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The Spatial Distribution of Meso- and Macroplastics in the River Rhine

Results of the Kor-net fishing in 2021 and 2022

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Colophon

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Preface

This report was written as a graduation internship for the Environmental Science for Sustainable Energy and Technology programme of Avans University of Applied Sciences in Breda. The graduation internship took place at Rijkswaterstaat Oost-Nederland within the department Netwerkontwikkeling en Visie (NOV) and team water quality and ecology.

I would like to thank everyone that has helped me during all the activities that have been done during the project duration. I want to express my gratitude to the crew of the ship on which the samples were taken; Pieter Visser, Leo Visser and Klaas Jelle de Berg. I want to thank Marleen Kalsbeek, Anke Cotteleer, Frank Kok, Hans Miedema, Harry Smit, and Jan Willem Mol of the department Centrale Informatievoorziening (CIV) and team Mobiel Meten (MM) for the preparations of the survey, supervision during the measurements and for executing and analysing the results of the ADCP measurements. Furthermore, I would like to thank everyone that helped with the measurements on board of the ship, and afterwards in sorting and counting the samples; Lorraine Minnaar, Iris van der Grift, Jakob Grosfeld, Frans Buschman, Paul Vriend, Wout Veelenturf, Anna Oosterwegel and Daniël van Nooten. I would like to thank Frank Collas from Rijkswaterstaat Zuid-Nederland for helping during one of the measuring days and providing feedback on my concept report, as well as my fellow students Lucas Vogels and Gallus Pasch who were able to review the draft version. I want to thank Samet Azman, my educational supervisor who was always reachable for questions and provided guidance and feedback where needed. Special thanks to Margriet Schoor, my supervisor from Rijkswaterstaat who has provided me with the opportunity to do this project and has shown great guidance and involvement throughout the entire project.

Abstract

The introduction of plastics in the 1930s had many advantages for society. Hygiene improved drastically and it was easy to use. Nowadays, it is almost impossible to imagine a world without plastics. Over the years, more information was gathered and also the downsides of plastics gained more attention. Production of plastics requires crude oil, and recycling is not easy because there are many different types of plastic. Most plastic is designed to be disposable, and these disposables do not always reach the correct facilities where they can be appropriately processed. Much plastic ends up in the sea and rivers serve as transport routes. However, it is largely unknown how much plastic is carried along by the Rhine. To develop a representative monitoring strategy, the spatial and temporal distribution of the plastic in the water column must be taken into account. To achieve this, samples were taken of the plastic in the Rhine in 2021 and 2022. This study investigates the spatial distribution of plastics in the river Rhine, with samples taken from 9 different places in the cross-section of the river over the years 2021 and 2022. The location is on the border of Germany and the Netherlands, in a river bend. The outer bend, on the right side, is in the Netherlands and the inner bend, left in the river is on German territory. A fishing ship was used with Kor-nets to catch the plastics from the river, after which the plastics were categorized and counted. Analysis showed that most plastics found (> 70%) were undefinable pieces of plastic film. Other abundantly found categories were string and cord, sanitary wet wipes, hard pieces of plastic, and food packaging. It was found that light pieces of plastics, like Styrofoam, are found mainly on the right side of the river on the surface. Heavy pieces of plastics, that are expected to show similar moving patterns as sediment, are the sanitary wet wipes. These were found in significantly higher concentrations on the bottom and on the left side of the river, in the inner bend. Almost no items of this category were found on the right side of the river. Furthermore, a linear regression showed that the plastic concentrations are influenced by the water height and whether this is rising or lowering. Plastic concentrations are found to be higher with higher water levels. The linear regression model with data from 2022 also showed that it matters whether the water height is increasing or decreasing. Rising water contains significantly higher concentrations of plastic than lowering water. In future research, with additional data, another bend in which the left side is the outer bend could be compared to this study to analyse whether the results from the spatial distribution are mirrored, or the spatial distribution is dependent on the side. It is also recommended to explore the relation of rising and lowering water during future research further, preferably with a large range of water heights.

Samenvatting

De introductie van plastics in de jaren dertig had veel voordelen voor de samenleving. De hygiëne verbeterde en het was gemakkelijk in gebruik. Een wereld zonder plastic is tegenwoordig bijna niet meer voor te stellen. In de loop der jaren is er meer kennis opgedaan en ook de nadelen van plastic kregen meer aandacht. Voor de productie van plastic is ruwe olie nodig en recycling is niet eenvoudig omdat er veel verschillende soorten plastic zijn. Het meeste plastic is ontworpen voor eenmalig gebruik en deze wegwerpartikelen komen niet altijd bij de juiste faciliteiten terecht waar ze op een correcte manier kunnen worden verwerkt. Veel plastic eindigt in zee en rivieren zijn transportroutes, ook van plastic. Hoeveel plastic er door de Rijn wordt meegevoerd is echter grotendeels onbekend. Om te komen tot een representatieve monitoringsstrategie is het van belang dat er rekening wordt gehouden met de ruimtelijke en temporele spreiding van het plastic in de waterkolom. Daarom zijn er in 2021 en in 2022 monsters genomen van het plastic in de Rijn. Dit rapport onderzoekt de ruimtelijke verspreiding van plastic in de Boven-Rijn, met monsters genomen op 9 verschillende plaatsen in de dwarsdoorsnede van de rivier over de jaren 2021 en 2022. De locatie ligt op de grens van Duitsland en Nederland, in een rivierbocht . De buitenbocht, aan de rechteroever, ligt in Nederland en de binnenbocht, links in de rivier ligt op Duits grondgebied. Om de plastics uit de rivier te verzamelen, werd een vissersschip gebruikt met Kor-netten, waarna de plastics werden gecategoriseerd en geteld. Analyse toonde aan dat de meeste gevonden plastics (> 70%) ondefinieerbare stukjes plastic folie of stukken daarvan waren. Andere veel gevonden categorieën waren touw en koord, vochtige hygiënische doekjes, harde stukken plastic en voedselverpakkingen. Het bleek dat lichte stukjes plastic, zoals piepschuim, vooral aan de rechterkant van de rivier aan de oppervlakte te vinden zijn. Zware stukken plastic, waarvan verwacht wordt dat ze vergelijkbare bewegende patronen vertonen als sediment, zijn de vochtige doekjes. Deze werden in significant hogere concentraties aangetroffen op de bodem en aan de linkerkant van de rivier, in de binnenbocht. Aan de rechterkant van de rivier werden bijna geen doekjes gevonden. Verder liet een lineaire regressie zien dat de plastic concentraties worden beïnvloed door de waterhoogte, en het feit of deze stijgt of daalt. De plastic concentraties blijken hoger te zijn bij hogere waterstanden. Ook liet het lineaire regressiemodel met gegevens uit 2022 zien dat het uitmaakt of de waterstand stijgt of daalt. Stijgend water bevatte significant hogere concentraties plastic dan dalend water. In toekomstig onderzoek, met aanvullende gegevens, zou een andere bocht waarin de linkeroever de buitenbocht is, vergeleken kunnen worden met dit onderzoek om te analyseren of de resultaten van de ruimtelijke verdeling gespiegeld zijn, of dat de ruimtelijke verdeling afhankelijk is van de zijde waar bemonsterd is. Ook wordt er aanbevolen om de relatie tussen stijgend en dalend water bij toekomstig onderzoek nader te onderzoeken, bij voorkeur met een grote spreiding aan waterhoogtes.

Contents

1 Introduction

1.1 Background

1.1.1 General Background

Since the introduction of plastics in the 1930s, the production rates have increased because of the beneficial properties of plastics in terms of hygiene and comfort [1]. Nowadays, plastics are a crucial component of the current economy. Between 2000 and 2016, as many plastics were produced as in all the years prior [2]. In 2020, 55 megatons of plastics were produced from non-recycled material [3]. Most plastics are designed as disposable materials, 75% of the plastic is produced to be waste [2]. It is estimated that a third of this plastic waste ends up in nature due to littering or inadequate disposal [3]. This plastic can break or rip under physical conditions and turn into pieces getting smaller and smaller.

The environmental effects associated with plastic pollution have been known for a while. Especially plastics in the marine environment and the negative consequences on marine ecosystems have received a lot of publicity over the last couple of years. Rivers are a major contributor of plastics that end up in the marine environment, as they function as a means of transportation for plastic from land to sea [8] [9]. It is estimated that 80% of the plastics in the marine environment originate from terrestrial sources [10]. Plastics that are either inadequately disposed of, or are stored in landfills can enter the water column of the river. They transport from land to river by the influence of hydrometeorological variables such as wind or rain, causing surface runoff [8]. Other examples of sources of plastic in rivers are through direct dumping, or sewage discharge [8].

A problem with plastic in the aquatic environment is that animals can get entangled in large pieces of plastic, causing injuries or death [4]. Furthermore, under influence of microbial activity and sunlight, plastics can degrade into smaller toxic parts [10]. Smaller pieces of plastic have been found in the stomachs of mammals, fish, and birds in large quantities. This can cause the digestive system to shut down, and toxins from the plastics can cause defects in the immune systems of animals [5]. Microplastics are also found in zooplankton and phytoplankton [6]. These microplastics and the toxins they carry can cause negative effects on animals higher up in the food chain through bioaccumulation [7] [10].

1.1.2 Prevention of plastics in rivers

As of the 3rd of July 2021, a ban on certain single-use plastics was introduced in the EU [15]. This ban is aimed at plastic cutlery, plates, cups, balloon sticks, cotton buds and more. These single-use plastics are responsible for 25% of the waste along the riverbanks of the Rhine and Meuse in 2019 [11]. Legislation like this is expected to help reduce the problem. However, to develop the right legislation, it is essential to have knowledge on the plastics that are currently found in the aquatic environment and their behaviour. With the sustainable development goals on which was agreed by the United Nations in 2015, nations are obliged to tackle environmental problems, including plastic pollution [14]. Appendix I shows a sustainability analysis, in which the project assignment is linked to the sustainable development goals, and how the topic contributes to these goals.

To reduce the number of plastics in the Rhine, information about which plastics are present in the river is needed. Thereby, the origin of these plastics can be estimated better. Until now, most research in this field has focused on floating plastics, microplastics and plastics on the riverbanks [11] [12] [13]. The quantity of macroplastics in the water column of the river is not widely researched yet. Therefore, it is important to determine the plastic concentration in the water column, including the spatial distribution within the river. In the current project, mesoplastics

(0.5 – 2.5 cm) and macroplastics (> 2.5 cm) in the river Rhine were researched, at different depths and locations in the cross profile of the river. A better understanding of the amount and types of plastic in the river will be created with this information. This can be used to develop and implement suitable measures to reduce the amount of plastic in rivers.

It is important to measure plastic concentrations in different places in the river since the discharge is dependent on numerous variables, and differs locally between positions in the water column. The depth, whether there are training structures (e.g. groynes) or not and the configuration of bends in the river all influence the flow rate. In river bends, the flow rate is higher in the outer bend than in the inner bend [17]. This is also the reason for the meandering of a river. Where the flow rate is high, sediment is taken up, and where the flow rate is low, sediment deposition takes place [17]. Another flow pattern due to the presence of river bends is the spiral flow or helicoidal flow. Because the velocity is higher in the outer bend, the water is higher on that side. Due to gravity, near the bottom of the river, the water moves in the opposite direction, creating a spiral flow, and sediment deposits in the inner bend of the river [17][14].

1.1.3 *Problem statement*

From 2018 until 2021, plastic samples have been taken from different river branches of the Rhine by Rijkswaterstaat in collaboration with Sportvisserij Nederland and the Radboud University using stow net fishing and smaller so-called 'larvae nets' [16] [17]. These samples were taken with different equipment than used in this research. This project will build upon the knowledge that has been gathered in the earlier research. The most important remaining question to be answered from this research was the influence of different places in the cross profile of the river. This has not been researched earlier. The current report gives an insight into the plastic distribution from left to right in the river and from the surface to the bottom.

1.2 Goal

This project aims to identify where the plastics in the Rhine are located and which categories of plastics contribute the most to the plastic content of the river. The following subgoals were formulated to reach the main goals:

- Analysing the different categories found in the plastics and creating an overview of which categories are found abundantly in both years of sampling.
- Analysing the effect of depth and location in the cross profile of the river on the plastic concentrations.
- Analysing the effect of temporal variation in plastic concentrations of the plastics found In 2021 and 2022
- Analysing the effect of water height and whether the water is rising or lowering, to see if this has a significant effect on the plastics found.

1.3 Boundaries

To reach the main goal of the project, boundaries have been set. These boundaries define the scope of the research and are listed below.

- This research focuses on mesoplastic (0.5 – 2.5 cm) and macroplastic (> 2.5 cm). In the analyses, no distinction was made between meso- and macroplastic.
- The dataset that has been researched in this report exclusively contains the results of the Kor-net fishing of 2021 and 2022.
- The project duration was 20 weeks, in which the samples from 2021 and 2022 were categorized and counted, and statistically analysed. The survey of 2022 was also part of the project.

1.4 Hypotheses

It is expected that most of the plastics that will be found in this research will be undefinable soft pieces of film. In earlier research, this category was dominant in the river Rhine above other categories [16] [17]. Expectedly, this is because of the transport through the river. It is possible that most plastics are ripped by rocky sediment or by ships, causing the large plastics to break down into smaller, undefinable pieces.

Regarding the spatial distribution, earlier research, which used smaller nets and sampled at different locations, has analysed three different depths [16]. Here, the highest concentrations were found on the top layer of the water column, however, this difference was not significant. Light particles would be expected to concentrate in the top layer and the middle, where the river discharge is highest. Heavier particles such as the harder plastics are expected to be more abundant on the bottom of the river. From left to right, the light particles, both suspended and floating, are expected to move with the river where the river flow is the most rapid. In this case, because the research takes place in a river bend, the outer bend, the right side, is expected to transport most plastics. However, a previous study with floating plastics on a straight part of the river Rhine showed large variances in the cross-section of the river [13]. It was suggested that the spatial spreading was mainly influenced by factors such as discharge and wind. Heavy particles laying on the river bed among the sediment, are expected to show the same behaviour as sediment. They are impacted by the spiral river flow in the river bend as explained in 1.1.2. This would mean that they would concentrate on the left side of the river.

High water is expected to have an impact on the plastic concentrations measured in the river. High water can transport plastic from the riverbanks and floodplains to the water column. Furthermore, high water is often caused by heavy rains, which can also contribute to plastic transport from land to river. Results of research in which plastic transport was measured in the river Seine, France show increased amounts of plastic observed during periods with high discharge [18]. In periods with rising water, it is expected that more waste is present in the water than during times where the water height is decreasing.

1.5 Reading Guide

Chapter 2 contains the methodology, in which all the steps undertaken to obtain and analyse the results are outlined. In the following chapter, results, all the analyses that have been done during the research are outlined. Chapter 4 contains the discussion. Here, the results are examined and compared to previous research that has been conducted. The conclusion can be found in chapter 5. Finally, chapter 6 contains recommendations that can be used for future research.

2 Methodology

2.1 Survey

Samples were taken with a Kor-net from a fishery ship at kilometre 860 of the river Rhine, which is near Lobith. The name of the ship was 'De Stern' and it is property of the 'Rijksrederij Nederland'. Figure 1 shows a picture of the ship with one of the nets. The Kor-net was explicitly made for this purpose and had a surface area of 4 m^2 and a maze width of 6 mm. Samples were taken using this equipment in 2021 and 2022. In 2021, the sampling duration was for a minimum of 30 minutes. The exact time was noted down.

Figure 1: Ship 'De Stern' of Rijksrederij Nederland with one of the nets used during the survey. Photograph taken by Pieter Visser.

Also, the local flow velocity in the river was measured by performing Acoustic Doppler Current Profiler measurements (ADCP). This is an accurate way to measure the velocity of the water at specific places in the river. With these measurements, the volume of water sampled can be determined, which is required to analyse the plastic concentrations. The ADCP transmits high-pitched sound waves and based on the signal that it receives back, velocities can be calculated. The principle is that objects approaching the instrument give back a higher-pitched signal than the transmitted signal, and objects moving away from the instrument give back a lower-pitched signal [19].

The samples were taken at different locations in the cross profile of the river, the left, middle, and right. The left side, in this case, is the South and the right side the North, looking in the same direction as the river flow (Figure 2). The middle and the right side were on the border of the fairway, and the left side was on the more shallow inner bend. There were also three different depths; the surface, the middle, and the bottom, resulting in nine measured locations. Bottom measurements were performed slightly above the bottom, since otherwise, stones would get in the net, causing it to break and the samples to be lost. Therefore, the net was placed in a frame that caused the net to stand approximately 5 - 10 centimetres above the bottom of the river.

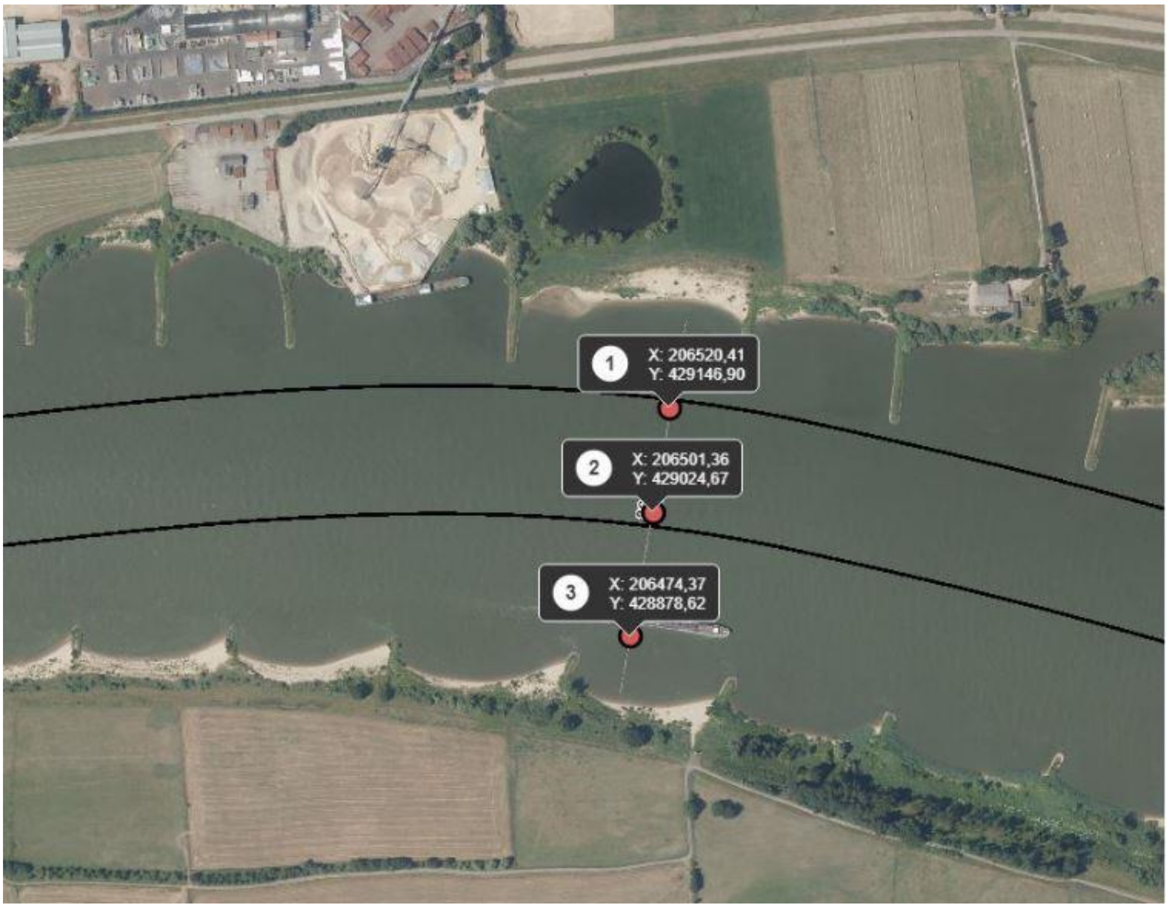

Figure 2: Locations where the samples were taken. 1) Right, 2) Middle, 3) Left [29]. The black lines indicate the borders of the fairway.

The same methodology was followed in 2022, but the measurements were performed 40 minutes to obtain more pieces of plastic in the samples. Four samples were taken for 20 minutes. This was because large quantities of debris were caught on that day, and 20 minutes was enough time for the samples to contain enough material for analysis still. A longer measuring time would have clogged the net, causing the flow rate through the net to decrease and the discharge determination (and the concentration) would no longer be accurate. In 2021, the sampling was performed only on one side of the ship. In 2022, nets were used on both sides of the ship simultaneously. On board of the ship, where possible, most of the organic matter was already sorted out to save time afterwards in cleaning the samples.

2.2 Sample Analysis

In 2022, it was attempted to remove most of the organic matter from the samples on board. This was possible when enough workers were on board and if the weather allowed it. It was necessary that it was light enough and not a lot of wind to make this possible. Otherwise, the plastics were not visible well enough, or there was too much movement, with the risk of plastics blowing away. The samples were laid out on a table and pincers were used to collect the plastics from the samples, as illustrated in Figure 3. The plastics were collected in plastic zip bags. It was essential that this was done carefully, for every piece of plastic to be sorted out. Sorting on board was not possible for all of the samples, because of lack of time or not adequate weather circumstances. Where this was not possible, which was the case for approximately 50% of the samples, the samples were sorted out in a later stage. Where possible, two different people worked on this step, to make sure that it was sorted to the highest extent possible. Sorting out a sample took, depending on the size of the sample, approximately 0.5 hours for smaller samples to 1.5 hours for the larger samples.

Figure 3: Sorting the samples on board of the ship.
Photograph taken by Pieter Visser.

After the organic matter was separated from the plastics, the samples were categorized and counted. The contents of the bags were emptied in a tray with a layer of water in it. This made it easier to distinguish the different types of plastic in the sample and the different kinds of waste did not stick to each other this way. The large parts were taken out first, and sorted onto another tray, without water. Each piece of plastic that was larger than 0.5 centimetres was sorted on this tray. Pieces of metal, clothing, sanitary items and cigarette butts were also taken out of the sample and sorted. Every piece was characterised into categories, using the OSPAR classification system [20]. Of each sorted sample, a picture was taken, in case something needed to be looked after at a later stage or for future researchers. Examples of these pictures can be found on the report cover. The contents of the sample were stored in the same bag that the sample was in before classification. If there were any comments, insecurities, or a brand, year, or language could be distinguished from the plastics, this was noted down as a comment. The sample analysis was performed for 57 samples that were taken in 2021 and 71 samples from 2022. This took approximately 30 minutes per bag, and 40 minutes per sample, taking into account that some samples consisted of multiple bags.

2.3 Data Analysis

The number of plastics for each category and each sample was entered into a *Microsoft Excel* spreadsheet. For future research, the data can be requested from Margriet Schoor (margriet.schoor@rws.nl). The data from 2021 and 2022 were analysed separately, and compared to one another. The analysis was performed using *R version 4.1.1* [21] and *RStudio version 1.4.1717* [22]. The information on the most abundant categories was visualized in bar plots that display the percentage per category of the total number of plastics found over all the samples taken in that year.

The concentrations of the plastics were determined using ADCP measurements that were performed on the days of sampling. These resulted in flow velocities on the exact locations of where the net was in the water column allowing to derive the sampled volume and hence concentrations. The ADCP measurements were not performed on each day of sampling.

Therefore, with public water data from Rijkswaterstaat [23], linear models were created between the total discharge of the whole river and the percentage that had flown through the net. These linear models were used to calculate the percentages through the net for the days on which no ADCP measurements were performed, after which the total volume of water through the net was calculated. With the total number of plastics and this information, the plastic concentrations were calculated. To analyse whether the total plastic concentrations in 2021 differed from the concentrations in 2022, Shapiro-Wilk test was used to test if the data was parametric, and a Mann-Whitney U test was performed to see if there were significant differences.

The data were collected in nine different positions of the river. Plastic concentrations were displayed using boxplots, showing the plastic concentrations over different places in the river. For certain categories, which were abundantly found, separate boxplots were made to see how their behaviour corresponds with the overall trend. Shapiro Wilk tests were used to see whether the data was parametric and Levene's test was used to check for equal variances. Kruskal-Wallis tests were used to analyse whether significant differences were present in the cross profile of the river and between the three different depths. If this was found to be significant ($p < 0.05$), a Dwass-Steel-Critchlow-Fligner test was used for pairwise comparisons, to see between which categories the analysis was significant.

Also, information on the water level, derived from public data of Rijkswaterstaat [23], was used to see whether the water level was rising or lowering. It was hypothesized that with an increasing water level, waste from the riverbanks could be taken up by the water, and flow through the water column. The measurements in both of the years were performed partly before and partly after a high water peak. The analysis was performed to compare the concentrations of plastics before and after the peak, to see whether this assumption was correct. Linear regression models were created for both years, analysing the water height against the plastic concentrations. A categorical factor was included in the model, to analyse whether it was of influence if the water height is increasing or decreasing. The adjusted R^2 was determined to see how much of the variance was explained by the model. P values smaller than 0.05 indicated significance.

3 Results

3.1 General

The samples had been taken in between the 12th and 19th of April 2021 and between the 6th and 20th of April 2022. Figure 4 shows the water height of the river at the measuring point in Lobith on the days around which the sampling took place.

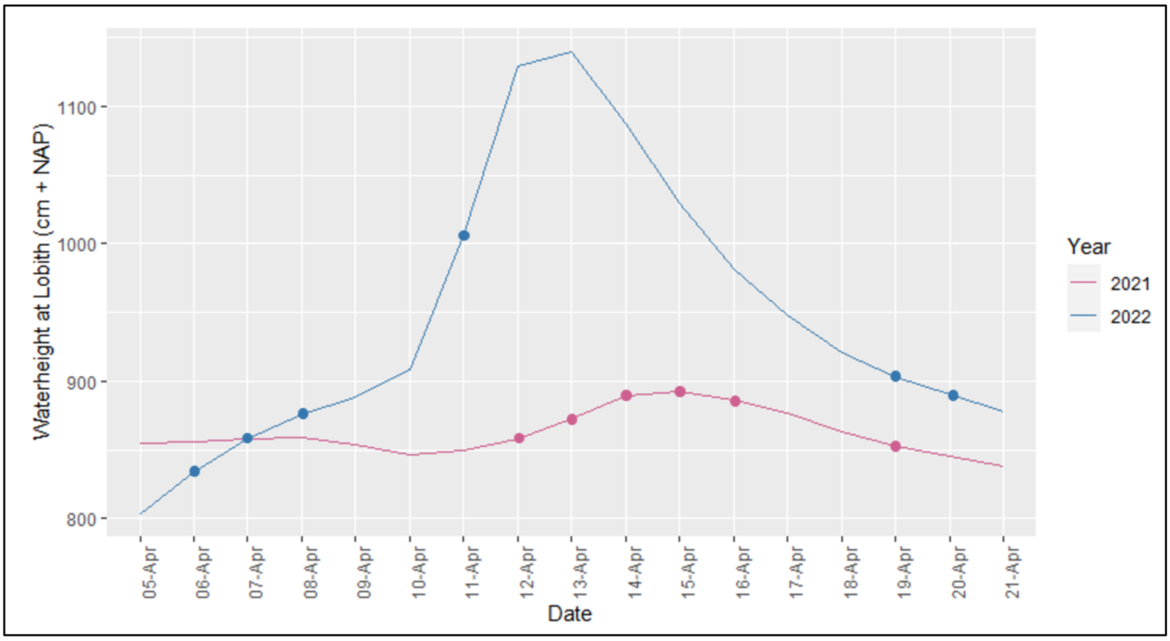

Figure 4: Water height during the days of sampling in 2021 and 2022. Daily averages were taken for the plot. The days on which samples were taken are marked with dots on the lines for both years.

In both of the years, samples were taken before and after a peak of high water (Figure 4). In both years, this was caused by a few days with a lot of rainfall in the catchment area of the river Rhine. With approximately 10 meters above NAP at Lobith, the groynes flow over and with approximately 11 meters, the water reaches the floodplains. It can be seen that both these circumstances happened during the peak around which was measured in 2022, where 1140 cm was reached on the 13th of April. In 2021, the peak was smaller, the groynes did not overflow. The water levels stayed below 900 cm.

3.2 Categories

In 2021, a total of 2471 pieces of plastics were found in the samples and 33 different categories were distinguished. In 2022, 4433 pieces of plastics were found, spread over 42 different categories. Table 1 shows the percentages of the most abundantly found categories from 2021 and 2022 next to each other.

Table 1: Percentages of abundantly found categories in 2021 and 2022

Category	**2021**	**2022**
Plastic/polystyrene pieces 0.5-2.5cm (soft plastic)	49.5%	38.0%
Plastic/polystyrene pieces 2.5-50cm (soft plastic)	23.2%	34.1%
String and cord (diameter <1cm)	6.5%	6.0%
Sanitary wet wipes	6.5%	3.8%
Plastic/polystyrene pieces 0.5-2.5cm (hard plastic)	3.2%	2.9%
Crisp/Sweets packaging	1.3%	1.3%
Food packaging	1.2%	1.3%
Cigarette butts	1.2%	0.8%
Tampons and tampon packaging	0.5%	1.6%
Styrofoam pieces 0.5-2.5cm	0.0%	2.2%

Of all the individual pieces of plastic collected during this research, in 2021 72.8% and in 2022 72.1% were unidentifiable pieces of soft plastic. These were pieces of soft plastic for which it could not be determined what the original product had been. This category was divided into small (0.5 - 2.5 cm) and large (> 2.5 cm) pieces. Although the total percentage of these undefinable plastics is similar, it stands out that in 2021, 2.13 times more small plastics were found than large plastics, while in 2022, 1.12 times more small plastics were found than large plastics. This means that relatively more large plastics were collected in the samples of 2022. As can be seen from Table 1, most of the abundantly found categories had similar percentages in 2021 and 2022. An exception is the presence of sanitary wet wipes which was 6.5% in 2021 and 3.8% in 2022. Also, Styrofoam pieces were responsible for 2.2% of the total plastic concentrations in 2022 but were not found in the samples of 2021. Figure 5 and Figure 6 show the percentages of the total concentrations of all the categories in 2021 and 2022.

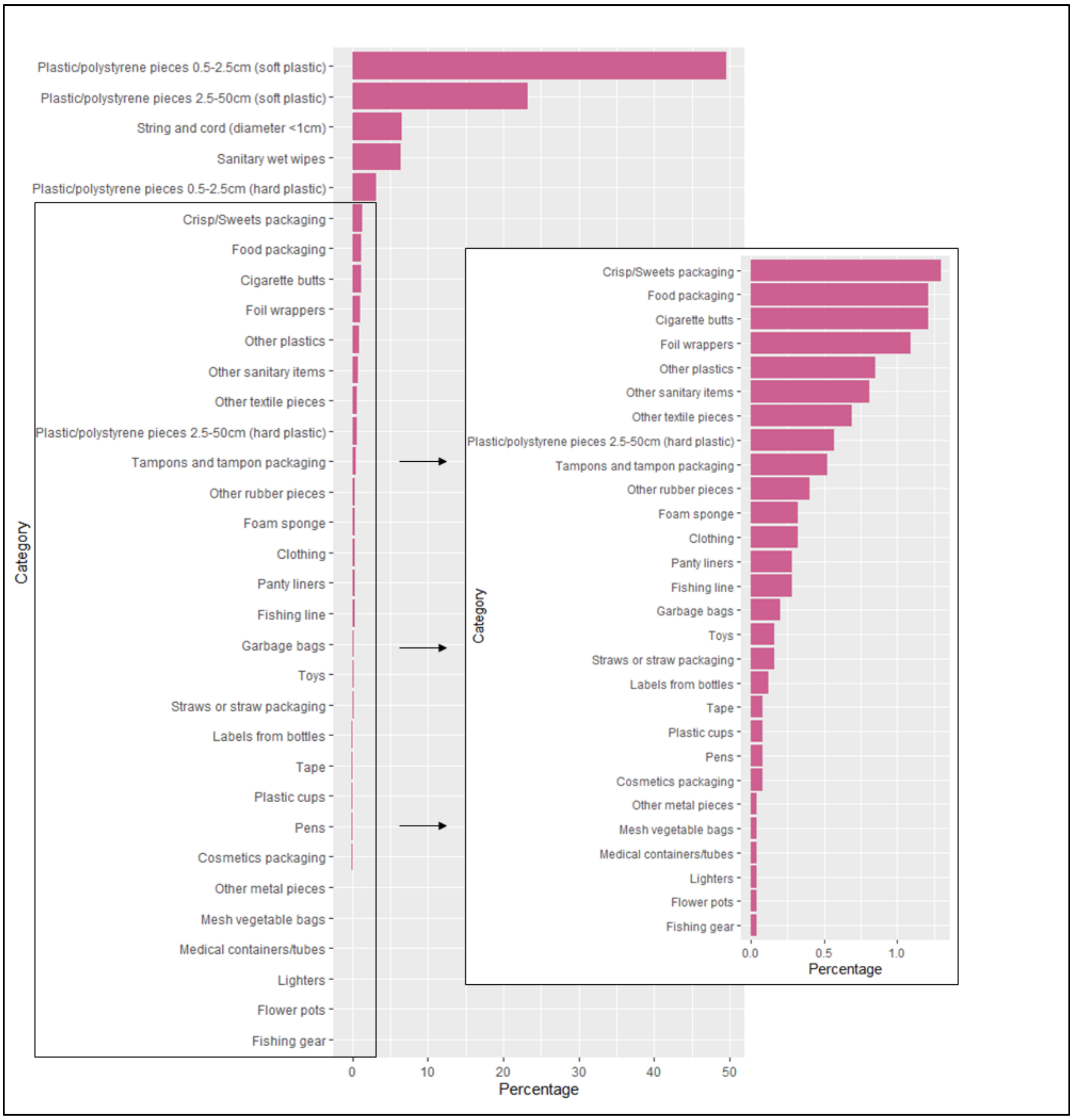

Figure 5: Categories found in the samples of 2021, expressed in percentages of the total number of plastics (n = 2471).

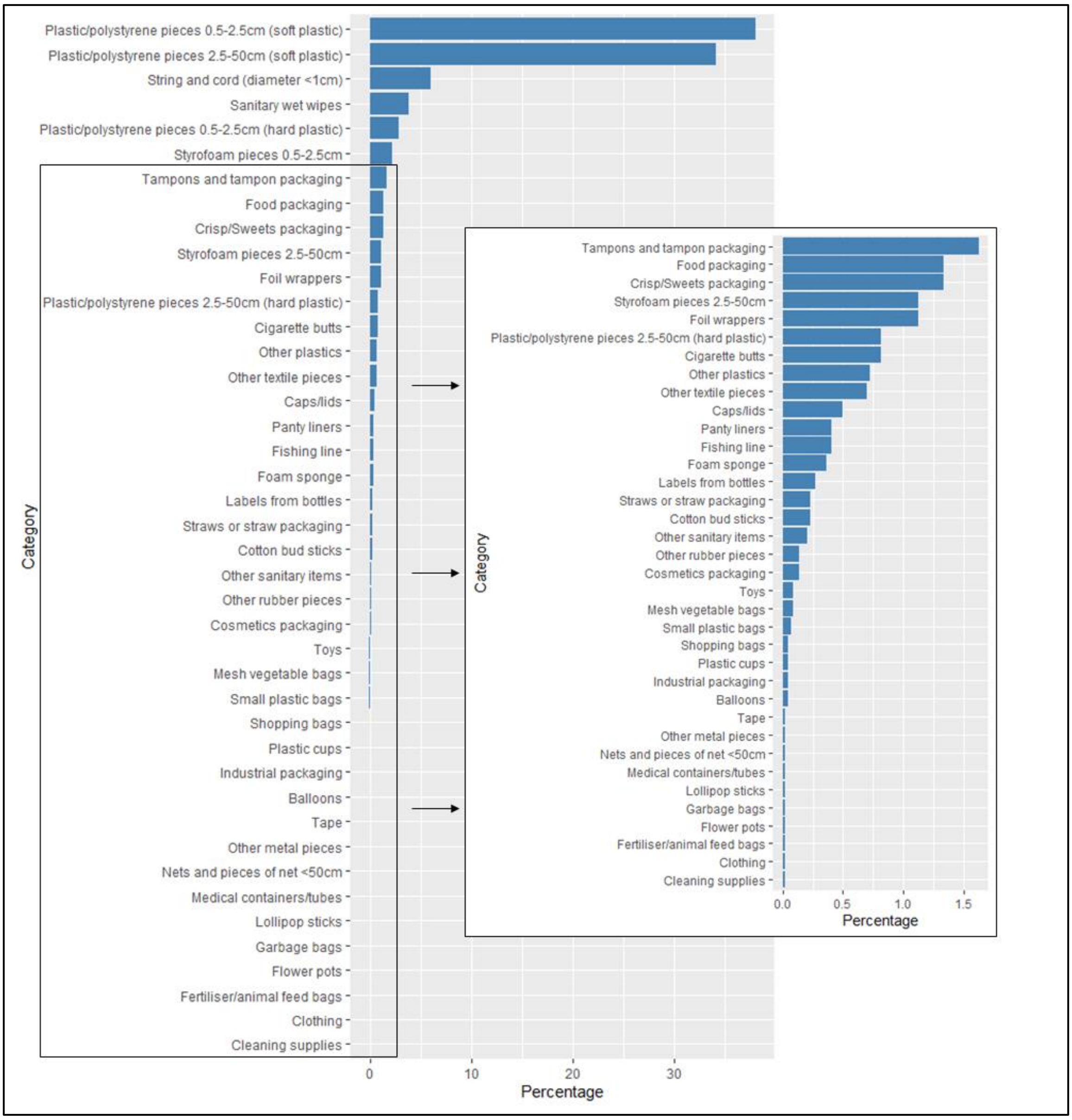

Figure 6: Categories found in the samples of 2022, expressed in percentages of the total number of plastics (n = 4433).

3.3 Spatial distribution

In 2021, 57 samples were collected from nine different locations in the water column. At least six samples have been taken from each location. In 2022, 71 samples have been taken with seven to nine different samples per location. Significantly higher concentrations of plastics were found in the samples of 2022 compared to the samples from 2021 (Mann-Whitney U $p < 0.001$). On average, 5.45 pieces of plastic per 1000 m^3 were found in 2022 and 2.36 pieces of plastic per 1000 m^3 in 2021.

Using the locations of the samples in the cross profile and depth of the river, analyses had been performed to if there are relations between these factors and the plastic concentrations. First, this was performed for all samples of 2021 and all samples of 2022 (Figure 7 and Figure 8).

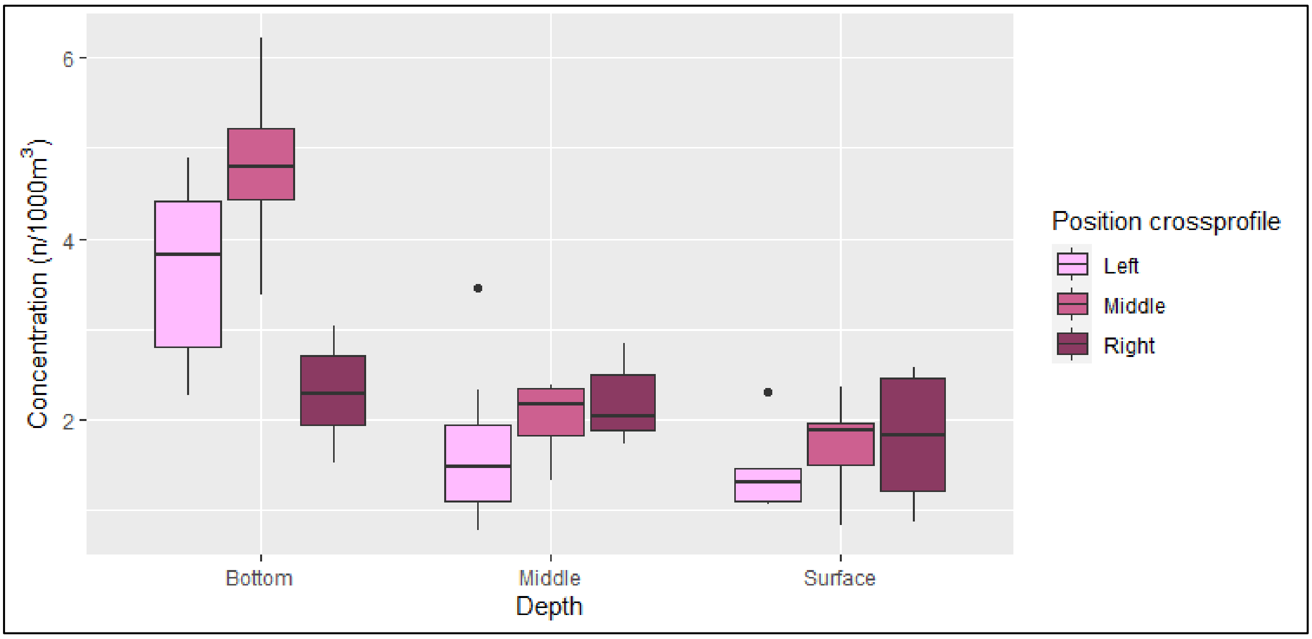

Figure 7: Concentrations of all plastics of 2021 per position. Shapiro-Wilk p < 0.001, data is not parametric. Kruskal-Wallis test from left to right: $\chi^2 = 2.81$ $p = 0.245$*. From top to bottom* $\chi^2 = 22.40$ *and* $p < 0.001$*, indicating significance. A pairwise comparison of the different depths can be found in Appendix II, Table 2.*

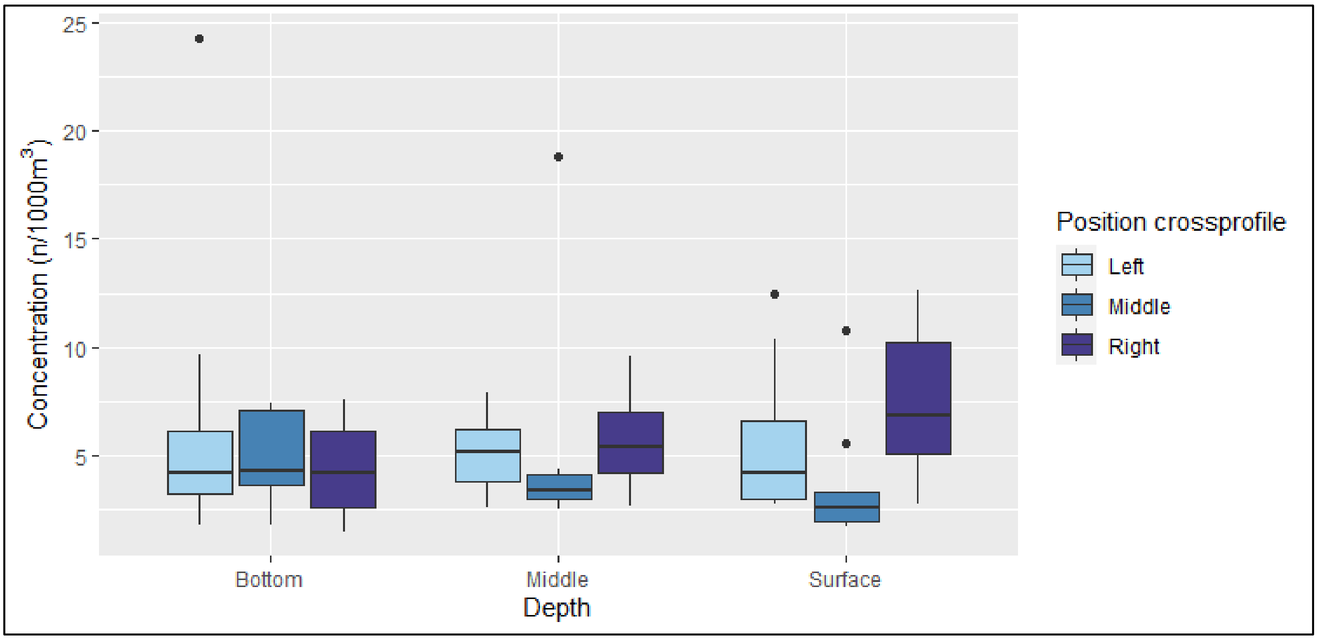

Figure 8: Concentration of all the plastics found per position in 2022. The data is not parametric (Shapiro-Wilk p <.001). No significant differences are seen in the concentrations of plastics over the water column (Kruskal-Wallis test $\chi^2 = 0.214$ *and* $p = 0.899$ *for depth and* $\chi^2 = 4.76$ *and* $p = 0.092$ *for position from left to right).*

A significant relation was seen between the plastic concentrations in 2021 and the depth in which the samples were taken. Near the bottom of the river, significantly higher concentrations were observed compared to the middle and top layer of the water column ($p < 0.001$ for both comparisons, see Appendix II, Table 2). From left to right, no significant relations were observed for the total concentrations of plastics. It does appear from Figure 7 that on the bottom, the highest concentrations were found on the left side of the river. The samples taken on the surface had the highest concentrations on the right side of the river. Another pattern that stands out is that in the middle, looking from left to right, the differences between concentrations are the highest, ascending from the top to the bottom.

The concentrations per position from 2022 (Figure 8) look different from the data points of 2021 (Figure 7). No significant relations were found with the position of the samples. Some of the trends do seem to overlap for both years. On the surface, plastic concentrations appear to be the highest on the right side of the river. And in the middle, from left to right, the differences in the water column are most clearly visible. These patterns were also seen in the analysis of 2021 (Figure 7). Furthermore, it stands out that there are a few data points that are detected as possible outliers with significantly higher concentrations. Most of these were taken on a day on which the water level was rising rapidly, and higher than measured on any other day.

Categories that were found abundantly, were analysed individually for their relation with the spatial data. 160 pieces of sanitary wet wipes were found in 2021, and 170 pieces in 2022. The analyses for sanitary wet wipes are illustrated in Figure 9 and Figure 10.

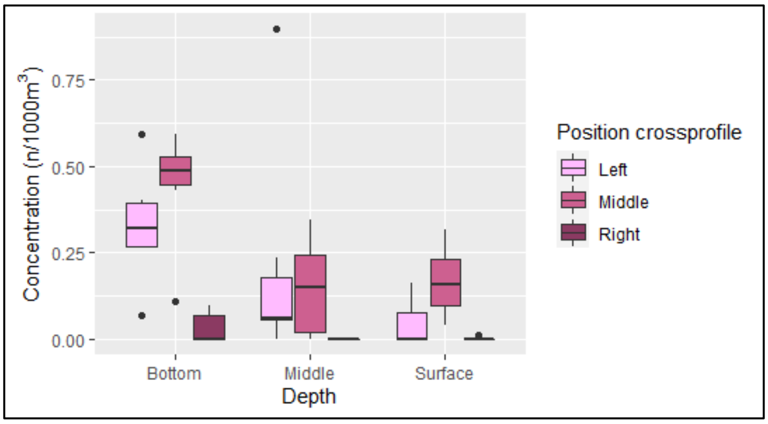

Figure 97: Concentration of sanitary wet wipes per position in 2021. The data is not parametric (Shapiro-Wilk $p < 0.001$). Significant differences were found from the top to bottom (Kruskal-Wallis $\chi^2 = 9.34$ and $p = 0.009$) and from left to right ($\chi^2 = 23.71$ and $p < 0.001$). Appendix II, Table 3 and Table 4 show pairwise comparisons for the significant relations.

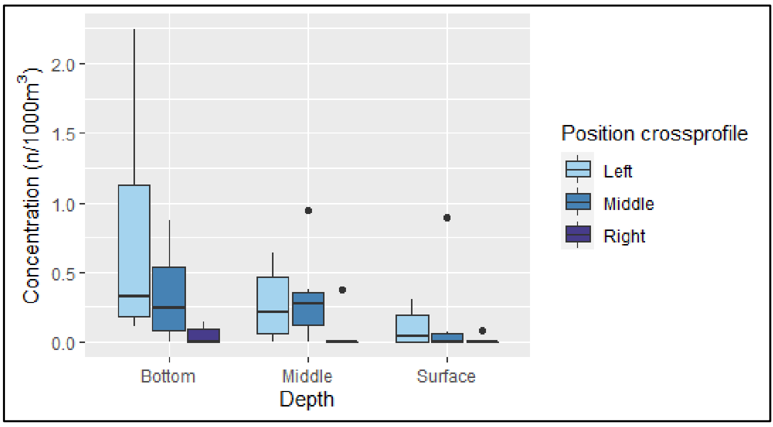

Figure 10: Concentration of sanitary wet wipes per position in 2022. The data is not parametric (Shapiro-Wilk $p < 0.001$). Significant differences were found from the top to bottom (Kruskal-Wallis $\chi^2 = 16.378$ and $p < 0.001$) and from left to right ($\chi^2 = 9.901$ $p = 0.007$). Appendix II, Table 5 and Table 6 show pairwise comparisons for the significant relations.

Significance was found for the concentrations of sanitary wet wipes in both 2021 and 2022, both in the different positions in the cross profile of the river and in the different depths that were researched. The data points out, as can also be seen in the plots of Figure 9 and Figure 10, that sanitary wet wipes are mostly concentrated on the left bottom of the river. On the right side of the river, almost no items of this category were found.

Another category which was found abundantly in the samples of both 2021 and 2022 is string and cord with a diameter < 1 mm. The spatial distribution for this category was also examined, and the visualized in Figure 11 and Figure 12.

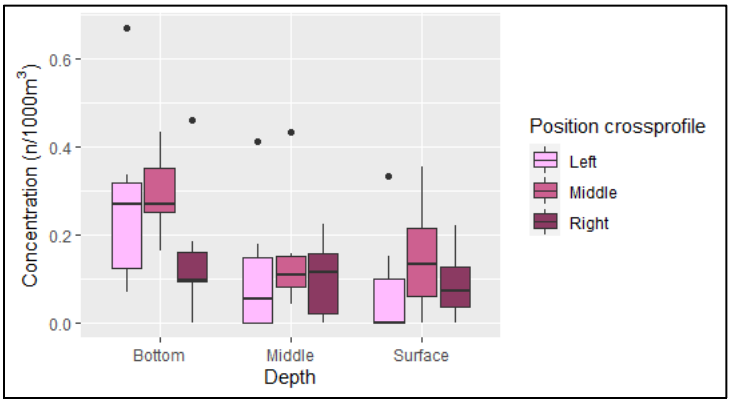

Figure 11: Concentration of string and cord per position in 2021. The data is not parametric (Shapiro-Wilk $p < 0.001$). Significant differences were found from the top to bottom (Kruskal-Wallis $\chi^2 = 9.97$ and $p = 0.007$). From left to right $\chi^2 = 4.54$ and $p = 0.103$. A pairwise comparison for the significant relation with the different depths can be found in Appendix II, Table 7.

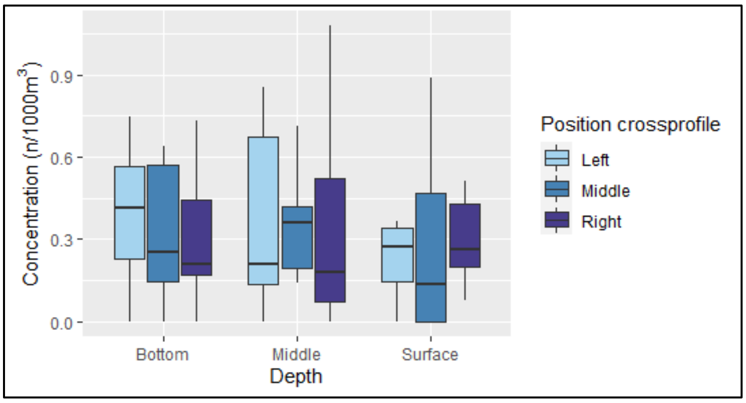

Figure 12: Concentration of string and cord per position in 2022. The data is not parametric (Shapiro-Wilk $p < 0.001$). No significant differences are seen in the concentrations of plastics over the water column (Kruskal-Wallis test $\chi^2 = 1.537$ and $p = 0.464$ for the different depths and $\chi^2 = 0.169$ and $p = 0.919$ for position from left to right).

String and cord appear to be relatively equally distributed between the different locations that were examined. However, a significant difference was found in the concentrations between the different depths in 2021. Here, near the bottom, the highest concentrations of this category were found ($p = 0.012$ for surface-bottom and $p = 0.032$ for middle-bottom). It should be noted that in the samples from 2021, in total higher concentrations were found on the bottom (Figure 7 and Appendix II, Table 2). The plots from string and cord seem comparable to the plots of the distribution of the total concentrations, meaning that plastics from this category are distributed in the same way as most of the plastics, which were the unidentifiable soft pieces of plastic. This category, which was responsible for the largest part of the total amount of plastics found, was also examined individually. Results of the analysis of this category are examined in Figure 13 and Figure 14.

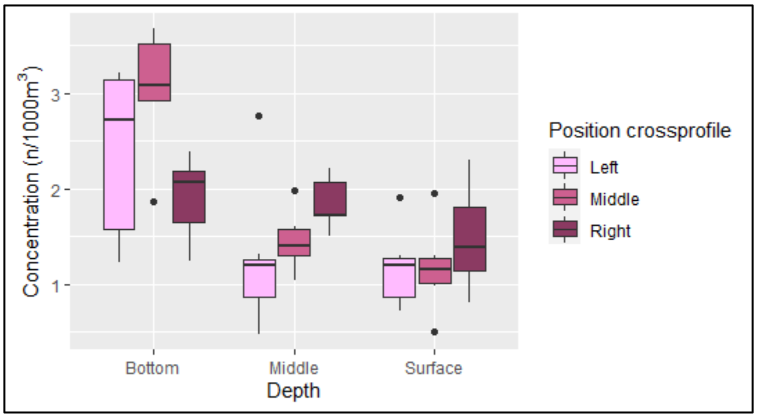

Figure 13: Concentration of undefinable soft pieces of plastic per position in 2021. The data is not parametric (Shapiro-Wilk $p = 0.003$). Significant differences were found from the top to bottom (Kruskal-Wallis $\chi^2 = 19.94$ and $p < 0.001$). From left to right $\chi^2 = 3.43$ and $p = 0.180$. A pairwise comparison for the significant relation can be found in Appendix II, Table 8.

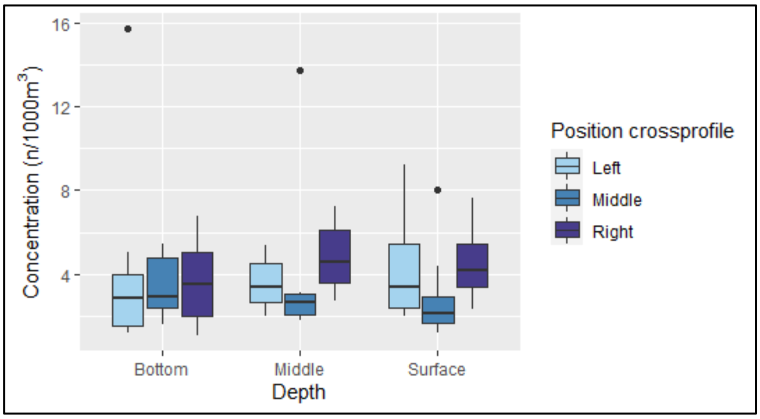

Figure 14: Concentration of undefinable soft pieces of plastic per position in 2022. The data is not parametric (Shapiro-Wilk $p < 0.001$). No significant differences are seen in the concentrations of plastics over the water column (Kruskal-Wallis test $\chi^2 = 0.810$ and $p = 0.667$ for the different depths and $\chi^2 = 5.846$ and $p = 0.054$ for position from left to right).

In the analyses of undefinable soft pieces, all of the unidentifiable pieces of plastics are analysed together. No distinction was made between the 'small' and 'large' categories which were separated beforehand in chapter 3.2. The undefinable pieces of plastics show a pattern which was also seen in the analysis of total concentrations where all the pieces of plastics were combined. This is an expected pattern since a large part (72.1% in 2021 and 72.8% in 2022) of all the plastics belong in this category. Significance was found between the different depths for the analysis of 2021 ($p < 0.001$ for surface-bottom and $p = 0.002$ for middle-bottom, see Appendix II, Table 8). The highest concentrations of these plastics were found near the bottom. This matches, similar to the previous analysis of string and cord, the total concentrations of plastics found. In 2022, no significant differences were found between the positions for this category.

Styrofoam was found in 5 out of the 71 samples taken in 2022. The data points out that Styrofoam is found almost exclusively on the surface on the right side of the river (left to right Kruskal-Wallis test $\chi^2 = 6.020$ and $p = 0.049$). This relation is not significant from top to bottom ($p = 0.065$), but it is found primarily on the surface. In 2021, no Styrofoam was found in the samples.

Hard pieces of plastic were also analysed, since they belong to the five most found categories for both 2021 and 2022 (2021 Kruskal-Wallis test from top to bottom $\chi^2 = 0.0559$, $p = 0.972$ and left to right $\chi^2 = 1.83$, $p = 0.400$. In 2022 from top to bottom $\chi^2 = 2.391$, $p = 0.303$ and from left to right $\chi^2 = 0.721$, $p = 0.697$). There were no significant differences found for this category. The concentrations of hard plastics seem to be distributed quite equally in the water column. Hard plastics are found in all different depths and also on all three positions in the cross profile of the river.

3.4 Relation with water height

The measurements were performed in both years before and after a peak of high water (Figure 4). This section analyses the influence of the water level and the effect of rising or lowering water on the plastic concentrations. A visualization of these factors is shown in Figure 15.

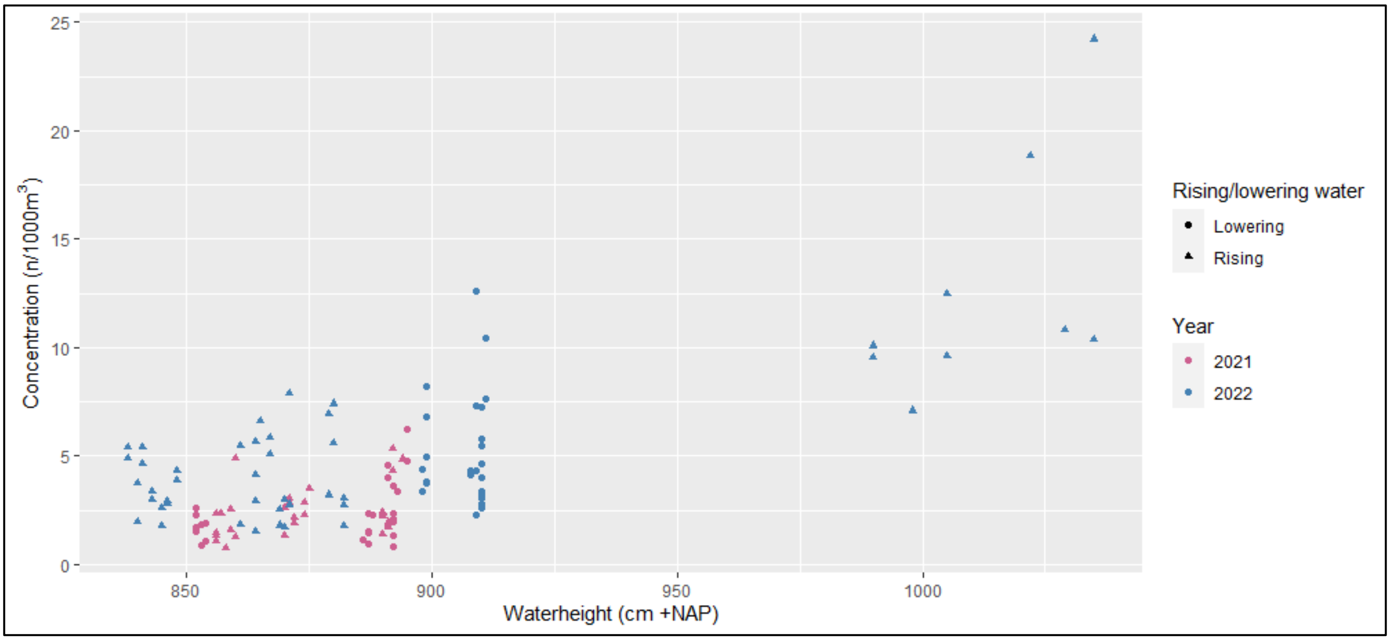

Figure 15: Plastic concentrations and water height of the Rhine at the measuring point in Lobith. Each data point represents the total concentration of a sample along with the water height at the time that the sample was taken.

A strong correlation was found between the water height and the concentrations of plastics (linear regression model $p = 0.003$ for 2021 and $p < 0.001$ for 2022). This indicates that high water results in an increased amount of plastics in the sample per volume of water. The plot also distinguishes between rising and lowering water. Appendix III (Table 9 and Table 10) show the outcomes of linear regression models of 2021 and 2022 where this factor was added to. In 2021, the R^2 of the model was 0.134, and in 2022 the R^2 was 0.538. This indicates more of the variance is explained by the model of 2022, but it also indicates that there are more factors that are of influence, as not all of the variance is explained.

From the data of 2022, it is visible that rising water results in significantly higher plastic concentrations than lowering water. The analysis shows that rising water contains more plastic per volume of water than lowering water. It should be stated that the measurements which were done with the highest water levels were only done while the water was rising. In 2021, there was no significant relation, probably because fewer samples were collected and the range of water heights in which was measured was not as large as in 2022.

4 Discussion

4.1 Categories

As described in the results, the category which was found most, unidentifiable pieces of soft film plastic in 2022 consisted of relatively more large pieces (> 2.5 cm) in comparison to the pieces that were found in 2021. The most likely explanation for this is the peak of high water that came in between the sampling days of 2022. Although there was also a peak in between the measurements of 2021, in 2022 this peak was much stronger. It reached above 11 meters, while in 2021 the highest peak was still below 9 meters above NAP. It may be that plastics laying on the floodplains, which were not broken down yet, became part of the water column by the rapid increase of water height. It is possible that with the higher flow velocities during the peak of 2022, the plastic was in the river for a shorter time, so the chance to break down into pieces is smaller. It should be stated that this is an assumption, which has not been researched yet.

Looking at the categories, undefinable pieces of plastic film were found most abundantly. This counts for both of the years in which were measured. This is in line with previous research with stow nets, in which this category was found in the same order of magnitude [17]. The origin of this could be plastic bags, packaging, or any other product for which thin plastics are used. Most probably, these pieces ended up in the water and whilst flowing through the river they ripped or broke because of rocky sediment, or boat trafficking.

String and cord with a diameter smaller than 1 cm were also found abundantly. It is even estimated that in reality, this category is responsible for a larger part of the total pieces of plastics since they are often thinner than the maze width of the net, and they are expected to easily flow through if they are not attached to some organic matter or other plastics. The origin of these items can be from fishing gear, pieces of clothing, or geotextiles. A field test could assess the catching efficiency of the net for this category, as well as other categories. The efficiency can be used to correct for the pieces of plastics that were not collected.

Sanitary wet wipes were found abundantly in both years of the research. It is possible that they came into the water through either sewage overflow, litter that was left behind on riverbanks, and from ships, either inland navigation or cruise ships. A recent study points out that 50% of the wet wipes that claim to be flushable on the label, contain PET and are therefore non-degradable [24]. When society is unaware of the damage caused by these products, the problem with irresponsible disposal of these products remains.

Over the years 2021 and 2022, respectively 33 and 42 different categories were identified. The differences between the year can be caused by the increased discharge that was observed in 2022. It can also be because there were more samples taken in 2022, and the measuring duration was longer than in 2021, making the chances of finding rare pieces of plastics higher. In the future, this could be tested using a species accumulation curve.

The analysis done using this research seems to be comparable to other research [16]. A more precise analysis can be made when data is available from different measuring techniques over the same period. Measurements have been done during the survey of 2022 using smaller nets, but this data is not yet achievable and this is out of the scope of this project. In the future, when this data is available, analyses can be done to assess the differences and similarities between different techniques.

4.2 Temporal variation

In 2022, significantly higher concentrations of the total number of plastics were found. This is probably due to the conditions in which were measured and not necessarily because the plastic concentrations in the river have increased. In 2022, the fluctuations in the water level were larger than in 2021. It is hard to conclude on the in- or decrease of plastics over time without measuring in the same conditions over multiple years. In previous research, suggestions have been made about the influence of COVID-19, where with heavier restrictions fewer plastics end up in the water column [16]. This could also be a possible cause for the lower concentrations in 2021 compared to 2022. Furthermore, with the same discharge and water height, differences could be influenced by heavy rainfall in a region hundreds of kilometres away, as the litter can come from the whole Rhine catchment area, so it is expected that many factors play a role in the plastic concentration.

The linear relations with plastic concentrations and water height for 2021 and for 2022 were both significant. However, in 2021 the R^2 value was 0.134 and in 2022 the R^2 was 0.538 (Appendix III). The analysis shows that higher water results in higher plastic concentrations, although it also shows from the R^2 values that more factors are of influence on the concentrations. Also, the data of 2022 pointed out that this relation is stronger with water that is rising than with lowering water. It is expected that plastic is either transported by high water from the floodplains to the water column, or due to heavy rainfall assimilated in the river, or a combination of both. It is also possible that plastics were buried under the sediments, and by the influence of high water became loose. This effect is stronger in periods with rising water than when the water height of the river is decreasing. Previous research hypothesized that as a consequence of high water, plastic waste from riverbanks can transport to the water column of the river [26]. The current relation that was found from the data of 2022 supports this hypothesis. However, it should be stated that the measurements where higher water was measured only took place when the water was rising. After the peak of high water, the first day on which was measured again, the water was already 1 meter lower. To improve the quality of this analysis, it is better to measure at the same water heights before and after a peak. However, in reality, this is difficult to achieve since the measurements need to be planned long before there are predictions on the river discharge. Also, field observations showed that water levels higher than 10 meters at the measuring point in Lobith are not feasible. The current is too strong for the ship to hold, even while using the anchor. A few samples were successfully collected under these conditions, but there were also samples lost because the nets would flip as a result of the strong current. This means that measurements could not be performed under conditions where floodplains are overflown, which is approximately at 11 meters, meaning that this influence cannot be measured as of now.

From the total plastic concentrations, it was seen that in 2021 significantly higher concentrations were found near the bottom of the river. This was not observed in 2022. Therefore, based on the data of only one year of measuring, different conclusions would be drawn than now. Maybe, with a higher level as seen in 2022, more mixing is taking place and plastics are more evenly distributed in the water column. Also, the analyses explaining the influence of water height and the influence of rising or lowering water differed between the years. Thus, measuring for multiple years, and researching different conditions and the influence of these conditions is important.

4.3 Spatial distribution

Looking at the distribution of the sanitary wet wipes, which are heavy and expectedly move over the bottom, in comparison to the very light particles of plastic, being Styrofoam for example, it appears that heavy particles concentrate mostly on the left bottom of the river, while light, floating particles are primarily observed on the right surface. This pattern is explained by the river bend in which was measured. The spiral flow of the river makes the particles in the middle and top layer flow to the outer bend, while the flow on the bottom of the river is moving in the opposite direction. It is known from previous research and theory that other particles, like sediments, flow through the river in this way [14]. It was hypothesized that plastics would also behave in such a way, but no research has confirmed this until now.

The spatial distribution of the sanitary wet wipes stands out from the results. In both years, significantly more sanitary wet wipes were found on the bottom of the river, and they were concentrated almost entirely on the left side of the river. This accumulation could be solely because of the spiral flow of the river, but preliminary results of ongoing research show that items of this category on the riverbanks of the Waal, are also significantly more abundant on the left side of the river compared to the right side [25]. These results were observed over a longer distance, with bends to the left end right. Therefore, it is likely that more factors influence the spatial distribution of these items, such as ship trafficking or the location of disposal in the river.

4.4 Reliability

The total number of plastics that have been found during this study is an underestimation of the total plastic content of the river, as there are chances of losing plastics that should be part of the analysis in different steps of the methodology. For example, during the survey, there were certain measurements with large amounts of organic matter in the nets. This may have caused the net to clog a bit, influencing the flow of the water through the net and thereby it is possible that fewer plastics are found. This is expected to have a low impact on the reliability since the sampling methodology was adjusted when this happened by reducing the sampling duration.

Also, as already mentioned in 4.1, some small pieces of plastic may have flown through the net, because they are smaller than the maze width of the net. The maze width is 0.6 cm and the study aims to catch all pieces of plastics that are larger than 0.5 cm, on their longest size. Pieces of plastic can flow through whilst the nets are in the water, but also afterwards when the nets are emptied. The nets need to be shaken for this, causing small pieces to be able to fall through the net. This is expected to affect the number of mesoplastics caught during the sample taking, and not much on the macroplastics.

In sorting out the samples, there is also an error margin which leads to an underestimation of the total number of plastics found. Some pieces are difficult to see because they stick to organic matter that is present in the samples. It was always attempted to perform this task as precisely as possible, and preferably with at least two people looking through the samples, but there is a chance that some of the plastics are missed while sorting out the samples. The difference in efficiency between sorting out on board and sorting out afterwards is also not researched. Field observations showed that it was easiest to perform this task in direct sunlight since the pieces of plastic are better visible this way. This was not always possible in sorting the samples afterwards.

ADCP measurements were not performed on all days on which were measured. Therefore, an extrapolation needed to be performed to estimate the volume of water that had flown through the net on the days when no measurements were taken (Appendix IV and Appendix V). This is less precise than performing ADCP measurements, but because of changes in planning it could not be achieved to perform ACP measurements on all of the measuring days. It is assumed that the extrapolation, which was done for 2022 with linear models, quite satisfactorily estimated the discharge at the specific locations. In most cases, quite high R^2 and p-values came out of the model. Moreover, the days on which no ADCP measurements were performed had similar total discharges as some of the days on which they were performed, causing the error margin to be small.

5 Conclusion

Most commonly found was the category 'undefinable pieces of plastic film'. This was an expected result, as hypothesized based on previous research. In 2021, relatively more small pieces of plastic (0.5 – 2.5 cm) in this category were found compared to the data from 2022. On average, larger pieces of plastic film were collected in 2022. Water height also increased more rapidly, and to a higher level than in 2021. Expectedly, larger parts were found in the river because of overflooding riverbanks, resulting in a transport of waste from the land to the river. Other abundantly found categories in the samples of both years were string and cord, small hard pieces of plastic and sanitary wet wipes.

The spatial distribution showed that near the surface of the water, plastic concentrations are the highest on the right side, which is the outer bend of the river. The differences between the top and bottom were most clearly visible in the middle of the river. The highest concentrations in the middle are found near the bottom and the lowest concentrations are near the river's surface. In 2021, significantly higher concentrations of plastics were found near the bottom of the river. In 2022, this was not observed. Analysis for the most abundant categories showed that undefinable pieces of plastic film show similar patterns to the total concentrations. In the middle and on the surface, concentrations were highest in the outer bend. String and cord seem to be distributed relatively evenly over the water column. The analyses for the spatial distribution of sanitary wet wipes showed significance with the highest concentrations on the bottom of the river and the left side. For both years, this came out of the results. A trend that was clearly visible from the analyses is that the light pieces of plastic such as Styrofoam and also undefinable pieces of plastic film seem to be most concentrated towards the surface and on the right side, the outer bend. Here, the river discharge is also the highest. Sanitary wet wipes are heavy items because they also trap organic matter and smaller pieces of plastic in the fibres. These items were mainly concentrated on the bottom of the inner bend. They were hypothesized to be transported similarly to sediment because of the spiral flow in the river. The hypothesis can be supported by these results, where light items concentrate towards the surface on the outer bend and heavier items concentrate towards the bottom of the inner bend.

Significantly higher concentrations of plastics were found in 2022 compared to 2021. On average, 5.45 pieces of plastic per 1000 m^3 were found in 2022 and 2.36 pieces of plastic per 1000 m^3 in 2021. The survey of 2022 was during a period with on average higher water levels than seen in 2021. A linear regression model showed, for both 2021 and 2022 that higher water levels result in higher concentrations of plastics found in the river. This was also a hypothesized result. During the surveys of both 2021 and 2022, there was a peak in the water height of the river. The linear model of 2022 showed significance in the variables for lowering and rising water height. This means that there is a difference in plastic concentrations before and after a high water peak is observed. During rising water, higher concentrations of plastics are observed.

6 Recommendations

There were clear differences seen between the two sides of the river. Light items such as Styrofoam were primarily seen in the outer bend on the surface, and heavier items were found mainly on the left side of the river, the inner bend. This is, for this study, most likely explained by the river bend. However, to be certain of this effect it would be recommended to collect data from another location, preferably close to the current location, where the right side of the river is the inner bend. In that way, the influence of river bends could be separated from other influences like input from a certain location on the left or right bank or the effect of shipping with heavily loaded ships sailing upstream closer to the left side of the river.

Performing a field test in which the catching efficiency of the net is tested, performed separately for different categories of plastic, is recommended to achieve a better understanding of the number of plastics that are not caught by the net. This can then be corrected for in the data of the current and future measurements to obtain a more representative dataset.

In this research, two separate analyses were done for the different locations from left to right and the different depths. Therefore, the interaction between these variables is not tested in this study. During future research, it is recommended to analyse all of the data together in a generalized linear model, using various explanatory variables to see if there are significant interactions and if these can be explained by certain patterns.

Furthermore, it has been observed that water height and plastic concentration form a significant relation, in 2021 as well as 2022. What could be explored further is the influence of either rising or lowering plastic concentrations. With the highest water levels measured here, only rising water was sampled. If data were collected from the same water heights, but different in whether the levels are rising or lowering, this influence could be explored further.

During the current study, meso- and macroplastic were summed up for analysis. A distinction is made between the two categories in some other research papers. If desired, future research can analyse this for the current samples as well. The dataset of 2022 is divided between the different size classes. In 2021, no distinction was made whilst counting. However, pictures were taken of each sample, and a ruler is present in all images. With the images, it can be tracked down which size the pieces were. Also, all samples were saved, if the pictures were unclear or something needed to be looked after further.

Furthermore, information was obtained on every piece of plastic where a brand, year, or language could be determined. The analysis of these pieces reaches too far to be included in this report, but it can be interesting for future analysis to dive into this data and identify which patterns can be found here. In Appendix II and Appendix III, this information is included. It would be expected that the German language is most abundant in plastics where a language can be found. The samples are taken close to the border with Germany, and the largest part of the Rhine is in Germany.

Out of the scope of this research is to analyse the datasets gathered from the Kor-net fishing to datasets achieved with other methods, such as the anchor pit fishing and the fishing with smaller nets. In future research, it should be explored whether the outcomes of these methods are similar to the data that has been gathered through this project.

Bibliography

[1] Plastics Europe, „Plastics - the Facts,” 2019. [Online]. Available: https://plasticseurope.org/wp-content/uploads/2021/10/2019-Plastics-the-facts.pdf. [Geopend 19 March 2022].

[2] R. Geyer, J. R. Jambeck en K. Lavender Law, „Production, use, and fate of all plastics ever made,” *Science Advances,* vol. 3, nr. 7, 2017.

[3] Plastics Europe, „Plastics - the Facts 2021,” 2021. [Online]. Available: https://plasticseurope.org/wp-content/uploads/2021/12/Plastics-the-Facts-2021-web-final.pdf. [Geopend 16 June 2022].

[4] A. A. de Souza Machado, W. Kloas, C. Zarfl, S. Hempel en M. C. Rillig, „Microplastics as an emerging threat to terrestrial ecosystems,” *Global Change Biology,* vol. 24, nr. 4, pp. 1405-1416, 2018.

[5] United Nations Environment Programme, „From Pollution to Solution - A Global Assessment of Marine Litter and Plastic Pollution,” UNEP, , 2021.

[6] L. C. M. Lebreton, J. van der Zwet, J. W. Damsteeg, B. Slat, A. Andrady en J. Reisser, „River plastic emissions to the world's oceans,” *Nature Communications,* 2017.

[7] J. R. Jambeck, R. Geyer, C. Wilcox, T. R. Siegler, M. Perryman, A. Andrady, R. Narayan en K. Lavender Law, „Plastic waste inputs from land into the ocean,” *Science,* vol. 347, nr. 6223, pp. 768-771, 2015.

[8] S. Lechthaler, K. Walschläger, G. Stauch en H. Schüttrumpf, „The Way of Macroplastic through the Environment,” *Environments,* vol. 7, nr. 10, 2020.

[9] United Nations Environmental Programme, „Drowning in Plastics - Marine Litter and Plastic Waste Vital Graphics,” 2021.

[10] S. K. Kale, A. G. Deshmukh, M. S. Dudhare en V. B. Patil, „Microbial degradation of plastic: a review,” *Journal of Biochemical Technology,* vol. 6, nr. 2, pp. 952-961, 2015.

[11] W. de Wit en N. Bigaud, „Assessing Plastic Ingestion from Nature to People,” Dalberg Advisors, Geneva, 2019.

[12] M. Cole, P. Lindeque, E. Fileman, C. Halsband, R. Goodhead, J. Moger en T. S. Galloway, „Microplastic ingestion by zooplankton,” *Environmental Science & Technology,* vol. 47, nr. 12, pp. 6646-6655, 2013.

[13] T. S. M. Amelia, W. M. A. W. M. Kalik, M. C. Ong, Y. T. Shao, H. J. Pan en K. Bhubalan, „Marine microplastics as vectors of major ocean pollutants and its hazards to the marine ecosystem and humans,” *Progress in Earth and Planetary Science,* vol. 8, nr. 12, 2021.

[14] United Nations, „Sustainable Development Goals,” [Online]. Available: https://www.un.org/en/sustainable-development-goals. [Geopend 14 June 2022].

[15] M. A. Boonstra en W. de Winter, „Wat spoelt er aan op rivieroevers? Resultaten van twee jaar afvalmonitoring aan de oevers van de Maas en de Waal.,” Schone Rivieren, 2019.

[16] T. Mani, A. Hauk, U. Walter en P. Burkhardt-Holm, „Microplastics profile along the Rhine River,” *Scientific Reports,* 2016.

[17] P. Vriend, C. van Calcar, M. Kooi, H. Landman, R. Pikaar en T. van Emmerik, „Rapid Assessment of Floating Macroplastic Transport in the Rhine,” *Frontiers in Marine Science,* 2020.

[18] J. M. Hooke, „River Meandering,” in *Treatise on Geomorphology*, San Diego, Academic Press, 2013.

[19] W. F. Tanner, „Helicoidal flow, a possible cause of meandering,” *Journal of Geophysical Research,* vol. 65, nr. 3, pp. 993-995, 1960.

[20] F. P. L. Collas, S. B. Oswald en W. C. E. P. Verberk, „Plastic in de waterkolom van de Boven-Rijn, Waal, en IJssel,” Radboud Universiteit, Nijmegen, 2021.

[21] S. B. Oswald, F. P. L. Collas, M. M. Schoor, F. Buschman en R. S. E. W. Leuven, „Abundance and composition of macro- and mesoplastic in the Waal river, the Netherlands,” Radboud Universiteit, Nijmegen, 2020.

[22] T. van Emmerik, R. Tramoy, C. van Calcar, S. Alligant, R. Treilles, B. Tassin en J. Gasperi, „Seine Plastic Debris Transport Tenfolded During Increased River Discharge,” *Frontiers in Marine Science,* vol. 6, 2019.

[23] M. Muste, K. Yu en M. Spasojevic, „Practical aspects of ADCP data use for quantification of mean river flow characteristics; Part I: moving-vessel measurements,” *Flow Measurement and Instrumentation,* vol. 15, nr. 1, pp. 1-16, 2004.

[24] OSPAR Commission, „Guideline for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area,” 2010. [Online]. Available: https://www.ospar.org/ospar-data/10-02e_beachlitter%20guideline_english%20only.pdf. [Geopend 22 February 2022].

[25] R Core Team, „R: A language and environment for statistical computing.,” R Foundation for Statistical Computing, Vienna, Austria., 2021. [Online]. Available: https://www.R-project.org/.

[26] Rstudio Team, „RStudio: Integrated Development for R.,” RStudio, PBC, Boston, MA, 2021. [Online]. Available: http://www.rstudio.com/.

[27] Rijkswaterstaat, „Waterinfo,” [Online]. Available: www.waterinfo.rws.nl. [Geopend 24 May 2022].

[28] O. Ó Briain, A. Marques Mendes, S. McCarron, M. Healy en L. Morrison, „The role of wet wipes and sanitary towels as a source of white microplastic fibres in the marine environment,” *Water Research,* vol. 182, 2020.

[29] T. van Emmerik, E. Strady, T. C. Kieu-Le, L. Nguyen en N. Gratiot, „Seasonality of riverine macroplastic transport,” Nature, 2019.

[30] L. Minnaar, „Spatial distribution of sanitary wet wipes,” To be published, 2022.

[31] SDG Nederland, „De 17 SDG's,” [Online]. Available: https://www.sdgnederland.nl/de-17-sdgs/. [Geopend 14 June 2022].

[32] European Comission, „Turning the Tide on Single-Use Plastics,” Publications Office of the European Union, 2021.

[33] M. Kalsbeek, „Monstername meso- en macroplastic in de Bovenrijn,” 2022.

Appendix I: Sustainability Assessment

This appendix is part of the assignments that need to be performed for the educational programme of the student: Environmental Science for Sustainable Energy and Technology. This section will focus on whether the topic of the project contributes to the Sustainable Development Goals (SDG's). The SDG's are a collection of 17 goals that have been agreed on in 2015 by all countries that are part of the United Nations and should be reached by 2030 [27]. The goals consist of multiple targets, making them more specific [27]. Figure 14 shows the 17 goals that have been set.

Figure 86: Sustainable Development Goals [28]

Of the goals, visible in Figure 16, the three most relevant goals to the executed project will be highlighted in this assignment, from a people, planet, and profit view.

Sustainable Development Goal 12: Responsible Consumption and Production
Goal 12 links closely to the project executed in this report. With projects like this one, knowledge of the types of plastics in the environment is gained. This information is valuable to reach the targets that belong to this goal because data on the types of waste in the environment are necessary to implement suitable measures for the realization of this goal. Target 12.5 describes the reduction of waste production by prevention, reusing, reducing, and recycling [28]. Target 12.8 is to guarantee that all people have access to relevant information and lifestyles that are in harmony with nature [28]. This study supports that target because the knowledge that is gained here will be used for further research and eventually to more awareness on the fact that waste does not belong in nature.

Sustainable Development Goal 14: Life Below Water
Goal 14 aims to conserve and sustainably use the oceans, seas and marine resources for sustainable development [28]. The study conducted here contributes to target 14.1; Prevent and significantly reduce marine pollution of all kinds. As described in the current report, rivers are a major contributor to marine plastic pollution. Knowledge on the quantity of plastics that flows through the rivers is essential to come to a strategy where marine pollution needs to be reduced

significantly. The current research contributes to a reliable monitoring strategy which can be used in the future. If such a strategy is successfully set up, it is possible that the impact of certain legislations can be tested, which will contribute to tackling the problems with plastic litter in the oceans.

Sustainable Development Goal 17: Partnership for the goals

The final SDG that is highlighted here might be the most important. It is about the partnership to reach the goals. Rijkswaterstaat closely works together with other institutes, and the knowledge gained by this project will be shared so that other institutes or parties can further develop the knowledge in this field, or compare their findings with other methods to the methods that have been used here. This is in line with target 17.16, which is about sharing knowledge to support the Sustainable Development Goals in all countries [28].

Appendix II: Pairwise comparisons

The following tables present the outcomes of the pairwise comparisons that were performed after significance was found in the Kruskal-Wallis tests as performed in the chapter 'Results'. Significant differences ($p < 0.05$) are indicated in bold.

Table 2: Dwass-Steel-Critchlow-Fligner pairwise comparison of the total concentrations of all plastics found in 2021. Significant differences were found between the concentrations on the surface and bottom ($p < 0.001$) and between the middle and bottom ($p < 0.001$).

Pairwise comparisons - Total concentration 2021

		W	p
Surface	Middle	2.11	0.296
Surface	Bottom	6.00	**< .001**
Middle	Bottom	5.24	**< .001**

Table 3: Dwass-Steel-Critchlow-Fligner pairwise comparison of sanitary wet wipes found in 2021. Significant differences were found between the sanitary wet wipes concentration between the middle and right and between the left and right side of the river.

Pairwise comparisons – Sanitary wet wipes concentration 2021

		W	p
Left	Right	-5.41	**< .001**
Left	Middle	1.99	0.337
Right	Middle	6.53	**< .001**

Table 4: Dwass-Steel-Critchlow-Fligner pairwise comparison of sanitary wet wipes found in 2022. Significant differences were found between the sanitary wet wipes concentration between the surface and bottom and between the middle and bottom of the river.

Pairwise comparisons – Sanitary wet wipes concentration 2021

		W	p
Surface	Middle	0.718	0.868
Surface	Bottom	3.987	**0.013**
Middle	Bottom	3.339	**0.048**

Table 5: Dwass-Steel-Critchlow-Fligner pairwise comparison of sanitary wet wipes found in 2022. Significant differences were found between the sanitary wet wipes concentration between the middle and right and between the left and right side of the river.

Pairwise comparisons - Sanitary wet wipes concentration 2022

		W	p
Left	Middle	-1.24	0.655
Left	Right	-5.59	**< .001**
Middle	Right	-4.39	**0.005**

Table 6: Dwass-Steel-Critchlow-Fligner pairwise comparison of sanitary wet wipes found in 2022. Significant differences were found between the sanitary wet wipes concentration between the surface and bottom of the river.

Pairwise comparisons - Sanitary wet wipes concentration 2022

		W	p
Surface	Middle	3.12	0.071
Surface	Bottom	4.42	**0.005**
Middle	Bottom	1.11	0.715

Table 7: Dwass-Steel-Critchlow-Fligner pairwise comparison of the concentrations of string and cord in 2021. Significant differences were found between the surface and bottom and between the middle and bottom.

Pairwise comparisons - string/cord concentration

		W	p
Surface	Middle	0.948	0.781
Surface	Bottom	4.050	**0.012**
Middle	Bottom	3.553	**0.032**

Table 8: Dwass-Steel-Critchlow-Fligner pairwise comparison of the concentrations of undefinable soft pieces of plastic in 2021. Significant differences were found between the surface and bottom and between the middle and bottom.

Pairwise comparisons - undefinable soft pieces of plastic concentration

		W	p
Surface	Middle	2.07	0.310
Surface	Bottom	5.79	**< .001**
Middle	Bottom	4.73	**0.002**

Appendix III: Outcomes Linear Models

The following tables present the outcomes of the linear models as described in chapter 3.4. Significance ($p < 0.05$) is indicated in bold.

Table 9: Linear model for the data of 2021, with water height against plastic concentrations with the factor of rising or lowering water added. The adjusted R^2 of this model is 0.134

Model Coefficients - Concentration (n/1000m^3) 2021

Predictor	Estimate	SE	t	p
Intercept	-24.1847	8.30893	-2.91	**0.005**
water height cm +NAP	0.0305	0.00951	3.21	**0.002**
Rising/Lowering:				
Lowering – Rising	-0.3169	0.30751	-1.03	0.307

Table 10: Linear model for the data of 2022, with water height against plastic concentrations with the factor of rising or lowering water added. The adjusted R^2 of this model is 0.538.

Model Coefficients – Concentration (n/1000m^3) 2022

Predictor	Estimate	SE	t	p
Intercept	-44.9910	5.56815	-8.08	**< .001**
Water height cm +NAP	0.0568	0.00624	9.11	**< .001**
Rising/Lowering:				
Lowering – Rising	-1.3592	0.65529	-2.07	**0.042**