Situation analysis of plastic waste management in Sri Lanka: An empirical evidence of microplastic contamination in Kelani River

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น.ส.เฮลัมบา อาราชิจ คาลานี เปเรรา

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เฮลัมบา อาราชิจ คาลานี เปเรรา :
การวิเคราะห์สถานการณ์การจัดการขยะพลาสติกในประเทศศรีลังกา:
ข้อค้นพบเชิงประจักษ์การปนเปื้อนไมโครพลาสติกในแม่น้ำคาลานี. (Situation analysis of plastic waste management in Sri Lanka: An empirical evidence of microplastic contamination in Kelani River) อ.ที่ปรึกษาหลัก : สุจิตรา วาสนาดำรงดี,
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แม่น้ำเคลานีเป็นแม่น้ำที่มีมลพิษมากที่สุดในศรีลังกาและเป็นแหล่งน้ำดื่มหลักสำหรับผู้คนหลายล้านคนในจังหวัดทางตะวันตก แต่มีการศึกษาน้อยมากที่ดำเนินการเพื่อประเมินมลพิษพลาสติกซึ่งจำกัดเฉพาะการศึกษาไมโครพลาสติกในบริเวณปากแม่น้ำ จากที่ทั่วโลกให้ความสนใจในการแก้ไขปัญหาแหล่งที่มาของขยะพลาสติกที่ปล่อยสู่มหาสมุทรมากขึ้น การศึกษานี้จึงได้รับการพัฒนาโดยมีวัตถุประสงค์เพื่อระบุมลพิษไมโครพลาสติก (Microplastic: MP) ในแม่น้ำเคลานี ซึ่งเป็นหนึ่งในเส้นทางหลักที่นำขยะพลาสติกสู่มหาสมุทรอินเดีย การศึกษานี้มุ่งที่จะระบุการปนเปื้อนของ MP ในจุดคดเคี้ยวของแม่น้ำ Kelani ระบุลักษณะของ MP ที่พบในน้ำผิวดิน และระบุปัจจัยที่เป็นไปได้ที่มีอิทธิพลต่อการเกิดขึ้น การศึกษานี้ใช้กระบวนการสุ่มตัวอย่างอย่างรวดเร็วโดยสุ่มตัวอย่างแบบใช้ภาชนะบรรจุและแบบตาข่ายในการเก็บตัวอย่างน้ำผิวดิน 21 ตัวอย่าง จากนั้น MP ถูกสกัดและจัดหมวดหมู่ตามขนาดโดยพบว่าขนาดของ MP ที่พบในตัวอย่างที่เก็บจากภาชนะบรรจุเป็นขนาดในช่วง 5 มม. - 2 มม. (55%) และพบ MP ขนาด 2 มม. - 1 มม. (58%) จากการใช้ตาข่ายเก็บตัวอย่าง พบว่า MP ส่วนใหญ่เป็นชิ้นส่วนพลาสติก (50.14%, 41.88%) และสีขาว (47.48%, 40.16%) เป็นสีเด่นทั้งในกลุ่มตัวอย่างและตัวอย่างสุทธิตามลำดับ ผู้วิจัยระบุชนิดของพอลิเมอร์โดยใช้สเปกโตรมิเตอร์ FT-IR (BRUKER, ALPHA II) พบว่าโพลิโพรพิลีนและโพลิเอทิลีนเป็นพอลิเมอร์ประเภทที่ตรวจพบมากที่สุดและพบโพลิสไตรีนเล็กน้อยในบางพื้นที่ การพบเม็ดพลาสติก (nurdles) ใน 5 ตัวอย่างสุทธิ 7 ตัวอย่างเป็นหนึ่งในการค้นพบที่สำคัญเนื่องจากเม็ดพลาสติกเหล่านี้คล้ายกับเม็ดพลาสติกที่รั่วไหลจากอุบัติเหตุเรือบรรทุกสินค้า M/V X-Press Pearl ไฟไหม้และจมในทะเลในเดือนพฤษภาคม 2021 เม็ดพลาสติกที่พบในตัวอย่างส่วนใหญ่เป็นพลาสติกประเภทโพลิเอทิลีน (81.9%) และพอลิโพรพิลีน (18.1%)
การศึกษานี้บ่งชี้ว่าไมโครพลาสติกส่วนใหญ่เป็นแบบทุติยภูมิโดยแตกตัวมาจากพลาสติกชิ้นใหญ่ ดังนั้น จึงได้มีการวิเคราะห์สถานการณ์การจัดการขยะพลาสติกในภาพรวมของประเทศผ่านการทบทวนวรรณกรรมและปรึกษาหารือผู้มีส่วนได้ส่วนเสีย ผลการศึกษาชี้ว่าแหล่งกำเนิดมลพิษพลาสติกทั้งขยะพลาสติกชิ้นใหญ่และไมโครพลาสติกมาจากการทิ้งขยะเกลื่อนกลาด การลักลอบทิ้งอย่างผิดกฎหมาย วิถีการจัดการขยะที่ไม่ดี การประกอบอุตสาหกรรมที่ทำให้เกิดการรั่วไหลของไมโครพลาสติก

สาขาวิชา	การจัดการสารอันตรายและสิ่งแวดล้อม	ลายมือชื่อนิสิต .....
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Helamba Arachchige Kalani Perera : Situation analysis of plastic waste management in Sri Lanka: An empirical evidence of microplastic contamination in Kelani River . Advisor: Dr. SUJITRA VASSANADUMRONGDEE Co-advisor: Dr Ananda Mallawatantri

River Kelani is the most polluted river in Sri Lanka and the primary source of drinking water for millions of people in western province but very few studies have been conducted to assess its plastic pollution, which were limited to microplastic studies in the river estuary. As the global attention is increased into tackling the sources of plastic litter released into the ocean, this study was developed with the aim of identifying the microplastic (MP) pollution in Kelani River, one of the main careers of plastic waste into the Indian Ocean. The study specifically aimed to identify the MP contamination in the meandering zone of Kelani River, characterize MPs found in the surface water and identifying possible factors influencing their occurrence.

A rapid sampling process was utilized using both bulk and net sampling methods to collect 21 surface water samples. MP were extracted and categorized accordingly based on their sizes. Most recorded MP size category in bulk samples was 5mm- 2mm (55%) and 2 mm- 1mm (58%) in net samples.Plastic fragments (50.14%, 41.88%) recorded significantly high numbers and white colour (47.48%, 40.16%) was the dominant colour in both bulk and net samples respectively. The polymer types were identified using the FT-IR spectrometer (BRUKER, ALPHA II). In both samples Polypropylene and the Polyethylene were the most detected polymer types with some Polystyrene at few sites. The presence of nurdles in 5 of the 7 net samples is one of the key findings as these nurdles are similar to the nurdles from the M/V X-Press Pearl cargo ship which was destroyed completely in May 2021. The nurdles found in the samples were made from mainly polyethylene (81.9%) and polypropylene (18.1%).

While identifying that majority of the MP were with secondary origins derived from macro plastic, a situation analysis was carried out, reviewing literature, and conducting a stakeholder consultation to identify the plastic waste management situation in the country. Based on that possible sources of macro and microplastic pollution in the river were identified as littering, fly tipping and illegal dumping, poor waste management practices, industrial activities leading to improper disposal and loss, sewage debris and canal discharge, abandoned fishnets. Finally, the management recommendations were provided accordingly.

Field of Study:	Hazardous Substance and Environmental Management	Student's Signature .....
Academic Year:	2021	Advisor's Signature .....
		Co-advisor's Signature .....

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CHAPTER 1

Introduction

Plastic has become prevalent globally, as a versatile material with its unique properties such as light weight, persistence, low cost, and strength (PlasticsEurope, 2017). In Asian region the exponential growth in plastic production over recent decades has increased the consumption rates, with increased rates of per-capita plastic use compared to other regions. Therefore, plastic waste has become an inevitable, arising issue in Asian region, especially in developing countries spreading out to remote areas as well (Free et al., 2014).

Majority of the plastic waste end up in water bodies, especially in marine water, due to mismanagement of waste and marine activities. Plastic waste can end up in water in various sizes, shapes different forms and various colours and can damage the aquatic ecosystems in many ways. Animals can entangle in large particles, and smaller particles can be swollen by animals, and it can block their digestive system or release harmful chemical substances that would threaten their life. Initial discovery of plastic litter dates to 1972 in oceanic environment with the documentation of buoyant plastics on marine water (Carpenter & Smith, 1972). Since then, several research studies have been conducted to estimate and identify the marine plastic litter. In 2016, 11% of globally generated plastic waste which is about 19 – 23 million tonnes, ended up in waterbodies (Borrelle et al., 2020). However, it is estimated that this amount to be increased more than twice and the amount of plastic will be greater than the amount of fish in the ocean by 2050 (Geyer et al., 2017).

In recent years, global attention is paid into tackling the sources of plastic litter released into the ocean, and it is discovered that majority of the wastes are mixed into the ocean by rivers (MacArthur et al., 2016). It was further realized that about 90% pollutants come from just 10 rivers around the world; where out of them, 8 are from Asian region: River Yangtze; Indus River; Yellow River; Hai He River; Ganges River; River Pearl; River Amur; Mekong River; and 2 from Africa: Nile and Niger (MacArthur et al., 2016). In India, Ganges River was found to be the highest polluted river in the world in recent studies. That being realized, still the available scientific data and countermeasures taken are at an insufficient level to overcome the issue of aquatic plastic pollution, millions of plastic wastes are still washed up to the ocean every year.

In such a world context, Sri Lanka is also having similar issues related to plastic waste management. According to recent studies, Sri Lanka has severely affected by mismanaged plastic waste causing the environmental issues due to rapid urbanization, lack of resources as a developing country (in term of technology, human resource, financial aspects) and other policy related issues in plastic waste management. As shown in Figure 1, Sri Lanka is among top 20 countries that emits plastic pollutants to the ocean.

It is estimated that in 2017, Sri Lanka's plastic waste generation is about 1.59MMT/ year and about 5% is mismanaged plastic waste (CEJ, 2021). Being an island that 60% of national protein requirement is fulfilled by fish and estimated that 13.5% of average household income is spent on fisheries products, marine plastic pollution obviously have severe impacts on residents' lifestyles. It was estimated that Sri Lankan's fisheries stocks of 300,000 tonnes in 1980 have reduced to just 53,000 tonnes in 2018, while one of the main causes is found to be as marine plastic pollution (Lakshman Kadiragamar Institute, 2021). Even in such a situation, there cannot be found a comprehensive scientific study on marine plastic litter, especially to identify the hotspots and main flows of plastic leakages to marine ecosystems. Therefore, this can be considered as a major drawback for the policy development and other counter measures that should be designed and implemented to reduce the marine pollution.

Rank	Country	% Share
1	Philippines	36.4%
2	India	12.9%
3	Malaysia	7.5%
4	China	7.2%
5	Indonesia	5.8%
6	Brazil	3.9%
7	Vietnam	2.9%
8	Bangladesh	2.5%
9	Thailand	2.3%
10	Nigeria	1.9%
11	Turkey	1.5%
12	Cameroon	1.1%
13	Sri Lanka	1.0%
14	Guatemala	0.7%
15	Haiti	0.7%
16	Dominican Repub	0.6%
17	Venezuela	0.6%
18	Tanzania	0.6%
19	Algeria	0.6%
20	Panama	0.5%

Figure 1: Top 20 countries that emits most marine plastic pollution

Hence, through this study, it was expected to identify the microplastic pollution in the Kelani river surface water via exploring available data related to micro plastic characterization, source identification and derive management recommendations to support local government, communities, and industries to develop ecofriendly plastic waste management practices, targeting main sources to reduce the aquatic plastic litter dumping thus leading to reduce plastic leakages via river flow.

This research is mainly based on Kelani River that pass across some of the most densely populated cities in Sri Lanka in Western province. Out of the 9 provinces in Sri Lanka, western

province is identified as the highest polluted area, accommodating both capital and business capital. Within Colombo city (business capital) municipal council alone, about 700 – 800 tonnes of waste have been collected daily while other municipal councils belong to the western province (Dehiwala-Mt. Lavinia, Kolonnawa, Sri Jayawardenapura Kotte, and Moratuwa) typically collects around 300 – 400 tonnes of waste daily. However, most of the mismanaged waste from the cities in the province are ultimately end up in water bodies where all will be washed up to the ocean. It is estimated that Sri Lanka release about 0.24 – 065MMT of marine debris into the ocean every year (CEJ, 2021).

Further this study focused on identifying micro plastic pollution in the river surface, using advanced technologies such as Fourier Transform Infrared Spectroscopy (FTIR) coupled with sampling methods both bulk and net sampling via a plankton net. These data along with a situation analysis of macro plastic pollution and waste management specifically the river (local level) and in the country (national level), conducted via literature review and key stakeholder consultation were used to provide management recommendation to prevent plastic pollution in the river and country.

1.1 Rationale of the study

As mentioned in the introduction it is identified that Kelani River is the heviest polluted river in the country and main carrier of plastic waste to the ocean from inland sources. However, despite of the significant impact caused by the pollution around the river, there is no record of a proper estimation of the plastic pollution found related so far. Even though water quality studies were found for Kelani River basin, a proper estimation of microplastic and macroplastic leakage through the river to the ocean is not carried out yet. Even In considering microplastic surveys carried out in the country according to literature (Dharmadasa et al., 2021; Hristova, 2021; Ranatunga et al., 2021), all have been conducted in the marine and coastal environment and at times only in the estuary

Therefore, there is a timely need of identification of macro and micro plastic pollution in the river along with sources and leakage pathways. The government and relevant authorities identifying the significance of these gaps are in the process of setting goals, planning, and initiating projects and programs to address them. As a result, in August 2021, the “National Action Plan on Plastic Waste Management 2021-2030” was published consisting total of 16 goals to overcome the issue of plastic pollution in the country. In the publication Goal 5

specifically is about reducing 80% of marine plastics pollution including both macro and micro plastics ending up in the ocean through land-based activities by 2030. Under the goal activity 5.2 is focus and encourage on studying the problems of micro-plastic to reduce random release of microplastics from industries such as textiles, cosmetics, and homecare.

In aligning with this goal, the study is one of the initiative studies in identifying the microplastic contamination in the Kelani River. While the research questions being what the characteristics of microplastic are found in the river surface water and factors influencing their occurrence in the Kelani River, which is the most polluted river that flows through highest populated cities with number of factories, local business authorities and households residing nearby the river and as mentioned prior through the province which has the highest generation of waste.

Microplastic survey was conducted to identify the characteristics of the microplastic in the surface water of the river carrying out a rapid sampling process. And then along with the help of a situation analysis referring available literature and conducting stakeholder consultation identify the macro plastic pollution, land base sources, waste management situation in the country and specifically the river and ultimately suggest management recommendations according to findings to reduce marine plastics pollution including macro and micro plastics ending up in the ocean through land-based activities.

1.2 Research Objectives

1.1. To identify and characterize microplastic in Kelani River surface water via rapid sampling.
1.2. To conduct a situation analysis of plastic waste management in Sri Lanka especially in Kelani River.
1.3. To provide management suggestions and recommendations to prevent micro and macro plastic pollution.

1.3 Scope

Geographical scope of this study is the Kelani River in the Western Province Sri Lanka. In sampling a rapid sampling process was conducted to characterize the micro plastic in the mid river surface water. Size, Shape, colour and the type of the polymers were identified. Then for the identification of the land base sources, and factors influencing the occurrences of

microplastic in the waters, macro plastic pollution and the waste management status of the river a situation analysis was conducted. In the situation analysis, plastic pollution, and waste management status in the country (national level) and specifically the situation of the Kelani River (local level) was explored engaging in literature reviews and key stakeholder consultations.

Finally, through the findings of the microplastic survey and situation analysis, management recommendations were provided to reduce marine plastics pollution including macro and micro plastics flowing into ocean through land-based activities.

CHAPTER 2

Literature Review

2.1 Plastic litter Classification

When it comes to plastic pollution measurement and documentation in aquatic environment, the nature of a particular plastic such as size, shape, colour, type, density, composition, and age plays an important role. Because these specific identification helps researchers to track this plastic back to its origins which helps to develop methodologies and technologies as well as policies to tackle the issue.

Characterization of plastic waste under these categories are often found in recent research papers related to aquatic plastic pollution (*Clean Cities, Blue Ocean*, 2021). Separation of plastics based on size is one of the most crucial steps to follow. Particle size of plastics is one of the major factors that determines the ecological relevance and environmental fate of the fragments ultimately serving as a logical method for policy makers and regulatory bodies to take design and implement relevant countermeasures (*Clean Cities, Blue Ocean*, 2021). The most common and frequently used plastic categories based on the size includes mega plastics, macro plastics, meso plastics, microplastics, and nano plastics.

Most of the time, Primary plastics are the plastics that produced with distinct size for a specific purpose. For instance, the pelletized resins used by manufacturers, Nurdles having a diameter of 5mm, and 20mg weight, etc. (Hammer et al., 2012). However, after entering the environment, primary plastics start degrading, and smaller pieces of plastics (secondary plastics) are broken down from primary plastics. (Besseling et al., 2017). Amidst controversies over the size ranges, “The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection” (GESAMP) suggested a method to sizing of plastics that expands the range of mega to nano plastics as in Table 1 (Kershaw et al., 2019).

Table 1: Size classification as suggested by GESAMP.

Terminology	Size Classification
Megaplastics	>1 m
Macroplastics	25-1000 mm
Mesoplatics	5-25 mm
Microplastics	<5 mm
Nanoplastics	<1 µm

Source: (Kershaw et al., 2019)

2.2 Microplastic contamination

All ranges of plastics contain additives and anthropogenic contaminants that are absorbed from sea water. Persistent, Bio accumulative, and Toxic substances (PBTs) are heavily included in these pollutants. When microplastics are swallowed by marine organisms, such substances can be mixed with digestive fluid and transferred into the tissues easily and it's most of the time undetectable (Alfaro-Núñez et al., 2021). Basically, 2 types of microplastics are identified based on its origin. Primary microplastics entered the environment as microplastics itself, and secondary microplastics are the results of breakdown from larger plastic components (Moore, 2020). This degradation of plastic is caused by photo degradation, thermo-oxidative degradation, abrasion, and other biological activities (Thompson et al., 2009).

Microplastics in freshwater flows or river can be categorized based on how it appears in the water body. It can appear as floating plastic, suspended plastic, riverbed plastic, plastic in the sediment, and plastics in biota (van Emmerik et al., 2020). These categories are determined by the hydraulics of river, shape, size, and other material properties such as specific gravity (SG) of the plastic. However, in secondary microplastics, the nature of degradation decides the properties of the microplastics (Kowalski et al., 2016). Therefore, conducting research of microplastic pollution in river is quite complex and not much of the updated data is available to analyze the situation of level of pollution.

However, this quantitative information of river and coastal region is useful when it comes to analyzing the level of plastic pollution assessment, risk assessment studies and other policy development studies (Koelmans et al., 2019). There were several studies conducted to assess the microplastic pollution specifically in river aquatics around the world (Schmidt et al., 2017). But considering the number of research done in Sri Lanka are very few, especially in terms of river plastic pollution. other than some of the ongoing projects and programs such as CounterMEASURE and "Surakimu Ganga".

Microplastic surveys conducted in the country waters are limited. And all of them are done either in estuaries of the rivers, coastal areas, marine surface water and beaches (Koongolla et al., 2018). But after the express pearl ship sinking disaster in May, 2021, much attention was paid in to studying the effect of micro plastics mainly because "Plastic Pallets (Nurdles)" spilled from the ship caused adverse damages in the coastal area, causing the death of large number of marine species (Partow et al., 2021).

According to the existing literature of previous studies other than the recent nurdle contamination happened, has identified the existence of MPs in surface water as well as beaches and the sizes are ranging from 1.5 to 2.5 mm and 3 to 4.5 mm respectively. Polyethylene (PE) and polypropylene (PP) were prominent, and some polystyrene (PS) foam was also discovered at few locations as well (Koongolla et al., 2018)

The following information contains some researches conducted in the Sri Lankan coastal areas, waters and estuaries.

A. Microplastic pollution in Marine Protected Areas of Southern Sri Lanka

In this study, two Marine Protected Areas (MPAs) were examined ("Bundala National Park (BNP)" and "Hikkaduwa Marine National Park (HNP)") for the existence of MPs in it's coastal and lagoon sediments as well as in water. Severely threatened species by MP contamination such as Coral ecosystems, birds, and turtles are commonly found these areas. Higher abundance of MPs was observed at both coastal sediments and waters in HNP (111±29 MPs/m^2 of sediments samples and 0.515±0.054 MPs/m^3 for water samples) compared to BNP (102±16 MPs/m^2 for sediments and 0.276±0.077 MPs/m^3 for water) respectively. Fragments were the most common shape while Polyethylene was the most common polymer type. This research was marked as the first of it's kind study to examine the MP contamination in MPAs in the country and can be used as a benchmark for similar studies to be carried on.

Time of the coastal sand sampling was around October 2018. There are 7 and 5 subsites for BNP and HNP respectively and for every sub site, a couple of 100 m transects were fixed along the high tide line as well as dune/vegetation line parallel to the shoreline. An 80 μm mesh plankton net (50 cm in diameter) was lowered from the side of the boat to collect coastal water samples, and GPS coordinates and the start time were noted. For 15 minutes, the boat traveled at a speed of 2-3 knots in a straight line 100–200 meters off the coast. The net was removed from the sea and the last GPS coordinates were noted after 15 minutes.

MP pollution has a significant impact on both MPAs. At BNP, all turtle nesting locations, including the dune areas where turtles typically nest, had significant MP concentrations. The reported MPs levels in Sri Lanka are significantly higher than previously reported levels, which may have a variety of effects on both hatchling and adult sea turtles.

While local MP input appears to dominate in HNP, the majority of MPs in BNP are likely transported by ocean currents. The most prevalent shapes were fragments and filaments, and

the most prevalent polymer kinds were PE, PP, and PS. MPs at both locations had substantial levels of oxidation, which led researchers to the conclusion that the majority of big (1.1–5.0 mm) MPs spend a significant amount of time in coastal regions. From the B1 to the B7 site, BNP revealed a decline in the abundance of MPs. The currents from the Southwest Monsoon may be to blame for this decline. MPAs are created to save the local flora and fauna. To protect this environment, specific laws and regulations have been placed in place. The results indicate that despite the protection afforded to these places or their distant location, MPs pollution is severe in both MPAs.(Dharmadasa et al., 2021).

B. Evidence of microplastics pollution in coastal beaches and waters in southern Sri Lanka

It is reported that MP is abundant in surface water and beach sediment in southern Sri Lanka along 91 kilometers of coastline. 60% of the samples exhibited MP contamination in the sand, and 70% in the coastal surface waters. Surface waters and beaches have a size range of 1.5 to 2.5 mm and 3 to 4.5 mm, respectively. With some polyestyrine (PS) at a few sites, the majority were found to be polyethylene (PE) and polypropylene (PP). At most sites, fragments from larger debris appear to be the predominant type of MP, and only 2 sites had virgin pallets, which made up 14% of samples. (Koongolla et al., 2018).

C. Microplastics in beach sand and potential contamination of planktivorous fish Sardinella gibbosa inhabiting in coastal waters of Negombo, Sri Lanka

In the current study, the amount of microplastic contamination in the beach sand in Pitipana, Catamaran, and Duwana beaches along Negombo, Sri Lanka's coast, was examined. In 2017, sampling was done every two months from March to November. Beach sand samples were taken from the top (0–1 cm) and bottom (10–11 cm) layers as well as from three areas that corresponded to each beach's low-tide, high-tide, and vegetation line. categorized according to the type of polymer. Additionally, samples of Sardinella gibbosa, a commercial fish, were taken from Pitipana's coastal waters and analyzed for potential microplastic contamination.

In comparison to other locations, the beach sand at Pitipana was extremely contaminated with microplastics of the 1–5 mm size, with a mean abundance (SD) value of 7.2–7.66 particles/m3. While foam predominated at Pitipana beach, fragment was the main kind at Catamaran and Dwana beaches. Pellets, however, were not found at any of the examined sites. PVC was the

main polymer type identified in the beach sand at Pitipana, while polyester predominated at Dwana and Catamaran beaches. According to the FTIR spectra, Sardinella gibbosa's stomach contents contained polyethylene and polypropylene, which suggests that planktivorous fish may have been contaminated with microplastics and that they may accumulate farther up the food chain. (Ranatunga et al., 2021).

D. Evidence of Microplastic Contamination in Surface Waters and Sediment of Kelani River Estuary

Analyze whether microplastics are present in the Kelani River estuary from the river's source to its mouth. There were 9 sampling points used. - from coastal waterways, mid-river, and riverbanks. February 2018 until November 2018. (wet and dry periods). Use of a 200 micron plankton net.

Surface water samples had a higher concentration of microplastics (7.0.28 to 2.51.323 items/m3) than sediment samples (4.0.5 to 10.4 item/kg). Plastic fibers (36%) recorded noticeably high percentages, and translucent color (29%) dominated the samples. The polymer types identified by ATR-FTIR spectroscopy included polyethylene, polyethylene terephthalate, polypropylene, polystyrene, and polyamide. The majority of microplastics had secondary origins in the decomposition of big plastic objects. (Thakshila & Ranatunga, 2019).

2.3 Kelani River

Kelani river which is the major river that flows across the above municipal council areas in Western province, is found to be a key carrier of plastic waste from land to the ocean. The Kelani River, the 4th longest (145km) and the 2nd largest river out of 103 rivers radially draining into the sea in Sri Lanka, remain as a vital resource for about 25% of Sri Lankan population which reside in its catchment region. It provides drinking water for about 4 million people living in the greater Colombo area alone (Ranatunga et al., 2021). However, according to recent research conducted by Center of environmental Authority (CEA), the water quality in the Kelani River is estimated to be very poor making the river to be the most polluted river in the country. It was identified that 40km stretch between Avissawella town and river outfall in Nothern Colombo causing the most pollution to the river basin. The causes for the poor-quality

water were found to be as the factories, local business authorities and households residing nearby the river (Rebert & Sathananthan, 2017).

2.3.1 Sources & Land use patterns

Identification of origins and land use patterns is crucial and required for dealing with river waste concerns. Public littering during recreational activities on riverbanks or directly into the river, cities, and harbors are therefore potential sources. Poor waste management practices, such as poorly managed landfill sites, fly tipping, industrial and agricultural activities that result in improper disposal or loss, and sewage-related debris from the discharge of untreated sewage, either due to a lack of waste treatment, are also potential sources.

Storm events can sweep any debris gathered in storm drains into rivers, either via combined sewer overflows during storms and storm water discharges or from facilities. (van der Wal et al., 2015).

When identifying the precise source of river garbage, it is extremely challenging. For instance, consumer goods packaging is frequently observed (on banks), but it can come from a variety of sources. Additionally, according to research, the industrial sector is a major contributor of the microplastics and trash found in waterways. (van der Wal et al., 2015). Microplastics in rivers can originate from two different sources: direct input, primary microplastics, which are fragments of degraded or broken down larger plastic pieces, or primary microplastics, which are pellets used as raw materials in the plastics industry or added to products as abrasives (such as cosmetics, air-blasting media). (Arthur et al., 2009; Bergmann et al., 2015). Other examples for secondary micro plastic are car tyres particles and textile fibres. Litter items caught on riverbank vegetation can thus be a source of micro plastic by physical breakdown of larger items.(GES, 2016)

The Kelani River originates in the central highlands in Nallathanniya, which is 2200 meters above mean sea level. It then travels through Kithulgala, Avissawella, flood plains, and ends in Colombo at Mattakkuliya, where it empties into the Indian Ocean. Likewise, the river is particularly susceptible to water pollution because it passes through areas that are industrial, urban, and agricultural. (Mahagamage et al., 2015).

More than 20% of Sri Lanka's population lives in the Kelani River basin, with 60% of them living in rural areas, 32% in cities, and 8% living in estate communities. The river also supplies around 80% of the water needed for greater Colombo. (Mahagamage & Manage, 2018). Compared to other river basins, the urban population in the Kelani River basin is the highest (DHI 1999). In addition, the Kelani River basin fosters socioeconomic activities like agriculture, hydropower production, sand and gem mining, urban and industrial development, tourism and power production, leisure, fishing, and transportation. As a result, the Kelani River is well known for its increasing pollution as a result of industrial discharges, subpar local authority service delivery, inadequate environment management, and governance (Illeperuma, 2000; Manage et al., 2020) as well as a lack of awareness and education (Mallawatantri et al., 2016).

Raw rubber factories, rubber latex factories, textile factories, food and beverage factories, steel manufacturing factories, fertilizer manufacturing factories, and other major wastewater-generating industries are all located in the meandering zone of the river (lower part of the Kelani river basin), close to the Biyagama export promotion zone and Seethawaka industrial zone (Manage et al., 2020).

Despite some studies carried out over the past three decades (Mahagamage & Manage, 2014; Manage et al., 2020) it is noted that there is little recent information available on the catchment's characteristics, land-use practices, and anthropological activities on the quality of water in the Kelani River basin and its meandering zone.

Land Use

The Colombo and Gampaha districts make up two-thirds of the Kelani River basin's meandering zone. As a result, each district's agricultural and land-use activities have a direct impact on the basin's surface and groundwater quality. The land-use patterns for agricultural operations in the Kelani River's meandering zone are shown in Figure 2.

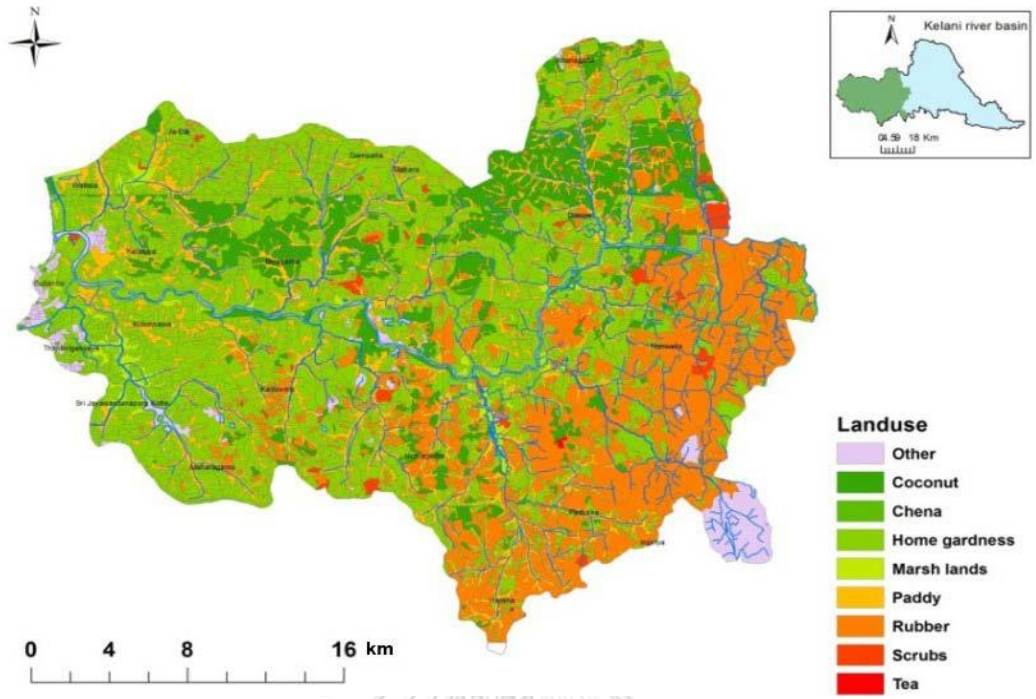


Figure 2: Land use practices in the meandering zone of the Kelani River basin; source: own elaboration based on data of Sri Lanka Survey Department [undated]
Source: (Manage et al., 2020)

2.3.2 Waste Management in Kelani River

Given that the larger area covered by the Kelani River basin and it's sub rivers and canals, Kelani river flows across several provinces and districts making a useful water resources for almost 20% of Sri Lankan population as mentioned previously. The river passes through most densely populated and highly industrialized areas in the country. According to Mallawathantri et al, (2016), the river passes through 3 provinces (Central, Sabaragamuwa and Western) and 7 districts. Majority of the river belongs to Kegalle district (44%) central province (47%).

Each district has been divided into a number of local authorities and divisional secretariats, according to the Sri Lankan government. Within the Kelani River basin, there are 3 municipalities and 37 local authorities. The local authorities of the specific Divisional Secretariat are responsible for waste collection and disposal. These local authorities may be a municipal council (as defined by the Municipal Councils Ordinance of 1947), an urban council (as defined by the Urban Councils Ordinance of 1939), or a local council (Pradeshiya Sabha Act – 1987). The Public Nuisance Ordinance and the National Environmental Act No. 47 of 1981 both make provisions for garbage management and disposal.

The Ministry of Local Government and Provincial Councils, the Ministry of Mahaweli Development and Environment, the Ministry of Megapolis and Western Province Development, the Central Environmental Authority, the Urban Development Authority, the National Solid Waste Management Support Center, and the Western Province Waste Management Authority are a few other institutions that are also involved at various stages.

2.3.3 CounterMEASURE Project

The project CounterMEASURE was launched in June 2020 to identify the sources and flow paths of plastic waste through rivers based on Mekong and Ganges rivers and it's second phase CounterMEASURE II project was initiated in August 2021 in two selected rivers of Sri Lanka as Kelani River and Maha oya. Sri Lankan government has come on board with the project along with the country's own program "Surakimu Ganaga" which was initiated to make all the countries rivers clean. UNEP as the managing body has partnered with other international partners, and Sri Lankan government, Central Environmental Authority (CEA), and IUCN are joining hands together to provide technical and other expertise knowledge (UNEP, 2020). Initially it was planned to collaborate with the project but sine the research work is still not finished, and the data and information are yet to be published. Could not incorporate them with the study. But in the future, collaborations might happen accordingly to share information of the findings.

2.4 Authorities, Policies, Laws, and Regulation Related to Plastic Waste Management in Sri Lanka

2.4.1 National Action Plan on Plastic Waste Management 2021-2030

Identifying the plastic waste production being gradually increasing in Sri Lanka, a need for a proper action plan has risen ever than before. In consideration of the current policy gaps in plastic waste management and level of waste generation, Sri Lanka has developed its "National Action Plan on Plastic Waste Management 2021 - 2030 (NAPPWM)" in collaboration with Ministry of Environment with technical and assistance from CCET, UNEP and financial assistance from Ministry of Environment Japan (MOEJ). Along with its primary objective of enabling a "Healthy life and cleaner environment for all", there are several key factors that have given attention for. Plastic pollution of aquatic bodies is among these key concerns that the

country expects to address (*National Action Plan on Plastic Waste Management Sri Lanka 2021-2030*, 2021).

Accordingly plastic waste in inland water bodies and marine environment are key issues to be concerned. There are few regulations such as “Marine pollution prevention act, 2008” and relevant private and public bodies such as MEPA and GIZ, etc. putting effort to reduce aquatic plastic pollution through policy and voluntary actions. But, these actions were not sufficient with current pollution level. Therefore, within the 16 key goals of NAPPWM of Sri Lanka, several key actions were described to direct and indirect actions against aquatic plastic pollution.

Under NAPPWM, Goals for the microplastics management is given under it main goals number 5 and 10. Specifically under goal 5, which is reduction of marine plastics pollution comprising macro and micro plastics flowing into ocean through land-based activities by 80% by 2030. Out of the 4 key activities under goal 5, 2 key activities specifically state the intention to take action against microplastics. Activity 5.2 – studying the issues of micro-plastic in order to reduce unintentional release of microplastics from industries such as textiles, cosmetics and homecare. and 5.3 – start and continuing studies of microplastics related health risks. The key activity 5.2 is listed as a short to medium term goal whereas 5.3 is categorized as medium to long term goal (*National Action Plan on Plastic Waste Management Sri Lanka 2021-2030*, 2021).

Under specific goal number 10, even though the direct attention is not given to micro plastics, one specific key activity (Activity 10.3) is addressing the issue which is indirectly related to microplastic issue. In goal 10.3, the concern is given to introducing product safety certification for recycled PET products while giving its due consideration to products with potential of generation of microplastics.

2.4.2 Ministry of Mahaweli development and environment

The subject of the ministry is under the jurisdiction of the Mahaweli Development and Environment Minister. The ministry's primary entity for trash management is the Central Environmental Authority (CEA).

2.4.3 Ministry of provincial councils and local government

The subject of the ministry is within the jurisdiction of the province Minister. Services for the community's convenience, comfort, and wellbeing must be provided by local authorities in each region. The local government executes;

- Regulatory and administrative functions
- Promote public health and sanitation
- Environmental sanitation
- Public thoroughfares and public utility services

Following the introduction of the 13th amendment to the charter in 1987, local governments were devolved to the provincial councils. In the future, provincial councils took over from primary authorities in terms of controlling and supervising local authority. The essential authorities-maintained control over the establishment, organization, and national coverage of the local government. Desk 2.15 displays a wide range of local governments' equipment and their actions. Additionally, the local government's provincial minister is in charge of overseeing the state of the neighboring authorities. The Municipal Commissioner or Secretary of the neighboring governments carry out the customary through-law regulations on SWM in the area that has been designated as under the authority.

Table 2: Local Government System

Local Governments	Laws and Established Year	Number of Authorities
Municipal Councils	Municipal Councils Ordinance (1947)	23
Urban Councils	Urban Councils Ordinance (1939)	41
Pradeshiya Sabhas	Pradeshiya Sabhas Act (1987)	

2.4.4 Status of SWM in Sri Lanka

Under the relevant penal statutes, local governments (LAs) in Sri Lanka are solely responsible for SWM. The Municipal Council ordinance, City Council, and Pradeshiya Sabha Act were given the authority under SMW. The majority of the local authorities place a higher importance on the development of physical resources that belong under their purview than SMW issues, which are given comparably less attention. However, Sri Lanka is home to 126 compost

websites. Additionally, 210 creditors and recyclers of plastic and polythene, as well as 12 authorized collectors of digital waste, were registered in Sri Lanka (Ministry of Mahaweli improvement and environment [MMDE], 2015).

2.4.5 Policies, Laws, and Regulation Related to Plastic Waste Management in Sri Lanka

The National Environmental Act (2008) License is required for waste management sector such as (Parliament Secretariat, 2015);

- MSW and other solid waste composting plants (excluding household composting).
- Solid waste recovery/recycling or processing plant having capacity 10 tonnes or more per day.
- Solid waste disposal facility having capacity 10 tonnes or more per day.
- All toxic and hazardous waste treatment facility or disposal facilities or recycling/recovering or storage facilities.
- Sources which generate health care waste

Regulation on MSW

- No person shall dump SW along sides of any national highway
- No person shall dump SW at any place other than places designated for such purpose by the relevant local authority or any person or body of persons authorized by them in that behalf.

Regulation on plastic and polythene

The following prohibitions and bans were proposed by the Environmental Ministry in the year of 2017.

- Prohibit the manufacture of polythene or any polythene product of 20 microns or below in thickness for in country use.
- Prohibit the sale, offer for sale, offer free of charge, exhibition or use of polythene or any polythene product of 20 microns or below in thickness within the country

- A written approval from CEA should be required for use of polythene or any polythene product of 20 microns or below in thickness for laminating and medical or pharmaceutical.
- Prohibit the manufacture of food containers, plates, cups and spoons from expanded polystyrene (PS) for in country use.
- Prohibit the sale, offer for sale, offer free of charge, exhibition or use of food containers, plates, cups and spoons from expanded PS for the country use.
- Prohibit the use of all forms of polyethylene (PE), polypropylene (PP), and products as decoration in political, social, religious, national, cultural or any other event or occasion.
- Prohibition of open burning of refuse and other combustible matters inclusive of plastic
- No person shall burn openly or cause to, allow or permit the open burning of refuse or other combustible matters inclusive of plastics.
- Prohibit the manufacture of any bag (carrying products or goods and including grocery bags) of HDPE as a raw material for in country use
- Prohibit sale, offer, for sale, offer free of charge, exhibition or use of any bag manufactured from HDPE as a raw material within the country. Exempted items: garbage bags and textile bags
- Prohibit the manufacture of food wrappers (lunch sheets) from polythene (HDPE, LDPE, PP) as a raw material for in country use.
- Prohibit sale, offer, for sale, offer free of charge, exhibition or use of food wrappers manufactured from polythene as a raw material within the country.

In 2021 following bans were made effective

a. Polyethylene Terephthalate (PET) or Polyvinyl Chloride (PVC) material for packing agrochemicals used for any process, trade or industry
b. any plastic item specified herein for any process, trade or industry: -
    a. Sachets having less than or equal to a net volume of 20ml/ net weight of 20g (except for packing food and medicines).
    b. Inflatable toys (except balloons, balls, water floating/pool toys and water sports gear).
    c. Cotton buds with plastic stems (except plastic cotton buds used for medical/clinical treatment).

A product made of polyethylene terephthalate, high density polyethylene, low density polyethylene, polyvinyl chloride, polypropylene, polystyrene, biodegradable plastic, or any other comparable raw material, or any combination thereof, is referred to here as a "plastic item."

2.4.6 Material Flow Analysis (MFA)

A systematic evaluation of the flows and stocks of materials within a system that is defined in space and time is called a material flow analysis. It links the materials' origins, routes, and final and intermediate sinks. All of a process's inputs, stocks, and outputs have an impact on the MFA's results. MFA's attributes make it appealing as a tool for supporting decisions in the management of resources, waste, and the environment. The fluxes and environmental loading become apparent through the balancing of inputs and outputs, and their sources can be found. In order to take corrective action or to encourage greater accumulation and future utilization, it is possible to identify the depletion or accumulation of material stocks.

2.5 Nurdles

Due to uncontrolled leaks into waterways or the ocean during the plastic production process and shipping, nudles, also known as pre-production plastic pellets, are a significant cause of plastic pollution in marine habitats (Jiang et al., 2021; Kershaw, 2015). These pellets, often referred to as nurdles, are the source of almost all plastic goods. They serve as the foundation for making plastics. Petrochemical chemical industries make these pellets, which are about the size of lentils.

Nurdles can be made of variety of polymer types including polyethylene, polypropylene, polystyrene, polyvinyl chloride, and mixing variety of additives to create pellets of different densities (Tunnell et al., 2020). It is estimated that every year, about 270 million metric tons of plastic is produced around the world, much of which begins its life as a plastic pellet (*Plastic Pellet Pollution*, 2022).

Nurdles are buoyant, lightweight, and difficult to manage when spilled; they have historically been observed washing up on beaches all over the world. (Eriksen et al., 2013; Fernandino et al., 2015; Tunnell et al., 2020). When spilt and not cleaned up most of these small light weight nurdles float in water and are easily blown, washed, or brushed into drains and ultimately ends

up in the sea. In the sea the spread is wide and quick, resulting their existence in ocean waters and beaches around the world from the middle of the pacific to the arctic circle. Furthermore, there is an increase in the number of big spills of nurdles at sea, because of ships transporting nurdles loosing tanks full of nurdles due to accidents, technical difficulties and bad weather (*The Great Nurdle Hunt, Tackling Worldwide Nurdle Pollution.*, 2022).

Similarly, Nurdles can be lost to the environment wherever they are handled along the plastics supply chain, including during production, transit, loading, storage, and fabrication facilities. Nurdles can be spread farther by wind, surface water currents, and tides after being released into the environment, or they can be deposited in coastal areas. (Karkanorachaki et al., 2018).

By definition nurdles are microplastics as they are less than 5mm in size and specifically primary microplastics as they enter the environment directly in microplastic form. (*The Great Nurdle Hunt, Tackling Worldwide Nurdle Pollution.*, 2022). Further they are estimated to be the second largest direct source of microplastic pollution in the ocean by weight. An estimate of 10 trillion plastic pellets are swept into waterways annually, adding on to and increasing the harmfulness of plastic pollution in the environment (*Plastic Pellet Pollution*, 2022).

2.6 M/V Xpress Pearl

In early June 2021, a ship named M/V Xpress Pearl, owned under Singapore company caught on fire and sank in Sri Lankan waters. This ship was carrying 1486 containers out of which 81 regarded as toxic harmful dangerous containers. There were 5 containers carrying nitric acid and 3 containers carrying plastic pellets each carrying a weight of 27000kg. once the ship caught on fire, continuously for 12 days about 300MT of oil was released to the ocean and when it sank, all the plastic and toxic materials in ship were released into the sea (Partow et al., 2021). This was considered as the worst maritime disaster to have happen in Sri Lanka.

Figure 3: Xpress Pearl ship caught on fire
Source:(*X-Press Pearl owners still trying to save cargo*, 2021)

Within a short time of 5 days since the disaster, white opaque nurdles sizing about 5mm, dark plastic pieces in irregular shapes, as well as both small (0.5mm) and larger (6cm) plastic pieces which are larger than nurdles have washed up in the western coast in Sri Lanka. (de Vos. Et al, 2021). A croud-sourced data collection was done just after the incident by Ocean Swell to track down the nurdles reaching distance. Data was filtered and verified through photographs, and it revealed that as long as 50km stretch of the western coastline is damaged by the spill. Figure 2 below illustrates the path of the ship, a map of washed up nurdles found after the crown-sourced survey, the sunken ship after the fire, status of the Pamunugama beach after 5 days ship catching fire, and lastly a picture of handful of burnt and unburnt plastics found on beaches.

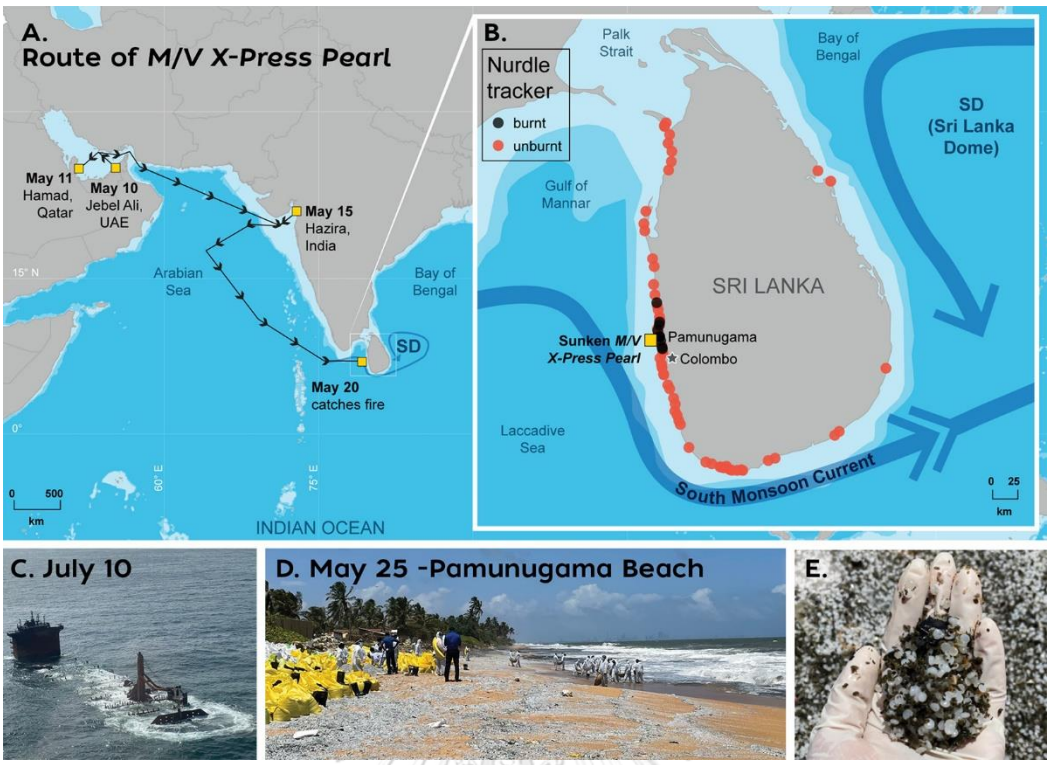


Figure 4: A)travel route, B) nurdle spill map by crowd source survey, C) sunken ship, D) plastic washed on the coast and, E) handful of burnt and unburnt plastic found on the shore.

Source:(de Vos et al., 2022)

Estimated about 3 billion tiny pallets have spilled in the water started clogging the beaches and nearby harbor. Environmental concerns were raised immediately by MEPA and over 5600 one day boats were banned from going for fishing. Immediate beach cleanups were commenced, and 34 containers had been filled with ship debris. After several days, endangered marine species such as turtles, dolphins, whales and several other fish species were washed up dead with burn marking on skin as well as plastic pallets in the body. over 200 marine deaths were discovered including 20 dolphins, 4 whales, and 176 sea turtles. It is reported that this incident has caused a significant irreversible damage to the marine environment and marine species in Sri Lankan waters (Sirilal & Illmer, 2021).

Upon the visual inspection of the washed debris, (de Vos et al., 2022) have categorized pallets into 3 groups. (i) Unburnt – which is pure white pallets which was not affected from the fire, (ii) degraded – deformed, decoloured pallets exposed to the fire but not completely burnt, and (iii) burnt – blackish, completely deformed pallets burnt by the fire. Similarly, based on physical properties as well as chemical properties these washed-up pallets were analyzed, and results were discussed. Another research finding reveals that high amount of microplastic pallets

(10.24 pallets/m^2) than earlier average in the same places (1.6 pallets/m^2) even after cleanups were done in “Sarakkuwa” beach in western coastal area (Sewwandi et al., 2022). In addition, low-density polyethylene, epoxy resins, olefin copolymers, aromatic polyamides, natural rubber, and polyethylene terephthalate were generally confirmed as the debris that had been discovered. Nurdles received in June and September showed evidence of sulfur pollution and physical erosion.

Figure 5: Burnt nurdle continuum of Xpress Pearl
Source: (de Vos et al., 2022)

After a year has passed since the tragedy, Sri Lanka is still cleaning the plastic pellets off its beaches and seeking compensation for the damage to the ecosystem. A expert commission looking into the extent of the damage to the marine and coastal environment has now determined that the tragedy is the worst in terms of ocean chemical and plastic contamination. Since then, beach cleanups have been carried out by youth organizations like "pearl protectors," who claim to have finished over 28 significant cleanup operations to date. However, more and more nurdles are coming ashore, and as the nation prepares for monsoon season, nurdles that had previously sunk to the seafloor or been entangled in underwater structures like corals are coming ashore.

These youth organizations are currently operating in a pretty challenging climate as the cost of organizing has even doubled since 2021 due to the nation's current economic crisis. According to maritime law experts, Sri Lankan authorities have been slow to petition for compensation and are averse to engaging in protracted legal battles over years in foreign courts. Sri Lanka has received an interim payment of $3.7 million in damages, but, in the view of experts, the country may be entitled to $5 billion to $7 billion in damages. Those larger numbers would provide a much-needed infusion of foreign currency as Sri Lanka is currently stuck in the greatest economic crisis in its history. Further delays, however, would reduce the island's chances of receiving adequate compensation for the environmental harm.

2.7 Plastic waste sampling

The sampling strategy of the plastic needs to relate to the problems that the analysis intends to resolve. Whether it is to identify accumulation hot spot, take countermeasures for a specific type of litter (prohibition of straws on tourist beaches), dispersion of floating ALDFG or distribution of river inputs.

Additionally, the sampling strategy is determined by the sampled area (sea surface or inland water column) and the size range of the observed litter Other considerations may play a role in location selection for sampling. Depending on the policy question being addressed, it may be possible to combine information about litter sources, such as the locations of potential sources such as fishing grounds, shipping routes, tourist beaches, wastewater outfalls, and river inflows, with sampling data collected from a fixed platform or vessel, such as a ferry, as well as bathymetry, sea surface temperature, salinity, and surface currents. The gathering of information to be as representative as possible is a major problem that frequently arises in sampling. Numerous factors, including seasonal variations in river outputs, ocean currents, changes in litter shape, size, buoyancy, movement to and from other compartments, as well as mechanisms of degradation and fragmentation, contribute to the highly variable distribution and abundance of plastic in water surface and columns (Kershaw et al., 2019).

So, to minimize and overcome these challenges key is the sampling design and repeated measurements, for instance short, repeated surface trawl surveys, helps in identifying the variability withing the water body. To understand the variance and error around the data, a minimum of three replicates is recommended (Kershaw et al., 2019).

2.8 Micro Plastic Sampling methods

I. Bulk water and Pump sampling

Utilizing a container (bucket, tray, or bottle) or a submersible water pump with a capacity ranging from a few litters to over 100 L, bulk water sampling is used to collect microplastics from the water's surface or subsurface. The water is subsequently filtered using a small mesh net, sieve, or filter paper with pores between 0.45 and 20 microns (20–80 m, for example). Nylon mesh filters cannot be visually checked for particles larger than 1 mm and then immediately evaluated with micro-FTIR spectroscopy without affecting the detection of plastic samples, hence glass fiber or stainless-steel filters are used. Bulk water sampling is more

effective in detecting very small microplastics and microfibers than net tows, which typically use a 330 m screen. Another technique for measuring surface waters is bucket sampling.

II. Continuous Plankton Recorder

Long-distance subsurface plastics sampling is successful with the Continuous Plankton Recorder (CPR). During their typical cruises, trade ships or ships of opportunity tow the CPR at a depth of around 10 meters. A slow-moving silk band filters water flowing through the CPR, catching plankton and microplastics, which are subsequently spooled into a storage tank with a preservative such formalin. However, In collecting plastic waste samples from water bodies, two common methods were found as using a tow net in surface or subsurface of water and collecting specific volume of water from a known location (Abeynayaka et al., 2020; Scircle et al., 2020). This tow net method is also known as on-site filtration method and the specific volume method is also called grab sampling.

III. On site filtration method

On-site filtration from tow nets is mostly used for inspection of large areas to take samples of floating or suspended plastic debris. The common practice is to use large nets called ‘manta nets/plankton nets/bongo nets’ with mesh sizes ranging from 100 – 300 µm (De-la-Torre et al., 2020).

However, requirement of supporting structures, limitation of accessible water bodies and filtration capacity are major drawbacks of on-site sampling methods. Further, nets must be placed in parallel in river or must be dragged with a boat in a still waterbody to create a flow through. Therefore, these issues make it difficult to prepare a proper, accurate database using this sampling methods, especially including all the particle sizes. Furthermore, due to limitations of access at different water bodies, using several sampling methods might have to be used that would lead to questioning the accuracy of results later (Abeynayaka et al., 2020)

In order to overcome these drawbacks, other sampling methods such as pump sampling and grab sampling are used in several research (Barrows et al., 2018; Han et al., 2020; Mao et al., 2020). Pump sampling involves pumping water manually through a filter and grab sampling involves collecting fixed amount of water for laboratory analysis. Via this method, all the plastics particles can be measured since the water is filtered separately. Therefore, without covering much of the area significant measurement can be taken with a high accuracy. However, due to the complexity of pumping systems, requirement of the number of equipment, low flowrates and handling difficulties, this method’s range of applications are limited.

(Li et al., 2020) have used a combined method of in-situ and pump sampling method which is a suction pump coupled with a net for sampling. The filtration systems are consisting of a metal cylinder where about 1cm size mesh is placed at the top and about 300µm size mesh is placed at the middle. At the bottom, a centrifugal pump is connected with at least about 0.2L/s flow rate. This sampling method can be used in river, marine as well as coastal environment. Even though both pumping and trawling methods are applicable in marine environments, in river and coastal regions, due to diversity of environments, application of both methods are not always possible and are limited by many factors. On the other hand, in marine and coastal regions, it is required to obtain significant number of samples and must cover considerable area to obtain accurate results and to possibly catch all ranges of plastic debris. Likewise, considering both factors, a combined version sampling method seems to be more effective and efficient.

2.9 Microplastic Identification

2.9.1 Fourier Transform Infrared (FT-IR) spectrophotometry

Unlike any other plastic waste, in a microplastic survey and analysis, due to the micro scale sizing of the samples, the analysis/ identification is difficult to carry out in naked eye. This could lead to errors and misleads that would eventually end up causing issues in ultimate policy making processes. Therefore, in order to clearly identify the sources of microplastics, Fourier Transform Infrared Spectrophotometer (FT-IR) is one of the commonly used technologies in conducting research. These FTIRs use infrared waves as a source of power to detect the molecules of the sampling. By matching the wave frequencies emitted by machine and the sample substances, a frequency spectrum is created at the receiving end. This spectrum is used to identify the substances contain in the sample as shown in Figure 4 (Arnaud, 2006).

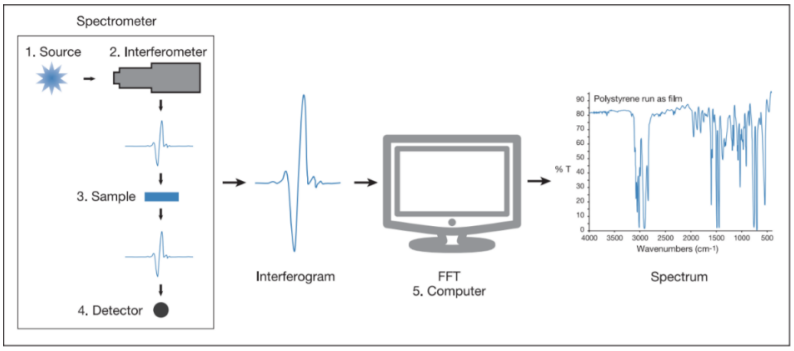


Figure 6: FTIR operation theory
Source: (Arnaud, 2006)

2.10 plastic waste management in rivers

2.10.1 River cleans up from clean current collision

- The Clean Currents Coalition has set up initiatives all around the world to clear plastic debris from significant river systems.
- Community leaders and lawmakers are tackling the plastic-waste problem with the aid of cutting-edge thinking and science.
- The success of environmental projects over the long run depends on community involvement.

Using scientific methods to address the issue of plastic garbage in waterways all over the world, the Clean Currents Coalition, a global network of local projects, aims to clean up the world's rivers.

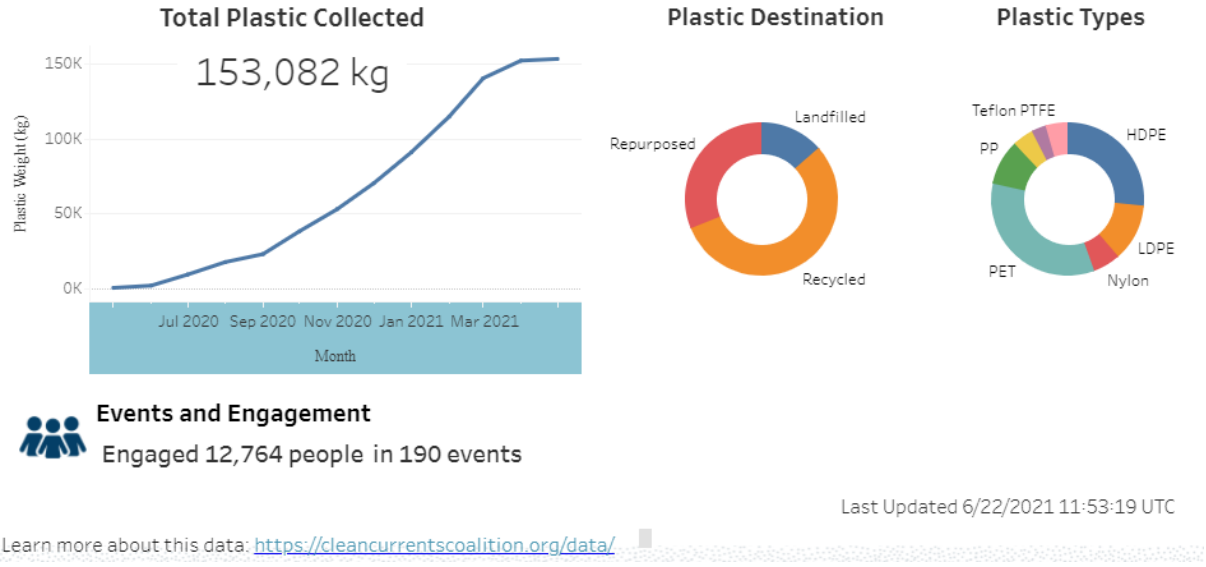


Figure 7: plastic collection from "cl Collision" projects
Source: (Wood, 2021)

By educating consumers, businesses, and community leaders about the pollution caused by plastics, projects hope to influence behavior. Community activities, meanwhile, involve the neighborhood in solving the issue.

8 examples are,

1. **A conveyor belt on the Athi River – Kenya**

Ten plastic catchment structures will be built along the Athi River and its tributaries, the Nairobi and Ngong Rivers, thanks to a collaboration between the social entrepreneur Chemolex Company and the nonprofit organization Smart Villages. More than 1,000 tons of material have been taken from Kenya's waterways by fences over the rivers, and this material is being removed from the river by a conveyor belt. Building supplies like plastic fence posts, paving slabs, flooring, and roofing are created using recycled garbage.

2. **The Citarum River concentrator – Indonesia**

Figure 8: The Citarum River concentrator – Indonesia
Source: (Coalition, 2022)

The severely polluted Citarum River in West Java, which can discharge 20 to 100 tons of rubbish daily, is projected to benefit from a plastic collection system. The plastic garbage is guided by active concentration modules positioned along the river to a collection station, where a collection wheel takes it out of the canal. The project will be run by the Indonesian NGO Greeneration Foundation in association with the local partner Waste4Change and the Finnish start-up RiverRecycle. The garbage will be recycled, composted, or used to make biofuels; non-recyclable plastics will be turned into low-sulfur fuel oil as a means of project funding.

3. The Kingston Harbour interceptors – Jamaica

Figure 9: The Kingston Harbour interceptors – Jamaica
Source: (coalision, 2022b)

In order to stop floating debris from entering the Caribbean Sea, the Netherlands-based nonprofit organization "The Ocean Cleanup" introduced Interceptor technology to be installed in the canals that flow into the Port of Kingston. The Ocean Cleanup's River solutions called interceptors are made to stop plastic from entering the oceans. Waste will be stopped, removed from the gullies, and delivered ashore for recycling or suitable disposal using a barrier and conveyor system. Along with these cleanup activities, The Ocean Cleanup is working with neighborhood NGOs to involve the Kingston community in these initiatives and educate Jamaican youth about plastic pollution.

4. Plastic waste traps on the Lat Phrao Canal – Thailand

Figure 10: Plastic waste traps on the Lat Phrao Canal – Thailand

Source: (Coalision, 2022c)

Lat Phrao Canal, one of the world's longest and most polluted rivers, extends 1.5 kilometers from the river through one of Bangkok's most densely populated neighborhoods. Two plastic cleaning systems with two extended arms and associated nets that catch waste floating just below the water's surface were put on the canal in July 2020 by the TerraCycle Global Foundation, a nonprofit. The arms have a metal-collecting catch attached on them. So far, more than eight tons of plastic debris have been taken out of the canal. A mechanism is being developed to inform Lat Phrau Canal locals about the plastic problem and the steps they may take to reduce it.

Different to kenya case. Initiated and funded by US based recycling NGO. The technology is much simpler than “the ocean cleanup” system. However, collected debris is removed manually. This might need certain human involvement as well. There is no information of what is been done to the collected waste. But, a community education program is also going along with this.

5. Constructing an AI-integrated trash wheel on the Juan Diaz River – Panama

Figure 11: AI-integrated trash wheel on the Juan Diaz River – Panama
Source: (Coalision, 2022a)

this trash wheel concept is somewhat new concept for the waste collection. A typical floating barrier will be installed to collect the floating plastic and will be collected through a conveyor

belt. However, the system can be powered either by solar, or water wheel (wheel rotated by river flow will generate necessary power).

6. **The Portoviejo River's floating curtain – Ecuador**

Figure 12: The Portoviejo River's floating curtain – Ecuador
Source: (Coalision, 2022a)

7. **Bamboo and booms on the Song Hong River – Vietnam**

Figure 13: Bamboo and booms on the Song Hong River – Vietnam
Source: (Coalision, 2022d)

These distinctive cleaning tools were made with locally sourced materials, are reasonably priced, and were created locally. The traps have two mesh-covered floating booms that direct floating trash to a trap that is attached to the riverbank by a bamboo platform, making emptying and maintenance simple.

A locally sourced materials used bamboo system. Low-cost device to be deployed. Smaller amount of area will be covered. No operational cost during the collection. But, may need regular clean-ups. Easy to be educated to the people in the riverbasin and can be locally made at lower cost. No recycling method is mentioned for the waste collected. Can be implemented in pilot scale in Kelani River for the testing purposes. Smaller communities can be successfully engaged.

8. **Tijuana River's "Brute Boom" – Mexico**

Figure 14: Tijuana River's "Brute Boom" – Mexico
Source: (Wood, 2021)

2.10.2 World Bank – Indonesia

This is a summary of a world bank project of the estimation of riverine and coastline plastic waste of Indonesia and its policy recommendations. Herewith, highlighted the policy recommendations from the document (*Plastic Waste Discharges from Rivers and Coastlines in Indonesia*, 2021)

- Strengthen solid waste management practices, knowledge and incentives in rural areas, in addition to ongoing improvements in urban areas.

    - Improve overall waste collection coverage (“closing the tap”) and provide better access to solid waste management facilities, particularly in rural areas.
    - Increase national sanitation campaigns at the household level, particularly in rural areas, to enhance community understanding of healthy waste behaviors and reduce the household practice of disposing waste directly into waterways.
- Invest in new, well-managed final disposal sites and upgrade existing sites, including those near waterways.
- Optimize the use of existing structures in waterways and drainage to prevent plastic waste from reaching the sea.
- Promote a circular economy to reduce plastics consumption and prevent plastic pollution.
    - Prevention should start at source and even at an earlier life-cycle stage, considering reduction of critical single-use plastic items and design for reuse, recovery and recycling of plastic waste, which can have many other social, economic and environmental benefits.
    - Cost-effective, impactful policy instruments such as taxes and incentives should be implemented.
- Systematically monitor and improve waste data.

2.10.3 Creating a circular economy for river plastic

The River Recycle company in Finland wants to put 500 cleanup and recycling stations along the rivers that carry the majority of the plastic trash to the oceans. In addition to a cleaner environment, the communities where the company's technology is used also gain from new jobs created to support the recycling process. The company claims that with 500 working systems in place, more than 3 million tons of waste will be removed from the environment annually, generating more than $300 million for host towns and employing more than 400,000 people (RiverRecycle, 2022).

2.11 The New UNEA Resolution

'End Plastic Pollution: Towards a legally binding instrument' is the latest UNEA inter-governmental negotiation committee established to develop specific contents of new plastic pollution treaty. This work is expected to be completed by 2024. Heads of State, Ministers of environment and other representatives from 175 nations gathered at Nairobi, Kenya, at the fifth session of the United Nations Environment Assembly on the 2nd of March 2022 to form this agreement. Several elements were considered for this development as follows,

- Global objectives to tackle plastic pollution in marine and other environments and its impacts
- Global obligations and measures along the full lifecycle of plastics, including on product design, consumption and waste management
- A mechanism for providing policy-relevant scientific information and assessment
- A mechanism for providing financial support to the treaty implementation
- National and international cooperative measures
- National action plans and reporting towards the prevention, reduction and elimination of plastic pollution
- Treaty implementation progress assessment

The resolution emphasizes the specific impacts of plastic pollution and it's transboundary nature which needs to be dealt with full life-cycle approach (IUCN, 2022). It also emphasizes the urgent need to improve the science-policy interface at all levels, to better understand the environmental effects of plastic pollution globally, and to promote effective and forward-thinking actions at local, regional, and global levels while acknowledging the significant role of plastics for society.

2.12 Extended producer responsibility (EPR) principle & Packaging waste

Concurrently, advances in packing technology have improved quality of life by reducing food waste, enabling commodities to be stored for longer periods of time, traveling great distances, and opening up new delivery routes in a careful and safe manner. However, pollution caused by packaging disposal is a timely need to be addressed urgently, designing products that are easier to recycle, minimizing the quantity of the packaging materials, finding environmentally friendly packaging and also investing in collection and recycling systems. Such a system is impossible to be established without stable source of funding and a strong coordinating body.

Private sectors produce and supply packaging, but the responsibility of the waste management and disposal usually relies on public sector and local authorities especially in low- and middle-income developing countries like Sri Lanka, which is often underfunded and not properly regulated. In such a situation, it is up for debate as to who should shoulder the administrative and financial burdens related to the rising volume of packaging trash. determining who should be involved in enhancing the infrastructure for packaging and recycling as part of the circular economy.

The concept of mandated Extended Producer Responsibility was deemed to have greater potential for accomplishing policy goals based on related prior experiences. Both upstream (such as better upstream technology for sorting and packaging recycling) and downstream (such as better upstream technologies for sorting and packaging recycling) (e.g. design for recycling). Germany's industry develops the idea of Extended Producer Responsibility in the late 1980s. EPR is a strategy based on the "polluter-pays" principle, which states that the package's creators are still accountable for it even after it has been disposed of. EPR systems are frequently created for electronic devices and batteries in addition to packaging, but the system is generally applicable to any product.

CHAPTER 3

Methodology

Firstly, the Microplastic survey was conducted in the surface water of the Kelani River meandering zone using two sampling methods as grab/bulk sampling and net sampling. Key places for grab sample collection were identified based on previous studies (Mallawatantri et al., 2016; Manage et al., 2020) and experts' suggestions. The locations were selected based on previous studies conducted related to water quality and flow monitoring locations that have being identified based on a scheme and standards and that covers the land use patterns and industrial outflows from the cities. In conducting net sampling, due to accessibility issues, as the net has to be mounted on to a boat, samples could be collected only from river mouth to Kelaniya city area. Sample collection and microplastic analysis was done during the months of March and April

For the analysis of physical characteristics (Size, shape, colour), inspected from naked eye using measuring equipment (eg.: Rulers and Vernier Caliper) for bigger samples or microscopic inspection method is used. For the chemical analysis, to identify the polymer types,FT-IR (Fourier Transform Infrared) spectrometer is used.

Secondly a situation analysis was conducted identifying the land base sources and waste management situation of the country and specifically related to the river (local and national level) ultimately based on the findings, offer management strategies to lessen the amount of macro- and microplastics that come from land-based activities and enter the ocean.

3.1 Sources of data and information

Primary data collection of microplastic survey was done collecting surface water samples from the identified sampling points using two methods as Bulk/Grab Sampling and Net Sampling. Secondary data were mainly collected related to the situation analysis of plastic waste management engaging in a literature review referring, and further some stakeholder consultations were conducted selecting a purposive sample.

3.2 Process framework

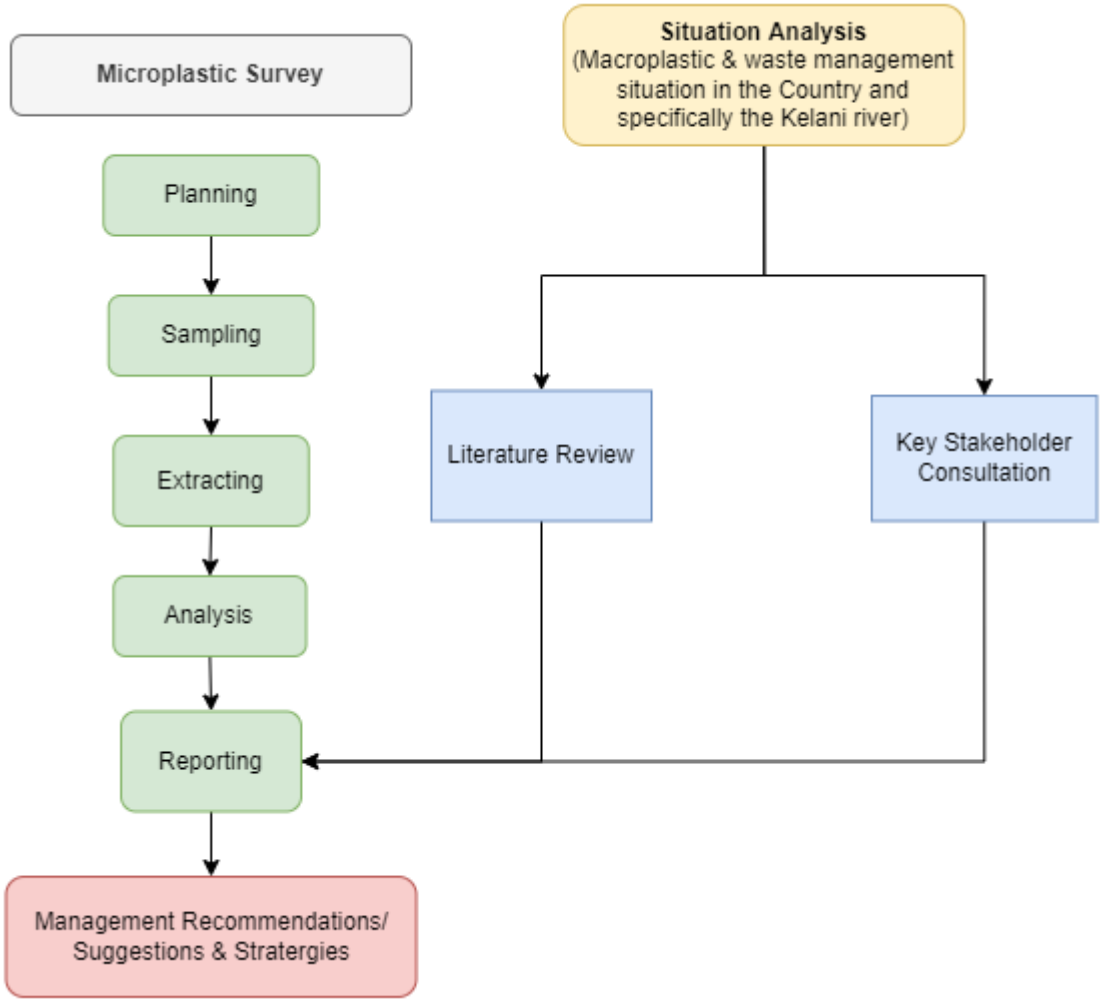


Figure 15: Overall Methodology of the Research Study

The above diagram showcases the framework of the methodology, the overall study consisted of a background study following a literature review to the overall methodology to achieve the objectives of the research. The microplastic survey consisted of mainly 5 steps namely planning, sampling, extraction, analysis and reporting. The “microplastic survey flow” and the means of engaging in the situation analysis will be further explained in the next section.

3.3 Microplastic survey flow

The methodology consisted of 5 steps starting from planning stage to reporting stage. When designing the survey, it is necessary to consider critical points such as cost, purpose, safety, and simplicity of the process. So, considering all factors following methodology was proposed.

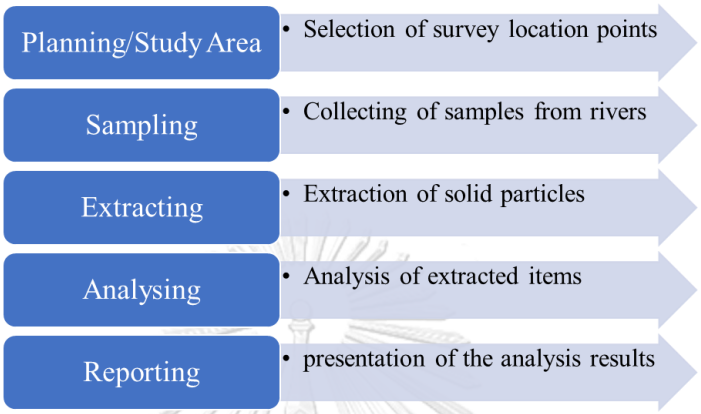


Figure 16: Methodology

3.3.1 Planning - study area

As shown in Figure 16, planning is the key and the very first component of the study which decides the survey location points and means of collecting the samples. Through series of discussions with field experts and past research data, critical points where sampling should be done were decided considering land use patterns and city outflows in the meandering zone of the Kelani River.

Seven key sampling locations were identified for the microplastic sample collection as mentioned in the Table 3 below,

Table 3: Sampling locations description

Location	**Sampling point name**	**Location coordinates**		**Description**
		Longitude	Latitude	
Seethawaka Ganga – L1				
	Sithawaka Ganga Closer to Awissawella	80.220571	6.953778	Sithawaka Ganga before Kelani River

Awissawella – L2				
	Kelani River, Kudagama Thotupala	80.203300	6.976801	after merging the Sithawaka Ganga and Kelani River
Pugoda – L3				
	Kelani River at Pugoda	80.123791	6.972822	After Sithawaka industrial zone and Avissawella town
Hanwella Bridge – L4				
	Kelani River at Hanwella	80.083153	6.909702	After several large towns and industrial districts
Kaduwela – L5				
	Kelani River Near Kaduwela Bridge	79.984863	6.936239	After travelling through a number of significant towns, industrial districts, and zones,
Kelaniya – L6				
	Kelani river near Kelani Temple	79.920639	6.949577	After passing the Kelaniya Town
Estuary of Kelani River – L7				
	Kelani River Outfall	79.871261	6.978728	Sea outfall

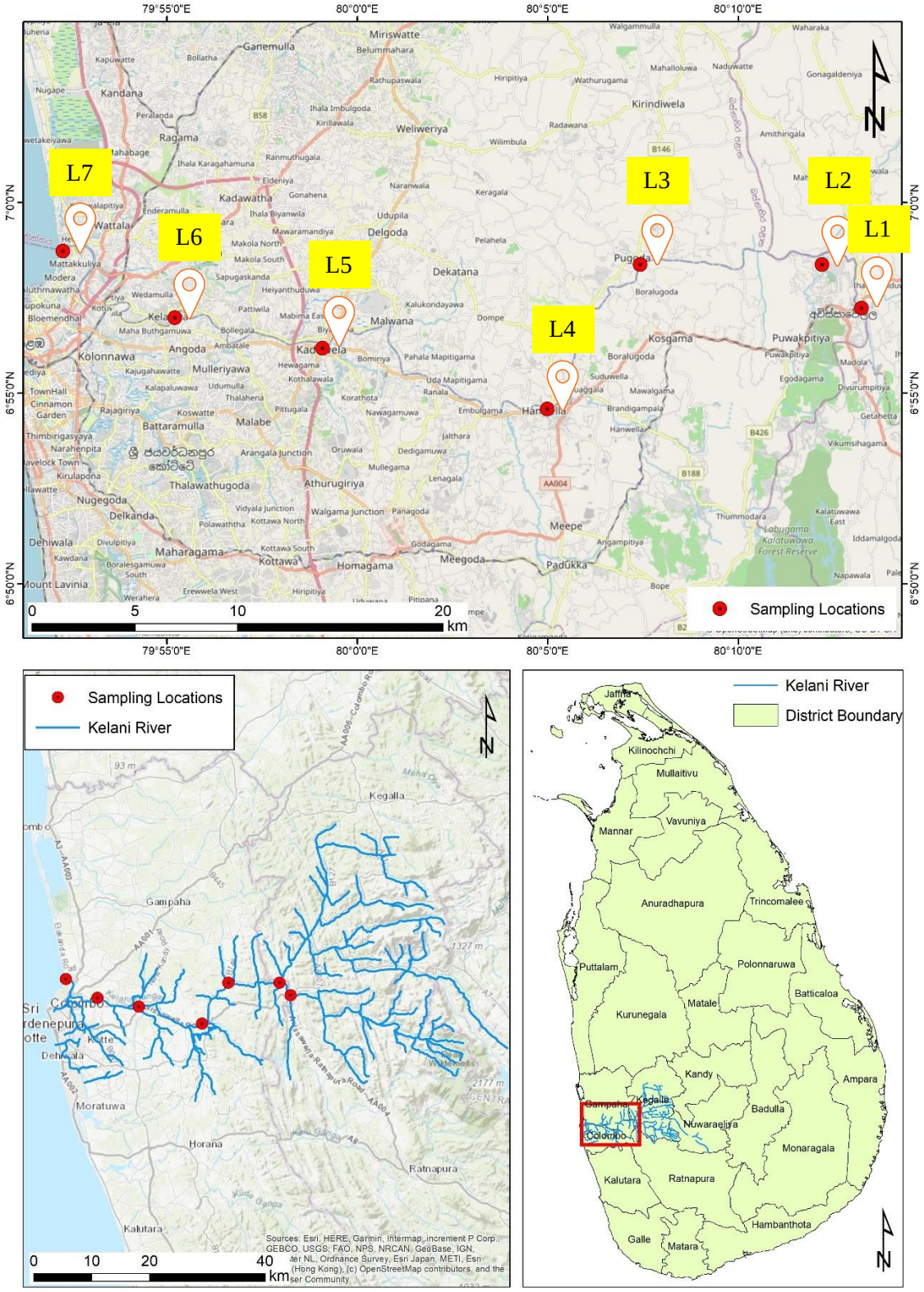


Figure 17: Sampling Locations – Grab Sampling

As mentioned in the literature review as grab/bulk sampling and the net sampling are the most common methods used in microplastic surface water sampling, both methods were used in the sampling. But when considering the net sampling couldn't access all key 7 locations as the net needed to be mounted on to a boat and due to accessibility issues the boat could reach up to two locations only. Starting from the river outfall, the estuary (L7) and to the Kelaniya (L6). So that in net sampling seven samples were collected covering up the area from L7 to L6 as shown in the map below

Figure 18: Sampling Locations – Net Sampling

Table 4: Net sampling – sampling locations

Location no	coordinates	
	longitudes	latitudes
A	79.870046	6.979485
B	79.884055	6.979234
C	79.881446	6.968713
D	79.880607	6.956358
E	79.894484	6.955132
F	79.901189	6.947180
G	79.916217	6.945903

3.3.2 Sampling

Bulk sampling

A stainless-steel bucket, rope and a sieve set were utilized in collecting the samples and glass jars were used to store the samples and transport to the laboratory. Sampling was done in March 2022 (dry season). In two sessions first collecting 25L surface water samples from each location and then collection 100L water samples from each location.

Altogether 14 samples were collected in bulk sampling and analysis was done.

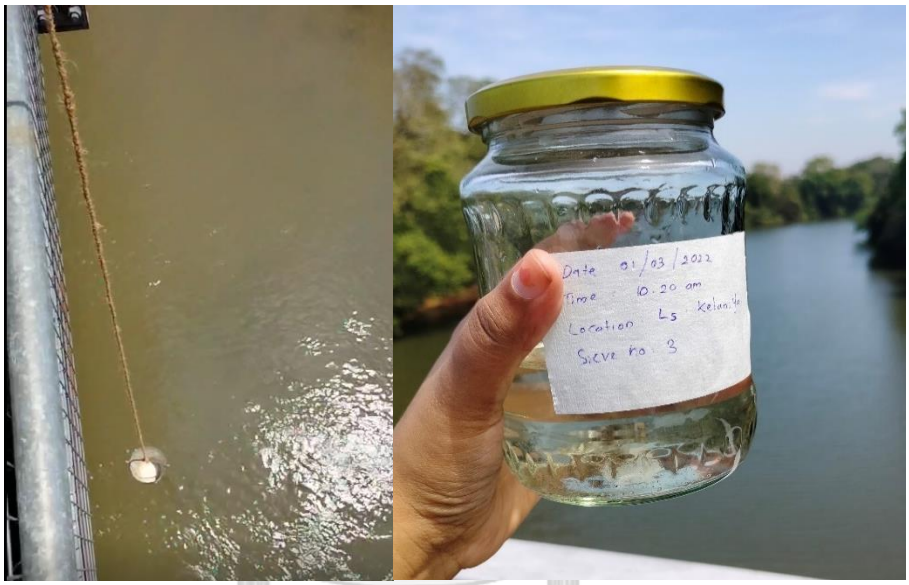


Figure 19: Collection of bulk samples and storing

Net Sampling

Figure 20: Plankton net used for the net sampling process

Net sample collection was conducted from the river mouth (Modara) to Kelaniya from seven points, (L7 to L6) using a 350 μm plankton net (shown in Figure 20 above). In the mid river surface water, net was mounted in a boat moving with the speed of 1–2 knots and GPS data were taken in each location as in Figure 18. Again, the collected sample were stored in glass bottles and transported to the laboratory.

Sampling time was decided considering the flow of the river, diameter of the net opening, speed of the boat and required volume to pass through. A volume of 100m^3 collected accordingly and the table of calculations and the used equations are included in the Appendix A.

Figure 21: Sample collection through net sampling method

Altogether, 21 samples were collected (14 bulk samples and 7 net samples) and extractions were done accordingly.

Contamination Control

In sample collection and analysis process great care was taken to control contaminations as much as possible to avoid microplastic samples been contaminated with outside. Several measures were taken until the analysis process is completed. When several samples were collected at once bucket, net and the sieve set was cleaned well and washed with distilled water, before taking the sample. Further, there will be close inspection of parts used for sampling before and after the process to make sure samples are not mixed with particles from the tools. Clean glass jars were used all time to store samples until further examination in the laboratory.

3.4 Quantification of Microplastics

3.4.1 Extraction

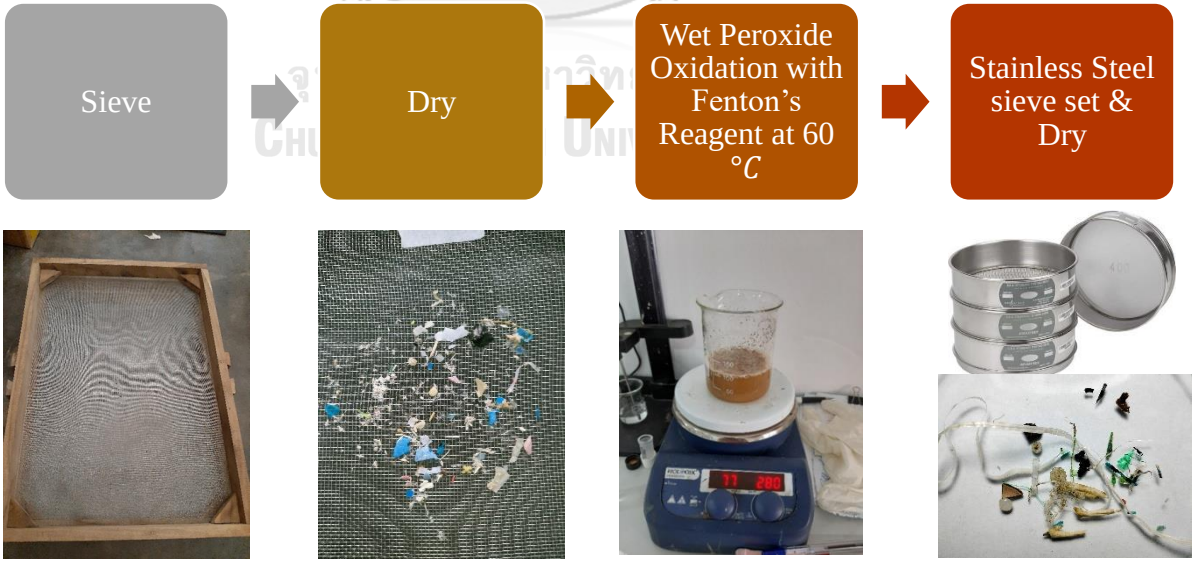


Figure 22: Microplastic extraction methodology

Once samples are collected, it is necessary to separate and sort out the plastic fragments from the sample as it can contain organic substances such as leaves, branches, and other

biodegradable elements. The separation is done using careful visual inspection in a lab with necessary equipment such as tweezers and brushes. Along with the separation of larger organic substances, they were washed down carefully with distilled water on to a 0.2 mm sieve to collect any attached plastic particles on to the sieve (as shown in Figure 22).

With the use of tweezers, the macro plastic fraction (>5 mm) was isolated from the samples and could be seen with the naked eye. Samples were dried before the extraction procedure to remove water and moisture and get dry mass. Using Fenton's reagent, moist peroxide oxidation was used to break down and eliminate organic materials from the samples after they had been held in 0.2mm sieves. As the reagent for the oxidation process, 20 ml of 0.05 M Fe (II) solution and 30 percent hydrogen peroxide solution were used. The samples were then agitated and heated to 600 ^{o}C.

The samples were put through 5 mm and 0.2 mm mesh sieves. With the naked eye, the macro plastic portion (N5 mm) was seen. The organic debris was removed from the microplastic fraction, which has particles between 0.3 mm and 5 mm in size (Masura et al., 2015; Hurley et al., 2018). The 0.2 to 5 mm fraction of the sample was placed in a glass beaker along with 20 mL of an aqueous 0.05 M Fe (II) solution and 20 mL of 30 percent hydrogen peroxide. The resulting mixture was then left at room temperature for 5 minutes before being heated to 60 °C and maintained there until gas bubbles could be seen. The beaker was taken off the hot plate as soon as the first bubbles appeared on the surface in order to prevent a severe reaction and the destruction of microplastics. The beaker was placed back on the hot plate and heated to 60 °C for a further 30 minutes after the solution had slightly cooled. Given that the gathered net samples had a high organic matter content, this technique was done twice for each sample and once more for the bulk samples (Bruge et al., 2020). Another popular approach that was not used in the extraction since the organic matter content was not very high was digestion with potassium hydroxide, KOH, at 60°C for 24 hours.

3.4.2 Analysis

After that a stainless-steel sieve set was used, with mesh sizes of 2 mm, 1 mm, and 500 μm to categorize MP based on their size. Observing through the naked eye, shapes and colours were identified as mentioned in Table 6 below. The polymer types were identified using the FT-IR spectrometer (BRUKER, ALPHA II).

Table 5: Sample Analysis Methods

Characteristics	Identification Method	Parameters
Size	Sieved using the standard sieve set and categorized	Length (mm/µm)
Shape	microscope	-
Colour	Naked eye/ microscope	-
Polymer type	FTIR spectrophotometry	Wave frequency

3.4.3 Reporting

Ultimate result of the sampling and analysis process is presented in tabular, graphical or in a map so that the overall analysis and area specific analysis would be much clearer. Comparisons were done among the locations as well as among sampling methods as much as possible. Further observations, information and data received related to macro plastic pollution in the river and waste management status after conducting the situation analysis were utilized to generate management suggestions.

3.5 Situation Analysis

In conducting the situation analysis of the macro plastic pollution and the waste management situation in the country, two methods were used as reviewing literature, and engaging in stakeholder consultation. Engaged in stakeholder consultation via focus group interviews and discussions, that was to be conducted via online and offline. A purposive sample was selected from the identified key stakeholder categories

Initially it was planned to interview regulatory bodies, city administration, urban local bodies, businesses (manufacturers and distributors of polymers/ Plastic Products/ Plastic Packaging), private waste management, etc. as included in the Appendix B- list of stakeholders. A total of 30 personals.

But unfortunately, with the prevailing situation in Sri Lanka due to economic crisis political instability and time constraints of the research, could not conduct the consultation as planned. Only 12 personals were interview. The question set utilized is in the Appendix C. The interviews were conducted in April & May 2022 and majority were conducted online or via telephone conversations.

CHAPTER 4

Results and Discussion

4.1 Relative abundance

Since the sampling was a rapid sampling done only in the surface water of the Kelani River, and still there is a need to do a replication. The data is not sufficient to provide a measurement of the abundance of microplastic in the river accurately. Therefore, the findings were provided as relative abundance comparing the findings of surface water of bulk samples and net samples of the river in meandering zone.

When comparing the relative abundance, first the bulk samples were taken into consideration as follows. Accordingly, as discussed previously grab sampling was conducted in two sessions, collecting 25L volume of surface water in one time and then again in the next session 100L volume in the second time.

Initially 25L volume of water was collected as a pilot survey sample collection. Since the presence of MP is detected in all the location expect for L3 (Pugoda) and since it was observed that the count of the MP is not sufficient, based on expert suggestions decided to go for another sample collection collecting 100L of water from the same locations.

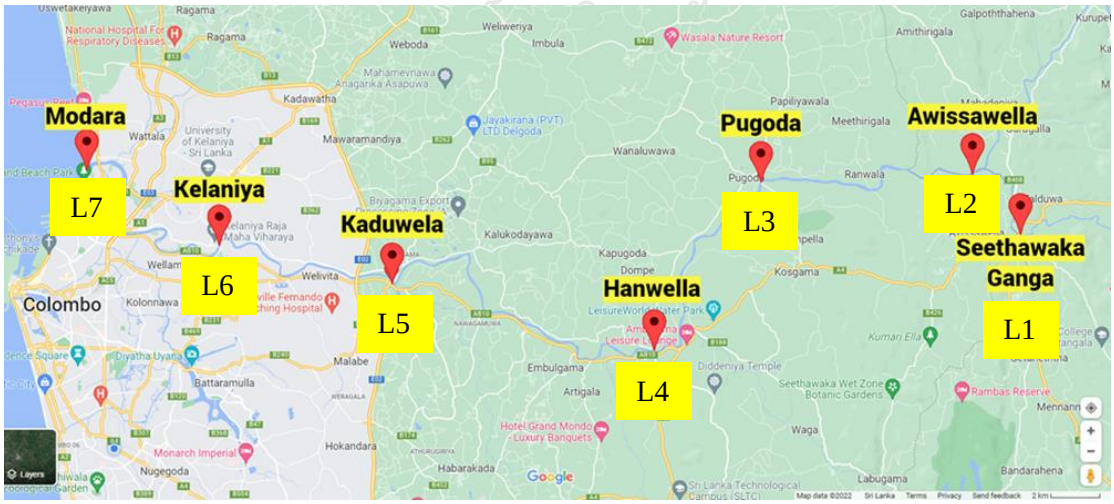


Figure 23: Grab sampling locations map

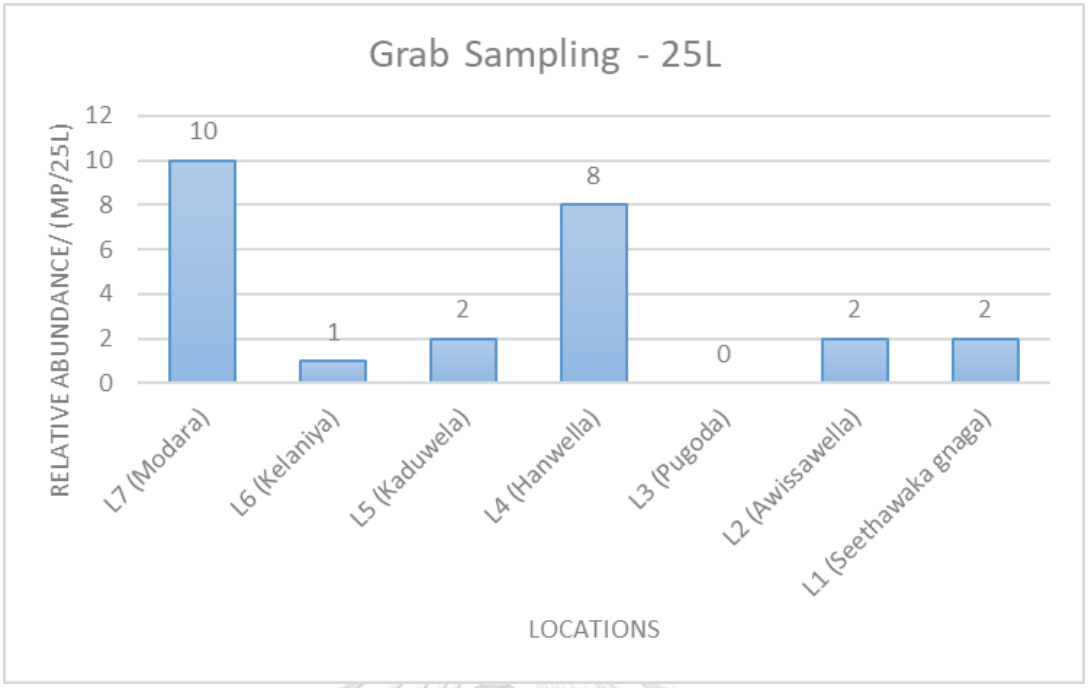


Figure 24: Relative abundance of grab sampling - 25L

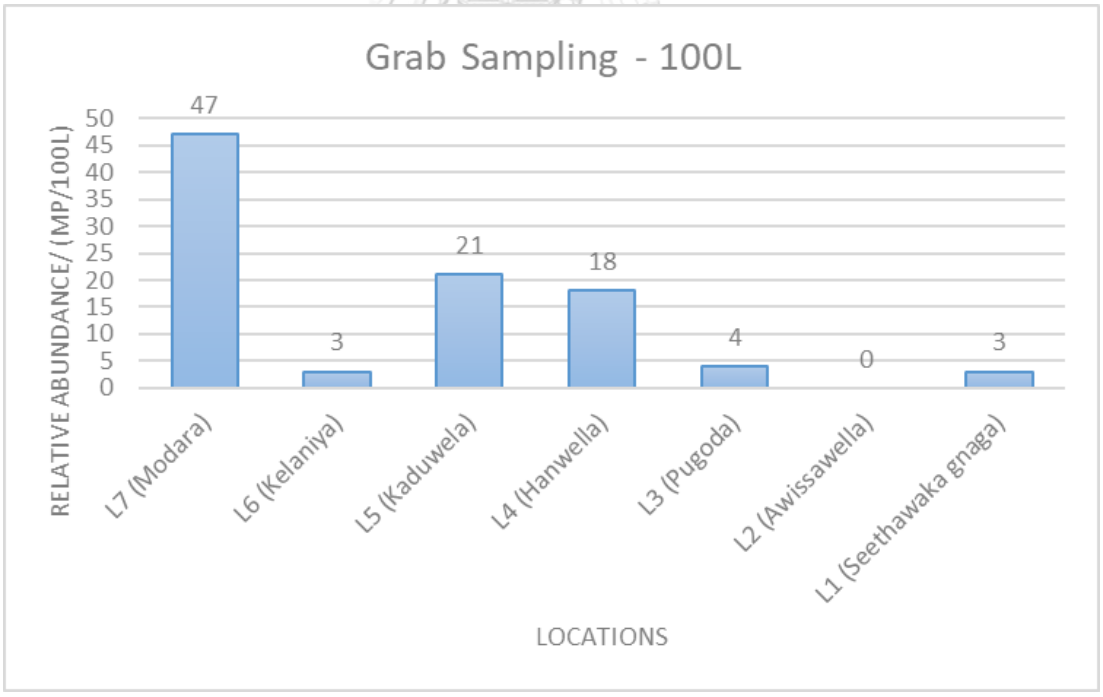


Figure 25: Relative abundance of grab sampling - 100L

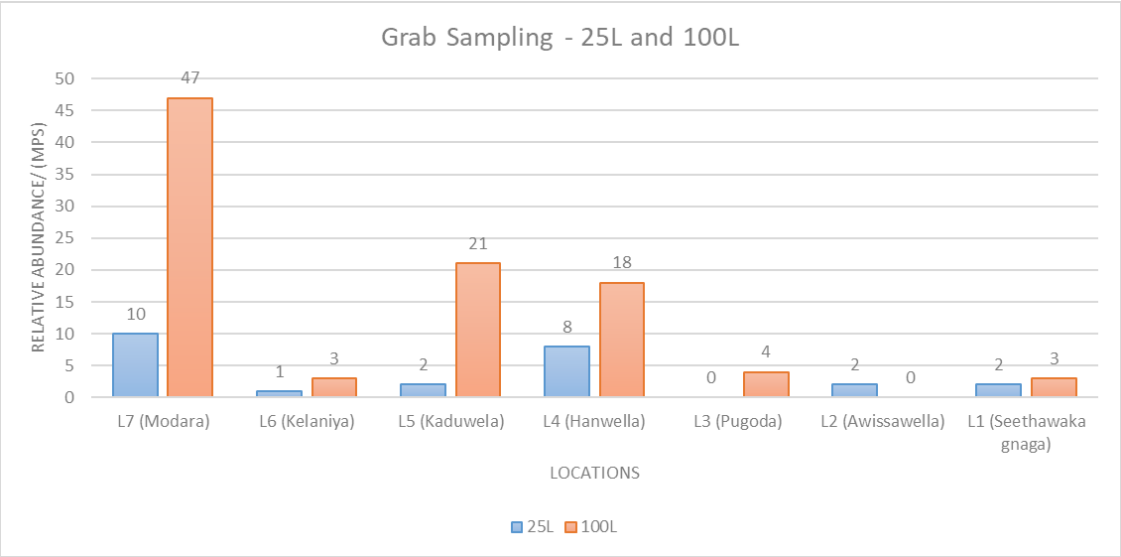


Figure 26: Comparison of relative abundance at two grab samplings

When the volumes are normalized, the two sessions of sampling could be compared as follows

Table 6: MP count per liter

Location	25L Session (MP units/L)	100L Session (MP units/L)
L1	0.08	0.03
L2	0.08	0.00
L3	0.00	0.04
L4	0.32	0.18
L5	0.08	0.21
L6	0.04	0.03
L7	0.40	0.47

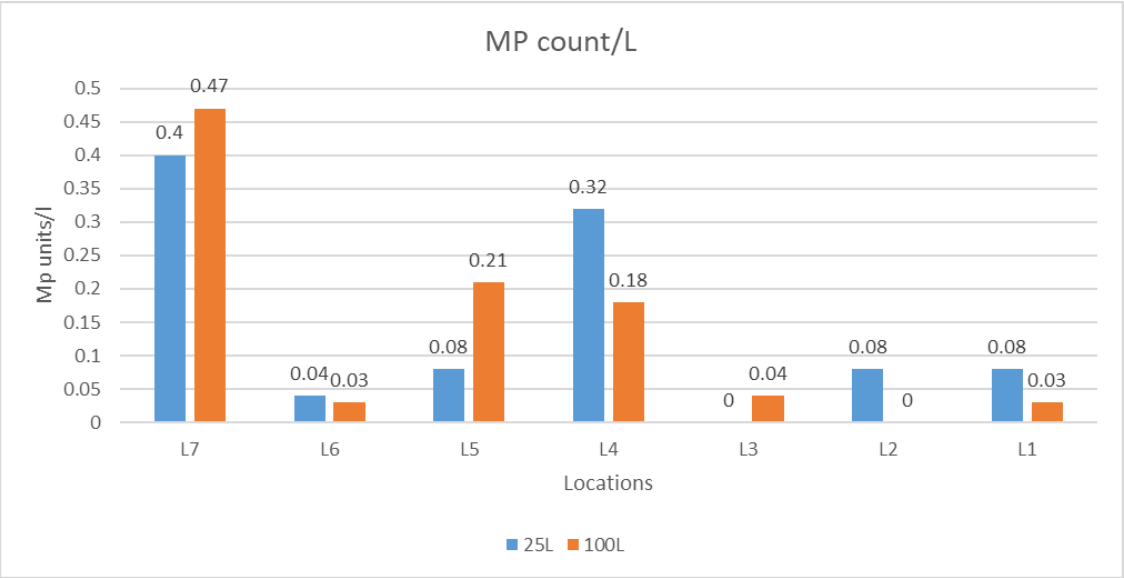


Figure 27: Comparison of MP count per liter

When comparing the two sample sessions of Bulk sampling 25L and 100L (figures 23, 24, 25), it could be seeing that highest count of microplastic was in the L7 point which is the Modara, where it is near to the Kelani River mouth. The amount was respectively 10 /25L and 47/100L. Hence the abundance of MP particles per Liter is 0.40 and 0.47 MP/L respectively.

The second highest count could be seeing in Hanwella (L4) & Kaduwela (L5) locations. Where Hanwella has a count of 8/25L and 18/100L and Kaduwela has a count of 2/25L and 21/100L. Hanwella and Kaduwela both locations are located after several major towns and industrial zones and areas.

In Modara (L7) other than the main out fall of the Kelani River, Hamilton Canal joins in, carrying lot of pollutants along with plastics. The Canal is a 14.5 km (9.0 mi) canal that runs through Negombo and connects Puttalam to Colombo. The Muthurajawela wetlands, which have since become an open and illegal rubbish dump, were intended to have salt water drained from them.

Figure 28: Waste dumping site in Muthurajawela
Source: (Chinthaka, 2019)

The Muthurajawela wetland is situated in the southern part of the Negombo lagoon, 30 kilometers north of Colombo. It is recognized as Sri Lanka's biggest saline coastal peat bog. The wetlands, which cover an area of more than 3,068 hectares, are popular with both tourists and residents for sightseeing, bird watching, and boat cruises. Furthermore, Under the Fauna and Flora Protection Ordinance, 1,777 hectares in the northern section were designated as a wetland sanctuary in 1996. (FFPO). Several reports indicate that official organizations in Sri Lanka authorized temporary dumping in 2017 before the rubbish mound in Meethotamulla, Kolonnawa, collapsed and caused an unpleasant accident in April. But amid the demonstrations urging the authorities to stop the unlawful dumping in the Muthurajawela marsh, the region has now become a permanent dumping site.

The Colombo Municipal Council (CMC) and other government agencies are still using the site to dump waste from the CMC, including the dump from the Kelaniya and Gampaha region, and local populations are complaining about their contempt for the environment.

Within the Muthurajawela wetland environment is the Pilapitiya paddy field, currently known as the Ambalammulla rubbish dump. The Katunayake-Seeduwa Urban Council has been disposing of solid waste at this location for more than 20 years. Additionally, a number of factories that are located in Muthurajawela, the surrounding area, and close to the wetland have been discharging hazardous waste and effluents into the protected areas. The production of dangerous pollutants into the Muthurajawela wetland is nevertheless permitted by some of these enterprises despite the fact that some of them have Environmental Protection Licenses.

Additionally, hospital garbage from Colombo Regular Hospital is also disposed of in the wetland area in addition to general waste. Burned and cremated waste is dumped in Muthurajawela's streams and then travels through the Hamilton Canal before ending up in the ocean.

Due to the rising number of dead fish in the lagoon, local fishermen are also being impacted by the waste disposal. High quantities of nitrates, sulphates, phosphates, calcium, and magnesium were identified in surface water samples and ground water samples taken from several locations in the Muthurajawela wetland, which were above the statutory permitted range. Residents have also expressed grave worries about the strong smell that the trash produces (EnvironmentalJusticeAtlas, 2022).

It was discovered that individuals once bathed and washed their clothing in the Hamilton Canal. However, because of this pollution, many are now afraid to enter the marsh and the canal. Those who are fishing are doing it because they have no other option.

Figure 29: Hamilton Canal map
Source: (Wijesighe, 2016)

Other than that Hamilton canal passes through an area with major cities with high population density due to the pollution caused by all the sewage lines from nearby houses, which point

directly into the canal. and passes the Ekala Industrial Zone (Najim & Kithsiri, 2021), which might be the reason for it being one of the most polluted canals.

Therefore, Modara L7 location is identified as the place with most MP pollution. As the estuary and the river outfall, waste seemed to accumulate that are coming from the Kelani River main water stream as well as from the Hamilton Canal that visibly contains huge amount of waste including macro plastic waste.

Furthermore, when Considering Sampling location L4 and L5, Hanwella and Kaduwela respectively, the amount of Macro plastic observed in both locations were comparatively high. Especially in Kaduwela near the sampling location there was a illegal dumpsite and littering could be observed on the bridge and beside the roads and in the small pathway toward the river bank. The following photographs were taken in there when conducting sample collection for the second time (100L session) and as that could be seen even in the river there seemed to be number of Macro plastic item including two garbage bags, assumed to be thrown from the Kaduwela bridge nearby.

Figure 30: Macro Plastic waste observations in Kaduwela

Again, when comparing the abundance of MP in locations, usually according to experts' ideas there is a trend of increasing the abundance when going from inland towards the ocean. But as that could be seeing in L6 (Kelaniya) location there is a drastic decrease in the count. The samples were collected from a bridge near a temple, and it was evident that the macro plastic pollution is in a controlled level. Didn't observe much littering nearby and another observation is the following awareness board established near the bridge that request people not to throw garbage as the water is taken for drinking. This was not observed in any other locations that the samples were collected.

Figure 31: notice board near the location 6 - Kelaniya temple bridge

That being said, the samples (25L and 100L) were collected in two periods within March and in both the abundance of MP in the location was very low 0.03 -0.04 items/L. Even though it was the intermediate/dry season.

It was identified that physical watershed and water body characteristics affect microplastic concentrations. Wet season influences microplastic concentrations via runoff and resuspension. Different scales of analyses can identify different influences on microplastic pollution. That's

why, spatially explicit analysis is critical to microplastic sources and delivery pathway. (Talbot & Chang, 2022).

Therefore, replication of the sampling in other seasons as well as concerning about the watershed and water body characteristics would lead to better representative sample.

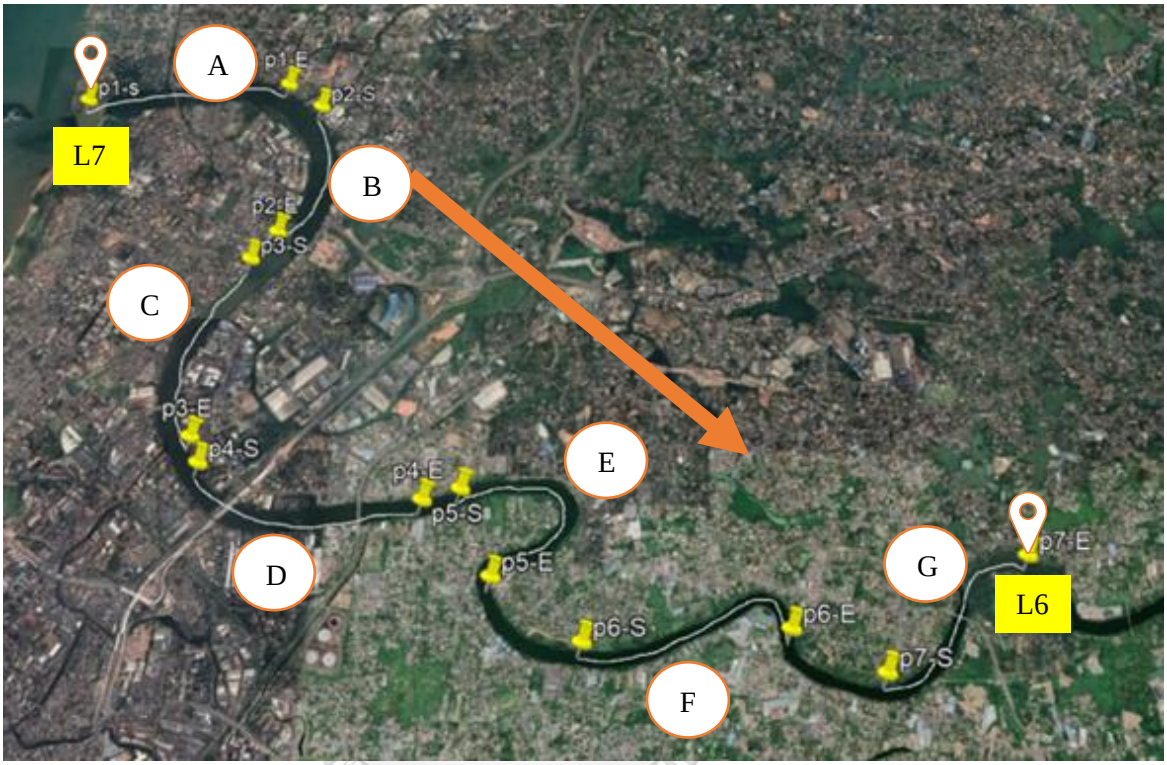


Figure 32: Net sampling locations map

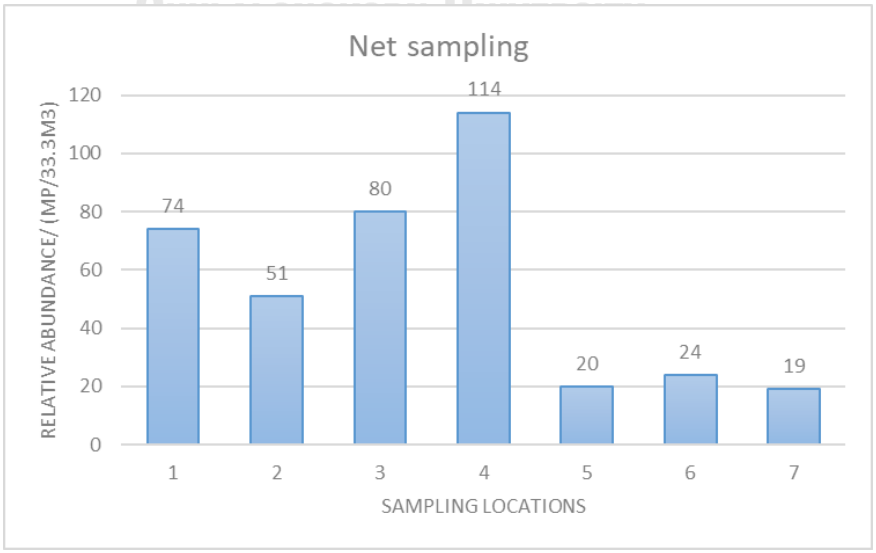


Figure 33: Relative abundance of net sampling

The following Table contains the Normalized MP count per cubic meter volume of water.

Table 7: Normalized MP count per cubic meter of water

Location	Net Sampling session (MP pieces /m^3)
G (Kelaniya)	0.57
F	0.72
E	0.60
D	3.42
C	2.40
B	1.53
A (River Outfall)	2.22

In net sampling, as shown above, comparatively a high amount of microplastic were observed in the location D, C, B, A more towards the river mouth (Modara area(L7) and lesser toward the Kelani (L6) Location. Which is similar with the results of bulk samples, as the abandance of MP in the surface water seemed to be lower in Kelaniya area when compared with Modara as in Figure 25. A comparison could not be exactly conducted as the locations of the Bulk samples were not as same as Net samples. As mentioned in the methodology due to access problems via the trawl even though initially it was planned to take samples from the seven locations it couldn't be done. All counts are included in the Appendix D for further reference.

4.2 Size, Shape Colour & Polymer Type

After using the stainless sieve set, with mesh sizes of 2 mm, 1 mm, and 500 µm to categorize MP based on their size, Size distribution was observed as in the Figure 34 (i) and (ii) in bulk samples and net samples respectively. Accordingly in bulk samples highest number of MP were in the range of 2-1 mm (55%) while in net samples majority of the MP were in the range of 5-2 mm (58%).

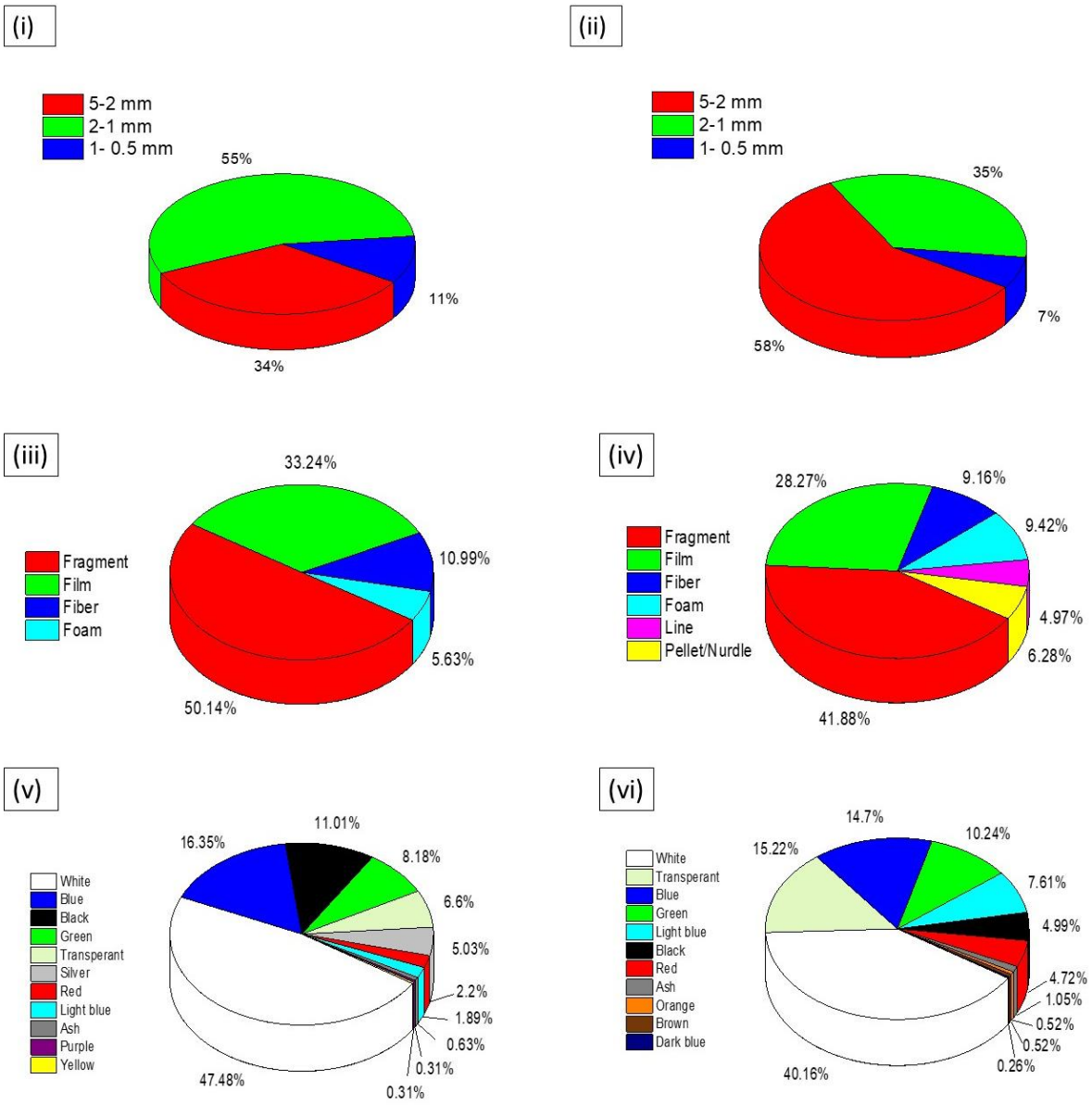


Figure 34: (i): Size distribution of MP in bulk samples, (ii): Size distribution of MP in net samples, (iii): Shape distribution of MP in bulk samples, (iv): Shape distribution of MP in net samples, (v): Colour distribution of MP in bulk samples, (vi): Colour distribution of MP in net samples

In all the bulk samples (14), fragments (50.14%) , followed by films (33.24%) and fiber were the most common shapes found. Majority of the samples were white (47.48%) in colour whereas blue and black were also prominent. In net samples (7) similar to bulk samples fragments (41.88%) followed by films (28.27%) and fiber were the most common shapes found in addition to the presence of foam and especially pellets/nurdles. Most prominent color of MP was again white followed by blue and translucent as further visualized in the Figure 34 above.

The Figure 35 below shows the different shapes of microplastics found during the sampling process.

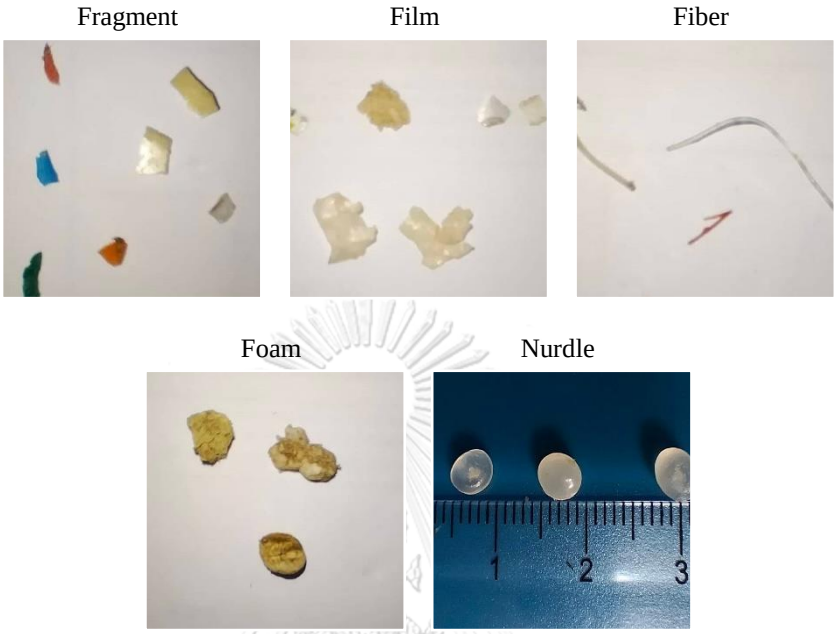


Figure 35: Shapes of microplastic found

As per the findings that could be seeing that in both bulk and net samples majority type of the shape was fragments. Which accounted for almost half of the samples. Microplastic fragments form through breakdown of larger particulate plastic by photolysis, thermo-oxidation, thermo-degradation, and possibly via biodegradation (Andrady, 2011). It could be said that fragments are secondary microplastics that are formed via fragmentation of the macro plastic in to larger number of smaller particles by afore mentioned process . (Tanaka & Takada, 2016). Therefore, further considering the abundance of macro plastic pollution in the river, it was assumed that the majority of MP are from secondary sources.

When the polymer types were identified of the collected MP samples via FTIR spectroscopy. Only 83 MP particles could be analyzed as the others were too small to be analyzed using the available type of FTIR technology as they would require a micro FTIR, which was not readily available.

In both bulk and net samples Polypropylene (PP) (48.19%) and the Polyethylene (PE) (38.55%) were the most detected polymer types with some Polystyrene (PS) (3.61%) at few sites. Figure 36 consist of the FTIR spectrum of main polymer types found in both samples.

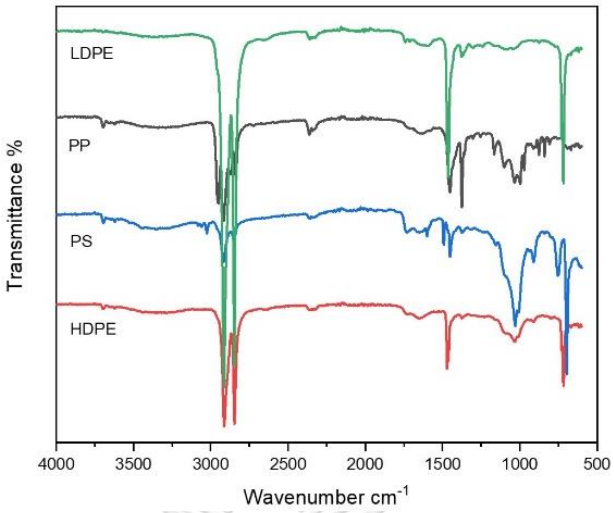


Figure 36: FTIR spectrum of main polymer types found in both samples

All the FTIR reports are captured and attached in the Appendix H

Polyethylene (PE)

Depending on the specific kind, polyethylene is a thermoplastic polymer with a large array of applications and a changeable crystalline structure. Tens of millions of tons are produced globally each year, making it one of the most frequently used polymers.

The most popular polyethylene compounds are LDPE, LLDPE, HDPE, and Ultrahigh Molecular Weight Polypropylene. Polyethylene is frequently divided into one of these major compounds. Compared to low-density polyethylene (LDPE), high-density polyethylene (HDPE) is significantly more crystalline and frequently utilized in completely different applications (LDPE). For instance, LDPE is frequently utilized in plastic packaging, such as plastic wrap and shopping bags. Contrarily, HDPE is frequently used in the building industry (Dhakal & Ismail, 2021; Rogers, 2015).

Polypropylene (PP)

Propylene monomers are combined to create the thermoplastic "addition polymer" known as polypropylene (PP). It is utilized in a wide range of applications, including as textiles, plastic parts for many sectors, including the automotive industry, and packaging for consumer goods (Maddah, 2016).

Polystyrene (PS)

Styrene molecules combine to produce polystyrene. In order to make a link with nearby styrene molecules, the double bond that connects the CH2 and CH portions of the molecule rearranges, creating polystyrene. It may create a tough, impact-resistant plastic that can be used to make furniture, cabinets (for TVs and computer monitors), glasses, and utensils. Styrofoam is created when polystyrene is heated, and air is pushed through the mixture. Styrofoam is a great insulator and is lightweight and moldable (Sastri, 2022).

4.3 Nurdles

The presence of nurdles in 5 of the 7 net samples is one of the key findings as these nurdles are similar to the nurdles from the M/V X-Press Pearl cargo ship which was destroyed completely in May 2021. The majority of the spilled nurdles were made from polyethylene (81.9%) and polypropylene (18.1%) . Where else nurdles found in the samples were also made from mainly polyethylene (81.9%) and polypropylene (18.1%). It showcases that nurdles might have entered from the river mouth into the river and moved upstream with the water currents. Further studies could be conducted regarding the fate and transport of the nurdles via the river and their weathering as some of the nurdles seems to be discolored, burnt, and reduced in size. Figure 32 consists of a picture of nurdles found in the net samples.

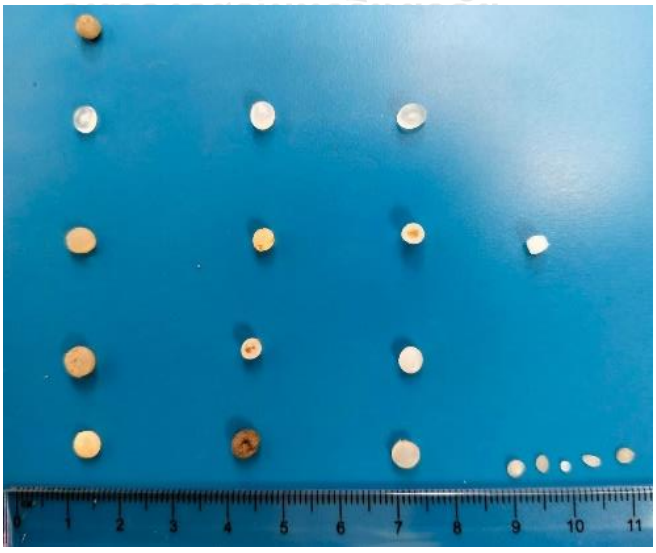


Figure 37: Nurdles/ Pellets found in the net samples

Even though it has been almost a year since the disaster still the debris of nurdles come to shore and the following were observes in beaches during the April of 2022. This questions the effectiveness of the cleanup and containment process carried out by the relevant authorities.

Following the damage caused by plastic nurdles, pallets and other burnt waste washed to the shoreline, immediate actions were taken by the involvement of UN, local communities, NGO's and youth organizations participation. Cleaning programs were initiated to remove these debris from beaches. First, sand together with nurdles was collected to bags and stored. But later a developed sieve was manufactured by a local to wash sand away and to separate nurdles and plastic debris. Using boats, some groups collected the nurdles floating on the water. These was done to minimize the damage that could do to the marine animals.

However, an investigation was launched to examine of the incident and make the responsible parties pay. But it was clarified via stakeholder consultations and was obvious to the public that the responsible bodies for handling the investigation, took actions very slowly and not in the proper procedure. Further Environmental groups and members of the clergy have alleged MEPA (Marine Environment Protection Agency) that there is a delaying in the cleanup actions and not even helping the communities for the cleanup processes which could lead increased damages to the marine environment. With the help of several parties and months of effort, beaches were cleared up to some level. But as of today also, nurdles and burned plastics are washing to the beaches even located far away from where the incident happened. As shown in Figure 33 below, nurdles have been found on May 2022 almost after a year from the incident in two distant places Galle face beach and Marawila beach.

Figure 38: Presence of plastic Nurdles found in (i) Galle face beach. (ii) Marawila beach

Other than the above observed results, it was decided to go for another sampling session to collect more bulk and net samples. With the country's situation and the time constraints could not go for another sampling session within the timeframe but it was planned to be conducted in the near future.

When considering the uniqueness about the spill, as mentioned in the introduction 70 – 75 billion (1680 tons) of preproduction plastic materials (nurdles) are being spilled during the Xpress pearl incident. Along with that, several extremely toxic chemicals including nitric acid have been spilled into the ocean while the ship was burning. It was said that the spreading patterns of the nurdles can change as the shapes and sizes are changed due to the burned percentage of nurdles and it is hard to predict (Hentz, 2022)

Furthermore, several types of plastics are found. Even though the majority are polyethylene, they also found polystyrene, polypropylene, polybutadiene rubber, expandable polymeric beads, and polycarbonates in addition. Although the form in which these plastics were packaged is unknown, polyethylene pellets have been found on beaches quite regularly. Although polystyrene is indicated as pellets in the cargo list, since it and polycarbonate both have densities greater than those of seawater, it is likely that they will sink and end up more frequently in the sediment than on beaches. The ship also carried a variety of plastic resins, including epoxy, which is covered in more detail below. Varied plastic materials have different

characteristics, such as density, which would affect how they spread in the water. Their chemical makeup differs as well, which affects how poisonous they are by nature.

Over 10,000 different compounds are utilized in plastics, and 2,400 of those are substances of concern, of which 50% are not at all regulated, according to a recent study. It is also known that some chemicals employed in plastics can seep out and cause harmful effects. Benzotriazole UV stabilizers are one form of plastic additive (BUVs). Throughout the world, plastics have a certain class of compounds that are frequently utilized in plastic items. BUVs have been demonstrated to leach from plastic debris and build up in birds after consumption. It has been demonstrated that a number of BUVs are hazardous to both people and animals. They can interfere with the balance of hormones and function as endocrine disruptors (Rubesinghe et al., 2022)

however, the level toxicity of the nurdles which combined with toxic chemicals have not been assessed even till now. According to the consultations conducted with the academia and experts the scenario was more evident. In the discussion with the Professor at Ecosphere Resilience Research Center, University of Sri Jayewardenepura, the issue was brought forward “With the spilled nurdles, other chemicals were also released into the environment, damage done by them and toxicities they caused together with nurdles were not properly assessed. As the evaluations got delayed, dilutions also might have occurred. So that Now it is impossible to evaluate the real damage done.

4.4 Observations during the field surveys

4.4.1 Macro Plastic

Figure 39: Some of the Macro plastic found in sampling

- The abundance of floating macro plastics in the river, as well as accumulated plastic waste near the surface water of riverbanks in some areas, as well as illegal dumpsites and littering, particularly near bathing spots and where small pathways lead to the river were observed during the visits.
- From river mouth to the Kelaniya area especially the houses and slums closer to the riverbank seems to be using the river as their waste dumping site.
- In the collected samples (21) macro plastics accounted for 49 pieces out of which packaging (39%), polythene bags (12%) and bottles (10%) were the most prominent.
- While collecting the MP net samples from the river mouth to Kelaniya, 402 pieces of macro plastic were observed floating downwards in the visual field with a 3 and ½ hour time frame
- Majority of them were polythene bags (29%), plastic bottles (28%) and packaging (22%). Some of the particles seemed to be degraded, torn fragments or films of the Macro plastics which may be due to the UV, mechanical and biological degradation.
- Figure 35 visualize the percentages of macro plastics collected in samples and observed while conducting the net sampling as follows,

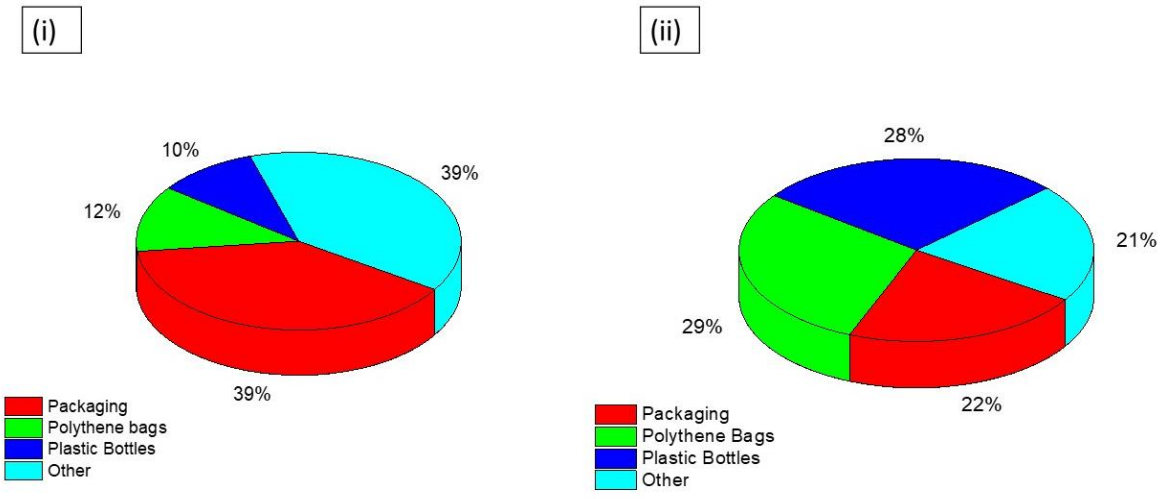


Figure 40: (i): Macro plastics found in all collected samples, (ii): Floating macro plastics observed while conducting net sampling

As that could be seeing the Macro Plastic pollution was very high in the river and the main plastic product categories found were packaging waste, polyethene bags and plastic bottles. Details findings are further included in the Appendix D. Therefore, as mentioned before under

the MP analysis. It was assumed that majority of the MP found were of secondary origin especially except the nurdles found in conducting net sampling. This was assumed based on the following factors,

- Abundance of Macro plastic pollution in the river
- Majority of the MP found being fragments that are assumed to be result of the fragmentation of the existing macro plastic litter
- The main types of macro plastics were identified as packaging waste, polyethene and plastic bottles. And when sampling it was observed that some of the MP particles seemed to be the fragments or films of the Macro plastics that were in the collected samples
- Furthermore, as the main Polymer types of the MP were identified as PP, PE and PS which are the main types of polymers used in making plastic packaging (PP, PS) polythene bags (PE) and Plastic bottles (PP)
- Moreover, when discussed with the experts and when going through the studies conducted in Sri Lanka in the Kelani River estuary as well as beaches and sediments it was evident that they also came in to conclusion that the MP found in the studies were mainly from secondary sources (Dharmadasa et al., 2021; Koongolla et al., 2018; Thakshila & Ranatunga, 2019).
- As mentioned prior in the literature review most of the time microplastic are found to be from secondary sources such as water bottles, packaging waste, fishing equipment's etc. (Isaac et al, 2021) which is difficult to trace back exactly.

4.4.2 Floating water hyacinth

In engaging in net sampling from river mouth the Kelaniya it could be seen that floating water hyacinth acting as a plastic transporter towards the ocean with the water currents. As shown in Figure 24 Plastic debris seemed to be entangled with the plants and move towards the ocean.

Figure 41: Water hyacinth observed attached with floating plastic debris

Water hyacinth

Water hyacinth or 'Japan Jabara' (*Eichhornia crassipes*) is a free-floating and flowering invasive aquatic plant present in many tank ecosystems in Sri Lanka. It originated from the Amazon Basin in South America and was introduced to Sri Lanka as an ornamental plant in 1905. Eventually, however, it became a common invasive plant in most water bodies. It typically spreads very quickly, mainly by runners (stolons), which produce new plants and doubles itself within 5–15 days, and by producing seeds through flowers (Kariyawasam et al., 2021; Wijesundera, 2008)

Recent studies indicate that water hyacinths may affect the movement of macro plastics in tropical freshwater ecosystems. Water hyacinths can entrap and collect vast amounts of floating waste, including plastic items, by forming large patches of a few and number of meters at the water's surface.

Few studies have measured the water hyacinths' contribution to the transfer of plastic in this area of research, which is still in its infancy. According to a recent study conducted in Vietnam, water hyacinth patches are the primary means of conveyance for macro plastic. These rapidly expanding, free-floating aquatic plants carried 78 percent of the detected macro plastics during the study period (Schreyers et al., 2021).

It would be interesting to further study this phenomenon related to the Kelani River as well. Further studying the spatial distribution of plastic and hyacinths across the river (some plants seem to be closer to riverbanks accumulating and entrapping plastic waste with them), when the water currents and higher flow rates occur due to rains, these plants tend to move towards the ocean. Not only that there is a possibility of them moving upwards the river as well. Because of this, it's critical to understand the function of water hyacinth as a river plastic aggregator and the differences between entrapped and free-floating pieces in order to better understand plastic movement and to make future monitoring and collection techniques more effective.

4.5 Situation Analysis

4.5.1 Kelani River waste management situation

Meandering zone is the most polluted area of the Kelani River basin consist of greater Colombo & Gampaha districts in western province (densely populated and most polluted province). The causes for the poor-quality water and plastic pollution were found to be as the factories, local business authorities and households residing nearby the river. According to the reviewed literature and stakeholder consultations with government agencies, it is also possible to conclude that the pollution is growing as a result of industrial discharges, littering, poor local authority service delivery, weak environment management, and governance, as well as insufficient awareness and education (Mallawatantri et al., 2016; *National Action Plan on Plastic Waste Management Sri Lanka 2021-2030*, 2021)

Several additional ministries, environmental and urban development bodies are involved at different phases in managing the pollution and plastic garbage in the Kelani River, even though

the local authorities are responsible for waste collection and disposal. The table in Appendix F further state these stakeholder agencies and their responsibilities with the various activities/actions for a cleaner kelani river. In addition to this, there are several national programs launched which has the scope to support the cleaning of Kelani River basin as follows (Mallawatantri et al., 2016),

1. Haritha Lanka programme
2. Combating land degradation (2016 – 2025)
3. Sri lanka comprehensive disaster management programme.
4. Pavithra ganga program – (now known as Surakimu Ganga Program)
5. Western region megapolis plan
6. Punarudaya programme.
7. Blue green Era: Sri Lanka next

However, the CEA reports that current situation of the water quality is not up to the satisfactory level specially in the lower area of the river near the mouth. It was found that highest deviations from the standard values from water quality parameters from the river mouth.

A recent observation made by CEA along with Sri Lanka Navy found that there are 1374 pollutant places along the Kelani river from river mouth to Seethawaka including 797 polluting sites from Colombo city and 577 from Gampaha district (*Kelani River polluted by 1,374 waste disposal sites - Minister*, 2021)

Therefore, even with the involvement of several governing bodies still the plastic waste management in the area seems to have inefficiencies such as poor local authority service delivery, especially in collection and disposal and not having a systematic monitoring and evaluation system for the waste management activities and projects conducted. With many governing bodies involved, effective and efficient coordination and collaboration among the institutes seemed to be lacking and thereby there is a need to improve communication and collaborations among the institutes. In consultations with the Environmental Ministry and Central Environmental Authority this need was further brought forth and discussed.

4.6 Material Flow Analysis (MFA)

The following MFA diagram, Figure 37 was an outcome of the National Action Plan on Plastic Waste Management (NAPPWM) 2021-2030.

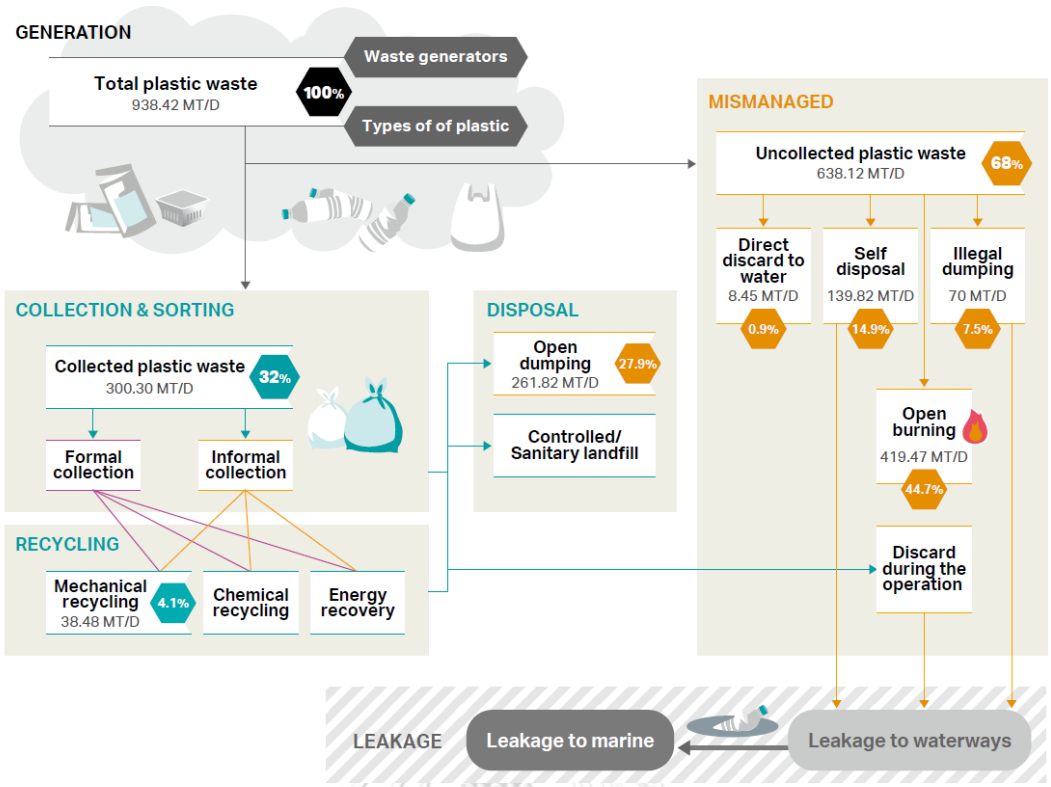


Figure 42: Material flow diagram of plastic waste in Sri Lanka
Source: (*National Action Plan on Plastic Waste Management Sri Lanka 2021-2030*, 2021)

According to the diagram, out of the 938MT of waste generated per day in Sri Lanka, only 300MT is collected where 261Mt goes for open dumping. Total uncollected waste remains as (638MT), which is 68% of the totals plastic waste generated, that ends up been openly burnt (44%) or disposed to the land and waterways polluting the environment (24%) (*National Action Plan on Plastic Waste Management Sri Lanka 2021-2030*, 2021). It is identified Plastic packaging, polythene bags and increasing amounts of single-use plastics are main contributors to the plastic pollution in the country. Even in the research study this was observed considering the abundance of macro plastics and their types, Majority of them being, packaging, polythene bags and single used plastics. Via the consultations with the Environmental Ministry and Central Environmental Authority it was further confirmed, and the Municipal council and local bodies further commented on the abundance of macro plastics.

Likewise considering the field survey and information found via literature survey and stakeholder consultation following potential sources were identified as land-based sources for plastic pollution in the river.

a) Littering and illegal dumping
b) Poor waste management practices

c) Industrial activities leading to improper disposal and loss
d) Sewage debris and canal discharge

As mentioned prior in the literature review most of the time microplastic are found to be from secondary sources such as water bottles, packaging waste, fishing equipment's etc. (Isaac et al, 2021) which is difficult to trace back exactly.

Even in considering the situation of the Kelani River it was observed that apart from the nurdles found in the net samples, majority seem to be from secondary sources as they seem to be fragments and films generated from degradation of macro plastics due to weathering or external force. This is further elaborated on the section of macro plastic. Therefore, via the first objective MP contamination in the river was identified and their origin is assumed with several evidence and consultations to be of secondary sources.

Other than the sources mentioned above another possible source of microplastic might be the abandon fish nets. While collecting samples floating fish nets were observed and got to know from the fishermen that when the fishing nets get tangled or torn due entanglement with boats or any objects they are just abandoned, and they are not aware of any other disposal mechanism. Anyway, still there are not enough evidence to exactly say that they come from a certain source and the pathway is such. So that in here the discussion are based on the possible sources of macro and microplastic from land-based activities based on the findings.

4.7 Littering, fly tipping and illegal disposal

As mentioned in the field observation, one of the key observations was that littering and illegal dumpsites beside the riverbanks, particularly near bathing spots and where small pathways lead to the river. Fly tipping was also observed where people drop garbage bags to the river from bridges and the houses and slums near the Modara and Kelani area seems to be using the river as their wastewater and garbage dumpsites.

Figure 43: Littering found nearby the riverine

4.7.1 Culture of littering

Littering is a habit that has developed as a result of carelessness and laziness. People toss trash around out of carelessness and without thinking about the consequences of their actions. Many people today are unaware of or undervalue the harm that littering causes to the environment. People presume that their own acts won't have a negative impact on society. The majority of people believe that someone else will do the cleanup for them. Therefore, it is often the responsibility of local governments and taxpaying citizens to clean up rubbish. people's disregard for their duty to maintain public spaces. This is a significant problem, particularly in developing nations.

Lack of infrastructure and disposal facilities and waste collection is another reason for littering and illegal disposal. Considering the situation of the Kelani River meandering zone, public littering and illegal dumping occurs from bridges, in small pathway towards the rivers during recreation on riverbanks or directly to the river.

While sampling observed people throwing garbage bags directly to the waters from bridges. Riverbanks especially recreational areas where men get together for partying and consuming alcohol. While partying consumed food packaging, bottles and cans are to be discarded along the bank and pathways towards the bank. Illegal dumpsites could be observed as well. Litter and garbage near bathing sites was also noticed, Shampoo sachet packets, toothpaste tubes, shampoo bottles and soap and washing powder packaging and discarded brushes were visible. Slums and houses on the banks use the river as their garbage disposal facility.

In stakeholder consultations littering and illegal dumping was also brought forward especially by policy makers. In the interview conducted with the environmental ministry officials and CEA reasons for such behavior brought forth. Accordingly due to lack of infrastructure and disposal facilities and waste collection system people perceived garbage as a burden and by discarding to the river, they feel free of it at even enjoy the site of it floating away as observed while doing field survey. They are not either aware or concerned about the outcome of it after the action. Just want to get rid of the burden.

As mentioned by the assistant director of environmental pollution control and chemical management division of the environmental ministry. Majority of the people don’t have easy access to waste collection system. Especially the people who reside outside the main city and in villages (sub urban and rural areas.). Only 40% of population is covered in waste collection system provided by local authorities. Garbage trucks and workers do not go to villages and

cities that are further away from main cities. So that most of the time what they do is either open burn or bury the waste as they do not have any other option. If there is a flowing water source nearby discarding the waste to the waterway also happen. Similar with the situation of the Kelani River. CEA official mentioned that they do have some directive to go to those areas at least once per month and collect the recyclables such as plastic waste and e-waste. As a developing country and a country facing the worst economic crisis of its history the problem of lack of infrastructure, facilities and resources is an unavoidable occurrence.

Thereby the officials stated that the regulations and fines cannot be properly enforced because without providing the services or guiding them for a proper means of disposal there is an ethical concern of regulating them

Except such less privileged communities in waste management infrastructure, during the discussions another group of people were brought forward. They are the people who are provided with a scheduled system but still do not comply with them and follow the regulations.

Even in Colombo Municipality council limits, where the days are assigned to collect different types of waste. People couldn't wait till the service is provided in the assigned day. Most of the times the waste collection happens as kitchen degradable waste, Recyclables (Mainly plastic, and sometimes glass) or Nonrecyclables. Even when such days are assigned as a mean of segregating the waste and as a system to utilize the services in an optimum way with the lack of resources in the country. For instance, when a specific day is assigned for plastic waste collection. Some people do not want to wait till the collection day. They just want to get rid of litter so most of the time what they do is burn. Ministry has conducted many awareness programs regarding the toxicity of burning. These were done in schools, and for children. Waste management is included in the school curriculum. But still, most of the people amidst being aware regarding the risk of toxicities tend to priorities convenience and getting rid of the burden

As mentioned in the observation's slums and houses near the riverbanks seemed to be using the river as a domestic waste dumpsite. When inquired regarding this matter from the regulator and the policy maker what they said was that majority of the people dwelling and have houses near Kelani riverbank are encroached and sometimes even are living illegally in reservoir areas. Politicians provide them infrastructures such as electricity, and after some years they get the legal authority to the land they live in. Such political influences are a real nuisance in Sri Lanka in all the sectors and is a huge barrier in establishing the law order in the country.

By the way during the interview with the Cleantech, the leading private waste management company in Colombo suburb area and one of the main waste collecting provider in the city

specifically mentioned that After covid, amount of waste got reduced in Colombo city. Before the COVID Pandemic the waste collected was around 7000MT but during the post pandemic period it got reduced up to 5560MT.

They further mentioned that the Littering is also got reduced specially in the city and shops in the city and that most of the litter comes from sewages and canals outside the main city and from industrial zones.

4.8 Poor waste management practices

As similar to what has been discussed prior solid waste management facilities and garbage collection coverage is in need of improvement. Furthermore, household sanitation, community awareness of proper waste disposal practices is lacking when considering the public attitudes and behavioral patterns, such as littering, unlawful dumping, and using the Kelani River as a dumping site. Another important aspect related to poor waste management practice is shortcomings in implementation and enforcement of the policies, rules and regulations.

Issues associated with recycling could also be taken under the poor waste management practices. As a mean of sustainable disposal of plastic waste recycling plays a major role. But because of poor segregation and lack of logistics (transportation and storage.) the plastic recycling industry is not operated in an optimum manner. This was brought form by MOE, CEA, IUCN, Cleantch and Katana Upcycles

As mentioned by MOE many strategies were utilized to create the link between recyclers and the plastic waste. Initially started collection centers named “Sampath Piyasa” around the country for people to collect and return recyclables. Officers were only available in the daytime and then in the nighttime, people started destroying the centers, breaking the equipment and incorporating all forms of garbage in the centers. Providing security for 24 ours to each center is not practical and is very costly. So the officers said that ultimately since the system was a failure they had to put a stop to it.

The waste given were not properly segregated. Even though the collection is done in Colombo, out of the city is very hard to do collection and transport as it is expensive. Recycling facilities are much developed and concentrated around western province. Is there a possibility of linking altogether and go for a sustainable system? The government should always be concerned about that.

All plastic cannot be recycled. Rest is burned as energy. Only two established such plants. Colombo waste to energy plant, and Insee cement plant to burn of residual plastic.

Similar to what have been discussed with the other regulatory bodies Colombo Municipal council officials talked about the issues related to waste logistics, segregation and mentioned the following. After garbage is collected. The storing is done only for recyclable waste; other waste is transferred straight to the disposal sites. Further the Non-recyclables are sent to the Waste to Energy plant at Kerawalapitiya.

They further mentioned that the most significant factor is lack of focus on MSW generation, which consequently increases MSW, especially the nondegradable waste. This is due to excessive packaging and the public buying things that are not needed or will not be uses for their daily activities (over consumption). Segregation of MSW not being done properly at the source is another problem that requires attention.

A prominent problem in transportation is that a suitable location is not available to unload carts and load to trucks. Currently this is done on the side of the road, which create traffic congestion, environmental pollution and littering of the area. The most significant problem with storage is the unavailability of adequate space for storage at source. As a result, when there is a delay in collection, waste tends to end up on road sides and waterways and also illegal dumping on road sides and waterways.

Lack of public support has a direct impact on MSW management. Difficulty in implementing any rules and regulations, less labour for MSW services, and lack of short-term and long-term plans are also problems associated with MSW management. As it was mentioned by the MOE and CEA officers, and according to the act, garbage is a property of the local authority. So that they do not want other institutes to get involved in managing it. But then there are incidents where they're also not doing this waste management properly and when the regulatory bodies try to intervene there is the resistance. So, it was identified that collaboration and coordination among the institutes are in need of improvement.

Corruption and political influences are also become reasons in the poor quality in waste management. For instance, in discussions, it was revealed that In procurements of machinery and equipment how the commissions get involved and due to corrupted officials and politicians the good are purchased at way too higher prices.

Aligning with the responses from other stakeholders Abans environmental services and Cleantech (pvt) Ltd, lack of infrastructure in waste transportation from outside the main city and storage was brought forth. As a leading private waste collector in the Colombo assigned by the CMC also shared their experiences related to recruiting labor force and the issues related how reluctant the workers are and they not educated, their attitudinal issues , and also monitoring difficulties.

4.9 Industrial discharges and outfalls

Even though rules and regulations are westered upon the industries to follow up waste treatment before discharging wastewater into a water body as mentioned in the Appendix E. that could be seeing that there is no mention of the limitations, standards related to plastic litter or microplastics. Also, there is a doubt whether the imposed treatment measure are carried out by the industries before discharging to the water. Rapid growth of industries located in close vicinity of the river and the number of polluting industries that discharge treated and untreated industrial effluents to the river is observed over time. The protection of water quality in natural rivers has thus become major issue from point of view of long-term reliability. Oil spills, dumping of waste from industries, sand mining, and industrial activities are the main causes of water pollution in the country. That being said the wastewater treatments are not being done accordingly and the compliance to the regulations and standards is not happening. The self-reporting mechanism is not also properly functioning, and the evaluation and monitoring done by the CEA is difficult due to lack of resources and laboratory facilities. According to the interviews with the MOE the water discharge fee is also not sufficient and therefore industries tend to pay the fees and do the dumping as they wish. Microplastics are correlated with urban land use, population density, and WWTPs (Talbot & Chang, 2022). As an existing source of water pollution in the country it is important to conduct further studies in such treatment facilities to see whether the presence of microplastics in the water at the source itself. If so relevant measure could be taken based on their abundancy of the micro plastics. A filtration method or a sieving system could be used to prevent MP being discharged to the river.

4.10 Sewage debris and canal discharge

The current wastewater management systems in place in Sri Lanka are abysmal. Being a developing country, Sri Lanka is also plagued with inefficiencies in wastewater management mentioned above. Sewer connections are only available for restricted areas in the Colombo city and for a few other major cities. Inherited from the colonial period, some sections of these systems are dilapidated and are in dire need of renovations and upgrades. Extension work on the pipe system is moving at a snail's pace and the existing systems do not have centralised treatment facilities. Wastewater collected from the Colombo sewerage system is dumped in to the sea in two locations. Many other fast-developing coastal towns follow this lead, making them leading contributors to marine pollution.

Beyond the limited area covered by pipe connected facilities, outskirts of city areas and surrounding suburbs mostly have to depend on onsite wastewater disposal methods. The common practices include individual facilities of septic tanks or open-bottom soakage pits for black water and open bottom wastewater pits for grey water. However, very often, grey water is channeled illegally to storm water drains directly or indirectly.

In underserved areas of Colombo and other cities, residents often have no choice but to share common toilet pits and dispose kitchen and bath water to storm water drains, creating uninhabitable conditions in the surrounding environments. Coupled with ill-designed storm water drains and run-off water disposal facilities, non-standard waste water disposal methods are the reason that Colombo and other major cities in the island are plunged into chaos during flash floods. Having such issues in drainage and sewage systems. It was identified that Plastic pollution and MP contamination could easily happen in the river as several Canal and sewage lines ends up in the mainstream of the Kelani river and other sub streams.

As discussed, earlier Hamilton canal which runs through Muthurajawela mash land pass through slum areas is a main source of water pollution in the river including plastic pollution and contamination. The canal joins the river in Modara before the outfall into the ocean and as per findings from the MP survey conducted. The highest reported MP count was from the Location where the canal gets mixed in. Cleantech further mentioned in the interview with them that most of the plastic litter comes from sewage and canals outside the main city and they do collaborations with other stakeholders and institutes in trying to clean up them as a responsible body in managing waste in the area. But still the situation is in need of a better sewage system and the canal cleaning or trapping need a sustainable solution rather than been cleaned up once in a while and then again resulted in clogging and accumulated with litter and plastic debris.

4.11 Abandon fish nets

Plastic pollution from fishing nets

During the net sampling process, many of the discarded fishing nets were observed throughout the journey. As per the interviews with the fishermen, got to know that when they are collecting the layed nets if any got stuck at any of the tree branches, rocks or any other item in the water, fishermen just cut the net off from the boat and leave it behind. Many floating Styrofoam pieces that were attached to the abandoned nets were seen during the sampling process and many entangled plastics to the nets were also observed. Also, when smaller boat rudders get strangled with layed fishing nets, fisherman cuts off the net to save the boat rudder.

During the sample examination, microplastics were observed that might have being broken from the fishing nets and discarded nets which could be identified as fiber. This abundance of the fishing nets can cause severe impacts on the riverine environment such as fish and other endangered species that is native to the environment can be entangled or, due to the degradation, small microplastics can be released to the water as well. These smaller MPs can end up in fish digestive system causing damages to human as well.

Figure 44: Secondary MPs found that are suspected from the fishing gear

Abandoned, lost, discarded fishing gear (ALDFG) and ghost fishing rules and regulations might be required accordingly to manage the situation. When questioned fishermen had no idea regarding the guidelines of disposal. When the Marine Environmental Protection Authority was consulted, it was discovered that schedule IV of the extraordinary gazette from 2013 forbade the disposal of nets, ropes, plastics, or other artificial synthetic materials that could float or remain suspended in the sea and seriously impede fishing, navigation, or other maritime

activities or endanger marine life.(MEPA, 2013) Any regulations could not be found related to the river dumping. Therefore, the requirement of similar regulations could be brought forth along with awareness creation of their management among fishing communities as they seem to lack knowledge related to disposal of nets Awareness creation over these matters could be carried out with the help of the authorities such as fisheries ministry and national aquaculture development authority.

4.12 Waste recycling situation in the country

The recycling of plastics in Sri Lanka is majorly done in-house by the production sector. Very few large-scale recyclers were found and most of their waste collection was done by an informal sector. They are collecting waste from industries and commercial properties, houses, streets and final disposal areas. These collectors provide a wider service to waste management sector by helping the government, private sector and people through direct and indirect manner.

Considering the global level, around 20 million people make their lives on informal waste collection sector. The main reasons were found as the poverty and unemployment. The working conditions of the informal waste collection sector is often very unsafe and unhygienic. Proper protective equipment nor safer methods have been used by these collectors during the collection compared to the time they spend on an unhygienic environment.

Considering the waste recycling status of Sri Lanka, there is no complete database found for the waste recyclers and collectors. However, the only list available is the list of registered waste recyclers and e-waste collectors under the central environmental authority. Registered recyclers and collectors were found in about 21 districts in Sri Lanka and about 65 registered waste recyclers and collectors were found in the Colombo district alone and about 46 was found in Matara. However, the actual values are more than that in most of the areas.

Out of several recycling methods, Sri Lanka is using mechanical recycling method by most of the recycling facilities. Colombo reported as the district with largest amount of waste recycled which about 3% and it is expected to grow to 7% in 2023. (Manapperuma, 2018). However, majority of the small – medium scale post-consumer recyclers fail to meet the global standards of the recycled products which leads to discouraging in the industry. Furthermore, high cost and insufficient quantities were also found as major problems in the recycling industry. Conversely, recent research shows that PET recycling rates have been increased significantly over past few years. This is mainly because several projects are supported by government and

some of the donor funds as well and industries. It was found that, since 2011 to 2020, PET collection has increased from 22MT to as high as 250MT per year. However, later it was again reduced to about 180MT in 2020 mainly due to the travel restrictions of Covid-19.

The Covid-19 has severely influenced the current waste management practices and even more increased the mismanaged waste amount. Recent research done in the households in Colombo reveals that in addition to the regularly used single-used plastic amount is increased due to the incidents related to Covid-19. This additional amount is caused by the covid-19 related single use plastic products such as disposable face masks, face shields, gloves and hand sanitizer products. Considering the disposal methods before and after covid, burning rate is considerably increased while handing over to collection, open dumping and recycling have shown as decrement in amount. Burying of waste is shown a slight increment as well. The papers suggest stronger involvement of the guidelines issued for plastic waste management, life cycle assessment and social analysis to get a more clear picture of the current status of the waste management practices (Jayasinghe et al., 2021).

Other than the above findings from the literature, As discussed under poor waste management practices MOE and CEA mentioned of the difficulty in creating the linkage of collected waste with the recyclers. Even though the collection happens in Colombo and other major cities outside the cities there is the issue lack of resources and funding for the collection mechanism and space to be stored till being transported. This was mentioned by the recyclers interviewed as cleantech Katana upcycle and Damro.

As discussed, prior when the collection centres like “Sampath Piyasa” could not be properly functioned and became a disaster due to lack of funding and resources. As recycling facilities are much developed and concentrated around western province an effective and efficient system of recyclable plastic collection, storage and transportation was identified as a timely need by all stakeholders interviewed.

During the interview with the MOE, one of the positive initiative that was revealed was that of one of mass scale producer and recycler of plastic who is successfully implementing a deposit refund system along with ‘Sathosa, (goods cooperative body) ’ for water bottles, where when the plastic bottles are returned by the public that they get compensated by money (value of Rs.10/- each).

The company stated their willingness to establish and operate collection centers around the country with the collaboration of MOE and CEA to collect the PET bottles for there ow recycling facility. But then even that was a positive initiative officers had to think of the

smallholder collectors and recyclers, as their livelihoods would be negatively affected. So what the regulators mentioned was that they are in the process of planning to go for a sustainable system where all the stakeholders in the recycling sector get involved and collaborate with each other to create a win-win situation for one another.

4.13 Policies, plans and actions on the ground

Many policies and guidelines formulated by various institutions in Sri Lanka already exist which directly and indirectly provide guidance and provisions in managing solid waste including plastic waste. Environmental policy (2003 & under revision), National waste management policy (2019), climate change policy (2011), cleaner production policies and strategies (2019), marine pollution prevention act (2008), sustainable development act (2017) are some of them.

As identified via the situation analysis, the gap is in implementation and taking actions accordingly. In consultations Environmental Ministry personals highlighted that them as policy makers have been developing the policies but the real challenge is in implementation.

Considering the need for addressing plastic pollution, the introduced National Action Plan on Plastic Waste Management (NAPPWM) in 2021 is an important initiative in paving the pathway for better plastic waste management in the country. Goal 5 of the national action plan, which specifically is about reduction of marine plastics pollution comprising macro and micro plastics flowing into ocean through land-based activities (*National Action Plan on Plastic Waste Management Sri Lanka 2021-2030*, 2021) as previously discussed which closely align with the ultimate purpose of this study

4.13.1 Introduction of an EPR system for PWM

The main goal of the project was to reduce plastic loadings into the coastal and marine environment by providing crucial "technical and advisory capacity assistance for a circular economy for plastic waste management." Additionally, this project concentrated on enhancing the supportive environment and enhancing stakeholder entities' capacity to implement a systematic post-consumer plastic management system throughout the nation with the involvement of all relevant stakeholders.

In order to provide strategic guidance and to speed up the process of establishing an EPR Policy in Sri Lanka, the project, which was launched in October 2018, established a Project Steering Committee with representation from all relevant stakeholders, including the Government Sector, the Private Sector, and important associations dealing with polythene and plastic production and recycling in Sri Lanka. In order to get their early comments for the creation of an EPR mechanism that is acceptable to all stakeholders, the project has held a number of meetings with important government agencies responsible for waste management as well as private sector organizations. Additionally, the project has paid for a Market and Socio-Economic Study, which will produce crucial country-specific data on plastic consumption and the potential for using circular economic concepts in Sri Lanka, allowing for decision-making that is both economically sound and based on science. A practical and effective EPR Roadmap with a public-private partnership strategy was to be delivered by the end of the project in September 2020 for acceptance by all stakeholders accountable for this issue. (*Introduction of an Extended Producer Responsibility System for Plastic waste Management*, 2019)

Based on the findings of the project EPR – Lessons learned from Sri Lanka

Specific strategies the EPR Roadmap included are as follows:

- Mandatory National Packaging Recycling and Recovery targets to be set for all industrial and commercial producers of consumer packaging waste;
- Post-consumer packaging waste to be collected, sorted, and recycled according to established national targets;
- Companies must publish their annual production of plastic and how much was recovered for recycling purposes using the reporting formats mandated by the Ministry of Environment;
- Companies must finance the infrastructure necessary to collect back the equivalent of the packaging they placed in the market within an agreed time period and must support consumer education campaigns on the prevention of littering or on the proper sorting of discarded packaging, among other topics;
- Data deficiency on plastic use by industries is evident in the country and therefore, the roadmap suggested that the Government of Sri Lanka impose mandatory reporting regulations alongside a monitoring and tracking system.
- Each household shall use four bins or separation units for organic, paper, plastic, and glass and metal or a minimum of two bins for recyclable and non-recyclable waste;

- Each local government body must be made accountable for efficient SWM by setting targets for plastic waste collection and must establish systems to impose penalties for not meeting targets and incentives for good performance; and
- Fines and penalties will be put in place with the Environment Planning and Economics Division of the Ministry of Environment empowered to impose them. Penalties would be placed on producers if they do not meet the agreed annual recycling target, households if they do not segregate their waste, and the public for littering, open dumping, or open burning.

Until the National Environmental Act is changed and laws are published to support the EPR, the Ministry of the Environment is willing to support the execution of the EPR Roadmap on a voluntary basis. A pilot program for lowering polyethylene terephthalate and high impact polystyrene is one of the EPR techniques that can be adopted on a voluntary basis. The National Cleaner Production Centre was hired by the CCC to create training materials for recyclers and other stakeholders in support of the future deployment.

Implementation

The EPR Roadmap's implementation schedule and timetable have not yet been decided by the Sri Lankan government. The Clean Cities, Blue Ocean Program grant from USAID will help CCC support the roadmap's implementation. CCC has started a pilot study to voluntarily deploy the proposed EPR system using a PPP approach. The two phases of the pilot project are dedicated to creating the appropriate frameworks and putting the EPR Model into practice. Establishing a collection and reporting framework through multi-stakeholder involvement is the core activity of Phase I, "Establish A Collection and Reporting System Framework," which is planned to last for 10 months, from May 2021 to February 2022. The operationalization of a pilot project on collection and reporting frameworks, as well as the documentation of the model and success factors for implementing a mandatory EPR system, will be the two main activities of Phase II, "Implement EPR Model on a Pilot Scale through a PPP Approach on a Voluntary Basis," which will start in March 2022 and be implemented over the course of a year. (Gillet, 2021)

Likewise, according to the information found via stakeholder consultations and news reports ("Ceylon Chamber and Ministry of Environment Propose ‘Collect-Back’ Plastic Waste Management Model for the Private Sector," 2022; "‘Collect-Back’ plastic waste management

model for private sector," 2022), going forward with this EPR plan in June 2022 the EPR system was launched as “Collect-Back’ plastic waste management model’.

‘Collect-Back’ plastic waste management model for private sector

The Ceylon Chamber of Commerce (CCC) and the Environment Ministry offered the "Collect-Back" model for plastic trash to the commercial sector with the primary goal of strengthening the waste management system in the business community. Collect-Back is an EPR paradigm that mandates recycling and reducing the usage of plastic packaging from all parties involved in the production of plastic trash.

The Central Environmental Authority (CEA) is tasked with closely observing the development of the suggested mechanisms and completing the legal requirements necessary to achieve the effective results. The Environment Ministry and CEA highlighted the need for the private sector to follow the EPR concept with the best available technology at the EPR model launch event earlier this week in Colombo. The response of the participating commercial sector was very encouraging.

The EPR road map was created in 2021 by the CCC and Biodiversity Sri Lanka (BSL), with funding provided by the US Agency for International Development (USAID). The Mandatory Reporting and Collect-Back (MRCB) model was implemented with the goal of establishing a strategic plan for managing plastic waste in Sri Lanka as advised by the EPR road map.

Users of plastic must declare their annual usage under this MRCB model and promise to pay back a predetermined proportion that is intended to approach 100% over a five-year period. In order to reduce plastic pollution, the project strives to enhance plastic trash collection and recycling.

"There is an urgent need for an integrated and coordinated strategy throughout the plastic value chain to develop a sustainable framework, assuring effective and effective plastic waste management," the CCC CEO stated. The Collect-Back Target methodology will assist provide an effective system of monitoring and assessment and encourage greater corporate accountability.

Through the online reporting system, the private sector will start reporting on waste collection and recycling. First, attention is given to two plastics: packaging made of high impact polystyrene (HIPS) and polyethylene terephthalate (PET). The results of the optional EPR

implementation will be documented so that future mandatory collection and reporting systems can learn from them. A high-level multi-stakeholder project steering committee, co-chaired by the secretary of the Environment Ministry and the secretary general of the CCC, directs the initiative. The CCC and Environment Ministry have also asked all private sector businesses that use plastic packaging to step up their voluntary plastic collection and recycling operations and start keeping the required records as of 2022 in order to show their commitment to EPR.

In stakeholder consultations with the private sector, ministry of environment and CEA the following information were further captured related to the EPR scheme. Collected plastic waste are to be disposed by the packaging producer and the collector itself or via partnerships. Recycling is promoted via partnerships with recyclers and collectors. As the manufactures might not be expertise and having the technology in recycling, outsourcing and partnerships are highly encouraged for a efficient recycling and disposal. Any way the producer is responsible in monitoring the collection recycling and disposal of the plastic waste generated by them.

So, adhering to the initiative PET bottles are being mainly considered. There production is to be monitored via a reporting mechanism and encouraged to recycle an agreed percentage. This recycling is done either by themselves, by another local recycler or exported after pressing into cubes, which is costly to be done. Therefore, in exporting crushed plastic waste is preferred but then the country is in need of technologies and the machinery that are costly to be imported, especially with the prevailing dollar crisis. Solution for such situation is innovating affordable and adoptable technology for the country.

Eco Spindles (Pvt) Ltd, Sri Lanka's largest plastics recycler, has successfully initiated such upcycle system where the collected plastics are transformed in to flakes via crushing and then used to produce products with high-quality synthetic monofilaments for cleaning tools/brushes and yarns for innovative textiles and also export.

Eco Spindles (Pvt) Ltd

Eco Spindles (Pvt) Ltd is a leading manufacturer in Sri Lanka for top quality monofilaments for cleaning tools and yarn for fabric manufacturers globally. As the largest plastic recycler in the country, they use the recycled plastics for the high grade yarn and filament manufacturing processes. Their eco-friendly products coming through cutting edge technologies are mainly exported and reaches some of the world leading fashion brands.

Their range yarns include several categories as shown below which emphasized the specific use and origin of the materials. Further, they provide a marketing value for each product by giving a customer a ‘tag’ which certifies that certain product is used how much of recycled materials.

Figure 45: Range of brands from Eco Spindles

Furthermore, monofilaments are manufactured for brushes and cleaning tools using different recycled materials as shown below,

PET POLYPROPYLENE PS NYLON PBT

Figure 46: Monofilaments materials from Eco Spindles

Simply their recycling process flow is as follows,

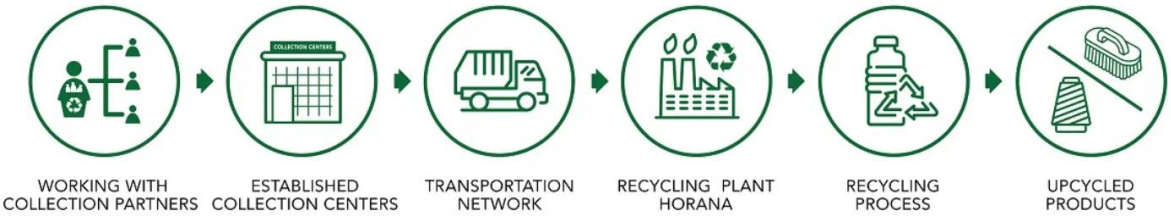


Figure 47: Recycling process flow of Eco Spindles

Eco spindlers have over 400 PET collection centers around the country which handles around 9 tonnes of PET plastics daily. At the end of the month, the recycling amount reaches as much as 250 tonnes of PET bottles throughout the year (Spindles, 2022)

Their upcycling and recycling initiatives create a sustainable environment while providing jobs such as PET collectors, handlers, transporters providing the financial support to their families.

The company has partnerships with several local and global product manufacturers, NGO's and other supporting organizations and is continuing and doing best to make this as an sustainable eco-environment for the country.

One of only two plants in the world and the only one in the nation that has the ability to produce polyester yarn directly from recycled polyethylene terephthalate (PET) plastic flakes is owned by the corporation. Their most recent extension of the yarn mill, which increased monthly production capacity by 120 percent from 100 tonnes to 220 tonnes, was finished in April 2022. Additionally, Eco Spindlers recently disclosed their intentions to produce recycled polyester yarn from textile waste and indicated that talks with textile producers are now ongoing. (*Eco Spindles helps Sri Lanka's circular economy for plastic recycling*, 2022).

Anyway, based on the discussions with the stakeholders including Clean Tech (brief description about the company is mentioned below), Eco Spindles and other recyclers. The collection of the plastic recyclables is not sufficient for the production thus have to import the flakes from other countries.

Collection of plastic waste in Colombo district is much better when compared with the other districts. This is mainly due to transportation issues logistics and storages issues.

When plastics are collected in villages, there is a need of a large space to store them till being transported mainly to Colombo and western province as majority of the recycling facilities are situated in western province. This requires high initial cost. And another burden is the transportation issue of these collected plastics to the recycling facility

There for it was sorted out that local informal collectors are efficient if connected and provided with sub collection centres with machinery to press and pack the collected so that the issue of needing a large space could be resolved even further making them easy to be transported. Then comes the issue of financing such facilities. The solution is the help of EPR model "collect back" where the manufacturers are made responsible for their production and waste generation and make them responsible for the final disposal of them as well. So, either they themselves should do the collection or else get the help of the local collectors, which is the most sustainable method that would create win -win situation but the companies should be responsible for facilitating such systems providing financial aids and technical support in building collection centres, machinery and transportation facilities etc.

In such a situation PRO (Producer Responsibility Organization) would come in very useful EPR PRO. In order to implement successful and practical EPR system, it is required to

implement a system that all these EPR activities and all the stakeholders are playing their part. Then only, the true use of the EPr system may come to an effect. Otherwise, even though a successful EPR system established, if it is not continuously monitored and assessed, discontinuation can lead to failure of the whole project. In such matters, Producer Responsibility Organizations (PRO)s play a critical role in the project. Since riverine plastic waste management requires a considerable level of community involvement PRO can be the organization which does the managing and communication part between the industry and communities. Once an EPR is implemented and all the funds, taxes, fees and all the payments can be handled through a PRO. Then when it comes to utilization of funds for the waste management purposes, these funds can be effectively put to use through an PRO's involvement (WWF, 2022).

Clean Tech (Pvt) Ltd

Founded in 2002 to streamline logistics for the Municipal Council's significant garbage, Cleantech has a long history of processing and providing innovative waste control solutions. The company gradually developed into a full-service trash management organization, earning the right to interact with government agencies and local councils as their primary service provider.

Over time, we expanded into a number of promising industries. Some of our major achievements include starting recycling in 2004; developing infrastructure specifically for operating and safeguarding a growing fleet of vehicles; drawing close the sanitation provider concept in 2006; entering the E-waste market; and expanding waste management facilities.

With the luxury of over 1800 employees, including environmental specialists, engineers, task-specialized staff, and experienced laborers, a fleet of over 150 trucks, and expanding facilities, Cleantech has become the industry leader in waste management. Currently, 102,200 tons of perishable garbage specifically designated for composting and around 150,000 tons of waste annually are handled. Together with the Universities of Moratuwa and Peradeniya, the company was exposed to scientific research on landfill engineering, and as a result, they were able to construct a successful landfill with the help of an environmental impact assessment (2006).

Cleantech services now include hygiene management, built environment management, resource recovery, e-waste, and advisory services in addition to solid waste management.

Solid waste Management

Hygiene Management

Built Environment Manageent

Consultation Services

Cicular Economy

Figure 48: Services of Clean Tech

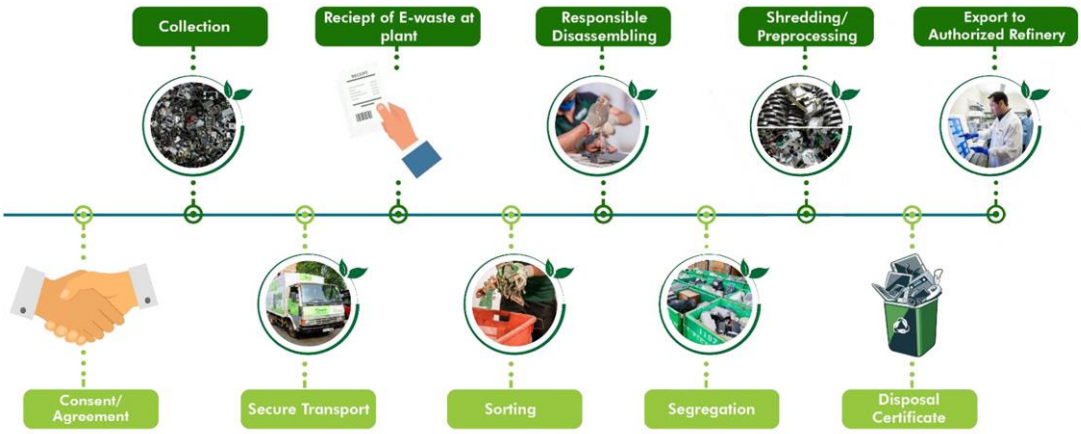


Figure 49: Resource and E-recovery flow chart

Source: (CleanTech)

4.14 Problems and barriers identified (briefed)

So that as mentioned in detail previously and included in the Appendix G following challenges could be identified via the discussions with the relevant authorities including government authorities, NGOs, field experts, and private sector related to plastic waste management in Sri Lanka. The identified challenges are briefed here while mentioning the stakeholders who stated them. Further information could be retrieved from the appendix that contain the interview minutes.

- Lack of effective and efficient coordination, communication and collaboration among the institutions involved in managing the waste as well as all stakeholders is one of the main challenges mentioned in almost all the interviews conducted.
- Goal 7 of the Action Plan (*National Action Plan on Plastic Waste Management Sri Lanka 2021-2030*, 2021) identifies the need for a strong Extended Producer Responsibility (EPR) system. As discussed before now the government authorities and the private sector together are paving path towards a better EPR system. But still it is not mandatory, and the system is in need of better structure supported by policies, rules and regulations.
- Lack of resources, such as financial, manpower, skills, and technical competencies, caused delays in the implementation of the majority of planned actions. As a developing country and a country in a economic crisis, this is one of the prevailing system that is unavoidable. All the stakeholders were concerned about that, and it was evident from the consultation interviews conducted.
- Need of effective awareness programs and campaigns are still required when considering the behavioral patterns and attitudes of communities and the general public such as littering, dumping on illegal dumpsite and using river as a garbage disposal site. Academia and IUCN stated that implementing effective awareness programs is lacking especially emphasizing on health and wellbeing of people and family.
- Issues in utilizing the grants and funding, was brought forward by an UNOP official actively engaged in grant management. how to distribute the grant among the organizations to carry out studies, the criteria and platform to engage in selection and ultimately closely monitoring and evaluation of the outcomes
- Lack of baseline data and information in conducting research was mentioned by the interviewed academia and also had to face this issue while conducting even this study,

It was really difficult to find the literature regarding the related studies. And even when the information was found they might not align with the study or scope of one's work.

- Lack of funding and facilities for research. Again, was mentioned by academia and IUCN the allocation from the budget is not sufficient as a percentage from the GDP.
- Requirement of incentives, technological support and supervision, monitoring and guidance to recyclers, and collector, especially small holder establishments and informal sectors.
- Another highlighted challenge by the representative of the IUCN is understanding the real value of environmental projects. With the inability to quantify the value and since there is no system for ecosystem or environmental accounting to calculate actual cost of pollution. And evaluate the conversational benefits. The policy makers and regulators have been unable to allocate the right amount as grants or fundings for the environmental projects directly through the budget.

4.15 Plastic & Economic Crisis

Need of a Market transformation

As Sri Lanka is currently facing its worst economic crisis, the country is having hard time allocating foreign reserves for the imports. Since the remaining funds are allocated to the essential goods, funds for importing plastic and related products will be extremely limited to only the essential medical supplies. Therefore, this will create a huge supply and demand gap for the plastic related products. This time can be effectively used to transform the market to introduce sustainable ecofriendly solutions to replace the plastic related products. The effect of higher price of ecofriendly products compared to plastics will be minimal given the higher needs of the society for similar products. If the right policies and legislations are put into the correct manner, the change of habit of the society can be relatively easier in order to adapt for sustainable replacements.

CHAPTER 5

Suggestions and Recommendations

5.1 Related to the river

As identified in the result and discussion section littering, fly tipping and illegal dumping, poor waste management practices, industrial activities leading to improper disposal and loss, sewage debris and discharge along with abandon fishnet are identified as main sources of macro and microplastic pollution in the river. So that following recommendations could be suggested to reduce the plastic pollution in the river caused by land base sources that ultimately leads to marine pollution

5.1.1 Littering management

In addition to solid waste management, cleantech services now offer advice services, resource recovery, hygiene management, built environment management, and e-waste management. More effective awareness campaigns are required to create awareness as the existing awareness generation is not sufficient.

Local governments must establish the necessary conditions if citizens are mandated to refrain from littering. The appropriate local authorities must take action to guarantee that more trash cans are erected in various locations for efficient waste disposal. Enough trash cans placed in public spaces, along walking routes, by bus stops, bridges, beaches, and fast-food restaurants will make it easier to collect and dispose of trash. The waste bins must be routinely emptied when placing them to prevent further issues caused by overfilling.

Some suggestions for Plastic littering management are further discussed herewith with the help of US EPA 2022 guidelines. Make aware the public about plastic recycling and give information to self-motivate the crowd to avoid littering in public. (Especially young generation) – they can be used as the target groups in order to start the action. Provide them more information regarding plastic pollution via littering, source, pathway and leakages, marine pollution etc. and how preventing littering can be benefitted in future. Make them the leaders and driving force towards sustainability and pollution reduction as they are the future of the society and changing attitudes and behavioral patterns of them are far easier than adults.

Make people involved in public places cleaning social projects and provide some recognition to motivate them to go forward and spread the word. Involve companies in such events to make sure they are noticed by these industries. Local authorities can impose fine system or punishment-based method for people who litters in public. Set up few examples and give publicity to make notice of it.

Local authorities can impose laws mostly for households, industries, shops, hotels and other facilities in urban areas to keep the surrounding clean and appoint a team to pay regular visits and take action against those who do not obey. This can be also done with the Kelani River mainly assigning the industries and industry zones in the main cities that Kelani River pass by and also make the households beside the riverbanks to be responsible for their waste generation and disposal. But in the meantime, the local authorities should provide them with the collection and bin facilities so that they have a better alternative in disposal of waste rather than throwing the garbage to the river.

Implement a user-friendly application to collect information of the common littering places and random litter in public roads and spread among the people. Include a mark system and Provide recognition, incentive, and publicity of those who achieve certain points at each month. For instance, mobile applications could be given as examples. In Countermeasure project a such system is introduced and is in development phase, which needed to be further localized catering the countries needs

Establishing regulations in to prevent throwing litter out of moving vehicles and public transportation. Inform the transport services to make aware of this to the people and provide them with sufficient facility to dispose waste inside the means of transportation eg. Inside the bus or train and guide them to use it. And when they are full transferring into a garbage disposal facility elsewhere or local authority

Establishment of more separate dustbin systems in public areas as the prevailing ones are not sufficient. Another thing is on them providing clear instructions regarding what type of a waste to discard in it., whether biodegradable waste, plastic / polythene, paper and cardboard, glass as well as E-waste.

Identification of littering hotspots

In order to address the littering issue and allow initiatives and actions to be taken successively, it is required to correctly identify the common littering spots along the river basin. Public

littering on riverbanks or directly in the water, waste from cities and harbors, poorly managed landfill sites, fly tipping, improper product disposal or loss from industrial and agricultural activities, debris from the discharge of untreated sewage, either due to a lack of waste-treatment facilities or from sewer overflows, and storm water discharges, which also sweep litter, are some of these potential causes of littering.

However, due to a number of circumstances, it is difficult to pinpoint the sources and distribution routes of riverine trash. Due to the robust level of accuracy of littering it is often failed to identify the exact littering pathways all the time. Most of the packaging waste were found often along the riverbanks and the littering spots are never the same for every case. Some recent research findings suggest several factors to manage riverine plastic littering issue (GES, 2016)

- Enhance our fundamental understanding of litter routes, behavior, and aquatic system fate.
- Transport of litter varies physically in rivers and temporally over a range of time ranges.
- Budgeting for resources at the macro, meso, and micro levels is inconsistent.
- modern approaches, like automated spectroscopic and imaging methods.
- methods for locating litter input hotspots cost-effectively.

many research findings point out that the key of proper riverine waste management is proper identification and estimation of riverine litter. These estimations can be helpful in a way to understand the common littering items, hotspots, pathways and suggested solutions can be provided in various levels to avoid the littering and save the aquatic environment.

In aligning, CEA, Ministry of Environment, and IUCN collaborating in the project Countermeasure has implemented such process in identification of littering hotspots recently and the findings are yet to be published. The methods used in monitory were a mobile application and a Go Pro camera system mounted in a vehicle. This could be identified as a good initiative in moving forward with plastic waste management in rivers.

Table 8: Short-, mid- and long-term recommendation for littering management

Short Term	Mid Term	Long Term
Increase the penalty charge/ fines (Current Range Rs.750-1500) MOE and CEA officers mentioned that the fines do not accurately implicate the cost of pollution. If the fines are increased and effectively enforces people might get reluctant to litter and engage in illegal dumping as they do not want to pay a higher fine	Garbage bin allocation And offer convenience in disposing and collecting litter. Empty bins regularly avoid overfilling. Increase the door-to-door waste collection facility Need of a improved garbage collection mechanism was a suggestion brought forth by all stakeholders as the prevailing system is not sufficient and as said by the MOE mainly covers the main cities and only around 40% of the population. And even in recycling the problem identified was with waste collection, transportation and linking with the recyclers. So that improvements in the waste collection system is a timely requirement. That should be achieved at least as a mid-term plan with the prevailing economic situation and the cost.	Policy amendments – Give sufficient power to the Environmental authorities Strengthen the legislations and policies and giving more power to the regulatory bodies is really important.
Enforce exciting legislations and fines effectively. All the stakeholders emphasized on the implementation and enforcement of rules and regulations and action plans. It was evident that even with a system of well-planned action plan and system of rules and regulations in written, There is no use if not implemented.	Establishment of a convey belt to trap the litter and prevent them from moving down the river. This should be further studied and should check the practicality, adoptability, technicality, and cost functions before the establishment.	School curriculum Development Improve Primary education curriculum and school curriculum – like in Japan let them practice by themselves. Application oriented changes. Encourage critical thinking and interactions rather than being self-oriented. But do not force them.

		Go beyond textbook education and let them get the first hand experience and practice. Proper education and awareness is the key in changing attitudes and it should be done in the early age.
Installation of more garbage bins in public areas and collection facilities – provide clear instructions in separation As observed during the surveys common bathing spots and recreational areas near the river seemed to be of having more discarded litter and illegal dumpsite. Possibility of installing a system of garbage collection via establishing bins would reduce the severity of littering	User-friendly application to collect information of the common littering places and random litter in public roads and Provide recognition, incentive, and publicity of those who achieve certain points. - Mobile App Already implemented by the Countermeasure project in pilot scale with the help of the officials. The app could be further adopted to a more user- friendly app and provide for the public to test.	Awareness campaign Highlighted by both Academia interviewed and IUCN and UNOP officials The suggestion was that the awareness campaigns should focus more on bringing forth the health concerns, toxicities caused by the macro and micro plastic pollution on people and family. Make the aware regarding the severity of the risk on lives.
River & Beach Cleanup As per findings from the consultation already river and beach cleanups are happening but not in a scheduled or systematic manner.		
Awareness Campaign Going for a creative campaign emphasizing more on the health risks associated with plastic pollution.		
prevent throwing litter out of moving vehicles and public transportation. Simply establishing a bin inside the vehicle (bus or train would address the issue.)		

5.1.2 Industrial activities - improper disposal and loss

According to the findings via consultations and situational analysis there is a need of close monitoring system to identify whether the rules and regulations that have been westered upon the industries regarding waste disposal and treatment are implemented accordingly. Maintaining a regular reporting mechanism was suggested by the personals from the Ministry of Environment along with increasing the amount of fines and punishment scale when the regulations are not followed up. As per now the according to the officials' fines do not truly implicate the true environmental costs and are not sufficient. Therefore, further studies should be carried out in identifying the exact numbers to implement the polluter payer mechanism well.

Table 9: Short-, mid- and long-term recommendation for improper industrial disposal

Short Term	Mid Term	Long Term
Requirement of a close monitoring system for industries regarding waste disposal and treatment. As discussed, prior the regulatory bodies were not satisfied with the Waste water treatment facilities maintained by the industries. And they stated of the need of a monitoring system.	Impose and increase the fines - truly implicate the true environmental costs	Plastic litter and MP has not specifically been included in waste treatment regulations or standards. Further studies are required in identifying the presence of MP and standards
Maintaining a regular reporting mechanism	Make industries and industry zones responsible for their waste generation and disposal	

Another important suggestion is that as discussed, plastic litter and MP has not specifically been included in waste treatment regulations or standards. Further studies could be conducted in such treatment facilities to see whether the presence of microplastics in the water at the

source itself. If so relevant measure could be taken based on their abundancy of the micro plastics like filtration methods and sieving.

5.1.3 River Cleanup

Based on the section 2.10.1 under river cleans up from clean current collision following suggestions could be proposed, Likewise the convey belt on the Athi River Kenya and plastic trap method on Lat pharaoh Canal Thailand, similar approach could be used in establishment of a convey belt near to the river mouth of the Kelani River, cooperating with industries identified as responsible for plastic pollution and a NGO or governmental organization. Generating fundings via an Extended Producer Responsibility (EPR) system communicating and getting the support from the riverside communities, coordination could be done by a government agency or a NGO. For the monitoring purposes, a committee can be appointed representing all relevant parties to make sure the contribution of each party is sufficient.

5.1.4 Poor waste management practices

Furthermore, aligning with the policy recommendations of the world bank report of Indonesia (*Plastic Waste Discharges from Rivers and Coastlines in Indonesia*, 2021) following policy recommendations could be derived as a developing country in the region with similar issues in plastic waste management

- Boost solid waste management strategies, education, and incentives
- give improved access to solid waste management facilities and increase total garbage collection coverage
- Increase household sanitation initiatives at the national level to improve community awareness of proper waste disposal practices and decrease household trash disposal into waterways. This is a much-needed endeavor when taking into account community and public attitudes and behavioral patterns, such as littering, unlawful dumping, and using the Kelani River as a landfill.
- Invest in new, well run ultimate disposal facilities and upgrade already-existing facilities, notably those close to waterways.
- designing drainage systems and structures in streams to stop plastic garbage from entering the ocean.

- Implementing cost-efficient, effective policy tools including taxes, fines, and incentives is recommended. Aside from providing incentives for river cleanups, waste collectors, and recyclers, taxes and fines could be imposed on the identified polluters, businesses, and households.
- Introducing a systematic monitoring and improving waste data, related to illegal dumping sites, littering spots, fly tipping.

Table 10: Short-, mid- and long-term recommendation for poor waste management practices

Short Term	Mid Term	Long Term
Strengthen solid waste management practices, knowledge and incentives.	Improve overall waste collection coverage and provide better access to solid waste management facilities	Increase national sanitation campaigns at the household level, to enhance community understanding of healthy waste behaviors and reduce the household practice of disposing waste directly into waterways.
Introducing a systematic monitoring and improving waste data, related to illegal dumping sites, littering spots, fly tipping.	Invest in new, well-managed final disposal sites and upgrade existing sites, including those near waterways.	Designing structures in waterways and drainage to prevent plastic waste from reaching the sea.
		Cost-effective, impactful policy instruments such as taxes, fines and incentives should be implemented. Taxes and fines could be westered upon the identified polluters, Industries and households and incentives could be provided for the river cleanups, waste collectors and recyclers.

5.1.5 Sewage, Canal debris and discharge

Table 11: Short-, mid- and long-term recommendation for sewage, canal debris and discharge

Short Term	Mid Term	Long Term
More scheduled cleanups Eg: Getaheththa Ela Hamilton Canal	Designing structures in waterways and drainage to prevent plastic waste from reaching the sea.	Improve and restructure the drainage and sewage systems
Plastic waste traps	Plastic waste traps	Impose and enforce wastewater treatment regulations

5.1.6 Abandoned fish nets

Preventive measures

- Development of guidelines and application system for gear marking. Making the owners responsible for their gears.
- Port state measures – critical in addressing the illegal fishing issues which adds unaccountable gears.
- Onshore collection/ payment for old/retrieved gear. (The Korean waste fishing gear buy back project)

Mitigating measures

- biodegradable nets and pots

Post cleanup measures

- Locating lost gear
- Better reporting of lost gear

5.2 Country situation

For the identified challenges as mentioned in the result and discussion section following recommendations and managerial approached could be suggested incorporating the suggestions provided by the stakeholders that were interviewed. Their responses are included in details in the Appendix G.

Clearly defining and disseminating the responsibilities among the governing bodies, while establishing a platform for all the parties to get together and share resources, knowledge, expertise, and technical support could be suggested for the challenge of communication and collaboration among stakeholders. Along with that another important requirement is a system to monitor and evaluate the waste management activities and projects carried out by different parties inclusive of a reporting mechanism. Thereby the impact and the worth of a project could be brought forth in a systematic manner

In improving the waste collection services, improving the livelihood & quality of life of waste collectors is crucial. It's not just about increasing salaries and giving financial benefits. But providing support in improving mental health and wellbeing, attitudinal changes and behavioral changes adding value to their livelihood and quality of life. Recycling could be further encouraged providing more incentives and facilitating with logistics and providing collected materials.

Awareness and education play a key role in plastic waste management. Even though thus is identified by the governing bodies and relevant measures are taken, when observing the attitudes and behavioral patterns of the public, it's questionable whether the actions taken to raise awareness and education are sufficient and effective. There is need of a creative programs and campaigns of awareness. Especial attention should be paid in incorporating and designing education curriculums in schools and educational institutes. And another highlighted fact in awareness generation that was highlighted during the consultations were that need of prioritizing the linkage between the plastic waste and ones and family's health. The severity of the damage it causes to all ecosystems, including wildlife, marine life and human should be highlighted.

In grant management issues, it was identified that the main cause of the issue as they have no proper project implementation methodology or structure to follow once project is initiated. Operations such as, hiring of human resources, identifying key players, subletting the projects, monitoring and evaluation, etc. are in need of structurization. A common procedure or common

body must be introduced in order to handle such cases and facilitate the procedure. A platform could be introduced for selecting the organizations based on criteria that is much focused on the outcome, realistic and achievable nature of the proposal. Monitoring and Evaluation of these outcome over the spending is also another requirement. Any way extra costs that need to be bared for external organization hired just for the preparation of documentations can be saved and be successfully utilized in the project itself if the government can facilitate this platform.

Lack of baseline data and information related to research is another challenge strongly felt even when conducting this research as either much research, programs, projects conducted, and their outcomes were not properly published or else not available online. Still the government sector mostly use physical document storage rather than online systematic storage of documents. Which is not efficient and practical and needed to be replaced by a online platform, online data repository a national data base to store and retrieve these information and the access given to all stakeholders and general public.

Lack of funding and facilities for research and requirement of incentives, technological support and supervision, monitoring and guidance to recyclers, and collector, especially small holder establishments and informal sectors along with collection center establishment and improvement of the technologies could be all done via a well-structured EPR system as discussed follows.

Packaging and single use plastic is identified as a main concern over the macro and micro plastic pollution (via secondary origin) based on the field survey findings as majority of the Macro plastic observed and collected were of packaging and via situation analysis it was further confirmed that packaging waste is the most common time of plastic polluter.

To address the global issue of packaging waste, different countries have applied various policy, technical and other initiatives according to country's situation. Circular Economy, EPR and Economic instruments (taxes, fees, deposit refund system, PAYT) were common initiatives found. Further, product standard development, ban of non-recyclable plastic are also found among the applied initiatives. So that considering the Sri Lankan context following policy instruments were further recommended to be improved.

5.3 Policy instruments

5.3.1 -EPR including fees and PRO

EPR, or Extended Producer Responsibility is a policy initiative implemented to make the manufacturer responsible for packaging waste after customer consumed the product. Currently, many governments seem to follow this initiative due to its capability of involve private parties along with government for the waste management (Public private partnership)

The EU-funded SWITCH-Asia program has started a plastic waste management campaign in Sri Lanka to promote a long-term strategy for a sustainable, transformative, and inclusive circular economy (SWITCH-Asia, 2022). The Sri Lankan government has implemented measures to lessen plastic pollution and enhance waste management, including an Extended Producer Responsibility (EPR) program to limit plastic use. Through the development of circular economy techniques in the plastic V/SC, the project contributes to the overarching goal of the European Green Deal 2019, and more specifically, the EU Circular Economy Action Plan 2020. As a result, the initiative creates synergies with two of the European Green Deal's policy priority areas (Hennlock et al., 2015):

1. preventing pollution: maintain the cleanliness of water streams and safeguard the biodiversity of lakes, rivers, and wetlands.
2. Sustainable product policies encourage the circular design of all products and drastically cut waste, particularly in resource-intensive industries like the textile business.

This is a very recently proposed system and based on the consultations it was further found that the implementation will be focused mainly on PET plastic and the system is not a mandatory system but a voluntary initiative.

Likewise in Sri Lanka majority of these polluter payer systems are not mandatory but voluntary. So that even though the aim of these systems is to force the manufactures to assume the responsibility for their waste, it has not been effective since majority get away when it is voluntary. For instance, in many EPR systems consist merely of taxes and levied (PREVENT Waste Alliance, 2020). As indicated in the literature review, returnable containers have been used in this situation, and producers are being urged to lower the thickness and weight of packing and containers. Shopping bag fees are also being contested..

5.3.2 Fees

Charging prices from plastic and packaging manufacturers on their production, waste, and applying licenses are every other manner of making industry pay for their contribution on plastic waste. At the side of EPR systems it was typically seen that those fee mechanism is implemented. The maximum generally used financial policy devices affecting plastic waste management within the eu-27 are expenses and charges for rubbish collection, producer obligation schemes for specific waste streams (as an instance packaging and beverage bottles) and fees and prices for waste disposal and remedy along with landfill and incineration taxes and restrictions (Hennlock et al., 2015)

In Sri Lanka also a fee system could be implemented for the major plastic manufacturers and producers when they are not taking responsibility or not taking sufficient responsibility to manage their waste creating especially in waste streams such as packaging and beverage bottles. Because as identified through the findings these the most prevalent type of plastic waste types in the country

Likewise considering the number of factories and local business authorities situated near the river and in the country based on polluter payer principle, it was observed that there is a requirement of a mandatory EPR system rather than the ongoing voluntary system. To make the system more efficient requirement of a PRO (Producer Responsibility Organization) was also realized.

5.3.3 PRO (Producer Responsibility Organizations)

In order to implement successful and practical EPR system, it is required to implement a system that all these EPR activities and all the stakeholders are playing their part. Then only, the true use of the EPR system may come to an effect. Otherwise, even though a successful EPR system established, if it is not continuously monitored and assessed, discontinuation can lead to failure of the whole project. In such matters, Producer Responsibility Organizations (PRO)s play a critical role in the project. Since riverine plastic waste management requires a considerable level of community involvement PRO can be the organization which does the managing and communication part between the industry and communities. Once an EPR is implemented and all the funds, taxes, fees and all the payments can be handled through a PRO. Then when it comes to utilization of funds for the waste management purposes, these funds can be effectively used through a PRO’s involvement (WWF Network, 2019).

5.3.4 Taxes

Similarly, to fees, taxes are also imposed on plastic packaging as a technique of creating the producer's responsibility of waste control. Under the EU law, all Nordic countries have imposed taxes and costs on plastic packaging. The extent of taxation is determined with the aid of each united states's countrywide goals and visions. (*Plastic Taxation in Europe*, 2022). Likewise, Sri Lanka can adapt a similar taxation system from the packaging manufacturing and selling companies. Another important fact is that whether these fees and taxations are sufficient compared to the environmental, economic and social costs as these monetary values have been questioned to be sufficient by the authorities are in need of quantifying the amount properly so that they could be allocated accordingly. Because as found while engaging in the stakeholder consultations that these taxes and discharge fees and penalties are not sufficient and properly implicate at least the implication costs.

5.3.5 Bans

The use of PET and PVC in the packaging of agrochemicals, sachet packets with less than or equal to a net volume of 20ml/net weight of 20g (except for packing food and medicines), some inflatable toys, and cotton buds with plastic stems (aside from plastic cotton buds used for medical/clinical treatment) are already prohibited in Sri Lanka as mentioned in section 5.9, and they will be outlawed completely in 2021. However, since the ban is imposed only in last year. this plastic item still seems to appear in the market from previous imports and productions. A proper follow up system is further needed to make sure these products no longer enter the market.

5.4 Market creation for upcycled and recycled products

5.4.1 Recycling vs Upcycling

Recycling is the process of disassembling waste and using it as a source of raw materials to create new goods. On the other hand, upcycling entails utilising materials in their present form without having to reduce them to their fundamental components. When a material is said to be easily recyclable, it means that it has a high recyclable property. Also, it does not show a significant deviation from the properties of the base material as well.

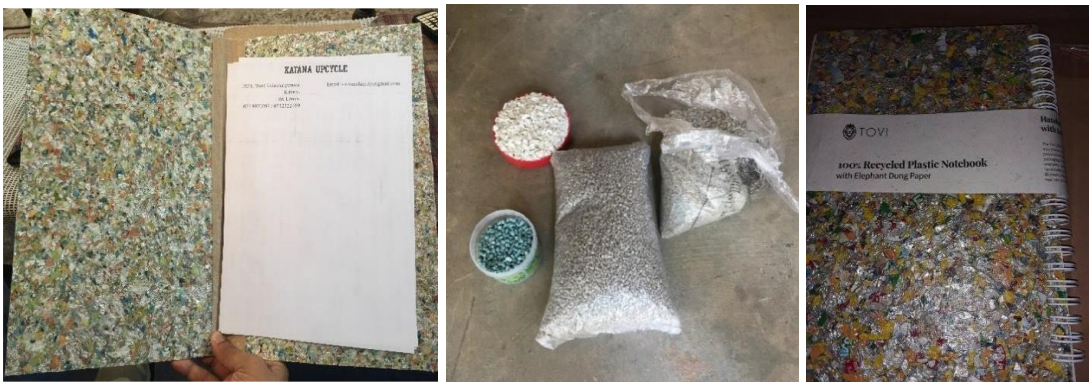
Recycling process is more focusing towards the mitigation of environmental impact of waste whereas upcycling is looking for the elimination processes. For an example. If we want to recover energy from garbage, we should consider turning non-recyclable materials into thermal or chemical energy sources. Also, reproduction of PET bottles from the collected plastic waste (PET) is another way of recycling. However, both of these options involved processing and operations which consumes series of operations, chemical mixing, thermal operations etc. this intermediate process could produce toxic emissions, harmful chemicals, non-recyclable materials as well as energy which is also another form of emission. Therefore, while we actually recycle some of the materials that could harm the environment, it could also create some negative impact on the environment as well.

Upcycling on the other hand is quite a new term to the society. As mentioned previously, upcycling is more focused on elimination of waste rather than mitigation. The importance of planning the product at the design stage for future upcycling is emphasized. This is referred as "designing out waste". So when once a certain product is utilized, then it can be reused with little to no alterations to the product. With this, the environmental impact from product recycling even after one utilization is omitted. Life Cycle Assessment (LCA) is often used tool in evaluation of materials environmental impact during the design stage for when it's designed for upcycling.

Comparing both process, upcycling involves comparatively less energy in cleaning and assembling, higher quality, produces significantly less toxic waste compared to recycling. However, considering the developing stage where this concept is now, these products can be expensive, not always commercially viable and can be difficult to manufacture.

As mentioned in the previous section Eco Spindle is a company that is successfully implementing such Upcycling system, where the collected plastics are transformed in to flakes via crushing and then used to produce products with high-quality synthetic monofilaments for cleaning tools/brushes and yarns for innovative textiles and also export.

Katana Upcycle is another establishment in where the majority of the plastics purchased are HDPE, LDPE, and PP, and the waste plastic is processed into recycled plastic pellets and upcycled goods.



Upcycled file cover Recycled Pallets Notebooks

Figure 50: Value added upcycled plastic products

Likewise, government should encourage and give incentives to encourage such upcycling companies while creating a market for them. Always encourage the recyclers to engage in value addition and quality maintaining rather than making them to clean press and pack the waste. At least make them sort and crush the waste as they have better market value as they could be directly used as a raw material in injection into a molding machines.

Encourage them and provide trainings and guidance to use locally available less cost technology to produce products such as Brushes, brooms, shoes, slippers, clothes, stationary, toys, furniture etc,

Introduce policies that would create a market place even locally like making the government, authorities and private companies responsible for purchasing certain percentage of their procurements to be from recycled and upcycled products. They need to be encouraged and connected with parties collaborated with markets. Such as tourism body, airport, hotels, conferences arrangement etc.

CHAPTER 6

Conclusion

The study confirmed the presence of MP in the meandering zone, surface water of the river. MPs were characterized accordingly and found that the majority of them were in the shapes of fragments and films made of PP and PE in prominent colours as white and blue. As two methods of sampling used in MP survey, Abundance detected varied from 0.47 MP pieces /L to 0.03 MP pieces/L in Bulk sampling and in Net sampling conducted from river outfall towards the city the MP abundance detected varied from 3.42 pieces/ m^3 to 0.57 pieces/ $m^{3.}$ Especial finding was the occurrence of nurdles in the upstream of the river, which is assumed to be because of the X-Press Pearl incident and needed to be studied further. It was realized that with the prevailing information identifying the exact sources and leakage pathways of MP is not possible so that there is a need of further studies and information to identify them accurately.

After characterization of the microplastic and identifying their polymers, there is a possibility of tracing back to their source, and if it is a primary source, it can be easily trace back to their relevant sources, for instance release from industries such as textiles, cosmetics, and homecare. That would be in line with the previously mentioned goal number 5 activity 2 of the national action plan, which encourages and focuses on researching the problems with microplastics in order to lessen unintended releases of microplastics from sectors including textiles, cosmetics, and homecare. But based on the findings of the study and based on the literature surveyed most of the times the microplastic are found to be from secondary sources, particles of initial macro plastic items such as water bottles, packaging waste, fishing equipment's etc. (Isaac et al, 2021) which is difficult to trace back exactly.

Therefore, in the study after identifying that the MP are of secondary sources and the abundance of the macro plastic pollution in the country and the river with the help of stakeholder consultations and plastic waste situation analysis possible sources were identified as Littering, fly tipping and illegal dumping, poor waste management practices, Industrial activities leading to improper disposal and loss, Sewage debris and discharge and abandoned fish nets.

And then the management recommendations were provided for the identification of possible sources, relating information from macro plastic pollution and waste management situation in the river.

Therefore it is expected that however the outcome could complement and align with target 5, which is to reduce marine plastic pollution, which includes macro and microplastics that enter the ocean through land-based activities, by 80% by 2030.

Furthermore, in light of the aforementioned challenges via the situation analysis of the plastic waste management, the Ministry of the Environment should establish collaboration and communication platforms among institutes, as well as monitoring and evaluation systems with reporting mechanisms for ongoing projects, activities, and their progress. Furthermore, government facilitating a criterion and a platform for subletting related projects to environmental organizations and other key stakeholders was also identified as a timely need. Because the government is short on funds to deal with plastic waste, it should strengthen the legal requirements for a mandatory EPR system that includes a producer responsibility organization (PRO) for better management. Novel awareness campaign emphasizing more of the health risks is also required to change the attitudes and behavioral patterns of littering, illegal dumping and fly tipping by the general public. Moving towards strong Private public and people partnership programs are required to make individuals more responsible in managing plastic waste. Market creation and value addition and encouraging upcycle products is another way forward.

And finally, it was realized that Sri Lanka is progressively initiating sound policies, rules regulations related to plastic waste management recently. And each stakeholders have many strengths in them with several ideas in how to manage the plastic pollution in the country. What Sri Lanka lacks is the effective enforcement of regulations and implementation along with the required resources and funding as a developing country. To overcome that effective and efficient coordination among the stakeholders creating a collaborative platform to prevent plastic pollution and introducing sound monitoring and evaluation systems in waste management activities is two of the main requirements. In regarding the Fundings and resources required, following the polluter payer mechanism and establishing the recent positively progressing voluntary EPR system with a Mandatory system along with a PRO (Producer Responsibility Organization) in near future would be a successful and sustainable solution.

6.1 Limitations of the Study

In this study, the collection of samples was random and rapid that the effect of specific and extreme environmental conditions are not taken into account. Therefore, seasonal variations such as monsoons are avoided during the sampling process. And also, the sampling was only conducted in the surface waters, without taking samples into account from sediments in the riverbank and other water columns in the river based on depths. The reason for engaging in only surface water sampling is that because based on the size of the microplastic there abundance is in the surface water (Vibhatabandhu & Srithongout, 2021)

Even though the sampling was random and rapid based on the constrains such as time, cost and purpose it was expected to gain a representative sample as much as possible from the selected locations, and of course since the study is one of the initiative studies conducted related to micro plastic pollution in the river, it is expected that it would be a good initiative and pilot study for other studies to come.
Furthermore, along with the survey carrying out a situation analysis related to macro plastic pollution and waste management situation, It was expected to produce an outcome that is more logical and justifiable and effective.

Even though the initial plan as in the proposal was to go for a collaboration with the Countermeasure project and collect samples using the same method in the same location and do a comparison. In two seasons. And utilize the project data related to Macro Plastic findings to identify the possible sources. conducting the stakeholder consultations. Due to the COVID pandemic, economic crisis, and political unrest in the country the project got delayed and still in the process of analysis and publication is going on. So that initial plan had to be changed. The data collected per now is not sufficient to identify the hotspots exactly and clearly. That is why it was suggested to collect more samples both Micro and Macro. Even though that identifying exact hotspot locations with the prevailing information. However, some possible hotspot areas were identified based on the MP and abundance of macro plastic observations. (Illegal dump sites and littering spots near the riverbank, pathways, bridges). Bathing spots in the river and picnic and partying spots near the river were identified around the sampling locations as places where plastic pollution could occur due to littering. So there is a possibility of generating GIS maps.

As the country is facing the worst economic crisis in the history, had to face lot of difficulties due to lack of necessary services, facilities and goods. In conducting MP survey and interviews

transportation issues arise due to the fuel crisis and also daily prolonged power cuts challenged the laboratory works and analysis.

6.2 Further Studies

It is expected to engage in further MP sample collection in the coming month, while carrying out more stakeholder consultations to get a much better outcome and to improve the results. Going back to the field was decided to improve the MP survey data with a replication to get a more representative sample. And for a further study, suggested by the professor who facilitated the research in Sri Lanka.

To replicate samples will be collected from same locations but along with surface water samples sediment samples will also be collected, it is also planned to collect macro plastic waste in the locations, as advised by the committee collecting macro plastic monthly and getting the volume and mass would give a data base to use in relating MP with secondary origins to Macro plastics Furthermore, GIS mapping could be done identifying the littering spots and dumpsites observed nearby when collecting samples and also while going upstream the river in collecting net samples.

In addition to that in polymer identification via FTIR spectroscopy analyzing the MP with their suspected macro plastic sources would lead in to identification and tracking of exact sources of the pollution

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Appendix A

Net Sampling

point	avg speed/(km/h)	river speed/(km/h)	time/ (min)	amount of water (m^3)
A	2.76	0.15	29.2	33.3
B	2.2	0.17	35.8	33.3
C	2.64	0.14	30.5	33.3
D	2.84	0.17	28.2	33.3
E	2.9	0.19	27.5	33.3
F	2.88	0.2	27.6	33.3
G	2.44	0.25	31.6	33.3

Equations and data used in calculations

Area of the net opening = $\frac{\pi D^2}{4}$

According to the observation during the sampling, the water column passed approximately through 1/3 of the total net cross sectional area. Therefore,

Average cross-sectional area of the water passed = $\frac{1}{3} \times \frac{\pi D^2}{4} = \frac{\pi D^2}{12}$

Flow rate ($\dot{Q}$) = $\frac{\pi D^2}{12}(v + V)$

Amount of water passed (Q) = $\frac{\pi D^2}{12}(v + V)t$

Time required to collect samples (t) = $\frac{\boldsymbol{Q}}{\frac{\pi D^2}{12}(\boldsymbol{v}+\boldsymbol{V})}$

Net opening diameter = 30cm

Appendix B

Table 2: Stakeholder list for data collection

Stakeholders	Count
Policy makers & Regulatory bodies	8
Municipal city administration	4
Urban local bodies	3
Manufacturers and Distributors	4
Importers	3
Private waste management (Collectors and Recyclers)	4
Supermarket chains	5
Academia and Experts in the field	6
NGOs	4
Environmental institutes and other organisations (IUCN,UNOPS,Chamber of commerce)	3
Projects	4
Total	30

Stakeholders	Count	Institutes
Policy makers & Regulatory bodies	8 (4)	Ministry of Environment Central Environmental authority
Municipal city administration	4 (1)	
Urban local bodies	3	
Manufacturers and Distributors	4	
Importers	3	
Private waste management (Collectors and Recyclers)	4 (4)	
Supermarket chains	5	
Academia and Experts in the field	6 (2)	
NGOs	4	
Environmental institutes and other organizations (IUCN, UNOPS, Chamber of commerce)	3 (2)	
Projects	4	
Total	30 (13)	

List of examples for the stakeholder categories are as follows,

Policy Makers

- **Ministry of Mahaweli Development**
  - Director (Policy Planning Monitoring)
  - Director (Education Training & Research)
  - Diputy Director (environmental Pollution control & Chemical management)
  - Assistant Director (Climate Change - 3 Personals)
- **Central Environmental Authority**
  - Environmental Pollution Control Division
  - Waste Management Division
  - Regional Operation Division
  - Legal Unit

Municipality/ Local Authority

- Colombo Municipalty council
- Sri jayawardhanapura Kotte Municipalty council
- Kaduwela Municipalty council

Main Producers & Importers

- **Plastic**
  - Lanka Plastic
  - Arpico
  - Phoenix Industries
  - MegaTech
  - Central Industries
  - Anton
  - Snackings (Pvt) Ltd

Collectors

- Ceylon Electricity Board.
- Clean Tech (Pvt) Ltd

Recyclers (Plastic)

- Eco Spindles
- Clean Tech (Pvt) Ltd
- Poly-Cycle (Pvt) Ltd
- Green Lanka
- Sachintha Plastic Manufature
- Emp PVC Technology

Supermarket Chains

- Arpico Super centre
- Cargills Food City
- Keells Super
- Laughs Super

Delivery Services

- Domex
- Delivery Malli
- Courier.Lk
- Kapruka
- Fedex

NGO's

- Environmental Foundation Limited
- Sevanatha Urban Resource Centre
- Environmental Journalists
- Biodiversity Sri Lanka
- Center of environmental Justice
- Green Movement Sri Lanka
- IUCN

Projects

- Plasticcycle

Academia

- Universiy of Sri Jayawardhanapura
- University of Peradeniya
- Wayamba University of Sri Lanka
- University of Colombo

Figure 1: Examples for some of the Stakeholders in different categories

Appendix C

Interview Questions for Municipal councils and local Authorities

Dumping and littering

1. What are the actions taken to manage illegal dumping and littering? (On the street walks, roads, beside roads, in riverbanks, to the river and ocean)
2. What are the rules and regulations associated with dumping and littering? (e.g. Fines and penalties available? How they are enforced?)
3. What are the issues associated and what can be improved?

Covid 19 waste management

Are there any special measures taken to tackle infectious waste and plastic waste arising from COVID19 pandemic?

Kelani River waste management

1. Who is responsible? For what?
2. What are the measures taken?
3. Available information related to plastic pollution in the river?
4. Measure needed to be taken to reduce dumping waste into the river?

Microplastic Contamination

1. Awareness on microplastic and their adverse effects?
2. Especial measures taken to reduce microplastic pollution

Collaborations with Stakeholders

1. Collaborations with other institutes, organizations, or private sector in plastic waste management?
2. What are the issues that occurs in collaborations and how to improve them?
3. Any suggestion to improve the effectiveness of awareness programs and community participation?

Policies, laws and regulations

National action plan of plastic waste management

1. Awareness regarding the plan?
2. Actions taken accordingly?
3. What needed to be improved in the plan?
4. Policy and regulation suggestions?
5. Opinion regarding a Mandatory EPR policy

Interview Questions for Ministry of Environment, Central Environmental Authority, & Marine Environmental Protection Agency

Policies, laws and regulations

National action plan of plastic waste management

1. Awareness regarding the plan?
2. Actions taken accordingly?
3. What are the challenges in implementing the plan?
4. What needed to be improved in the plan?
5. Policy and regulation suggestions?
6. Opinion regarding a Mandatory EPR policy

Dumping and littering

1. What are the actions taken to manage illegal dumping and littering? (On the street walks, roads, beside roads, in riverbanks, to the river and ocean)
2. What are the rules and regulations associated with dumping and littering? (e.g. Fines and penalties available? How they are enforced?)
3. What are the issues associated in managing and what can be improved?

Covid 19 waste management

1. Especial measures taken? Effectiveness? What needed to be improved?

Kelani River waste management

1. Who is responsible? For what?
2. What are the measures taken?
3. Available information related to plastic pollution in the river?
4. Measure needed to be taken to reduce dumping waste into the river?

Based on observation

1. What are the management suggestion and what actions that can be taken to prevent the following activities?
    1.1. Floating Water Hyacinths in the river seems to be a plastic waste transporter to the sea especially in the later area of meandering zone opening to the estuary
    1.2. Use of river as a waste dump site by the dwellers and the households near the river
    1.3. Littering from bridges
    1.4. Illegal dumping sites near the riverbanks, bathing sites and bridges

Microplastic Contamination

1. Awareness on Microplastic and their adverse effects?
2. Especial measures taken to reduce microplastic pollution?
3. Awareness on Microplastic pollution in the River? And suggestions for management

Xpress Pearl Incident

1. Remediation actions taken and their effectiveness
2. Lessons learned? and what are the measure taken to avoid happening such incident again?

Collaborations with Stakeholders

1. Collaborations with other institutes, organizations, or private sector in plastic waste management?
2. What are the issues that occurs in collaborations and how to improve them?
3. Any suggestion to improve the effectiveness of awareness programs and community participation?

Interview Questions for Academia & Experts

Policies, laws and regulations

National action plan of plastic waste management

1. Awareness regarding the plan?
2. What needed to be improved in the plan?
3. Policy and regulation suggestions?
4. Opinion regarding a Mandatory EPR policy
5. Any suggestion to improve the effectiveness of awareness programs and community participation?

Covid 19 waste management

1. Opinion on the effectiveness of measures taken?
2. What needed to be improved?

Kelani River plastic waste management

Based on observation

1. What are the management suggestion and what actions that can be taken to prevent the following activities?
    1.1. Floating Water Hyacinths in the river seems to be a plastic waste transporter to the sea especially in the later area of meandering zone opening to the estuary
    1.2. Use of river as a waste dump site by the dwellers and the households near the river
    1.3. Littering from bridges
    1.4. Illegal dumping sites near the riverbanks, bathing sites and bridges

2. Recommendations related to plastic waste management in the river to prevent marine pollution via the river?

Microplastic Contamination

1. Awareness on Microplastic and their adverse effects?
2. Especial measures needed to be taken to reduce microplastic pollution?
3. Awareness on Microplastic pollution in the River? And recommendations for management

Xpress Pearl Incident

1. Remediation actions taken and their effectiveness

Lessons learned? and what are the measure that should be taken to avoid happening such incident again?

Appendix D

Microplastic count in bulk sampling – 100L

location	Location name	>2mm			2-1 mm			1mm-500microns		
L1	Seethawaka Bridge	film	trans	1						
			blue	2						
L2	Awissawella									
L3	pugoda	fragment	trans	1				fragment	ash	1
			white	1						
			ash	1						
L4	Hanwella	films	white	1	films	white	10	fragments	silver	1
		fragments	silver	1		blue	1			
					fragments	silver	4			
L5	Kaduwela	fragments	white	6		blue	1	fragments	other	1
						light blue	1			
			blue	1	fragments					
			light blue	1		black	3			
						white	1			
			black	1	foam	white	5			
L6	Kelaniya	fiber	green	1				fiber	green	1
		film	white	1						
L7	Modara					green	1		green	1
						red	1	fiber	blue	1
		fiber	green	1	fiber	blue	1			
			blue	1		white	1			
						trans	1		white	1
			trans	1		white	1	fragments	green	1
			blue	4	films	blue	1			
		film	red	2		trans	2		other	1
			white	2		red	1	film	blue	1
			other	1		blue	1			
					fragments	green	1			
						black	2			
		fragments				white	9			
			other	1		other	4			
			white	1						

Microplastic count in net sampling

		5-2mm						2-1 mm						1mm-500microns					
	colour	fragments	fiber	films	foam	line	pallets	fragments	fiber	films	foam	line	pallets	fragments	fiber	films	foam	line	pallets
A	ash							1											
	green	2	3	1		1		5	3			1							
	red		1					4	2										
	white	1		2	2	1	2				5				1				
	other																		
	trans			7			1												
	blue	1		1				7	4			3		2					
	light blue	1												2					
	dark blue																		
	orange																		
	brown																		
	black									7									
B	ash																		
	green	1		2				2											
	red	1	1											2					
	white	5		10	4	1	4				5								
	other																		
	trans		1	6															
	blue			2				2	1										
	light blue																		
	dark blue																		
	orange	1																	
	brown																		
	black																		
C	ash	1																	
	green	1	2	4					3										
	red	1																	
	white	2	2	7		1	3	4			5	1							
	other			1															
	trans			2				1	1										
	blue	1		7						2				2	1				
	light blue	1		5						12									
	dark blue																		
	orange																		
	brown	2																	
	black	3	1	1															
D	ash																		
	green	1	1			1		1						2					
	red	1										1		2					
	white	9		6	3		7	7					2	1		2		5	
	other																		
	trans	3		1			3	24	1	3									
	blue	12	2											3					
	light blue							2											
	dark blue							1											
	orange		1																
	brown																		
	black			3				2		1									
E	ash																		
	green								1										
	red																		
	white	4		3	5	1			1	1		1							
	other																		
	trans			1															
	blue																		
	light blue							2											
	dark blue																		
	orange																		
	brown																		
	black																		
F	ash	1																	
	green		1																
	red	1																	
	white	5		3	7		2												
	other																		
	trans																		
	blue	1																	
	light blue	2																	
	dark blue																		
	orange																		
	brown																		
	black			1															
G	ash	1																	
	green																		
	red													1					
	white	8		1		1													
	other																		
	trans			3															
	blue	1												1					
	light blue	1												1					
	dark blue																		
	orange																		
	brown																		
	black																		

Macro plastic count via Observations

	A	B	C	D	E	F	G
plastic bottles	24	27	14	17	8	14	7
polythene bags	5	3	5	3	1	1	2
shopping bags	24	11	25	21	6	4	5
wrapping	8	18	7	2		1	3
lids	5	5		2	1	1	1
fertilizer bags	3	2	2	1		5	1
bite packet	1					1	1
masks		2	2			5	
styroform		4	1	2	1	1	3
net		1					
plastic cups		1		2	1	2	1
yougort cups		2	2		1	1	
plastic ball		1		1			
yougort spoon		1					
shampoo bottle		1				1	1
tooth brush			1		2		
milk packet			2	1		1	1
polythene pieces			2	1			1
pills card			1			1	
chocolote foil			1				
tea packets			1				
rasamusu			1				
polythene waste bags			3	1	2	5	1
shampoo packet			2				
astra cup			2				
sausage packet			1				
ice cream bucket	2	3	1				
detergent packet			1				
ice cream packet					1	1	
yougort drink					1		
lunch sheet				2			3

balm				1			
milk powder packet				1			
smak						7	
glue bottles						2	
toffe bottle						2	
biscuit packet							1
harpic bottle							1
plastic pieces			5				

Summary of Macro plastic Count

Type	Location						
	A	B	C	D	E	F	G
packaging	11	24	21	7	3	12	8
polythene bags	29	14	30	24	7	5	7
plastic bottles	24	27	14	17	8	14	7
others	8	11	16	8	6	24	8

Appendix E

Policies and institutional set-up for wastewater management:

Discharging wastewater in to the environment without proper treatment is not allowed in Sri Lanka. However, use of safe wastewater in agriculture is not adequately encouraged by present policies. Central environmental Authority under the Environmental Ministry, National Water Supply and Drainage Board, Ministry of Agriculture and Environmental Health and Occupational Health unit under the Ministry of Health are the main institutions involved in wastewater management. Various environmental legislations and standards are in force pertaining to wastewater collection treatment and disposal. The key legislation is the National Environment Act (NEA) no 47 of 1980 which was amended in 1988 and 2000. This act encompasses not only wastewater management but also broad objective of protection of environment which include pollution control. The Central Environmental Authority (CEA) was established in 1981 under the NEA and it is one of the main implementing arm of the national environmental policy. The CEA 4has been entrusted with wider regulatory powers since its inception by amending the NEA in 1988 and the year 2000. The principal powers entrusted with these amendments include inter alia the following,

a) Activities resulting in the discharge of pollutants to the environment should have a license issued by the CEA, in accordance with standards and criteria stipulated by the authority.
b) To list the activities which will discharge deposit or emit waste into the environment as “prescribed activities" and to ensure that no person shall carry out such activity except under a license issued by the authority.

Wastewater discharge standards stipulated under the NEA according to the type of industries and discharge methods. The following sets of wastewater discharge standards are prescribed in the National Environmental (protection and quality) Regulation no. 1 of 1990 (Gazette extraordinary no. 595/16, dated 2nd February 1990)

- General standards for discharge of effluents into inland surface waters,
- Tolerance limits for industrial effluents discharged on land or irrigation purpose.
- Tolerance limits for industrial and domestic effluents discharged into coastal areas.
- Tolerance limits for effluents from rubber factories discharged into inland surface waters
- Tolerance limits for effluents from textile industry discharged into inland surface water.

- Tolerance limits for effluents from tanning industry discharged into inland surface water If specific standards are not laid down general discharge standards are to be adhered.

These standards are been revised at present. To minimize the water pollution caused by industry effluents CEA has appointed Cabinet approved committee to make decisions on locating industries nearby water bodies. (High and medium polluting industries) main objective of this committee is to decide on location of the industry so nearby rivers are not polluted. In addition following laws are being implemented which are relevant to water and waste water management.

1) The irrigation ordinance (No.32 of 1946 with amendments) which consolidates laws relating to irrigation.
2) The National Water Supply & Drainage Board (NWS&DB) Act. (No.02 of 1974 as amended) which describes the statutory duties of the NWS&DB to provide water for public, domestic & industrial purpose.

In order to achieve water conservation and to protect the quality of water, the following policy measures have been adopted.

1) A National Water Resource council, supported by the water resource secretariat has been established to address all water related issues in a holistic manner. This council will be a high-level advisory body comprising government agencies and all stakeholders.
2) A Ministry of Water Resource has been established which will oversee the water resources council. The National Water Resource Authority and the Water Resource Tribunal.
3) A Water Resource low and a master plan for water use are being developed.
4) A National Water Resource policy will be developed in order to make optimum use of the water resource and to resolve capacity demands between irrigation & power generation.

The practice of selling wastewater for farming is not heard in Sri Lanka. Mechanisms for quality control of wastewater irrigated produce/product are not adequately developed in Sri Lanka.

Appendix F

Kelani river waste management situation

S/N	Ongoing activities	Agency
1	Conservation and management of catchment areas.	Forest Department (FD), Land Use Policy Planning Department (LUPPD), Dept. of Agriculture
2	Protection of river banks	Irrigation Department(ID), Coast Conservation and Coastal Resources Management (CC & CRM) within 2 Km from river mouth
3	Water quality monitoring	Central Environment Authority (CEA), National Water Supply and Drainage Board(NWSDB), Water Resources Development Board (WRDB)
4	Water purification, supply and regulation and sewerage management	NWSDB
5	Developing and Institutionalizing Water Safety Planning(WSP)	NWSDB
6	Regulating sand mining by issuing license	Geological Survey and Mines Bureau(GSMB)
7	Establishment of soil conservation boards in railway stations and beside main roads raising awareness	Natural Resources Management Centre of Department of Agriculture
8	Establishment of soil conservation demonstration sites and awarding for soil conservation activities	Natural Resources Management Centre of Department of Agriculture
9	Management of solid waste	Solid Waste Management Authority, Local Authorities(LAs)/ CEA
10	Education and Awareness	CEA, NWSDB, Education Department, Relevant Agencies
11	Sustainable use of Agricultural lands	Department of Agriculture (DoE)
12	Mapping of land use pattern	LUPPD / CEA
13	Coordination and monitoring of the project activities.	CEA and Ministry of Mahaweli Development & Environment, Ministry of Urban Development & Water Supply
14	Protection of Peak Wilderness Sanctuary	Department of Wildlife Conservation(DWC)
15	Protection of Kelani Valley Forest reserve	Forest Department
16	Protection of Uda Malimboda Forest Reserve	Forest Department
17	Protection of Labugama-Kalatuwawa Forest reserve	Forest Department
18	Protection of Idikada Mukalana forest reserve	Forest Department
19	Implementing Pavithra Ganga Programme	Ministry of Mahaweli Development &Environment
20	Introducing guidelines for drinking water quality and support WSP	World Health Organization(WHO)
21	Establishing a multi stakeholder approach, piloting WSPs for CBO Managed Water, incorporation Water Safety in Education Curriculum	United Nations Children's Fund (UNICEF)
22	Community education programmes	CEA, NWSDB, UNDP/Coca Cola Every Drop Matters

23	Providing pipe borne water and septage treatment plants, operationalization of the Department of National Community Water Supply, preparation of a comprehensive Water Supply and Sanitation Sector Program and a strategy to mitigate the aggravating effects of drinking water quality on CKDu	The World Bank
24	Conducting related research	International Water Management Institute(IWMI)
25	Support to NWSDB for information dissemination of importance of pipe water conservation and regulation and Kelani river classification from Awissawella to downstream.	Japan International Cooperation Agency (JICA)

Source: https://portals.iucn.org/library/sites/library/files/documents/2016-011.pdf

Appendix G

Plastic waste management in Sri Lanka

Discussions with Stakeholders

Agency: Ministry of Environment, CEA

Participants:

Designation	Name
Assst. Director, Environment pollution control and chemical management division	Ms. Sujeewa Fernando
Technical Coordinator, surakimu Ganga Secretariat	Dr. Manoj Prasanna
Asst. Director, Environmental Planning and Economics	Mr. Leel Randeni
Asst. Director, Solid Waste Management Unit. CEA	

Discussion conducted by: Ms. Kalani Perera

Date: 27th April 2022

Questions discussed	Answers and suggestions
Awareness regarding the NAPPWM	One of the interviewees was directly involvement in making the action plan (Ms. Sujeewa) Other 2 were indirectly involved as well.
Implementation of the action plan and other policies and regulations related to plastic waste management	Action plan is in the process of implementation Bans and regulations imposed in 2017 are in different level of success rates. In 2021, bans imposed by the ministry were too sudden and there was a resistance. (specially regarding the ban f sachet packets) Banned products – inflatable toys, plastic cotton buds, plastic pesticide bottles, plastic sachets <20ml/ 20g.

	Even though they were banned last year, still the products are in the market because the time is given to finish the stocks. To prevent the economic lost and also to make time for the rise of alternatives. Manufacturing industries were monitored to prevent further manufacturing of banned products. Monitoring and raiding was done by CEA officers established in district offices. Raiding data is not published – therefore, general public is not aware of raiding. Fee was only 10,000 previously. Manufacturers used to go to the court, pay the fine and continue the process when get raided. Because fine was very small compared to their profit. Specially in colombo, there were manufacturers who paid the fine and continue manufacturing even more than 3-4 times. So that the fine was increased up to 100,000lkr. Biodegradable lunch sheet, only very few producers manufacture in the right way. What others do is make a mixture of plastic as produce as biodegradable products. Testing is very difficult due to lack of resources, laboratory facilities, and the huge variations among the products.
Challenges in implementation	Taking legal actions is a process involving several institutes - environment ministry or CEA can't directly take the offender to the court. The involvement of the police, and consumer affairs authority, are needed. So that it takes time, process get delayed, communication and coordination issues arose. When it is the 1st time, no fine is imposed for the offender. Only a warning letter. There are cases where some offenders complied after receiving the warning letter. Multinational companies plays with the loopholes in the law. They are the most tactful offenders. (Unilever). When the sachet packets were banned below 20ml, Unilever made a combined sachet containing 4x 6ml (24ml)sachets which produced as before without stopping the sachet production.

	Once the warning is issued, they stopped the production. When the rules and regulations are imposed most of the companies try to find gaps and loopholes in the law for their conveniences.
Mandatory EPR policy	To impose EPR regulations The act was very recently amended. Because the act did not contain a provision to make regulations for EPR system. Still it is in the process as the approval is required from the cabinet. And it requires some time. EPR regulations are draft and kept till the approval is granted for act amendment. Voluntary EPR systems are encouraged to be implemented by companies since 8yrs. But the problem was lack of interest in them. When trying to imposes regulations, resistance from chamber of commerce. Bottle refund systems by sathosa Instead of EPR packaging agreement (political involvement) – didn't let that happen. Dump rehabilitation guideline – available in website With EPR can increase the recycling rate Now the recycling is 4-7%. PET bottles – 30% There are recycling industries, there are plastic waste – but the problem is the link many strategies were utilized to create the link. Initially started collection centers named "Sampath Piyasa" for people to collect and return recyclables. (officers will be available in the day time – in the night, some people have destroyed the centers, have broken the equipment, put other forms of garbage etc.) Providing security for 24 hrs is not practical and costly. The wase given were not properly segregated. Is EPR more offer regulatory rule? As businesses are sensitive to profit gaining, when introducing to EPR, is it introduced as a beneficiary tool that would drive businesses towards more gains and sustainability (green image, reputation, internationally recognition, image as environment service providers, return on investment)

	In voluntary EPR, initially they were asked to collect only 5% of their production. Next year 10%, but they were not attended to it continuously. For an instance, Coka cola has pledged to take back plastic it produced in other countries, but it was not functioning in sri lanka. And also invest in water projects. But not in sri lanka. Waste water is not properly treated and it was disposed into kelani river. A mega plastic bottle is 350 Rs. Liquid cost is only 20 Rs. There is a huge profit margin. They used to establish collection bins. But there were no proper collection system from the bins. There are also not willing to go for an MOU with another waste logistic company as it acquire a cost. Only used the collection bins as a promotional activity where the bin was in the shape of a coca cola bottle. Since Promotion of their brand is not ethical for a government involved collaborative project, and also coke as a beverage with health concerns, they were asked to change the shape of the collection bin. And now just a mesh type bin is used. Even the plastics were collected, they did not take the responsibility of linking with the recyclers. The biggest weakness in recycling was designing a collection mechanism. Government do not have enough money to maintain collection centers. So the private sector have to invest on collection mechanism linking with the recycler.
Issues related to recycling	The plastic collection and the linkage is not sufficient. Even though the collection is done in colombo, out of the city is very hard to do collection and transport as it is expensive. Business is restricted to certain limit. Smallholder recylers are more affected. Recycling facilities are much developed and concentrated around western province. If manufacturers could arrange Collect back system, while delivering the products, the transportation issue can overcome.

	Positive – one of the mass scale producer and recycler who is implementing a deposit refund system along with sathosa suggested that they could establish and operate collection centers around the country. But then smallholder collectors and recyclers livelihoods will be negatively affected. Is there a possibility of linking altogether go for a sustainable system? The government should always be concerned about that.
Future programs	In the process of finding fundings for a program of collection days. "Parisara pola" – Environmental fair. "kasala pola" – waste fair. Ask people recyclable waste (e-waste, paper, glass, plastic) and pay some compensation. This is happening in pilot scale. Recyclers come and buy waste they need. Usually happen in large open space. (playground and open land). Previously the date and time announced around area. The plan is to go for 25 programs of collection days for each district. The problem is the funding. Still not found. All plastic cannot be recycled. Rest are burned as energy. Only 2 established such plants. Colombo waste to energy plant. Insee cement plant. Residual plastic. Local authorities send residual plastic to them. Collect – bundle up – press – pile – send Other than that, also sent to places with incinerators. Also planned to send to sanitary landfills. (karawakkadu). Currently most of the times what now happens is open dumping. Empowering local individual collectors – collaborate with NGO projects. Collaborate with "samurdhi recipients. Started from Kurunegala. They collect waste from nearest village and given to a supervisor. "Samurdhi bank" provides a space to store. And recycler is assigned to that collection center. To make a visible change, need more funding.

Current issues	Funding Government has vested responsibilities of waste management into several ministries. There are issue of coordination communication and collaboration. Time to time ministry portfolios gets changed. Projects, programs and institutes which was under on ministry is gazzeted into another within one night. So some projects which was done halfway through have to be transferred. So that the coordination after is very difficult. Xpress pearl for instance, went through a similar situation. First the MEPa was under environment ministry, and the processes were easy higher level of management (secretary) is same but after, when the institute was listed under another ministry, coordination problems came up. This is mainly because of political influence. In other countries, when portfolios are designed it is for a fixed period of time. Even though there is a political change, they do not change. With the political instability in Sri Lanka ministers change frequently and they do changes as they wish to the planned work and alter it. When the ministry of environment make policies related to waste management in 2020, waste was removed from its mandate. So that they do not have nay legal authority to implement the policies. Even though they can make policies indirectly considering environment protection, but still they lack power in implementing as it is not included in the mandate. Under megapolice, A Disposal ministry was established. Now known as urban development authority. Which is a state ministry. And the subject of waste was transferred and the mandate was given to them. With the lack of resources and funding the programs and projects were conducted with lot of difficulties and when the ministries change those work have to be transferred and sometimes it is hard to collaborate and communicate.

	The sustainability and outcomes of projects conducted by NGO's are doubtful. Overlapping of the projects, similar projects conducted in places, no proper outcome, not sustainable. There's a trend of showing off that they're doing the project but, they are concerned about the money only.
Is there a method of monitoring the funding, progress and outcome of projects conducted in the country.	The ministry has monitored amount of funding received by sri lanka for waste management projects and it was measured as huge amount. But their outcome is not visible and not satisfsctory. Ministry informed all embassies to inform the ministry when they're funding for plastic waste projects.
Attitude changes related to littering and dumping	Don't have adequate infrastructure. People don't have easy access to waste collection system Only 40% of population is covered in waste collection system provided by local authorities. Garbage truck do not go to villages and cities that are further away from main cities. Most of the time they are either open burned or buried as they do not have any other option. CEA have some directive to go to those areas at least one per month and collect the recyclables such as plastic waste and e-waste. So that lack of infrastructure is a big problem since there are no facilities, regulations cannot be properly enforced. Even eith facilities some do not comply with the regulations. In CM area waste is segregated, properly collected and given to the recyclers. Days are assigned to collect the certain type of waste. Even if a specific date is assigned for plastic waste, some people do not want to wait and dispose ore burn earlier. Most of the time they burn. Ministry has conducted many awareness programs regarding the toxicity of burning. These were done in schools, and for children. Waste management is included in the school curriculum.

Awareness regarding projects among institutes	When there's a project there's a steering committee. In that, the representatives from institutes from stakeholders from waste management. Awareness regarding the project among institute depend on that representative's contribution, participation and collaboration. There are issues in steering committee selection as well. whether the right person is chosen.
Initiatives from CEA	Took a big fund around Rs. 4Billion recycling centers, recycling machines, composting yards were given to local authorities around the country. They are not properly maintained by LA's. when there is a breakage or maintenance they do not allow the CEA to involve. According to the act, garbage is a property of LA. So that they do not want other institutes to get involved in managing it. But, they're also not doing this garbage management properly. In procurements of machinery, due to corruption – taking commissions. (invoiced amount is 3 time the actual value).
Is there a platform to share information A coordinate among stakeholders?	Ministry had a plan recently to conduct a symposium related to plastic projects to give the stakeholders give the opportunity to share their projects, programs and outcomes to identify where are the overlaps, what are the productive outcomes sometimes these projects involve lot of funding but not a satisfactory outcome is observed. Consultant are paid in high amounts.
suggestions	Need a system change in every aspect
Littering, illegal dumping	Throwing litter from bridges. – satisfaction of getting rid of the burden. They might not have a proper place to dispose. So when accumulated garbage is thrown away it is a relief. Most of the people dwelling and have houses near kelani river bank are encroached and sometimes even in reservoir areas. And they use river as dumping site. Politicians provide them infrastructures such as electricity, and after some years they get the legal authority to the land they live in.

Plastic waste management in Sri Lanka

Discussions with Stakeholders

Agency: Colombo Municipal council (CMC)

Participants:

Designation	Name
Chief district Engineer (solid waste Management)	

Discussion conducted by: Ms. Kalani Perera

Date: 10th May 2022

Questions discussed	Answers and suggestions
Existing MSW Management System in Colombo Municipal Council	The Colombo Municipal Council is responsible for managing MSW in the Colombo City. The Municipal Engineers Department's Solid Waste Management Division is in charge of MSW management in its entirety. The overall management is carried out by the Division with the assistance of the private sector. The municipality monitors the private sector-managed areas to ensure that the collection process is carriedout smoothly. At present, trade refuse is collected only from commercial places. MSW is separated into three categories: biodegradables, recyclables and non-recyclables. Segregation of MSW at the source is carried out by the citizens. At present, quarantine waste has been added as another category of MSW. Quarantine waste is not separated but collected as mixed waste. The collection system of the municipality covers the whole city. The door-to-door collection system, or collection truck system, is carried out in the Municipality as the method of collection.

	A collection schedule is given to the public by the Municipality indicating the days of collection of different types of MSW. Biodegradable waste is collected in compactor trucks, while non-recyclable waste is collected in compactor trucks or open trucks. Recyclable waste is collected in a tractor with divided compartments. As the compactor trucks, cannot reach most of the underserved settlements, all categories of MSW are collected in carts and transferred to the compactor trucks or open trucks. The storage is done only for recyclable waste; other waste is transferred straight to the disposal sites. Non-recyclables are sent to the Waste to Energy plant at Kerawalapitiya. Recyclables are stored at recycling centers and eco kiosk in Colombo city where recycling waste collectors come to collect them. The quarantine waste is also sent to the Waste to Energy plant at Kerawalapitiya.
Garbage collection details	Colombo city is divided into 6 districts as, • District 1 • District 2A • District 2B • District 3 • District 4 • District 5 Waste collected as degradable, recyclable and non recyclable. Weekly, Days are assigned for each type o be collected. Only for few main roads, daily collection is available. For other areas twice a week of thrice a week based on the population. Specifically district 4,5 are given to managed by private sector. • District 4 – Abans environmental Services (pvt) Ltd. (sweeping/ brushing, roadside drain cleaning/ Weeding/ removal of strings, banners, posters/ removal of debris and tree cutting on charge)

	• District 5 – CleanTech (pvt) Ltd. (sweeping/ brushing, roadside drain cleaning/ Weeding/ removal of strings, banners, posters/ removal of debris, collection garbage from premises and tree cutting on charge)
The Existing Problems in MSW Management	The most significant factor is lack of focus on MSW generation, which consequently increases MSW, especially the nondegradable waste. This is due to excessive packaging and the public buying things that are not needed or will not be uses for their daily activities (over consumption). Segregation of MSW not being done properly at the source is another problem that requires attention. A prominent problem in transportation is that a suitable location is not available to unload carts and load to trucks. Currently this is done on the side of the road, which create traffic congestion, environmental pollution and littering of the area. The most significant problem with storage is the unavailability of adequate space for storage at source. As a result, when there is a delay in collection, waste tends to end up on road sides and waterways. Another significant problem is illegal dumping on road sides and waterways. This will reduce the environmental quality of the area, create mosquito breeding grounds, and increase health problems. Disposal of large equipment such as refrigerators and washing machines, as well as other wastes such astires, ceramic/porcelain, wind shield glass create problems to the municipality. lack of public support has a direct impact on MSW management. Difficulty in implementing any rules and regulations, less labour for MSW services, and lack of short-term and long-term plans are also problems associated with MSW management.
Suggestions to Overcome the Problems in MSW Management Systems	Priority should be given to the reduction of waste, and this can be done by conducting public awareness programmes not only in the

	municipality area but across the whole island. This can be achieved by involving the public and private sector establishments. The government should be involved in media campaigns that could educate citizens on ways of reducing MSW and its impact on humans and the environment. The door-to-door collection system should be carried out daily if possible, in all underserved areas where the problem persists the most. It is also important to practice MSW segregation more effectively at the source. This can be carried out by implementing training programmes for the community. In areas where illegal dumping occurs, 24-hour surveillance should be implemented. A monitoring system in the Colombo Municipality area to ensure the proper MSW management process is carried out is another crucial step. Providing distinct training to the staff, supervisors, and workers in the solid waste management division of the municipality, is also of utmost importance. As per the National Policy of Sri Lanka, the municipality should encourage the 3R system in the daily activities of its citizens. More awareness programmes should be carried out in the city in a more systematic manner. Education in this regard from childhood is most important in handling the situation. Therefore, more focus should be given to school children. Awareness should be carried out among citizens regarding the economic benefits of recycling at home. Encouragement and support for the creation of handcrafts and other items from recyclable materials as well as promotion of these items among citizens, is another viable option. Implementing more recycling and E-waste collection centers and expanding the existing recycling centers can be recommended. Non-degradable polythene waste can be used as bitumen in road construction work, find the possibility of using bottom ash from waste to energy plant in construction work without

	sending it to sanitary land fill, involve private sector establishments in taking back large electrical equipment as a disposal method, and find the possibility of using crushed ceramic and porcelain waste in construction as filling material are some of the strategies that can be adopted by the municipality to overcome the disposal problems. More rules and regulations regarding MSW management should be implemented by the government. The municipality can change their by-laws according to the present situation. A sustainable approach is needed to establish effective MSW management in the Colombo Municipal Council. Integrated solid waste management is the best option in this regard by considering the waste management hierarchy. Community contribution and participation in the MSW management process is very important in order to make the sustainable approach a success.

Plastic waste management in Sri Lanka

Discussions with Stakeholders

Agency: Abans Environmental Services (Pvt) Ltd., CleanTech (pvt) Ltd.

Participants:

Designation	Name
Operational Manager, Abans Environmental Services (Pvt) Ltd	Mr. Senevirathne
Head of Sustainability, CleanTech (pvt) Ltd	Mr. Kasun Thennakoon
Asst. Manager, Business Development, Abans Environmental Services (Pvt) Ltd.	Ms. Kavindya Basnayake.

Discussion conducted by: Ms. Kalani Perera

Date: 13th May 2022

Questions discussed	Answers and suggestions
About Abans Environmental Services	Abans Environmental Services provide integrated facility management services including maintenance, housekeeping, janitorial services, street cleaning, city beautification, solid waste management, pest control and hygiene control as well as tea services. Equipped with modern cleaning technologies and well-versed cleaning professionals, They are geared to offer an unparalleled service to the clients who rely on their expertise. Pioneers in the commercial cleaning and janitorial industry, a reliable customer-centric service provider. Abans Environmental Services has been actively engaged in street cleaning and waste managing in Colombo and suburbs to assist the Colombo Municipal Council's efforts in keeping the city clean and beautiful.
About CleanTech (pvt) Ltd	Cleantech carries was initially formed in 2002 to facilitate logistics for the Municipal Council solid

	waste. The company gradually developed into a complete waste managing entity which acquired the privilege of collaborating with government bodies, municipal councils and became their core service provider. Over the years, Diversified into several prospective sectors and initiation of recycling (2004), developing an infrastructure for operating and maintenance of the vehicle fleet (2005) with adequate environmental safe guard, approaching the sanitation service concept (2006), entering into the E-waste market, developing waste management facilities.
Abans Environmental Services operations	4 years MC tender. Mc provide the dumpsite for final disposal Firstly, dumpsite from bluemandal shifted to Meethotamulla. After meethotamulla collapse, temporary dumpsite at kohilawaththa marshland (muthurajawela), Ambathale, kotikawaththa. Then shifted to bopitiya. Now being dumped to Kerawalapitiya waste park managed by SLLRDC (Sri lanka land development corporation). Recently, waste to energy plant in kerawalapitiya. Pershables – compost Non recyclables (polythene bags) Recycling PET, E-waste Daily wage for janitors, junk shop scavengers.
Waste management situation	After covid, amount of waste got reduced in colombo city. 7000MT to 5560MT. Littering is also reduced specially in the city and shops in the city.
cleanups	Kirulapone canal cleanups with the involvement of police, navy boats. Hamilton canal (muthurajawela mashi land) Kohilawatta canal Most of the litter comes from sewages and canals outside the main city. Diyasapura – trapper surface debris Canal cleaning, specially deep cleaning – labour issues Beach cleanups - Wana arana - Civil security force involved - Canal cleaning payment basis SLLRDC – bere lake.

	CSR activities by Abans Environment services and CleanTech
Challenges – Abans Environmental Services	Final disposal Recruiting labour force – reluctant, not educated, attitudes, monitory issues.
Work of CleanTech, Abans Environmental Services and involved projects.	Project from environment ministry – • producer responsible disposal o Party must dispose after recycling or must create partnership with another party to dispose the waste. Partnerships are encouraged in every manner. o Ex – john keels starting a recycling plant is useless, waste of money. Therefore, they better outsource it by collaborating with recycling company. As per the new initiative, even the main party is not the main recycler they are responsible for monitoring the operation. o Released on end of may. No specific starting date o At the moment, only PET bottles are considered. Their daily production is monitored through MOE monitoring board. All these manufactured bottles must be recycled. (through them or other party). – can recycle, give to recycler local, export by pressing(shipping costlier). o Therefore, they go to crushing. Only “eco spinder” have sustainable solution for this. Crush – small particles – export for fabrics manufacture. • As per the system, the external recycling party must be accountable for the bottles manufactured by PET producer. They issue a certificate claiming that they have collected and recycled certain amount of plastic bottles from the responsible company. This certificate can be used by the PET producer company to renew their licnence annually or increase production.

	○ This is an online system released on 7th June. manadatory from march 2023. • Clean tech currently give to eco-spindlers, planning to crush and export. • Currently whole PET collected waste doesn't go to eco spindles. Thus, they additionally import PET material to create the yarn required. Collection only in colombo – transport issue – Solutions - ○ Villagers – old goods collector – currently not doing due to high initial cost. Need large spacing. ○ need to press and pack. Better to provide initial cost, equipment support through state or other EPR party. (kandy, Kurunegala, trinco) plastic • have many solutions than PET • have better price as well. Sold to a manufacturer as it is about 120rs/kg • some people do value addition. Collect – sort and crush (these have better market). Can be directly used as raw materials in injection molding machines. • Brushes, brooms, shoes, slippers are made using these crushed plastics. Need policy support to market these products(as recycled products). But currently these manufacturers face various restrictions when marketing these products. (municipal councils sometimes doesn't approve) • Crushed plastic are expensive here because of import restrictions. And high dollar rate. otherwise plastic virgin raw material import from China is way cheaper. Therefore, crushed plastic export is not an good option. • One company "ranco" manufactures toys dustpans. They have completely used virgin raw materials until 2021 . later adopted to recycled as well. ○ Need policy support

	○ Proper monitoring and evaluation method. ○ If disposed plastics are properly managed, no need to import. • Monitoring and evaluation are weak. • Currently monitored by "sulu haa madya parimaana". They don't conern about recycling matter. • Recycling companies are monitored and evaluated – only for license renewal. Products – they don't care. ○ Ex – bailed plastic from cleantech. Must show what end user is being used to. Whether you have the license and how long. Agreements are needed. Agreements must clearly state how the value added products are being used at what purpose, quantity etc… • They are evaluating all the required documents at the licencing stage. But not in between. • Guy in katana upcycling – make new products from recycled platics like diaries etc… they need to be encouraged. Needs to be connected with parties collaborated with marketing people. Such as tourism body, airport, hotels, conferences arrangement etc. • There is no direct involvement is done by government. Only by biodiversity forum, and ngos. ○ Current minister is pushing this ne EPR system. Funded by USA. Regulated through government. • Currently there is an issue with the companies about publishing PET bottle manufacturing figures as their sales details can go out. Practical difficulties. That's why hard to make mandatory. • Recycled materials can only be used to make fabric yarn, and brushes. • India has large number of such recylers. We cannot export these recycled materials

	to india because they minimum requirement is 40 ton from 1 container. With current facilities and collection rate only 1 ton per day is possible (it will take 40days of operation, collection and sorting as per current rate). Otherwise they won't accept as the shipping is costlier.
	• African contries, are way cheaper for PET (10-15rs) than sri lanka (65rs). Therefore need to encourage yarn production in sri lanka as we have garments.
	
	• Current issues
	  o Transport outside colombo.
	  o Daily collection is hard. Therefore need collection points.
	  o Collaborative partnerships are in discussion (hemas, elephanthouse,pepsi) establish collection points and stratergies outside colombo.
	  o Technological improvement is needed. – last year only value addition (crushing) is started.
	  ▪ Current 2 crushers, 1 sieve is produced by themselves. 250 – 300kg/day
	  ▪ Plastic purity is not an issue. Mostly clean.
	  ▪ Janitors are encouraged t o separate plastic from general waste. Paid.
	  ▪ Currently not washed at the beginning.
	  o In PET
	  ▪ Cold wash – crush – hot wash – dry – spinning(processing)
	• E-waste – direct export
	  o Ex – tv
	  ▪ Plastic
	  ▪ Circuit board
	  • There must be specific types.
	  • Largely done by Mitsubishi

	• There is a minimal amount of composition mix to achieve before export. There should be a several types of e-waste. Not 1 type. ▪ Glass ▪ Metal o Large number of exporters. o 1 plant was done in Ratmalana. For metal mining from e-waste not opened. o Foreign, state support available for the products for export market.
Other private SWM companies involved in Colombo	CareKleen – medium scale business SuperCompost – small holder business

Plastic waste management in Sri Lanka

Discussions with Stakeholders

Agency: University of Sri Jayewardenepura, Open university of Sri Lanka

Participants:

Designation	Name
Professor at Ecosphere Resilience Research Center, University of Sri Jayewardenepura	Prof. Meththika Withanage
Senior Lecturer, Open university of Sri Lanka	Dr. Kalinga Padmalal.

Discussion conducted by: Ms. Kalani Perera

Date: 09th May 2022

Questions discussed	Answers and suggestions
Xpress Pearl incident – remediation actions taken and their effectiveness. Lessons learned.	Mainly done by MEPA. Partially successful actions. Tried best with the available resources. Even though Local inventors introduced simple mechanical devices for the cleaning processes, later all was removed and followed extensive cleaning processes like digging, manual sieving which consumes more labour. Because of the monsoons, beaches were getting filled and nurdles were getting buried. Hard to scavenge and dig out and do cleanup. Stay persistent in the environment, not good for the eco system. Remediation action and compensating action were delayed. Damage done to sea grass beds, corals, mangrows, lagoons not estimated. No research done. Neglected. Require advanced instruments. with the nurdes spilled there are other chemicals were also released. Damage done by them were not properly assessed.

	Actions were again delayed. Dilution might have occurred. Now could not evaluate the real damage. Long term monitoring not happened. Fishermen were given some compensation. Apart from that the compensation received for the damage was not sufficient. No conclusive results of the damage. No political willingness to get the right compensation. Communicqtion issues. Legal approach was not effective. Even after 1 year, still could observe the pollution as nurdles get washed over to the beaches once in a while.
MP contamination awareness	Specially after the incident, people are much aware about the MP up to certain extent. But they do not know about the toxicity and the hazardousness of MP, additives, BPA, plasticycer. Very few knows about them. MP studies are mainly conducted in coastal areas. Very limited inland and soil studies.
Challenges in conducting research	Lab infrastructure and resource limitation Very limited high-tech instruments. Where it's available, not being properly utilized. Collaboration and communication among institutes is very poor. Not keen in research. Very small amount is allocated in the budget from GDP. Lack or no baseline data available. No repository of information for finding and results, funding, etc. Lot of administrative documentation and paperwork in getting funds from donors. Many delays take a lot of time. Outcome is less. Frustrating and time consuming.
Suggestions to improve	Increase research fundings and encourage to do effective research. Introduce a database for baseline data. Online Data and information repository for available funds, ongoing projects, research outcomes. Online system for proposal submission and funding request.

	Encourage collaboration among institutes both national and international Qualitative measures rather than the quantitative. Pay much focus on implementation on the available rules and regulations. Rather than being in paper, enforce them properly and monitor processes. For example – carry out fining effectively. Improve Primary education curriculum and school curriculum – like in Japan let them practice by themselves. Application oriented changes. Encourage critical thinking and interactions rather than being self oriented. But do not force them. Go beyond textbook education and let them get the first hand experience and practice. Proper education and awareness is the key in changing attitudes and it should be done in early age.

Plastic waste management in Sri Lanka

Discussions with Stakeholders

Agency: IUCN

Participants:

Designation	Name
Country Representative, IUCN	Dr. Ananda Mallawathanthri

Discussion conducted by: Ms. Kalani Perera

Date: 09th May 2022

Questions discussed	Answers and suggestions
Xpress Pearl incident – remediation actions taken and their effectiveness. Lessons learned.	Actions taken were not proactive Actions taken were not systematic Didn't follow standard operating system Poor coordination All resulted in aggravated damage Try to contain the pollution as much as possible. Actions were delayed and not sufficient. Approach was wrong for insurance and claim. It should have been m ore systematic. With purpose of recovering and proper compensation.
EPR system	Initially voluntary based. It's important to identify the areas that could go wrong and needed to be improved. So that an effective mandatory EPR system could be introduced. Voluntary EPR system is mainly for PET - 1st yr to collect back and recycle upto 20% - 2nd and 3rd year – go upto 50%
Challenges	Infrastructure - Lack of resources Understanding the value of environmental projects Communication among policymakers Inability to quantify the value

	No system for ecosystem or environmental accounting and calculate actual cost of pollution. Inability to include in national budget Evaluating conversational benefits Coordination communication gap among institutes
Awareness regarding MP	Studies are being carried out on beach samples, river samples and fish. Majority know about MP but have not perceived appropriately. Awareness regarding MP and health relationship is low.
suggestions	Education and awareness generation Emphasize health linkage rather than natural beauty or clogging of drains, etc. Explain more on people and family health Effectively enforce penalties for offenders and incentives for recyclers and collectors. Finding better substitutes EPR system to strengthen the plastic waste management and recycling Government to cross subsidize companies involved in PWM

Appendix H

A-1

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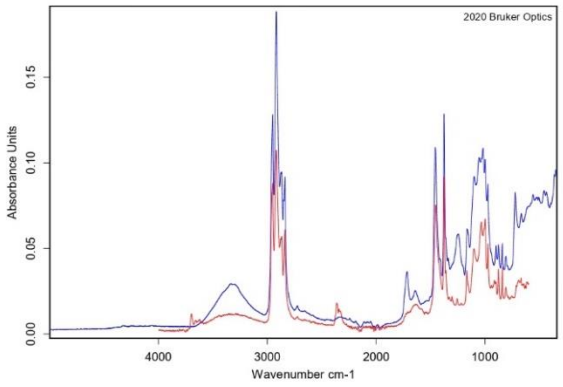

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Supplier	unknown
Filler	Flax
Filler Content	ca. 20-30%
Color	natural
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

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	673	PP	9003-07-0		

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E-1

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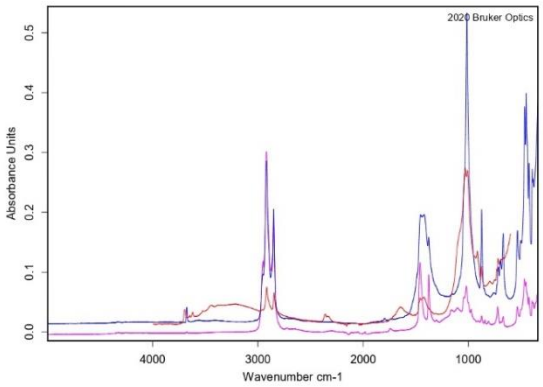

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Substance	polypropylene/ethlyene propylene diene rubl
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Supplier	Albis
Filler	talc
Filler Content	?
Color	natural
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

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	396	TPV			
	355	PP/EPDM			

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H-1

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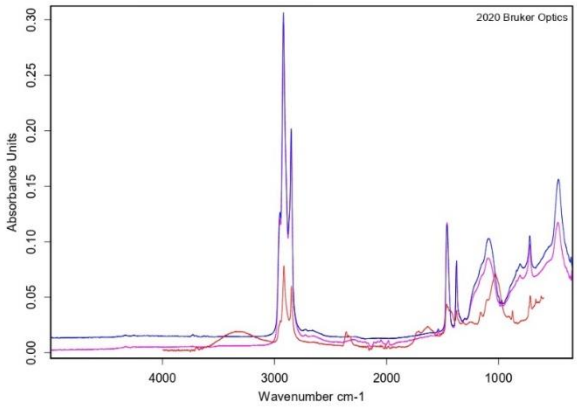

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CAS Registry Number	
Substance	polypropylene/olefin based thermoplastic ela
Trade Name	Daplen EF261A1
Supplier	Borealis
Filler	unknown
Filler Content	0-
Color	black
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	589	TPV			
	586	PP/TPO			

Color	File	Path	Spectrum Type
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K-1

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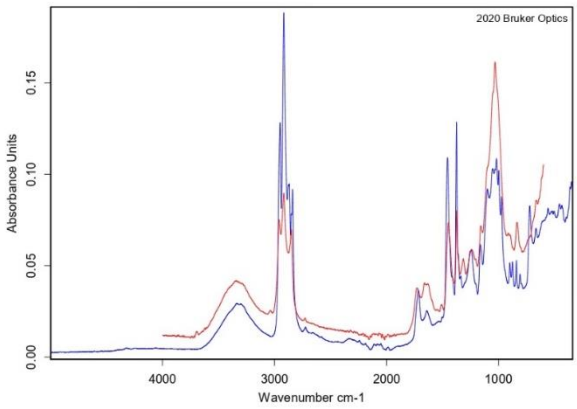

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Substance	polypropylene
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Supplier	unknown
Filler	Flax
Filler Content	ca. 20-30%
Color	natural
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	480	PP	9003-07-0		

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K-2

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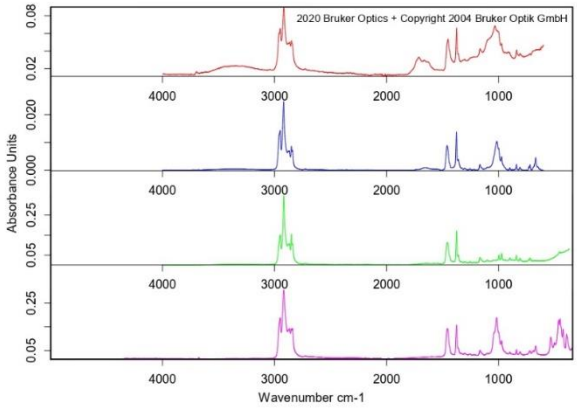

Polymer	TPV
CAS Registry Number	
Substance	thermoplastic vulcanizate
Trade Name	Forprene 6M0 901 D50
Supplier	PolyOne
Filler	unfilled
Filler Content	0-
Color	black
Processing Method	injection molding
Applications	automotive, building and construction, consu

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	693	Blend of Polypropylen and Ethylen / Propylen (PP + EPDM)			
	663	TPV			
	620	Polypropylene (PP)			

Color	File	Path	Spectrum Type
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K-3

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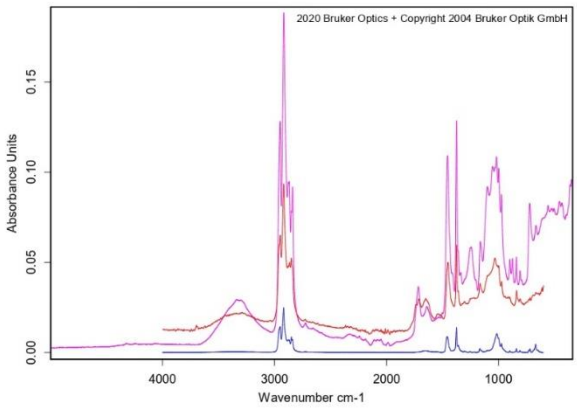

Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	PP Flachs
Supplier	unknown
Filler	Flax
Filler Content	ca. 20-30%
Color	natural
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	553	Blend of Polypropylen and Ethylen / Propylen (PP + EPDM)			
	548	PP	9003-07-0		

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K-4

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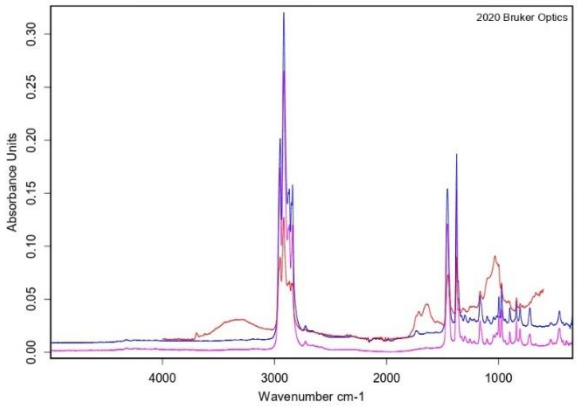

Polymer	PP-C
CAS Registry Number	9010-79-1
Substance	polypropylene copolymer
Trade Name	Purell EP 274 P
Supplier	LyondellBasell
Filler	unfilled
Filler Content	0%
Color	natural
Applications	Healthcare Applications,Medical Devices
MVR/MFR	15g/10min[2,16/230°C]

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	734	PP	9003-07-0		
	726	PP-C	9010-79-1		

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K-5

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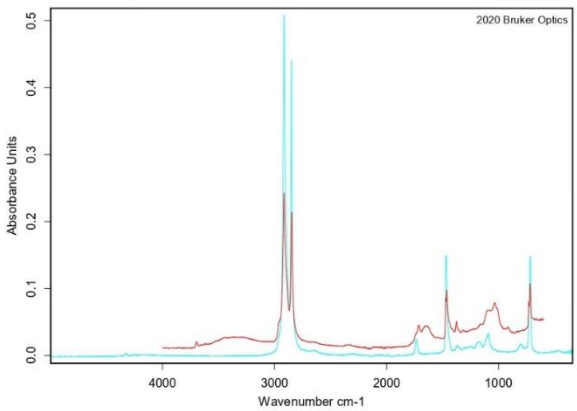


Polymer	PE vernetzt
CAS Registry Number	
Substance	cross-linked polyethylene
Trade Name	Visico ME4425
Supplier	Borealis
Filler	unfilled
Filler Content	0
Color	natural
Applications	cable jackets, low voltage insolations
MVR/MFR	1 g/10 min [2,16 kg/ 190 °C]

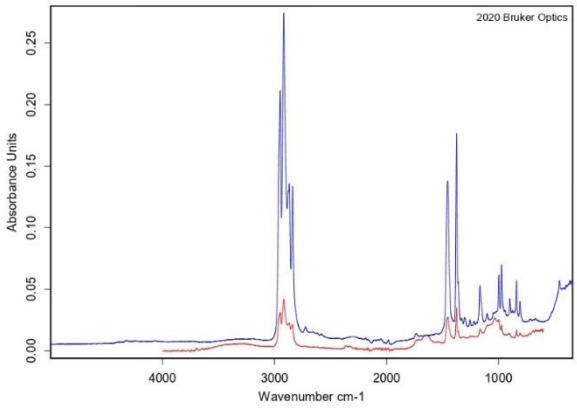
Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	589	PE vernetzt			

Color	File	Path	Spectrum Type
	K-5.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

Page 1 of 1

K-6

Search Library **4/4/2022 1:49:43 PM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	Thermofil GPP 1630
Supplier	Asahi Kasei
Filler	Glass fibres
Filler Content	30%
Color	black
Measurement Technique	DiamondATR
Sample Preparation	surface material

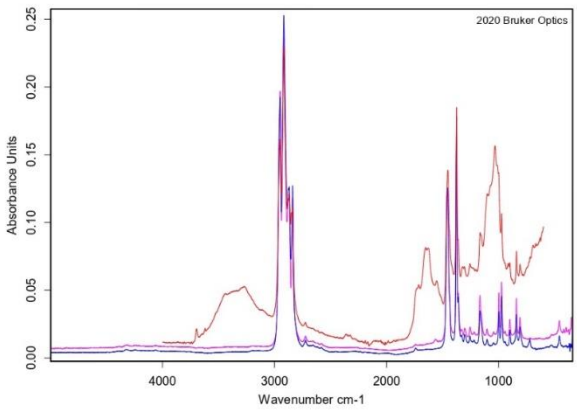
Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	574	PP	9003-07-0		

Color	File	Path	Spectrum Type
	K-6.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

Page 1 of 1

K-7

Search Library **4/4/2022 1:52:40 PM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	TechnoFiber PP LGF 40-10-01 LHE
Supplier	TechnoCompound
Filler	Long glass fibres
Filler Content	40%
Color	black
Processing Method	injection molding
Applications	automotive, electrical parts

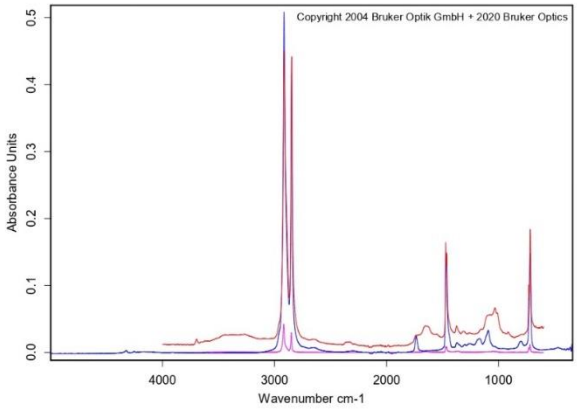
Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	791	PP-C	9010-79-1		
	788	PP	9003-07-0		

Color	File	Path	Spectrum Type
	K-7.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

Page 1 of 1

K-8

Search Library **4/4/2022 1:54:36 PM**



Polymer Classification	High Density Polyethylene (PE-HD)
Trade Name	Hostalen GU 7746
Manufacturer	Hoechst AG
Colour	nature
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Ge-Crysta
Entry No.	104
Library name	BPAD.S01
Library description	Bruker Optics ATR-Polymer Library

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	852	PE vernetzt			
	807	High Density Polyethylene (PE-HD)			

Color	File	Path	Spectrum Type
	K-8.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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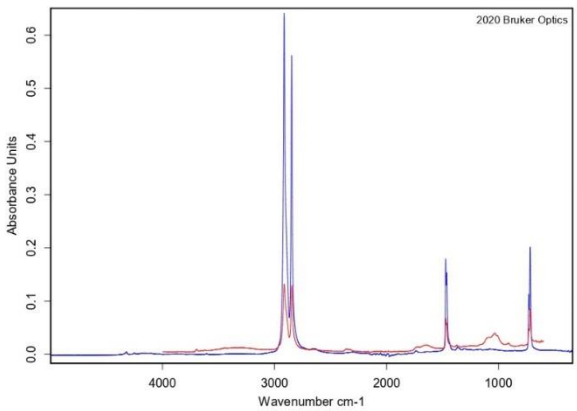
K-9

Search Library **4/4/2022 1:56:36 PM**



Polymer	PE-HD
CAS Registry Number	9002-88-4
Substance	polyethylene, high density
Trade Name	Hostalen GC7260
Supplier	LyondellBasell
Filler	unfilled
Filler Content	0
Color	natural
Processing Method	injection molding
Applications	closures, toys, housewares, packaging, industr

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	688	PE-HD	9002-88-4		

Color	File	Path	Spectrum Type
	K-9.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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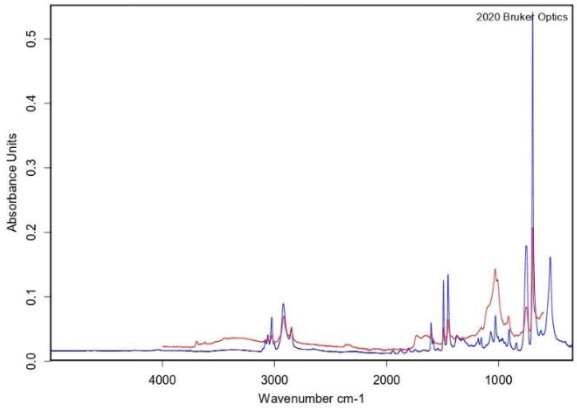
K-10

Search Library **4/4/2022 1:58:42 PM**



Polymer	PS
CAS Registry Number	9003-53-6
Substance	polystyrene
Trade Name	Styrolution 165 N
Supplier	Ineos
Filler	unfilled
Filler Content	0%
Color	natural
Melting Point	180
Young´s modulus (RT)	3300

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	794	PS	9003-53-6		

Color	File	Path	Spectrum Type
	K-10.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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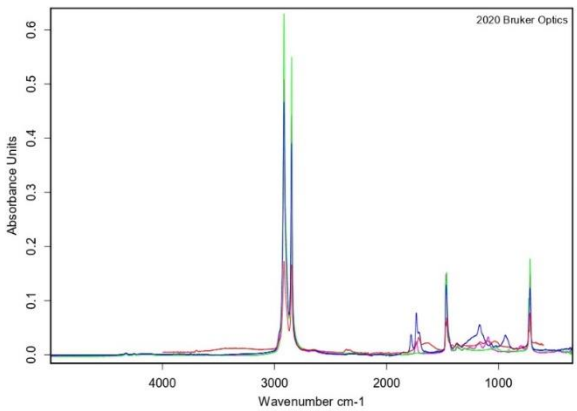
M-1

Search Library **4/4/2022 2:03:33 PM**



Polymer	PE vernetzt
CAS Registry Number	
Substance	cross-linked polyethylene
Trade Name	Visico ME4425
Supplier	Borealis
Filler	unfilled
Filler Content	0
Color	natural
Applications	cable jackets, low voltage insolations
MVR/MFR	1 g/10 min [2,16 kg/ 190 °C]

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	741	EBA	25750-84-9		
	714	PE vernetzt			
	692	PE-HD	9002-88-4		

Color	File	Path	Spectrum Type
	M-1.3	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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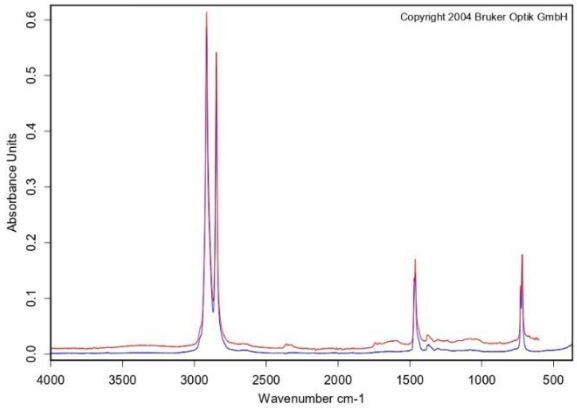
M-2

Search Library **4/4/2022 2:05:26 PM**



Polymer Classification	Low-Density Polyethylene (PE-LD)
Trade Name	Escorene EX 376
Manufacturer	ESSO
Colour	nature
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Diamond
Entry No.	71
Library name	BPAD.S01
Library description	Bruker Optics ATR-Polymer Library

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	996	Low-Density Polyethylene (PE-LD)			

Color	File	Path	Spectrum Type
	M-2.1	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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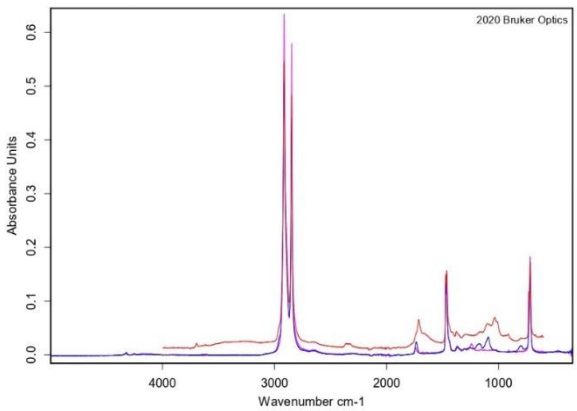
M-3

Search Library **4/4/2022 2:07:45 PM**



Polymer	PE-HD
CAS Registry Number	9002-88-4
Substance	polyethylene, high density
Trade Name	Lupolen 4261 A.Q.416
Supplier	LyondellBasell
Filler	unfilled
Filler Content	0
Color	natural
Processing Method	sheet extrusion, extrusion
Melting Point	131

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	813	PE vernetzt			
	726	PE-HD	9002-88-4		

Color	File	Path	Spectrum Type
	M-3.3	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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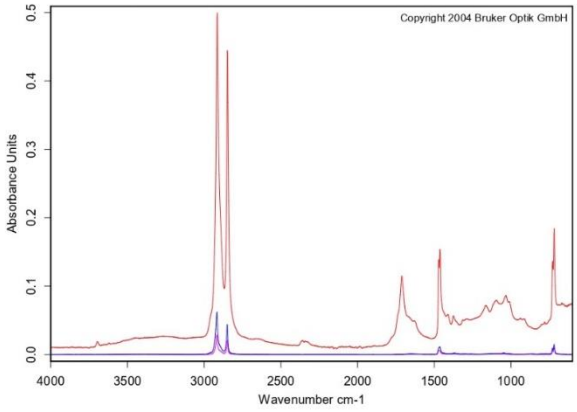
M-4

Search Library **4/4/2022 2:09:43 PM**



Polymer Classification	High Density Polyethylene (PE-HD)
Trade Name	Rigidex HP 6070 EA
Manufacturer	BP
Colour	black
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Ge-Crysta
Entry No.	208
Library name	BPAD.S01
Library description	Bruker Optics ATR-Polymer Library

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	764	Low-Density Polyethylene (PE-LD)			
	733	High Density Polyethylene (PE-HD)			

Color	File	Path	Spectrum Type
	M-4.1	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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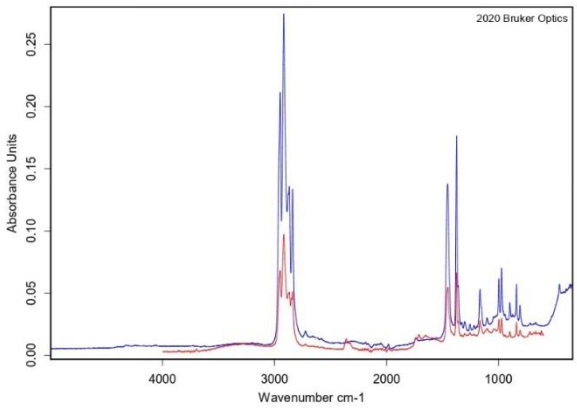
M-5

Search Library **4/4/2022 2:11:37 PM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	Thermofil GPP 1630
Supplier	Asahi Kasei
Filler	Glass fibres
Filler Content	30%
Color	black
Measurement Technique	DiamondATR
Sample Preparation	surface material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	840	PP	9003-07-0		

Color	File	Path	Spectrum Type
	M-5.2	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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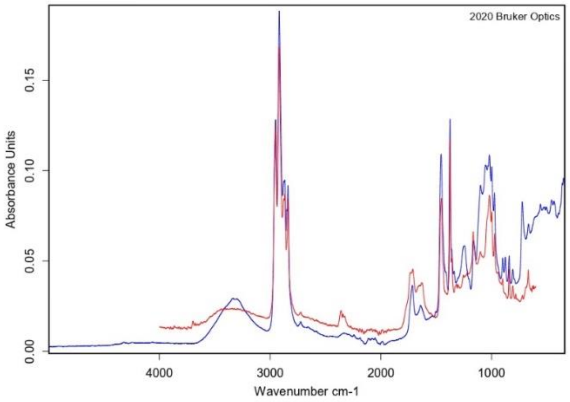
M-7

Search Library **4/4/2022 2:15:24 PM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	PP Flachs
Supplier	unknown
Filler	Flax
Filler Content	ca. 20-30%
Color	natural
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	835	PP	9003-07-0		

Color	File	Path	Spectrum Type
	M-7.1	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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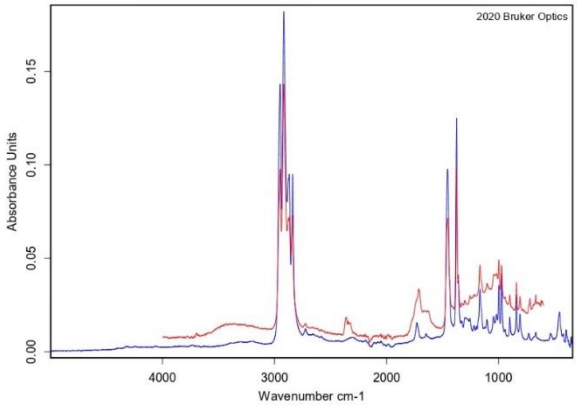
M-8

Search Library **4/4/2022 2:17:31 PM**



Polymer	PP-H
CAS Registry Number	9003-07-0
Substance	polypropylene homopolymer
Trade Name	Exxonmobil PP 1055E2
Supplier	ExxonMobil
Filler	unfilled
Filler Content	0
Color	natural
Processing Method	injection molding
Applications	media packing, containers and other articles r

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	837	PP-H	9003-07-0		

Color	File	Path	Spectrum Type
	M-8.1	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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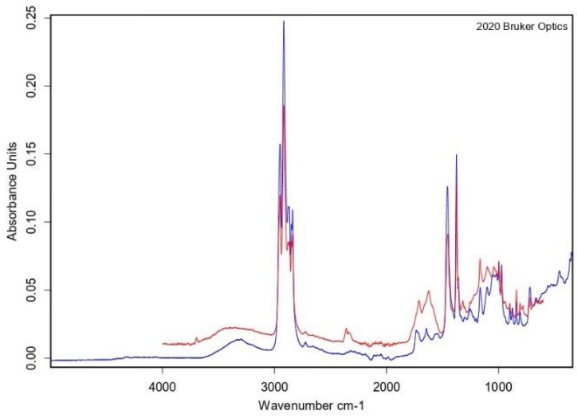
M-9

Search Library **4/4/2022 2:19:27 PM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	V830 Maedje
Supplier	Holstein Flachs
Filler	Flax
Filler Content	40%
Color	natural
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	689	PP	9003-07-0		

Color	File	Path	Spectrum Type
	M-9.1	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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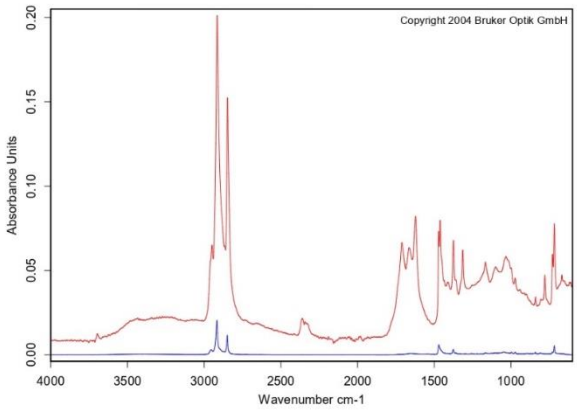
M-10

Search Library **4/4/2022 2:20:54 PM**



Polymer Classification	Polypropylene (PP)
Trade Name	Hostalen PPN 7780 GV 20
Manufacturer	Hoechst AG
Colour	nature
Chemical / Physical Descriptio	20% glass-fibres, Homopolymer
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Ge-Crysta
Entry No.	111
Library name	BPAD.S01

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	443	Polypropylene (PP)			

Color	File	Path	Spectrum Type
	M-10.1	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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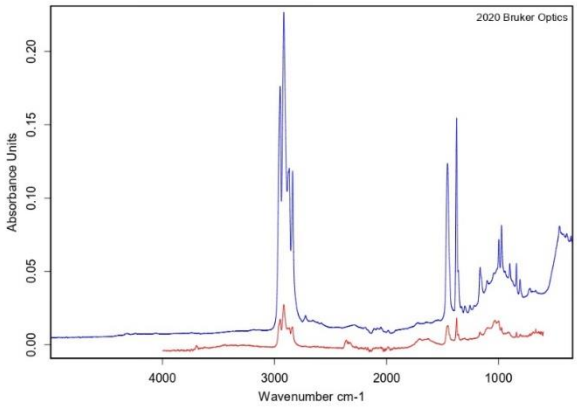
M-11

Search Library **4/4/2022 2:01:07 PM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	Latene AG3UVH
Supplier	Lati
Filler	Glass fibres
Filler Content	30%
Color	black
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	472	PP	9003-07-0		

Color	File	Path	Spectrum Type
	M-11.1	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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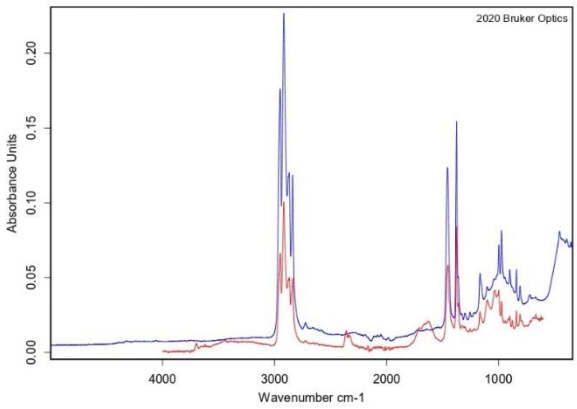
M-12

Search Library **4/4/2022 2:22:19 PM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	Latene AG3UVH
Supplier	Lati
Filler	Glass fibres
Filler Content	30%
Color	black
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	662	PP	9003-07-0		

Color	File	Path	Spectrum Type
	M-12.1	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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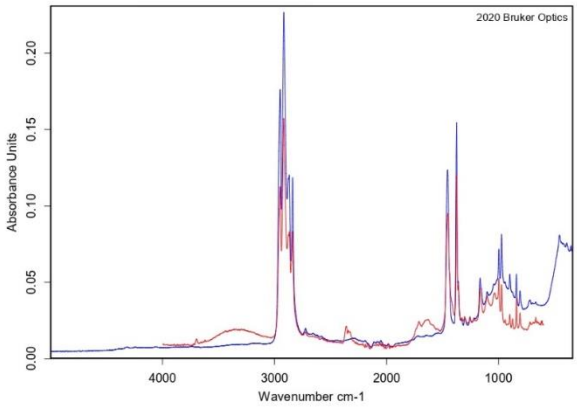
M-13

Search Library **4/4/2022 2:24:10 PM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	Latene AG3UVH
Supplier	Lati
Filler	Glass fibres
Filler Content	30%
Color	black
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	827	PP	9003-07-0		

Color	File	Path	Spectrum Type
	M-13.1	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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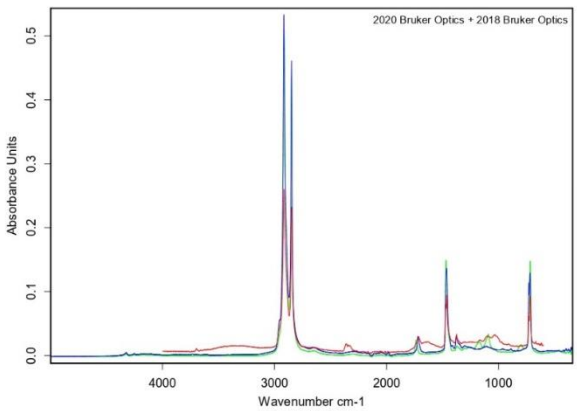
M-14

Search Library **4/4/2022 2:26:20 PM**



Polymer	PE vernetzt
CAS Registry Number	
Substance	cross-linked polyethylene
Trade Name	Visico ME4425
Supplier	Borealis
Filler	unfilled
Filler Content	0
Color	natural
Applications	cable jackets, low voltage insolations
MVR/MFR	1 g/10 min [2,16 kg/ 190 °C]

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	690	Luwax AL 3			
	613	PE vernetzt			

Color	File	Path	Spectrum Type
	M-14.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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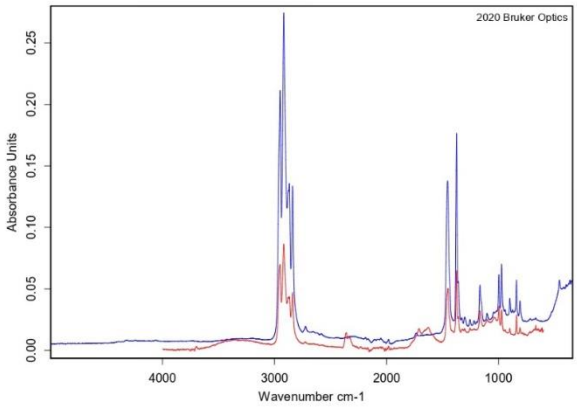
M-15

Search Library **4/4/2022 2:28:04 PM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	Thermofil GPP 1630
Supplier	Asahi Kasei
Filler	Glass fibres
Filler Content	30%
Color	black
Measurement Technique	DiamondATR
Sample Preparation	surface material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	710	PP	9003-07-0		

Color	File	Path	Spectrum Type
	M-15.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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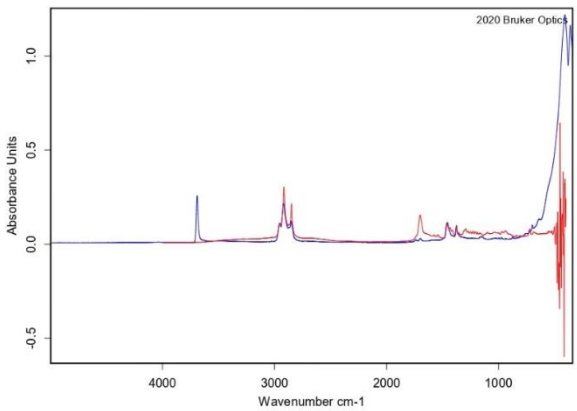
ns 1-3

Search Library **3/31/2022 11:44:24 AM**



Polymer	TPE
CAS Registry Number	
Substance	TPO or TPV
Trade Name	Gammaflex 90FR3
Supplier	PTS
Filler	unknown
Filler Content	0-
Color	black
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	689	TPE			

Color	File	Path	Spectrum Type
	ns-1-3.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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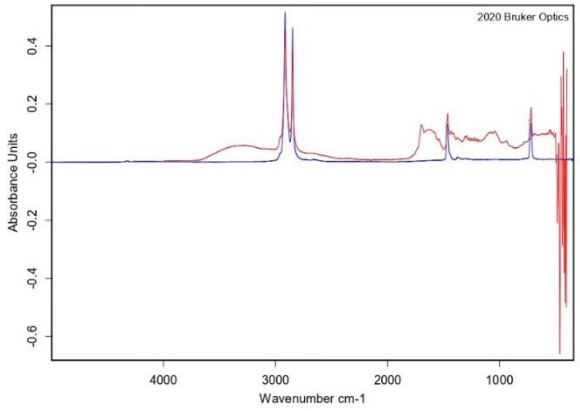
ns 1-5

Search Library **3/31/2022 11:53:21 AM**



Polymer	PE-LLD
CAS Registry Number	9002-88-4
Substance	polyethylene, linear low density
Trade Name	Exxonmobil LL6201
Supplier	Exxonmobil
Filler	unfilled
Filler Content	0
Color	white
Applications	housewares, lids
Melting Point	122°C

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	763	PE-LLD	9002-88-4		

Color	File	Path	Spectrum Type
	ns-1-5.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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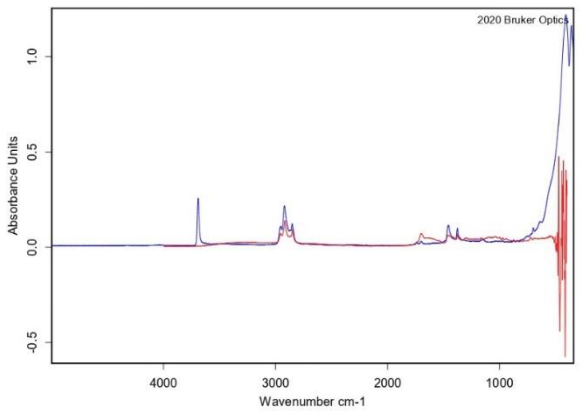
ns 1-8

Search Library **3/31/2022 12:00:52 PM**



Polymer	TPE
CAS Registry Number	
Substance	TPO or TPV
Trade Name	Gammaflex 90FR3
Supplier	PTS
Filler	unknown
Filler Content	0-
Color	black
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	588	TPE			

Color	File	Path	Spectrum Type
	ns-1-8.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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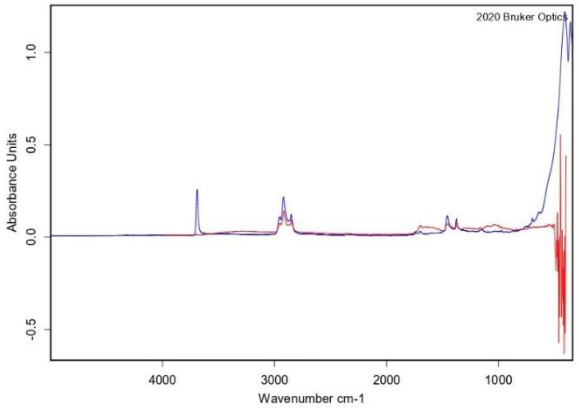
ns 1-9

Search Library **3/31/2022 12:03:10 PM**



Polymer	TPE
CAS Registry Number	
Substance	TPO or TPV
Trade Name	Gammaflex 90FR3
Supplier	PTS
Filler	unknown
Filler Content	0-
Color	black
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	807	TPE			

Color	File	Path	Spectrum Type
	ns-1-9.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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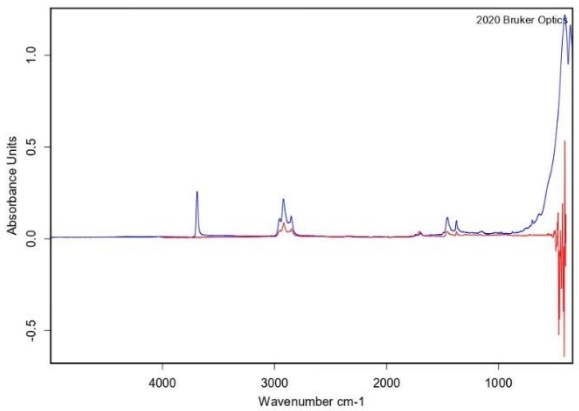
ns 2-1

Search Library **3/31/2022 12:08:27 PM**



Polymer	TPE
CAS Registry Number	
Substance	TPO or TPV
Trade Name	Gammaflex 90FR3
Supplier	PTS
Filler	unknown
Filler Content	0-
Color	black
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	700	TPE			

Color	File	Path	Spectrum Type
	ns-2-1.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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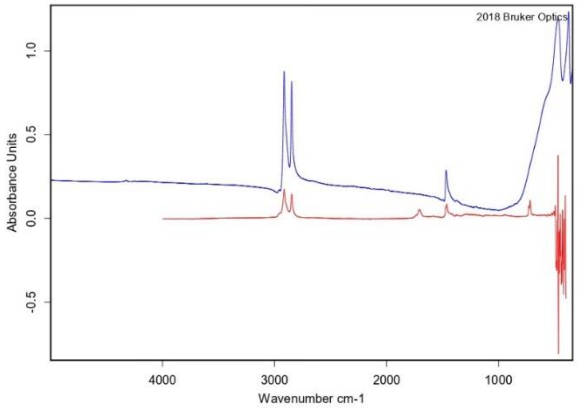
ns 2-3

Search Library **3/31/2022 12:23:21 PM**



Additive Name	Litocolour weiß K70 PE
CAS Registry Number	
Application	colour batch
Chemical and Application Info	white
Additive Content	70 %
Measurement Technique	Diamond-ATR
Sample Reference	Kunststoff Institut Lüdenscheid Add0020
Entry No.	19
Library name	KIMW ATR-IR POLYMER LIBRARY VERSION 2.(
Library description	IR-Spectra of Additives, Diamond-ATR

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	664	Litocolour weiß K70 PE			

Color	File	Path	Spectrum Type
	ns-2-3.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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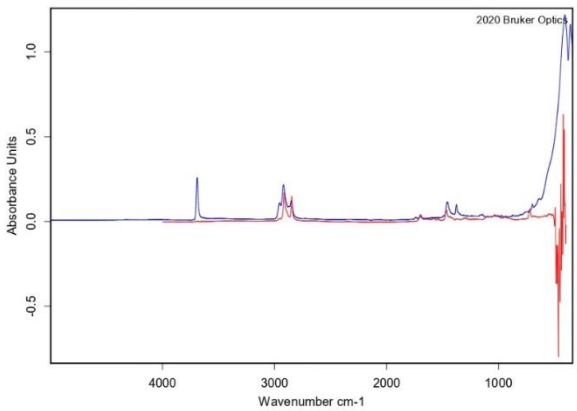
ns 2-5

Search Library **3/31/2022 12:31:39 PM**



Polymer	TPE
CAS Registry Number	
Substance	TPO or TPV
Trade Name	Gammaflex 90FR3
Supplier	PTS
Filler	unknown
Filler Content	0-
Color	black
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	602	TPE			

Color	File	Path	Spectrum Type
	ns-2-5.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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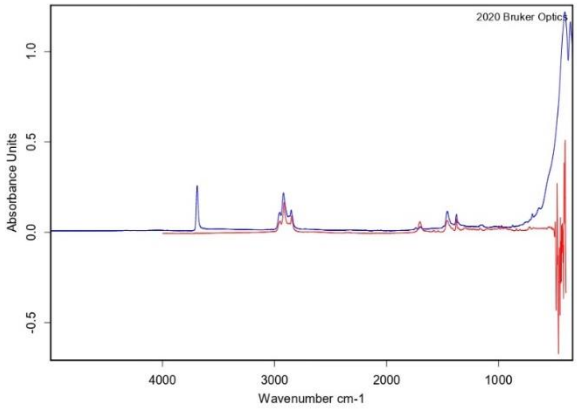
ns 2-7

Search Library **3/31/2022 12:37:18 PM**



Polymer	TPE
CAS Registry Number	
Substance	TPO or TPV
Trade Name	Gammaflex 90FR3
Supplier	PTS
Filler	unknown
Filler Content	0-
Color	black
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	692	TPE			

Color	File	Path	Spectrum Type
	ns-2-7.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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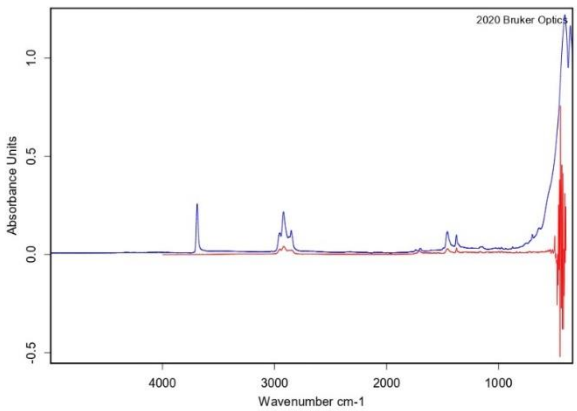
ns 2-8

Search Library **3/31/2022 12:48:16 PM**



Polymer	TPE
CAS Registry Number	
Substance	TPO or TPV
Trade Name	Gammaflex 90FR3
Supplier	PTS
Filler	unknown
Filler Content	0-
Color	black
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	447	TPE			

Color	File	Path	Spectrum Type
	ns-2-8.1	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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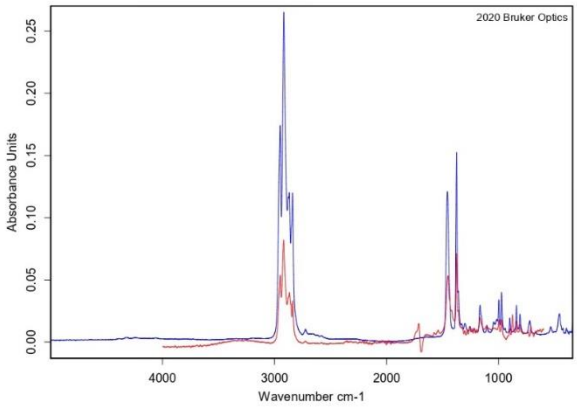
ns 2-12

Search Library **3/31/2022 1:02:45 PM**



Polymer	PP-C
CAS Registry Number	9010-79-1
Substance	polypropylene copolymer
Trade Name	Purell EP 274 P
Supplier	LyondellBasell
Filler	unfilled
Filler Content	0%
Color	natural
Applications	Healthcare Applications,Medical Devices
MVR/MFR	15g/10min[2,16/230°C]

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	713	PP-C	9010-79-1		

Color	File	Path	Spectrum Type
	ns-2-12.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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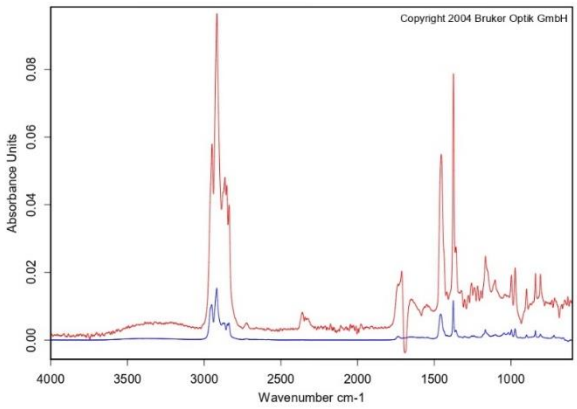
ns 3-2

Search Library **3/31/2022 1:12:06 PM**



Polymer Classification	Polypropylene (PP)
Trade Name	Daplen DSC 1011
Manufacturer	DSM
Colour	black
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Ge-Crysta
Entry No.	42
Library name	BPAD.S01
Library description	Bruker Optics ATR-Polymer Library

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	693	Polypropylene (PP)			

Color	File	Path	Spectrum Type
	ns-3-2.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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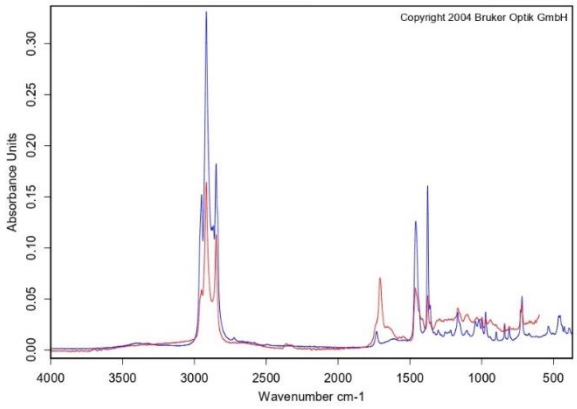
ns 3-3

Search Library **3/31/2022 1:14:08 PM**



Polymer Classification	Blend of Polypropylen and Ethylen / Propylen
Trade Name	Keltan TP 0550
Manufacturer	DSM
Colour	black
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Diamond
Entry No.	123
Library name	BPAD.S01
Library description	Bruker Optics ATR-Polymer Library

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	704	Blend of Polypropylen and Ethylen / Propylen (PP + EPDM)			

Color	File	Path	Spectrum Type
	ns-3-3.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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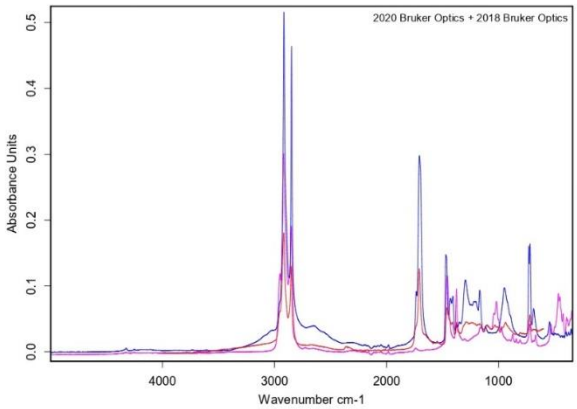
ns 3-4

Search Library **3/31/2022 1:16:16 PM**



Polymer	PP/EPDM
CAS Registry Number	
Substance	polypropylene/ethlyene propylene diene rubb
Trade Name	Alfater XL A70I 4GP 0000
Supplier	Albis
Filler	talc
Filler Content	?
Color	natural
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	584	montan wax	8002-53-7		
	553	PP/EPDM			

Color	File	Path	Spectrum Type
	ns-3-4.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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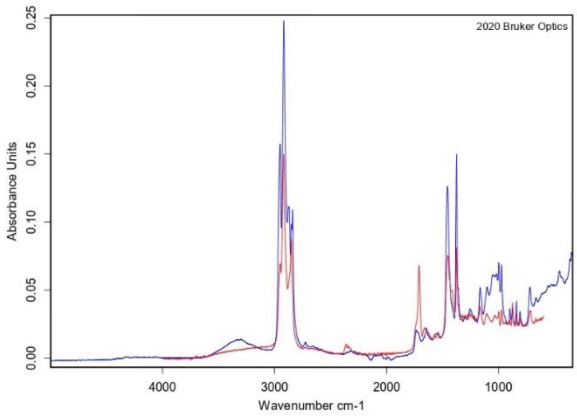
ns 3-6

Search Library **3/31/2022 1:22:07 PM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	V830 Maedje
Supplier	Holstein Flachs
Filler	Flax
Filler Content	40%
Color	natural
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	663	PP	9003-07-0		

Color	File	Path	Spectrum Type
	ns-3-6.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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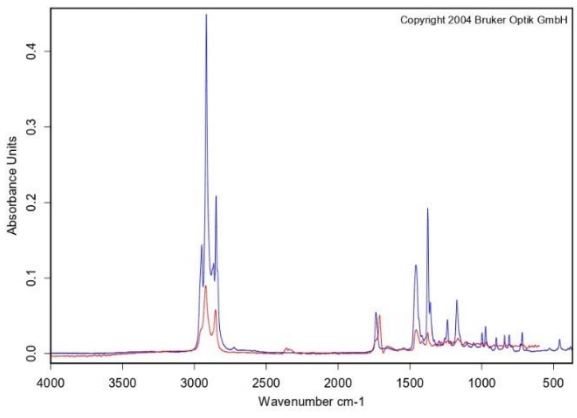
ns 3-7

Search Library **3/31/2022 1:24:03 PM**



Polymer Classification	Polypropylene (PP)
Trade Name	Hostalen PPH 1850
Manufacturer	Hoechst AG
Colour	nature
Chemical / Physical Descriptio	Homopolymer
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Diamond
Entry No.	105
Library name	BPAD.S01

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	346	Polypropylene (PP)			

Color	File	Path	Spectrum Type
	ns-3-7.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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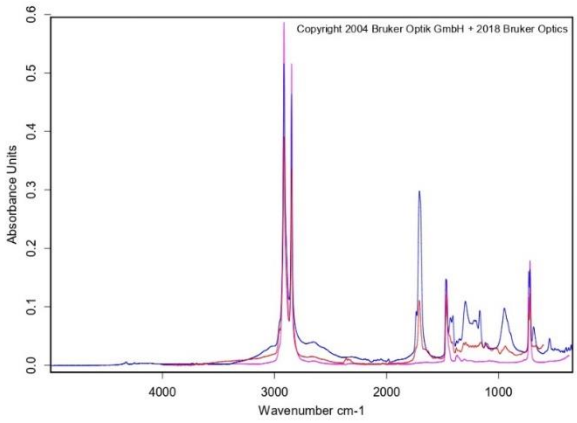
ns 3-8

Search Library **3/31/2022 1:26:21 PM**



Polymer Classification	Low-Density Polyethylene (PE-LD)
Trade Name	Escorene EX 376
Manufacturer	ESSO
Colour	nature
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Diamond
Entry No.	71
Library name	BPAD.S01
Library description	Bruker Optics ATR-Polymer Library

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	873	montan wax	8002-53-7		
	798	Low-Density Polyethylene (PE-LD)			

Color	File	Path	Spectrum Type
	ns-3-8.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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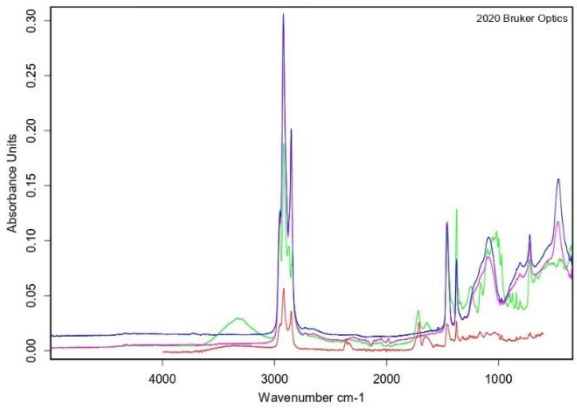
ns 3-9

Search Library **3/31/2022 1:29:56 PM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	PP Flachs
Supplier	unknown
Filler	Flax
Filler Content	ca. 20-30%
Color	natural
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	450	TPV			
	449	PP/TPO			
	411	PP	9003-07-0		

Color	File	Path	Spectrum Type
	ns-3-9.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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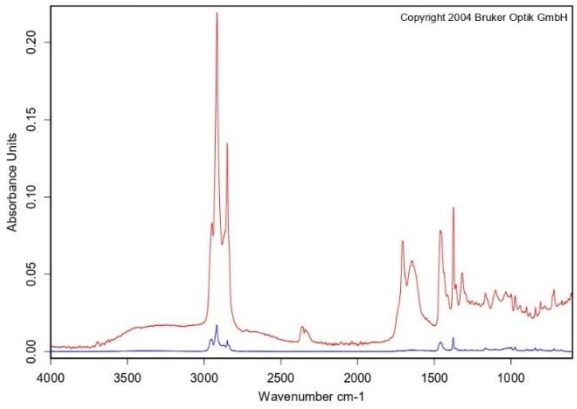
ns 3-11

Search Library **3/31/2022 1:35:15 PM**



Polymer Classification	Polypropylene (PP)
Trade Name	Hostalen PPU7580 TV 10
Manufacturer	Hoechst AG
Colour	nature
Chemical / Physical Descriptio	10% talc, Homopolymer
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Ge-Crysta
Entry No.	120
Library name	BPAD.S01

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	629	Polypropylene (PP)			

Color	File	Path	Spectrum Type
	ns-3-11.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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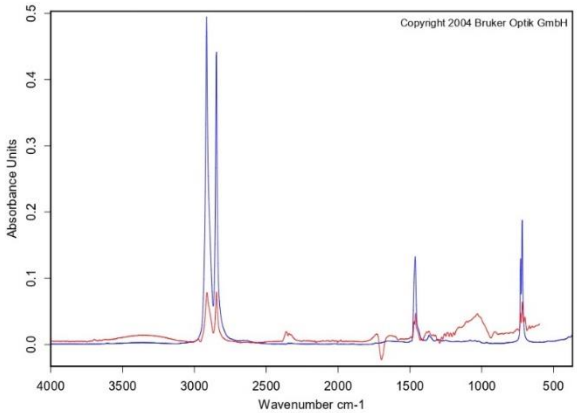
ns 4-2

Search Library **3/31/2022 1:55:18 PM**



Polymer Classification	High Density Polyethylene (PE-HD)
Trade Name	Hostalen GU 7746
Manufacturer	Hoechst AG
Colour	nature
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Diamond
Entry No.	103
Library name	BPAD.S01
Library description	Bruker Optics ATR-Polymer Library

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	360	High Density Polyethylene (PE-HD)			

Color	File	Path	Spectrum Type
	ns-4-2.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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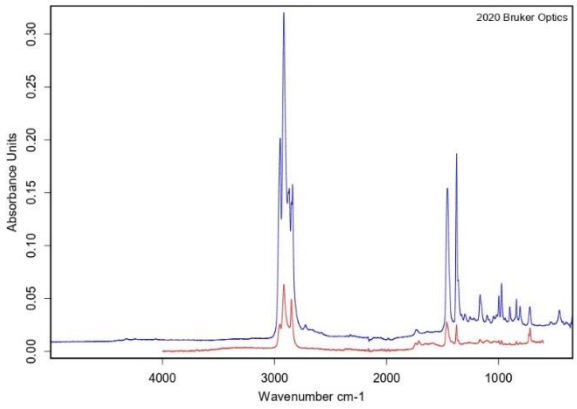
ns 4-3

Search Library **3/31/2022 2:35:58 PM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	Nilflex 6L Nero D60
Supplier	Taro Plast
Filler	unknown
Filler Content	0-
Color	black
Processing Method	injection molding
Applications	industrial or automotive application

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	601	PP	9003-07-0		

Color	File	Path	Spectrum Type
	NS-4-3.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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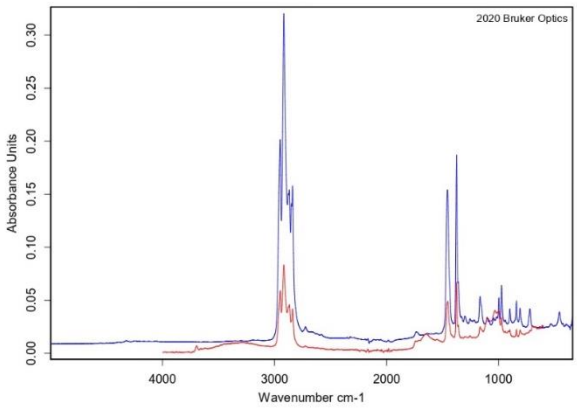
ns 4-4

Search Library **3/31/2022 2:42:34 PM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	Nilflex 6L Nero D60
Supplier	Taro Plast
Filler	unknown
Filler Content	0-
Color	black
Processing Method	injection molding
Applications	industrial or automotive application

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	784	PP	9003-07-0		

Color	File	Path	Spectrum Type
	ns-4-4.1	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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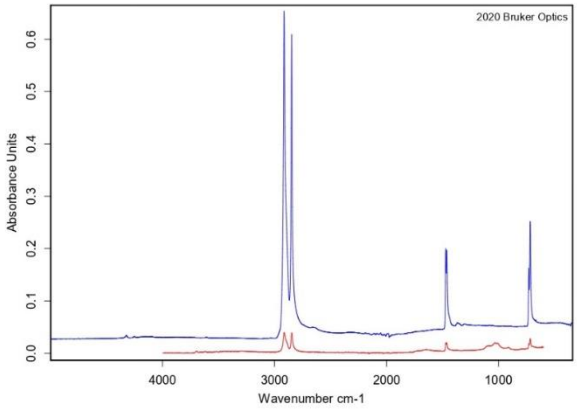
ns 4-5

Search Library **3/31/2022 2:45:08 PM**



Polymer	PE-HD
CAS Registry Number	9002-88-4
Substance	polyethylene, high density
Trade Name	Vestolen A 6060R
Supplier	Sabic
Filler	unfilled
Filler Content	0
Color	black
Applications	gas, drinking water and waste water piping
Melting Point	128

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	523	PE-HD	9002-88-4		

Color	File	Path	Spectrum Type
	ns-4-5.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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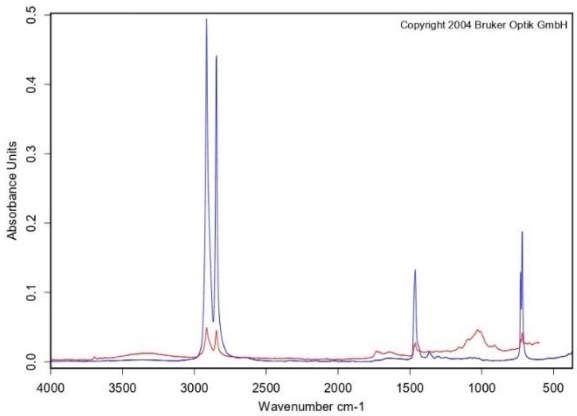
ns 4-6

Search Library **3/31/2022 2:48:19 PM**



Polymer Classification	High Density Polyethylene (PE-HD)
Trade Name	Hostalen GU 7746
Manufacturer	Hoechst AG
Colour	nature
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Diamond
Entry No.	103
Library name	BPAD.S01
Library description	Bruker Optics ATR-Polymer Library

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	542	High Density Polyethylene (PE-HD)			

Color	File	Path	Spectrum Type
	ns-4-6.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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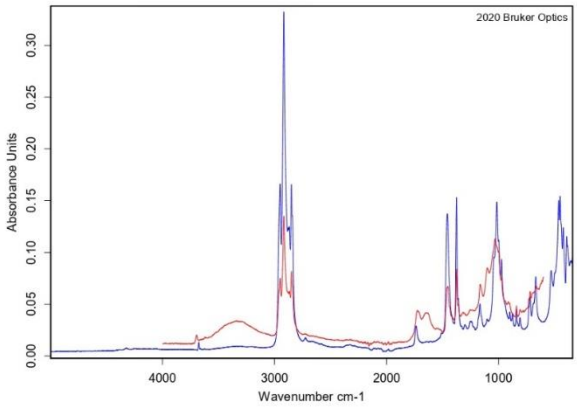
ns 4-7

Search Library **3/31/2022 2:50:13 PM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	PPRT1000E20
Supplier	unknown
Filler	talc
Filler Content	?
Color	black
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	679	PP	9003-07-0		

Color	File	Path	Spectrum Type
	ns-4-7.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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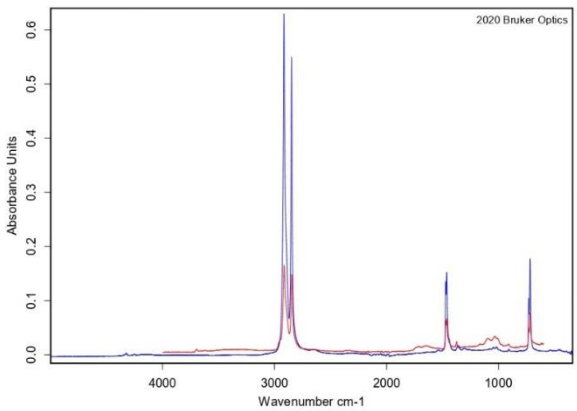
ns 4-8

Search Library **3/31/2022 2:52:57 PM**



Polymer	PE-HD
CAS Registry Number	9002-88-4
Substance	polyethylene, high density
Trade Name	Alcudia 49070-UV
Supplier	Repsol
Filler	unfilled
Color	natural
Applications	container, tanks
MVR/MFR	9 g/ 10 min [21,6 kg/ 190 °C]
Density	0,949

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	719	PE-HD	9002-88-4		

Color	File	Path	Spectrum Type
	ns-4-8.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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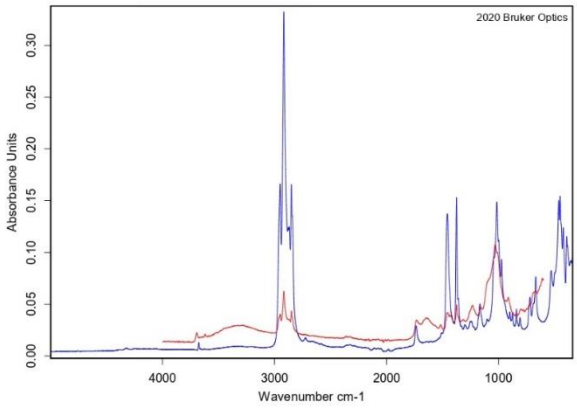
ns 4-9

Search Library **3/31/2022 2:54:59 PM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	PPRT1000E20
Supplier	unknown
Filler	talc
Filler Content	?
Color	black
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	621	PP	9003-07-0		

Color	File	Path	Spectrum Type
	ns-4-9.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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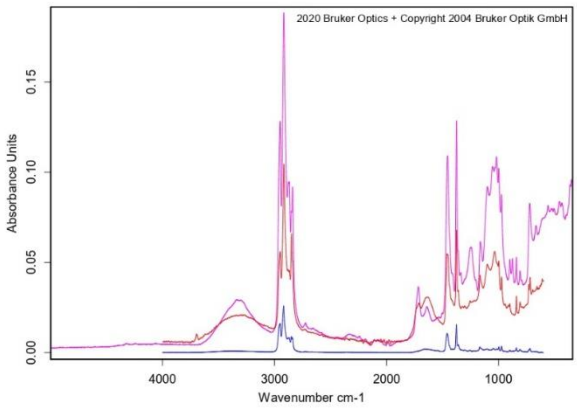
ns 4-10

Search Library **3/31/2022 2:59:43 PM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	PP Flachs
Supplier	unknown
Filler	Flax
Filler Content	ca. 20-30%
Color	natural
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	713	Blend of Polypropylen and Ethylen / Propylen (PP + EPDM)			
	698	PP	9003-07-0		

Color	File	Path	Spectrum Type
	ns-4-10.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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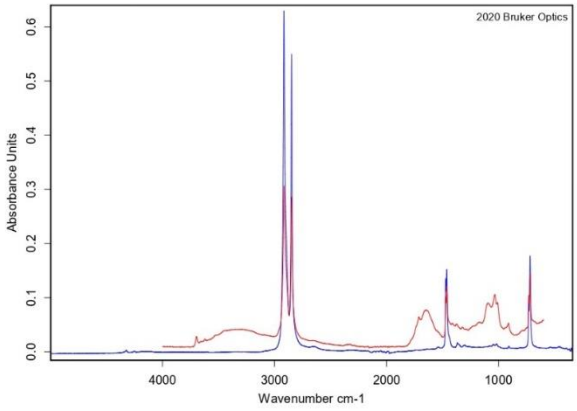
ns 5-4

Search Library **4/4/2022 10:46:06 AM**



Polymer	PE-HD
CAS Registry Number	9002-88-4
Substance	polyethylene, high density
Trade Name	Alcudia 49070-UV
Supplier	Repsol
Filler	unfilled
Color	natural
Applications	container, tanks
MVR/MFR	9 g/ 10 min [21,6 kg/ 190 °C]
Density	0,949

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	696	PE-HD	9002-88-4		

Color	File	Path	Spectrum Type
	ns-5-4.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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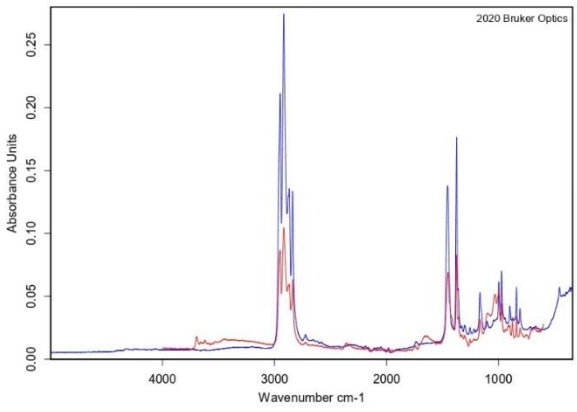
ns 6-3

Search Library **4/4/2022 10:57:26 AM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	Thermofil GPP 1630
Supplier	Asahi Kasei
Filler	Glass fibres
Filler Content	30%
Color	black
Measurement Technique	DiamondATR
Sample Preparation	surface material

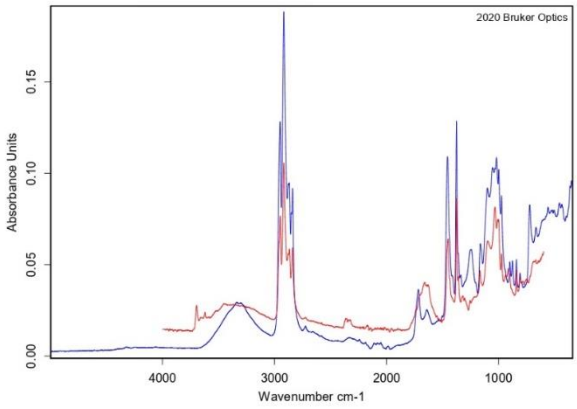
Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	704	PP	9003-07-0		

Color	File	Path	Spectrum Type
	ns-6-3.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

Page 1 of 1

ns 6-4

Search Library **4/4/2022 11:02:44 AM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	PP Flachs
Supplier	unknown
Filler	Flax
Filler Content	ca. 20-30%
Color	natural
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	711	PP	9003-07-0		

Color	File	Path	Spectrum Type
	ns-6-4.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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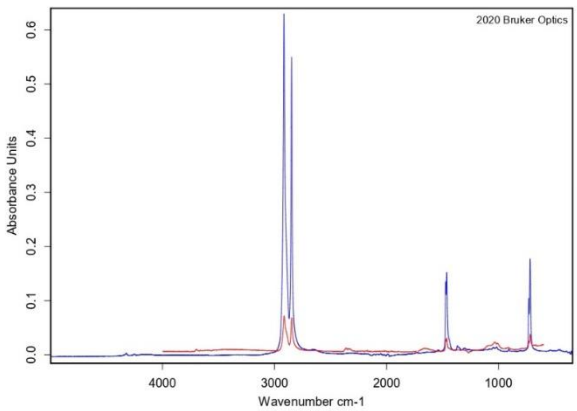
ns 6-5

Search Library **4/4/2022 11:06:09 AM**



Polymer	PE-HD
CAS Registry Number	9002-88-4
Substance	polyethylene, high density
Trade Name	Alcudia 49070-UV
Supplier	Repsol
Filler	unfilled
Color	natural
Applications	container, tanks
MVR/MFR	9 g/ 10 min [21,6 kg/ 190 °C]
Density	0,949

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	630	PE-HD	9002-88-4		

Color	File	Path	Spectrum Type
	ns-6-5.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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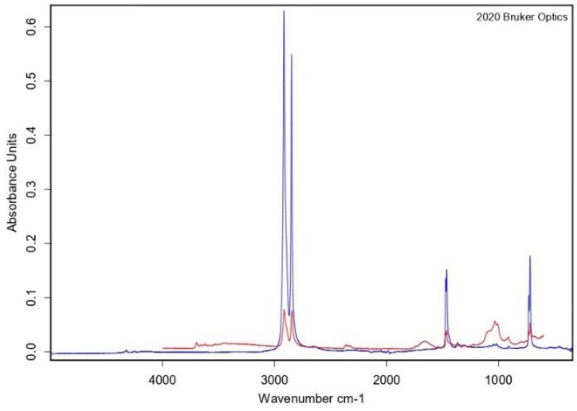
ns 6-6

Search Library **4/4/2022 11:08:12 AM**



Polymer	PE-HD
CAS Registry Number	9002-88-4
Substance	polyethylene, high density
Trade Name	Alcudia 49070-UV
Supplier	Repsol
Filler	unfilled
Color	natural
Applications	container, tanks
MVR/MFR	9 g/ 10 min [21,6 kg/ 190 °C]
Density	0,949

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	531	PE-HD	9002-88-4		

Color	File	Path	Spectrum Type
	ns-6-6.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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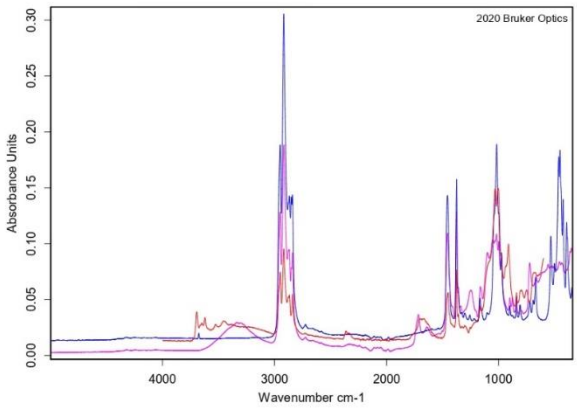
ns 6-7

Search Library **4/4/2022 11:10:35 AM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	PP Flachs
Supplier	unknown
Filler	Flax
Filler Content	ca. 20-30%
Color	natural
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	625	TPV			
	616	PP	9003-07-0		

Color	File	Path	Spectrum Type
	ns-6-7.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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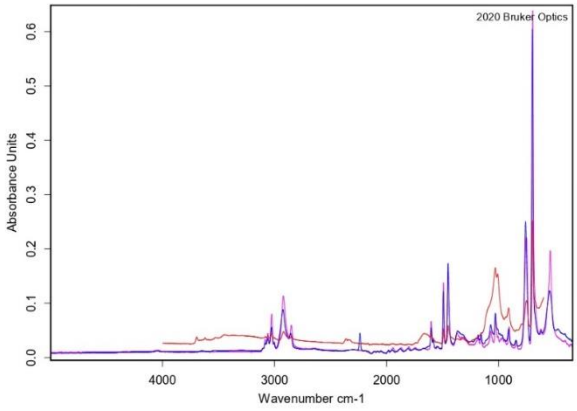
ns 6-8

Search Library **4/4/2022 11:13:56 AM**



Polymer	PS
CAS Registry Number	9003-53-6
Substance	polystyrene
Trade Name	Styrolution PS 124L
Supplier	Styrolution
Filler	unfilled
Filler Content	0-
Color	natural
Processing Method	injection molding, thermo forming
Young´s modulus (RT)	3200

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	724	SAN	9003-54-7		
	712	PS	9003-53-6		

Color	File	Path	Spectrum Type
	ns-6-8.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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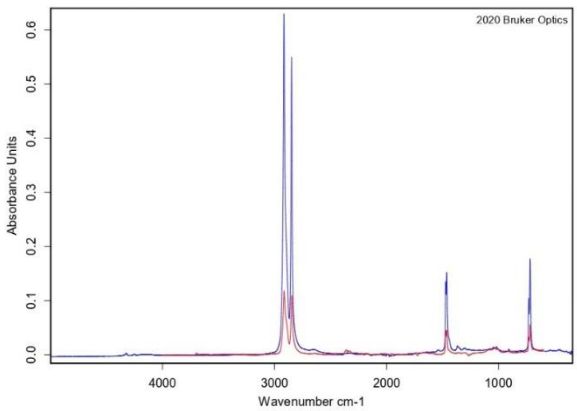
ns 6-9

Search Library **4/4/2022 11:17:09 AM**



Polymer	PE-HD
CAS Registry Number	9002-88-4
Substance	polyethylene, high density
Trade Name	Alcudia 49070-UV
Supplier	Repsol
Filler	unfilled
Color	natural
Applications	container, tanks
MVR/MFR	9 g/ 10 min [21,6 kg/ 190 °C]
Density	0,949

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	716	PE-HD	9002-88-4		

Color	File	Path	Spectrum Type
	ns-6-9.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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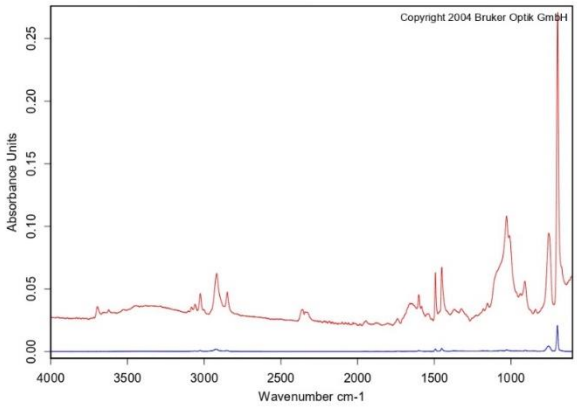
ns 6-10

Search Library **4/4/2022 11:19:39 AM**



Polymer Classification	Polystyrene (PS)
Trade Name	Polystyrol 165 H
Manufacturer	BASF AG
Melting Point	Melt Temperature Range: 180 - 280 C
Density	1050 kg/m3
Colour	clear
Chemical / Physical Descriptio	Polystyrol 165 H is a high molecular weight, g
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Ge-Crysta

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	826	Polystyrene (PS)			

Color	File	Path	Spectrum Type
	ns-6-10.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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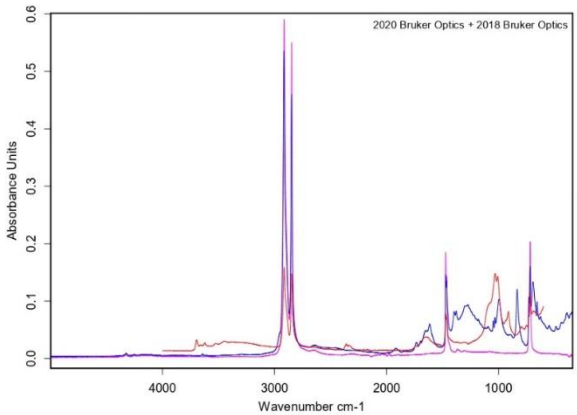
ns 7-1

Search Library **4/4/2022 11:21:51 AM**



Polymer	PE-HD
CAS Registry Number	9002-88-4
Substance	polyethylene, high density
Trade Name	ExxonMobil HMA 025
Supplier	ExxonMobil
Filler	unfilled
Filler Content	0
Color	natural
MVR/MFR	8 g/10 min [2,16 kg/190 °C]
Density	0,964

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	498	Hydrocerol ITP 845			
	409	PE-HD	9002-88-4		

Color	File	Path	Spectrum Type
	ns-7-1.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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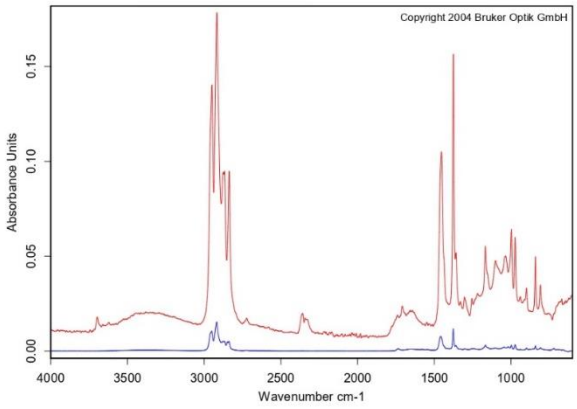
ns 7-2

Search Library **4/4/2022 11:24:48 AM**



Polymer Classification	Polypropylene (PP)
Trade Name	Daplen DSC 1011
Manufacturer	DSM
Colour	black
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Ge-Crysta
Entry No.	42
Library name	BPAD.S01
Library description	Bruker Optics ATR-Polymer Library

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	851	Polypropylene (PP)			

Color	File	Path	Spectrum Type
	ns-7-2.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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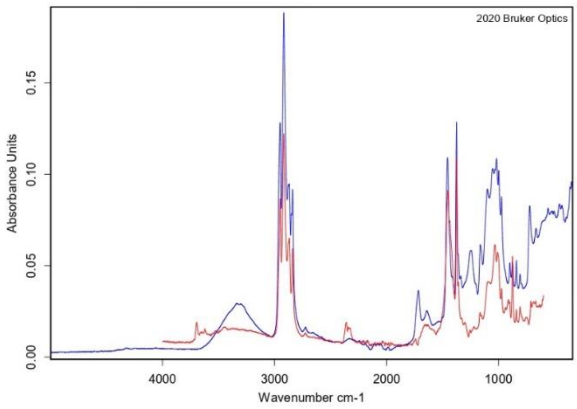
ns 7-3

Search Library **4/4/2022 11:26:37 AM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	PP Flachs
Supplier	unknown
Filler	Flax
Filler Content	ca. 20-30%
Color	natural
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	738	PP	9003-07-0		

Color	File	Path	Spectrum Type
	ns-7-3.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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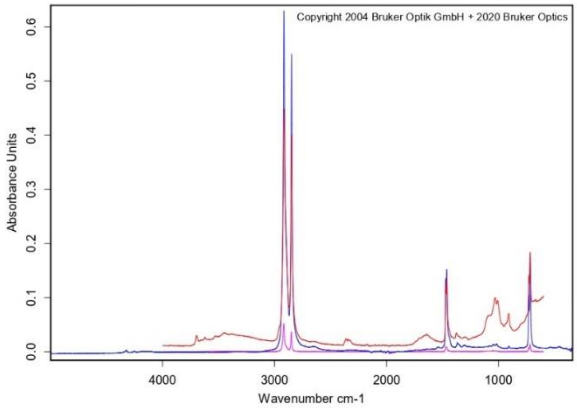
ns 7-4

Search Library **4/4/2022 11:28:52 AM**



Polymer Classification	Low-Density Polyethylene (PE-LD)
Trade Name	Lupolen 4261 A
Manufacturer	BASF AG
Colour	black
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Ge-Crysta
Entry No.	132
Library name	BPAD.S01
Library description	Bruker Optics ATR-Polymer Library

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	661	PE-HD	9002-88-4		
	640	Low-Density Polyethylene (PE-LD)			

Color	File	Path	Spectrum Type
	ns-7-4.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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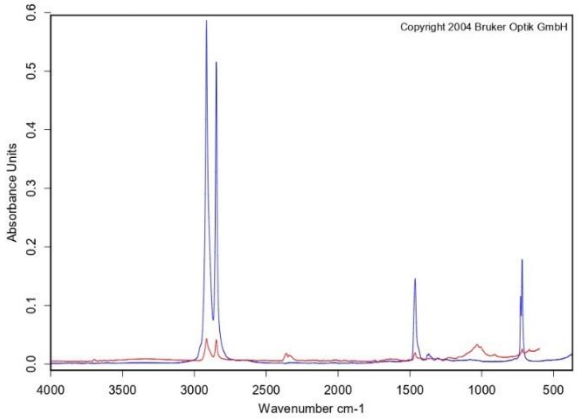
ns 7-5

Search Library **4/4/2022 11:31:51 AM**



Polymer Classification	Low-Density Polyethylene (PE-LD)
Trade Name	Escorene EX 376
Manufacturer	ESSO
Colour	nature
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Diamond
Entry No.	71
Library name	BPAD.S01
Library description	Bruker Optics ATR-Polymer Library

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	304	Low-Density Polyethylene (PE-LD)			

Color	File	Path	Spectrum Type
	ns-7-5.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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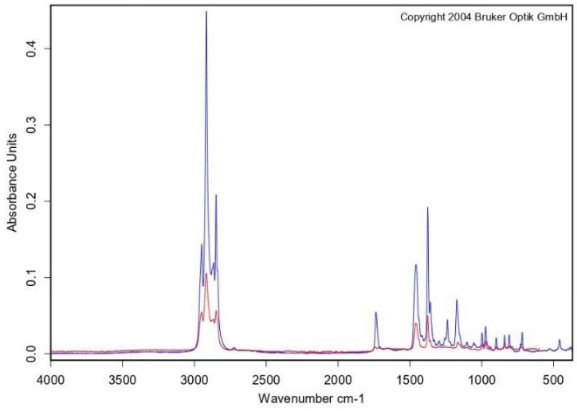
P 1-1

Search Library **4/4/2022 12:41:01 PM**



Polymer Classification	Polypropylene (PP)
Trade Name	Hostalen PPH 1850
Manufacturer	Hoechst AG
Colour	nature
Chemical / Physical Descriptio	Homopolymer
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Diamond
Entry No.	105
Library name	BPAD.S01

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	905	Polypropylene (PP)			

Color	File	Path	Spectrum Type
	P-1-1.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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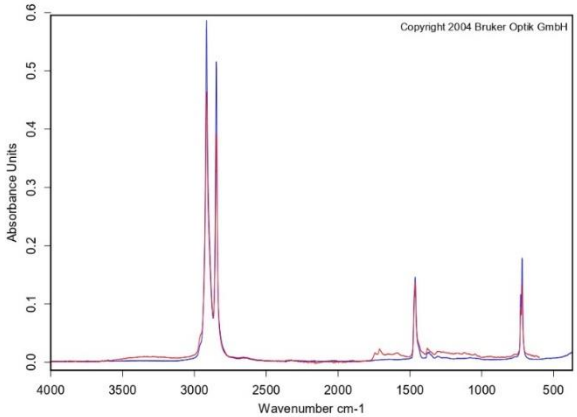
P 1-2

Search Library **4/4/2022 12:44:40 PM**



Polymer Classification	Low-Density Polyethylene (PE-LD)
Trade Name	Escorene EX 376
Manufacturer	ESSO
Colour	nature
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Diamond
Entry No.	71
Library name	BPAD.S01
Library description	Bruker Optics ATR-Polymer Library

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	994	Low-Density Polyethylene (PE-LD)			

Color	File	Path	Spectrum Type
	P-1-2.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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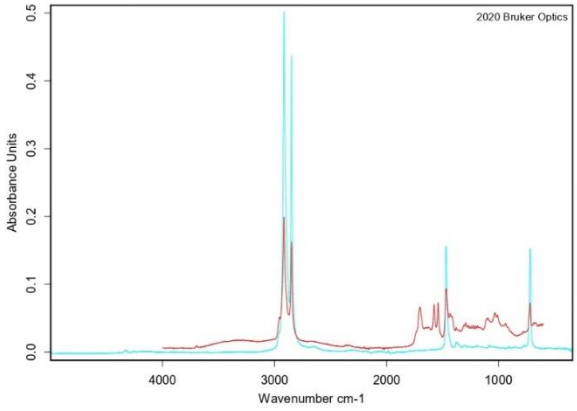
P 2-1

Search Library **4/4/2022 12:49:16 PM**



Polymer	PE-LLD
CAS Registry Number	9002-88-4
Substance	polyethylene, linear low density
Trade Name	Admer GT-6E
Supplier	Mitsui
Filler	unknown
Filler Content	0-
Color	natural
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	495	PE-LLD	9002-88-4		

Color	File	Path	Spectrum Type
	P-2-1.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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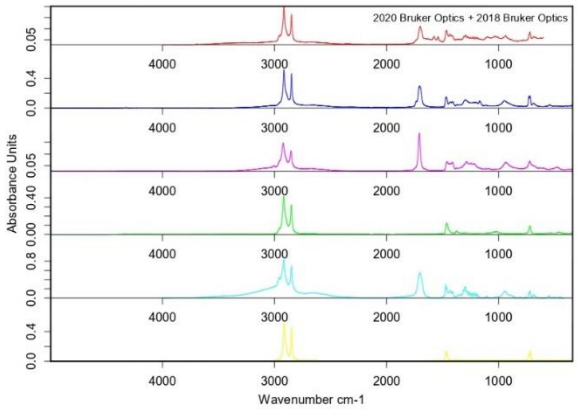
P 2-2

Search Library **4/4/2022 12:53:46 PM**



Polymer	PE-LLD
CAS Registry Number	9002-88-4
Substance	polyethylene, linear low density
Trade Name	Exxonmobil LL6201
Supplier	Exxonmobil
Filler	unfilled
Filler Content	0
Color	white
Applications	housewares, lids
Melting Point	122°C

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	406	montan wax	8002-53-7		
	363	Ölsäure	112-80-1		
	357	SEBS			
	355	STEARIC ACID	57-11-4	C18H36O2	284.49
	326	PE-LLD	9002-88-4		

Color	File	Path	Spectrum Type
	P-2-2.1	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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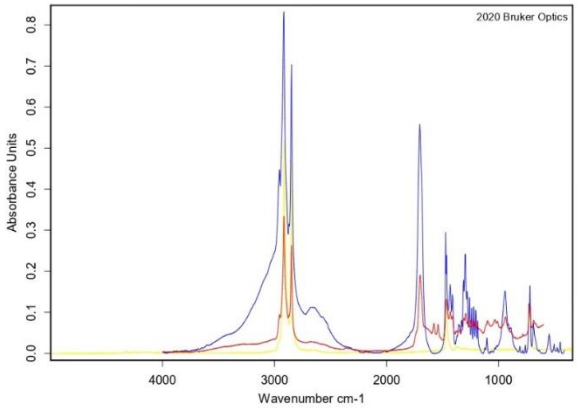
P 3-1

Search Library **4/4/2022 1:01:16 PM**



Polymer	PE-LLD
CAS Registry Number	9002-88-4
Substance	polyethylene, linear low density
Trade Name	Exxonmobil LL6201
Supplier	Exxonmobil
Filler	unfilled
Filler Content	0
Color	white
Applications	housewares, lids
Melting Point	122°C

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	392	STEARIC ACID	57-11-4	C18H36O2	284.49
	301	PE-LLD	9002-88-4		

Color	File	Path	Spectrum Type
	P-3-1.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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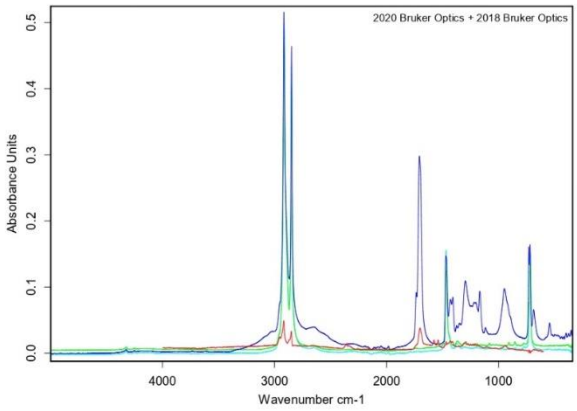
P 3-3

Search Library **4/4/2022 1:06:13 PM**



Polymer	PE-LLD
CAS Registry Number	9002-88-4
Substance	polyethylene, linear low density
Trade Name	Admer GT-6E
Supplier	Mitsui
Filler	unknown
Filler Content	0-
Color	natural
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	363	montan wax	8002-53-7		
	242	PE-MD	9002-88-4		
	241	PE-LLD	9002-88-4		

Color	File	Path	Spectrum Type
	P-3-3.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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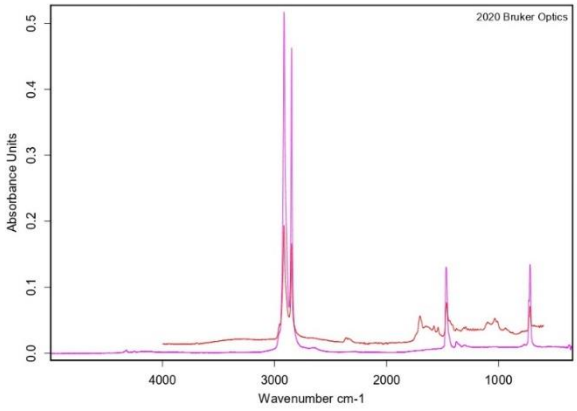
P 4-1

Search Library **4/4/2022 1:08:16 PM**



Polymer	PE-LLD
CAS Registry Number	9002-88-4
Substance	polyethylene, linear low density
Trade Name	Exxonmobil LL6201
Supplier	Exxonmobil
Filler	unfilled
Filler Content	0
Color	white
Applications	housewares, lids
Melting Point	122°C

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	653	PE-LLD	9002-88-4		

Color	File	Path	Spectrum Type
	P-4-1.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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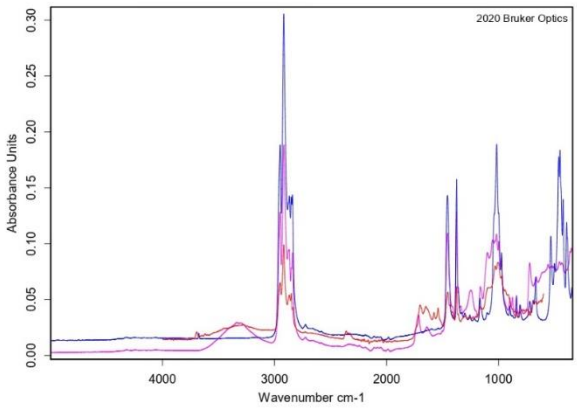
P 4-2

Search Library **4/4/2022 1:10:32 PM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	PP Flachs
Supplier	unknown
Filler	Flax
Filler Content	ca. 20-30%
Color	natural
Measurement Technique	DiamondATR
Sample Preparation	cut surface, core material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	402	TPV			
	383	PP	9003-07-0		

Color	File	Path	Spectrum Type
	P-4-2.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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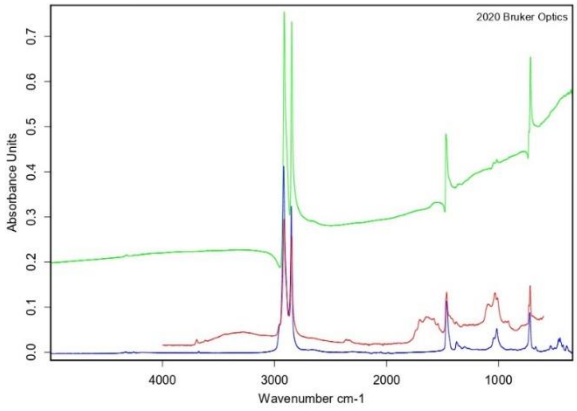
P 4-3

Search Library **4/4/2022 1:12:19 PM**



Polymer	PE-HD
CAS Registry Number	9002-88-4
Substance	polyethylene, high density
Trade Name	Hostalen GM 9350c
Supplier	LyondellBasell
Filler	unfilled
Filler Content	0%
Color	black
Processing Method	blow molding, extrusion blow molding, injecti
Applications	fuel tanks

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	774	OBC	26221-73-8		
	727	PE-HD	9002-88-4		

Color	File	Path	Spectrum Type
	P-4-3.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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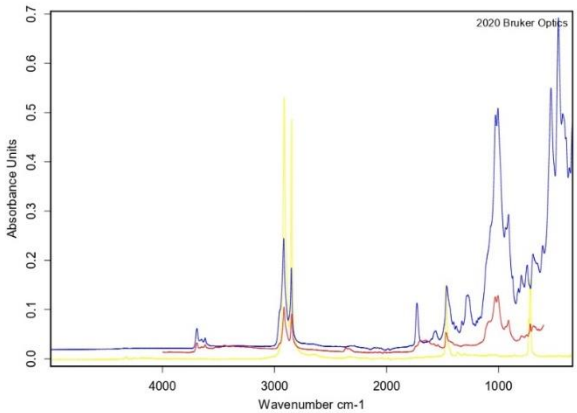
P 6

Search Library **4/4/2022 1:14:19 PM**



Polymer	PE-HD
CAS Registry Number	9002-88-4
Substance	polyethylene, high density
Trade Name	Histif 5431 Z
Supplier	LyondellBasell
Filler	unfilled
Filler Content	0
Color	natural
Processing Method	extrusion blow
Young´s modulus (RT)	1200

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	613	CM	63231-66-3		
	361	PE-HD	9002-88-4		

Color	File	Path	Spectrum Type
	P-6.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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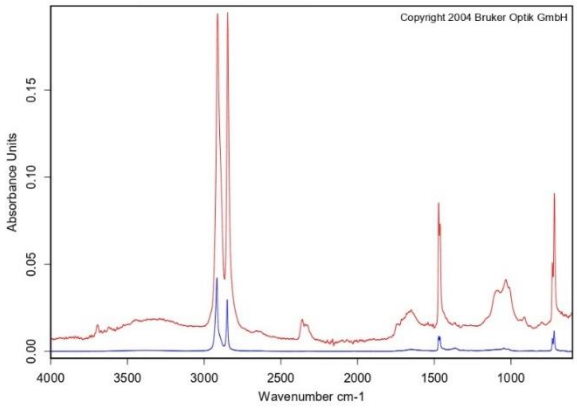
PU 2

Search Library **4/4/2022 1:27:41 PM**



Polymer Classification	High Density Polyethylene (PE-HD)
Trade Name	Hostalen GU 7746
Manufacturer	Hoechst AG
Colour	nature
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Ge-Crysta
Entry No.	104
Library name	BPAD.S01
Library description	Bruker Optics ATR-Polymer Library

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	693	High Density Polyethylene (PE-HD)			

Color	File	Path	Spectrum Type
	PU-2.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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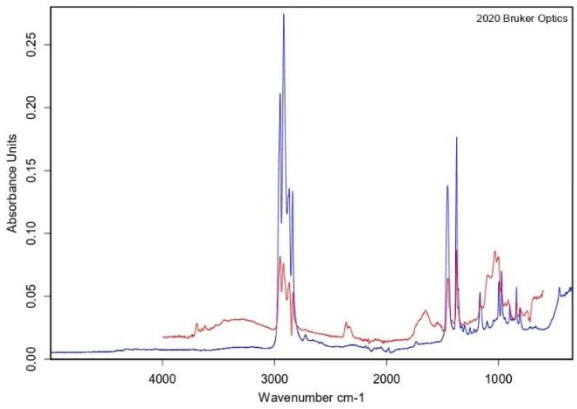
PU 4

Search Library **4/4/2022 1:32:45 PM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	Thermofil GPP 1630
Supplier	Asahi Kasei
Filler	Glass fibres
Filler Content	30%
Color	black
Measurement Technique	DiamondATR
Sample Preparation	surface material

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	550	PP	9003-07-0		

Color	File	Path	Spectrum Type
	PU-4.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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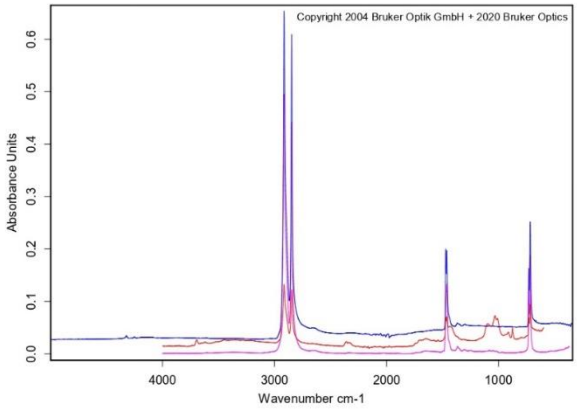
S-1

Search Library **4/4/2022 1:16:41 PM**



Polymer Classification	High Density Polyethylene (PE-HD)
Trade Name	Hostalen GU 7746
Manufacturer	Hoechst AG
Colour	nature
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Diamond
Entry No.	103
Library name	BPAD.S01
Library description	Bruker Optics ATR-Polymer Library

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	555	PE-HD	9002-88-4		
	467	High Density Polyethylene (PE-HD)			

Color	File	Path	Spectrum Type
	S-1.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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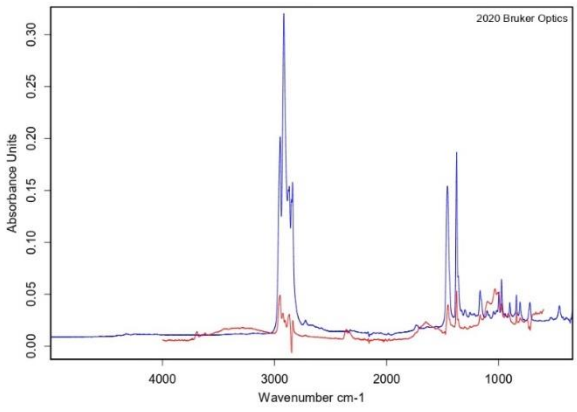
S-2

Search Library **4/4/2022 1:19:05 PM**



Polymer	PP
CAS Registry Number	9003-07-0
Substance	polypropylene
Trade Name	Nilflex 6L Nero D60
Supplier	Taro Plast
Filler	unknown
Filler Content	0-
Color	black
Processing Method	injection molding
Applications	industrial or automotive application

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	270	PP	9003-07-0		

Color	File	Path	Spectrum Type
	S-2.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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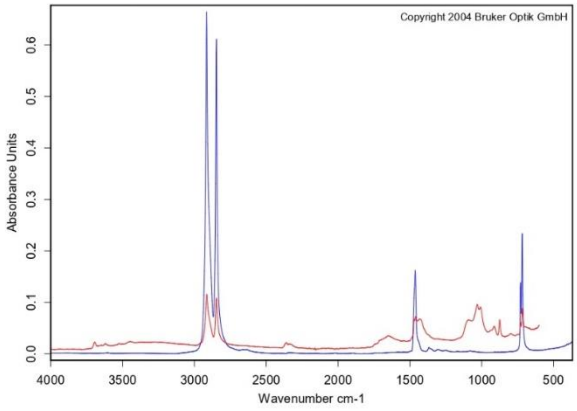
S-3

Search Library **4/4/2022 1:21:57 PM**



Polymer Classification	High Density Polyethylene (PE-HD)
Trade Name	Lupolen 6031 M
Manufacturer	BASF AG
Colour	black
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Diamond
Entry No.	134
Library name	BPAD.S01
Library description	Bruker Optics ATR-Polymer Library

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	430	High Density Polyethylene (PE-HD)			

Color	File	Path	Spectrum Type
	S-3.0	C:\Users\esd\Documents\Bruker\OPUS_8.7.10\DATA\MEAS	Query Spectrum

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VITA

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