INVESTIGATION ON PLASTIC WASTE UTILIZATION AND MANAGEMENT IN FISHERY HARBORS OF SRI LANKA

P.M.S.R.Muhandiram

228044X

Degree of Master of Science in Civil Engineering

Department of Civil Engineering

University of Moratuwa

Sri Lanka

August 2023

INVESTIGATION ON PLASTIC WASTE UTILIZATION AND MANAGEMENT IN FISHERY HARBORS OF SRI LANKA

P. M. S. R. Muhandiram

228044X

The thesis submitted in partial fulfillment of the requirements for the degree

Master of Science in Civil Engineering

Department of Civil Engineering

University of Moratuwa

Sri Lanka

August 2023

DECLARATION

I hereby declare that this thesis entitled "Investigation on plastic waste utilization and management in fishery harbors of Sri Lanka" is the result of my original work and has not been submitted in part or in whole for any other degree or diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgment is made in the text. All sources used in this thesis have been duly acknowledged and referenced.

Also, I hereby grant to the University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature	Date
…………………………….	02/11/2023

The above candidate has carried out research for the Master under our supervision.

Name of the Supervisors;

Prof. Rangika Umesh Halwatura

Signature;	Date;
…………………………….	……………………………

Prof. Karl S. Williams

Signature;	Date;
…………………………….	21/09/2023

Prof. Champika Liyanage

Signature;	Date;
……………………………….	…………………………….

ABSTRACT

Fishery harbors (FH) are recognized as hot spots for coastal pollution as intensive anthropogenic activity takes place there. According to previous beach surveys conducted in the country, plastic was recognized as the major polluter. However, there are no studies being conducted which target plastic waste generation inside FH located in Western Province of Sri Lanka. The study was conducted from October 2022 to September 2023. For this study, weekly accumulation study method was followed along the land-water interface to collect primary data.

Throughout the study period, a total of 34,188 anthropogenic debris pieces weighing 2650.47 kg were recorded from 59 data collection points within five FH. Plastic has become the major polluter both by count and by weight. By count it was 29,141 (85.24%) and by weight it was 1578.07 kg (59.53%). Therefore, plastics was recognized as the major polluter in FH located in the Western Province of Sri Lanka. By count only, rubber, metal, glass, processed wood and fabric represented 7.99%, 1.98%, 1.95%, 1.78% and 1.06% of the total anthropogenic debris respectively. The spatial variation in plastic debris accumulation was statistically significant in all five FH, while seasonal variation was statistically significant at Beruwala, South Dikkowita and Panadura FH. Plastic debris accumulation rates were 1.45, 2.21, 1.57, 0.98 and 0.17 items/m^2/week for Beruwala, North Dikkowita, South Dikkowita, Panadura and Negombo FH respectively. The top ten debris, fishery industry related plastic debris, single use plastics and transboundary plastic products represented 84.64%, 10.71%, 60.94% and 0.27% of the total plastic debris collected from the five FH. Lower percentage of transboundary plastic products highlights that the problem is primarily a result of mismanagement of plastic waste within the harbor. There was a strong positive (r=0.883) correlation between number of plastic debris recorded and plastic weight. Correlation between monthly rainfall and monthly average number of plastic debris recorded had a very weak positive correlation for Beruwala, North and South Dikkowita FH whilst being negative for Panadura and Negombo FH. Correlation between the tide level and number of plastic debris recorded was weakly negative (r= -0.280). Stranding debris count was significantly higher than the floating debris at FH. Therefore, conducting cleanup projects at FH during low tide will be much more effective, with a priority on addressing stranding debris.

A Stakeholder workshop and a questionnaire survey were conducted as a secondary data collection method. This was to reveal the perceptions and, attitudes of stakeholders as well as to find policy gaps related with plastic debris generation inside FH. Over half of the fishermen (51%) believe that the poor waste management of plastic within the FH by the Ceylon Fishery Harbors Corporation is the primary contributing factor for large amount of plastic waste generation. It highlighted the requirement of improving awareness among fishery communities, properly implementation of existing regulations and integrated stakeholders involvement.

Key words: *Fishery harbors, Plastic pollution, Coastal environment, Coastal contamination*, *Anthropogenic debris*

ACKNOWLEDGMENT

I wish to express my deepest gratitude to my research supervisor, Prof. R.U. Halwatura of the Department of Civil Engineering, for his invaluable guidance, unwavering encouragement, and immense knowledge. I am also thankful to him for providing me with the opportunity to conduct research under his supervision.

Furthermore, I highly appreciate the support and guidance provided by my supervisors, Prof. Karl S. Williams and Prof. Champika Liyanage, both from the School of Engineering, University of Central Lancashire. Their encouragement and patience throughout the research study were immensely valuable, and I am grateful for their constant feedback on the study.

The support given by the chairman and Mr. Nuwan of the Ceylon Fishery Harbors Corporation is really appreciated. I wish to express my greatest appreciation for all fishery harbor managers, all staff members and all the fishermen working at Beruwala, Panadura, Negombo, North and South Dikkowita fishery harbors.

I also extended my kind appreciation to all team members of Pro Green Laboratory and all the academic and non-academic staff of the Department of Civil Engineering, and everyone who helped me to complete this research successfully.

Special thanks should be given to Mrs. Poorni Naanayakkara for her support in preparing drawings using AutoCAD, and to Miss Sewwandi Alwis for her proofreading.

Finally, I wish to express my gratitude to my beloved parents, wife, all family members, and friends for their enormous patience and encouragement throughout this research. Additionally, I would like to thank all those who contributed to the successful completion of my research.

DEDICATION

This dissertation is dedicated to my loving parents and wife for their endless love, support, and encouragement!

Also my supervisors Prof.R.U.Halwathura, Prof.Karl S. Williams and Prof.Champika Liyanage for giving me this valuable opportunity to conduct research!

Most heartfelt

Gratitude and dedication to all the Sri Lankan citizens who provide their support to free education

TABLE OF CONTENTS

DECLARATION ..... **ii**
ABSTRACT ..... **iii**
DEDICATION ..... **v**
TABLE OF CONTENTS ..... **vi**
TABLE OF FIGURE ..... **ix**
LIST OF TABLE ..... **xiii**
LIST OF ABBREVIATIONS ..... **xiv**
LIST OF APPENDICES ..... **xv**
1 INTRODUCTION **1**
1.1 Background of the study 1
1.2 The research problem 3
1.3 Importance of the study 4
1.4 Overall aim of the study 11
1.5 Research objectives 12
1.6 Research Methodology 13
1.7 Key Findings 15
1.8 Dissertation structure 16
2 LITERATURE REVIEW **17**
2.1 Chapter introduction 17
2.2 Plastic classifications 18
2.3 Benefits of plastics 20
2.4 Types of plastic pollution 21
2.4.1 Land based plastic pollution 21
2.4.2 Ocean based plastic pollution 22
2.5 Marine plastic pollution 23
2.5.1 Economic impacts of marine plastic pollution 23
2.5.2 Ecosystem impacts of marine plastic pollution 24
2.5.3 Human health impacts of marine plastic pollution 25
2.5.4 Micro plastic level impacts of marine plastic pollution 26
2.6 Plastic waste management strategies 27
2.6.1 Global plastic waste management strategies 27
2.6.2 Local plastic waste management strategies 28
2.7 Fishery industry 29

2.7.1 Fishery industry in Sri Lanka 29
2.7.2 Impacts of seasonal variation on fishery industry of Sri Lanka 34
2.7.3 Problems associated with plastic waste generation in local fishery harbors 35
2.7.4 Research Questions 36
2.8 Chapter Summary 37
3 METHODOLOGY 39
3.1 Chapter Introduction 39
3.2 Research method 39
3.2.1 Study sites 40
3.2.2 Correlation between the number of plastic debris collected and weight of plastic debris collected 46
3.2.3 Correlation between monthly rainfall and monthly average number of plastic debris collected 47
3.2.4 Correlation between tide level and the number of stranding and floating plastic debris collected 48
3.2.5 Comparison between the number of stranding and floating plastic debris collected 49
3.2.6 Seasonal variation of plastic debris accumulation 49
3.2.7 Spatial variation of plastic debris accumulation 50
3.2.8 Size class of plastic debris 51
3.2.9 Single Use Plastics (SUPs) 52
3.2.10 Transboundary Marine Litter (TBML) 53
3.2.11 Manufactured years of food wrappers 54
3.2.12 Fishery industry contribution on plastic waste generation 54
3.2.13 Stakeholder’s workshop 55
3.2.14 Questionnaire surveys 56
3.3 Chapter Summery 57
4 RESULTS AND DISCUSSION 58
4.1 Chapter introduction 58
4.2 Results overview 58
4.2.1 Results overview based on total number of debris 60
4.2.2 Results overview based on total weight of debris 62
4.2.3 Composition of plastic debris recorded 65
4.2.4 Level of anthropogenic pollution in harbor wise 68
4.3 Correlation between number of plastic debris recorded and plastic weight 71

4.4 Correlation between monthly rainfall and monthly average number of plastic debris recorded 72

4.5 Correlation between the tide level and number of plastic debris recorded 74

4.6 Difference between stranding and floating debris....76

4.7 Seasonal variation of plastic debris accumulation 80

4.8 Spatial and temporal variation of plastic debris accumulation....83

4.8.1 Spatial and temporal variation of plastic debris accumulation at BFH 83

4.8.2 Spatial and temporal variation of plastic debris accumulation at NDFH and SDFH 85

4.8.3 Spatial and temporal variation of plastic debris accumulation at PFH 89

4.8.4 Spatial and temporal variation of plastic debris accumulation at NFH....91

4.9 Size classes composition of plastic debris....92

4.10 Top ten plastic debris items....94

4.11 Single Use Plastics (SUPs)....95

4.12 Fishery industry related plastic debris....97

4.13 Transboundary Marine Litter (TBML) 99

4.14 Manufactured year of food wrap....104

4.15 Questionnaire survey....109

4.16 Stakeholders workshop 114

4.17 Chapter Summary 116

5 CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORKS....120

5.1 Conclusion 120

5.2 Recommendations....122

5.3 Future Work 124

6 REFERENCES 126

7 APPENDIX 142

7.1 Appendix A (Questionnaire surveys form) 142

7.2 Appendix B (Data collection sheets)....143

TABLE OF FIGURE

Figure 1.1: Sri Lanka – Population by Districts, 2012 7
Figure 1.2: Nominal GDP shares by province in 2019 7
Figure 1.3: The annual quantity of plastic waste discharged into the ocean via rivers, categorized by country (Meijer et al., 2021) 8
Figure 1.4: Areas of high marine biodiversity (Jefferson & Costello, 2020) 10
Figure 2.1: The primary classifications of plastics 19
Figure 2.2: The coastal zone, as defined by the Coast Conservation Act of Sri Lanka 30
Figure 2.3: Harbors locations of Sri Lanka 31
Figure 2.4: Sri Lanka's maritime zones 32
Figure 3.1: Selected FH located in the Western Province of Sri Lanka 41
Figure 3.2: Data collection points located in NDFH (Red color- Stranding debris collection points; Blue color- Floating debris collection points) 42
Figure 3.3: Data collection points located at SDFH (Red color- Stranding debris collection points; Blue color- Floating debris collection points) 42
Figure 3.4: Data collection points located at BFH (Red color- Stranding debris collection points; Blue color- Floating debris collection points) 43
Figure 3.5: Data collection points located at PFH (Red color- Stranding debris collection points; Blue color- Floating debris collection points) 43
Figure 3.6: Data collection points located at SDFH (Red color- Stranding debris collection points; Blue color- Floating debris collection points) 43
Figure 3.7: Grouping anthropogenic debris collected from a data collection point 44
Figure 3.8: Weighting the plastic debris collected from a data collection point 47
Figure 3.9: Size class catalogue 52
Figure 3.10: Foreign food wrapper and beverage bottle 53
Figure 3.11: A food wrapper with invisible manufacturing date 54
Figure 3.12: Stakeholders workshop conducted at CEA on 21st of March, 2023 56
Figure 3.13: Conducting Questionnaire surveys with the participation of fishermen 57
Figure 4.1: Total number of debris collected from all FH during the study period 60
Figure 4.2: Total number of different types of debris collected from each FH during the study period 61

Figure 4.3: Total weight of different types of debris collected from all FH during the study period 62
Figure 4.4: Total weight of different types of debris collected from all FH during the study period 63
Figure 4.5: Rubber sheets collected at NDFH 64
Figure 4.6: Total number of different subtypes of plastic debris collected from all FH during the study period....................65
Figure 4.7: Water channel opening through a trash rack close to NFH 66
Figure 4.8: Water channel directly opening into the BFH 66
Figure 4.9: Plastic beverage bottles departure form....................67
Figure 4.10: Debris generated at NDFH workshop....................68
Figure 4.11: Covered storehouses located at BFH....................68
Figure 4.12: Matrix plot of plastic weight (kg) and number of plastic debris 71
Figure 4.13: Matrix plot between the tide level and number of stranding plastic debris recorded 74
Figure 4.14: Matrix plot between the tide level and number of floating plastic debris recorded .75
Figure 4.19: Cleaning personal collecting floating debris using a hand net 76
Figure 4.15: Interval plot of stranding and floating plastic debris collected from BFH 77
Figure 4.16: Interval plot of stranding and floating plastic debris collected from NDFH 78
Figure 4.17: Interval plot of stranding and floating plastic debris collected from SDFH....................78
Figure 4.18: Interval plot of stranding and floating plastic debris collected from PFH....................79
Figure 4.20: Boxplot of mean number of plastic debris collected during different seasons from BFH....................80
Figure 4.21: Boxplot of mean number of plastic debris collected during different seasons from SDFH 81
Figure 4.22: Boxplot of mean number of plastic debris collected during different seasons from PFH 81
Figure 4.23: Spatial variation of plastic debris accumulation at BFH 83
Figure 4.24: Temporal variation pattern of plastic debris accumulation at BFH....................84
Figure 4.25: Spatial variation of plastic debris accumulation at NDFH 85
Figure 4.26: Spatial variation of plastic debris accumulation at SDFH....................86
Figure 4.27: Temporal variation pattern of plastic debris accumulation at Dikkowita FH....................87

Figure 4.28: Floating debris accumulation at point number 4 of NDFH in two different seasons (A; First Inter-monsoon season, B; South-West monsoon season)..88
Figure 4.29: Spatial variation of plastic debris accumulation at PFH...89
Figure 4.30: Temporal variation pattern of plastic debris accumulation at PFH 90
Figure 4.31: Spatial variation of plastic debris accumulation at NFH 91
Figure 4.32: Temporal variation pattern of plastic debris accumulation at NFH..........................91
Figure 4.33: Size class composition of plastic debris 92
Figure 4.34: Top ten debris items according to collected data from all five FH for one year of period 94
Figure 4.35: Top ten debris items according to Ocean Conservancy International Coastal Clean-up data, 2017 95
Figure 4.36: Total number of SUPs and Non-SUPs collected from all FH during the study period 96
Figure 4.37: Total number of SUPs and Non-SUPs collected from each FH during the study period 96
Figure 4.38: Total number of Fishery industry related and Non-fishery industry related plastic debris collected from all FH during the study period...98
Figure 4.39: Total number of Fishery industry related and Non-fishery industry related plastic debris collected from each FH during the study period 98
Figure 4.40: Total number of TBML collected from all FH in each month 100
Figure 4.41: Total number of TBML collected from each FH...101
Figure 4.42: Contribution of different countries to TBML accumulated at FH without Dikkowita FH 103
Figure 4.43: Contribution of different countries to TBML accumulated at Dikkowita FH 104
Figure 4.44: A food wrapper (Anchor Newdale pouch pack) manufactured in 2008................105
Figure 4.45: Composition of food wrapper manufactured year 106
Figure 4.46: Total number of food wrappers collected from all FH during the study period 106
Figure 4.47: Manufactured years composition of food wrappers collected from all FH in each month 107
Figure 4.48: Percentage composition of food wrappers manufactured year 108
Figure 4.49: Age distribution of interviewed fishermen 109
Figure 4.50: Educational background of interviewed fishermen 110

Figure 4.51: Fishermen perception on source of plastic waste generation 110
Figure 4.52: Poor waste management of CFHC 111
Figure 4.53: Fishermen perception on banning plastic products inside FH...............................111
Figure 4.54: A poster displaying at NDFH 113

LIST OF TABLE

Table 4.1: Total number of different debris types collected from each FH during the study time 69

Table 4.2: Pearson correlation values between monthly rainfall and monthly average number of plastic debris collected 73

LIST OF ABBREVIATIONS

Abbreviation	Description
BFH	Beruwala Fishery Harbor
CC	Climate change
CFHC	Ceylon Fishery Harbor Corporation
EU	Europe Union
FH	Fishery harbor
GHG	Green House Gases
MPA	Marine Protected Area
MPW	Marine plastic waste
MT	Metric tons
NARA	National Aquatic Resources Research and Development Agency
NFH	Negombo Fishery Harbor
NDFH	North Dikkowita Fishery Harbor
NOAA	National Oceanic Atmospheric Administration
PFH	Panadura Fishery Harbor
SDFH	South Dikkowita Fishery Harbor
SDG	Sustainable Development Goal
SLCG	Sri Lanka Coast Guard
SUPs	Single Use Plastics
TBML	Transboundry marine litters
WP	Western Province
WMA	Waste Management Authority

LIST OF APPENDICES

7.1 Appendix A (Questionnaire surveys form)……………………………….126

7.2 Appendix B (Data collection sheets)……………………………………...127

1 INTRODUCTION

1.1 Background of the study

This study was the first attempt to quantify the spatial distribution and temporal variation of marine debris generation at fishery harbors (FH) located in the Western province of Sri Lanka. This study provided preliminary information to policymakers on qualitative and quantitative details of plastic waste generation at FH to take suitable measures to manage the problem. For that composition, distribution and abundance of marine debris, their morphological features such as size and weight of the macro plastic debris of surveyed FH were systematically investigated.

Coastal pollution has become a pressing concern in recent years, while FH emerging as significant hotspots for plastic waste generation due to the intensified anthropogenic activities they accommodate (Niroshana et al., 2013). The detrimental impact of such pollution on marine ecosystems and the well-being of coastal communities cannot be overstated. Previous research, based on beach surveys conducted in the country, has identified plastic as the primary contributor to this coastal pollution (Jang et al., 2018). Plastic waste, with its persistent nature and widespread use, poses many challenges to coastal environments, disrupting ecosystems and potentially entering the food chain.

There is a notable research gap exists on the plastic waste generation within FH, located in Sri Lanka. While broader studies have provided insight into coastal plastic pollution, there is a distinct lack of focused research on the factors influencing plastic waste generation and accumulation patterns within a FH context. This limited knowledge hinders the development of targeted interventions and policy measures needed to mitigate the adverse effects of plastic pollution within these socially and economically vital FH premises.

The present research endeavor will utilize a mixed-methods technique, incorporating both quantitative and qualitative techniques for data collecting. Key stakeholders, such as fishermen and harbor officials, will be engaged in the research through the administration of surveys and interviews. The quantitative data will provide insights into the volume and types of plastic waste generated, while the qualitative data will help identify the existing practices and challenges in plastic waste management. By triangulating these findings, a comprehensive understanding of the current situation will be obtained, enabling the formulation of targeted interventions to address the issue effectively.

To bridge this knowledge gap and provide a comprehensive understanding of plastic waste generation within FH, this study was undertaken. The study aimed to assess the scale and scope of plastic pollution within FH by adopting the weekly accumulation study method, which enabled detailed data collection along the land-water interface. By systematically investigating the types, quantities, spatial and temporal variations of anthropogenic debris, including plastic, this research contributes valuable insights into the dynamics of plastic waste accumulation within FH.

Furthermore, this study explores the underlying factors driving plastic waste accumulation within FH, including potential correlations with environmental variables such as rainfall and tide levels. By unraveling the relationships between plastic debris and these factors, the study not only enhances our understanding of the issue but also lays the groundwork for evidence-based strategies to effectively manage plastic waste within FH.

In addition to scientific investigations, this study incorporates a holistic approach by engaging stakeholders through workshops and questionnaire surveys. These interactions provide a platform to capture the perceptions, attitudes, and concerns of various stakeholders, including fishery communities and other relevant stakeholders.

In summary, the escalating issue of coastal pollution, driven by intensified human activities, underscores the need for targeted research and interventions within FH. This study seeks to address the critical knowledge gap surrounding plastic waste generation in these areas, contributing vital insights for the development of sustainable solutions and policy measures to mitigate the impacts of plastic pollution and foster the well-being of coastal ecosystems and communities.

1.2 The research problem

Plastic waste has become a global environmental concern, with its adverse impacts on ecosystems and human health being increasingly recognized. In the context of FH, where human activities are prevalent, the issue of plastic waste becomes even more significant. The Western Province of Sri Lanka, known for its extensive coastline and thriving fishery industry, faces the challenge of plastic waste accumulation in its harbors according to comments made by Ceylon Fishery Harbors Corporation (CFHC) officers. Therefore, this research project aims to investigate the utilization and management of plastic waste in FH located in the Western Province of Sri Lanka.

Globally plastic waste generation has become major problem and annually a considerable amount of these plastic debris are ending up in marine environments due to improper waste management practices. Specially, FH activities has recognized as a key contributing factor for the marine plastic waste (MPW) generation (Niroshana et al., 2013).

Plastic debris can entangle marine animals, leading to injury or death, and can also be ingested, causing internal injuries and affecting the overall health of marine organisms (Eriksen et al., 2014). Moreover, the presence of plastic waste in FH can result in contaminating the fish harvest, reducing aesthetic appeal, hindering tourism potential of nearby beaches and negatively impacting the livelihoods of the coastal communities.

Previous research has primarily focused on marine pollution in general, with limited attention given to the unique challenges and opportunities related to FH. This study project endeavors to examine the utilization and management practices pertaining to plastic waste in the specified places, with the objective of making a valuable contribution towards the formulation of efficient methods for plastic waste management within FH.

In summary, the primary objective of this study endeavor is to provide insights into the utilization and management practices pertaining to plastic waste within FH. This study aims to contribute to the development of sustainable and context-specific strategies for plastic waste reduction and management in FH by comprehending the distinctive difficulties and opportunities related with FH. Another objective of this research initiative is to advance the conservation of marine ecosystems and enhance the welfare of the populations that depend on the fishing sector.

1.3 Importance of the study

Since direct and indirect economic damage and non-economic damage caused by MPW is less studied, it is important to find answers for these research gaps to initiate policy-making processes (Arabi & Nahman, 2020). Also the United Nations Sustainable Development Goal 14 (SDG 14) has highlighted the importance of sustainable use of marine resources while conserving them. Studying debris accumulation patterns on beaches are crucial to investigate about the litter flows into the ocean (Meakins et al., 2022). Hence conducting scientific studies to identify the sources of MPW and their effects are required for policy development related to SDG 14 (Issifu & Sumaila, 2020).

FH is an interface between fish capturing process and their consumption (Jha et al., 2022). With the intensive anthropogenic pressures placed inside harbor premises (Rebai et al., 2022), there is a high probability of generating waste materials and they can be recognized as hot spots for coastal pollution (Niroshana et al., 2013). Plastic pollution and other pollution taking place at FH premises can affect the level of sustainability of the fishery industry.

Since the FH is a part of the coastal environment, any kind of pollution that takes place at the harbor premises can affect the coastal ecosystem as well (Sciortino, 2010). Fishery industry is responsible for generating around 20% of the MPW currently circulating in world oceans (Morales-Caselles et al., 2021). Therefore, special attention must be drawn to planning, constructing and maintaining FH to avoid the coastal pollution (Jha et al., 2022).

In 2016, an estimated 11% of the global plastic waste produced was deposited in aquatic ecosystems, resulting in a quantity of around 19-23 million metric tons. Without improvements in waste management infrastructure, it is projected that the amount of plastic debris entering the ocean will increase substantially by 2025 (Jambeck et al., 2015). If current trends continue, it is estimated that by 2030, the annual plastic waste entering aquatic environments could reach 53 million metric tons (Borrelle et al., 2020). Lebreton and Andrady (2019) have predicted a staggering annual generation of MPW reaching 155-265 metric tons by 2060. This prediction indicates a threefold increase compared to current values, with the highest contribution expected from Asian and African regions.

As plastic waste production persists and accumulates in the environment over extended periods (Andrady, 2015), the associated negative impacts are likely to escalate (Beaumont et al., 2019). The coastal regions are pivotal in this issue, contributing significantly to the problem. Each year, approximately 9 million tons of MPW are generated from land-based coastal areas, solidifying these areas as major sources of plastic pollution (Jambeck et al., 2015). The trend suggests a continued increase in plastic waste from coastal zones, further exacerbating oceanic plastic contamination (Welden, 2020). Notably, Wang et al., (2019) estimated that around 85% of the current global marine debris is composed of plastic items, underlining the urgency of managing MPW generation. These statistics highlight the critical nature of the problem and the importance of the management of MPW generation. Since FH has been recognized as a hotspot for MPW generation, its management is crucial.

The coastal areas had significant economic expansion due to the development of the fishery sector, tourism industry, and basic infrastructure. Consequently, urbanization occurred at a rapid pace (CZMP, 1990). This process led to the generation of large quantities of waste materials in these areas and it highlighted the requirement of taking measures to prevent coastal pollution and implementing proper waste management systems. Arulnayagam (2020), has pointed out the requirement of rapid response to coastal zone plastic pollution in Sri Lanka, since the problem has become much more severe during the last few years.

According to Samarasinghe et al., (2021), the annual growth rate of plastic usage in Sri Lanka is experiencing a 16% rise. Western Province is responsible for approximately 60%

of the total solid waste generation of the country per day which is similar to approximately 4,200 metric tons (Karunarathne, 2015). But only around 50% of the total waste generated is collected properly according to Central Environmental Authority (CEA) and the Waste Management Authority (WMA) calculations. The rest of the debris may have been dumped into the open environment, and a considerable amount of it will end up in the ocean.

Even though the accumulation of marine debris along the coastal region can cause many negative impacts on marine ecosystems, sources of marine litter generation and their quantities are less studied in Sri Lanka. This deficiency of data availability is a major reason for difficulties in understanding the problem and suggesting suitable solutions (Gunasekara et al., 2014).

Sri Lanka alone produces about 1.59 million tonness of plastic debris per year and a considerable amount of that ends up in the coastal zones (MoE, 2021). The amount of plastic waste generation can be depending on the population density and Gross Domestic Product (GDP) (Lebreton & Andrady, 2019). When the Western province of Sri Lanka is considered, it records the highest population density of the country with 1,600 person per km^2 (Census, 2012) and secure 39.1% of the country's total nominal GDP which is the highest contribution from a single province (CBSL, 2019). These factors are indicating the high probability of generating large amount of MPW from Western Province and conducting studies related to plastic waste generation in such an area is very important to the process of finding solutions.

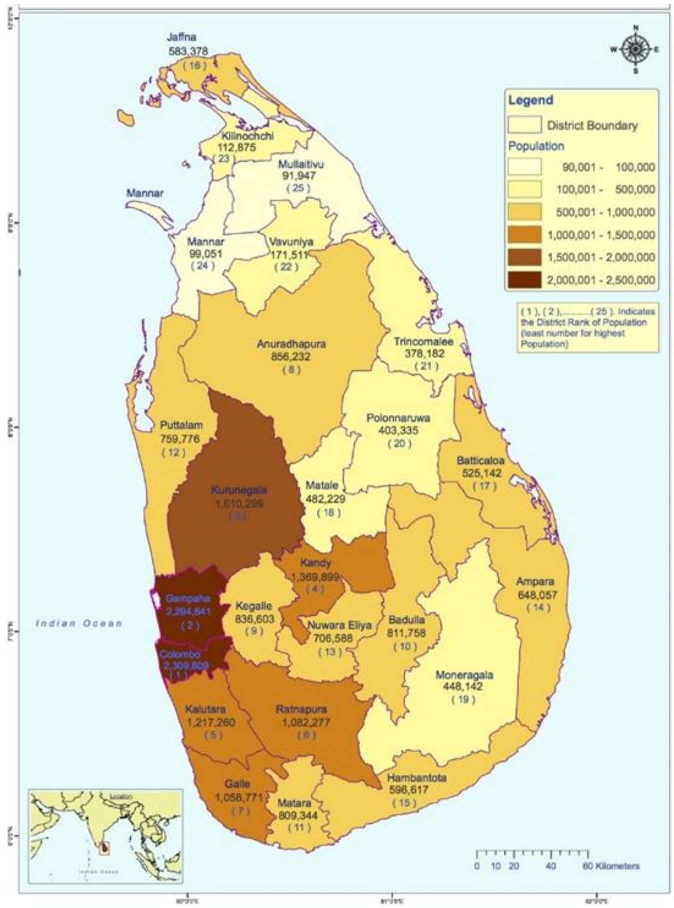


Figure 1.1: Sri Lanka – Population by Districts, 2012

Source: Department of Census and Statistics

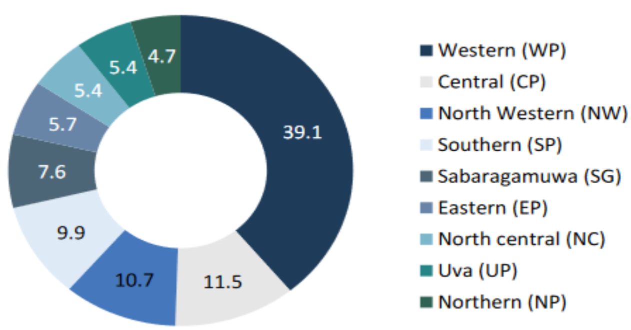


Figure 1.2: Nominal GDP shares by province in 2019

Source: Central Bank of Sri Lanka

Managing waste generation properly has become a hurdle, especially in many developing countries like Sri Lanka (Dharmasiri, 2020). To make decisions related to recycling of plastic waste generated, spatial information is crucial (Hidalgo-Crespo et al., 2022). As a result of limited public cleaning resources availability and large-scale disposal of plastic trash, increasing the amount of MPW generation from developing nations has become a major problem. Available resources must target the places where plastic waste generated in larger quantities with a high probability of reaching the ocean at the end. Such places are named as “hotspots” and identifying those places are important for cost effective management (Dasgupta et al., 2022). From this study it identified the hotspots located in FH premises over 8 months of period.

Meijer et al., 2021 have revealed that small streams coming along urban areas are highly polluted from plastic debris and 1,000 rivers are responsible for generating about 80% of the global MPW annually (Meijer et al., 2021). Some of the FH located in the Western Province of the country are connected to streams, and some FH are in close proximity to river mouths. These factors can have an effect on the patterns of plastic debris accumulation inside FH, making it important to study them for proper waste management.

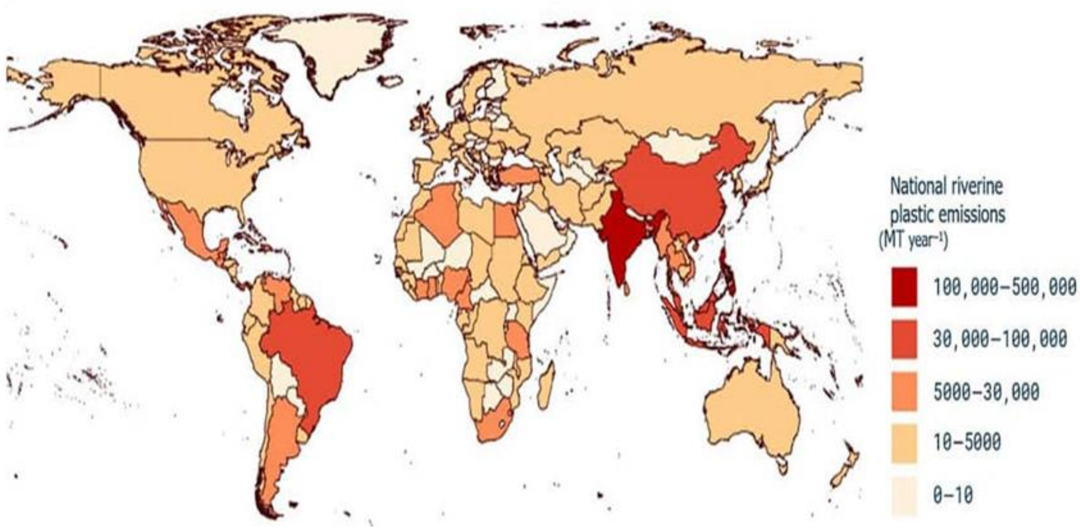


Figure 1.3: The annual quantity of plastic waste discharged into the ocean via rivers, categorized by country (Meijer et al., 2021)

A significant portion of Sri Lanka's coastal zone is characterized by the presence of wetlands, which serve as conduits for the transportation of plastic trash into these coastal areas via river, stream, and drain systems. Therefore, the river system is considered as a "non-point source of pollution" which can damage the coastal ecosystem. Sri Lanka has 103 rivers and most of them initiate from the central part of the country and radiate along the country with providing some environmental benefits such as carrying sand, clay and silt for the beach nourishment process and providing habitats for various organisms while causing some environmental damages like carrying pollutants to damage coastal environment system. The composition and the amounts of pollutants can vary based on time and space since debris enter into the coastal zone from different locations (CZMP, 2006).

From a survey conducted in Sri Lanka in 2018, with the collaboration of National Aquatic Resources Agency (NARA), Sri Lanka and Institute of Marine Research (IMR), Norway, it has been found that four-fifth of the small size MPW are reaching to the ocean through rivers and canals system of the country (NARA, 2018).

Sri Lanka has been recognized as a country which sustains both high species endemism and high species richness of marine organisms. Therefore, it is considered as one of the "hottest" hotspots for marine biodiversity (Jefferson & Costello, 2020). Those marine biodiversity hotspots are threaten by MPW and immediate actions should be taken to conserve them.

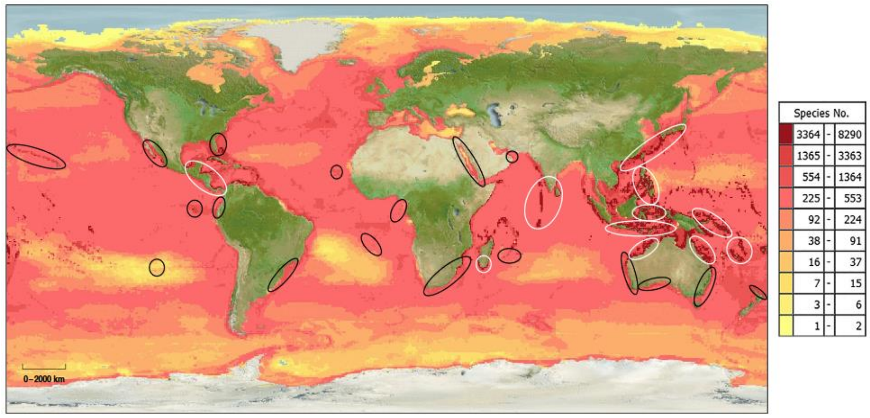


Figure 1.4: Areas of high marine biodiversity (Jefferson & Costello, 2020)

Irrespective of the quality of existing waste management strategies, TBML can cause various negative impacts on the entire coastal ecosystem. Therefore, it is very important to find out their sources and distribution patterns to effectively manage the problem. But very few studies have been conducted related to TBML in Sri Lanka (Ranjula et al., 2023).

Food wrappers are particularly tough and resistant to breaking, as they need to preserve food items effectively. Due to this durability, they can persist in the environment for extended periods. Therefore, special attention should be given to addressing this type of debris. Understanding the quantity of food wrappers, potential sources of their generation, and the rate of their input would be valuable for developing future policies and strategies to tackle this issue. Additionally, this information could serve as a useful proxy measurement for assessing overall plastic waste generation in FH.

Single Use Plastics (SUPs) are designed for human consumption and the generation rate of SUPs is directly proportional to the level of urbanization. Jang et al., (2018), has highlighted the serious requirement of implementing restrictions on packaging materials (SUPs) related with the commodity chain to avoid the large MPW generation in Sri Lanka. Understanding the extent of SUPs pollution in FH will provide a valuable proxy for assessing overall SUPs pollution within the entire coastal zone.

The quantification of plastic waste generated by the fisheries industry within FH holds significance in comprehending, regulating, and reducing the social, economic, and environmental consequences of plastic pollution. This endeavor also ensures adherence to legislation and fosters sustainability within the fishery sector.

Identifying the scale of plastic waste generation enables the stakeholders such as policymakers, environmental agencies, and the fishery industry itself to develop effective strategies for mitigating this pollution. It helps in setting realistic goals and targets for reducing plastic waste inside FH.

1.4 Overall aim of the study

The primary objective of this study endeavor is to conduct a thorough examination of the spatial patterns, temporal fluctuations, and fundamental determinants that contribute to the production of plastic garbage at FH, which is located in the Western Province of Sri Lanka. This study aims to address a significant information gap by offering valuable insights into the extent and magnitude of plastic contamination in these crucial coastal areas. Moreover, the objective is to make a contribution towards the advancement of sustainable methods and policy interventions that can effectively tackle the detrimental environmental consequences linked to the generation of plastic waste in FH.

The issue of coastal pollution, specifically the widespread presence of plastic garbage, has become a prominent global issue with detrimental effects on marine ecosystems and human welfare. FH have been identified as areas where significant amounts of plastic waste are generated. This is mainly because to the high levels of human activity taking place within these locations. Nevertheless, prior studies have primarily concentrated on more general aspects of marine pollution, paying limited attention to comprehending the precise mechanisms underlying the production of plastic waste inside FH. The lack of information in this area is a significant obstacle to the advancement of focused interventions and efficient policy measures necessary to address the severe repercussions of plastic pollution in these socially and economically vital FH areas.

The present study utilizes a comprehensive mixed-methods technique to investigate the generation of plastic waste within FH. This strategy incorporates a combination of quantitative and qualitative data collection methodologies. This research endeavors to gain a comprehensive understanding of the accumulation of plastic waste within FH by systematically examining various categories, quantities, and spatial and temporal variations of human-generated waste, with a particular emphasis on plastic waste. Moreover, this study examines the underlying mechanisms that contribute to the accumulation of plastic waste, including potential associations with environmental variables such as rainfall and tidal levels. This study not only contributes to our understanding of the problem but also establishes a foundation for implementing evidence-based approaches to efficiently address plastic waste management in the context of FH.

1.5 Research objectives

The study comprises of following objectives:

I. Comprehensive literature review to identify harbor locations and plastic consumption in fishery industry/harbors

The primary objective of this study is to identify FH located in the Western Province of Sri Lanka and their plastic consumption. This objective aims to gather comprehensive existing information on the plastic waste generation across the globes.

II. Identification and quantification of plastic waste in selected FH

The second objective of this research is to identify and quantify the plastic waste generation inside the FH located in the Western Province. This objective aims will fulfill by collecting plastic debris accumulated inside FH located in the Western Province.

III. Investigate the spatial and temporal trends/variations of plastic waste of the selected FH

The third objective of this study is to investigate the spatial and temporal variation of plastic debris accumulation in FH located in the Western Province of Sri Lanka. To investigate these trends, data will be collected from different locations of each fishery harbor for an extended period of time.

IV. Identify the policy gaps in the FH of Sri Lanka

The final objective of the study is to identify the policy gaps related to FH operations and waste management processes inside FH located in the Western Province of Sri Lanka. For that questionnaire surveys and stakeholders workshop will be conducted.

By addressing these research objectives, this study aims to understand the plastic waste utilization inside FH located in the Western Province of the country and its management.

1.6 Research Methodology

The methodology included the following steps,

i. Conducted a literature review on identifying harbor locations and plastic consumption in FH
ii. Collected marine debris along the land-water interface of five FH for 12 months of period
iii. Conducted questionnaire surveys and stakeholders workshops to identify possible reasons for the observations made throughout the time and to identify their perceptions on plastic waste utilization and policy gaps
iv. Analyzed the data using statistical tools and visualization to make comments about the collected data.

The first step of this research involved conducting a comprehensive literature review on FH and their plastic utilization. This review encompassed various scholarly articles, research papers, and reports to gather a wide range of information on the subject. Using this available information, the structure of the study was determined. This literature review would serve as a foundation for developing a sound research framework.

Hand picking method was used to collect stranding debris, and a hand net was used to collect floating debris. Then the debris was grouped based on types and subtypes. Measurements of the collected debris was taken (e.g., weight and surface area of plastic debris). The study was conducted for 12 months duration to quantify marine debris accumulation inside FH, identify spatial and temporal variations, investigate the impacts of rainfall and tide level, and differentiate between stranding and floating plastic debris counts. Additionally, the study aimed to quantify the contribution of single-use plastics, foreign plastic debris, and plastic debris related to the fishery industry to the total plastic debris collected inside the harbor.

Based on the primary data collected from FH, questionnaire surveys, and stakeholders workshops were conducted with the participation of major stakeholders, including fishers, to find out possible reasons behind the observations and their perception on plastic waste management inside FH. Policy gaps behind the mismanagement of marine debris was further discussed.

The acquired data was subsequently subjected to analysis utilizing statistical software tools, including Microsoft Excel and Minitab 19. The statistical software Minitab was utilized to determine if there was a statistically significant spatial and seasonal variation in the quantity of plastic debris that was gathered. The correlation between plastic weight and plastic counts, correlation between monthly rainfall and tide level with the number of plastic debris were calculated using Minitab 19. Also, to compare the number of stranding and floating debris, Minitab statistical software was utilized. AutoCAD was used to visualize and analyze the spatial distribution of plastic debris density across all 5 FH. These findings would be important in identifying the hotspots of plastic waste generation and their temporal variations. Further, appropriate strategies could be developed and implemented to optimize the utilization of limited resources available inside FH.

By employing these methodologies, this research aimed to deepen our understanding on plastic waste generation inside of the country. Ultimately, the findings of this research would facilitate the development of effective and sustainable marine plastic waste management tool to implement for all FH located in Sri Lanka and the worldwide.

1.7 Key Findings

The major findings of the study are summarized as followed:

1. By both count (85.24%) and weight (59.53%), plastic debris is the major pollutant in FH located in the Western province of the country.
2. There are significant spatial variations in plastic debris accumulation among all five FH and hot spots were identified.
3. The correlation between monthly rainfall and monthly average number of plastic debris recorded was very weak positive for Beruwala, North and South Dikkowita FH while it was weak negative for Panadura and Negombo FH.
4. There is a significant seasonal variation in plastic debris accumulation at Beruwala, South Dikkowita, and Panadura FH. However, no such significant seasonal variation was recorded for other two FH.
5. Nearly 87% of the food wrappers were manufactured in 2023 and 2022, indicating that the vast majority of the food wrappers were very recently produced. Otherwise, a considerable number of food wrappers older than two years would have to be recorded. Therefore, it can be concluded that plastic food wraps do not persist for a long time inside the FH, and this observation may be applicable to all other types of debris as well.

6. Around 51% of the harbor personals considered poor waste management of CFHC as the key contributing factor to plastic waste generation inside FH in larger quantities.
7. The contribution of Transboundary Marine Litter (0.27%) to the total amount of plastic waste generated within FH is relatively insignificant in terms of quantity.

1.8 Dissertation structure

Chapter 01 delivers the introduction to the research topic, and the first section of the chapter briefly describes the background of the study, followed by the research problem, importance of the study, research objectives, and a summary of the methodology, main findings, and the arrangement of the research report.

Chapter 02 describes the literature review of the study. This section provides a comprehensive overview of plastics and their impacts on the economy, ecosystem, and human health. It also provides a comprehensive overview of the fishery industry, its importance, and problems associated with the industry. Geography of the country, coastal zone, and weather climate of the country are also discussed in this chapter, which are relevant to plastic debris accumulation patterns in FH.

Chapter 03 provides the detailed methodology used in the research study, including the research design, data gathering procedures, schedule, and data analysis technologies throughout the different processes, are also presented in this chapter.

Chapter 04 presents the result obtained from the analysis process. This section reports the findings of the study based on the results of the data analysis and discusses the results and findings along with the objectives of the study. And also major findings are discussed along with the research objectives while evaluating how the results and findings are consistent with the same in the literature.

Chapter 05 illustrates the conclusion, recommendations, and suggestions for further research to improve the understanding of the study and future work that can be done based on this research.

2 LITERATURE REVIEW

2.1 Chapter introduction

The effective management of plastic waste has emerged as a critical concern in the context of sustainable development and environmental conservation. Sri Lanka, with its extensive coastline and thriving fishery industry, faces the significant challenge of plastic pollution in its FH.

The literature review seeks to analyze and synthesize the existing body of knowledge related to plastic waste in coastal ecosystems. By exploring a diverse array of academic articles, research papers, reports, and publications, this chapter aims to gain valuable insights into the patterns of plastic waste generation, its sources and its impacts.

Through this literature review, it aims to contribute to the broader understanding of plastic waste issues in coastal ecosystems and fishery industry. Ultimately, this chapter seeks to guide policymakers, researchers, and stakeholders towards the sustainable management of plastic waste, promoting the preservation of marine ecosystems and safeguarding the well-being of coastal communities.

The primary goal of this study was to perform a thorough literature analysis, carefully analyzing available sources to determine the precise harbor sites and assess the magnitude of plastic use within the fishery sector operating in FH. In order to provide a strong basis for future objectives, it was imperative to gather insights from both international and local studies. While there has been extensive study on coastal plastic pollution, there exists a noticeable dearth of studies particularly addressing FH in Sri Lanka. Due to the limited availability of relevant literature, it was imperative to incorporate findings from foreign studies in order to shape this research technique and tailor internationally suggested guidelines to this specific environment.

The second objective aimed to ascertain and measure the amount of plastic waste generated inside five specifically chosen FH in Sri Lanka. Throughout the span of a year, the aforementioned objective was successfully accomplished via meticulous data collecting and analysis. This enabled to thoroughly assess the magnitude and characteristics of plastic garbage generation in these pivotal coastal areas.

In alignment with the second purpose, the third objective focused on examining the spatial and temporal fluctuations in the generation of plastic waste within the chosen focal area. Through a meticulous examination of the gathered data, it was able to identify noteworthy patterns and variations, thereby providing insights into the temporal and spatial dynamics of plastic waste accumulation.

The fourth and final objective centered on identifying policy gaps within the FH of Sri Lanka. While this objective may necessitate further efforts and collaboration among relevant stakeholders, significant strides were made in uncovering and highlighting key policy deficiencies that impede effective plastic waste management in these vital coastal environments.

2.2 Plastic classifications

According to NOAA definition, plastic is synthetic or semi synthetic polymers which is derived from petrochemical compounds and they can have different sizes, colors and shapes. Mesoplastics (>2.5 cm) and micro plastics (<5 mm) are the two main types of plastics based on their size (Thevenon et al., 2014).

Different types of plastics offer specific advantages and applications in various industries. Based on the chemical composition of plastics, it can be divided into several groups. Polyethylene Terephthalate (PET or PETE) is a commonly utilized material renowned for its lightweight, strength, and transparency, making it common in food packaging and polyester fabrics. High-Density Polyethylene (HDPE), which falls under the category of Polyethylene plastics, possesses notable attributes such as robustness and the ability to withstand moisture and chemicals. Consequently, it finds applicability in many items such as pipes, construction materials, containers and cartons. In contrast, Polyvinyl Chloride (PVC or Vinyl) is a hard thermoplastic material that possesses notable chemical and weather resistant properties, rendering it highly esteemed in the fields of building and advanced applications such as electrical wiring. Its germ-resistant properties have led to medical applications, though its potential to release toxins throughout its lifecycle poses health concerns. Low-Density Polyethylene (LDPE) is a softer alternative used as a liner in beverage cartons and for corrosion-resistant surfaces. Polypropylene (PP) stands out for its durability and heat resistance, fitting well in hot food storage and packaging scenarios while retaining shape and strength. Polystyrene (PS or Styrofoam) serves as an affordable, insulating material widely used in food, packaging, and construction industries. However, like PVC, concerns about toxin leaching, such as neurotoxic styrene, raise health issues related to its usage.

Within the linear economy model, which is the most commonly practiced economic model in the world, after the consumption of plastic items, they are often simply discarded. This is a significant factor contributing to the generation of plastic debris in larger quantities.

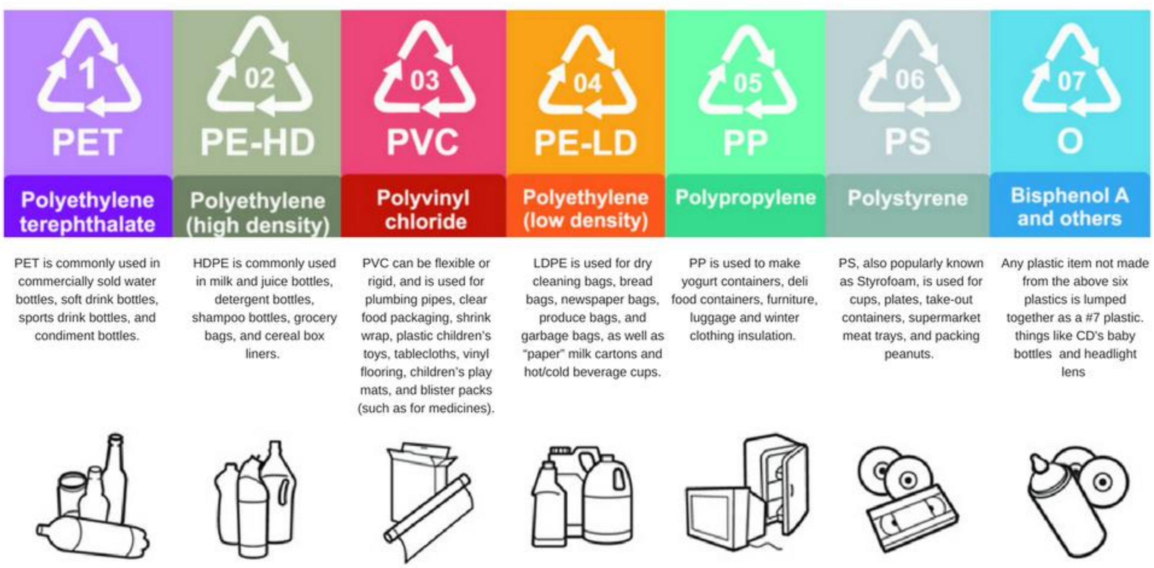


Figure 2.1: The primary classifications of plastics

Source: Greenpeace

2.3 Benefits of plastics

Plastics have become an integral part of modern life and have revolutionized various industries, providing numerous benefits that have significantly improved our daily lives. Plastic has become an indispensable material in several sectors, including packaging, building and construction, and textiles, due to its versatile features such as being inexpensive, moisture and heat-resistant, strong and durable, lightweight, flexible, and readily accessible (Babafemi et al., 2018 ; Geyer et al., 2017).

The versatility of plastics is a key factor of its success. This attribute encompasses their ability to fulfill an array of roles within industries, owing to their adaptability to different forms, sizes, and functions. Moreover, plastics possess a remarkable cost-effectiveness, which has played an important role in their widespread consumption. The relatively low production costs of plastics translate to products that are affordable for consumers across socioeconomic strata, thus enabling access to a higher standard of living for a broader segment of society.

Exceptional resistance to both moisture (Fischer, 1970) and heat (Crompton, 2014) make plastics an ideal for applications that involve exposure to varying climatic conditions, such as packaging and outdoor construction. This capability ensures that products made from plastics remain intact and functional, even in challenging environments, thereby extending their longevity and enhancing overall reliability.

Plastics' inherent strength and durability are characteristics that have further cemented their importance in numerous industries (Ghernouti & Rabehi, 2012). The capacity of plastics to withstand mechanical stress, impacts, and wear over time makes them essential for applications that require robust materials. This strength-to-weight ratio is particularly advantageous in fields like automotive manufacturing and aerospace engineering, where the desire for lightweight components does not compromise structural integrity.

The lightweight nature of plastics is another standout feature that significantly contributes to their appeal (Alqahtani & Zafar, 2021). This attribute has a cascading effect on energy consumption, transportation costs, and overall efficiency in various sectors. The reduced weight of plastic-based products translates to lower fuel consumption in transportation, leading to environmental and economic benefits.

Flexibility of plastics enable their use in number of industries (Kumar & Khan, 2020). This adaptability is especially valuable in industries such as textiles and consumer goods, where the ability to mold plastics into intricate shapes and forms paves the way for imaginative and ergonomic product designs.

Their widespread production is coupled with high availability of plastic (Webb et al., 2012). A well-established supply chain, ensures a consistent and accessible source of materials for industries across the globe. This accessibility contributes to the integration of plastics into diverse applications, from everyday products to cutting-edge technologies.

2.4 Types of plastic pollution

Plastic pollution can be divided into two main aspects as, land based and ocean based plastic pollution. Understanding these two main aspects of plastic pollution is crucial for devising effective strategies to mitigate its impact. Efforts to reduce plastic pollution involve measures such as improving waste management systems, promoting recycling, raising public awareness, advocating for policy changes, and developing alternatives to single-use plastics.

2.4.1 Land based plastic pollution

Plastic land pollution refers to the widespread accumulation of plastic waste on land surfaces, including urban areas, natural environments and rural landscapes. It is a significant environmental issue with far-reaching consequences for ecosystems, human health, and overall well-being. Geyer et al., (2017), has estimated that the global plastic waste generation is around 6,300 million metric tons in 2015 and out of that only 9% of the waste is recycled approximately. Majority of the debris is sent to landfills or to the environment without any proper management. Percentage of that amount is 79% and the rest of the 12% is sent for incineration. Under the current rate of plastic manufacturing and management strategies, total plastic waste which will end up in the environment and landfills by 2050 has been estimated as 12,000 million metric tons.

Plastic waste often originates from various sources, including improper disposal, littering, inadequate waste management systems, and industrial activities. When plastic waste is not effectively managed, it can be carried by wind, rain, or water bodies, ending up in natural habitats, parks, open spaces, and even agricultural fields. Addressing plastic land pollution requires a comprehensive approach that includes improved waste management practices, recycling infrastructure, public awareness campaigns, and policy interventions. Efforts to reduce plastic consumption, promote responsible disposal, encourage sustainable packaging alternatives, and support innovative recycling technologies are crucial to mitigating the negative impacts of plastic pollution on land environments.

2.4.2 Ocean based plastic pollution

Plastic ocean pollution, also known as MPW, refers to the extensive presence of plastic waste in the world's oceans and other marine environments such as coastal environments. The percentage of total plastic waste is 80% out of the total marine debris (IUCN, 2021). Ocean Conservancy, 2015 report revealed that total MPW weight circulating in the ocean exceeds 150 million tons. At coastal areas, plastic debris are mainly generated as a result of unsustainable fishery industry and urbanization (Monteiro et al., 2022). After the generation, due to its lightweight floating capacity and strong durable nature, plastic has ubiquitously been distributed in all oceans including Arctic. Therefore, it has become the most abundant type of litter in the ocean (Zhukov, 2017). This pervasive issue has gained significant attention due to its alarming ecological, economic, and human health implications. Plastic pollution infiltrates marine ecosystems via diverse pathways, encompassing activities such as littering, substandard waste management practices, illicit disposal, and the discharge of industrial effluents. Plastic waste from urban areas, coastal regions, and inland waterways can be carried by wind, rivers, and currents, accumulating in vast oceanic garbage patches and affecting marine ecosystems on a global scale. The total weight of the MPW in the ocean will exceed the total weight of the fish stock remaining in the ocean by 2050 (Ellen MacArthur Foundation, 2016). Proper waste management, recycling initiatives, and the development of more environmentally friendly plastics are crucial steps to mitigate the environmental impact of ocean based plastic pollution.

2.5 Marine plastic pollution

According to UNEP, marine debris has been defined as intentionally or unintentionally disposed solid items from land which ends up in the oceans through wind currents and water flows (UNEP, 2016). According to Ribbink's interpretation, debris items remain in the estuaries, intertidal zone and ocean are defined as marine debris (Ribbink et al., 2018).

Plastic debris can cause some direct health issues to coastal communities, impact negatively on the marine ecosystem services (Beaumont et al., 2019) and cause economic damages by impacting on the fishery industry and tourism industry through reducing the aesthetic value (Neumann et al., 2015).

2.5.1 Economic impacts of marine plastic pollution

Quantifying the economic impacts of MPW is crucial to make evidence-based policy development (Arabi & Nahman, 2020). The economic damage caused by tons of MPW per year has been estimated as 3,300-33,000 USD. In this calculation, it has considered only the impacts on marine natural capital. Therefore, the actual total economic damage can be much higher than these estimations (Beaumont et al., 2019). UNEP has calculated the global annual economic losses caused by MPW on fishery and tourism industries as 13 billion dollars (UN News, 2014).

Removing MPW is a very critical and inefficient as it is very expensive and time consuming process (Beaumont et al., 2019). Burt, et al 2020 have estimated total cost and human effort required to remove the remaining marine debris accumulated at Aldabra Atoll (a UNESCO World Heritage Site) island based on the beach cleanup project that took place in 2019 in the island. To remove the remaining 513 tons of marine waste, it would require around 4,680,000 dollars and effort of 18,000 human working hours.

2.5.2 Ecosystem impacts of marine plastic pollution

Fishery industry depends on some natural ecosystem services and these services can be interrupted as a result of MPW. Mouat et al., (2010) have confirmed that MPW can negatively affect the viability, safety, income and the total production of the fishery industry. If these services are interrupted, it can cause many negative impacts on the wellbeing of coastal communities as well (Naeem et al., 2016).

As a result of entanglement and ingestion of MPW, thousands of marine organisms are killed (Dasgupta et al., 2022). From a study conducted in the Mediterranean Sea, it has been recorded that 44 marine species were entangled with MPW, 116 marine species were ingested MPW and 170 species were using MPW as a substrate to rafting (Anastasopoulou & Fortibuoni, 2019). In a study conducted in the Arctic region (Abate et al., 2020), 89% of the surveyed samples of Northern Fulmars have been ingested MPW and now nearly all bird species living in the region have been recorded with the same problem (Abate et al., 2020). According to a study conducted by Compa and the team surrounding the Mediterranean Sea in 2019, 84 marine species had ingested plastic debris. The study revealed that coastal marine species are more susceptible to ingesting MPW compared to open sea marine species. Ingestion of plastic debris can cause internal organ damage and nutrient deficiencies in marine organisms due to the false sense of fullness in the stomach. Additionally, ingesting plastic debris containing harmful chemicals like pesticides and flame retardants can lead to serious health impacts on marine organisms (Compa et al., 2019).

MPW are able to persist for a long time and in most of the cases they are able to float on the ocean body with their low density, plastics can spread over a long range of distance (Welden, 2020). Also microbial pathogens can grow on the surfaces of MPW (Kirstein et al., 2016). This type of floating MPW can act as a carrier for some pathogenic invasive alien species (IAS) to travel long distances across the ocean and IAS can threaten the native species and some conservation efforts as well (Barry, et al., 2023). When susceptible marine organisms are exposed to these pathogenic species carried by MPW, it can make various negative impacts on them like developing antibiotic resistance (Hale et al., 2020).

The Euphotic zone is the uppermost layer of the ocean and at the beginning, plastic debris were mainly found in this zone. Photosynthesis and other important biogeochemical processes mainly take place in this zone (Galgani & Loiselle, 2021). When phytoplankton species ingest MPW, their growth rate and the efficiency of photosynthesis get reduced and ultimately, it can cause an increase in atmospheric GHG concentration by reducing the carbon dioxide absorbance capacity via photosynthesis process (Bauman, 2019). From the manufacturing process to the final discarding process, plastic is contributing to the generation of GHG and it has been recognized as one of the major contributor for the climate change (CC) process. Plastic waste dispersal range in marine environments also increases along with the extreme weather conditions (such as floods and storms) which is directly linked with the CC. Therefore, plastic pollution is a factor which influences the CC and the wise versed (Ford et al., 2022).

With the increased consumption of personal protective equipment (PPE) during the COVID-19 pandemic situation, plastic waste generation has increased. During the COVID-19 epidemic, incineration emerged as a prominent technique for the disposal of plastic waste because to the heightened utilization of plastic products. This method also can contribute to emitting more GHG into the atmosphere (Shams, 2021).

2.5.3 Human health impacts of marine plastic pollution

In the early 1970s, scientific study of MPW began, and these studies have continued to the present day (Lessy, 2020). During the last few decades, many studies have been conducted globally on the purpose of studying the effects of MPW on ecosystem services and the economy (Gall & Thompson, 2015). But so far, scarce research has been conducted on human health impacts of the MPW (Davison, 2021).

In the process of plastic manufacturing, many chemical additives are added to make desirable characters (Kirstein et al., 2016). Adding chemical additives during the manufacture process of plastics, absorption and adsorption of toxic compounds from the ocean and accumulation of micro plastics along the food chains (Eriksen et al, 2014; Almroth & Eggert, 2019) have the potential to cause various health impacts to human. These chemicals can accumulate and biomagnifies along the food chain especially in higher trophic levels including human (Teuten et al., 2009).

2.5.4 Micro plastic level impacts of marine plastic pollution

Plastic debris are withstanding for the degradation process for centuries, it has become a main contributor to the marine debris (Dasgupta et al., 2022). In the natural environment, plastic degradation is a very slow process and it can be taken place due to photo-oxidation (induced by solar UV radiations), thermo-oxidation (induced by solar heat), hydrolysis of the plastic polymer compounds and microbial biodegradation. But in the ocean ecosystems hydrolysis and microbial activities are very limited. Therefore, floating plastic debris on the ocean surface and stranding plastic debris on beaches can undergo mainly photo-oxidation and thermo-oxidation only (Andrady, 2015). Larger plastic debris breakdown into small plastic pieces and these fragments are named as micro plastics (Bergmann et al., 2015). These small plastic particles can easily get into food webs. According to 2021 estimations, 24.4 trillion micro plastic particles which is similar to 82-578 million tons of weight are there in the ocean currently (Isobe et al., 2021). To prevent the entering of these particles into the food webs, management actions should be taken strongly with no any mistakes (Shams, 2021).

In Sri Lanka, according to Nansen survey findings, they have recorded micro plastic debris across all the sample collection points located in the coastal zone and about 80% of the fish stocks had been depleted with the negative impacts made by micro plastics (Mongabay, 2019).

2.6 Plastic waste management strategies

Plastic waste management strategies are essential to address the growing issue of plastic pollution and its environmental impact. These strategies aim to reduce the generation of plastic waste, improve waste collection and disposal methods, promote recycling, and encourage responsible plastic use. These strategies collectively aim to reduce the negative impact of plastic waste on the environment, conserve resources, and create a more sustainable and plastic responsible society.

2.6.1 Global plastic waste management strategies

Globally, various methods are following to avoid plastic waste generation and minimize its impact on the environment. The R3 concept (Reduce, Reuse, Recycle) is a commonly practiced method worldwide, aimed at encouraging individuals, industries, and communities to reduce plastic consumption, reuse items where feasible, and actively engage in recycling programs (Mills, 2012). According to Macintosh et al. (2020), the adoption of prohibitions or limitations on the manufacturing, distribution, and utilization of plastic goods can be a viable strategy for diminishing plastic consumption and substantially mitigating the development of litter. Innovating biodegradable, compostable, and reusable alternative products for plastics and promoting their adoption is essential for decreasing plastic waste generation. These process can be facilitated by increasing community participation, formulating policies, and enhancing relevant legislation (Tan et al., 2021).

The concept of Extended Producer Responsibility (EPR) mandates manufacturers to assume responsibility for the disposal and recycling of their plastic products. This approach has been adopted by numerous countries, including those in Asia. However, developing countries encounter several challenges when implementing the EPR concept. To mitigate issues associated with EPR, it is vital to involve informal sectors in the process, enhance waste collection services, and clearly delineate producer responsibilities (Johannes et al., 2021).

Plastic taxation also serves as an effective strategy for managing plastic waste generation, particularly in European countries (De Weerdt et al., 2020). The basic components of this approach are the implementation of taxes or levies on plastic products, aiming to discourage their usage and produce cash for waste management and environmental conservation.

2.6.2 Local plastic waste management strategies

As an island nation, Sri Lanka has undertaken various initiatives to address issues related to plastic pollution. These initiatives encompass short-term measures, such as the banning of specific plastic products, mid-term actions involving partnerships with local and international entities, and long-term strategies focused on transitioning from a linear economy model to a more circular one. Additionally, efforts include raising community awareness through workshops and awareness programs.

In 2017, the Central Environmental Authority (CEA) of Sri Lanka imposed a ban on the production of polythene products with thicknesses below 20 microns and Styrofoam boxes as part of an overarching strategy to reduce plastic waste generation. However, this measure encountered challenges in its implementation due to insufficient involvement of relevant stakeholders and resistance from plastic manufacturers (NewsIn Asia, 2017). Given that over 400 private companies in Sri Lanka are engaged in plastic-related manufacturing processes, some of which are critical to public health, telecommunications, and water sanitation, any product bans should be gradually phased in to avoid unforeseen negative societal impacts (Sri Lanka Export Development Bank, 2020).

In 2018, the Ministry of Mahaweli Development initiated efforts to enhance accountability concerning plastic waste generation and improve waste recycling capabilities by collaborating with the Ceylon Chamber of Commerce (Daily FT, 2019). Subsequently, in 2019, Sri Lanka joined the United Nations' Basel Convention, aiming to closely monitor the movement of plastic materials across territories.

Despite these initiatives, the plastic waste issue in Sri Lanka continues to escalate, underscoring the need for further policy development. The Central Environmental

Authority (CEA) and the Marine Environment Protection Authority (MEPA) are two prominent governmental entities responsible for engaging in partnerships with diverse stakeholders in order to establish and execute waste management policies. Collaboration between these institutions and existing plastic waste management systems like John Keell's Plasticcycle could lead to improved outcomes.

2.7 Fishery industry

Agriculture is considered as the oldest livelihood of the human while fishing is the second oldest (Amutha, 2013). Fish protein fulfills about 10% of the total protein requirement of the world. Therefore, it is considered as a principal source of animal protein across the globes (Pakshirajan, 2022). According to a study conducted in 2021, approximately 20% of marine plastic debris is generated as a result of unsustainable fishery industry practices (Morales-Caselles et al., 2021). The potential adverse effects of plastic consumption on both seafood species and human consumers are believed to be significant (Wootton et al., 2022).

One main source of generating marine debris is fishermen not following best practices of discarding debris (Prasetiawan et al., 2022). Fishing activities, coastal areas and river mouths are among the major sources which contribute to generating MPW (Löhr et al., 2017). As per the European Union fishing fleet, marine debris leads to an annual economic loss of approximately 81.7 million dollars in the fishing industry (Van Acoleyen et al., 2013).

2.7.1 Fishery industry in Sri Lanka

Sri Lankan coastal areas serve as a major income generator by sustaining different economic sectors. Industrial sector, tourism industry and fishery industry are among them.

As per the provisions outlined in the Coast Conservation (Amendment) Act, No. 49 of 2011, the coastal zone has been primarily delineated as extending 300 meters landward from the Mean High Water Line (MHWL), and 2 kilometers seaward from the MHWL.

According to calculations made by Martinez et al., (2007), globally the economic contribution of the coastal zone and the open ocean is more than 60%. Costanza et al., (2014) have calculated the annual global economic contribution made by the coastal zone and the open ocean related ecosystem services as 49.7 trillion dollars.

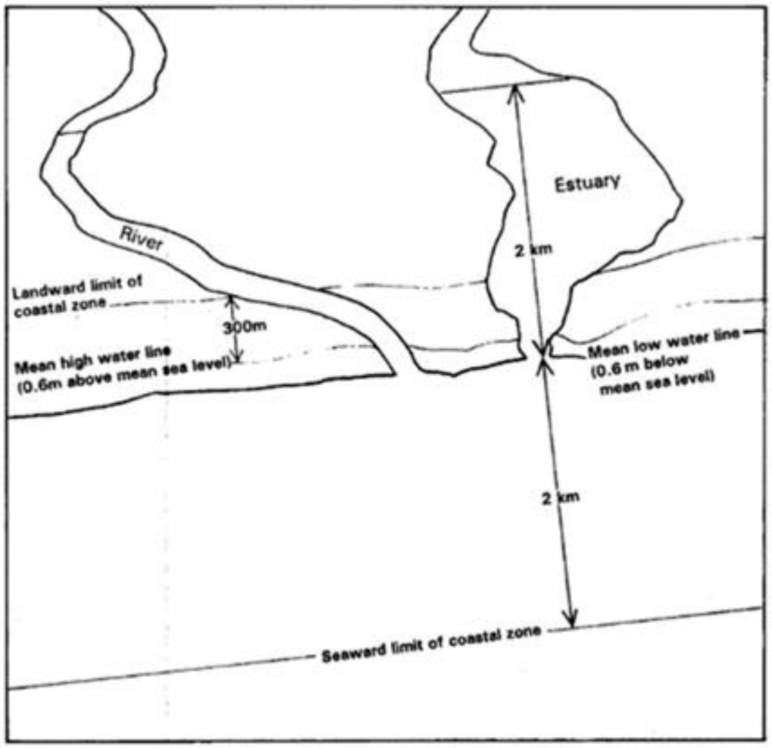


Figure 2.2: The coastal zone, as defined by the Coast Conservation Act of Sri Lanka
Source: Balasuriya, 2018

Since FH constitutes an integral component of the coastal surroundings, any form of pollution occurring within the harbor area has the potential to impact the coastal ecosystem and the vice versa as documented by Sciortino in 2010.

Currently, there are 21 actively operating FH under the CFHC located strategically across the country. These harbors play an important role in supporting the nation's vibrant fishing industry, providing essential infrastructure and facilities for fishers and related businesses. They serve as vital hubs for the landing, processing, and distribution of seafood, contributing significantly to both local and international seafood markets.

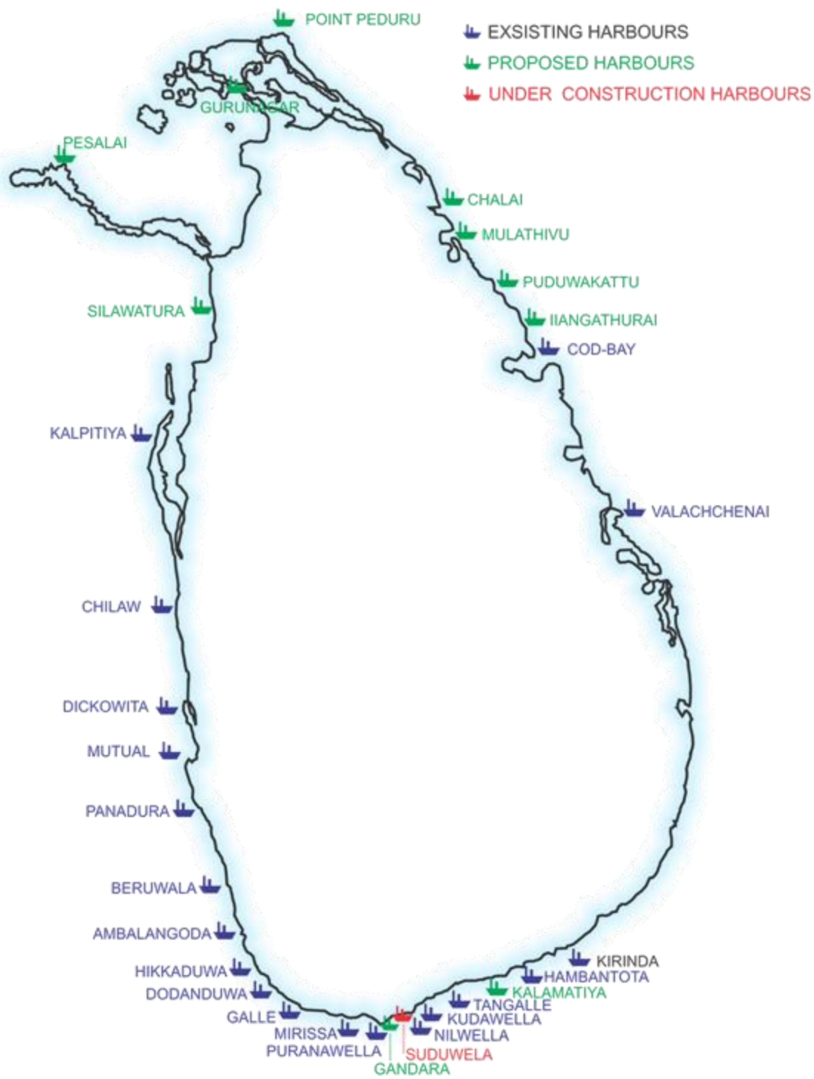


Figure 2.3: Harbors locations of Sri Lanka
Source: CFHC

Sri Lanka has a 517,000 km^2 larger Exclusive Economic Zone (EEZ) which is extended up to 200 nautical miles. Since this area is 7.8 times larger than the total land area, it is considered that Sri Lanka has a high water to land ratio. This EEZ is rich with marine organisms which is supporting the persistence of the fishery industry in the country (Edirisinghe et al., 2018). These marine organisms consist of 1,800 fish species, 30 marine mammal species, 5 turtle species, few sea snake species and invertebrates such as coral species (MoE, 2012). Territorial sea is an area with 21,500 km^2 and it is extended up to 12 nautical miles. All resources contained in this area belong to Sri Lanka.

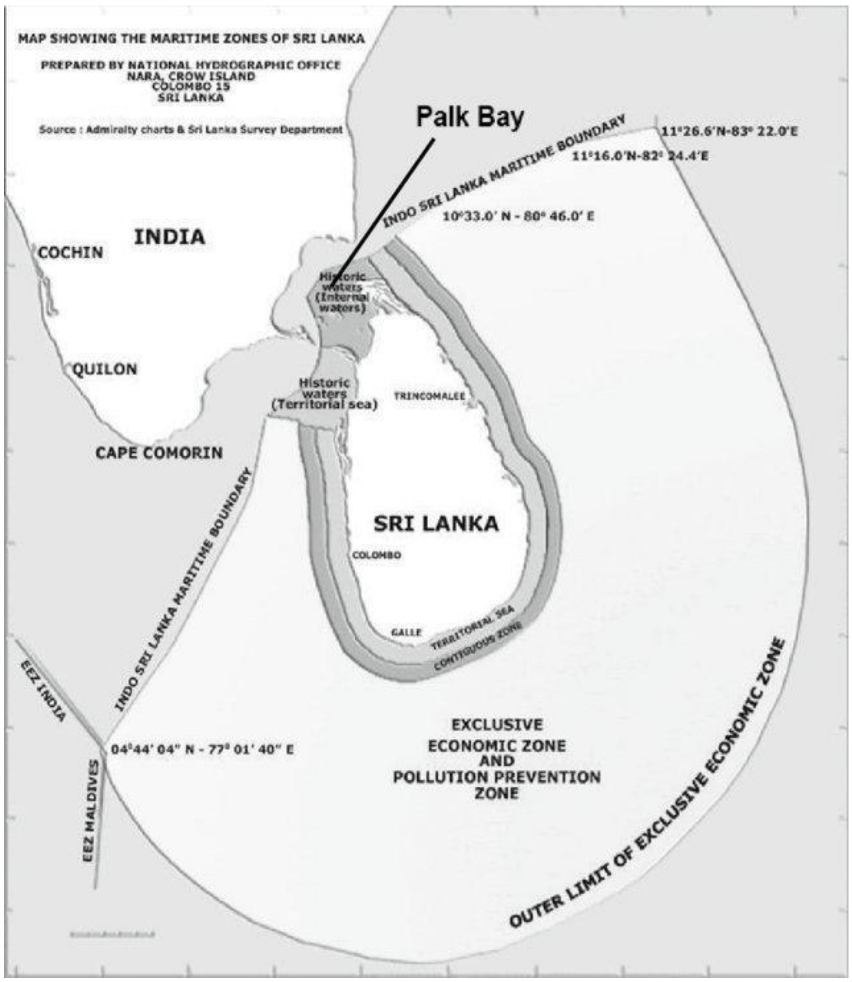


Figure 2.4: Sri Lanka's maritime zones
Source: Scholtens, 2016

Fishing has been one of the major professions from ancient times. Marine fisheries and inland fisheries are the two major components of the fishery industry practiced in Sri Lanka. According to Edirisinghe et al. (2018), marine fisheries can be categorized into two main types: coastal fisheries and offshore fisheries. Based on estimations from 2016, the average proportion of household expenditure allocated to fish consumption is reported to be 13.5% (CBSL, 2018).

In Sri Lanka, the fishery industry contributes approximately 1.3% to the total Gross Domestic Product (GDP) of the country and 2.5% of the foreign revenue. It supplies approximately 70% of the total protein requirement of the country (Weerasekara et al., 2015). About 560,000 people are directly or indirectly employed in the fishery industry. Though the fishery sector is significantly contributing to the GDP of the country, it can cause some severe effects on the coastal ecosystem by threatening the sustaining of the industry itself unless it is managed properly (CZMP, 2006). Hence, it is imperative to prioritize the sustainable exploitation of fishing resources while concurrently safeguarding and conserving them (NARA, 2017).

Already there are 50,591 fishing vessels registered in Sri Lanka 2019 (Gallagher et al., 2023). With the remaining unexploited resources availability in the country (Weerasekara et al., 2015) and its capability to boost some other subsidiary industries (Kori & Chandra, 2022), there is a high potential to increase the contribution to the fishery industry to the expansion of the economy of the country.

The country's fishery harvest volume may be influenced by seasonal variations (Yapa, 2000). Similarly, the accumulation of plastic debris along coastal areas is also subject to seasonal fluctuations (Kurniawan & Imron, 2019). Consequently, understanding these seasonal patterns is crucial for effective management of plastic waste generation in the FH.

Based on precipitation patterns, Sri Lanka is divided into three major regions: the dry zone, the wet zone, and the intermediate zone. West coast belongs to the Wet Zone of the country and it receives 2,500-5,000 mm annual precipitation. Therefore, rainfall is a considerable environment parameter in the study area.

2.7.2 Impacts of seasonal variation on fishery industry of Sri Lanka

Castillo-Rivera (2013), suggested that rainfall is a key factor that determines the seasonal fluctuations in the abundance of fish species. Therefore, seasonal variations directly affect the fishery industry of the country. Plastic debris accumulation patterns can also change with these seasonal variations (Kurniawan & Imron, 2019).

Yala and Maha are the two major seasons which are experienced in Sri Lanka. The Yala season is activated from May to August due to the influence of the South-West monsoon, while the Maha season is active from September to March as a result of the North-East monsoon. From May to September of the year, with the activation of the South-West monsoon, Western coast is exposed to heavy rains. Also from April to May and October to November with the activation of Inter-monsoon and Tropical cyclones respectively, the coastal area receives a considerable amount of rain (Manchanayake & Madduma Bandara, 1999).

As a result of shifting monsoon throughout the year, wind climate also changes from light to moderate speed (Mangor, 2002). Throughout the monsoon period, wave heights become higher and wave periods become lower. But during the inter-monsoon period, wave heights become lower and wave periods become higher. Wave climate around the country depends on both the South-West monsoon and North-East monsoon. During the South-West monsoon from May-July both the Southern and Western coast become moderate energy zones while North-East monsoon from both Southern and Western coasts become low energy zones (Survey Department, 2007).

During that North-East monsoon in Southern and Western coast of Sri Lanka, primary productivity in the surface waters get reduce (De Vos et al., 2014) and this can be impact on the fishery harvest. In the South-West monsoon season, surface currents move from West to East. Consequently, ocean currents from the Arabian Sea make direct contact with the Western Province coastline (De Vos et al., 2014) potentially leading to a higher influx of floating plastic debris into the country during this period.

Even though Sri Lanka is not frequently exposed to cyclones when Inter Tropical Convergence Zone (ITCZ) is moving from North to South towards the equator during

October to November, there is a possibility to occur some cyclone events in the country (Dela, 2002).

2.7.3 Problems associated with plastic waste generation in local fishery harbors

Due to the lack of adequate facilities, including essential infrastructure, there are challenges in effectively managing plastic debris at FH. A study conducted in 2017 by Weerakoon and their team along the Southwestern and Western coastal zones of Sri Lanka confirmed that beaches situated near FH exhibit a significant accumulation of microplastic litter (Weerakoon et al., 2018). According to Wijethunga et al., (2019), the Southern coastal zone of Sri Lanka experiences heightened plastic waste generation and accumulation due to three main factors: unsustainable coastal fishery practices, unsustainable tourism industry activities, and operational actions within the harbors. These findings collectively underscore the magnitude of the plastic waste challenge within FH.

Petrochemical compounds like plastic debris are major polluters generated in urban areas of Sri Lanka which can degrade the quality of fish harvest and various coastal habitats whilst negatively impacting the near shore fishery industry (Weerasekara et al., 2015).

Though there are many studies conducted related to MPW in Sri Lanka, very little attention has been paid on intentionally or non-intentionally discarded fishing gear into the ocean (Gallagher et al., 2023). Discarded fishing gears are named as “ghost fishing” since there is a possibility to continually harm the marine fauna if they enter into the ocean than other types of marine plastic debris as they are intentionally designed and manufactured to capture fish (Brown et al., 2005). From a pilot study conducted in Sri Lanka based on 325 fishing boats, it has estimated 22,593 kg of plastic fishing gear has been disposed of into the ocean from 2021-2022. Only 194 fishing boats had engaged with discarding plastic fishing gear into the marine environment with an average of 116 kg per boat (Gallagher et al., 2023).

2.7.4 Research Questions

Given the complex and diverse difficulties related to the development of plastic waste in local FH within Sri Lanka, this study aims to tackle a number of crucial research inquiries. The aforementioned inquiries have been methodically developed to direct inquiry and cultivate a thorough comprehension of the dynamics of plastic waste in FH.

a) What are the drivers and magnitude of plastic waste generation in Sri Lankan FH?
This question seeks to uncover the driving forces behind plastic waste generation within FH and the specific factors contributing to heightened plastic waste accumulation, considering the impact of unsustainable coastal fishery practices, and operational actions within these harbor facilities. Through a systematic analysis, we aim to discern the overall magnitude of plastic waste generated.

b) What is the nature and extent of plastic debris in FH located in the Western Province of Sri Lanka?
This research question delves into the composition of plastic debris in FH, focusing not only on typical macroplastics but also on the often-neglected category of fishing gear inadvertently discarded into the ocean. By quantifying these materials, this study aims to provide a comprehensive profile of the plastic waste challenge in FH.

c) How do spatial and temporal variables influence plastic debris accumulation in FH?
This question is designed to elucidate the spatial and temporal dynamics of plastic debris accumulation in FH. By investigating how factors such as location of data collection points, tide levels, monthly rainfall and seasonal variations impact the distribution of plastic waste, it aims to better understand the patterns of plastic debris accumulation along the land-water interface of FH.

d) What role does the fishery industry play in plastic waste generation, and how can policy gaps be addressed?
With a focus on the direct contribution of the fishery industry to plastic waste generation, including items like buoys, floats, and other fishing gear, this research

question evaluates the specific involvement of the industry in this environmental challenge. Furthermore, it explores how identified policy gaps can be addressed and informs the development of targeted interventions for more effective plastic waste management within FH.

e) How do stakeholders' attitudes and perceptions influence plastic waste utilization and management within FH?

To gain insights into the human dimensions of plastic waste generation and management, this question investigates the attitudes and perceptions of various stakeholders, including fishermen and relevant harbor authorities. By conducting workshops and questionnaire surveys, it aimed to understand the dynamics between stakeholders and their roles in mitigating the plastic waste challenge.

The study aims to solve the research issues by providing a detailed analysis of the complex issue of plastic waste generation in the context of FH in Sri Lanka. Through a methodical examination of this issue, the study aim is to make a valuable contribution to the formulation of precise approaches and governmental measures that can efficiently tackle the problem of plastic pollution while promoting the prosperity of coastal ecosystems and communities.

2.8 Chapter Summary

The given paragraph discusses several aspects related to plastic debris, its types and benefits of plastics, plastic pollution, marine plastic pollution, plastic waste management strategies, and the fishery industry in Sri Lanka.

The paragraph begins by defining plastic as synthetic polymers derived from petrochemical compounds, categorized into different sizes and types. It highlights meso plastics and micro plastics as main types based on size. Various types of plastics have specific advantages in different industries, like PET's use in packaging and HDPE's resistance for containers and pipes.

Plastics provide benefits like versatility, cost-effectiveness, resistance to moisture and heat, and strength. They are integral in industries such as packaging, construction, and textiles. Plastics' lightweight nature reduces energy consumption and transportation costs, while their flexibility enables use in various industries.

Plastic pollution has two main aspects: land-based and ocean-based. Land-based plastic pollution involves widespread accumulation of plastic waste on land, causing environmental and human health issues. Ocean-based plastic pollution, mainly from improper fishing practices, leads to plastic waste accumulation in oceans, endangering marine life and ecosystems.

The economic, ecosystem, and human health impacts of plastic pollution are discussed. Plastic waste management strategies aim to reduce waste generation, improve recycling, and promote responsible plastic use. Global and local strategies include the R3 concept, bans on plastic products, and plastic taxation.

The fishery industry in Sri Lanka plays a crucial role economically and in food supply. However, plastic waste generation from unsustainable practices and discarding fishing gear pose significant challenges. The industry's impact on coastal ecosystems underscores the need for sustainable practices.

In conclusion, the paragraph covers the diverse aspects of plastic debris, its impact on the environment, plastic waste management strategies, and its effects on the fishery industry in Sri Lanka.

3 METHODOLOGY

3.1 Chapter Introduction

This chapter presents the methodology adopted for the research study, which aims to comprehensively investigate plastic waste utilization and management practices in FH located in Western Province of Sri Lanka. To achieve this objective, the study employs the accumulation study method, focusing on collecting debris found along the land, water interface of the FH.

3.2 Research method

This study utilized a comprehensive methodology to investigate plastic waste dynamics within Sri Lankan FH. This methodological approach consisted of three interconnected stages aimed at providing a robust understanding of plastic waste generation and management within FH.

Stage 1: Observations and plastic waste sampling analysis

> The primary data collection process involved observations and plastic waste sampling within FH. Internationally recognized guidelines from the "NOAA Marine Debris Monitoring and Assessment Project," specifically the "Shoreline Survey Guide" by Burgess et al. (2021) and the "Shoreline Survey Field Guide" by Opfer et al. (2012), were adapted to ensure adherence to best practices because there are no standardized survey protocols for FH settings. This stage allowed for a quantitative assessment of plastic waste, enabling the creation of a foundational dataset.

Stage 2: Stakeholder workshop

> The second stage involved a stakeholder workshop conducted on March 21st at the Central Environmental Authority (CEA) auditorium. This participatory approach engaged major stakeholders, including officers from the Ceylon Fishery Harbors

Corporation (CFHC), Coastal Guard officers, Ceylon Fisheries Corporation officers, and fishermen. The workshop served to elucidate stakeholder perspectives, uncover policy gaps, and foster dialogue. While primary data collection addressed the physical aspects of plastic waste, secondary data collection through the workshop captured the perceptions, attitudes, and contextual information, enhancing the overall analysis.

Stage 3: Questionnaire survey

Since questionnaires can capture a diverse array of responses from stakeholders and disclosing the attitudes and behaviors toward plastic waste, at the third stage, a questionnaire survey was employed to gauge the attitudes and perceptions of stakeholders, particularly fishermen. The questionnaire format was chosen for its ability to efficiently capture uncontroversial insights, making it a suitable method to further enhance the study's comprehension of plastic waste within FH.

These three methodological stages were executed cohesively to facilitate a holistic investigation, encompassing physical waste analysis, stakeholder perspectives, and the attitudes of a vital stakeholder group. The amalgamation of these approaches aimed to inform the development of effective waste management strategies and policy recommendations for Sri Lankan FH.

3.2.1 Study sites

Belt transects were conducted along five FH (Beruwala, Dikkowita South and North, Panadura and Negombo) located in the Western Province of Sri Lanka to gather primary data on debris accumulation.

The selection of the study site, the Western Province, is underpinned by a careful consideration of key socioeconomic and environmental factors that influence plastic waste dynamics. The research in the field has highlighted two significant determinants of marine plastic pollution: population density and Gross Domestic Product (GDP). Jambeck et al. (2015) underscored the direct correlation between population density and the volume of debris that finds its way into marine ecosystems. Concurrently, Lebreton and Andrady (2019) connected this phenomenon with a nation's GDP, indicating that areas with higher economic activity tend to generate more plastic waste.

In the Western Province, these characteristics exhibit a significant degree of alignment. According to the 2012 Census, the region in question has the highest population density in the country, estimated at approximately 1,600 inhabitants per square kilometer. Moreover, it assumes a pivotal position in the economic landscape of Sri Lanka, making a huge contribution of 39.1% to the country's nominal GDP, which represents the most significant provincial input.

This unique juxtaposition of a dense population and robust economic activity signifies that the Western Province is an epicenter for plastic waste generation. Thus, conducting this study in this area is not only scientifically merited but also critical from a practical standpoint. The heightened potential for marine plastic waste generation underscores the need to establish a baseline dataset for understanding the issue.

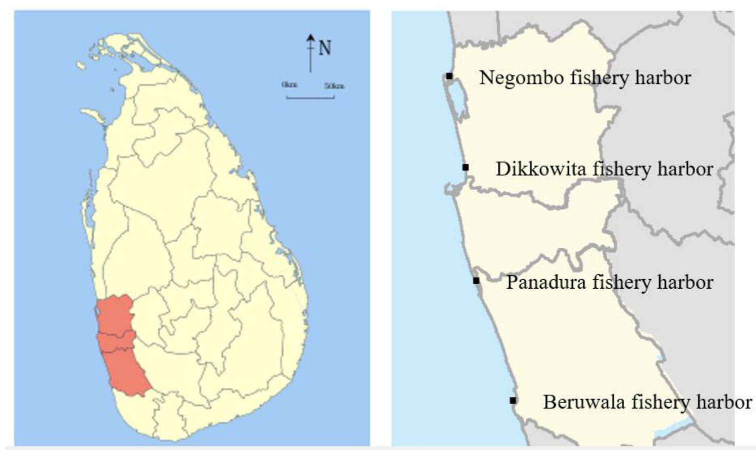


Figure 3.1: Selected FH located in the Western Province of Sri Lanka

All belt transects were 10m x 1m in size and 10-20% of the total length of each FH was surveyed. Data collection points in each FH were predetermined based on the accessibility to particular location, available resources and the objectives of the study. In BFH; 16 points, PFH; 13 points, SDFH; 14 points, NDFH; 12 points and NFH; 4 points were selected. At NDFH and SDFH, data collection points were numbered in a single sequence from P1 to P26, as these two areas operate within the same harbor premises despite functioning as two separate basins.

Figure 3.2: Data collection points located in NDFH (Red color- Stranding debris collection points; Blue color- Floating debris collection points)

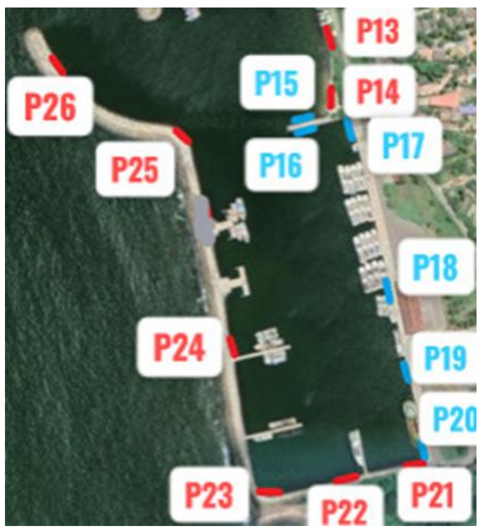


Figure 3.3: Data collection points located at SDFH (Red color- Stranding debris collection points; Blue color- Floating debris collection points)

Figure 3.4: Data collection points located at BFH (Red color- Stranding debris collection points; Blue color- Floating debris collection points)

Figure 3.5: Data collection points located at PFH (Red color- Stranding debris collection points; Blue color- Floating debris collection points)

Figure 3.6: Data collection points located at SDFH (Red color- Stranding debris collection points; Blue color- Floating debris collection points)

FH consisted of three types of components such as sandy beaches, breakwater structures and jetties. Floating debris were collected along the jetties and stranding debris were collected along the sandy beaches. Along the breakwater structures, floating debris was collected when stranding debris collection was not possible. To collect stranding debris, the hand picking method was used while hand net method was utilized to collect floating debris. Standing debris items were collected from 0.5-1 m above from the high tide line. Floating debris was collected from the water section of land water interface along jetties and at the points where access is limited to hand picking.

Before the commencement of the study, all debris accumulated at selected locations were cleared. Then, all man made debris items newly added on to the identified points in each FH were collected, air dried, grouped, weighted and recorded.

Figure 3.7: Grouping anthropogenic debris collected from a data collection point

3.2.1.1 Selection of data collection points

For the study, data collection points were selected with the purpose of generating an AutoCAD map to represent plastic debris density with contour lines while also considering the accessibility of particular locations and the availability of resources. Therefore, instead of randomly selecting the data collection points similar to most of the other studies here it is selected non-randomly. Along straight areas, samples were collected from the tip, middle point and the end point. If the straight line is very long, additional points were added with equal distance. To generate much sharper contour lines at bending points, two samples were collected from bends.

3.2.1.2 Data collection

Plastic products larger than 2.5 cm are classified as macro plastics (Romeo et al., 2015). Every piece of visible man made debris that measured more than 2.5 cm or 1 inch (the size of a bottle lid) at each sample collection location was gathered into a different bag. All the debris was cleaned from any sand or mud and group based on their type as plastic, metal, glass, rubber, processed wood and fabrics. Then, keep 2-3 hours for air drying and during that time, counts were recorded based on types and size class. The size class of plastic debris was categorized using Gómez et al., 2020 and Zhang et al., 2020, whereas the type of debris were classified using the National Oceanic and Atmospheric Administration (NOAA), Marine Debris Monitoring and Assessment Project (MDMAP), and Marine Debris Item Categorization Guidelines. Finally, the total dry weight of different types of debris were weighted to the nearest 0.001 kg for each point using a digital scale.

3.2.1.3 Data storage

Collected data were arranged and stored in a datasheet developed based on NOAA Marine Debris Monitoring and Assessment Project (MDMAP) Marine Debris Item Categorization Guide 2021. The datasheet with some slight modification made to suit the FH located in Sri Lankan. Cigarette tips, shotgun shells and wads were omitted since not a single item of these types were recorded throughout the study time. Rice bags, cigarette filter, fish wraps were newly added to the original list since there were many of them recorded.

Six types of debris items were collected as plastic, metal, glass, rubber, processed wood and fabric and they were further divided into 49 subtypes. Top ten litter items, Single use plastics (SUPs) and fishery industry related debris count were extracted using these data sheets.

3.2.1.4 Data analysis

To comprehensively analyze the data collected, Minitab 19 was used as the statistical software package to conduct descriptive data analysis. Statistical analysis is a cornerstone which facilitating the extraction of meaningful insights from complex datasets.

Data were checked for normality. Based on normality tests, p value, parametric or non-parametric statistical methods were used. One-way ANOVA was used to identify the significant difference among points whilst Tukey HSD was used to identify in which point pair has the statistically significant difference. The level of significance used was 0.05 ($p < 0.05$). Graphics were generated using Minitab 19, AutoCAD 2016 and Microsoft Excel 2013.

3.2.2 Correlation between the number of plastic debris collected and weight of plastic debris collected

Total number of plastic debris collected from each data collection point was tested for the correlation with total weight recorded from particular locations. The Pearson correlation value was measured to evaluate the linear relationship between plastic weight and number of plastic debris recorded.

Correlation analysis was conducted to explore the dynamic relationship between the number and weight of plastic debris. The approach to this analysis involved the utilization of the Pearson correlation coefficient, a well-established statistical measure highly regarded for its capacity to gauge linear relationships between two variables.

In the specific context of the study, it was imperative to ascertain whether an increase in the number of plastic debris collected exhibited a linear association with the escalation in the total weight of plastic debris at various data collection points. This robust statistical foundation ensured that the analysis yielded scientifically robust and interpretable conclusions regarding the intricacies of plastic waste dynamics within FH.

Figure 3.8: Weighting the plastic debris collected from a data collection point

3.2.3 Correlation between monthly rainfall and monthly average number of plastic debris collected

To investigate the interplay between monthly rainfall and plastic debris accumulation, a two-step process was followed. Firstly, data on monthly rainfall was meticulously collected from the Sri Lankan Meteorological Department, ensuring the accuracy and reliability of this meteorological information. This data encompassed the temporal variations in rainfall across the study period.

Secondly, corresponding to each month, the study calculated the average count of plastic debris recorded at each FH. By dividing the total number of plastic debris collected in a particular month by the number of data collection sessions, an average weekly figure was derived. This was further multiplied by the number of actual weeks within that particular month, resulting in a monthly average number of plastic debris collected for each FH. This method allows for a more meaningful and comparable analysis of monthly data across the FH. This statistic quantified the level of plastic debris accumulation within the respective FH on a monthly basis.

To analyze the relationship between these two sets of data, the study utilized the Pearson correlation coefficient. This widely accepted statistical tool was employed to systematically investigate whether there is a discernible connection between the monthly amount of rainfall and the quantity of plastic debris observed at the FH. The Pearson correlation offers a precise numerical representation of this potential relationship.

The objective of the investigation was to ascertain whether there existed a discernible correlation between variations in monthly rainfall and the quantity of plastic debris observed in the FH. The use of this methodology facilitated the investigation in yielding a scientifically substantiated comprehension of the potential impact of meteorological variables, specifically rainfall, on the occurrence of plastic garbage within the FH.

3.2.4 Correlation between tide level and the number of stranding and floating plastic debris collected

To explore the potential link between tide levels and the quantity of stranding and floating plastic debris found within FH. In order to conduct this analysis, a systematic process was established.

At the commencement of data collection for each day, meticulous records of the prevailing tide levels were secured. This information was sourced from a reputable online platform, specifically the "Tide Chart" (https://www.tideschart.com/) website. It provided accurate and standardized data regarding the tide levels, ensuring consistency and reliability. Simultaneously, it recorded the total number of plastic debris instances observed for both stranding and floating debris categories at the respective FH.

Following data collection, the study employed the Pearson correlation coefficient. This analytical method was chosen for its ability to assess and quantify the potential linear relationship between tide levels and the quantity of plastic debris, both stranding and floating, collected on each day. The Pearson correlation aimed to determine if as the tide levels rose or fell, the amount of stranding and floating plastic debris also exhibited a corresponding pattern of increase or decrease.

The objective of this analysis was to scientifically evaluate whether tide levels influenced the presence and quantity of plastic debris within the FH. Such systematic exploration provided valuable insights into the environmental dynamics of plastic waste in relation to tidal patterns.

3.2.5 Comparison between the number of stranding and floating plastic debris collected

The normality of the data was assessed using the Anderson-Darling normality test. This statistical evaluation was employed to determine whether the dataset conformed to a normal distribution or whether it exhibited significant deviations from the normal distribution. If p-value is higher than 0.05, it considered as a normal distribution.

Subsequently, the Mann-Whitney test was carried out, given the non-normal distribution of the data. The Mann-Whitney test is particularly suited for datasets that do not follow a normal distribution. This analysis aimed to investigate whether there were noteworthy distinctions between two significant categories: stranding and floating plastic debris. Specifically, the focus was on determining if there existed a significant difference in the median quantities of stranding and floating plastic debris recorded within the FH.

In total, debris data from 59 collection points located within these five FH were meticulously collected and documented. Among these 59 data points, 32 featured stranding debris, while the remaining 27 contained records of floating debris. It's important to acknowledge that the study recognized the impracticality of making the same comparison for the NFH due to the unavailability of stranding debris collection points within its specific premises.

3.2.6 Seasonal variation of plastic debris accumulation

To comprehend the seasonal dynamics of plastic debris, data was categorized into distinct periods: October to November (Second Inter-monsoon season), December to February (North-East monsoon), March to April (First Inter-monsoon season), and May to September (South-West monsoon). This categorization allows for a more detailed examination of plastic waste trends over the year, as different seasons may influence waste accumulation patterns.

The adherence to normal distribution of the data was ensured using the Anderson-Darling normality test ($P>0.05$). This step is crucial as it validates the suitability of parametric statistical tests, like ANOVA, which rely on the assumption of normally distributed data.

If the distribution was normal, one-way ANOVA test was applied to identify potential variations in the mean plastic debris numbers across the seasons. This test determines whether there are statistically significant differences between the seasons. In cases where such differences are found, it suggests that seasonal factors significantly influence plastic waste accumulation.

In instances where the ANOVA test detects significant differences, the Tukey HSD test was employed to pinpoint which specific seasonal pairs exhibited these distinctions. This level of detail aids in understanding the specific season-to-season variations in plastic waste within FH.

These methods are essential for conducting robust seasonal variation analysis. They allow for the drawing of statistically supported conclusions about the influence of different seasons on plastic debris accumulation. This level of detail is critical for forming a comprehensive understanding of the seasonal dynamics of plastic waste in FH.

3.2.7 Spatial variation of plastic debris accumulation

To ensure the statistical soundness of the analyses, Anderson-Darling normality test was applied to the data. This test is fundamental as it confirms the adherence of the dataset to a normal distribution ($P>0.05$), thus validating the appropriateness of employing parametric statistical methods.

To ascertain whether there were any significant variations in the average quantities of plastic waste gathered from sample collecting points situated at specific FH, a one-way ANOVA test was employed.

The statistical techniques validate the validity of the analysis and support the drawing of well-substantiated conclusions regarding plastic debris distribution and variations. This analysis is indispensable for the identification of hotspots, areas within FH that accumulate significantly higher quantities of plastic debris compared to other points. The importance of this step lies in its ability to pinpoint specific locations where plastic waste concentration is notably elevated, providing essential insights into the distribution patterns of plastic debris within FH. By identifying these hotspots, the methodology enables a focused and targeted approach to addressing plastic waste management. This not only contributes to the scientific rigor of the study but also offers valuable guidance for the development of effective mitigation and intervention strategies within the FH under investigation.

3.2.8 Size class of plastic debris

One crucial aspect of the process involves the segmentation of plastic debris based on size classes, wherein fragments bigger than 2.5 cm are divided into five unique size categories labeled as A (5cm x 7.5cm), B (10cm x 15cm), C (15cm x 20cm), D (20cm x 30cm), and E (>D). The utilization of size classes, as determined by the studies conducted by Gómez et al. (2020) and Zhang et al. (2020), facilitates a more thorough examination of the plastic debris that has been gathered.

The selection of these size categories serves to organize and group plastic debris based on their surface area, as this parameter significantly influences the potential environmental impact and interactions with marine life. This understanding about the size class composition of plastic debris is important for the management process as well, as it informs strategies for more targeted and effective mitigation efforts in FH.

However, it is noteworthy that certain items such as 'lures and line' and 'rope and nets,' due to their irregular shapes and unique characteristics, were not grouped based on size. This precise categorization of plastic debris is essential for a rigorous scientific analysis of the environmental dynamics within FH, offering detailed insights into the types and sizes of plastic waste that may pose varying ecological risks.

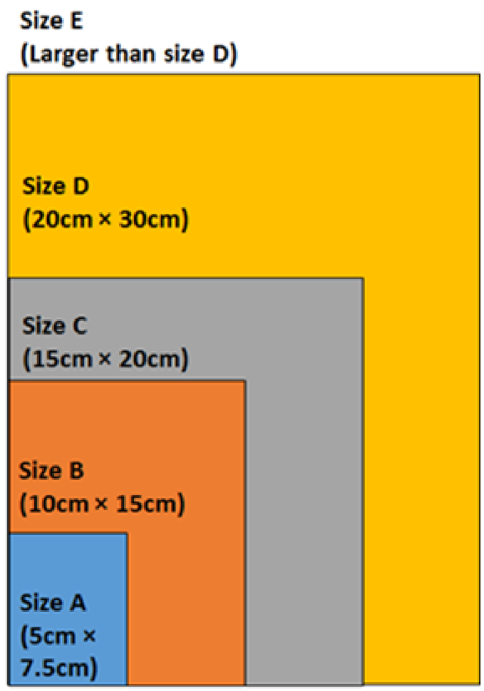


Figure 3.9: Size class catalogue

3.2.9 Single Use Plastics (SUPs)

SUPs represent a specific category of plastic items designed for a singular application, intended for disposal or recycling after use. This category includes items such as bags, rice bags, beverage bottles, bottle or container caps, cups, food wrappers, other jugs and containers, straws, utensils, six-pack rings, and personal care products. These items are widely acknowledged for their disposability, which often leads to their improper disposal in marine environments, significantly contributing to plastic waste pollution.

The examination of the accumulation patterns of these SUPs is of paramount importance due to their widespread use and subsequent environmental implications. Focusing on SUPs unveils the extent of their presence within FH, providing insight into the specific types of prevalent plastic waste. This understanding not only serves as a foundation for targeted waste management strategies but also aids in developing awareness and policies to curb the proliferation of SUPs and mitigate their detrimental effects on marine ecosystems and communities.

3.2.10 Transboundary Marine Litter (TBML)

Plastic debris encountered during the study was systematically categorized based on its origin, distinguishing between items originating from local sources and those classified as TBML. Notably, for TBML items, the specific type and subtype, along with the country of manufacture, were meticulously documented, contingent on label visibility.

This differentiation by origin is pivotal for several reasons. Firstly, it allows for the identification of potential sources and pathways of plastic debris influx into the FH. By discerning whether an item is of local or foreign origin, it is possible to trace the origins of pollution. This is a crucial step in the formulation of effective strategies to address plastic waste pollution at its source.

Moreover, this method offers insights into the transboundary nature of marine litter, shedding light on the dynamics of plastic waste transport across borders. Understanding the types and origins of TBML is valuable for international cooperation and policy development to mitigate the impacts of cross-border plastic pollution.

In summary, the systematic categorization of debris by origin serves as a cornerstone for unraveling the complexities of plastic waste accumulation and dispersal within the FH. This knowledge, encompassing local and transboundary sources, is invaluable for developing targeted interventions and international collaborations aimed at mitigating the environmental impact of plastic debris.

Figure 3.10: Foreign food wrapper and beverage bottle

3.2.11 Manufactured years of food wrappers

By identifying the manufacture year of plastic food wrappers, the study delves into the temporal aspect of plastic waste pollution. Understanding the age and origin of wrappers provides insights into the persistence of plastic materials in the environment. This information aids in elucidating the potential lifespan of these items and their durability in marine environments, thus contributing to a comprehensive assessment of their environmental impact.

Also, food wrappers serves as a valuable proxy for understanding the age of various other plastic debris, even when such information is absent. It provides an approach to assessing the age and durability of plastic items inside FH. By extrapolating from the wrappers to other plastic debris, it can gain insights into the persistence and aging patterns of plastics in marine environments, which is essential for a holistic evaluation of their environmental impact.

Figure 3.11: A food wrapper with invisible manufacturing date

3.2.12 Fishery industry contribution on plastic waste generation

Buoys, floats, lures, lines, ropes, nets, and fish wrappers represent a particular category of plastic debris significantly linked to the fishery industry. These items are integral to fishing activities and are often used intensively. The study sought to illuminate the specific environmental consequences of the sector by isolating and examining them.

The inclusion of these specific items aligns with the study's objective to not only understand the overall plastic waste issue but also to identify the role and practices of the fishery industry in plastic waste generation. Recognizing the industry's influence on plastic debris accumulation is essential for developing targeted strategies and interventions.

3.2.13 Stakeholder's workshop

The stakeholder workshop was a pivotal component of this research methodology, enabling collaboration with key stakeholders in the FH context. These stakeholders included officers from the Ceylon Fisheries Harbor Corporation (CFHC), Coastal Guard officers, Ceylon Fisheries Corporation officers, Non-Governmental Organizations (NGOs), and waste collectors. The workshop used a Focus Group Discussion (FGD) format to gather valuable insights and observations related to plastic waste management within FH.

The FGD format is a well-established qualitative research technique known for its effectiveness in gathering insights from diverse participants. It involved the formation of small groups, each comprising approximately 8-10 participants, representing the different stakeholder categories. Each group was facilitated by a skilled recorder, often a postgraduate student, who played a crucial role in recording and documenting the critical points extracted during the discussions. The use of a skilled recorder ensured that qualitative data, including comments, observations, and insights, were captured accurately.

In addition to support data reliability, the stakeholder workshop had a broader purpose: to enrich the research data and generate valuable insights. The comments and insights provided by the stakeholders have the potential to confirm or refine initial findings, thus adding depth to the research. This is particularly valuable for a study of this nature, focusing on a multifaceted issue like plastic waste management within FH.

An integral part of the workshop's objective was to identify policy gaps and implementation challenges associated with plastic waste management within FH. This is critical for the formulation of effective and feasible recommendations to enhance plastic waste management practices. The workshop provided a platform for stakeholders to share their experiences, concerns, and suggestions, which contributed significantly to the research's policy-related goals.

Figure 3.12: Stakeholders workshop conducted at CEA on 21st of March, 2023

3.2.14 Questionnaire surveys

In addition to the stakeholders workshop, questionnaire surveys were conducted as the main research instrument with the participation of fishermen (n=150) to understand their attitude and perception on plastic waste utilization and management inside FH. Since questionnaire surveys provide uncontroversial and brief information on the regarded matter, it was adopted as the most suitable method to be used in the study. Questionnaire survey was developed based on Suresh & Suresh, 2022 and Arulnayagam, 2020 studies conducted in Sri Lanka (Appendix A). Gender, age and education background of the all 150 interviewers were recorded at the beginning while giving the instructions about the questionnaire survey and purpose of the study. Age was categorized into 5 groups as <20 years, 20-29 years, 30-39 years, 40-49 years and >50 years. Education background was categorized into 5 groups as illiterate, primary education, secondary education, graduate and postgraduate.

Figure 3.13: Conducting Questionnaire surveys with the participation of fishermen

3.3 Chapter Summery

The Methodology chapter presents a comprehensive and systematic approach to investigate plastic waste utilization and management practices in FH across Sri Lanka. The chapter emphasizes the adoption of the accumulation study method, which involves collecting plastic debris found along the land-water interface of FH. The research methodology aims to quantify plastic waste accumulation, characterize the types of plastic debris, assess spatial and temporal variations, and inform effective waste management strategies.

4 RESULTS AND DISCUSSION

4.1 Chapter introduction

In this chapter, qualitative and quantitative data on waste generation in the study sites of BFH, NDFH, SDFH, PFH and NFH in the Western province, their spatial temporal and seasonal variation, correlation between number of plastic debris collected with plastic weight, tide level and rainfall, contribution of SUPs, top ten polluters, fishery industry related plastic debris and TBML on total waste generation inside FH, major stakeholder's perception on waste generation were revealed.

This study addressed a critical research gap by focusing on plastic waste generation within FH, an area where limited prior research had been conducted globally. With the achievement of the second and third objectives of the study which has mentioned in the 1.5 chapter, it provided valuable insights into the quantity and variation of plastic waste in FH. To attain the fourth objective, further collaboration and effort are required among stakeholders. Nonetheless, the study already unveils substantial policy gaps that must be addressed to mitigate the pressing issue of plastic pollution in FH, ensuring the sustainability of these essential coastal ecosystems.

4.2 Results overview

Throughout one year of the study period, a total number of 34,188 debris items weighing 2650.47 kg were recorded from the total 59 belt transect points located in five FH. Plastic debris accumulation rates for each FH were calculated as 1.45, 2.21, 1.57, 0.98 and 0.17 items/m2/week in BFH, NDFH, SDFH, PFH and NFH respectively.

Beach cleanup programs and regular cleaning processes that take place at harbor premises can have an effect on the number of debris recorded from the accumulation study. But inside FH, cleanup programs conduct very rarely and no such events were conducted during data collection time for the study. Cleaning personnel were informed about the data collection points and they avoided collecting debris from such locations. Therefore, the effects of cleaning efforts on the debris recorded is negligible.

NOAA Shoreline Survey Guide in 2021 has recommended two types of shoreline survey methods to be conducted to monitor debris at coastal areas named as “accumulation studies” and “standing-stock studies”. The majority of the studies has been conducted based on standing-stock methods though this method provides only crude qualitative and quantitative details on debris accumulation patterns and not a good indicator for the level of debris accumulated at adjacent coastal water bodies (Ryan et al., 2009).

The limitations of the standing stock method in monitoring long-term patterns of litter accumulation rates can be overcome by employing the accumulation study method. This approach can also be utilized to assess trends in marine litter quantities and calculate the rate at which debris is deposited along the shoreline (Ryan et al., 2009). This method can also determine the effects of climatic events on debris accumulation patterns and the possible debris flow into the ocean (Morishige et al., 2007). Also it provides a proxy value for the debris load at sea (Smith & Markic, 2013) and it can be utilized to identify debris types and measure their weight. Therefore, the accumulation studies method was utilized instead of the standing-stock method though it is much labor and time intensive process.

The level of error in accumulation studies can be dependent on the time interval between two consecutive debris collection surveys (Eriksson et al., 2013). The effects of sampling intervals on the rate of debris accumulation had been examined in some studies. Based on those results, United State National Marine Debris Monitoring Program (USMDMP) has found that there is no significant relationship between the debris accumulation rate and the sampling intervals (Sheavly & Register, 2007). But, some studies have confirmed that short term fluctuations can take place on debris accumulation rates due to changes of environmental parameters like tide level and wind direction and those effects can be buffered to certain extent using longer time intervals compared to daily sampling (Ryan et al., 2009). With the practical difficulty of daily sampling, sampling frequency is set as one week for the study. Weekly data collection was conducted for 8 months from October 2022 to May 2023.

4.2.1 Results overview based on total number of debris

According to the data collected and recorded from the accumulation study method, the total count of plastic was 29,141 and it represented the highest number of debris by count. The total counts of 2,731, 678, 668, 609 and 361 represent the number of rubber, metal, glass, processed wood and fabric respectively.

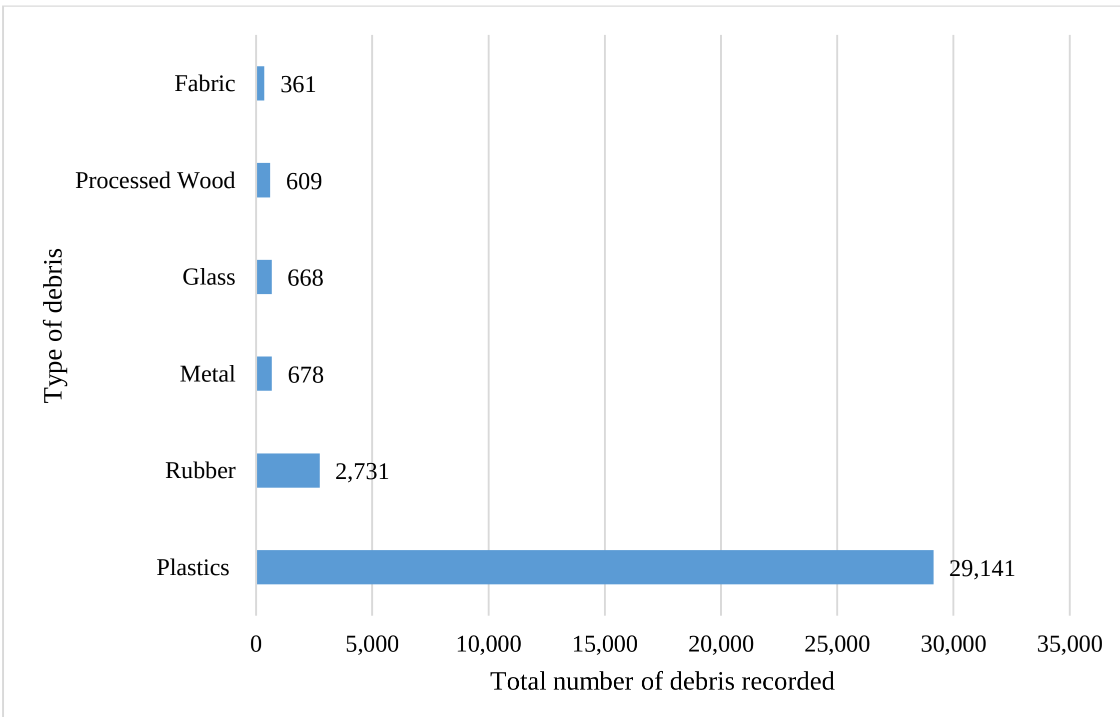


Figure 4.1: Total number of debris collected from all FH during the study period

Plastic was the most abundant type of debris in all FH. In the case of NDFH and SDFH, rubber had a considerable total count after plastic. The majority of the rubber debris consisted of fragments discarded during fishery vessel repair processes.

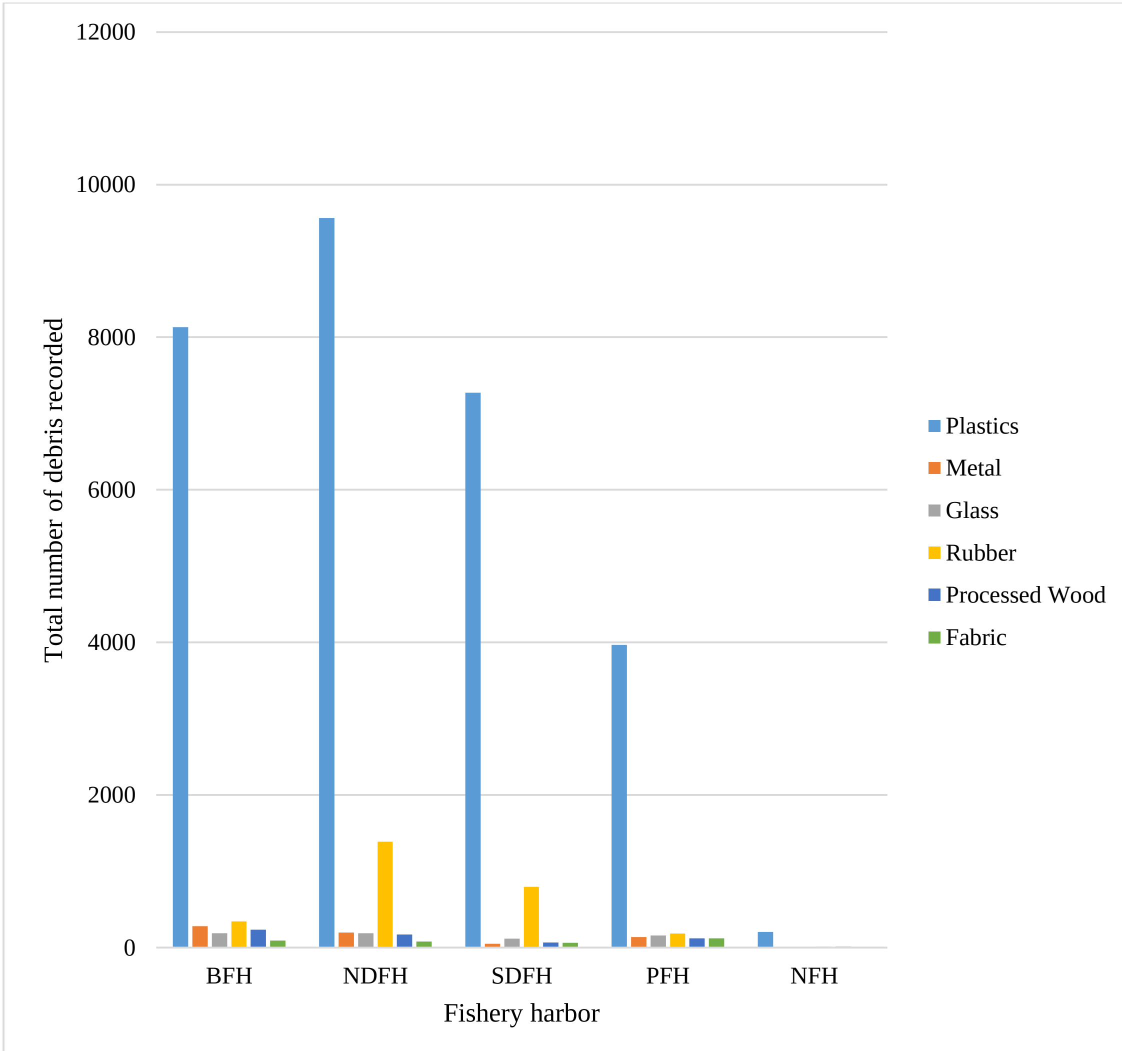


Figure 4.2: Total number of different types of debris collected from each FH during the study period

In a number of previous studies conducted along shorelines, plastic has been recognized as the major polluter by count in coastal environment systems. From a study conducted in 2016, along 22 beaches located across Sri Lanka it has found that, by the number of items 93.3% of the marine debris are plastics (Jang et al., 2018). As per some other regional and global examples, Kerala coast of India; 73.8% (Daniel et al., 2020), Ternate island in Indonesia; 77% (Lessy, 2020), in North and Central Adriatic sea; 80% (Pasquini et al., 2016), in Rügen island of German; 83% (Hengstmann et al., 2017), in Central West coast of India; 83.02% (De Kalyan et al., 2023), in Europe Union; 84% (Addamo et al., 2017) and in Belgium; 95.5% (Van Cauwenberghe et al., 2013) of the marine debris were consist with plastic debris.

According to this study, the percentage of plastic debris is 85.24%, indicating that the level of plastic pollution inside FH falls within the same range as plastic pollution in other coastal areas.

4.2.2 Results overview based on total weight of debris

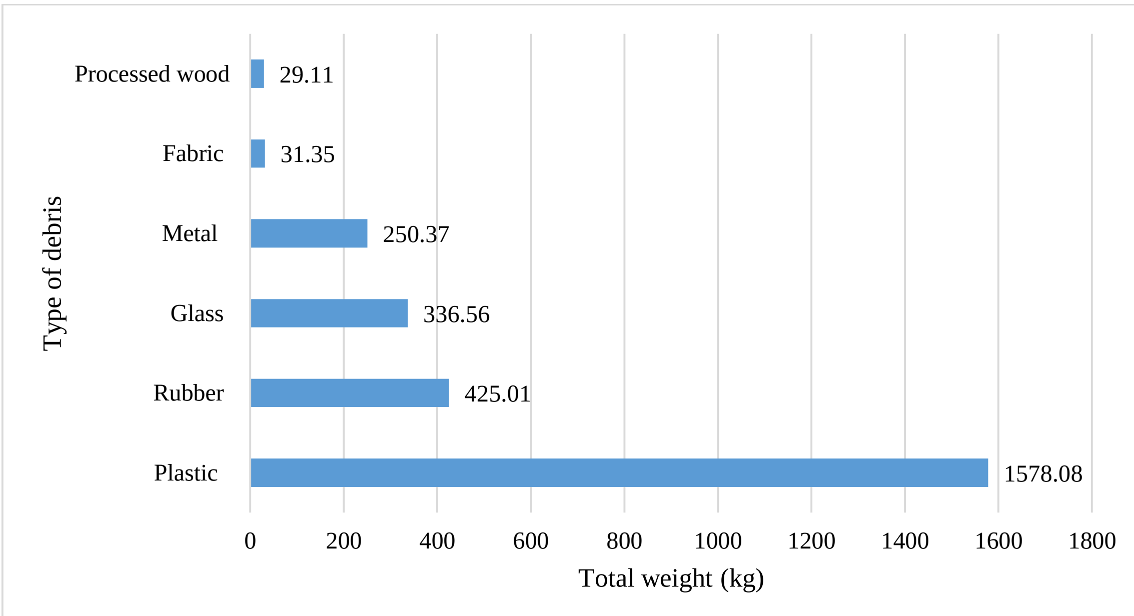


Figure 4.3: Total weight of different types of debris collected from all FH during the study period

According to the data collected from the accumulation study method, the weight of the total plastic was 1,578.08 kg and it represented 59.53% of the total weight of debris collected. According to calculations by Beaumont et al., (2019), the estimated economic damage caused by a ton of MPW per year ranges from 3,300-33,000 USD. Based on these calculations, it is estimated that an annual economic damage of approximately 5,207-52,076.31 USD (equivalent to 1,688,057-16,882,618 Sri Lankan Rupees) was incurred throughout the study period. The weight of 425.01 kg, 336.56 kg, 250.37 kg, 31.35 kg and 29.11 kg represented the weight of rubber, glass, metal, fabric and processed wood respectively.

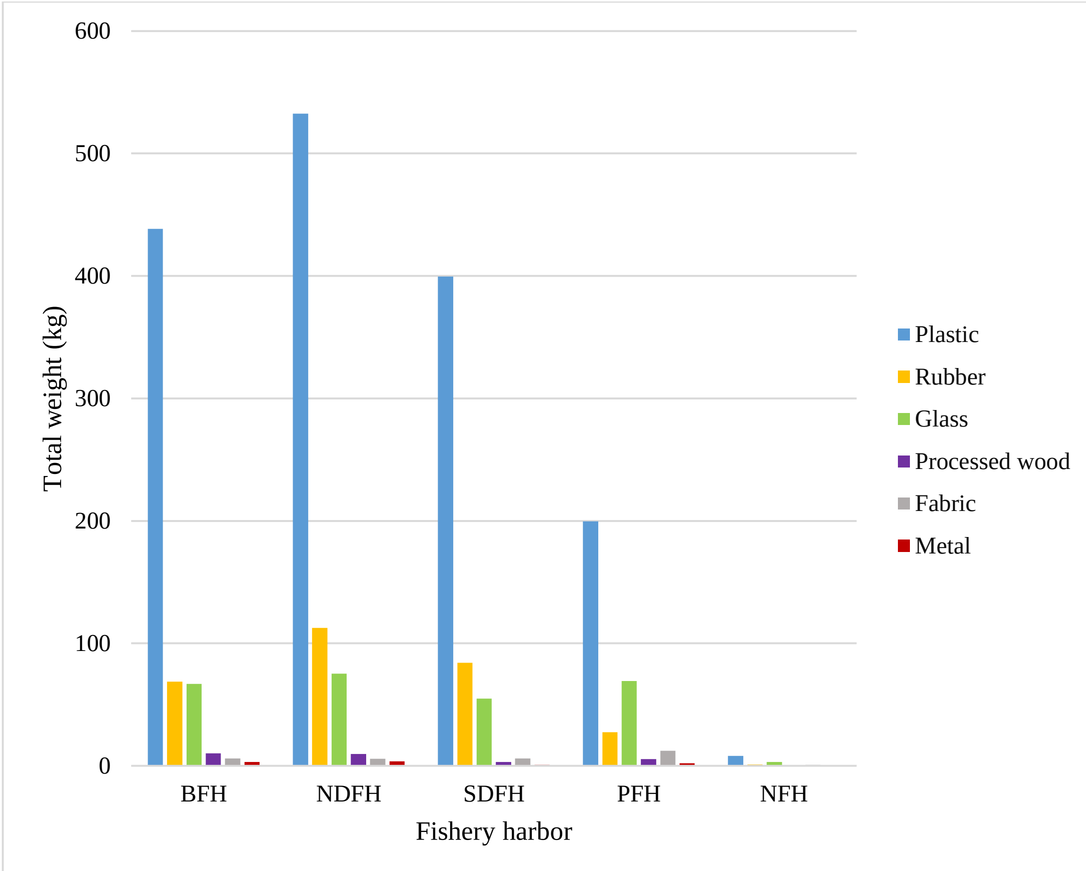


Figure 4.4: Total weight of different types of debris collected from all FH during the study period

In regards to BFH, NDFH and SDFH, rubber became the second major polluter by weight. But in PFH and NFH rubber became the third major polluter after plastic and glass. In BFH, NDFH and SDFH, the amount of rubber debris was comparatively higher than the rubber debris from PFH and NFH. There were boat repairing workshops situated in BFH and NDFH and rubber debris was mainly generated during the repairing process of fishery vessels.

Boat decks are covered with the rubber sheets since they are excellent insulators which are able to absorb vibrations made by the engine and it increases the gripe of the floor. Also they are low weight and cheaper products. Therefore, rubber sheets consumption is higher in FH and a special attention should be paid on rubber waste generation in the management process especially at FH located with workshops.

Figure 4.5: Rubber sheets collected at NDFH

In a number of previous studies conducted along shorelines, plastic has been recognized as the major polluter by weight as well. From the study conducted by Jang and the team in 2016, along 22 beaches located in Sri Lanka, they have found that plastic debris contribute 85.7% by weight to marine litter (Jang et al., 2018). Daniel and the team have found that 59.9% of the marine litter weight represented by plastic debris at the Kerala coast, India (Daniel et al., 2020).

Both by the number and the weight, plastic was the major polluter and rubber was the second polluter inside FH located in the Western Province of Sri Lanka. The total count of plastic outnumbered other types of debris by 85.24%. But when it comes to the weight of plastic debris, it outnumbered others by 59.53% only. This could be due to two main reasons. The first is that plastic is a light weight polymer type with low density nature. Second, a considerable amount of plastic debris items recorded from the study were smaller in size (61% of the plastic debris were smaller than 10 cm x 15 cm).

A total number of 2,731 (7.98%) rubber debris were recorded and it represented 425.01 kg (16.03%) as the weight.

Based on these calculations and findings, it can be concluded that the level of plastic pollution inside FH are very similar with the range of plastic pollution outside FH. At the same time it needs to be concerned that some studies had considered either the weight of debris or the number of debris. Some studies had considered both. Also, data collection varied based on the type of debris. Therefore, comparing values taken from different studies is difficult because different bases were used (Ryan et al., 2009).

4.2.3 Composition of plastic debris recorded

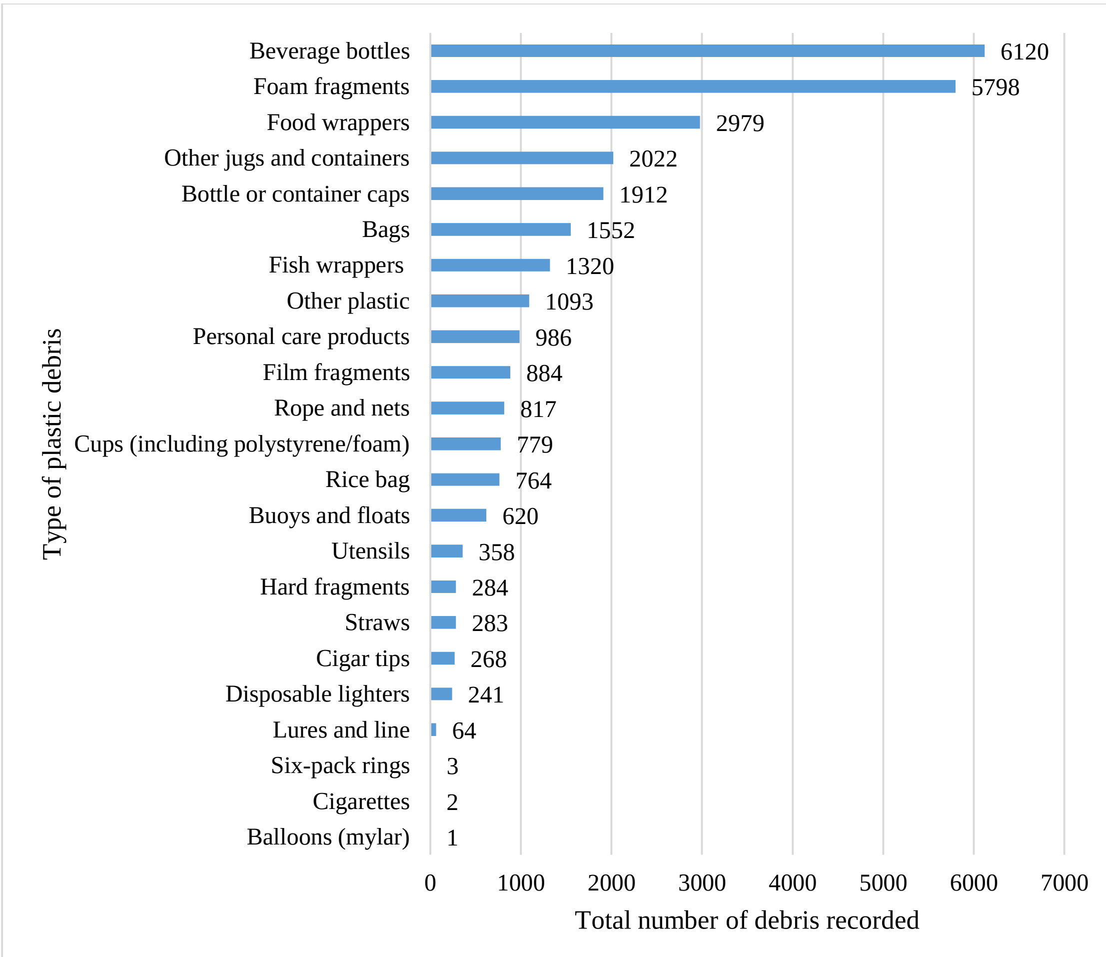


Figure 4.6: Total number of different subtypes of plastic debris collected from all FH during the study period

A total number of 48 subtypes of debris were collected, of which belonging to 6 types. Plastic debris was further categorized into 22 subtypes.

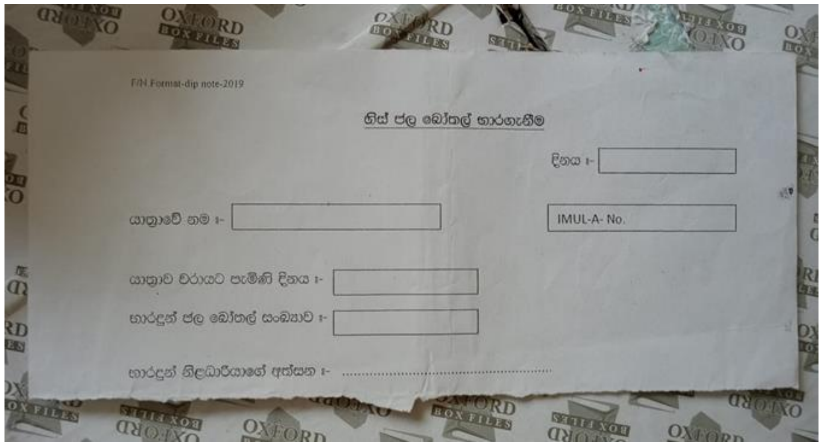
Among the overall plastic debris recorded from five FH throughout the 12 months of study period, the leading item was beverage bottles (n = 6,120). In regards to individual harbors, in BFH and PFH, beverage bottles were the top polluter. It was difficult to identify the exact sources of generation of beverage bottles. They could come to the harbor premises through water channels, river flows, tidal current, windblown and be accumulated as a result of mismanagement of plastic waste inside FH.

Both BFH and PFH can take beverage bottles from inland sources through their water channels unlike NDFH and SDFH. To minimize this threat, trash racks should be constructed along the openings of water channels leading into the harbor.

Figure 4.7: Water channel opening through a trash rack close to NFH

Figure 4.8: Water channel directly opening into the BFH

Based on the findings, it highlighted the requirement for managing beverage bottle waste inside the FH with special attention. The CFHC has introduced a plastic departure form system to minimize the discarding of plastic beverage bottles into the ocean.



F/H Format-dip note-2019

හිස් ජල බෝතල් භාරගැනීම

දිනය :-

යාත්‍රාවේ නම :-

IMUL-A- No.

යාත්‍රාව වරායට පැමිණි දිනය :-

භාරදුන් ජල බෝතල් සංඛ්‍යාව :-

භාරදුන් නිළධාරියාගේ අත්සන :- ....

Figure 4.9: Plastic beverage bottles departure form

According to this system, all fishery vessels are required to record the number of plastic bottles they have when they leave and return the same amount when they come back. The Sri Lanka Coast Guard (SLCG) is also involved in the monitoring process. Maintaining this form is compulsory for obtaining permission for the next departure from both SLCG and CFHC. However, currently, this system is not being strictly followed at any FH. If it is possible to properly implement this system again, it will be helpful in reducing the accumulation of beverage bottles inside the FH as well.

Second prominent plastic debris item was form fragments (n = 5,798). With the nature of heat insulation, form fragments are commonly used when manufacturing and repairing fishery vessels.

There is a large workshop located at NDFH to repair fishery vessels and regularly it generates large amounts of form fragments as a result. With the effects of windblown and surface runoffs, they can come into the intertidal zone and end up in the ocean.

Figure 4.10: Debris generated at NDFH workshop

Though there is a boat repairing yard located at BFH as well, it consists of a large storehouse covered with a roof to avoid the effects of rainfalls. But in the case of NDFH, there is no such covered storehouse. If it is possible to construct a storehouse close to the boat repairing yard in NDFH, it will be helpful to reduce the large number of debris accumulated at intertidal zones with intense rainfalls.

Figure 4.11: Covered storehouses located at BFH

4.2.4 Level of anthropogenic pollution in harbor wise

Based on the data collected from this study, the highest plastic debris accumulation rate was observed at NDFH followed by SDFH. Therefore, plastic debris generation rate was highest at Dikkowita FH.

Table 4.1: Total number of different debris types collected from each FH during the study time

	Harbor				
Type	BFH	NDFH	SDFH	PFH	NFH
Plastic	8133	9561	7271	3969	207
Metal	282	196	51	138	11
Rubber	346	1388	799	185	13
Processed wood	235	171	66	124	13
Glass	191	191	116	159	11
Fabric	92	79	62	121	7

At NDFH the intensity of fishery related activities are much higher compared to SDFH. Around 30 large multi-day boats (>50 feet) have been registered at SDFH and it provides berthing facilities for 20 to 30 multi-day vessels at a time. Local Multi Day boats (<50 feet) have been registered under NDFH. About hundreds of vessels are used to operate constantly. Fishery related activities like preparing to depart, landing the fish harvest, sorting, selling, transporting and repairing fishery vessels frequently occur there. These activities can generate plastic debris and reach the intertidal zone, where the data collection was conducted for this study. Also, there is a boat repairing yard located at NDFH where large amounts of plastic and other debris are regularly generated.

Colombo is the financial capital of the country and it contributes more than a half to the total GDP of the country (MCUDP, 2018). According to the CBSL Annual Report 2019, Colombo has recorded the highest population density of the country. Dikkowita FH is located 10 km away from Colombo and it is considered to be the largest FH located in South Asia. It is located about 3 km away from the Kelani river estuary, which is the most polluted river and second largest river in Sri Lanka (Abeysinghe & Samarakoon, 2017).

The amount of plastic debris released into the coastal ecosystems are directly proportional to the GDP (Lebreton & Andrady, 2019) and population density (Jambeck et al., 2015). Also, the level of fishing activities are directly proportional to the level of plastic waste generation (Li et al., 2016). Weideman and the team have confirmed that beaches located closer to river mouths recorded higher amounts of plastic debris compared to other beaches (Weideman et al., 2023). Since all these factors take place together at Dikkowita FH, it is possible to generate plastic debris at such a high rate.

BFH, NDFH and SDFH have covered structures with large breakwaters. Thus, the waste coming to the harbor premises is stagnant inside. Because of that, the accumulation rate of debris is high in BFH (1.45 items/m2/week), NDFH (2.21 items/m2/week) and SDFH (1.57 items/m2/week). PFH and NFH have comparatively less covered harbor structures. Therefore, debris accumulation rate is comparatively lower in PFH (0.98 items/m2/week) and NFH (0.17 items/m2/week). BFH has a water channel that is opened into the FH meanwhile PFH is situated across the Bolgoda estuary. In these both contexts, debris from inland sources also come into these FH. In the case of NDFH and SDFH, they have no such water flows that come inside the harbors from inland sources.

The entire area of the NFH consists of jetties and it located in the mouth of the Negombo Lagoon where it is a very small FH with no breakwater or sandy beach to strand debris. Lagoon water flow reaches into the harbor through a mangrove ecosystem. Yin et al., 2020 have recognized mangroves as a vulnerable ecosystem to accumulate plastic debris and they may act as a barrier for debris to reach the harbor. In the case of NFH, there is a possibility that with the considerable amounts of the debris stagnated in mangroves, less amount of debris can reach the harbor.

In BFH, plastic, rubber and metal were the three major contributors to the pollution. Among them Plastic was the most abundant pollutant. The most prevalent forms of plastic debris found in the area were beverage bottles, food wrap and foam fragments. In NDFH, plastic, rubber and metal were the three major polluters in order. Foam fragments, beverage bottles and food wrap were the three most prominent forms of plastic debris collected in NDFH. In SDFH, plastic, rubber and glass were the three major polluters in order. Foam fragments, beverage bottles and food wrappers were the three most prominent forms of plastic debris collected in SDFH. At PFH, plastic, rubber and glass were the three major polluters in order. Beverage bottles, foam fragments and bags are the three most prominent forms of plastic debris in PFH. At NFH, plastic, rubber and processed wood were the three major polluters in order. Bags, foam fragments and beverage bottles were the three most prominent plastic debris found in NFH.

The fishing industry often relies on plastic materials for fishing equipment, packaging and storage. As a result of that, plastic consumption has been essential within the context. In the linear economy model, plastic items are often discarded without recycling after consumption. Hence, the generation and accumulation of plastic debris continually grows. The presence of debris items may indicate a lack of proper waste management practices. Improper disposal of plastic waste can make negative impacts on marine ecosystems and sustain the fishery industry as well. Therefore, management of plastic waste generation has become an urge to ensure the long-term health and sustainability of FH for current and future generations.

4.3 Correlation between number of plastic debris recorded and plastic weight

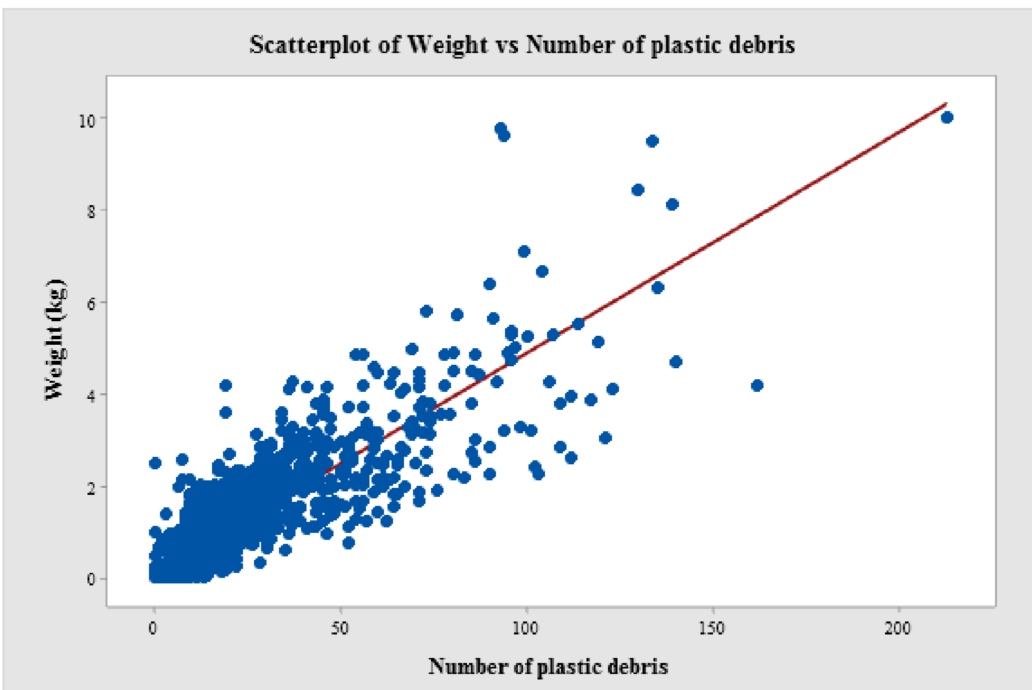


Figure 4.12: Matrix plot of plastic weight (kg) and number of plastic debris

Pearson correlation was used to determine the strength and direction of the linear relationship between the plastic weight and the number of plastic debris collected. Since the Pearson correlation value was 0.883, it can be concluded that there was a strong positive correlation between the number of plastic debris and their weight. This insight enhances the understanding of plastic pollution dynamics and offers a practical tool for predicting plastic debris weight based on its count, enabling informed and targeted environmental interventions.

Positive correlation indicates that as the number of plastic debris increases in the FH, their weight tends to increase as well. Since the value is close to +1, it suggests that the relationship can be approximately a straight-line trend. When the number of debris increases, there is a high tendency to increase the weight proportionally. A close correlation value (r=0.95) was derived from a study conducted in Cape Town, South Africa (Chitaka & von Blottnitz, 2019). This convergence of findings across different locations underscores the potential applicability to various marine environments as well.

4.4 Correlation between monthly rainfall and monthly average number of plastic debris recorded

Pearson correlation was used to identify the strength and direction of the linear relationship between the monthly rainfall and monthly average number of plastic debris recorded at each FH.

There was a very weak positive correlation between monthly rainfall and monthly average number of plastic debris collected from BFH, NDFH and SDFH. The correlation was weak negative for PFH and NFH. This means that when the rainfall increases, the number of plastic debris collected tends to be decreased, and the vice versa.

During the intense rainfalls, ocean currents also can become much stronger and it may carry plastic debris out of the harbor premises. This might be a reason for the observed moderate negative correlation at PFH and NFH.

Table 4.2: Pearson correlation values between monthly rainfall and monthly average number of plastic debris collected

Fishery harbor	Pearson correlation
BFH	0.066
NDFH	0.049
SDFH	0.129
PFH	-(0.211)
NFH	-(0.394)

PFH is located at the estuary of Bolgoda River while NFH is connected to Negombo lagoon. When the rainfall increases, the water flow also becomes much stronger and thus it reduces the amount of plastic debris accumulated at the harbor premises and a larger portion of the plastic debris flush into the ocean without remaining inside the harbor.

At PFH, the negative value is lower than compared to NFH. PFH has a breakwater structure and it can be caused to reduce the flushing effect compared to NFH where there is no any breakwater structure and directly open into the sea. This factors might have made the difference between negative values of PFH and NFH.

Since the correlation between monthly rainfall and monthly average number of plastic debris collected from BFH, NDFH and SDFH is closer to zero, it can be conclude that the correlation between rainfall and the amount of plastic debris collection is very weak. Monthly average number of plastic debris recorded may depend on multiple factors such as wind speed and wind direction, intensity of fishery and boat repairing activities, and beach cleanup projects etc. other than the monthly rainfall. Further studies on those relevant factors are also required to explain the observed relationship in depth to make a comprehensive conclusion.

Monthly rainfall data were collected from the Department of Meteorology, Sri Lanka and nearest rainfall data collection stations' data were utilized to calculate the correlations for each FH. But these rainfall values can be a bit differ from the exact value at the FH and it is possible to make some errors when making conclusions.

4.5 Correlation between the tide level and number of plastic debris recorded

The investigation into the relationship between tide levels and the abundance of stranding and floating debris within the study has revealed valuable insights into the complex dynamics governing marine debris distribution. A weak negative correlation between the total number of both stranding and floating plastic debris and tide level were observed.

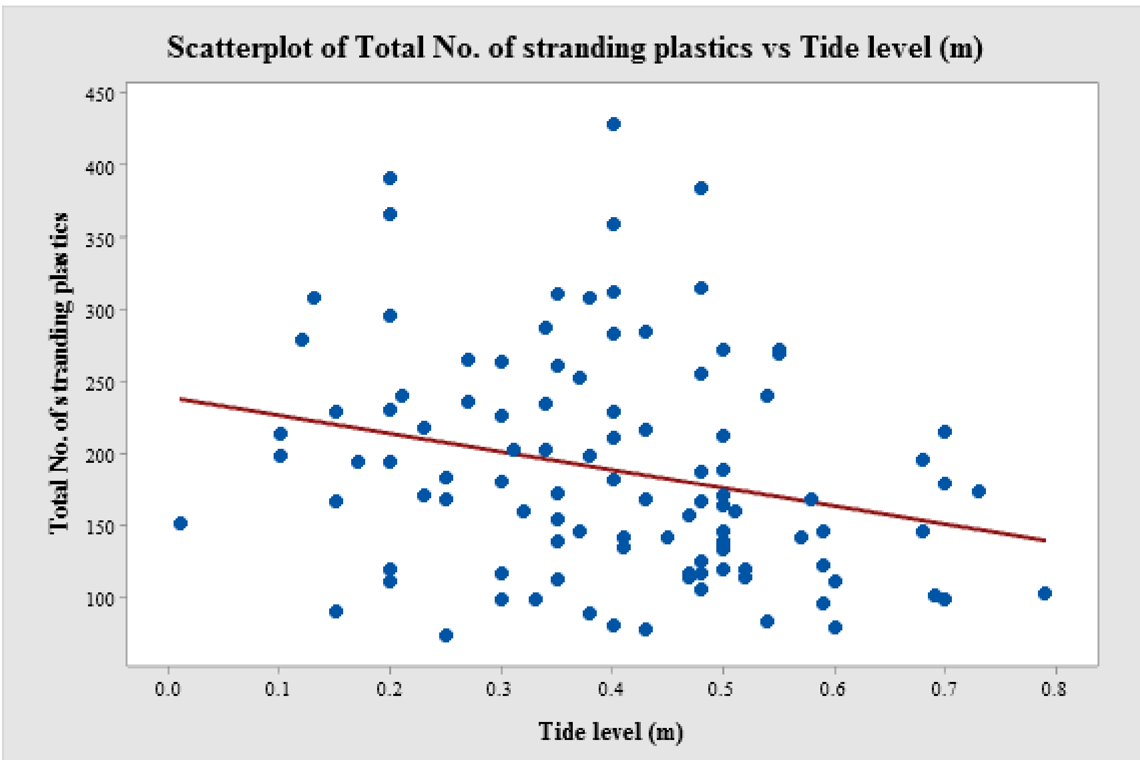


Figure 4.13: Matrix plot between the tide level and number of stranding plastic debris recorded

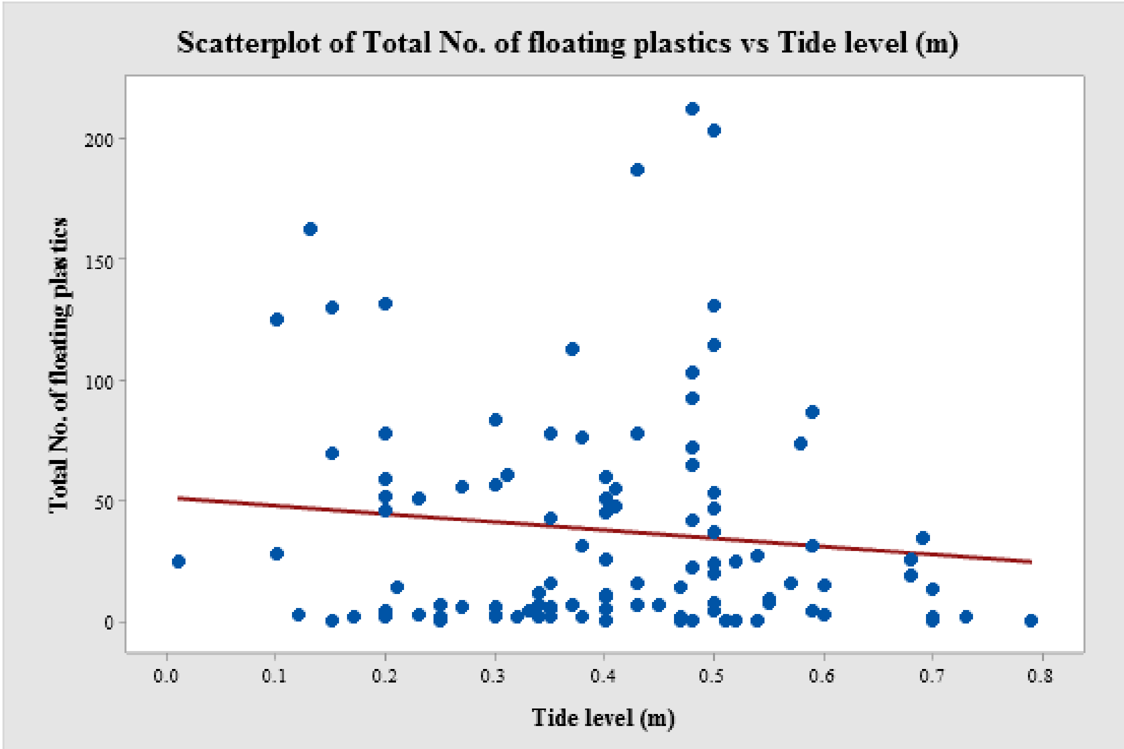


Figure 4.14: Matrix plot between the tide level and number of floating plastic debris recorded

The correlation analysis showed a weakly negative correlation of -0.115 and -0.257 for floating and stranding debris respectively. During the high tide, MPW are brought into the land areas and overtakes the low shore areas. During the low tide, these MPW are accumulated along the shoreline (Ikhwan et al., 2021).

Weak negative correlation between tide level and the amount of stranding debris recorded in the study indicates that when the tide level increases, the amount of stranding debris tends to decrease slightly. Very weak negative correlation between tide level and the amount of floating debris recorded indicates that when the tide level increases, the amount of floating debris also tends to decrease slightly. Since both correlations are weak, tide level alone is not a strong predictor of the amount of debris recorded inside FH. Some other factors like seasonal variations, wind effects and anthropogenic activities can influence the amount of plastic debris accumulated in FH.

The study's exploration of the correlation between tide levels and debris concentration presents a significant contribution to understanding of marine debris dynamics. In general, it can be recommended that the low tide period is the most effective time to conduct beach cleanup projects other than high tide period. This is much more applicable for stranding debris collection than floating debris collection as the correlation value for stranding debris is higher than floating debris. By translating this knowledge into practice through well-timed cleanup initiatives, FH stand to significantly enhance their waste management practices, resulting in the more prudent utilization of available resources and the creation of more sustainable coastal environments.

4.6 Difference between stranding and floating debris

Mann-Whitney test results revealed that there is a significant difference ($P < 0.05$) between the median of stranding and floating debris for BFH, NDFH, SDFH and PFH. For all these FH, the median of stranding debris was significantly higher than the floating debris.

Figure 4.15: Cleaning personal collecting floating debris using a hand net

As per the finding of the study, it confirmed that the total count of stranding debris was significantly higher than the total count of floating debris at all FH (NFH was not considered for this comparison as there is no stranding debris collecting point at NFH). Only a fraction of plastic debris is floating on the surface, while others sink to the bottom of the water body. However, most of the stranded debris remains on the surface, and the process of burial is slow. This could be a reason for the significantly higher number of stranded plastic debris compared to floating plastic debris. Additionally, the effect of tidal fluctuations can be act as a flushing force to remove plastic debris floating on the surface of a water body.

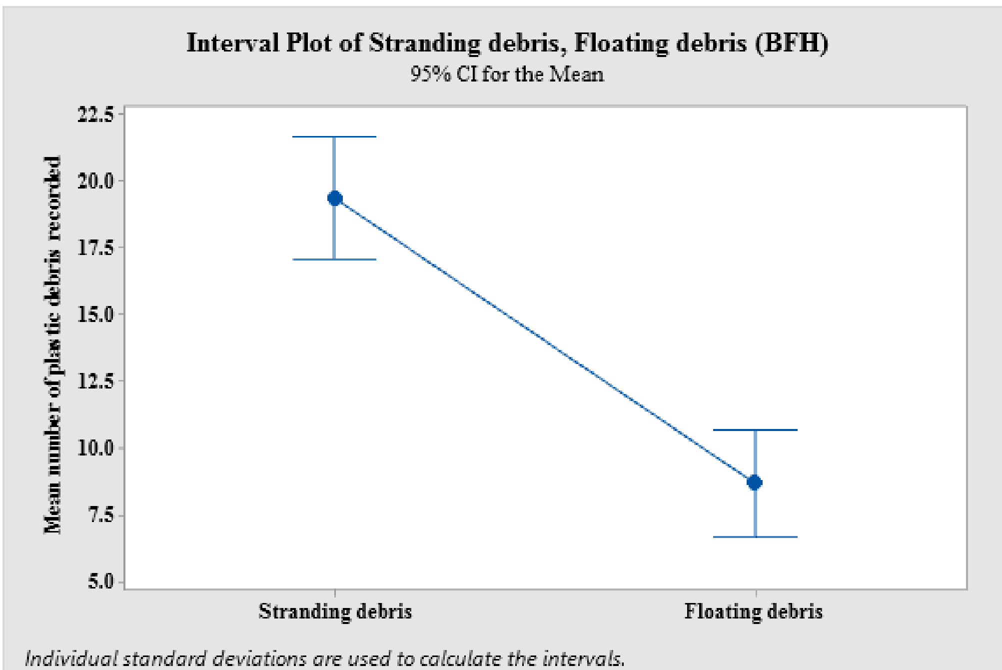


Figure 4.16: Interval plot of stranding and floating plastic debris collected from BFH

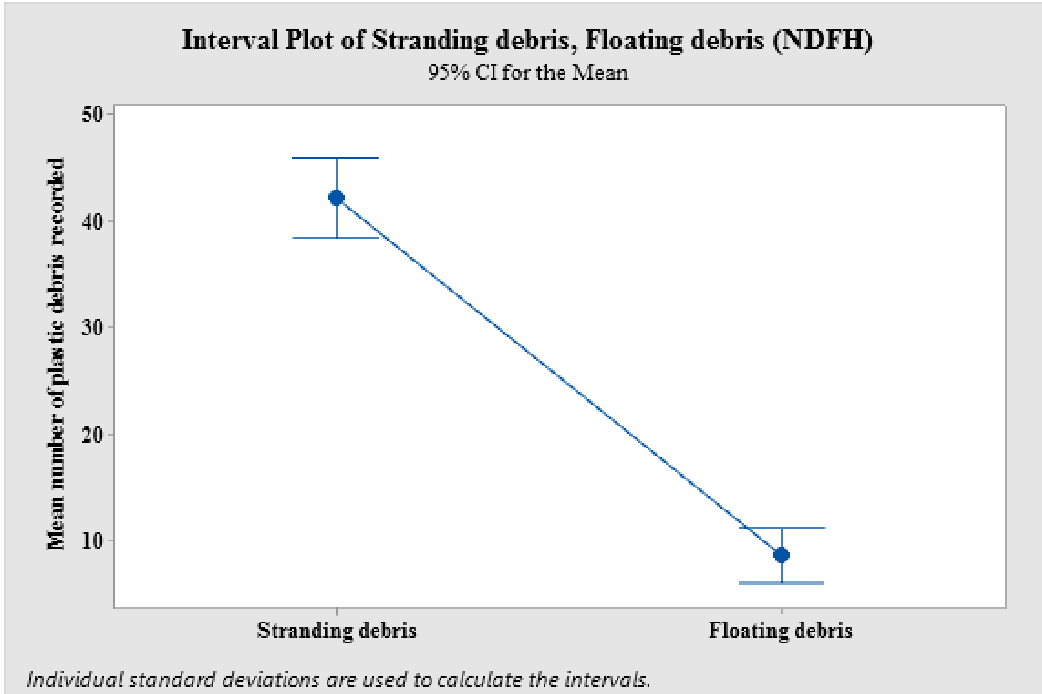


Figure 4.17: Interval plot of stranding and floating plastic debris collected from NDFH

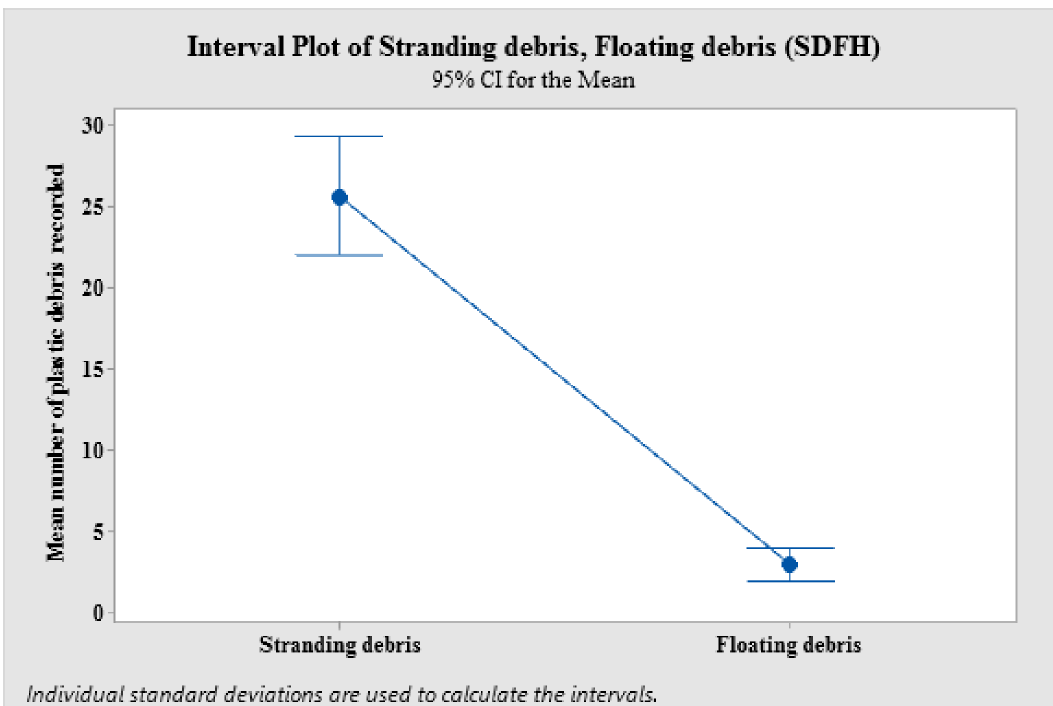


Figure 4.18: Interval plot of stranding and floating plastic debris collected from SDFH

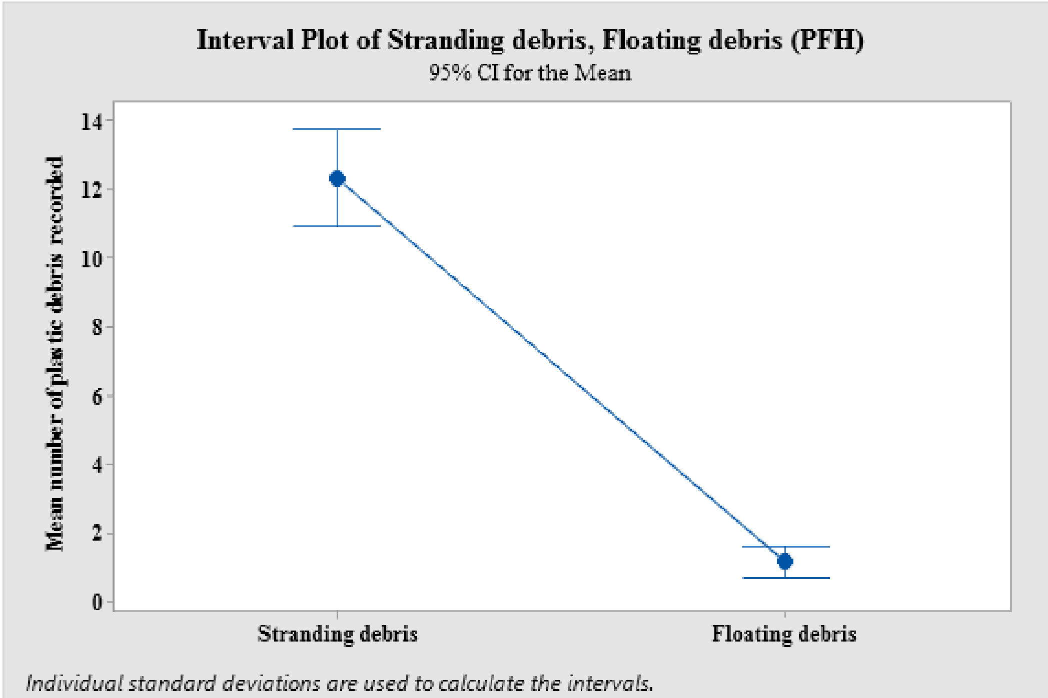


Figure 4.19: Interval plot of stranding and floating plastic debris collected from PFH

Cleaning personnel were concerned about the debris generated at jetty areas and less attention paid on debris collected at breakwater and sandy beaches. This poor awareness also can be a reason for waste generation inside FH.

Cleaners were assigned to collect floating debris accumulated nearby jetties in BFH and NDFH by using hand nets. This was able to be seen only in BFH and NDFH. But these research findings suggest that collecting floating debris would not be very effective in reducing the total number of the plastic debris circulating inside the FH since the number of stranding debris is significantly higher than floating plastic debris. The main benefit of removing these floating debris accumulated close to the jetty is the reduction of probability of fishing boat propellant getting stuck with floating debris.

This analysis was of significant importance in the research, as it aimed to elucidate the discrepancies between stranded and floating plastic garbage inside the study area of the FH. The rigorous utilization of these statistical tests on this huge dataset facilitated a reliable assessment of these disparities, thereby enhancing the holistic comprehension of plastic waste dynamics within the framework of these FH.

4.7 Seasonal variation of plastic debris accumulation

One way ANOVA test, P value for BFH, SDFH, and PFH were less than the significance level ($P < 0.05$). Therefore, the null hypothesis which considers that the mean number of plastic debris collected from four seasons are equal was rejected while accepting the alternative hypothesis. It is determined that the mean number of plastic trash collected from BFH, SDFH, and PFH exhibits a notable seasonal change.

The mean amount of plastic debris collected during the second intermonsoon and North-East monsoon is significantly higher than the mean amount collected during the first intermonsoon and South-West monsoon, according to the BFH Tukey HSD test results.

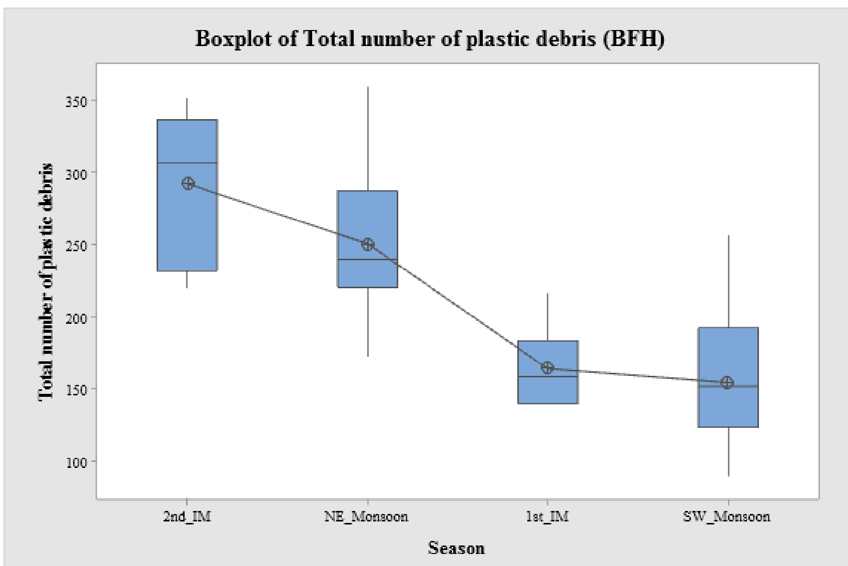


Figure 4.20: Boxplot of mean number of plastic debris collected during different seasons from BFH

The mean amount of plastic debris collected during the first, second, and North-East monsoons is substantially higher than the mean amount collected during the South-West monsoon, according to the findings of the SDFH Tukey HSD test.

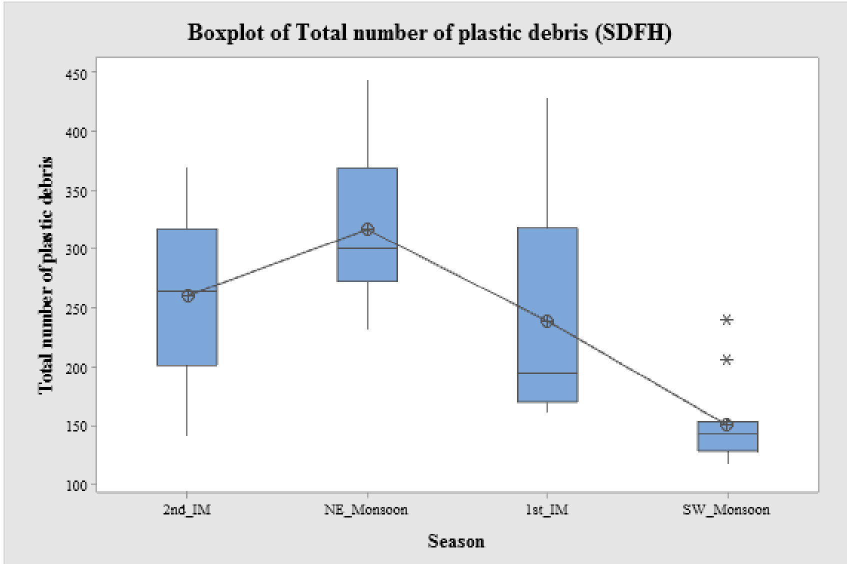


Figure 4.21: Boxplot of mean number of plastic debris collected during different seasons from SDFH

According to Tukey HSD test results of PFH, the mean number of plastic debris collected during the North-East monsoon are significantly higher than the mean number of plastic debris collected during the South-West monsoon.

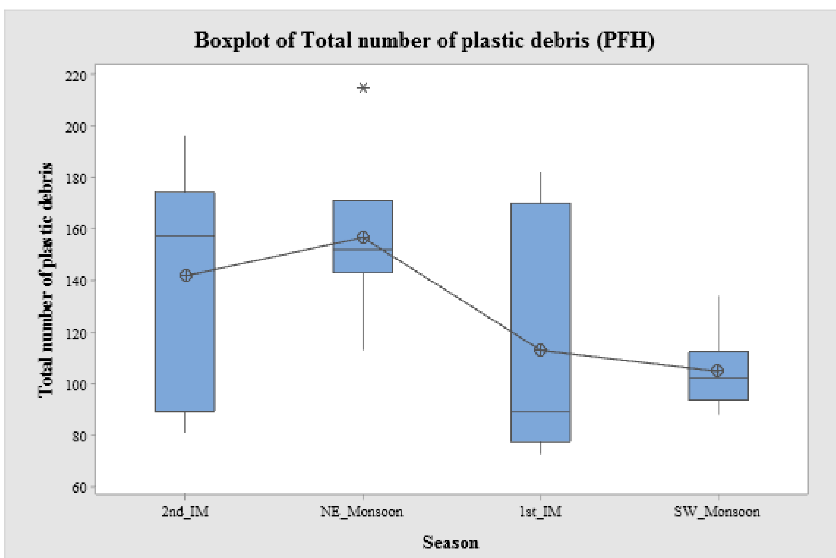


Figure 4.22: Boxplot of mean number of plastic debris collected during different seasons from PFH

These results indicate that between October and February, during the Second Inter-monsoon and North-East monsoon, more plastic garbage was collected. When comparing the generation of plastic waste at BFH, SDFH, and PFH during that period to the first inter-monsoon and South-West monsoon seasons, which spanned March to April and May to September, respectively, special emphasis should be given to it.

For NDFH, and NFH the One-way ANOVA test showed that P-values were larger than the significance level ($P > 0.05$). The null hypothesis, which considers that the mean number of plastic debris collected from four seasons, are equal, was not rejected. Therefore, it can be concluded that NDFH ($p=0.511$), and NFH ($p=0.497$) are not experiencing a significant difference when it comes to the mean number of plastic debris collected from four different seasons of the year.

The North-East monsoon produced the greatest amount of plastic trash at SDFH and PFH, whereas the South-West monsoon produced the least amount. The second intermonsoon at BFH saw the greatest amount of plastic trash, whereas the south-west monsoon saw the least amount. It can be concluded that, generally speaking, the least amount of plastic debris accumulates along FH located in the Western province during the South-West monsoon season, which runs from May to September, because a significantly lower mean number of plastic debris were collected during the monsoon for BFH, SDFH, and PFH.

Western province of the country received the maximum amount of rainfall (100-3000 mm) during the South-West monsoon. This can be a reason to flush the plastic debris from land water interface and reducing the number of debris recorded. During the North-East monsoon, maximum amount of the rainfall received to North and Eastern parts of the country while very low amount of rainfall received to Western province. Therefore the flushing of plastic debris due to surface runoff in the land-water interface is minimum and it can be caused to increase the number of plastic debris collected from that zone. Conducting beach cleanups along the land-water interface during that season (North-East monsoon) in FH can be much effective in plastic debris collection.

4.8 Spatial and temporal variation of plastic debris accumulation

The mean numbers were compared among each data collection point of FH using one way ANOVA test. One way ANOVA test, P value for all five FH were less than the significance level ($P < 0.05$). Therefore, the null hypothesis which considers that the mean number of debris recorded at each point were equal was rejected while accepting the alternative hypothesis. It can be concluded that there is a significant spatial variation in mean number of plastic debris recorded among data collection points of each FH. Tukey HSD test was used to identify in which pairs had the significant difference.

4.8.1 Spatial and temporal variation of plastic debris accumulation at BFH

According to Tukey HSD test results, P3, and P4 located in BFH recorded a significantly higher mean value compared to P7, P8, P9, P12, P13, P14, and P16 points in BFH. P3 and P4 points are located in the bend midway between the land and the breakwater.

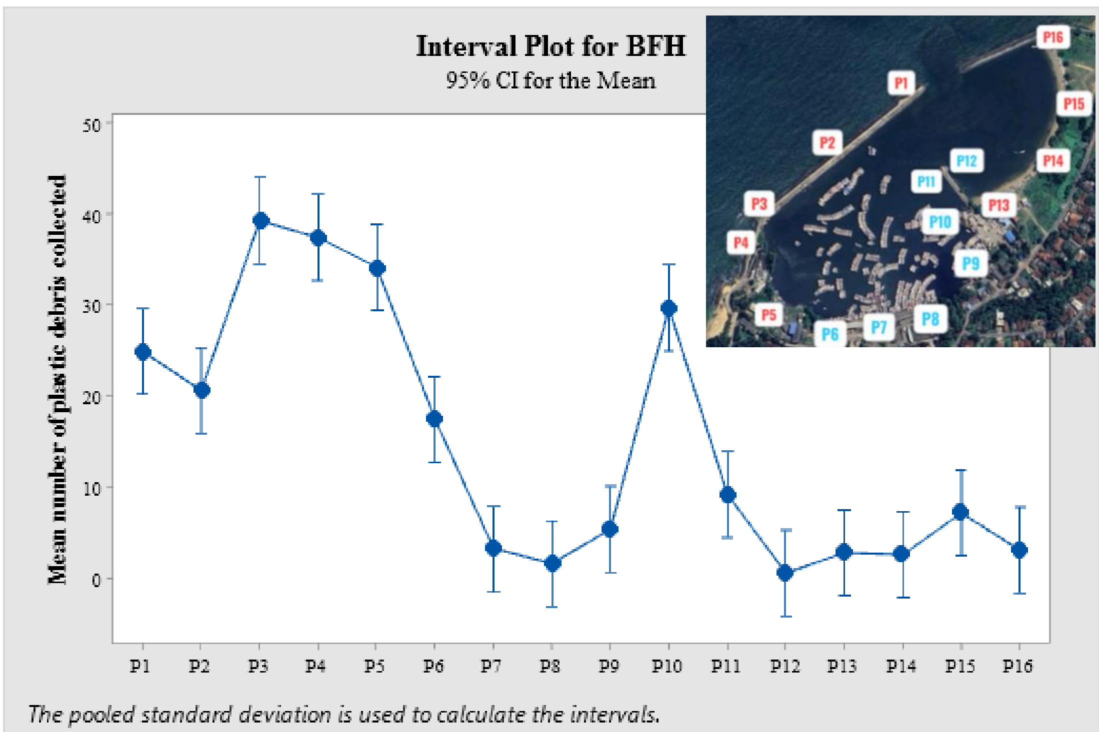


Figure 4.23: Spatial variation of plastic debris accumulation at BFH

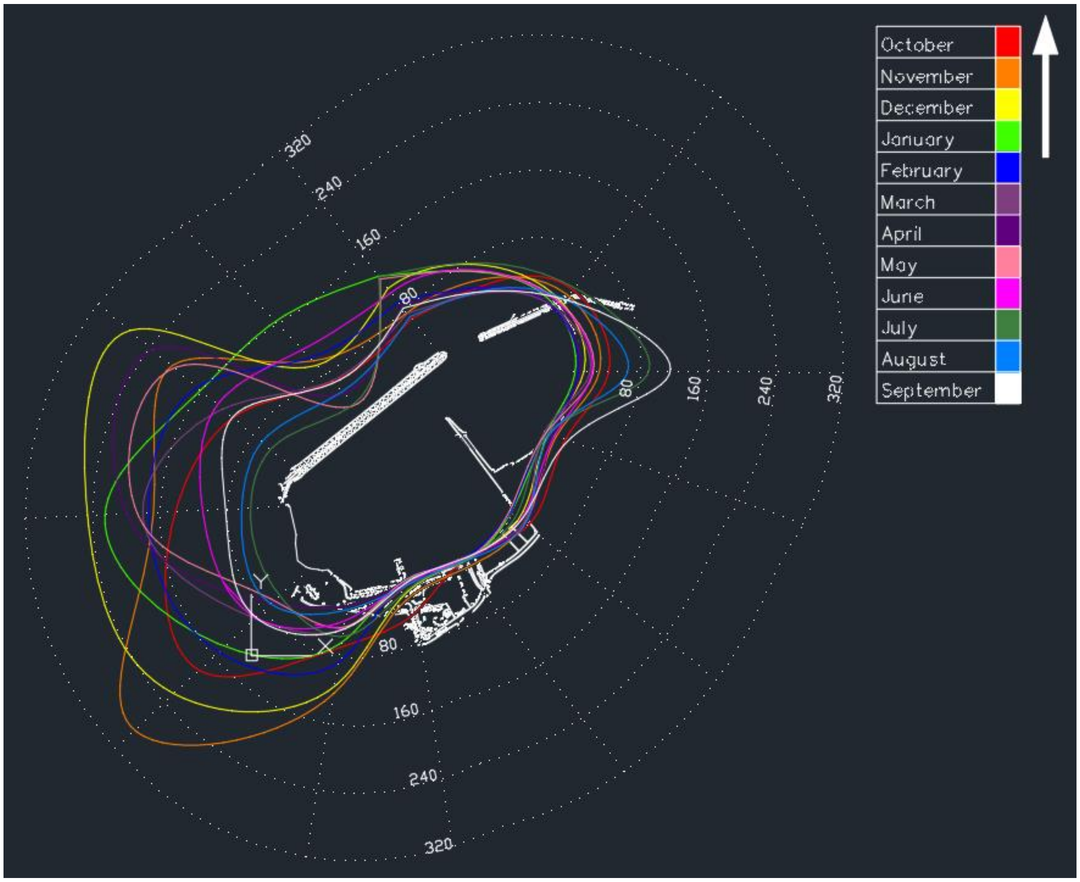


Figure 4.24: Temporal variation pattern of plastic debris accumulation at BFH

When it compared the right side of the harbor premises where one day boats operate with the left side where multi day boats operate, less amount of plastic debris were recorded from right side. Also the temporal fluctuations were very narrow towards the right side of the harbor. But towards the left side, monthly average number of plastic debris recorded were comparatively higher and temporal fluctuations were also very broad. Hence, the temporal variation is very characteristic in the left side compared to the right side. From a study conducted in Indonesia, it has been confirmed that multi day fishing boats produce higher amounts of waste with wide diversity compared to one day fishing boats (Prasetiawan et al., 2022). Furthermore the water channel coming through Beruwala town opened into the left side of the harbor. These factors can affect the high amount of plastic waste generated at the left side.

Highest plastic debris density (yellow color line) was recorded in December (during the North-East monsoon). For the year of 2022, Beruwala received the highest amount of monthly rainfall in October which was 1119.60 mm. This huge rainfall might have flushed the plastic debris remaining in the intertidal zone into the ocean. December is a festive season and plastic consumption and plastic waste generation can be increased during that time of the year. Water channel coming through the Beruwala town could bring some amount of this plastic debris into the BFH premises and it would cause increasing the total number of plastic debris recorded.

4.8.2 Spatial and temporal variation of plastic debris accumulation at NDFH and SDFH

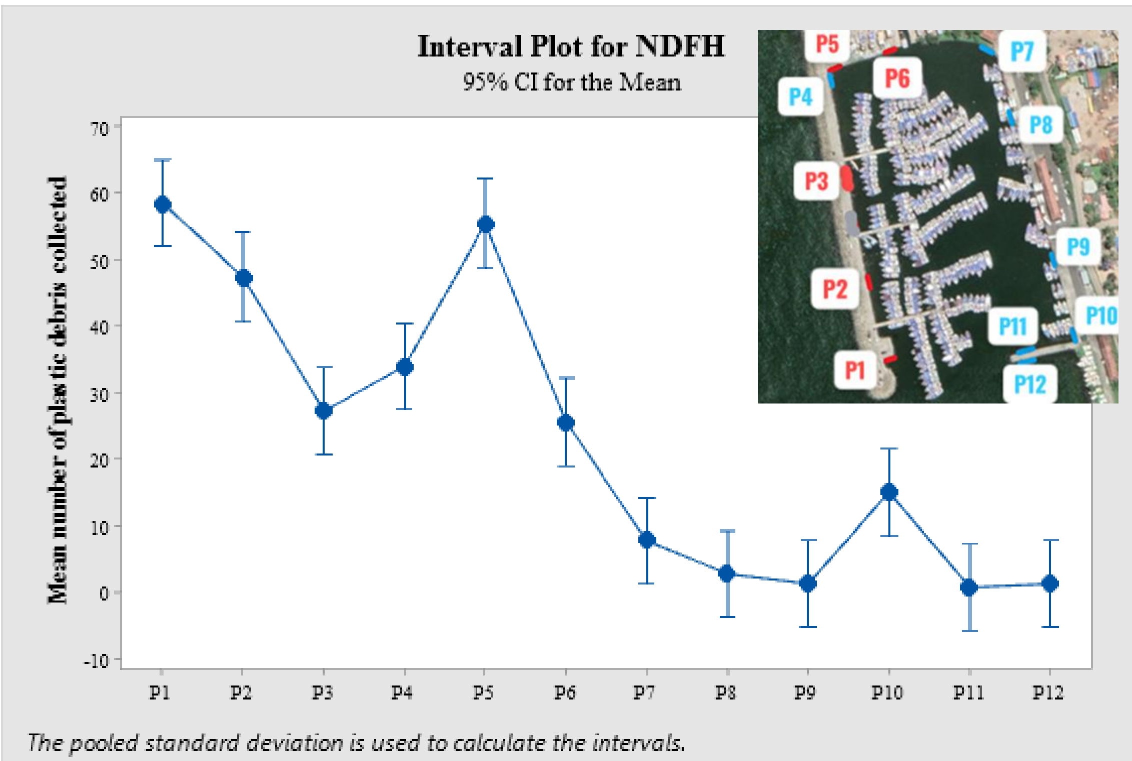


Figure 4.25: Spatial variation of plastic debris accumulation at NDFH

P1, and P5 in NDFH recorded a significantly higher mean value of the total count compared to P7, P8, P9, P11, and P12 situated in NDFH. P5 was located in the bend midway between the land and the breakwater. Also, the boat repairing yard is located close to P5. This can be a reason to increase the plastic debris accumulation close to this point. Number of plastic debris gathered in front of the jetties were comparatively low. But P10, where located between jetties and groins recorded a slightly higher amount of debris compared to other points located in front of the jetties.

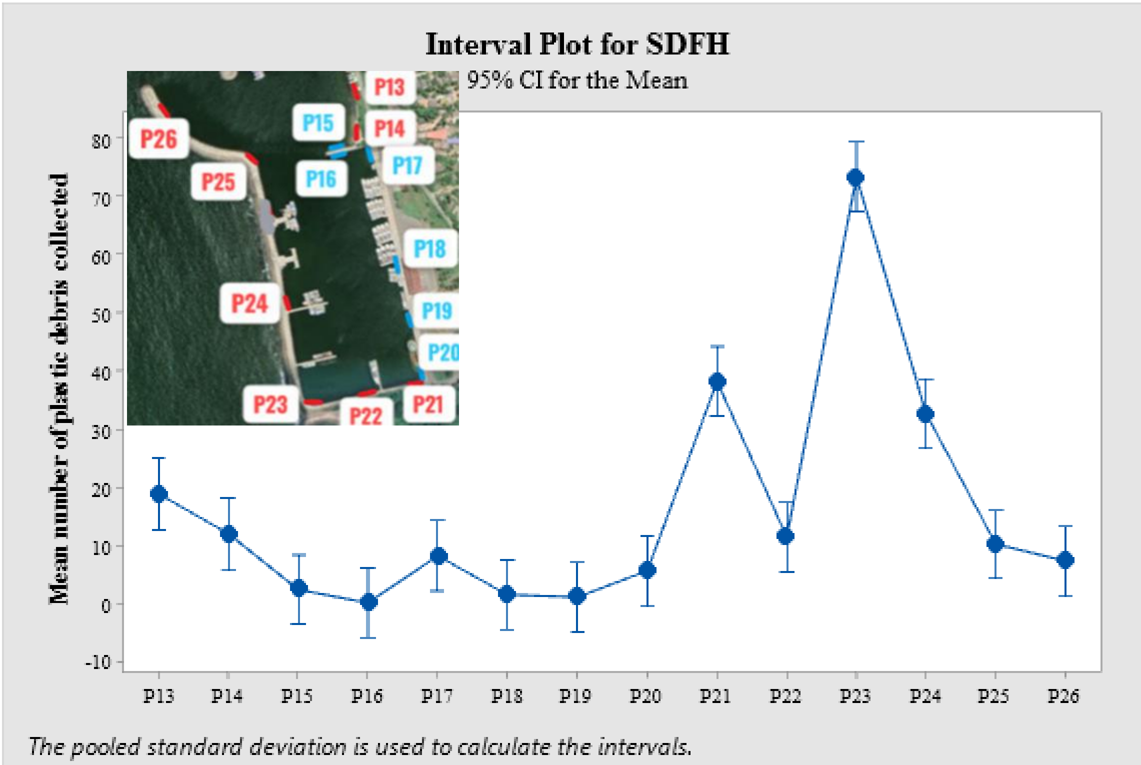


Figure 4.26: Spatial variation of plastic debris accumulation at SDFH

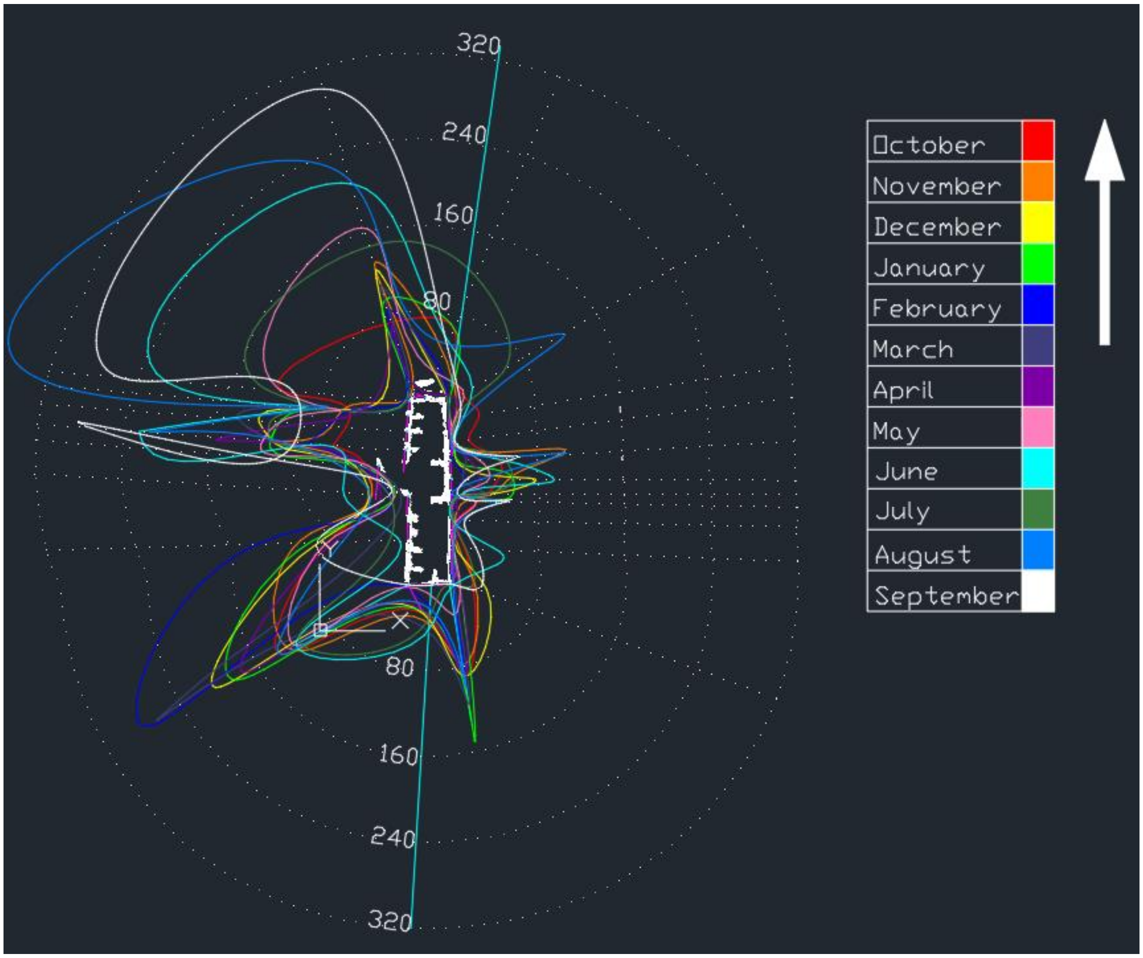


Figure 4.27: Temporal variation pattern of plastic debris accumulation at Dikkowita FH

P23 in SDFH recorded a significantly higher mean value compared to all other points in SDFH. P21 and P24 are the second and third highest debris accumulated points. But there was no significant difference between P21 and P24.

There was a sudden fluctuation observed at P4 of NDFH during June, August and September (South-West monsoon).

Figure 4.28: Floating debris accumulation at point number 4 of NDFH in two different seasons (A; First Inter-monsoon season, B; South-West monsoon season)

The South-West monsoon and 2nd Inter-monsoon take place during May and October, respectively. During the South-West monsoon, Western provinces experience heavy rain and strong wind currents. During the 2nd Inter-monsoon, the whole country experiences widespread heavy rain with rough winds, occasionally resulting in floods and landslides. These environmental parameters may flush plastic debris from inland sources through the Kelani River to the ocean. According to the fishermen's point of view, during that time of the year, ocean currents are directed towards the North, and these currents can carry debris into the harbor premises.

In both NDFH and SDFH, a considerable amount of plastic debris was collected along the breakwater structure, compared to the breakwater structure at BFH.

At SDFH, the highest amount of plastic debris was collected from P23, which is located along a bend structure between the breakwater and land. In February (blue color line), the highest average number of plastic debris was recorded from that point. Throughout the study time, SDFH received the minimum monthly rainfall in February, which was 79.30 mm. P21 located at SDFH also recorded a considerably higher amount of plastic debris throughout the study time.

4.8.3 Spatial and temporal variation of plastic debris accumulation at PFH

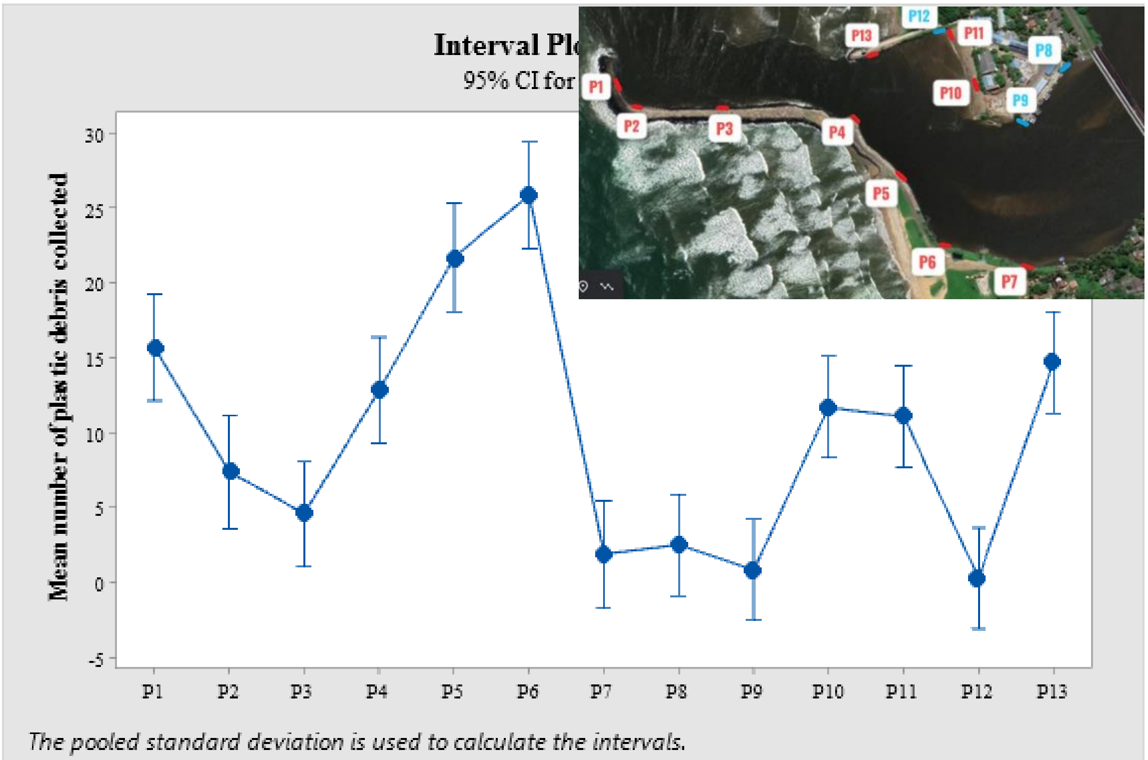


Figure 4.29: Spatial variation of plastic debris accumulation at PFH

At PFH, P6 recorded a significantly higher mean value compared to P7, P8, P9, and P12 points. P6 is located along a bend structure between the breakwater and land. P5 and P1 are the second and third highest debris accumulation points. However, there was no significant difference between P1 and P5. Most of the debris accumulated at the points which meet the Bolgoda River and its reflected water currents. The highest amount of plastic debris was recorded during February (blue color line) at PFH. During January and February, PFH received the lowest amount of rainfall compared to other months. This could have caused a reduction in the flow rate of the Bolgoda River and an increase in the remaining plastic debris along the breakwater structures. A characteristic fluctuation can be seen at P6 where the Bolgoda River directly faces the point.

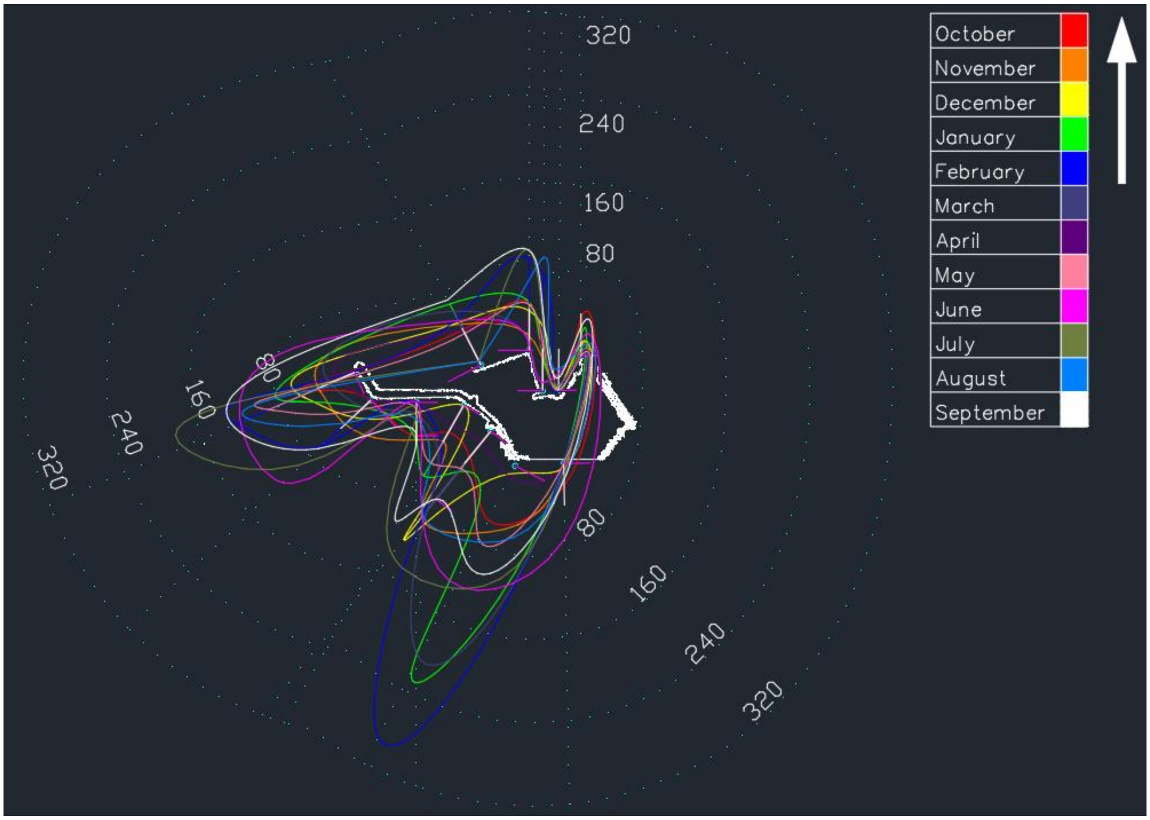


Figure 4.30: Temporal variation pattern of plastic debris accumulation at PFH

4.8.4 Spatial and temporal variation of plastic debris accumulation at NFH

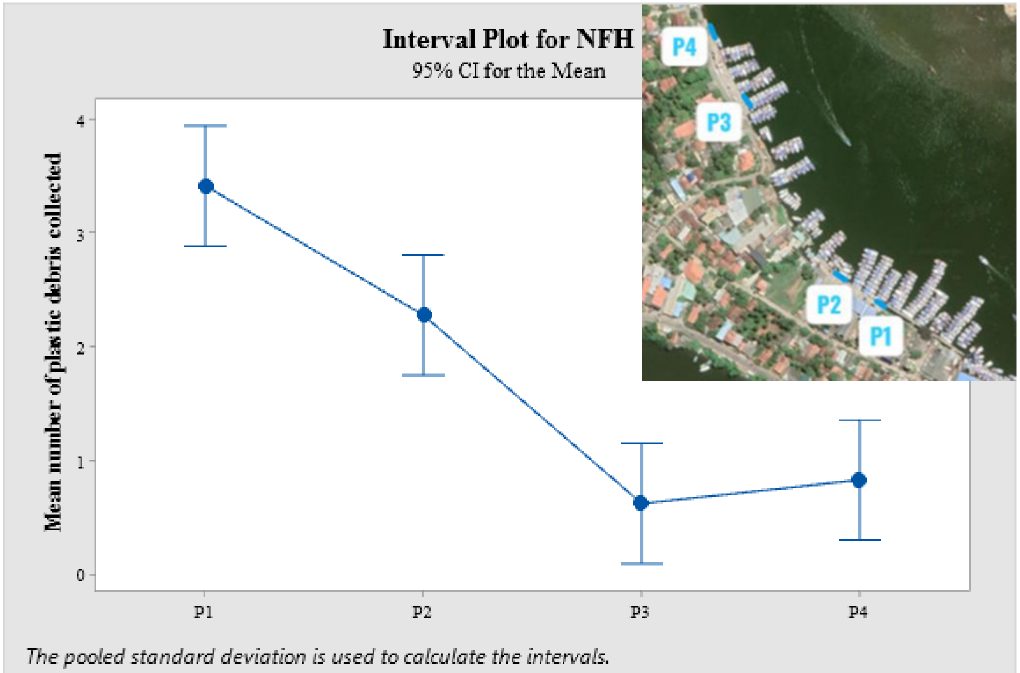


Figure 4.31: Spatial variation of plastic debris accumulation at NFH

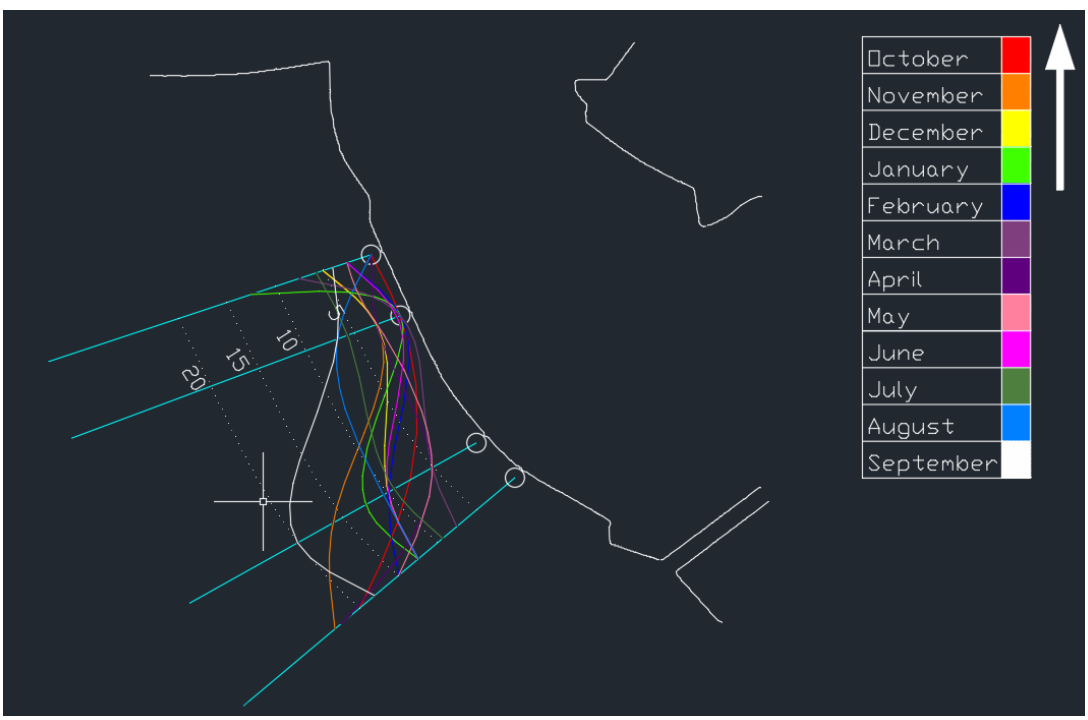


Figure 4.32: Temporal variation pattern of plastic debris accumulation at NFH

P1 in NFH recorded a significantly higher mean value compared to all other points. P2 and P4 are the second and third highest debris accumulated points. There was a significant difference between P2 and P4 as well. NFH recorded the lowest amount of plastic debris and temporal variation compared to all other FHs located in the Western province. The highest amount of plastic debris was recorded in September (white color line) during the South-West monsoon season.

4.9 Size classes composition of plastic debris

Size class B (10cm x 15cm), size class A (5cm x 7.5cm) and size class D (20cm x 30cm) are the first, second and third most prominent plastic debris sizes recorded from five FH according to one year of data collection. Least number of debris were recorded from size class E (>D) which was the largest surface area in the size category.

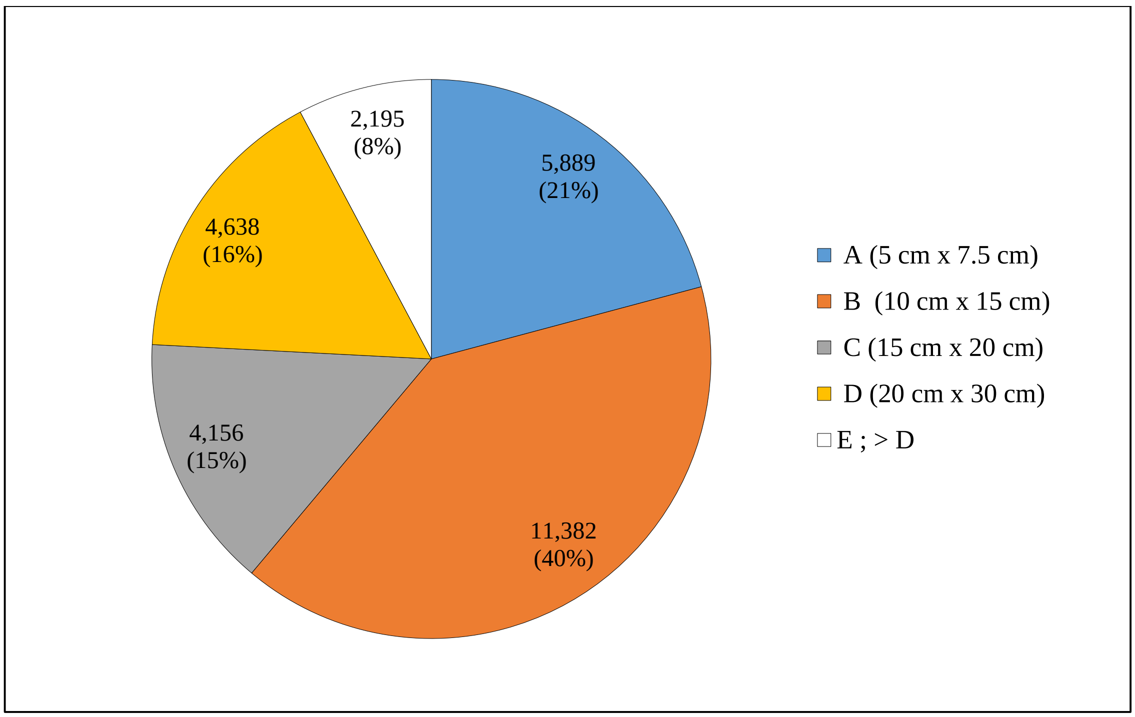


Figure 4.33: Size class composition of plastic debris

According to a study conducted at Concepción Bay in central Chile, it has found that 42% of the plastic debris items belonged to 2.5 cm x 10 cm size class (Gómez et al., 2020). In South China, least percentage contribution was made by >10cm plastic debris (Zhang et al., 2020).

Based on this study findings, only 8% were larger than 20 cm x 30 cm and more than a half (about 61%) of the plastic debris collected at harbor premises were smaller than 10 cm x 15 cm. Out of that, 21% of the plastic debris was smaller than 5 cm x 7.5 cm. These smaller plastic fragments are more susceptible to being ingested by marine organisms at various trophic levels, including plankton, fish, and even larger marine predators. Such ingestion can have detrimental consequences on marine life, leading to reduced foraging efficiency, internal injuries, and, in some cases, death. Furthermore, the persistence of these smaller plastic particles in the marine environment, owing to their increased surface area-to-volume ratio, results in prolonged exposure to potentially toxic chemicals associated with plastics. This can lead to a higher likelihood of chemical leaching and bioaccumulation in the food web, ultimately affecting not only marine species but also human populations that rely on seafood. By addressing this predominant size class, it can effectively reduce the introduction of smaller plastic fragments into the marine environment, thereby diminishing the associated ecological and human health risks.

4.10 Top ten plastic debris items

Based on the data recorded over the 12-month study period, it identified the ten most abundant types of plastic debris within the five FH. In total, 24,666 plastic items were collected, all belonging to the top ten plastic debris categories. These top ten debris types represented 84.64% of the total plastic debris and 72.14% of all recorded marine debris.

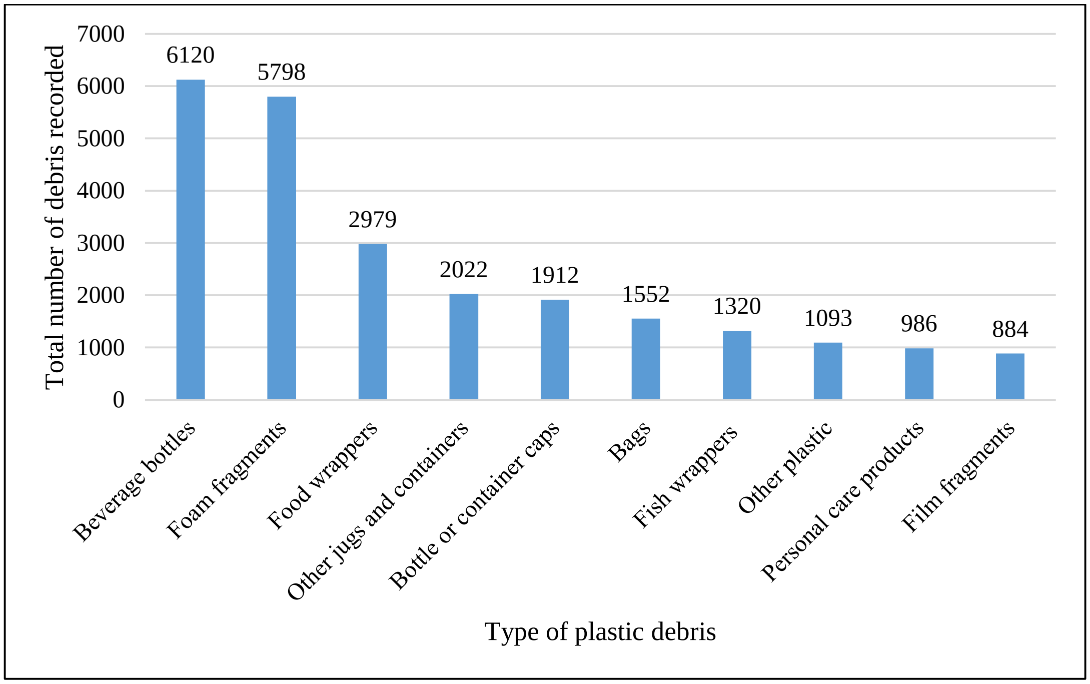


Figure 4.34: Top ten debris items according to collected data from all five FH for one year of period

Top ten polluters in beaches from the EU represented 63% of the total marine debris according to a study conducted in 2016 (Addamo et al., 2017). In Cape Town, South Africa, it was 57% (Chitaka et al., 2019). According to Ocean Conservancy International Coastal Clean-up data, 2017 which was conducted across 112 countries, 54.19% of the marine debris recorded belonged to the top ten category. Based on a study conducted from 2018 to 2019 in Solomon Islands, top ten items represented 55.8% and broken glasses also included into the list (Binetti et al., 2020).

When compared with globally available data, 85% is a quite higher percentage which means that inside FH, plastic debris diversity is limited. For example, the top two debris items (beverage bottles and foam fragments) together represented 40.89% out of the total plastic debris recorded and 34.86% out of the total marine debris recorded. Therefore, in the process of management, special attention should be paid on this characteristic feature of abundance variation from normal range. To develop new policy and to find solutions policymakers, industry leaders and researchers should rely on these kinds of findings.

Figure 4.35: Top ten debris items according to Ocean Conservancy International Coastal Clean-up data, 2017

4.11 Single Use Plastics (SUPs)

Total number of 17,759 SUPs were recorded from all five FH throughout the 8 month study time. Beverage bottles (n=6,120), food wrappers (n=2,979), other jugs and containers (n=2,022), bottle or container caps (n=1,912), bags (n=1,552), personal care products (n=986), cups (n=779), rice sacks (n=764), utensils (n=358), straws (n=283), six pack rings (n=3) and balloon mylar (n=1) were the numbers that accounted the total count of 17,759 SUPs. SUPs represented 60.94% of the total plastic debris recorded. Therefore, SUPs represent the largest proportion of plastic debris.

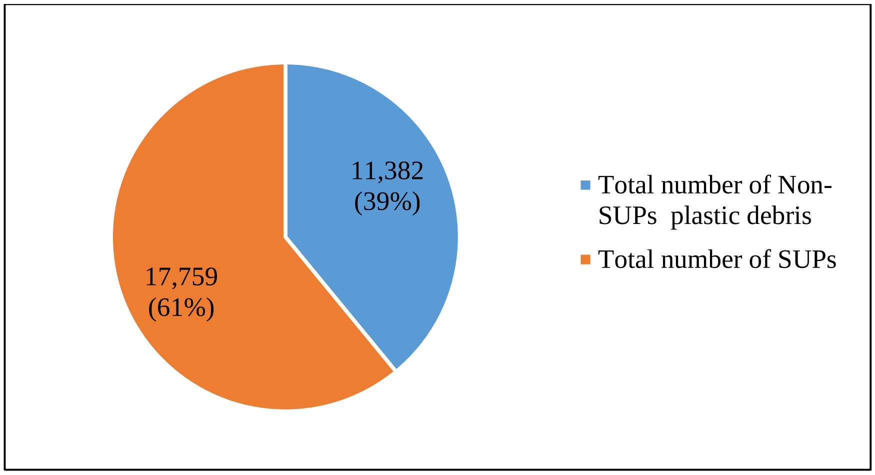


Figure 4.36: Total number of SUPs and Non-SUPs collected from all FH during the study period

The highest amount of SUPs were recorded from BFH approximately 73.15% of the total plastic debris recorded. Continuous input of plastic debris from highly urbanized areas through the water canal can be the reason. In all FH, SUPs outnumbered non SUPs.

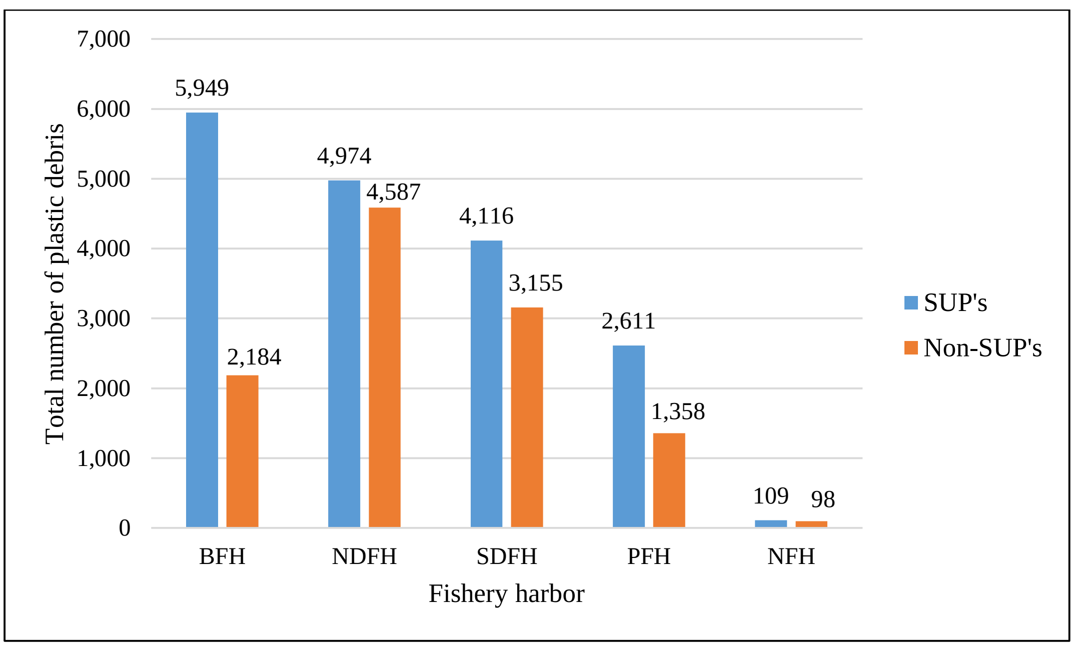


Figure 4.37: Total number of SUPs and Non-SUPs collected from each FH during the study period

Based on citizen science programs conducted from 2011 to 2018 along 172 coastal areas located in the Mediterranean Sea, SUPs represented 33% of the total marine debris (Consoli et al., 2020). From a beach litter survey conducted at the Bay of Lalzi and Bay of Durres in Albania in 2018, SUPs accounted for 48% out of all debris recorded (Gjyli et al., 2020). According to 2016 Europe Union (EU) beach litter survey data collection, approximately 50% of the marine debris were SUPs (Addamo et al., 2017). SUPs accounted for 74.9% of the total marine debris collected at Iskenderun Bay, in Turkey (Büyükdeveci & Gündoğdu, 2021). SUPs constituted more than 82% of the plastic debris recorded at Marine Protected Area (MPA) located in Vietnam (Nguyen & Nguyen, 2022).

The global percentage composition of SUPs has varied in a broad range and this can be due to a number of reasons. The variation of data collection method and selected location to data collection, seasonal variation, level of anthropogenic impacts and proximity to urban areas are some factors that might influence the percentage composition of SUPs.

According to this study, SUPs represented 60.94% of the total plastic debris recorded and it is in between the range of global average percentages previously recorded based on beach surveys.

4.12 Fishery industry related plastic debris

Buoys and floats, lures and line, rope and nets and fish wrappers were considered as fishery industry related plastic debris. Since rubber sheets and form fragments are used for the fishery vessels construction process, they are also related with fishery industry waste. But in this study, it considered plastic waste directly generated during the fishery activities only.

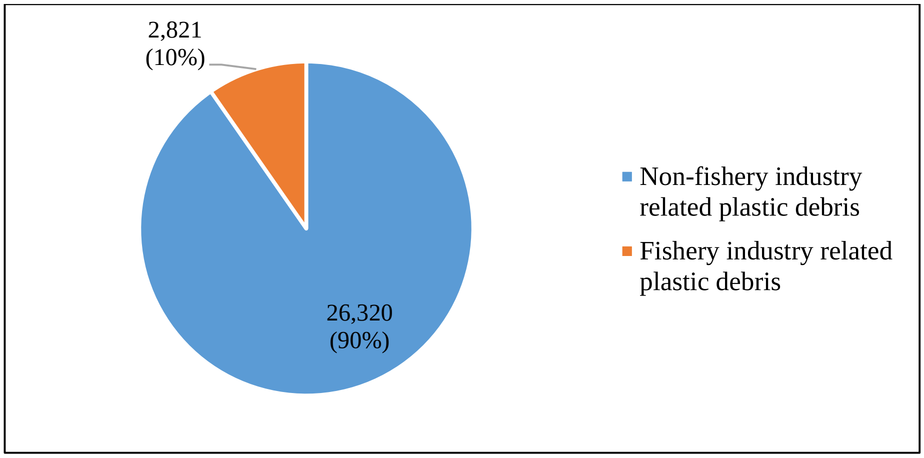


Figure 4.38: Total number of Fishery industry related and Non-fishery industry related plastic debris collected from all FH during the study period

Total number of 2,821 fishing industry related plastic debris were collected from five FH throughout the 12 months study period. Buoys and floats (n=620), lures and line (n=64), rope and nets (n=817) and fish wrappers (n=1,320) were recorded and it is similar to 9.68% of the total plastic debris recorded. Highest amount of fishery industry related plastic debris were recorded from NDFH and lowest were recorded from NFH.

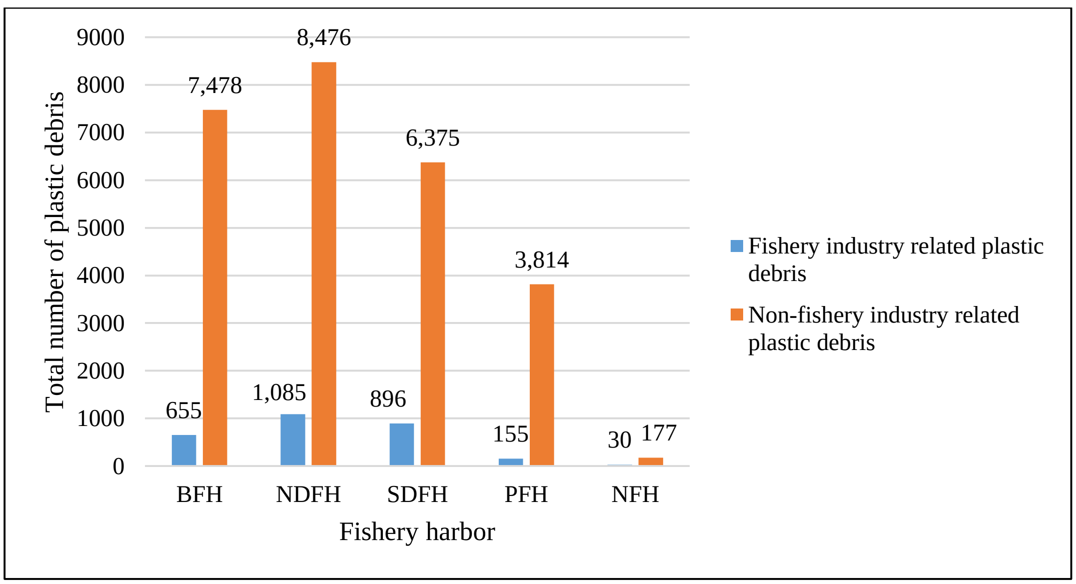


Figure 4.39: Total number of Fishery industry related and Non-fishery industry related plastic debris collected from each FH during the study period

From a previous study conducted in Sri Lanka, fishing gear represented about 20% of the total MPW (Jang et al., 2018). According to 2016 Europe Union (EU) beach litter survey data collection, fishery industry related debris represent about 15% of the total plastic waste (Addamo et al., 2017). From a survey conducted in 11 beaches located along Gulf, Oman, it has found that 25.36% of the debris were fishing industry related items (Claereboudt, 2004). From 2017 to 2018, Daniel and the team conducted beach surveys along six beaches located in the Kerala coast of India to record plastic debris accumulation. Based on that study 36% of the plastic debris were fishery industry related debris (Daniel et al., 2020).

Based on those findings, the contribution of fishery industry related debris on the overall pollution at FH located in Sri Lanka is comparatively lower. With the restrictions of imports and inflated price, fishermen tend to reuse available resources to maximum level. Discarded fishing gears have economic values in some other sectors. As an example, fishing nets are used to make fences to cover economic crops. Further, discarding or misplacing debris related to the fishery industry into the deep sea can be a reason to record less number of debris in FH.

Rice sacks are used to store and transport ice into fishery vessels. Probably most of the rice sacks recorded from the study area may have been released from this chain. Total number of 764 rice sacks collected from five FH. If rice sacks are considered as a fishery industry related debris, the total percentage contribution to plastic debris will reach up to 12.30%.

4.13 Transboundary Marine Litter (TBML)

Total number of 81 transboundary debris were recorded from one year of the study and it included food wraps (n=68), plastic beverage bottles (n=7), plastic container (n=3), personal care products (n=1), other plastics (n=2). All of the foreign debris that had crossed boundaries were plastics. Foreign plastic debris percentage to total plastic debris recorded was 0.27%.

From a study conducted based on 9 beaches, located in the Western Province of Sri Lanka where the current study sites are also located, it calculated the transboundary PET bottle percentage as a ratio to total PET bottles. Based on that, TBML represented 13% (Ranjula et al., 2023).

In this study, the total number of PET bottles recorded were 6,120. Among them, there were only 7 transboundary PET bottles. Therefore, the transboundary PET bottle percentage is 0.11% which is very lower than Ranjula's study conducted in Sri Lanka.

The reason for this variation can be the generation of local beverage bottle waste inside the FH in larger quantities compared to beaches located outside from previous study.

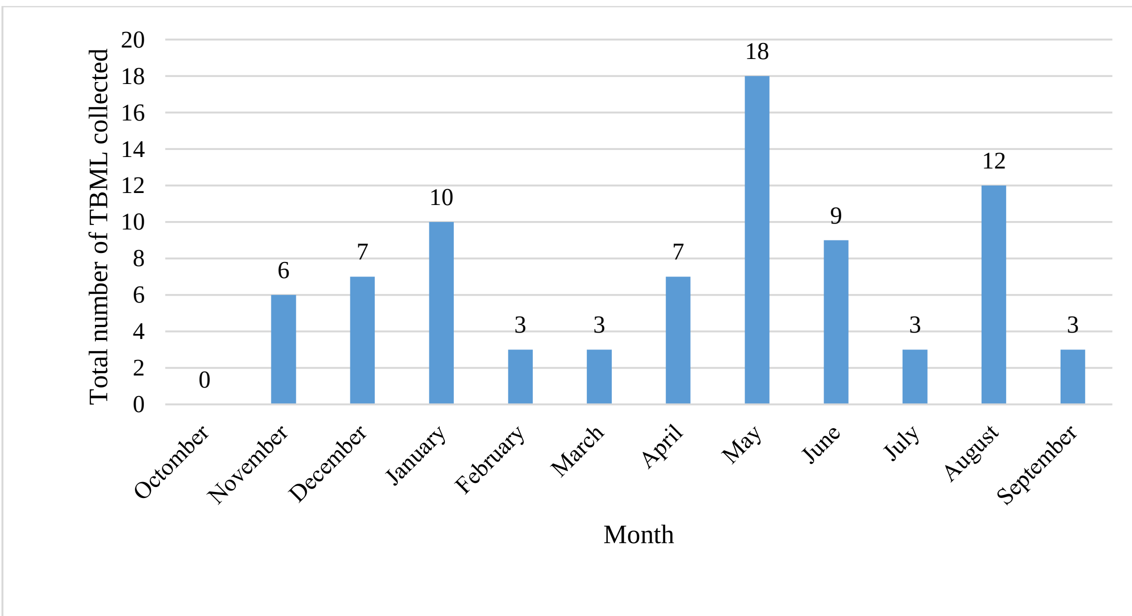


Figure 4.40: Total number of TBML collected from all FH in each month

Between October 2022 and September 2023, TBML was recorded and monitored. No TBML was recorded in October 2022. Starting from this point, the total number of TBML was gradually increased up to January 2023. Then there was a sudden reduction of the total count of TBML in February and March 2023. Hereafter, the total number of TBML increased at a higher rate and the highest number of TBML was recorded in May 2023 (n=18). Then the number of TBML gradually reduced until July 2023.

According to (Ranjula et al., 2023), the highest numbers of TBML were recorded at Moratuwa, Dehiwala, Dikkowita and Negombo Beach Park in May. This could be a result of the activation of South-Western monsoon which lasts from May to September of each year. During that time, seasonal wind enters into the country from the South-West region carrying moist air from Arabian and Indian oceans. With the effect of this strong wind current, TBML could enter the FH located along the Western Province of the country in large quantities.

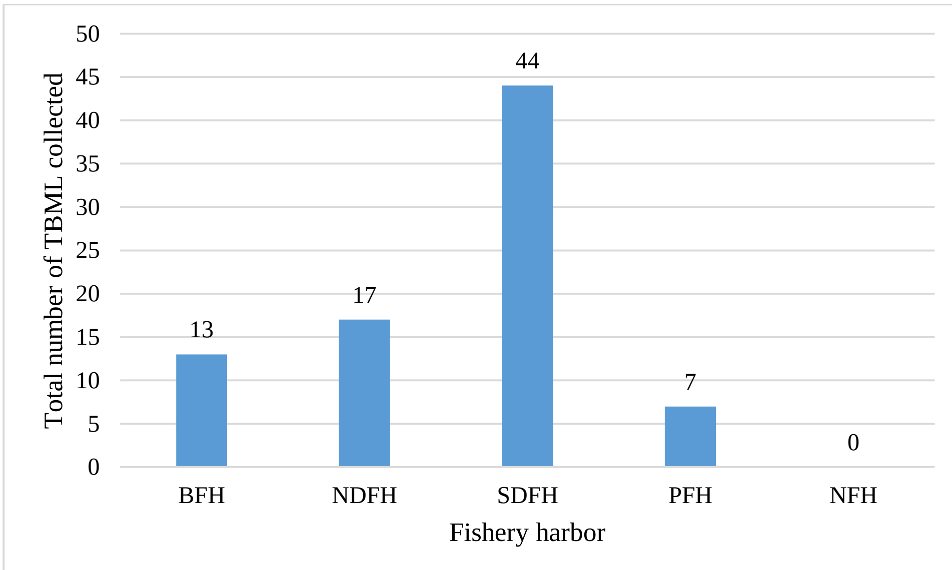


Figure 4.41: Total number of TBML collected from each FH

Highest amounts of TBML were recorded in SDFH. Second highest amounts of TBML were recorded in NDFH. There was no TBML recorded in NFH. BFH and PFH were the harbors with the third and fourth highest amount of foreign debris recorded in FH.

The effectiveness of the natural 'flushing' mechanism in reducing marine debris inflow is strikingly evident in NFH and PFH. NFH, located at the mouth of the Negombo Lagoon, and PFH, situated along the Bolgoda River mouth, benefit from their geographic placements. These positions play a pivotal role in significantly limiting the inflow of TBML. In PFH, only 7 TBML items were recorded, and remarkably, not a single TBML item was found in NFH, representing the lowest counts of TBML among all the FH studied.

The primary reason for this noteworthy contrast can be attributed to the robust flushing effect created by the inland water flows at these harbors. These domestic water flows originating within the country act as a natural 'flushing' force, which efficiently restricts the influx of marine debris carried by oceanic currents. This emphasizes the importance of taking into account both geographical and environmental factors when devising strategies for plastic waste management within FH, especially in locations where such natural flushing forces can be harnessed to mitigate the inflow of marine debris.

According to Ranjula et al., 2023, highest amounts of TBML were recorded from Maggona beach which is located very close to the BFH and lowest amount of TBML were recorded from Negombo Beach Park which is located very close to NFH. From the study conducted at five FH, the second largest amount of TBML were recorded from NDFH while the lowest was recorded from NFH. These findings are very parallel with the previous findings made by Ranjula et al., 2023.

The total number of TBML recorded in NDFH (n=17) was not as much as SDGH (n=44) even though they are situated adjacent to each other. This might be due to wind and water current patterns which restrict the movement of TBML from SDFH to NDFH.

Out of the total number of 81 TBML recorded, 70 (86.41%) of them were manufactured in the Asian region. 9 belonged to Europe (11.11%) and one food wrap was manufactured in South America (1.23%). One plastic debris item was unable to be recognized for its country of manufacture. According to findings of Ranjula (2023) and the team, Asia, Europe and South America continents had generated 90.4%, 1% and 0.1% of debris respectively. As per this study and Ranjula’s study, debris from the Asian region has become higher than the debris from the rest of the regions. The percentages of the observation of regions in both studies were close.

Out of 81 TBML, 61 (75.30%) were recorded collectively from NDFH and SDFH. 44 (54.32%) were from SDFH where international fishery vessels operations are specialized. Most of the fishery vessels come from East Asia including Indonesia to this harbor.

Since the situation of Dikkowita FH (for both NDFH and SDFH) is different from all other FH located in the Western Province of the country, separate graphs were prepared to represent the contribution of different countries to foreign debris generation at Dikkowita FH and all other FH without Dikkowita.

India is the primary contributor of foreign debris at FH, located in the Western Province of Sri Lanka (without Dikkowita FH), accounting for 40% of the TBML. According to the findings of Ranjula et al. (2023), India's contribution was significantly higher at 66.79%, although their study was specifically focused on PET bottles. This disparity in percentages may be attributed to the different focus of the two studies.

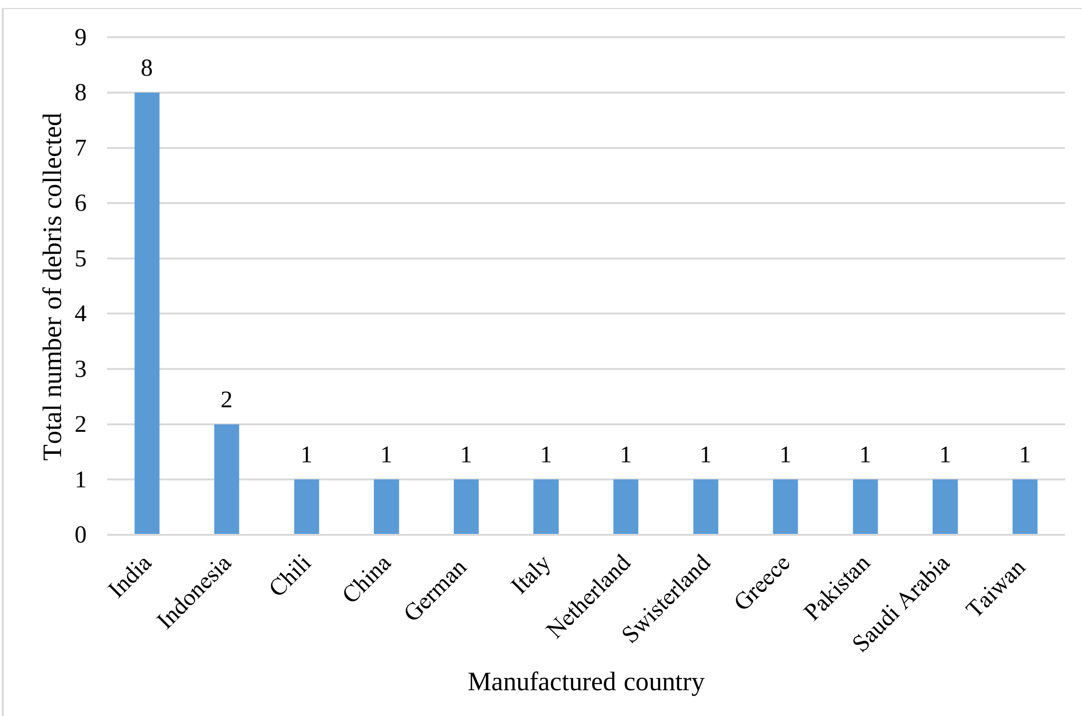


Figure 4.42: Contribution of different countries to TBML accumulated at FH without Dikkowita FH

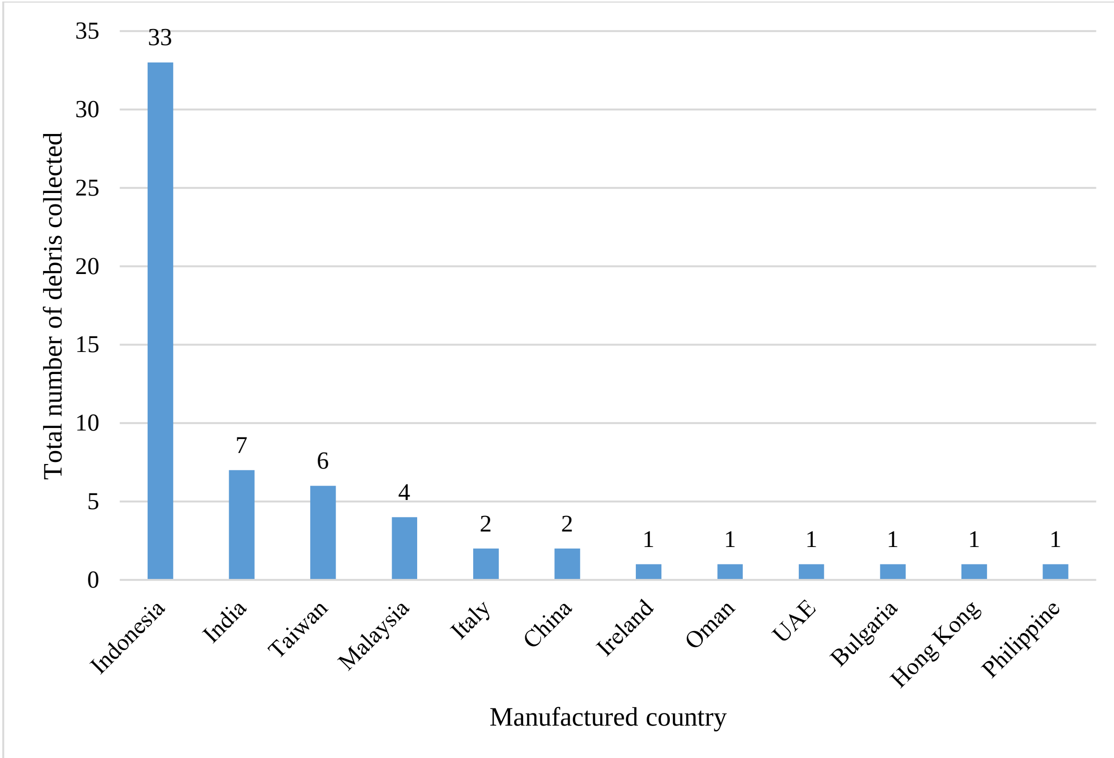


Figure 4.43: Contribution of different countries to TBML accumulated at Dikkowita FH

Indonesia is responsible for 55% of the foreign debris collected at NDFH and SDFH while India is responsible for only 11.66%. These results reveal that there is a possibility of discarding debris from foreign fishery vessels at Dikkowita FH.

Therefore, policy development should be based on these findings and the study highlighted the need for transboundary collaboration among countries in the region to develop integrated management strategies that are scientific and market driven approaches.

4.14 Manufactured year of food wrap

Out of the total number of 2,960 food wraps collected, manufactured year was visible only in 1,220 (41.21%) food wraps. The oldest food wrap among them was manufactured back in 2008. The majority of the food wrappers are from the years 2022 (n=543) and 2023 (n=531), indicating that they are relatively new. The number of wrappers decreases as it move back in time, with fewer wrappers from 2021 (n=83) and even fewer from 2020 (n=31). The "Before 2020" (n=32) category encompasses the wrappers manufactured before 2020, but this group is the smallest in terms of quantity, reinforcing that older wrappers are less common in the sample.

Figure 4.44: A food wrapper (Anchor Newdale pouch pack) manufactured in 2008

Highest number of food wraps were collected from BFH. Among them, majority of food wraps (n=239) had been manufactured in 2022. Similar trend was observed in PFH where majority of food wraps (n=88) belonged to 2022. In NFH, only 11 food wraps were recorded within the 12 months of study period. Out of them, three food wraps were manufactured in 2022 and the other eight were from 2023. The second most common manufacturing year for the food wraps was 2023. However, at NDFH, SDFH, and NFH the second most prominent manufacturing year was 2022.

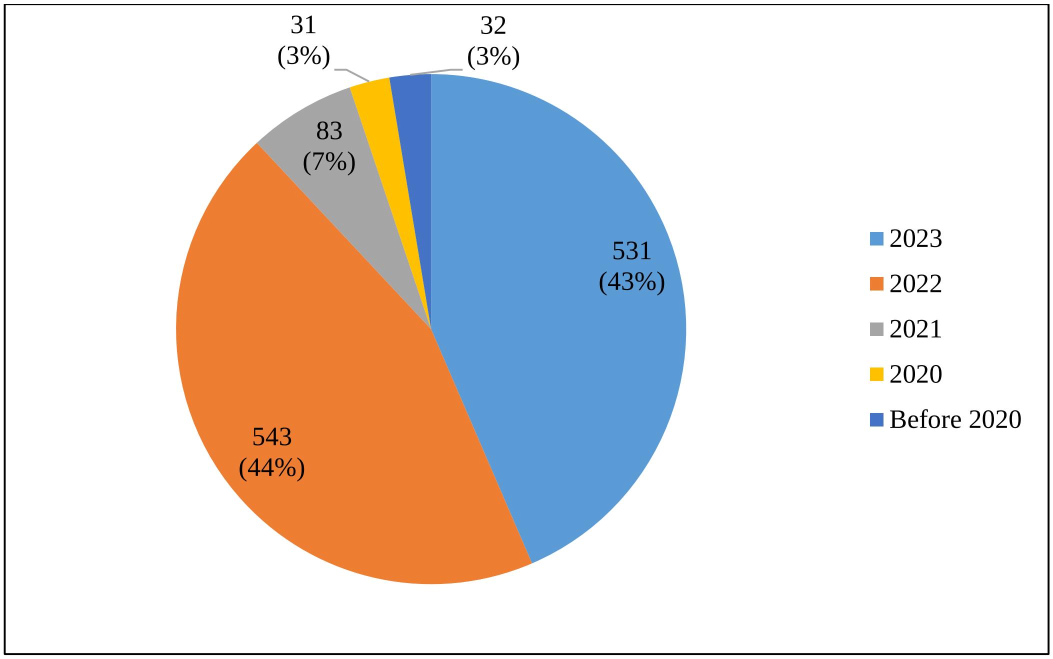


Figure 4.45: Composition of food wrapper manufactured year

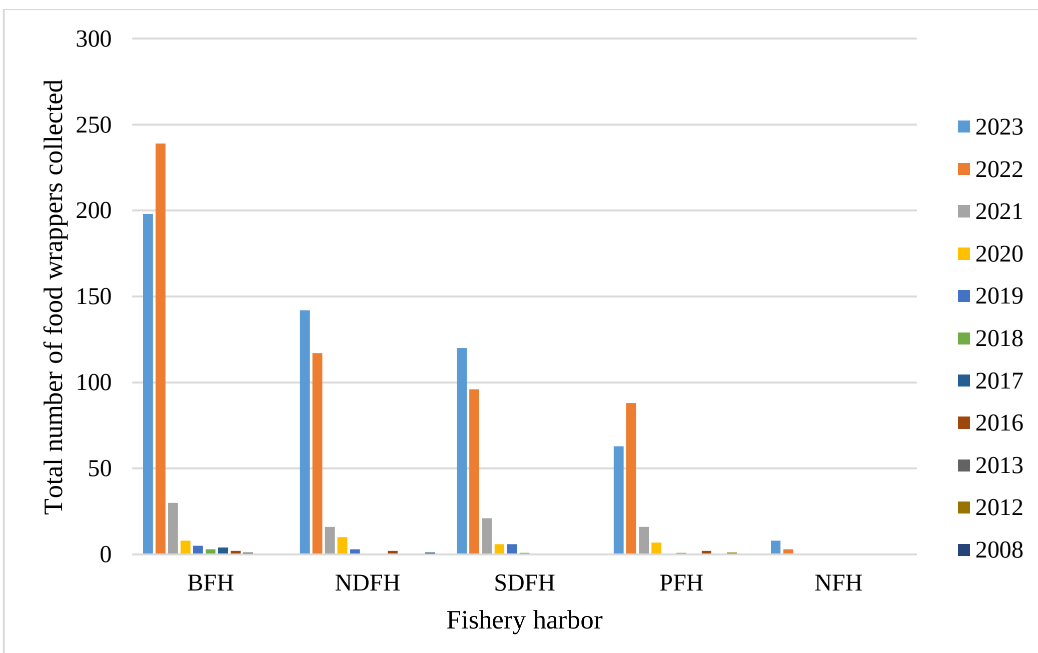


Figure 4.46: Total number of food wrappers collected from all FH during the study period

The highest amount of food wraps was collected in August 2023, and the second-largest quantity was recorded in December 2022. The lowest amount of food wraps was collected in October 2022. In December 2022, a rapid increase was observed compared to the previous month (November 2022). December is a festive season with Christmas and New Year celebrations, and food consumption could be higher during this period. Hence, this could be a reason for the rapid increase in the count of food wraps observed in December.

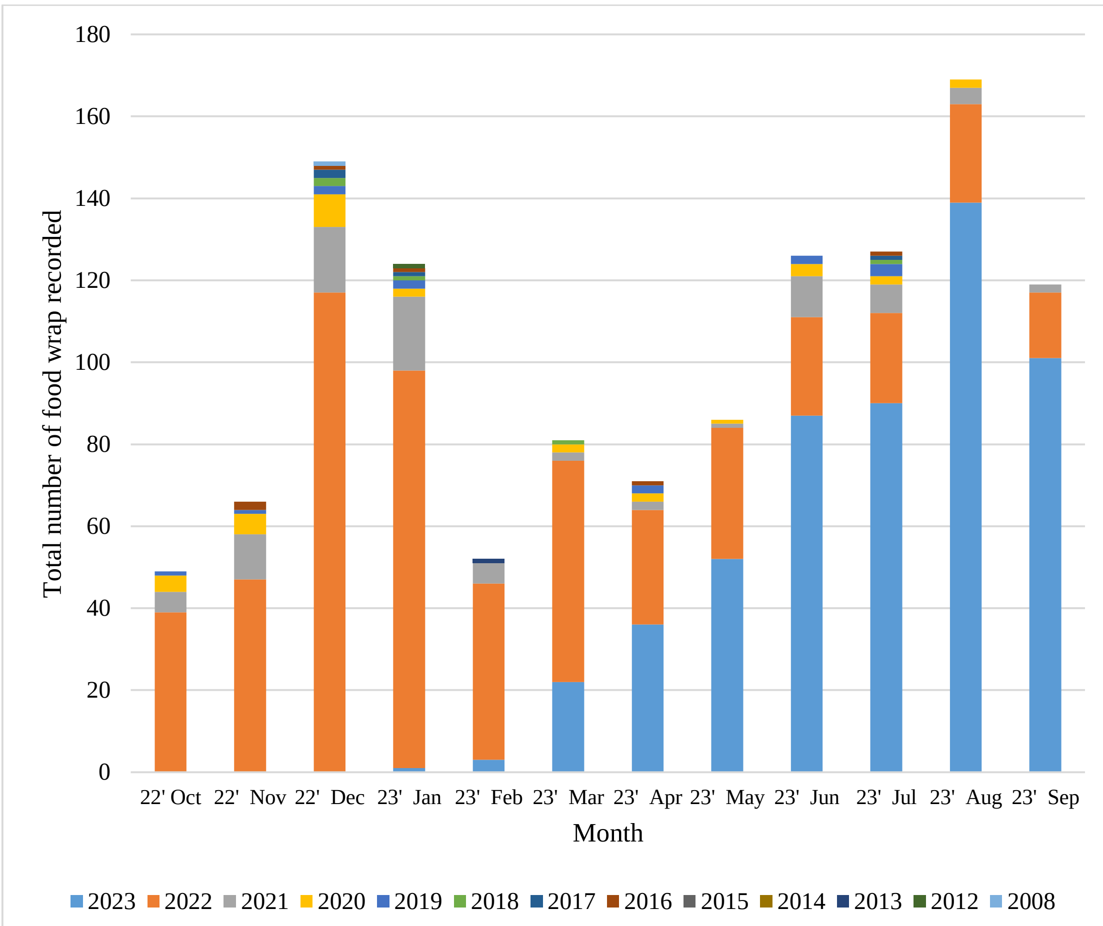


Figure 4.47: Manufactured years composition of food wrappers collected from all FH in each month

Food wraps manufactured in 2023 could be recorded from January 2023 onward and it reveals that there should be direct and rapid sources that cause accumulation of food wraps in FH. Mismanagement of plastic debris by fishermen inside FH, water channels and river flows coming across urban areas and wind activities could be some of the possible sources. The total count of food wrap manufactured in 2022 decreases gradually while the total count of food wrap manufactured in 2023 increases gradually. Nine months after the beginning of the year, in September 2023, total count of food wraps manufactured in 2023 reached up to 531 which was more than half (55.60%) of the total food wrap recorded in the year of 2023. Meanwhile, in January 2023, total number of food wraps manufactured in 2022 and 2021 were represented 78.22% (n=97) and 14.51% (n=18) out of the total respectively and it had been reduced to 13.44% (n=16) and 1.68% (n=2) by the end of September 2023.

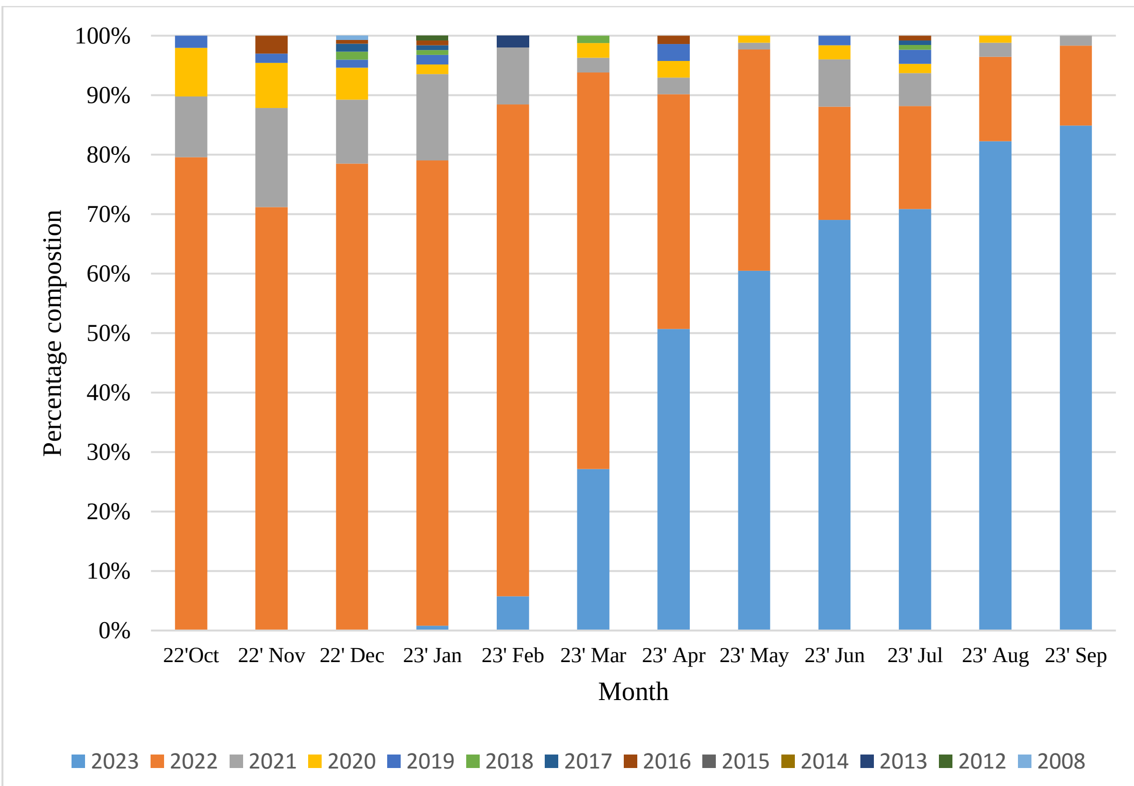


Figure 4.48: Percentage composition of food wrappers manufactured year

According to these findings, old food wraps were rapidly replaced by the recently generated food wraps and this could be a similar process for other plastic debris as well. If so, it can be concluded that FH do not retain plastic debris for a long time.

Annual or biannual dredging are done to remove excess sand, silt and debris accumulated at the bed of the harbor, beach cleanup projects conducted by CFHC and collecting debris by harbor cleaning personals can be the reasons to reduction of older food wraps though the rate is not sufficient to reduce the overall debris load.

4.15 Questionnaire survey

All the participants were men, and 34% of them belonged to the 30-39 years old age category. 29%, 14%, 13%, and 10% belonged to the 20-29 years, 40-49 years, <20 years, and >50 years old age categories, respectively.

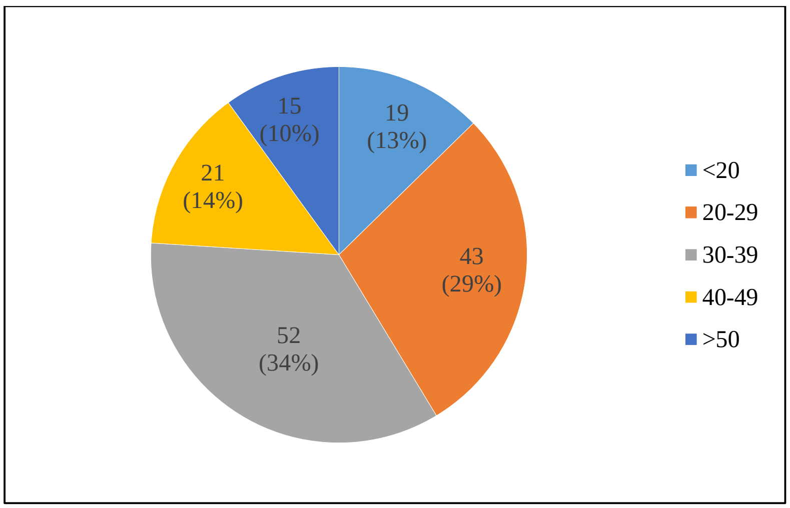


Figure 4.49: Age distribution of interviewed fishermen

No graduate or postgraduate person was met during the survey. Seventy-two percent of the fishermen (n=108) had completed their secondary education, while 5% were illiterate (n=5), and 23% had completed their primary education only (n=35). These results depict that fishermen communities are not well-educated compared to other coastal communities.

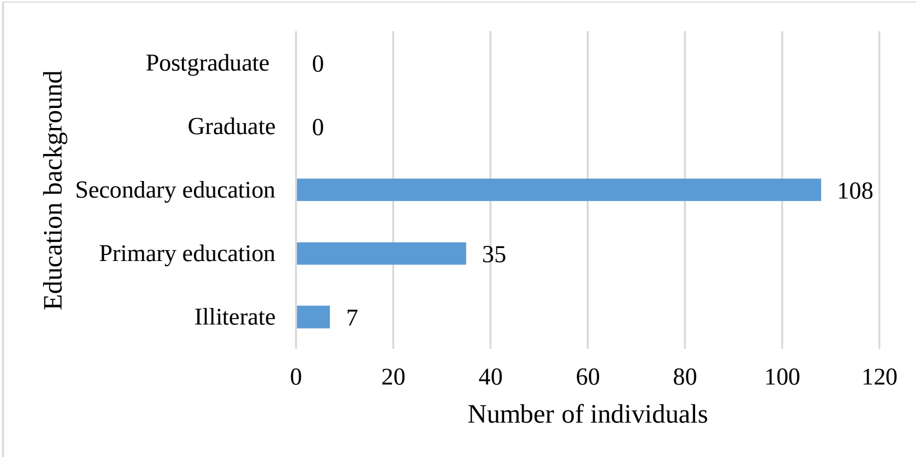


Figure 4.50: Educational background of interviewed fishermen

All the fishermen who were interviewed (n=150) are men, and all of them are aware of and concerned about the plastic pollution that takes place at the harbor premises. Around 51% of them (n=77) considered poor waste management of CFHC as the key contributing factor to this problem. About 36% of them (n=54) believe that fishermen's bad practices are the key contributing factor. Approximately 13% of them (n=19) consider outside sources (river flows, water canals, tide, and wind currents) that carry debris into the FH premises as the key contributing factor for plastic waste generation inside the harbors.

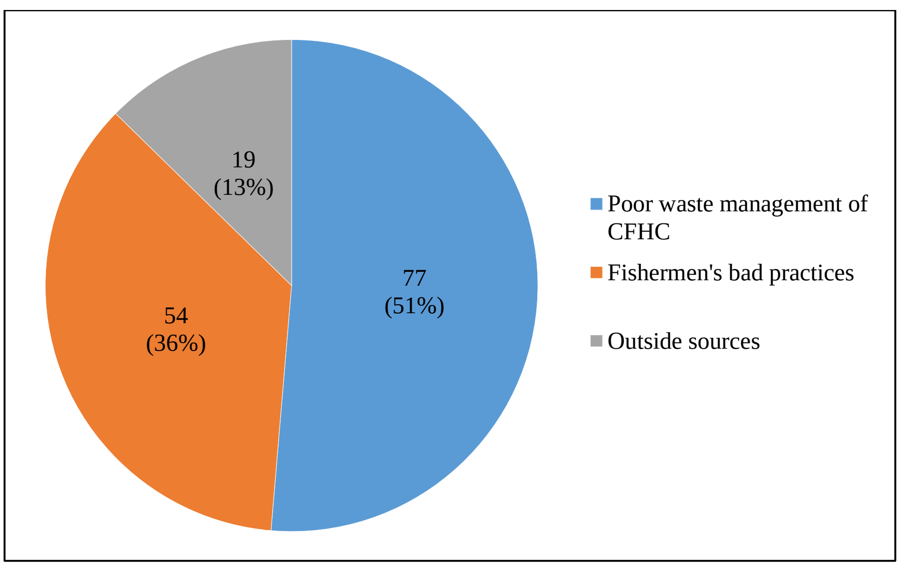


Figure 4.51: Fishermen perception on source of plastic waste generation

Figure 4.52: Poor waste management of CFHC

About 79% of them (n=119) considered that the problem is becoming much more severe with time. Approximately 56% of the respondents (n=84) believe that plastic waste management strategies should be implemented by the government, while 44% (n=66) believe that it should be initiated by the community itself. One hundred thirteen interviewees (75%) said that they properly discard debris into the bins, while 37 (25%) emphasized that the lack of enough discarding facilities at harbor premises has made proper disposal difficult.

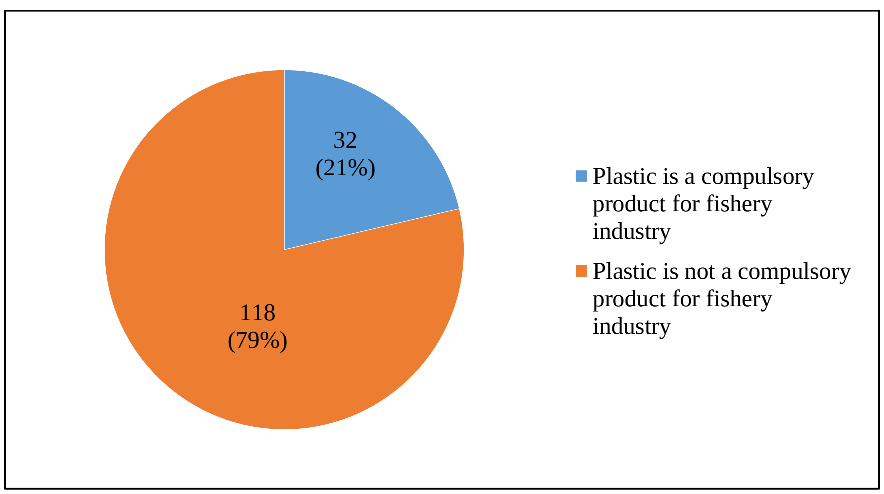


Figure 4.53: Fishermen perception on banning plastic products inside FH

Around 79% of the participants (n=118) are willing to continue fishery activities while banning plastic materials if there are available alternatives to be utilized instead of plastics. However, 21% of the fishermen (n=32) adhere to plastic products due to their versatile usage, and they do not want to switch to alternative options. Therefore, when introducing any alternative, it should be a cost-effective product, easy to use, frequently available in the market, durable, and easy to use.

According to Arulnayagam, (2020) findings Sri Lankans are much aware of negative impacts of SUPs and willing to minimize the utilization of SUPs. Suresh & Suresh, (2022) findings emphasized the high level of awareness among Sri Lankans on the negative impacts of plastic debris and their willingness to reduce plastic utilization. About 86% of the interviewers believed that coastal areas are threatened by the negative impacts of plastic debris and 90% of the people had experienced that the problem is increasing. About 21% of the respondents believe that the plastic waste management strategies should be implemented by the government while 69% believe that it should be initiated from the community itself. About 92% of the interviewers are ready to minimize plastic consumption. But many of them do not desire to take rapid actions (Suresh & Suresh, 2022). According to the Eurobarometer survey conducted in 28 European Union countries, it was revealed that 72% of the respondents have already reduced their consumption of plastic materials, while 87% of the respondents were aware of the negative environmental impacts caused by plastic debris.

When comparing these values given by previous studies with the current study, it highlights the lack of awareness and education among the fishermen. Previous studies have been conducted based on coastal communities instead of directly targeting fishermen.

All the interviewed fishermen were men. The interviewed fishermen's educational background was lower compared to the average coastal communities. In the Arulnayagam study, 91.7% of the participants were graduates or postgraduates, while no graduate or postgraduate person was interviewed during the current study. Therefore, environmental literacy can be lower among fishing communities compared to others with their lower educational background.

Interviewers' perception on marine plastic pollution can depend on how they engage with coastal environment, occupation, personalities and various socio demographic factors (Davison et al., 2021). Based on the data collected from structured interview surveys and the observations conducted throughout the study time, fishermen's awareness on plastic waste management should be further improved. For that, conducting awareness program and workshops, displaying posters and implementing new rules and regulations will be useful.

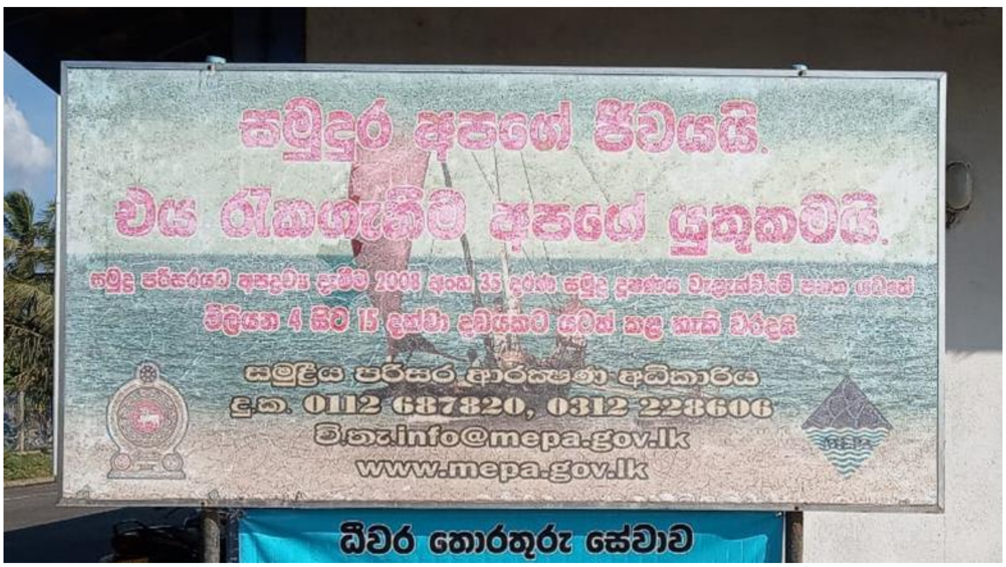


Figure 4.54: A poster displaying at NDFH

From a study conducted in Pangandaran Indonesia, it has been recognized that fishermen discarding debris without utilizing a dustbin can act as a potential source to generate marine debris (Prasetiawan et al., 2022). Developing the fishermen's behavior to maintain the high quality of yield, will led to obtain much sustainable harvest (Prasetiawan et al., 2022). Conducting workshops and awareness program will enhance fishermen behavior changes towards the positive direction. Balasubrahmaniam et al., (2009) confirmed based on a study conducted in India that educates the fishermen can positively influence their behavior.

4.16 Stakeholders workshop

Stakeholders workshop involves the cross-verification and validation of data, which is fundamental in enhancing the reliability and credibility of the information collected. Through the FGD, the data obtained could be verified by multiple sources and perspectives, thereby strengthening the research findings. Beyond data reliability, the workshop enriched the research data by providing a platform for stakeholders to share their experiences, concerns, and suggestions. These firsthand accounts and insights added significant depth to the research.

One of the primary objectives of the stakeholder workshop was to identify policy gaps. The insights and feedback from the stakeholders revealed on areas where existing policies may be inadequate or ineffective in addressing the issue of plastic waste management. By conducting the workshop in the FGD format, these gaps could be identified with a higher degree of accuracy.

In addition to policy gaps, the workshop aimed to uncover the implementation challenges associated with plastic waste management within FH. These challenges often emerge in the practical application of policies and regulations. The workshop's discussions provided a comprehensive view of these challenges, ranging from logistical issues to cultural and behavioral factors affecting the success of plastic waste management initiatives.

The workshop discussions underscored the importance of implementing stricter regulations, particularly concerning multi-day boats, which were identified as significant contributors to plastic debris. These larger vessels, due to the nature of their extended operations, generate plastic debris in more substantial amounts than single-day boats. Consequently, there is a critical need to establish and enforce comprehensive regulations targeted at the responsible disposal of plastic waste generated by multi-day boats. This approach not only reduces the generation of plastic waste but also ensures that existing waste is managed effectively.

The current lack of recycling or upcycling capacity for fiberglass in any FH located in Sri Lanka represents a significant gap in the plastic waste management process. To bridge this gap, special attention should be paid to fiberglass waste generation. It is noteworthy that Municipal Councils do not collect fiberglass waste, and a high amount of fiberglass waste is generated in FH, particularly due to boat repairing workshops. Developing recycling or upcycling facilities for fiberglass waste would not only enhance the sustainability of FH but also alleviate the burden of non-biodegradable waste on the local environment.

Efficient transportation of collected plastic debris from FH to recycling centers is a critical step in the waste management process. The workshop emphasized the need to improve transportation facilities, ensuring that collected plastic waste is promptly and effectively transferred to recycling centers. This recommendation addresses a logistical challenge that often impedes successful plastic waste management and contributes to the accumulation of debris within the harbors.

The lack of sufficient human resources to effectively clean harbor premises is another critical challenge. This issue was further exacerbated by the low basic monthly salary, which currently stands at approximately 26,000 Rupees (83.6 USD). This minimal wage rate significantly affects the motivation and retention of cleaning personnel. As such, addressing this challenge is paramount for the success of plastic waste management within FH.

One of the primary recommendations emerging from the workshop is to consider increasing the salary rates for cleaning personnel. Given the vital role they play in maintaining harbor cleanliness and managing plastic waste, a higher salary rate can serve as a compelling incentive for them to remain engaged in this critical work. A more competitive salary not only recognizes the significance of their role but also attracts and retains a dedicated workforce, ultimately leading to cleaner and more sustainable FH.

If increasing salary rates proves challenging due to budget constraints, an alternative approach can be considered. The workshop discussions highlighted that some of the waste generated at harbor premises, such as fish wrap, rice sacks, and PET bottles, possess market value and demand. To empower the cleaning personnel and provide an additional income source, granting them permission to collect and sell these valuable waste items to collectors can be a practical solution. This approach not only benefits the personnel but also contributes to a cleaner FH environment.

The lack of opportunities available for integral actions against plastic waste generation by fishery industry-related stakeholders, waste management industry-related stakeholders, and researchers highlighted the importance of bringing these diverse groups together to collaborate effectively. Stakeholder workshops, such as the one conducted in this research, provide a platform for these groups to align their efforts, share their expertise, and develop a coordinated approach to tackle the plastic waste problem. Such collaborative efforts are essential for creating holistic and sustainable solutions for plastic waste management in FH.

4.17 Chapter Summary

In this chapter, all the data collected over a 12-month period at five FH located in the Western Province are presented, along with the analysis of the results. The study's results indicated that plastic waste was a critical issue in these FH, with the highest accumulation rate observed in the largest harbor, NDFH. Factors such as GDP, population density, and fishing activity were linked to higher plastic debris generation rates. Specific debris compositions and sources varied among harbors, with debris retention influenced by harbor structures, water flow patterns, and mangrove ecosystems. The study emphasized the importance of proper plastic waste management to ensure the long-term sustainability of FH and marine ecosystems, as the fishing industry's reliance on plastics contributes to ongoing debris accumulation and environmental impacts.

The study employed Pearson correlation to assess the relationship between plastic debris weight and the number of plastic debris collected, revealing a strong positive correlation (r = 0.883). This suggests that an increase in the number of plastic debris corresponds to an increase in their weight, indicating a proportional relationship. This result aligns with similar findings from a study in Cape Town, South Africa.

The study also examined the correlation between monthly rainfall and monthly average plastic debris count. BFH, NDFH, and SDFH showed a very weak positive correlation between rainfall and debris count. In PFH, and NFH displayed weak negative correlations, implying that higher rainfall corresponds to lower debris collection, possibly due to flushing debris out to sea.

The study also examined the correlation between tide level and plastic debris count, revealing a weak negative correlation for both floating and stranded debris. During high tides, plastic debris gets deposited onto the shorelines, while low tides leave debris stranded. However, other factors also impact debris accumulation. A comparison between stranded and floating debris demonstrated significantly higher median values for stranding debris across multiple harbors, indicating that stranded debris consistently exceeds floating debris. This highlights the need for targeted efforts in managing stranded debris. Seasonal variations were also explored, with a significant variation observed in BFH, SDFH, and PFH. At BFH, mean plastic debris count was notably higher during the 2nd Inter-monsoon and lower during South-West monsoon. Both at SDFH and PFH, higher amount of plastic debris accumulated during the North-East monsoon while lower during South-West monsoon.

In contrast, other two harbors did not show significant seasonal differences in debris counts. Overall, the study provided valuable insights into plastic debris patterns and their relationships with various environmental factors within FH.

The study investigates plastic debris accumulation and its spatial-temporal patterns in five FH located in the Western province of Sri Lanka. One-way ANOVA tests reveal significant variations in mean plastic debris numbers across different data collection points within each harbor. Tukey HSD tests further identify points with significantly higher debris accumulation, such as P3 and P4 in BFH, P1 and P5 in NDFH, P23 in SDFH, P6 in PFH and P1 in NFH.

Weak negative correlations between rainfall and debris collection at PFH and NFH, indicate increased rainfall leading to decreased debris accumulation due to flushing effects and other factors. Single-use plastics (SUPs) constitute a significant portion (61%) of the debris collected, with beverage bottles, food wrappers, and other items being predominant. Fishery industry-related plastic debris accounts for around 10% of total debris, with differences among harbors attributed to their fishing activities and local practices. TBML from foreign sources represents a small percentage, predominantly from Asian countries. The study suggests strategies for better waste management in these FH, including increasing cleaning personnel's salaries, allowing them to sell valuable debris, and addressing spatial and temporal patterns of debris accumulation.

The findings also highlight the prevalence of small plastic debris (<10 x 15 cm^2) being the most common, indicating the need for focused management strategies. The study notes variations in food wrap manufacturing years and their rapid replacement, suggesting that FH do not retain plastic debris for long periods due to regular cleaning and dredging activities. The research underscores the importance of effective waste management practices and the need to consider spatial and temporal factors in implementing strategies for reducing plastic debris accumulation in these critical coastal environments.

The study focuses on the awareness, perceptions, and attitudes of fishermen towards plastic pollution in FH in Sri Lanka. All interviewed participants were men, with the majority (34%) falling in the 30-39 years age category. No graduate or postgraduate individuals were encountered during the survey, and 72% of fishermen had completed secondary education, indicating relatively lower education levels within the fishing communities compared to other coastal communities. Despite their lower education levels, all interviewed fishermen were aware of and concerned about plastic pollution at the harbor premises. Around 51% attributed poor waste management by CFHC as the main contributor to the problem, while 36% believed that fishermen's practices were responsible, and 13% pointed to external sources bringing debris into the harbors. Most respondents considered the issue to be worsening over time, and opinions were divided on whether plastic waste management strategies should be initiated by the government or the community. Compared to previous studies conducted in Sri Lanka and other regions, the current study found a lower level of awareness and education among fishermen. The study highlights the need for improving awareness and education programs among fishermen and suggests conducting workshops, implementing rules and regulations, and involving stakeholders to address plastic waste generation in FH. The study's stakeholder’s workshop identified key policy gaps and potential strategies to manage plastic waste, including the need for stricter regulations on multi-day boats, addressing fiberglass waste, improving transportation for recycling, and fostering collaboration among different stakeholders involved in waste management and research.

5 CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORKS

5.1 Conclusion

The first objective was to conduct a comprehensive literature review to identify FH locations and plastic consumption in the fishery industry/harbors. It is worth emphasizing that while numerous studies have explored coastal pollution, only a limited body of research has delved into the specific domain of FH. This knowledge gap, especially in the context of Sri Lanka, posed a unique challenge during the literature review phase of this research project.

The study has not only bridged this gap but has also provided valuable data and insights into the state of plastic debris in FH. The results of this study align with previous research along shorelines, consistently identifying plastic as the dominant pollutant. These findings underline the high prevalence of plastic pollution, not only within the selected FH but also in coastal areas worldwide.

This research project's contribution is twofold: it addresses the scarcity of studies dedicated to FH waste generation and offers a vital dataset that serves as a foundation for future research and policy development in the region.

The second objective was to identify and quantify plastic waste in selected FH. The research recorded a total of 29,141 plastic debris items across the studied harbors. Plastic accounted for 85.24% of the debris by count, reaffirming that plastic is the primary pollutant within these harbor premises. The presence of rubber debris, particularly in harbors with fishery vessel repair workshops, highlights the significance of effectively managing waste generated within fishery operations.

The third objective was to investigate the spatial and temporal trends and variations of plastic waste within the selected FH. The study has provided insightful correlations between the number and weight of plastic debris, monthly rainfall, and tide levels, offering a deeper understanding of the dynamics of debris accumulation in these harbor environments. It is evident that various factors, including local geography, monsoon seasons, and the intensity of fishery activities, impact plastic debris accumulation in each FH.

The final objective was to identify policy gaps within the FH of Sri Lanka. The research has illuminated several key areas where policy intervention is essential. For instance, since it is evident that the majority of the TBML comes from India and Indonesia, it highlights the need for transboundary collaboration among these countries to develop integrated, science-driven, and market-based management strategies.

The findings regarding the manufacturing year of food wraps have revealed a gradual replacement of older food wraps with recently generated ones. This suggests that FH do not retain plastic debris for extended periods, which can be attributed to activities such as regular dredging, beach cleanup projects, and harbor cleaning.

Moreover, the questionnaire survey among fishermen has highlighted the educational and awareness gaps in the fishing communities. While fishermen acknowledge the plastic pollution issue and its consequences, their awareness of potential solutions and the need for alternative materials to plastics is still developing. This underscores the necessity of educational and awareness programs tailored to these communities and the need for efficient waste management solutions within the harbor premises.

In conclusion, this research has made significant strides in understanding the plastic pollution issue within Sri Lankan FH. It is evident that plastic is the dominant pollutant, but the nature and sources of this pollution vary between harbors. These findings should serve as a basis for targeted policy interventions and localized management strategies. The sustainability and health of marine ecosystems and the fishing industry rely on proactive measures to mitigate the impact of plastic pollution, conserve fishery resources, and secure a prosperous future for coastal communities.

5.2 Recommendations

Based on the findings of the study the following recommendations were grasped.

1. Special attention should be paid to the identified plastic debris accumulating hot spots for particular months of the year. By focusing on these hot spots, the efficiency of cleaning efforts can be significantly improved, as these locations tend to accumulate a large amount of plastic debris. For hot spots that are difficult to access using vehicles, the strategic placement of waste collection bins will facilitate proper disposal and prevent further plastic pollution.
2. Given that plastic is the major pollutant in FH located in the Western province of the country, it is imperative to prioritize and allocate resources for targeted plastic waste management efforts. Comprehensive waste management plans should be implemented to reduce plastic debris accumulation and its negative impact on marine ecosystems and coastal communities.
3. The variable correlation between the total number of plastic debris and monthly rainfall observed across these FH underscores the need for site-specific strategies in conducting beach cleanups. For BFH, NDFH, and SDFH, where an increase in rainfall is associated with higher plastic debris accumulation, it is more effective to conduct beach cleanups during periods of increased rainfall. But since the correlation is very weak for BFH, NDFH, and SDFH, cleanup efforts should consider other factors influencing debris accumulation, such as local currents or anthropogenic activities as well. Conversely, at PFH and NFH, where the opposite relationship holds true, cleanup efforts should be prioritized during drier months when plastic debris tends to accumulate. Such tailored cleanup scheduling, based on local rainfall patterns and its influence on plastic debris dynamics, is essential for optimizing the effectiveness of cleanup initiatives along FH shorelines.
4. Optimal timing for beach cleanups is during low tide, as there is a negative correlation between the tide level and the number of plastic debris recorded. Utilizing low tide periods will facilitate easier access to coastal areas and enhance the effectiveness of cleanup efforts.

5. Collecting stranding plastic debris is of utmost importance, given that its count is significantly higher than the floating plastic debris count. Targeting stranding debris during cleanup efforts will have a more substantial impact in reducing plastic pollution in FH.
6. Continued efforts to educate and raise awareness among fishermen are crucial in tackling plastic waste generation and pollution. Implementing educational programs and campaigns can empower fishermen to adopt sustainable practices, reduce plastic waste, and promote responsible waste disposal.
7. Addressing plastic waste generation requires an integrated approach involving all stakeholders, including government authorities, fishing industry representatives, waste management organizations, and local communities. Collaboration and cooperation among these stakeholders are essential to develop and implement effective plastic waste management strategies.
8. The presence of foreign debris manufactured in the Asian region highlights the need for a collaborative approach among countries to address TBML pollution. Regional cooperation, information sharing, and joint efforts are vital to prevent the movement of plastic debris across borders and minimize the environmental impacts.
9. Emphasis should be placed on plastic debris smaller than 10 cm x 15 cm, as the majority of the plastic debris falls into this size class. Small size plastics pose unique environmental challenges due to their potential to be absorbed toxic compounds in higher amounts and ingested them by marine organisms and enter the food chain. Implementing measures to manage and reduce small-sized plastic pollution is crucial for safeguarding marine biodiversity and human health.
10. CFHC waste management mechanism should be further improved with the collaboration of relevant stakeholders.

In conclusion, these recommendations derived from the plastic debris collection study provide valuable insights and practical guidance to enhance plastic waste management in FH of the Western province. By adopting a holistic and informed approach, stakeholders can work collectively to mitigate plastic pollution and preserve the marine environment for current and future generations.

5.3 Future Work

1. Long-term monitoring and replicating the study in other regions of the country: Conducting long-term monitoring of plastic waste accumulation in FH will provide valuable data on trends and patterns over extended periods. By analyzing the data over several years, researchers can identify seasonal variations, long-term changes, and potential impacts of policy interventions very accurately. Extending the investigation to FH in other provinces or countries will broaden the understanding of plastic waste utilization and management practices in different contexts. Comparative studies will offer valuable insights and potential solutions applicable to a broader range of locations.
2. Circular economy approaches: Exploring circular economy approaches, such as recycling, up cycling, and eco-design, can promote the responsible use of plastic materials and reduce waste generation. Evaluating the feasibility of implementing circular economy practices within FH can lead to innovative solutions for plastic waste management.
3. Community engagement and social behavior studies: Conducting community engagement initiatives and social behavior studies will help understand the attitudes and behaviors of stakeholders, including fishermen, local communities, and tourists, towards plastic waste management. This knowledge will aid in tailoring effective communication and educational campaigns.
4. Integrated waste management systems and collaborative partnerships: Developing and implementing integrated waste management systems at FH will enhance waste segregation, recycling facilities, and proper waste disposal. Creating a circular waste management system will contribute to reducing plastic waste leakage into the marine environment.

5. Technology and innovation in waste management: Embracing technology and innovation, such as smart waste bins, remote sensing technologies, and data analytics, can improve waste management efficiency and accuracy. Implementing smart technologies can streamline waste collection and enable real-time monitoring of plastic waste.

In conclusion, the study on plastic waste utilization and management in FH can pave the way for various future developments and possibilities. Embracing innovative technologies, circular economy approaches, and collaborative partnerships will contribute to more sustainable waste management practices, safeguarding marine ecosystems and coastal communities from the growing threat of plastic pollution.

6 REFERENCES

1. Abate, T. G., Börger, T., Aanesen, M., Falk-Andersson, J., Wyles, K. J., & Beaumont, N. (2020). Valuation of marine plastic pollution in the European Arctic: Applying an integrated choice and latent variable model to contingent valuation. Ecological Economics, 169, 106521.
2. Abeysinghe, N. D. A., & Samarakoon, M. B. (2017). Analysis of variation of water quality in Kelani River, Sri Lanka. *International Journal of Environment, Agriculture and Biotechnology*, *2*(6), 238965.
3. Addamo, A. M., Laroche, P., & Hanke, G. (2017). Top marine beach litter items in Europe. *A review and synthesis based on beach litter data. MSFD Technical group on marine litter. Report No. EUR29249*, 148335.
4. Almroth, B. C., & Eggert, H. (2019). Marine plastic pollution: sources, impacts, and policy issues. *Review of environmental economics and policy*.
5. Alqahtani, F. K., & Zafar, I. (2021). Plastic-based sustainable synthetic aggregate in Green Lightweight concrete–A review. *Construction and Building Materials*, *292*, 123321.
6. Amutha, D. (2013). A Study on Fishing in Tuticorin District. Available at SSRN 2196700.
7. Anastasopoulou, A., & Fortibuoni, T. (2019). Impact of plastic pollution on marine life in the Mediterranean Sea. In Plastics in the Aquatic Environment-Part I: Current Status and Challenges (pp. 135-196). Cham: Springer International Publishing.
8. Andrady, A. L. (2015). Persistence of plastic litter in the oceans. *Marine anthropogenic litter*, 57-72.
9. Arabi, S., & Nahman, A. (2020). Impacts of marine plastic on ecosystem services and economy: State of South African research. South African Journal of Science, 116(5-6), 1-7.
10. Ariyawansa, S., Ginigaddarage, P., Jinadasa, K., Chandrika, J. M., Arachchi, G. G., & Ariyaratne, S. (2016). Assessment of microbiological and bio-chemical

quality of fish in a supply chain in Negombo, Sri Lanka. Procedia Food Science, 6, 246-252.

11. Arulnayagam, A. (2020). Public perception towards plastic pollution in the marine ecosystems of Sri Lanka. *American Journal of Marine Science*, *8*(1), 6-13.
12. Babafemi, A. J., Šavija, B., Paul, S. C., & Anggraini, V. (2018). Engineering properties of concrete with waste recycled plastic: A review. *Sustainability*, *10*(11), 3875.
13. Balasubrahmaniam, S., Jeeva, J. C., & Sreenath, K. (2009). Adoption of hygienic practices in fish landing centers and markets.
14. Balasuriya, A. (2018). Coastal area management: Biodiversity and ecological sustainability in Sri Lankan perspective. In *Biodiversity and climate change adaptation in tropical islands* (pp. 701-724). Academic Press.
15. Barry, P. J., Beraud, C., Wood, L. E., & Tidbury, H. J. (2023). Modelling of marine debris pathways into UK waters: Example of non-native crustaceans transported across the Atlantic Ocean on floating marine debris. *Marine Pollution Bulletin*, *186*, 114388.
16. Basel Convention. (2019). Basel Convention Home Page. [Online] Available at: http://www.basel.int [Accessed 23rd April, 2023]
17. Bauman, B. (2019). Why Plastics Can Be Garbage For The Climate. Yale Climate Connections. [Online] Available at: https://www.yaleclimateconnections.org/2019/08/how-plastics contribute-to-climate-change/ [Accessed 29 April 2023].
18. Beaumont, N. J., Aanesen, M., Austen, M. C., Börger, T., Clark, J. R., Cole, M., ... & Wyles, K. J. (2019). Global ecological, social and economic impacts of marine plastic. Marine pollution bulletin, 142, 189-195.
19. Bergmann, M., Gutow, L., & Klages, M. (2015). *Marine anthropogenic litter* (p. 447). Springer Nature.
20. Binetti, U., Silburn, B., Russell, J., Van Hoytema, N., Meakins, B., Kohler, P., ... & Maes, T. (2020). First marine litter survey on beaches in Solomon Islands and

Vanuatu, South Pacific: Using OSPAR protocol to inform the development of national action plans to tackle land-based solid waste pollution. *Marine Pollution Bulletin*, *161*, 111827.

21. Borrelle, S. B., Ringma, J., Law, K. L., Monnahan, C. C., Lebreton, L., McGivern, A., ... & Rochman, C. M. (2020). Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. Science, 369(6510), 1515-1518.
22. Brown, J., Macfadyen, G., Huntington, T., Magnus, J., & Tumilty, J. (2005). Ghost fishing by lost fishing gear. Final Report to DG Fisheries and Maritime Affairs of the European Commission. Fish/2004/20. Institute for European Environmental Policy/Poseidon Aquatic Resource Management Ltd joint report, 151.
23. Burgess, H., Herring, C., Lippiatt, S., Lowe, S., & Uhrin, A. V. (2021). NOAA Marine Debris Monitoring and Assessment Project Shoreline Survey Guide.
24. Burt, A. J., Raguain, J., Sanchez, C., Brice, J., Fleischer-Dogley, F., Goldberg, R., ... & Turnbull, L. A. (2020). The costs of removing the unsanctioned import of marine plastic litter to small island states. Scientific reports, 10(1), 1-10.
25. Büyükdeveci, F., & Gündoğdu, S. (2021). Composition and abundance of benthic marine litter in the fishing grounds of Iskenderun Bay, northeastern Levantine coast of Turkey. *Marine Pollution Bulletin*, *172*, 112840.
26. Castillo-Rivera, M. (2013). Influence of rainfall pattern in the seasonal variation of fish abundance in a tropical estuary with restricted marine communication.
27. CBSL. (2018). Sri Lanka Socio Economic Data 2018. [Online] Available at: https://www.cbsl.gov.lk/sites/default/files/cbslweb_documents/statistics/Sri_Lanka_%20Socio_Economic_Data_2018_e.pdf [Accessed on 23 April 2023].
28. CBSL. (2019). "Provincial Gross Domestic Product (PGDP) – 2019" Available at: https://www.cbsl.gov.lk/sites/default/files/cbslweb_documents/press/pr/press_20201220_provincial_gdp_2019 e.pdf [Accessed on 16 May 2023].
29. CBSL Annual Report 2019 | Central Bank of Sri Lanka. Retrieved April 27, 2023, from https://www.cbsl.gov.lk/en/publications/economic-and-financial-reports/annual-reports/annual-report-2019 [Accessed on 18 June 2023].

30. Census of Sri Lanka. (2012). “Census of population and housing”. Provisional information based on 5% sample. pp 1-102.
31. Cheung, P. K., Cheung, L. T. O., & Fok, L. (2016). Seasonal variation in the abundance of marine plastic debris in the estuary of a subtropical macro-scale drainage basin in South China. *Science of The Total Environment*, *562*, 658-665.
32. Chitaka, T. Y., & von Blottnitz, H. (2019). Accumulation and characteristics of plastic debris along five beaches in Cape Town. *Marine pollution bulletin*, *138*, 451-457.
33. Chiu, C. C., Liao, C. P., Kuo, T. C., & Huang, H. W. (2020). Using citizen science to investigate the spatial-temporal distribution of floating marine litter in the waters around Taiwan. *Marine Pollution Bulletin*, *157*, 111301.
34. Claereboudt, M. R. (2004). Shore litter along sandy beaches of the Gulf of Oman. *Marine pollution bulletin*, *49*(9-10), 770-777.
35. Coast Conservation (Amendment) Act, No. 49 of 2011 https://www.srilankalaw.lk/YearWisePdf/2011/COAST_CONSERVATION_(AMENDMENT)_ACT,_NO.49 OF 2011.pdf [Accessed on 20 July 2023].
36. Compa, M., Alomar, C., Wilcox, C., van Sebille, E., Lebreton, L., Hardesty, B. D., & Deudero, S. (2019). Risk assessment of plastic pollution on marine diversity in the Mediterranean Sea. Science of The Total Environment, 678, 188-196.
37. Consoli, P., Scotti, G., Romeo, T., Fossi, M. C., Esposito, V., D'Alessandro, M., ... & Andaloro, F. (2020). Characterization of seafloor litter on Mediterranean shallow coastal waters: evidence from Dive Against Debris®, a citizen science monitoring approach. *Marine pollution bulletin*, *150*, 110763.
38. Costanza, R., De Groot, R., Sutton, P., Van der Ploeg, S., Anderson, S. J., Kubiszewski, I., ... & Turner, R. K. (2014). Changes in the global value of ecosystem services. *Global environmental change*, *26*, 152-158.
39. Crompton, T. R. (2014). Engineering plastics. Smithers Rapra.
40. CZMP. (1990). “Coastal Zone Management Plan”. Sri Lanka Coast Conservation Department Colombo, Sri Lanka. pp. 1-2.

41. CZMP. (2006). 'Sri Lanka Coastal Zone Management Plan', Amendment under the Section 12(5) of the Coast Conservation Act No. 57 of 1981
42. Daily FT. (2019). Planet or plastic: is Sri Lanka making the right choices? [Online] Available at: http://www.ft.lk/environment/Planet-or-plastic-is-Sri-Lanka-making-the-right-choices/10519-676698 [Accessed 30th April, 2023].
43. Daniel, D. B., Thomas, S. N., & Thomson, K. T. (2020). Assessment of fishing-related plastic debris along the beaches in Kerala Coast, India. *Marine pollution bulletin*, *150*, 110696.
44. Dasgupta, S., Sarraf, M., & Wheeler, D. (2022). Plastic waste cleanup priorities to reduce marine pollution: A spatiotemporal analysis for Accra and Lagos with satellite data. Science of the Total Environment, 839, 156319.
45. Davison, S. M., White, M. P., Pahl, S., Taylor, T., Fielding, K., Roberts, B. R., ... & Fleming, L. E. (2021). Public concern about, and desire for research into, the human health effects of marine plastic pollution: Results from a 15-country survey across Europe and Australia. Global Environmental Change, 69, 102309.
46. De, K., Sautya, S., Dora, G. U., Gaikwad, S., Katke, D., & Salvi, A. (2023). Mangroves in the "Plasticene": High exposure of coastal mangroves to anthropogenic litter pollution along the Central-West coast of India. *Science of the Total Environment*, *858*, 160071.
47. De Vos, A., Pattiaratchi, C. B., & Wijeratne, E. M. S. (2014). Surface circulation and upwelling patterns around Sri Lanka. *Biogeosciences*, *11*(20), 5909-5930.
48. De Weerdt, L., Sasao, T., Compernolle, T., Van Passel, S., & De Jaeger, S. (2020). The effect of waste incineration taxation on industrial plastic waste generation: A panel analysis. *Resources, conservation and recycling*, *157*, 104717.
49. Dela, J. D. (2002). State of the Environment in Sri Lanka: A Report for SAARC. *Colombo, Ministry of Environment and Natural Resources (MoENR)*.
50. Dharmasiri, L. M. (2020). Waste management in Sri Lanka: challenges and opportunities. *Sri Lanka J social sci*.

51. Edirisinghe, K., Wansapala, J., & Wickramasinghe, I. (2018). Review of marine fishery status along the supply chain in Sri Lanka.
52. Ellen MacArthur Foundation. (2016). the new plastics economy—Rethinking the future of plastics. Available at: https://www.ellenmacarthurfoundation.org/assets/downloads/EllenMacArthurFoundation_TheNewPlasticsEconomy Pages.pdf. [Accessed on 20 June 2023].
53. Eriksson, C., Burton, H., Fitch, S., Schulz, M., & van den Hoff, J. (2013). Daily accumulation rates of marine debris on sub-Antarctic island beaches. *Marine pollution bulletin*, *66*(1-2), 199-208.
54. Eriksen, M., Lebreton, L. C., Carson, H. S., Thiel, M., Moore, C. J., Borerro, J. C., ... & Reisser, J. (2014). Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. PloS one, 9(12), e111913.
55. Fischer, F. (1970, April). Moisture resistance of plastic packages for semiconductor devices. In *8th Reliability Physics Symposium* (pp. 94-100). IEEE.
56. Ford, H. V., Jones, N. H., Davies, A. J., Godley, B. J., Jambeck, J. R., Napper, I. E., ... & Koldewey, H. J. (2022). The fundamental links between climate change and marine plastic pollution. Science of the Total Environment, 806, 150392.
57. Galgani, L., & Loiselle, S. A. (2021). Plastic pollution impacts on marine carbon biogeochemistry. Environmental Pollution, 268, 115598.
58. Gall, S. C., & Thompson, R. C. (2015). The impact of debris on marine life. *Marine pollution bulletin*, *92*(1-2), 170-179.
59. Gallagher, A., Randall, P., Sivyer, D., Binetti, U., Lokuge, G., & Munas, M. (2023). Abandoned, lost or otherwise discarded fishing gear (ALDFG) in Sri Lanka–A pilot study collecting baseline data. Marine Policy, 148, 105386.
60. Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science advances*, *3*(7), e1700782.
61. Ghernouti, Y., & Rabehi, B. (2012). Strength and durability of mortar made with plastics bag waste (MPBW). *International Journal of Concrete Structures and Materials*, *6*(3), 145-153.

62. Gjyli, L., Vlachogianni, T., Kolitari, J., Matta, G., Metalla, O., & Gjyli, S. (2020). Marine litter on the Albanian coastline: Baseline information for improved management. *Ocean & Coastal Management*, *187*, 105108.
63. Gómez, V., Pozo, K., Nuñez, D., Přibylová, P., Audy, O., Baini, M., ... & Klánová, J. (2020). Marine plastic debris in Central Chile: Characterization and abundance of macroplastics and burden of persistent organic pollutants (POPs). *Marine Pollution Bulletin*, *152*, 110881.
64. Gunasekara, A. J. M., Priyadarshana, R. N., Ranasinghe, T. S., Ranaweera, R. P., Fernando, E., Shanika, J. A., ... & Ranatunga, R. R. M. K. P. (2014). Status of marine debris accumulated in coastal areas of Sri Lanka. In *Proceedings of the International Forestry and Environment Symposium* (Vol. 19, p. 758).
65. Hale, R. C., Seeley, M. E., La Guardia, M. J., Mai, L., & Zeng, E. Y. (2020). A global perspective on microplastics. *Journal of Geophysical Research: Oceans*, *125*(1), e2018JC014719.
66. Hengstmann, E., Gräwe, D., Tamminga, M., & Fischer, E. K. (2017). Marine litter abundance and distribution on beaches on the Isle of Rügen considering the influence of exposition, morphology and recreational activities. *Marine pollution bulletin*, *115*(1-2), 297-306.
67. Hidalgo-Crespo, J., Álvarez-Mendoza, C. I., Soto, M., & Amaya-Rivas, J. L. (2022). Quantification and mapping of domestic plastic waste using GIS/GPS approach at the city of Guayaquil. Procedia CIRP, 105, 86-91.
68. Ikhwan, Z., Harahap, R. H., Andayani, L. S., & Mulya, M. B. (2021). Optimizing The Waste Management Of Coastal And Marine Litters To Support Environmental Cleanliness In Reducing Plastic Debris And Saving Penyengat Island. *NVEO-NATURAL VOLATILES & ESSENTIAL OILS Journal| NVEO*, 5380-5392.
69. Isobe, A., Azuma, T., Cordova, M. R., Cózar, A., Galgani, F., Hagita, R., ... & Zhang, W. (2021). A multilevel dataset of microplastic abundance in the world's upper ocean and the Laurentian Great Lakes. *Microplastics and Nanoplastics*, *1*, 1-14.

70. Issifu, I., & Sumaila, U. R. (2020). A review of the production, recycling and management of marine plastic pollution. Journal of Marine Science and Engineering, 8(11), 945.
71. IUCN Issues brief 2021, "Marine plastic pollution" - https://www.iucn.org/resources/issuesbrief/marine-plastic-pollution [Accessed on 26 June 2023].
72. Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., ... & Law, K. L. (2015). Plastic waste inputs from land into the ocean. Science, 347(6223), 768-771.
73. Jang, Y. C., Ranatunga, R. R. M. K. P., Mok, J. Y., Kim, K. S., Hong, S. Y., Choi, Y. R., & Gunasekara, A. J. M. (2018). Composition and abundance of marine debris stranded on the beaches of Sri Lanka: Results from the first island-wide survey. *Marine pollution bulletin*, *128*, 126-131.
74. Jefferson, T., & Costello, M. J. (2020). Hotspots of marine biodiversity. *Encyclopedia of the World's Biomes*.
75. Jha, A., Panda, B., & Agrawal, J. D. (2022). Study on Wave Transformation and Tranquillity Studies for the Development of Fish Landing Facility at Ajanur, Kasargod, Kerala. In River and Coastal Engineering: Hydraulics, Water Resources and Coastal Engineering (pp. 377-388). Cham: Springer International Publishing.
76. Johannes, H. P., Kojima, M., Iwasaki, F., & Edita, E. P. (2021). Applying the extended producer responsibility towards plastic waste in Asian developing countries for reducing marine plastic debris. *Waste Management & Research*, *39*(5), 690-702.
77. Kang, J. H., Kwon, O. Y., Lee, K. W., Song, Y. K., & Shim, W. J. (2015). Marine neustonic microplastics around the southeastern coast of Korea. *Marine pollution bulletin*, *96*(1-2), 304-312.
78. Kariyawasam, S., Madhuwanthi, A., & Wilson, C. (2019). The role of stakeholders in managing polythene and plastic waste in coastal cities of Sri Lanka: a case study

of the Dehiwala-Mt. lavinia municipal council region. In *E3S Web of Conferences* (Vol. 96, p. 02003). EDP Sciences.

79. Karunarathne, H. M. L. P. (2015, November). Municipal solid waste management (MSWM) in Sri Lanka. In *Proceedings of the National Symposium on Real Estate Management and Valuation* (pp. 113-126).
80. Klemchuk, P. P. (1990). Degradable plastics: a critical review. *Polymer Degradation and Stability, 27*(2), 183-202.
81. Kori, S., & Chandra, P. (2022). Numerical Simulation of Wave Conditions for Mangrol Fishing Harbour. In River and Coastal Engineering: Hydraulics, Water Resources and Coastal Engineering (pp. 161-168). Cham: Springer International Publishing.
82. Kirstein, I. V., Kirmizi, S., Wichels, A., Garin-Fernandez, A., Erler, R., Löder, M., & Gerdts, G. (2016). Dangerous hitchhikers? Evidence for potentially pathogenic Vibrio spp. on microplastic particles. *Marine environmental research*, *120*, 1-8.
83. Kumar, R., & Khan, M. A. (2020). Use of plastic waste along with bitumen in construction of flexible pavement. *Int. J. Eng. Res. Technol, 9*, 153-158.
84. Kurniawan, S. B., & Imron, M. F. (2019). Seasonal variation of plastic debris accumulation in the estuary of Wonorejo River, Surabaya, Indonesia. *Environmental Technology & Innovation*, *16*, 100490.
85. Landon-Lane, M. (2018). Corporate social responsibility in marine plastic debris governance. *Marine pollution bulletin*, *127*, 310-319.
86. Lebreton, L., & Andrady, A. (2019). Future scenarios of global plastic waste generation and disposal. *Palgrave Communications*, *5*(1), 1-11.
87. Lessy, M. R. (2020, October). Benthic marine litter accumulation at selection beaches in Ternate Island, Indonesia. In *IOP Conference Series: Earth and Environmental Science* (Vol. 584, No. 1, p. 012018). IOP Publishing.
88. Li, W. C., Tse, H. F., & Fok, L. (2016). Plastic waste in the marine environment: A review of sources, occurrence and effects. *Science of the total environment, 566*, 333-349.

89. Lin, P. I., Ku, G. C. M., Lin, H. H., Hsu, C. H., Chi, H. C., & Chen, Y. C. (2022). Investigating Sources of Marine Litter and Developing Coping Strategies in Scuba Diving Spots in Taiwan. *Sustainability*, *14*(9), 5726.
90. Lippiatt, S., Opfer, S. and Arthur, C. (2013a) Marine Debris Monitoring and Assessment: Recommendations for Monitoring Debris Trends in the Marine Environment, NOAA Technical Memorandum. Available at: https://repository.library.noaa.gov/view/noaa/2681 [Accessed on 23 June 2023].
91. Löhr, A., Savelli, H., Beunen, R., Kalz, M., Ragas, A., & Van Belleghem, F. (2017). Solutions for global marine litter pollution. *Current opinion in environmental sustainability*, *28*, 90-99.
92. Macfadyen, G., Huntington, T., & Cappell, R. (2009). *Abandoned, lost or otherwise discarded fishing gear* (No. 523). Food and Agriculture Organization of the United Nations (FAO).
93. Macintosh, A., Simpson, A., Neeman, T., & Dickson, K. (2020). Plastic bag bans: Lessons from the Australian Capital Territory. *Resources, Conservation and Recycling*, *154*, 104638.
94. Manchanayake, E. P., and Madduma Bandara, C. M. 1999. Water resources of Sri Lanka. In: Natural Resources of Sri Lanka 2000. Colombo: National Science Foundation
95. Mangor, K. August 2002. Background Document for the Chapter on Shoreline Management of the Second Revision of the CZMP. unpubl. Institutional Strengthening Component of the Coastal Resources Management Project, ADB TA No. 3477-SRI.
96. Martínez, M. L., Intralawan, A., Vázquez, G., Pérez-Maqueo, O., Sutton, P., & Landgrave, R. (2007). The coasts of our world: Ecological, economic and social importance. *Ecological economics*, *63*(2-3), 254-272.
97. MCUDP, 2018. Metro Colombo urban development project. Ministry of Megapolis and Western Development. Progress presentation made by June 2018

98. Meakins, B., Preston-Whyte, F., Silburn, B., Binetti, U., Glassom, D., Barry, J., ... & Maes, T. (2022). Standing stock and daily accumulation of beach litter in KwaZulu-Natal, South Africa. Regional Studies in Marine Science, 53, 102421.

99. Meijer, L. J., Van Emmerik, T., Van Der Ent, R., Schmidt, C., & Lebreton, L. (2021). More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. *Science Advances*, *7*(18), eaaz5803.

100. Mills, R. (2012). What it means to go green: reduce, reuse, repurpose, and recycle.

101. Ministry of Environment, 2021. National Action Plan on Plastic Waste Management 2021–2030. Ministry of Environment (MoE), SriLanka. Available online: https://www.unep.org/ietc/resources/report/national-action-plan-plastic-waste-management-2021-2030 [Accessed on 29 May 2023].

102. MoE, 2012. The National Red List 2012 of Sri Lanka; Conservation Status of the Fauna and Flora. Colombo, Sri Lanka: Ministry of Environment. viii + 476pp.

103. Mongabay (2019). Microplastics a key factor in Sri Lanka's plunging fish stocks, survey shows. Available online: https://news.mongabay.com/2019/06/microplastics-a-key-factor-in-sri-lankas-plunging-fish-stocks-survey-shows/ [Accessed on 20 June 2023].

104. Monteiro, I. B., Dantas, D. V., Makrakis, M. C., Lorenzi, L., Ribeiro, S. A., Pezzin, A. P. T., Silveira, V.F., & Gentil, E. (2022). Composition and spatial distribution of floating plastic debris along the estuarine ecocline of a subtropical coastal lagoon in the Western Atlantic. Marine Pollution Bulletin, 179, 113648.

105. Morales-Caselles, C., Viejo, J., Martí, E., González-Fernández, D., Pragnell-Raasch, H., González-Gordillo, J. I., ... & Cózar, A. (2021). An inshore–offshore sorting system revealed from global classification of ocean litter. *Nature Sustainability*, *4*(6), 484-493.

106. Mouat, J., Lozano, R. L., & Bateson, H. (2010). *Economic impacts of marine litter*. Kommunenes Internasjonale Miljøorganisasjon.

107. NARA. (2017). Socio –Economic and Marketing Research Division: Fisheries Industry Outlook- 2017. [Online] Available at: http://www.nara.ac.lk/wp-content/uploads/2017/09/Fisheries-Industry-outlook-2017.pdf [Accessed 28th May, 2023]

108. NARA. (2018). Launching Ceremony of Dr.Fridtjof Nansen Preliminary Cruise Report. [Online] Available at: http://www.nara.ac.lk/?page_id=7268 [Accessed 17th June, 2023]

109. Niroshana, K. H. H., H. B. Asanthi and P. B. T. P. Kumara (2013). "An assessment of water quality and pollution in Puranawella fishery harbour, Dewinuwara, Sri Lanka". Available online: file:///C:/Users/KAWS/Downloads/6157-21804-1-PB.pdf [Accessed 24th April, 2023].

110. Neumann, B. et al. (2015) 'Future coastal population growth and exposure to sea-level rise and coastal flooding - A global assessment', PLoS ONE, 10(3). doi: 10.1371/journal.pone.0118571.

111. NewsIn.Asia. (2017). Sri Lanka's ban on polythene, styrofoam comes into effect. [Online] Available at: https://newsin.asia/sri-lankas-ban-polythene-styrofoam-comes-effect/ [Accessed 25 March 2023].

112. Nguyen, T. T., & Nguyen, T. P. (2022). Marine Plastic Litter in Phu Quoc Marine Protected Area, Vietnam: Current Status and Mitigation Approaches. *InżynInżynieria Mineralna (Journal of the Polish Mineral Engineering Society)*, *1*, 107-113.

113. Nyberg, B., Harris, P. T., Kane, I., & Maes, T. (2023). Leaving a plastic legacy: Current and future scenarios for mismanaged plastic waste in rivers. Science of the Total Environment, 869, 161821.

114. Ocean Conservancy (2017). Together for our ocean: International coastal cleanup 2017 report. *IC Cleanup, Editor*.

115. Ocean Conservancy, McKinsey Center for Business and Environment. Stemming the tide: land-based strategies for a plastic-free ocean. 2015. Available

from:
https://www.mckinsey.com/w/media/McKinsey/Business%20Functions/Sustainability/Our%20nsights/Stemming%20the%20tide/Stemming%20the%20tide%20Land%20based%20strategies20for%20a%20plastic%20free%20ocean.ashx. [Accessed 24th May, 2023]

116. Opfer, S., Arthur, C., & Lippiatt, S. (2012). NOAA Marine Debris Shoreline Survey Field Guide.

117. Opie, B. (2021). *Seasonal and long-term change in the abundance, accumulation and distribution of beach litter within Table Bay, Cape Town, South Africa* (Master's thesis, Faculty of Science).

118. PlasticsEurope (2015). An analysis of European plastics production, demand and waste data. Plastics–the facts, 147

119. Prasetiawan, N. R., Sudirman, N., Salim, H. L., Ati, R. N. A., Kepel, T. L., Daulat, A., ... & Sukoraharjo, S. S. (2022, December). Preliminary Study Of Marine Debris Composition From Fisherman Activities: A Case Study On Cikidang Fishing Port, Pangandaran. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1118, No. 1, p. 012082). IOP Publishing.

120. Rebai, N., Mosbahi, N., Dauvin, J. C., & Neifar, L. (2022). Ecological Risk Assessment of Heavy Metals and Environmental Quality of Tunisian Harbours. Journal of Marine Science and Engineering, 10(11), 1625.

121. Ribbink, A., Baleta, T., Martin, S., Mbongwa, N., & Bray, D. (2018). Guideline to marine litter monitoring.

122. Samarasinghe, K., Pawan Kumar, S., & Visvanathan, C. (2021). Evaluation of circular economy potential of plastic waste in Sri Lanka. *Environmental Quality Management*, *31*(1), 99-107.

123. Santos, R. G., Machovsky-Capuska, G. E., & Andrades, R. (2021). Plastic ingestion as an evolutionary trap: Toward a holistic understanding. *Science*, *373*(6550), 56-60.

124. Scholtens, J. (2016). *Fishing in the Margins: North Sri Lankan Fishers' Struggle for Access in Transboundary Waters*. Universiteit van Amsterdam [Host].

125. Sciortino, J. A. (2010). *Fishing harbour planning, construction and management*. Rome, Italy: Food and Agriculture Organization of the United Nations.

126. Shams, M., Alam, I., & Mahbub, M. S. (2021). Plastic pollution during COVID-19: Plastic waste directives and its long-term impact on the environment. Environmental advances, 5, 100119.

127. Silva-Cavalcanti, J. S., Barbosa de Araujo, M. C., & Ferreira da Costa, M. (2009). Plastic litter on an urban beach—a case study in Brazil. *Waste Management & Research*, *27*(1), 93-97.

128. Sri Lanka Export Development Bank. (2020). Plastic & Plastic Product Industry: Plastic Product Manufacturing In Sri Lanka. [Online] Available at: https://www.srilankabusiness.com/plastic/overview.htm [Accessed 25 May 2023].

129. Survey Department of Sri lanka. 2007. National Atlas of Sri Lanka. 2nd ed. Colombo: Survey Department of Sri Lanka

130. Tan, W., Cui, D., & Xi, B. (2021). Moving policy and regulation forward for single-use plastic alternatives. *Frontiers of Environmental Science & Engineering*, *15*, 1-4.

131. Ten Brink, P., Schweitzer, J. P., Watkins, E., Janssens, C., De Smet, M., Leslie, H., & Galgani, F. (2018). Circular economy measures to keep plastics and their value in the economy, avoid waste and reduce marine litter (No. 2018-3). Economics Discussion Papers.

132. Teuten, E. L., Saquing, J. M., Knappe, D. R., Barlaz, M. A., Jonsson, S., Björn, A., ... & Takada, H. (2009). Transport and release of chemicals from plastics to the environment and to wildlife. *Philosophical transactions of the royal society B: biological sciences, 364*(1526), 2027-2045.

133. Thevenon, F., Carroll, C., & Sousa, J. (2014). Plastic debris in the ocean: the characterization of marine plastics and their environmental impacts, situation analysis report. *Gland, Switzerland: IUCN, 52*.

134. Tiseo, I. (2022). Global Plastic Production 1950–2021. *can be found under https://www. statista. com/statistics/282732/global-production-of-plastics-since-1950/(accessed 28.12. 2022)*.

135. UN News. (2014). Plastic waste causes $13 billion in annual damage to marine ecosystems, says UN agency, Retrieved from: https://news.un.org/en/story/2014/06/471492-plastic-wastecauses-13-billion-annual-damage-marine-ecosystems-says-un-agency

136. UNEP (2016) Marine plastic debris and micro plastics – Global lessons and research to inspire action and guide policy change. United Nations Environment Programme, Nairobi.

137. Van Acoleyen, M., Laureysens, I., Stijn, L., Raport, L., Van Sluis, C., Kater, B., ... & Ferreira, M. (2013). ARCADIS final report marine litter study to support the establishment of an initial quantitative headline reduction target.

138. Wang, M. H., He, Y., & Sen, B. (2019). Research and management of plastic pollution in coastal environments of China. Environmental pollution, 248, 898-905.

139. Webb, H. K., Arnott, J., Crawford, R. J., & Ivanova, E. P. (2012). Plastic degradation and its environmental implications with special reference to poly (ethylene terephthalate). *Polymers*, *5*(1), 1-18.

140. Weerakoon, W. R. W. M. A. P., Samaranayake, T. B. D. T., Jayasiri, H. B., & Arulananthan, K. (2018). Quantitative analysis of micro-plastic contamination in beach sand at the Western and Southwestern coastal stretches in Sri Lanka. *International Scientific Sessions*.

141. Weerasekara, K. A. W. S., Jayampathi, O. M. M. D., Hettige, N. D., Azmy, S. A. M., Amarathunga, A. A. D., Wickramaarachchi, W. D. N., ... & Liyanage, N. P. P. (2015). Assessment of water pollution status of selected Fishery harbours

located in the southern province of Sri Lanka. Journal of Environmental Professionals Sri Lanka, 4(2).

142. Welden, N. A. (2020). The environmental impacts of plastic pollution. In Plastic waste and recycling (pp. 195-222). Academic Press.

143. Wijethunga, H. S., Athawuda, A. M. G. A. D., Dias, P. C. B., Abeygunawardana, A. P., Senevirathna, J. D. M., Thushari, G. G. N., ... & Jayamanne, S. C. (2019). Screening the effects of microplastics on selected invertebrates along southern coastal belt in Sri Lanka: a preliminary approach to coastal pollution control.

144. Wootton, N., Nursey-Bray, M., Reis-Santos, P., & Gillanders, B. M. (2022). Perceptions of plastic pollution in a prominent fishery: building strategies to inform management. *Marine Policy*, *135*, 104846.

145. Yapa, K. K. (2000). Seasonal variability of sea surface chlorophyll-a of waters around Sri Lanka. Journal of Earth System Science, 109, 427-432.

146. Zhukov, A. (2017) the distribution, abundance and characteristics of plastic debris along the Coast of Grândola, Portugal Degree Programme in Sustainable Coastal Management. Yrkeshogskolan Novia

7 APPENDIX

7.1 Appendix A (Questionnaire surveys form)

Investigation on plastic waste utilization and management in fishery harbors of Sri Lanka

1) Gender ; Male ….. Female …..

2) Fishery harbor ; BFH ….. NDFH ….. SDFH …… PFH …..
NFH …..

3) Age category ;
<20 ……
20-29 ……
30-39 ……
40-49 ……
>50 ……

3) Education background ;
Illiterate …..
Primary education …..
Secondary education …..
Graduate …..
Postgraduate …..

4) Are you aware and concerned about the plastic pollution that takes place at the harbor premises?

Yes ….. No …..

5) What is the key contributing factor for the plastic waste generation inside harbor premises?
   - Poor waste management of CFHC …..
   - Fishermen's bad practices …..
   - Outside sources (river flows, water canals, tide and wind current)…..

6) Throughout the time what happened to the rate of plastic debris accumulation inside harbor?
   - Increased …..
   - Decreased …..
   - Constant …..
   - No idea …..

7) Who should responsible for implementing plastic waste management strategies inside harbor premises?
   - The government …..
   - Coastal community …..
   - Others ….. (Explain; …………………………………………………………….)

8) What do you do for the plastic waste generated?
   - Discard debris into the bins …...
   - Discard debris into open environment ……
   - Sanitary landfilling ……
   - Burn …..
   - Send to plastic recycling centers …..

9) Can you continue the fishing activities if plastic products ban?
   - Yes, we can ……
   - No, we can't ……
   - Not sure ……

10) Are you following plastic departure form system?
   - Yes, I'm following ……
   - No, I'm not ……

7.2 Appendix B (Data collection sheets)

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
Date	21-C	26-C	2-N	9-N	15-N	30-N	8-D	15-D	21-D	28-D	4-J	12-J	18-J	3-F	7-F	3-M	9-M	29-M	4-A	19-A	26-A	18-M	30-M
Total weight	0.57	0.37	0.12	0.57	1.615	1.77	2.13	2.295	2.715	1.75	2.035	2.04	1.925	2.47	2.84	1.98	2.32	1.365	1.595	1.65	0.485	2.365	2.32
Tide level	>0.5m	>0.2	<0.4	>0.1	>0.3	<0.48	>0.38m	<0.4	<0.48	>0.2	>0.31	<0.5	>0.4	<0.41	<0.23m	<0.5	>0.57	>0.35m	>0.68	>0.57	<0.38m	<0.7m	>0.59 m
Plastics																							
Film fragments		2		3		1				2		1	1		2	1						2	
Foam fragments						1	1	1	2	2	5	5	16	3	2		2	4	1	2		8	3
Hard fragments																							1
Bags	3	1		1	1	4	1		2	4		2	2		2	1	1	3	3	1			2
Rice bag		2	1		2	2	2	5	10	4	5	2	4	1	6	2		3	2	4		6	2
Beverage bottles	6	5	6	5	6	9	9	7	5	9	5	6	4	5	6	5	4	7	6	5	8	8	7
Bottle or container caps		1			2										1		1	1	2	2		1	3
Cups (including polystyrene/foam)	2				1	2					1								1	1		2	
Food wrappers	2	1		1	4	3	4	1	1	5	3	2	2	1	2	1	2		2	3	3	4	1
Other jugs and containers		2				4	1	2	2	4	5	4	2	3	4	2	2	6	4	3		2	1
Straws									5		3						1						1
Utensils																							
Six-pack rings									1														
Cigar tips		1	2														1			1			2
Cigarettes																							
Disposable lighters																			1				1
Buoys and floats	1			1			1	1	1	1			1		1					2			1
Lures and line														1		1					1		
Rope and nets											2				2		2						
Fish wrappers	3		3	4	3		3		5		4	2	4	1	1	1		1	3	1			1
Personal care products						2	2	2		3	1			2			1			1			2
Balloons (mylar)																							
Other plastic	1				1				1		2	1	1						1		1	2	
METAL																							
Metal fragments																							
Aerosol cans																		2					
Aluminum/tin cans	5	3	1	2		3					1			1	1		2			3			2
Other metal				1						1		1	1			1						1	
GLASS																							
Glass fragments																							
Beverage bottles	1																1		1				2
Jars																							
Other glass						1									1								
RUBBER																							
Rubber fragments							1		1			1	1					2		1		4	1
Balloons (latex)																							

P1 P2 P3 P4 P5 P6 P7 P8 P9 P10 P11 P12 P13 P14 P15 P1 …

	A	B	C	D	E	F	G
1	Plastics	Beruwala	N.Dik	S.Dik	Panadura	Negombo	Total
2	Film fragments	186	164	175	112	10	647
3	Foam fragments	551	1736	1225	577	14	4103
4	Hard fragments	50	70	93	28	4	245
5	Bags	263	260	168	380	16	1087
6	Rice bag	240	105	163	50	1	559
7	Beverage bottles	1408	1307	906	739	14	4374
8	Bottle or container caps	423	312	538	88	9	1370
9	Cups (including polystyrene/foam)	206	132	144	72	6	560
10	Food wrappers	923	452	500	252	13	2140
11	Other jugs and containers	496	325	362	214	4	1401
12	Straws	109	35	59	19	2	224
13	Utensils	73	50	104	21	2	250
14	Six-pack rings	2	0	0	0	0	2
15	Cigar tips	62	37	19	35	6	159
16	Cigarettes	0	0	0	0	0	0
17	Disposable lighters	51	43	56	24	1	175
18	Buoys and floats	112	157	101	23	4	397
19	Lures and line	9	19	5	17	0	50
20	Rope and nets	149	172	188	18	9	536
21	Fish wrappers	184	390	462	39	3	1078
22	Personal care products	197	191	252	84	3	727
23	Balloons (mylar)	0	0	1	0	0	1
24	Other plastic	210	222	251	134	8	825
25		5904	6179	5772	2926	129	20910