact cost of plastic recycling is not possible without market research and knowing exact process to be used as recycling process highly depends on the input of the process which in this case is composition of the waste in Nalaikh. In general recycling mixed waste is economically not feasible due to high cost of complex separation process and on the other hand recycling separated plastic waste would reduce cost significantly but unfortunately currently separation of waste is not legalized and not incentivized enough. Impact of recycling was accessed in “situation 3” where we assumed recycling is profitable enough to operate recycling plant, recycling plant can be built in 5 years and 5 tons of plastic waste can be separated from household waste during winter through regulating plastic waste separation properly and 2.5 tons of plastic waste can be separated from household waste during summer. Additional important aspect of the recycling, specifically in Nalaikh is providing jobs for the waste pickers as they are highly experienced at separating plastic from the waste and main reason for them to collect waste is to sell them and if they are provided with proper jobs waste lost due to waste scattering would be significantly decreased and fire risk at disposal site would decrease significantly as well.

Recovery method was not considered due to its negative impacts of flue gas and ash to the environment.

Lastly proper collection and disposal was considered where proper collection is referring to “situation 8” where collection of illegal dumped waste is improved and “situation 5” where disposal method is improved to reduce loss of waste through wind and runoff. Generally, these methods are not as effective at reducing amount of waste generated, rather these methods potentially reduce impact of plastic to the environment assuming plastic waste disposed at disposal site has less environmental impact compared to directly disposing plastic waste to the environment.

5.2. Future situations

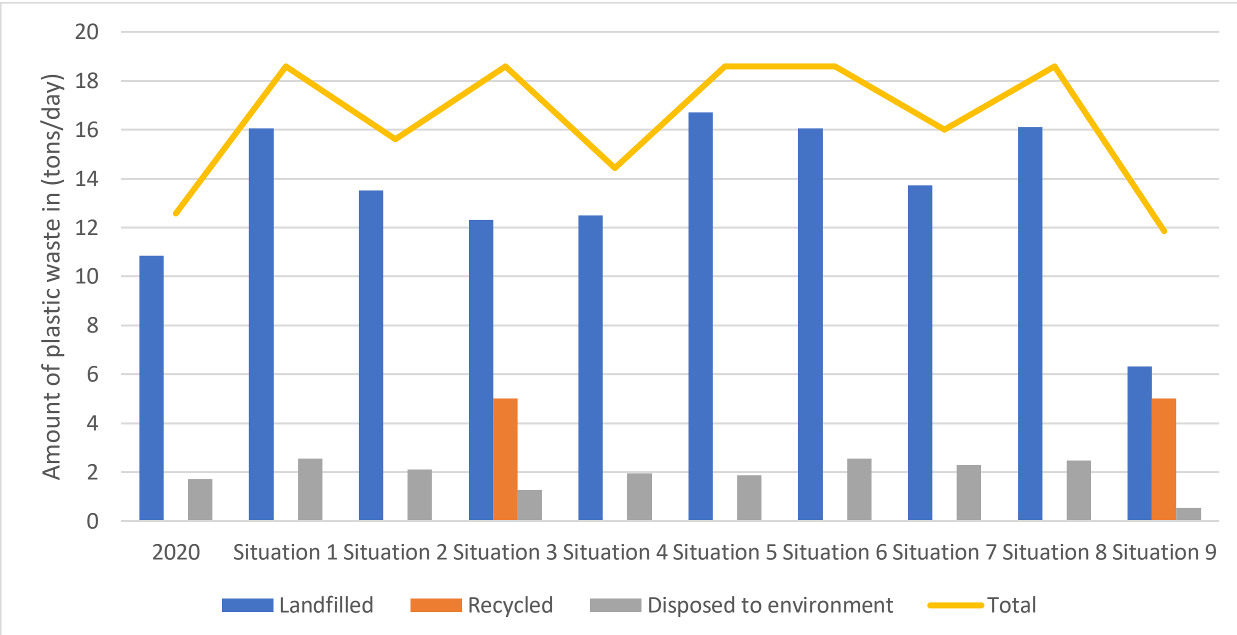


Figure 20. Comparisons of different future situations compared to current situation during winter.

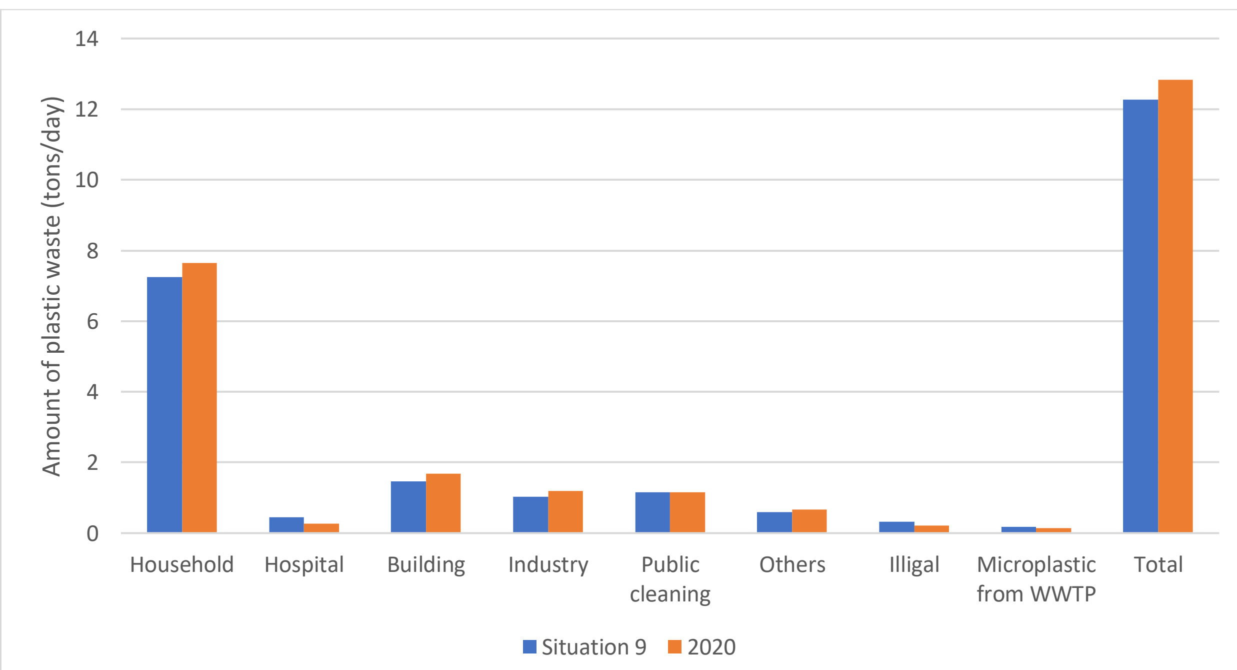


Figure 21. Comparison between current situation and situation 9 during winter

Based on population data of Nalaikh in last 20 years Nalaikh's population is expected to keep on growing in the future and in 2050 population is expected to reach 60450 compared to current population of 36911.

Future situations in winter

With that population growth no measures to deal with plastic waste situation 1 occurs where total amount of plastic waste generation is increased from 12.47tons per day in 2020 to 18.59tons per day and in even longer term growth is expected to keep on going and most importantly amount of plastic directly disposed to the environment increases from 1.72tons per day in 2020 to 2.55tons per day.

With situations 2 to 8 we considered effectiveness of different methods.

- In situation 2 we considered situation where general household waste. Compared to situation 1 where no direct measures were taken total amount of plastic waste less, however compared to current situation amount of waste is still significant and over longer period of the amount of plastic waste would keep on increasing. Therefore, taking measures to reduce household waste is not sufficient enough.
- In situation 3 we considered situation where recycling plant with capacity of 5tons/day during winter and 2.5tons/day during summer is operating. Amount of plastic waste disposed to the environment is 1.27tons/day which is way less than current situation and total amount of plastic waste is 1.72tons/day of current situation and total amount of waste generated it comparable to current situation. However, amount of waste landfilled is still higher than current situation and over long period of the time amount of the waste in plastic cycle is same as situation 1 where no measures were taken. Therefore, even though situation 3 reduces impact to the environment in short term but overall does not have enough impact.
- In situation 4 we considered situation where usage of plastic has been reduced by specifically preventing usage of plastic products. In this situation amount of waste disposed to the environment is comparable to situation 2 but total amount of waste is 14.43tons/day compared to 15.62tons/day and similar to situation 2, measures in situation 4 is not sufficient enough in a long term.
- In situation 5 we considered situation where landfill conditions are improved and loss to plastic waste to the environment decreased. Total amount of waste generated is same as situation 1 where no measures were taken, but amount of waste disposed to the

environment changes. Overall, this measure does not solve problem of increasing plastic waste.

- Situation 6 had least impact where we considered situation where amount of microplastics in wastewater is reduced by reducing usage of personal care products containing microplastics, which is expected considering how small proportion of plastic sources from microplastics in the personal care products, but it is important to note that it will be easiest method to implement.
- In situation 7 we considered situation where plastic usage in multiple sectors by replacing plastic with other materials. Impact of the measure was comparable to situation 2 as total amount of waste was nearly same with situation 7 at 16.01 tons/day compared to 18.49tons/day of situation 2 but amount of plastic disposed to the environment is more compared to situation 2 where amount of plastic disposed to the environment is 2.29tons/day for situation 7 compared to 2.11tons per day of situation 2. Therefore, similar to situation 2 this measure is not enough to have enough impact.
- In situation 8 we considered situation where collection of illegal dumping was improved. Result of situation 8 is comparable to situation 5 where total amount of waste is not changed. Therefore, similar to situation 5 this measure does not solve problem of increasing plastic waste.

With these results either these measures have to be done drastically meaning instead of setting a goal to reduce by implementing direct prohibition of plastics in some sectors or several different measures has to be taken. In situation 9 we considered a situation where all of the measures are implemented together and results are first of all amount of total waste is almost halved where amount of total waste generated in situation 9 is 6.85tons/day compared to 12.57tons/day and amount of landfilled waste is reduced form 10.86tons/day to 6.31tons/day and amount of waste disposed to the environment is reduced from 1.72tons/day to 0.54tons/day which is reduce of 3.2 times. Because of the current high amount of plastic material usage, it would be hard to reduce amount of plastic usage significantly therefore using several measures at the same time is required. With situation 9 amount of plastic waste is expected to keep on going down in long term unless there is drastic chance occurs. After 2080 plastic waste from household wouldn't be become less than 5tons/day and at that point recycling plant would not have enough input and expected to be closed. It is important to note that some of the results might not be accurate in the future as we made multiple different assumptions and making assumptions more accurate would help to get more accurate results. Therefore, after 2080 impact of recycling would be significantly low but.

Future situations in summer

During summer results suggests similar conclusion where situation 2-8 does not have enough impact to deal with plastic pollution problem. Differences between summer and winter would include situation 3 has less impact in summer compared to the winter as recycling amount is significantly less due to household plastic waste being way less than winter and is not enough to supply for 5tons/day. During summer 5tons/day of plastic waste can be supplied if illegal dumped waste is collected and separated properly. Another difference is impact of situation 4 in summer is less compared to winter which is due to difference between amount of household waste generated during summer being way less compared to winter and we made assumptions based on percentage. Results during summer also suggest that multiple methods have to be implemented together to have enough impact to deal with plastic pollution problems.

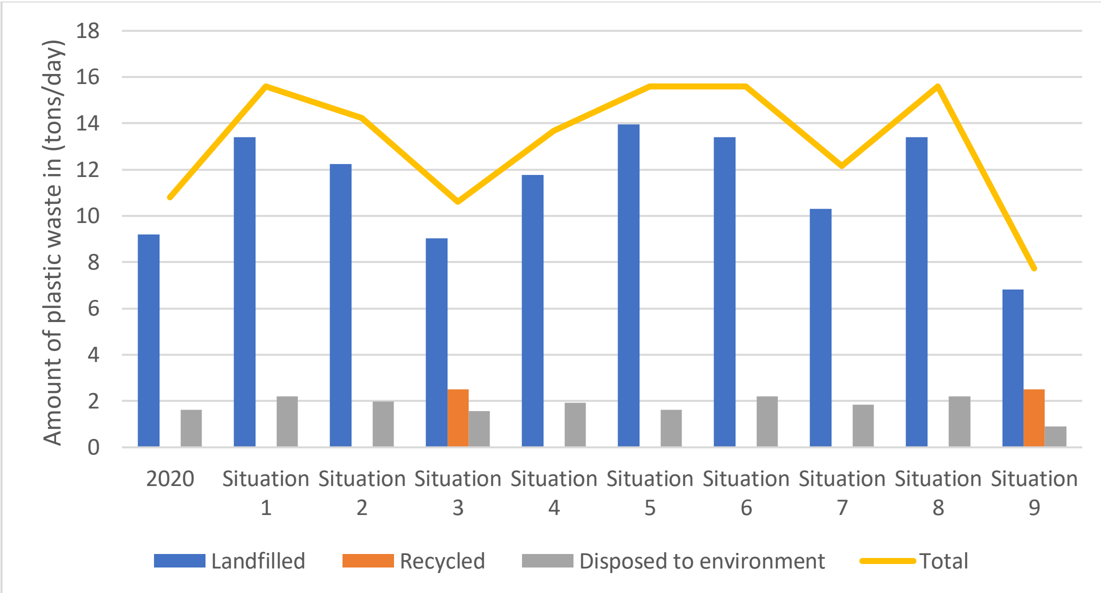


Figure 22. Comparisons of different future situations compared to current situation during summer.

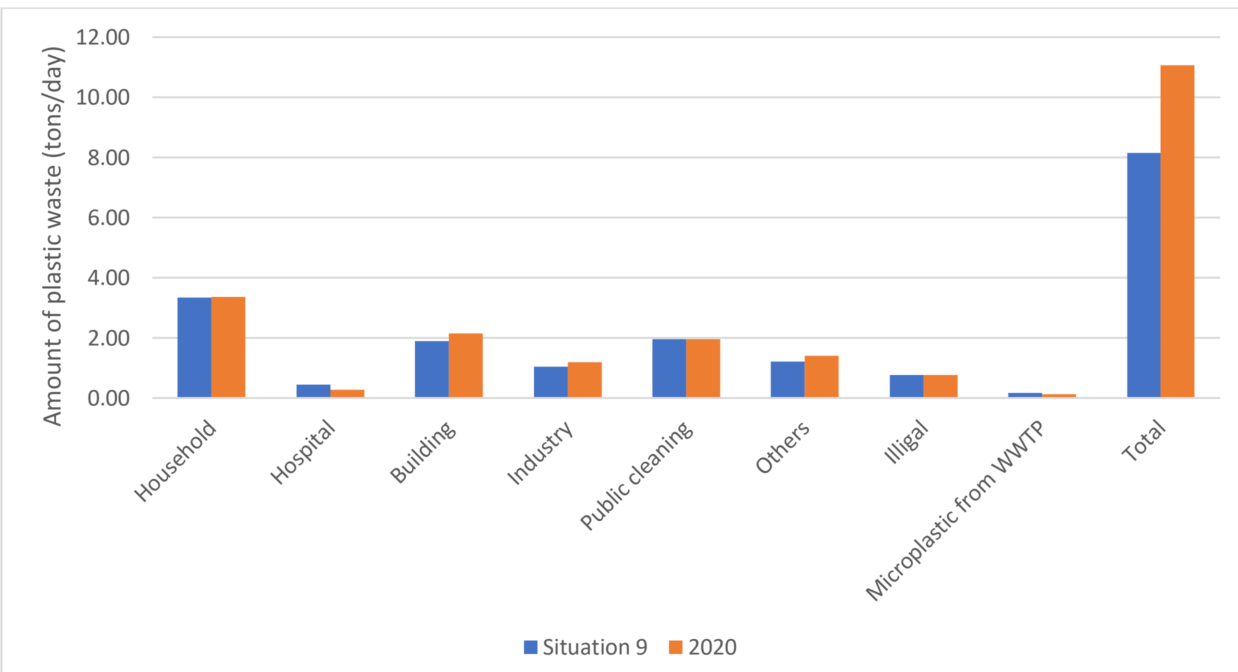


Figure 23. Comparison between current situation and situation 9 during summer

6. Conclusions and recommendations

6.1. Recommendations

1. Making material flow calculations based on material lifetime and demand would potentially lead to more accurate results or instead of using assumptions calculating based on experimental works such as taking samples from Nalaikh's disposal site, household waste, industrial waste or survey on plastic usage pattern, lifetime of plastic products, number of industries, degradation time of plastic materials would make the calculations more accurate.

2. There is a possibility to calculate material flow calculations of microplastics only, but it would require observations of degradation process of plastic in the environment of Nalaikh for calculations of secondary microplastics and additionally experiments on finding amount of microplastic generated from car tires would be advised. Additionally, finding out amount of microplastics in effluent and sludge of WWTP in Nalaikh would be helpful. Additionally, at the moment of writing this thesis impact of the microplastics is not well known and studying it would help us to understand microplastics better.

3. Even though there are many news articles on illegally dumped waste in Terelj national park Impact of those wastes are poorly studied and studying this impact is very important as Terelj national park is essential part of water supply of Ulaanbaatar city.

4. Disposal site of Nalaikh poses potential threat to the environment but exact impact of it is not well known, therefore it is important to access exact impact of disposal site in the future is required.

5. In this thesis work economic impacts of the measures to reduce plastic usage were not considered. Therefore, further research on economic impacts should be considered, especially for economic incentive to build recycling plants and impact of separate collection on recycling process cost.

6. For the recycling process itself process highly depends on the waste composition, impurities, plastic types, and additives in the plastic. Therefore, studies on waste composition of Nalaikh, common impurities in plastic products, additives used in plastic products that are used in Nalaikh or in Mongolia in general, and amount of different plastic types are required to choose proper recycling process and for polyethylene recycling process reading [17] and its reference materials is highly suggested.

7. For the learning purposes [41] is highly recommended literature as it gives really good background information on many different aspects of plastic.

6.2. Conclusions

1. Plastic materials impacts environment negatively in multiple different ways and plastic pollution is one of them. Plastic pollution is potential big problem for Nalaikh, especially if no measures are taken as Nalaikh's population is on increasing trend and amount of plastic waste would get increased accordingly.

2. There is potential to build plastic recycling plant which would significantly decrease impact of the plastic in the environment in a short term.

3. Even though recycling can have impact in short term, total amount of plastic is not reduced by recycling, therefore more direct method such as replacing and reducing plastic usage must be implemented.

4. Implementing only one measure is not enough to deal with future plastic pollution problem in a long term, therefore multiple measures have to be implemented at the same time.

5. Degradation of the pure plastic is well known process, however majority of the plastic products contain additive materials which slows down degradation process and in general makes it harder to know exact degradation process.

6. Microplastics are present in Tuul river basin, which suggest potential microplastics in Terelj national park and presence of the microplastics in effluent and sludge of the WWTP in Naliakh is expected.

7. Illegal dumping in Terelj national park is a one of the important plastic waste sources and it is especially a big problem during summer.

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Appendix

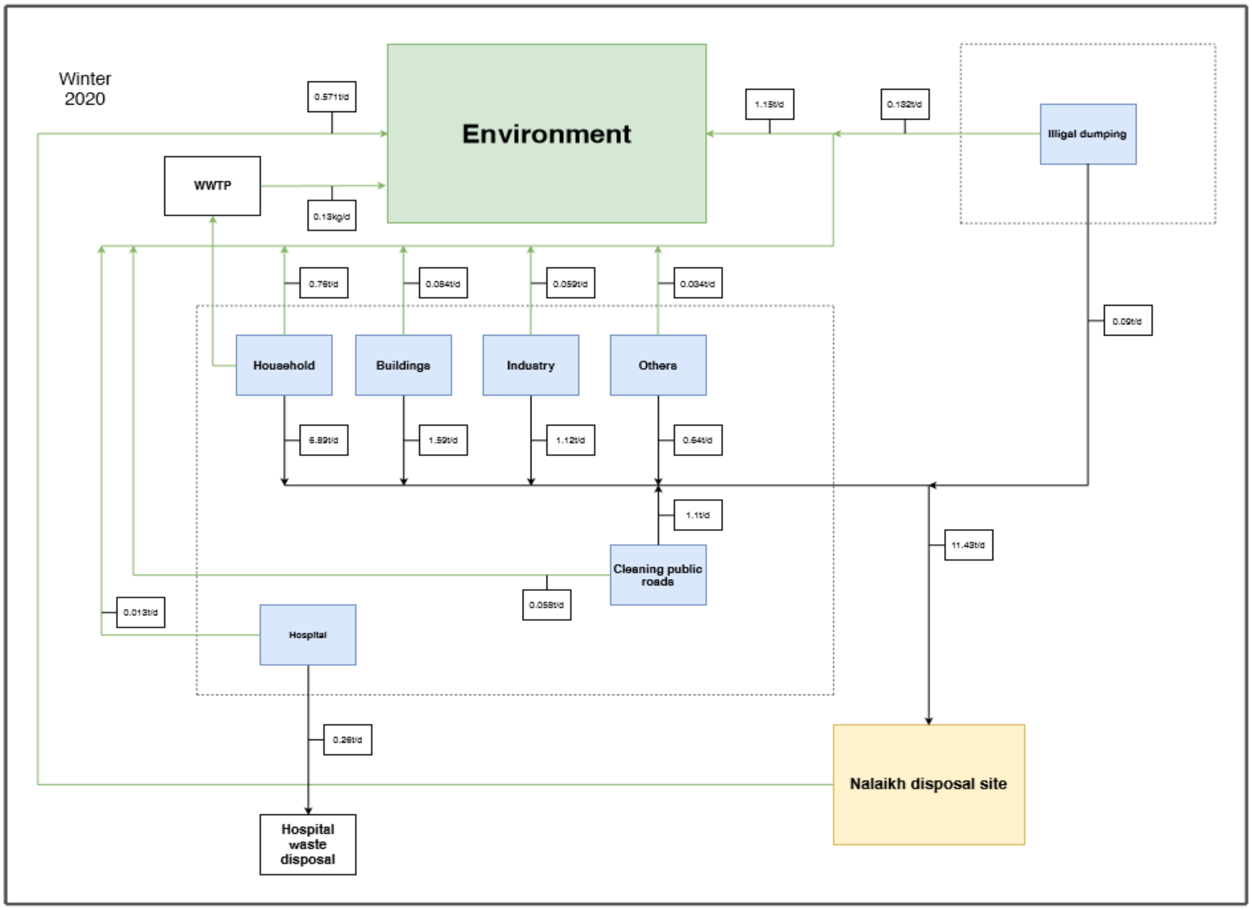

Figure 24. Material flow diagram of Nalaikh in winter, 2020

Table 6. Overall waste generated in 2020

Plastic disposed to environment (2020)	Winter	Unit	Summer	Unit	Overall	Unit
Household	139.61	tons	61.22	tons	200.83	tons
Hospital	2.50	tons	2.50	tons	5.01	tons
Building	15.27	tons	19.58	tons	34.85	tons
Industry	10.80	tons	10.80	tons	21.60	tons
Public cleaning	10.56	tons	17.85	tons	28.41	tons
Others	6.14	tons	12.71	tons	18.85	tons
Illigal dumping	24.23	tons	84.00	tons	108.23	tons
Loss from disposal site	104.27	tons	88.24	tons	192.51	tons
Total	313.40	tons	296.89	tons	610.29	tons

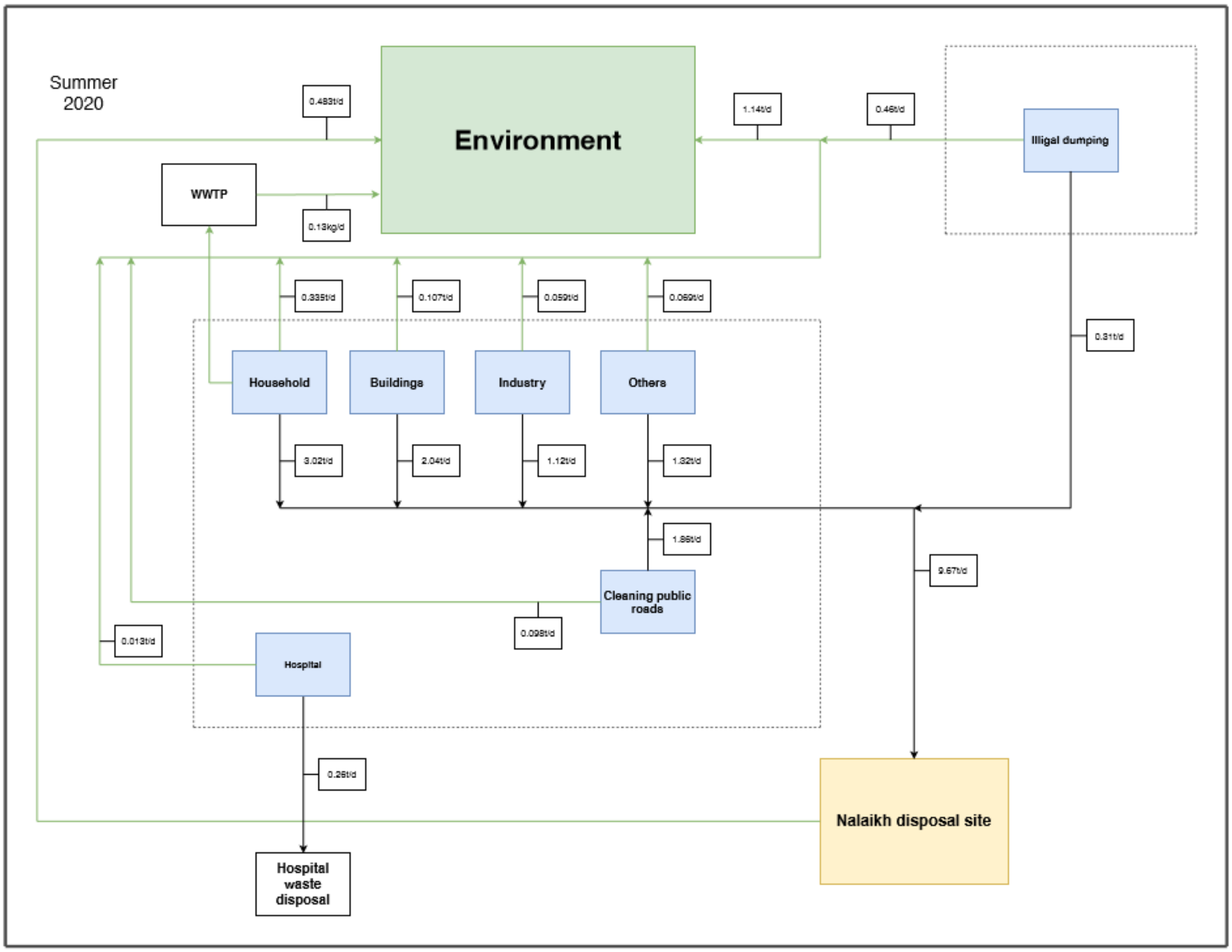

Figure 25. Material flow diagram of Nalaikh in summer, 2020

Table 7. Plastic waste final deposition in different future situations during winter (units are in tons/hour)

Plastic waste (winter)	2020	Situation 1	Situation 2	Situation 3	Situation 4	Situation 5	Situation 6	Situation 7	Situation 8	Situation 9
Landfilled	10.86	16.04	13.50	12.32	12.49	16.72	16.04	13.72	16.11	6.31
Recycled	0	0	0	5	0	0	0	0	0	5
Disposed to environment	1.72	2.55	2.11	1.27	1.94	1.87	2.55	2.29	2.48	0.54
Total	12.57	18.59	15.62	13.59	14.43	18.59	18.59	16.01	18.59	6.85

Table 8. Plastic waste final deposition in different future situations during summer (units are in tons/hour)

Plastic waste (summer)	2020	Situation 1	Situation 2	Situation 3	Situation 4	Situation 5	Situation 6	Situation 7	Situation 8	Situation 9
Landfilled	9.19	13.41	12.23	9.02	11.77	13.97	13.41	10.29	13.41	6.83
Recycled	0	0	0	2.5	0	0	0	0	0	2.5
Disposed to environment	1.63	2.19	1.99	1.57	1.91	1.63	2.19	1.86	2.19	0.90
Total	10.81	15.60	14.23	10.60	13.68	15.60	15.60	12.15	15.60	7.73

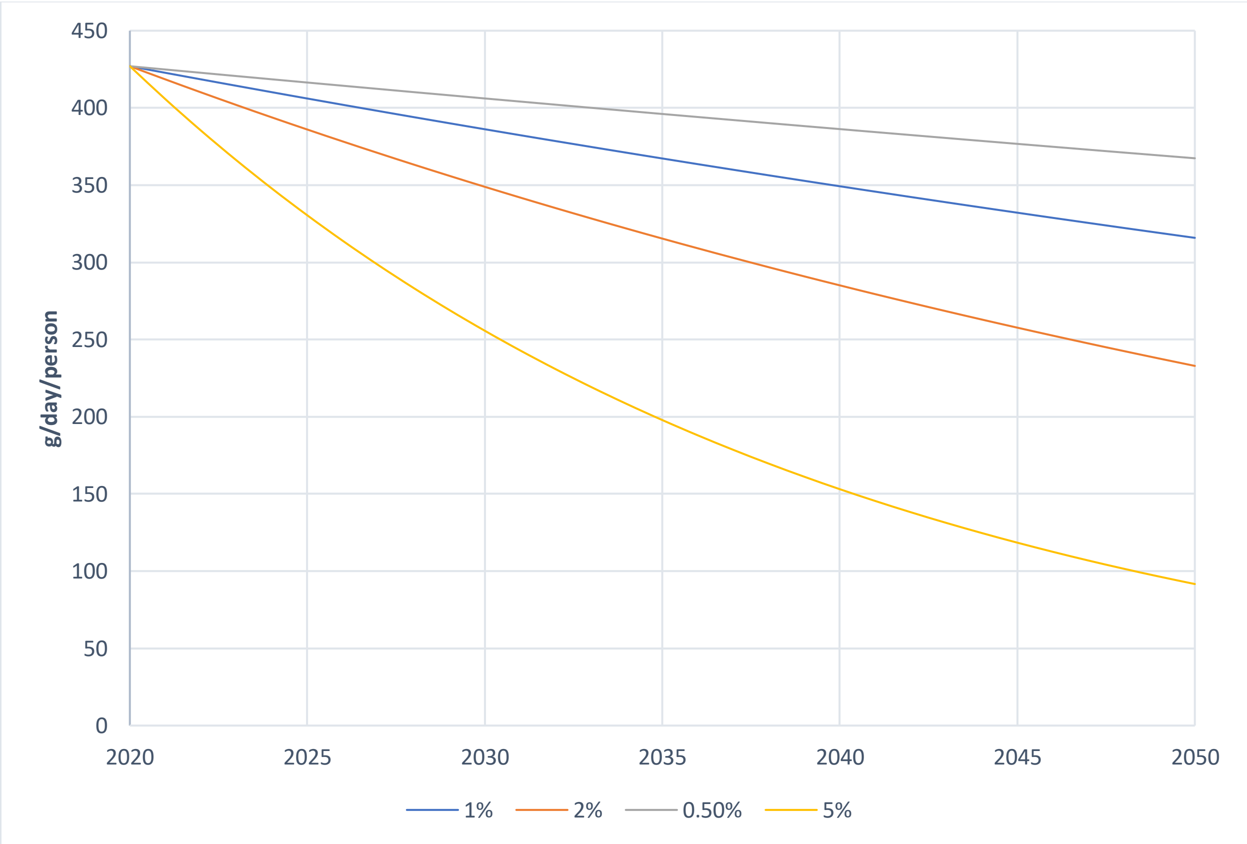

Figure 26. Waste generation amounts in situation 2 with different assumptions

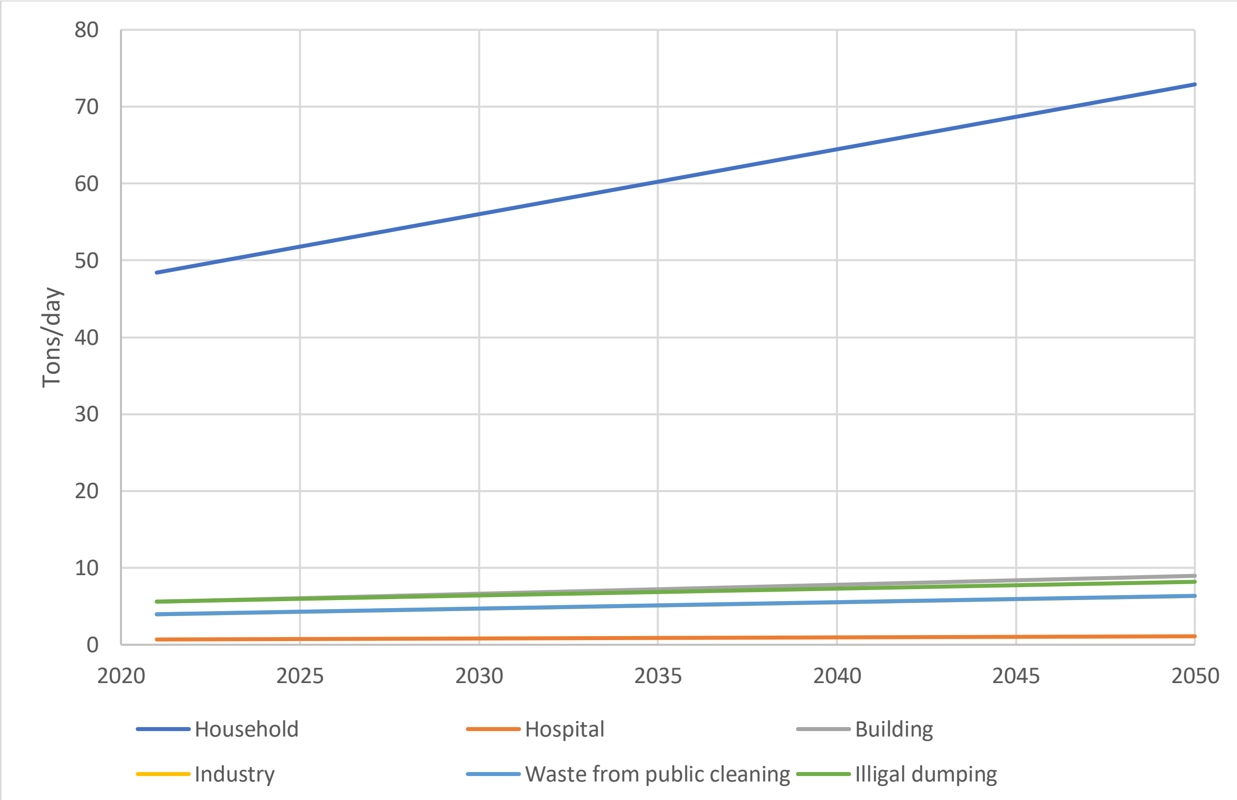

Figure 27. Prediction of waste generation from different sectors in the future in situation 1 (2021-2050)

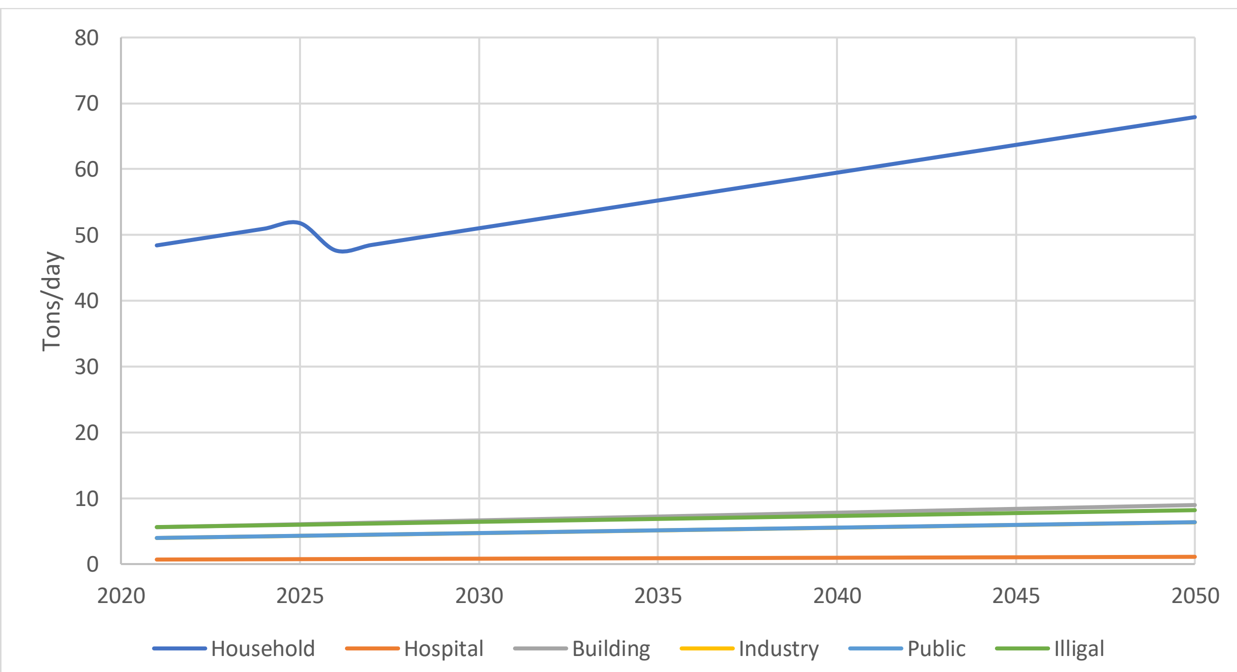

Figure 28. Prediction of waste generation from different sectors in the future in situation 3 (2021-2050)

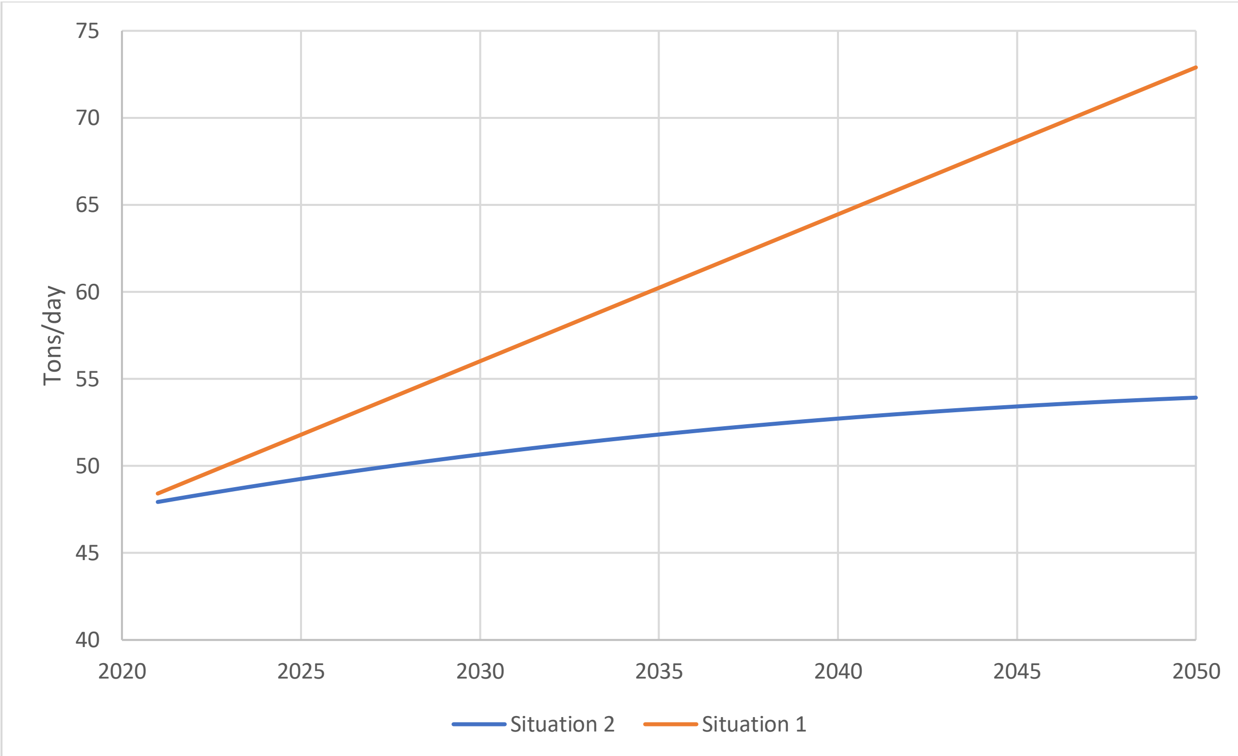

Figure 29. Household waste comparison of situation 1 and situation 2 (2021-2050)

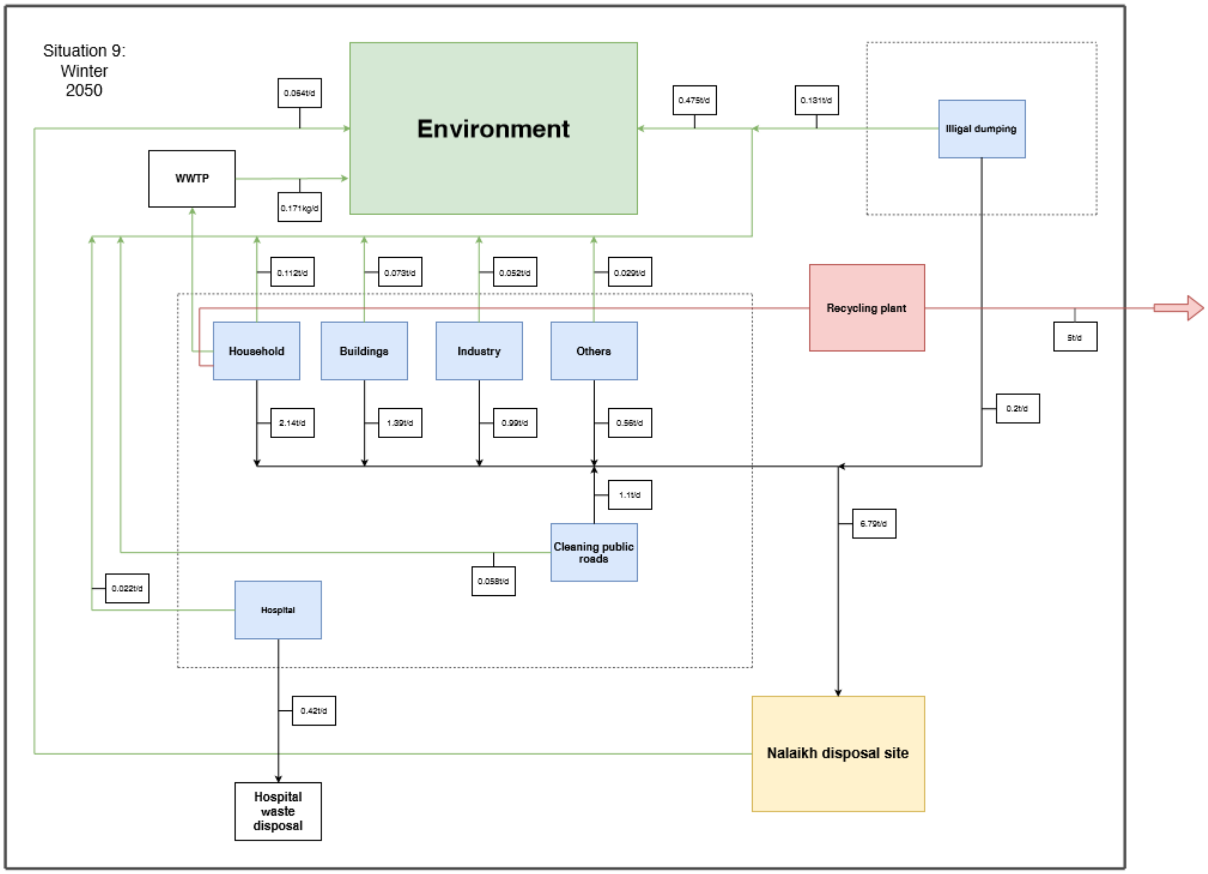

Figure 30. Material flow diagram of plastic waste in situation 9 (winter, 2050)