The spatial distribution of sanitary wet wipes on the riverbanks of the Waal

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Master Thesis Project	The Spatial Distribution of sanitary wet wipes on the riverbanks of the Waal

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Abstract
Rivers and streams play a significant role in transporting terrestrial plastic debris to the ocean. To date, little research has been done on riverine plastics and therefore, relatively little is known about the composition, quantities and environmental risks of fluvial plastics. Sanitary waste often is a main share of the total plastic litter found in rivers suggesting urban sewages as a possible source. In previous research on the Waal but also other branches of the Rhine, specifically sanitary wet wipes are found to be abundant. In response, this study aims to create an overview of the current problem, explanations, and possible solutions regarding sanitary waste, of which specifically wet wipes by researching part of the river Waal downstream of Nijmegen in combination with research on Nijmegen's sewage system. Higher concentrations of sanitary wet wipes were located at the inside bends compared to the outside bends. Also, vegetated areas contain higher concentrations of wipes than those with grass or no vegetation, areas with stones as substrate and the downstream parts of a groyne field contain higher concentrations of wipes than the other parts. These results can partially be explained by looking at sediment transport patterns as they appear to be similar. However, explaining their dynamics is complex as more factors are included than mentioned in this study. Furthermore, no direct link could be made between the sewage system of Nijmegen and the results of the study. This study provided new insights about the transport dynamics of sanitary wet wipes and additionally about existing knowledge gaps regarding riverine macroplastics and where further research is needed.

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1. Introduction

1.1. Background

Plastic has become a serious environmental hazard. The global annual production of plastics has rapidly increased over the last 50 years and is now over 360 million tons (PEMRG, 2021). Despite existing ways to recycle and reuse plastics, approximately 60% of all plastic produced has ended up in the environment (Al-Zawaidah, Ravazzolo & Friedrich, 2021), causing harm to ecosystems, habitats and human health (Lechner et al., 2014; van Emmerik & Schwarz, 2019). Plastic litter can impact organisms through entanglement in, or ingestion of plastic items by these organisms which may lead to death or severe suffering (Werner et al., 2016). The presence of plastics can also change ecosystems by altering the environments of organisms resulting in e.g., the exchange of 'alien' species between ecosystems or smothering of surfaces to which organisms must adapt (Kühn, Bravo Rebolledo & van Franeker, 2015). Eventually, prolonged exposure to UV-light and physical abrasion cause plastics to fragment into the environment (Barnes et al., 2009). The accumulation of these plastic fragments is of particular concern because they are difficult to remove from the environment and have the potential to be ingested by a much wider range of organisms (Barnes et al., 2009). These microscopic fragments, so-called microplastics, end up in other body tissues from the gut when taken up by organisms and humans as final consumer where they cause damage and presumably leak harmful chemicals (Barnes et al., 2009). Previous research on aquatic plastic pollution has therefore focused on microplastics rather than macro- or mesoplastics and are predominantly related to marine ecosystems (Blettler et al., 2018) as the oceans and marine systems are a sink of plastic litter, especially fragmented. By investigating plankton samples, it is demonstrated that the abundance of microplastics is increasing significantly (Barnes et al., 2009). Interestingly, about 80% of the input stems from terrestrial sources in which rivers and streams play a significant role in this as they are major transport vectors of terrestrial plastic debris to the ocean (Lebreton et al., 2017; Lechner, 2020).
Despite the importance of fluvial inflow of plastic pollution, we know relatively little about the composition, quantities and environmental risks of fluvial plastics. The main share of riverine plastic pollution by mass is macroplastics (Al-Zawaidah Ravazzolo & Friedrich, 2021). Not only do rivers act as transport pathway, recent studies now also suggest that they act as land-derived macroplastic storages (Liro et al., 2020). Considering the related environmental risk of the long preservation characteristic of macroplastics in nature and its role in the contribution of plastic emissions into the world's oceans, where they presumably are more harmful due to fragmentation, it is important to research these. Moreover, the accumulation of macroplastics potentially increases flooding risks by blocking drainage systems or clogging in-channel structures or other infrastructure systems (Al-Zawaidah Ravazzolo & Friedrich, 2021). In recent years, awareness about the threat of riverine macroplastics grew and a shift from marine toward land-based sources in literature is observed (Kallenbach et al., 2022).

Plastics, and in particular macroplastics, enter rivers and streams in various ways including, for example, riverside dumping or leakage of urban waste through the wind (Van Emmerik & Schwarz, 2019; Al-Zawaidah Ravazzolo & Friedrich, 2021). From here, plastic litter transportation is influenced mainly by precipitation-driven surface runoff, wind, and river flow. It can be deposited (temporarily) on riverbanks, in sediment, in vegetation, and riverine biota, leading to variation in residence time in a river (Roebroek et al., 2021). The plastic's properties cause differences in plastics' dynamics in this transportation process dividing them into floating plastics at the surface, suspended plastics along the water column, or plastics over the riverbed (Van Emmerik & Schwarz, 2019; Van Emmerik et al., 2020) which also influences its residence time. In addition, previous research shows that population density, water discharge and the Human Development Index (HDI) have the strongest correlations with riverine plastic outflows. However, existing knowledge and data regarding macroplastics are still insufficient in linking sources, transport pathways and fate (Al-Zawaidah, Ravazzolo & Friedrich, 2021). An important urban source is presumably related to the sewages as previous counts of plastic in the Thames (Morrit et al., 2014) as well as on the riverbanks of the branches of the Rhine (Vierwind & Lhoest, 2021) found that a large share of the items were sanitary products. Amongst these sanitary products are products such as tampons, cotton swabs and wet wipes.

Focussing on the Waal and Maas, there was a 20% share of sanitary wet wipes among the plastic waste found between 2017 and 2019 (Vierwind & Lhoest, 2021). By identifying two sewage overflows near so-called sanitary hotspots, a direct link between them is suggested. These hotspots were based mainly on the number of cotton swabs (>35 cotton swabs/100 items) as these were found predominantly, but also on the percentage of sanitary wipes and other sanitary products (>8%). In response, Vierwind (2021) investigated the content of a sewage overflow in Soest to gain knowledge about its contribution to the plastic and specifically sanitary waste in the rivers. She found an 83% share of sanitary wipes among the total waste items captured after two sewage overflows. However, a difference in the amount and categorical distribution of plastic items between the water column and riverbanks of the Waal exists (Oswalda et al., 2020). Looking at the water column, no sanitary wet wipes were present in 2019. In October 2020 it quadrupled compared to September 2020 (Collas, Oswald & Verberk, 2021), additionally indicating temporal differences.
As previously mentioned, the distribution of these products is assumed to be strongly influenced by flow hydrodynamics, river morphology and riverbank vegetation (Al-Zawaidah Ravazzolo & Friedrich, 2021) and dependent on a plastic's own properties (Van Emmerik et al., 2020). These factors can all play a role in explaining spatial and temporal differences. Considering this, previous research has already suggested that patterns of plastic debris transport perhaps are similar to patterns of sediment transport (Barnes et al., 2009) and should be regarded as a new kind of sediment particle, besides the mineral and organic types (Liro et al., 2020).

1.2 Aims and expectations

In ongoing research about in and outflow of plastic in a groyne field, over 500 sanitary wet wipes were found in one groyne field (Grosfeld, 2022). The question immediately arose whether this is representable for all groyne fields along the Waal. In response, this study will focus on sanitary wet wipes on the riverbanks of the Waal near Nijmegen. Precisely how sanitary wet wipes move through water, how their exchange dynamics between the riverbanks and water column are and where they originate from, is yet unclear. Gaining knowledge about the dynamics of riverine macroplastics, and in this case sanitary wet wipes, helps efficiently remove it, thereby preventing it from fragmentation and from ending up in the oceans. Additionally, it contributes to the development of management measures and ideally preventive measures by identifying the source.

Therefore, this research aims to create a better overview of the current problem, explanations, and possible solutions regarding sanitary waste, of which specifically wet wipes, by trying to answer the following questions:

1. What are the hydrological factors influencing the spatial distribution of sanitary wet wipes along the riverbanks of the Waal and are they comparable to the river's sediment transport patterns?

   This question is divided into the following sub-questions:
   a. Is there a difference between the north and south bank?
   b. Is there a difference between the inside and outside bend?
   c. Do the groyne field characteristics vegetation type, substrate, and location within a groyne field influence the distribution?
2. What role does Nijmegen's sewage system play in this?
3. What is the current approach in tackling this problem and can the results of this study be used to improve this?

This study will count and analyse the concentration of wet wipes on the riverbanks of the Waal downstream of Nijmegen. It is expected that the wipes will have similar transport dynamics as sediment and will, therefore, show differences between the north and south bank, the inside and outside bends, as well as within a groyne field. Specifically, it is expected that the most influencing factor will be the bend type in which the inside bends are expected to contain the highest concentration of sanitary wet wipes since this is where deposition of sediment occurs. Their distribution is also expected to be influenced by vegetation type, substrate and location within a groyne field. Furthermore, it will provide new insights on the possible source that is suggested to be urban sewages by not only looking at its location but including sediment dynamics.

2. Background

2.1 Fluvial sediment dynamics

It has been suggested that, like sediments, flow hydrodynamics control the distance and intensity of macroplastic transport and that therefore, it follows similar patterns to sediment transport. Simultaneously, it interacts mechanically with water and sediments also transported by the river (Liro et al., 2020). Therefore, this paragraph will discuss the fluvial sediment dynamics of the Waal and factors that influence this.

Originally, the Waal is a meandering river that transports sediment to the sea, eroding outside bends and depositing inside bends, leading to the avulsion of the river. A higher discharge generally corresponds with more sediment transport. However, this is not linear due to various influencing factors such as water surface slope and whether the discharge is increasing or decreasing (ten Brinke & Scheifes, 2004). At present, the Waal is an important shipping route and human interventions have changed the dynamics of the river. It is characterized by its many groynes that limit the river's meandering and create small beaches, i.e., groyne fields, in between them that form the riverbanks as we know them (ten Brinke, 2003; Kleinhans et al., 2013).

2.1.1 Fluvial geomorphology

The shape of a meandering river maintains a complex and uneven distribution of flow and sediment processes (Kasvi et al., 2017). When entering the bend, the high-velocity core (HVC) is situated at the inner bend and gradually moves towards the outer bend. This outward flow causes the water to elevate at the outer bend and enforces a downward flow along the bed that continues towards the inner bank near the bed and upwards again at the inner bank. This process continues and is called the *helical flow* (figure 1).

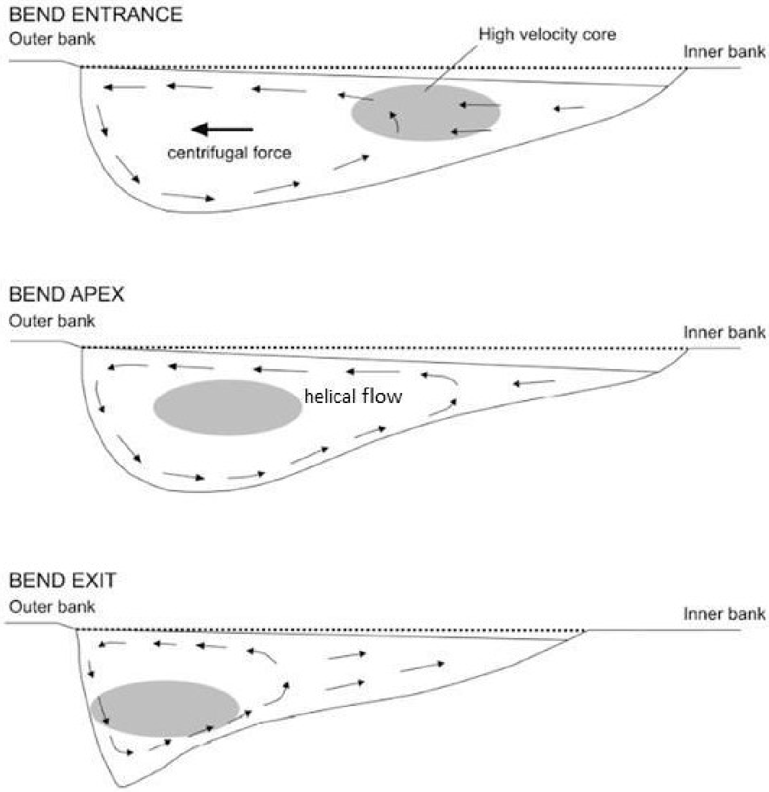

Figure 1. A simplified model of the flow structure in a meander bend. The three sections represent the beginning, middle and end of the bend. (Source: Kasvi et al., 2017).

This helical flow structure plays an important role in cross-stream processes. It induces lateral or transversal flows that are different in strength throughout the cross-sections of a river bend. Naturally, it leads to erosion of the outer bank whereafter the sediments are carried towards the inner bank and deposited (Berendsen, 1996, p. 187). These river flows are affected by channel geometry as well. Generally, shear stress and erosion increase downstream from the bend apex along the outer bank where the highest velocities persist due to centrifugal force and acceleration of secondary flow currents (Donovan et al., 2021). However, the location in the bend with the strongest erosion and sedimentation depends on the bend radius and discharge as well since this influence the HVC pathway (figure 2). The HVC moves towards the outer bend further upstream at lower discharges or when the river has a mild bend. At higher discharges or in presence of a sharp bend, the HVC moves towards the outerbend further downstream (Berendsen, 1996, p. 187; Kasvi et al., 2017).

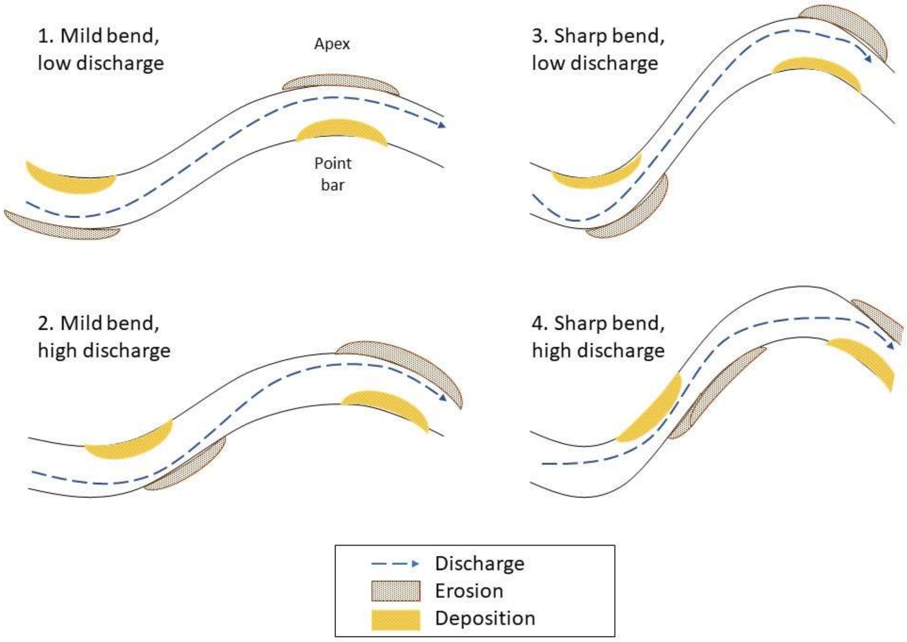

Figure 2. The location of erosion and deposition in a river bend influenced by bend radius and river discharge.

Other research on riverbank sedimentation found that the distribution of sedimentation over the north and south bank is the result of variety in flow patterns across the river (Sorber, 1997). For the Waal, they found more sedimentation at the south bank caused by a smaller sediment grain size and larger discharge influx into the river from the south side.

In addition, many other variables play a role in the erosion and sedimentation of rivers such as friction or flow resistance, flow depth or width:depth ratios and the processes are therefore much more complex (Donovan et al., 2021).

2.1.2 Groyne influence

The flow pattern in groyne fields is indirectly dependent on discharge as some water of the main channel is diverted into the groyne fields by the groynes. This induces a circulation flow that enters downstream and exits upstream of the groyne field. Additionally, a smaller circulation flow appears close to the downstream groyne in groyne fields of a 200 m width or larger (figure 3). The flow strength varies depending on the vessels passing the groyne field and the discharge. The distance between groynes and the navigation traffic are two factors that are, therefore, assumed to control sediment exchange between the groyne fields and the main river channel. Because of this, the groyne fields are constantly changing by erosion and sedimentation (ten Brinke & Scheifes, 2004). It seems that underwater volume and distance of the channel fairway from the riverbank are the main influencing factors of the water and sediment transport within a groyne field with the largest sediment transport occurring with a small distance of the fairway and a large underwater volume (ten Brinke, 2003). However, since 2015, the groynes in the Waal were lowered by the project Ruimte voor Rivieren causing the groynes to be flooded 2/3rd of the time instead of the 1/3rd before 2015. Consequently, processes described by ten Brinke are weakened.

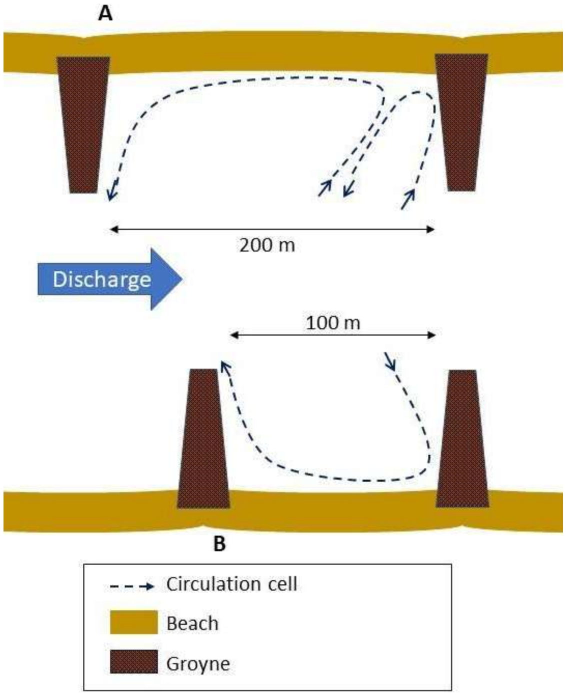

Figure 3. Flow circulation cells in groyne field with a (A) large and (B) small width.

2.1.3 Shipping traffic influence

A navigating ship creates waves and currents caused by the pushing up of water at the bow of a ship and the lowering of the water level at the sides of the ship. This leads to the filling and emptying of the groyne fields as well as extra friction at the riverbed causing more sediment to move. It follows the circulation cell current that is present in a groyne field, transporting sediments from the groyne field back into the channel. The bigger the ship, the stronger the currents and consequently, larger erosion. Previous research already showed a lowering of the river beds in the groyne fields of the Waal river due to erosion caused by the currents that ships create (ten Brinke, 2004). Interestingly, the fields on the south bank experienced more erosion than the north banks presumably because heavier ships that ship goods into the land from sea fare along the south bank.

2.2 The sewage system of Nijmegen

Sewages and its overflows are suggested as a plausible source of riverine sanitary waste (Morrit et al., 2014; Vierwind & Lhoest, 2021). Nijmegen, as the largest city located adjacent to the Waal, has a sewage system that predominantly consists of mixed sewers that lead both wastewater and rainfall through the same pipes to the sewage treatment. With heavy rainfall, the sewage can overflow causing wastewater to end up in surface water that is usually a park, pond or a ditch. This may lead to the pollution of freshwaters (Vierwind & Lhoest, 2021). To optimize the quality of water that eventually ends up in our freshwaters, Nijmegen's sewage system contains two waste sedimentation basins (translated from "berg bezink basin") where excessive wastewater can discharge into. It allows waste to sink in whereafter the filtered water is pumped back into the sewage system (Nijhof, 2022). The main part of Nijmegen's sewage is connected to the pumping area De Biezen (figure 4, a), from where it is transferred to the sewage water treatment in Weurt. When the capacity of De Biezen is exceeded and the pumps are unable to transfer all water, water overflows, first in a nearby park and after in the Waal (figure 4) (Welman & Zuurman, 2014). But there are multiple other overflows that discharge into surface freshwaters first that act as a buffer of the sewage system. When the water lowers again, water flows back into the sewage system so that it can still be transported to a sewage water treatment.

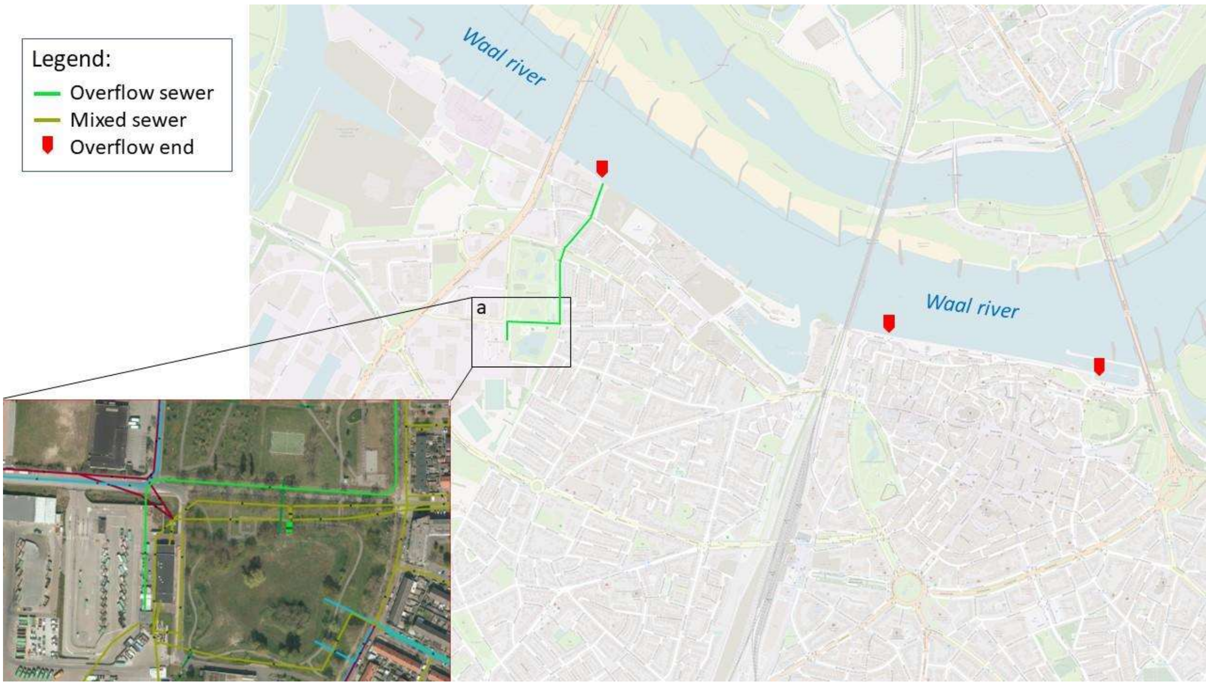

Figure 4. A map of Nijmegen that displays the sewage overflows that discharge on the Waal and (a) drainage area De Biezen where water is transferred from to the sewage water treatment in Weurt.

Most municipalities north of the Waal transfer sewage water to Arnhem Zuid and do not have any sewers discharging on the Waal directly.

2.3 Policy

Understanding the dynamics of riverine plastic debris, and in this case sanitary wet wipes, is fundamental in effectively targeting clean up events and assessment of the present and future environmentally related risks. Since 2019, Rijkwaterstaat started focussing on researching and monitoring plastic in and around the Dutch rivers. While conducting research on migration fish, the samples taken contained more plastic than fish. Remarkably, in the European Water Framework Directive (WFD) (2000/60/EC), plastics are not included as a priority substance. The WFD's purpose is to protect European water bodies which also means reaching a "good chemical status" and a "good ecological status" in which substances that play a role in this are ranked (European Commission, 2000). Resulting from the WFD, is the River Basin Management Plan for the Rhine (RBMP) (stroomgebiedbeheerplan) that identifies the knowledge gap on plastic litter and expresses the urge for expanding on scientific knowledge on the issue (Ministerie of Infrastructuur en Milieu, 2015). From this perspective, Rijkswaterstaat Oost-Nederland (RWS-ON) currently aims to develop mitigation and management measures, preferably preventive management measures. To achieve this, they are doing research in collaboration with universities such as Radboud Nijmegen and Wageningen University and Research, and NGOs related to the subject that add to the monitoring of plastic litter in and around the Rhine and branches, including the Waal. Monitoring plastic debris in the Waal as the largest branch of the Rhine (Gensen, Warmink & Hulscher, 2018) is particularly crucial in developing the optimal management strategy. It is essential for the reduction of riverine litter, as it provides the data required to identify and characterize litter items, their sources and variation over time and space (Van Emmerik et al., 2020).

According to Al-Zawaidah et al. (2021), management of riverine plastic litter should be done through 1) reduction of inflow of waste, 2) removal of riverine waste, and 3) proper disposal of riverine waste. In recent years, various initiatives have started monitoring plastic litter on the riverbanks of the rivers and branches of the Rhine and Meuse in the Netherlands. Because this is usually done through clean-up events, they contribute directly to the removal of riverine plastic litter. Moreover, they provide data on which research on plastic litter in and along the Waal is based on, so-called *citizen science*.

Van Emmerik & Vriend (2021) have proposed a road map for the long-term monitoring of plastic litter in the Dutch rivers, commissioned by Rijkswaterstaat. It will provide an overview and offers a flexible framework upon which projects and research can be formulated. The road map can adapt to technical developments and new insights which help prioritise other projects and research and determine the optimal order of execution. It acts on different levels based on the larger questions regarding plastic litter (figure 5). Several studies have been conducted in cooperation with Wageningen University and Research, Radboud University Nijmegen, and interns from other schools as well (overview in table 1 and figure 5). This study (project nr 1 in table 1) will provide new information on the distribution and amount of sanitary wet wipes on the riverbanks of part of the Waal. Additionally, it explores possible sources and evaluates sampling methods.

Table 1. Projects of RWS-ON and their description and place in the road map based on expansions level, level and the objective that represent the larger questions in the road map. Project 1 is this study.

	Study or project	***Author***	***Expansion***	***Level***	***Objective***
1	The distribution of sanitary wet wipes	Minnaar, 2022	Riverbank	1, 2	(1) Method sampling approach; (2) Distribution, approximate amount, possible source
2	Abundance and composition of macro- and mesoplastic in the Waal river, the Netherlands	Oswald, 2020	Watercolumn	1, 2	(1) Method sampling approach, (2) Approximate amount, material type
3	Netmeting kor-netten bovenrijn 2021 & 2022	Rus, 2022	Watercolumn	2, 3	(2) Distribution, material type, approximate amount, possible sources; (3) Over time comparison with previous year studies
4	De mogelijke impact van riviercruises op de plasticvervuiling in de Rijn	Van Klink, 2021	Over coupling each expansion	2	(2) Source, material type, approximate amount
5	Plastic in de waterkolom van de IJssel, Waal en Boven-Rijn	Collas, 2021	Watercolumn	1, 2	(1) Method measure approach, testing consistency of method; (2) Monitoring, distribution
6	Tracking floating plastic	Goelema, 2021	Floating	1, 2, 3	(1) Method measure approach; (2) Monitoring, distribution; (3) Transport routes
7	Exchange dynamics of plastic litter in a groyne field	Grosfeld, 2022	Riverbank	1, 2	(1) Determining amount, method selection; (2) Material type, distribution

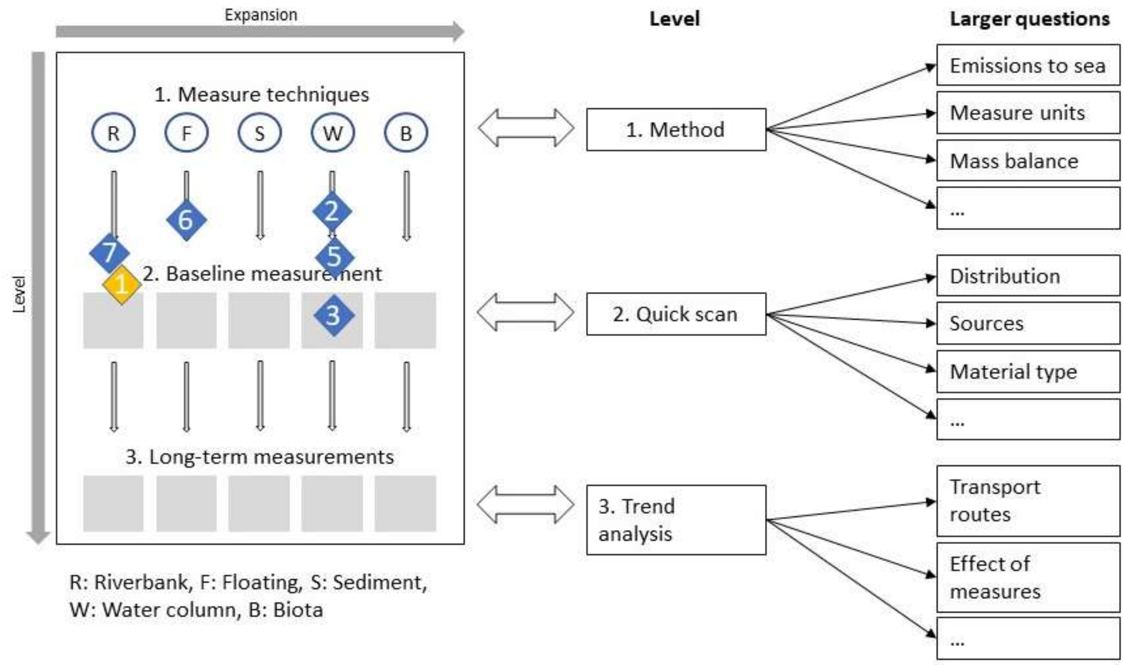

Figure 5. The road map in which the current projects of RWS-ON are displayed with blue diamonds and numbered as described in table 1. This project one is displayed in yellow.

In combination with the EU legislative act on single use plastics (SUPs), the following measures regarding plastic litter have been implemented in July 2021:

- A ban on SUPs that include drinking straws, plastic cutlery, and cotton buds, amongst other things.
- A mandatory logo that states the presence of plastic in a product including tampons, sanitary towels, and sanitary wet wipes.
- Plastic bottles require deposit to stimulate recycling.

However, to date there are no concrete goals with quantitative measures regarding riverine waste. RWS expects to have gained enough insights into the problem to be able to develop these in 2024. Exchange of information and results between other parts of RWS in the Netherlands is necessary for this and supported also through the road map of van Emmerik & Vriend (2021). By looking at the road map, research specifically on plastics in sediment and biota is needed. Most important, to be able to discover transport routes and detect other trends, long-term monitoring is crucial. For example, when looking at the water column, continuing monitoring with kor-nets is important in this. This method seems reliable, resulting from project 2 and 5. For riverbank plastic litter, the Schone Rivieren initiative plays an important role.

3. Methods

3.1 Study area

The Rhine originates from the Alps and flows through Switzerland and Germany to the Netherlands. It enters the Netherlands at Lobith where it splits into three branches: the Waal, the IJssel and the

Nederrijn-Lek rivers (Klijn, Asselman & Wagenaar, 2018) of which the Waal is the largest of the three. The complete catchment area is 218.339 km^2 and that of the Rhine delta is 58400 km^2. The study area is part of the river Waal in the Netherlands and includes both the south and north riverbanks from Nijmegen to Winssen, which is downstream of Nijmegen (figure 6). A stretch of approximately 10 km on each side was sampled during a period of three weeks between 7 and 25 March 2022. On 21 and 22 April, some parts are measured again. The average discharge of the Waal is about 1500 m3/s. During the study period the discharge and water level at Lobith lowered from 2100 to 1275 m3/s and 9 to 7.85 m respectively in the first count, and was between 1850 and 1700 m3/s, and 8.9 and 8.7 m in the second count (figure 7). These values are measured by the RWSOS Rivieren system and obtained upon request through Rijkswaterstaat. This corresponds to the average discharge and water level of Lobith at this time of year of which about 60-70% discharges through the Waal (ten Brinken & van Zetten, 2020). Therefore, these values are somewhat lower at the study area.

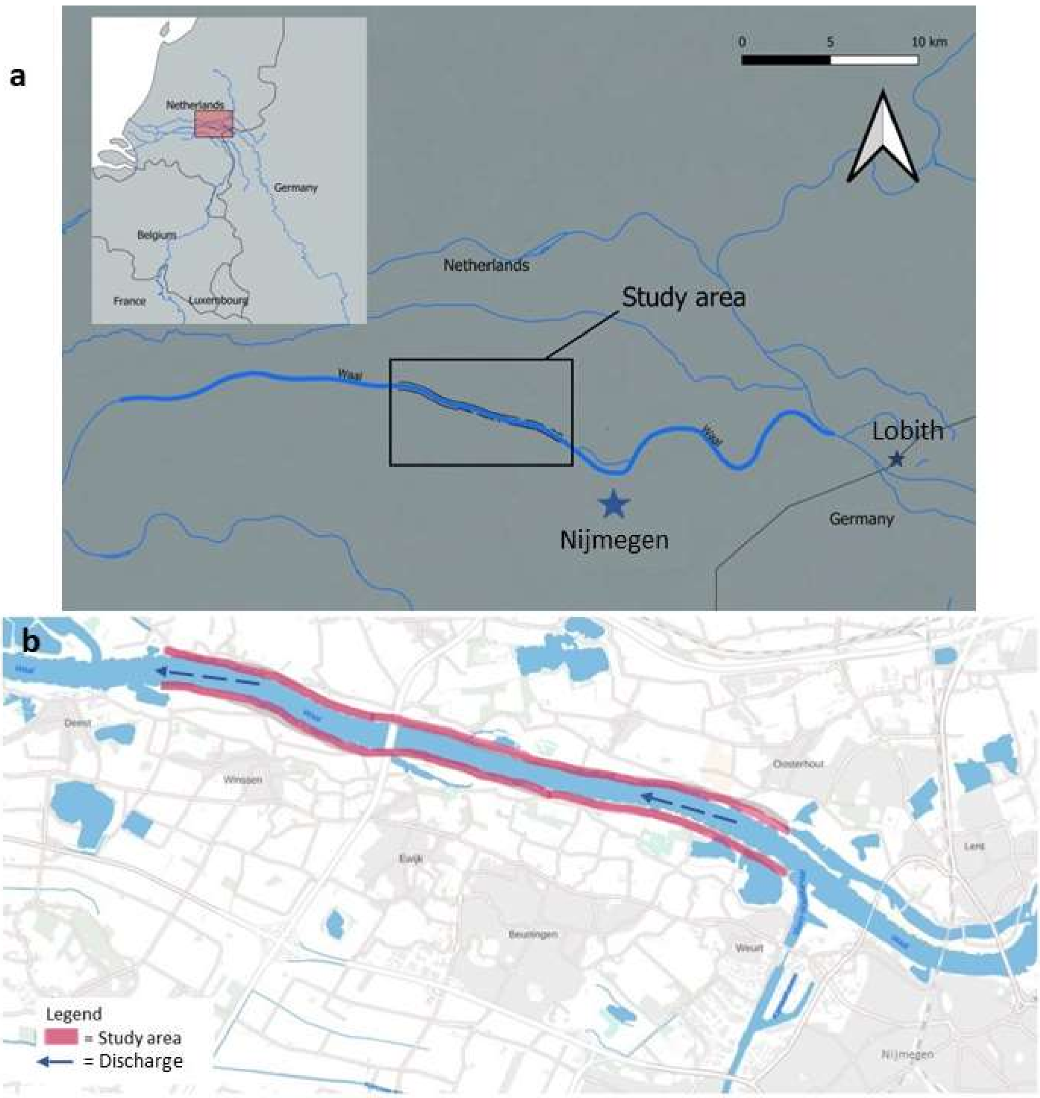

Figure 6. Study area: (a) The study area is located in the Netherlands close to the border of Germany and is part of the river Waal; and (b) reaches from Weurt to Winssen (South) and from next to Nijmegen (North) to Oosterhout.

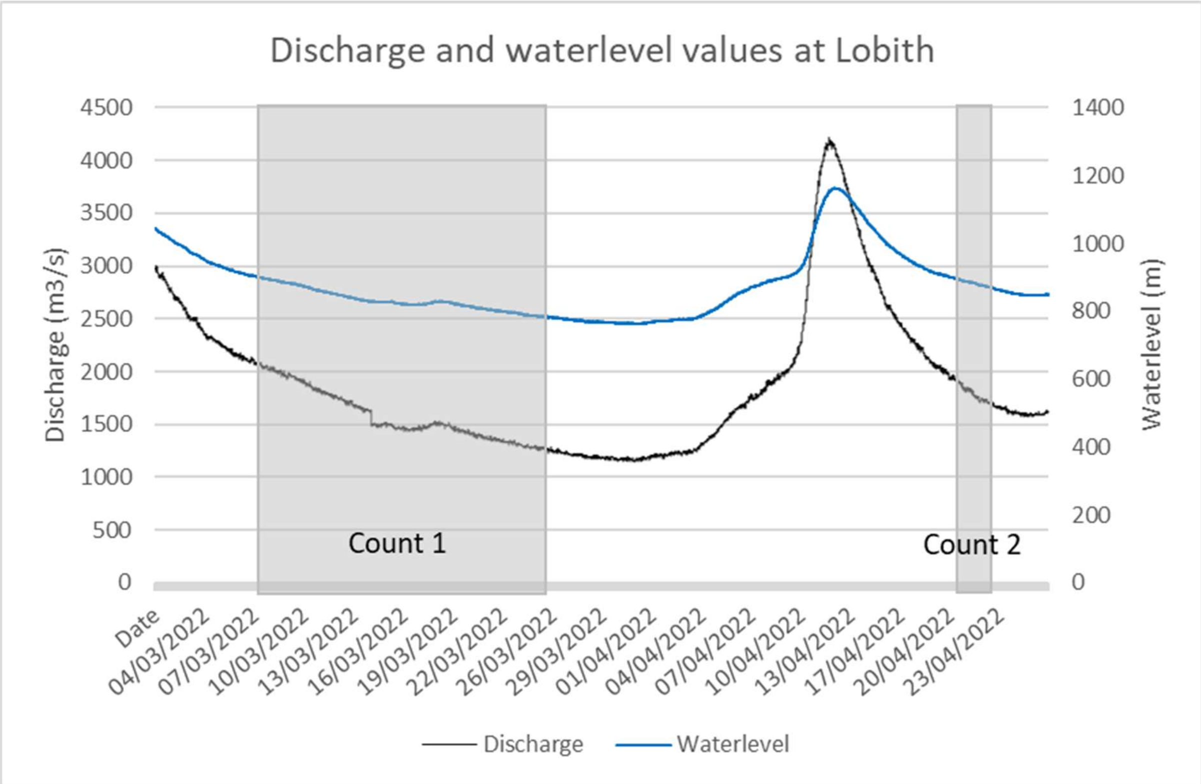

Figure 7. Discharge and water level variation at Lobith during the study period. (Source: RWSOS Rivieren)

3.2 Sampling approach

The number of sanitary wipes on the riverbanks along the Waal is counted based on the protocol of the Schone Rivieren initiative. This is an initiative in cooperation with IVN Natuureducatie, Plastic Soup Foundation and Stichting de Noordzee, and supported by Rijkswaterstaat, which consists of volunteers that aim for plastic-free rivers by organising clean-up events of the riverbanks of the Dutch rivers, hereby contributing to the monitoring of plastic debris along the riverbanks. During these clean-ups, the plastics found are counted and categorised according to the river OSPAR-protocol (OSPAR commission 2010). It contains a list of categories of plastics and other litter among which is the category *sanitary wipes or parts of it* that is used in the current study. Furthermore, it instructs to count over the area between the flood line and the waterline. A flood line forms when the water pushes debris up on the beach where it stays when the water lowers again. Therefore, the highest flood line can be recognized by debris lined up at the end of the groyne field, as shown in figure 8b. These guidelines are used for the current research, counting the number of sanitary wipes in each third of a groyne field, between the highest flood line and the waterline of the groyne field (see figure 8). The wipes do not have to be intact and parts of it are counted as one as well. This way, the number of sanitary wipes per third groyne field is determined. The groynes themselves are not included. The flood line and waterline vary due to variation in discharge and consequently, the areas vary in size. The route is covered by foot during the day, usually between 9am and 2pm over a timespan of three weeks in which north and south bank were alternated. It started at Winssen, walking upstream whereafter it ends in Weurt at the south bank and in Oosterhout at the north bank nearby Nijmegen. The counting is done by collecting the sanitary wet wipes or parts of it by hand by two persons.

Figure 8. (a) Characteristics of the groyne fields; (b) Picture of a floodline; (c) Picture of a groyne.

There is a second count to determine the new influx of sanitary wipes after a month. Between the two counts, discharge and water levels have risen and lowered again. Due to time management, the second count measures a few locations in the study area that are considered representative of the entire study area. During the first count, coordinates of the boundaries of the areas are noted to measure between the same boundaries during the second count.

3.3 Variables

Multiple variables are taken into consideration and documented during the counts, and pictures were taken for clarification.

3.3.1 Groyne field part

The groyne fields typically are between 150 and 200 meters wide. In this study they will be divided into thirds by eye, marking these areas by writing down the coordinates of the area's boundaries indicated by a geocaching navigator. This way, the upstream, middle and downstream part of the groyne field can be compared. Due to the variation of position in water level, the flood line and waterline, the areas vary in size.

3.3.2 Vegetation and substrate

Vegetation type and substrate will be observed and categorized by eye. Often a groyne field consists of both sand and stones, and shrubs and trees, for example. This is noted but regrouped into one category that best represents the groyne field (see data analysis).

3.3.3 River bend

Whether the groyne field is located at an inside or outside river bend is determined afterwards based on a map.

3.3.4 Sewage overflows

Data on sewage overflows within and upstream of the study area is collected by contacting governments and municipalities, as well as the authors of the previous study by Vierwind & Lhoest (2021) researching the possible link between sanitary waste and sewage overflows. An interview with Arthur Nijhof who works in sewer management of Nijmegen has been conducted.

3.4 Schone Rivieren data

The data collected in the present study are compared to the sanitary data gathered by the Schone Rivieren initiative to create a better overview of the temporal distribution. This data contains counts of sanitary products on various locations within the study area between 2017 and 2021. Examples of sanitary products are *sanitary towels, cotton swabs, shampoo bottles* or *condoms.* The counting was done as described in 7.1, using the OSPAR-protocol and over areas of a 100 meter length and 20 meter width. The concentration sanitary wet wipes per m2 is calculated for these locations and compared to the present study's data.

3.5 Data analysis

Data were analysed in Rstudio (version 1.3.1). To normalize the data, the concentration of sanitary wet wipes was calculated for each area by dividing the number of wipes it contained by the surface area. This remains a non-negative dataset that is zero inflated and therefore, data analysis is done using a gamma distribution (Collas, Oswald & Verberk, 2021). To use a gamma distribution, a +0.00001 transformation is done on the concentration data first. An addition of 0.00001 is neglectable. The fitness of the gamma distribution is checked through graphical inspection of the empirical and theoretical CDFs whereafter is concluded that the assumption is met. The data analysis consists of two models, each analysing the influence of factors of a different spatial scale. The first analysis will determine the effect of the bend type (inside or outside bend) and riverbank side (north or south) on the concentration wet wipes using a generalised linear model (GLM) with a gamma distribution and log link . The second analysis will focus on the influence of characteristics of a groyne field on the concentration wipes. It will determine the effect of vegetation type, substrate and groyne field part using a GLM with a gamma distribution and log link as well. Vegetation type is divided into three groups: 1) no vegetation; 2) grass and; 3) vegetation (straw/high grass, shrubs, trees). Substrate is divided into four groups, based on the predominant substrate: 1) sand; 2) pebbles; 3) stones and; 4) clay. Groyne field part is divided into 1) the downstream part; 2) middle and; 3) upstream part of the field.

The selection criteria for the best fit model follows two steps in which several models with increasing complexity are compared. First, the influence of the individual factors and their additive effect are modelled separate. These models are compared and model selection was based on the lowest AIC (Akaike information criterion) value. Second, interaction effects are added to the best model after which they are again compared using the AIC value to find the best fit model. Thereafter, the corresponding post hoc tests were conducted.

Finally, the differences within a river meander wavelength were visualized by plotting the number of wet wipes in different parts over a wavelength of a river bend. To do this, the location in the river bend of the groyne field areas was determined first. The wavelength of a river consists of an inside and outside bend for both sides and a point of crossover. It is divided into six parts as displayed in figure x. Based on a bathymetric map of the study area from RWS is determined for both bank sides whether a groyne field area lies at the beginning of the wavelength, starting at the point of crossover (1), at the outside bend (2), downstream of the outside bend (3), upstream of the inside bend (4), the inside bend (5) or downstream of the inside bend (6) (figure 9).

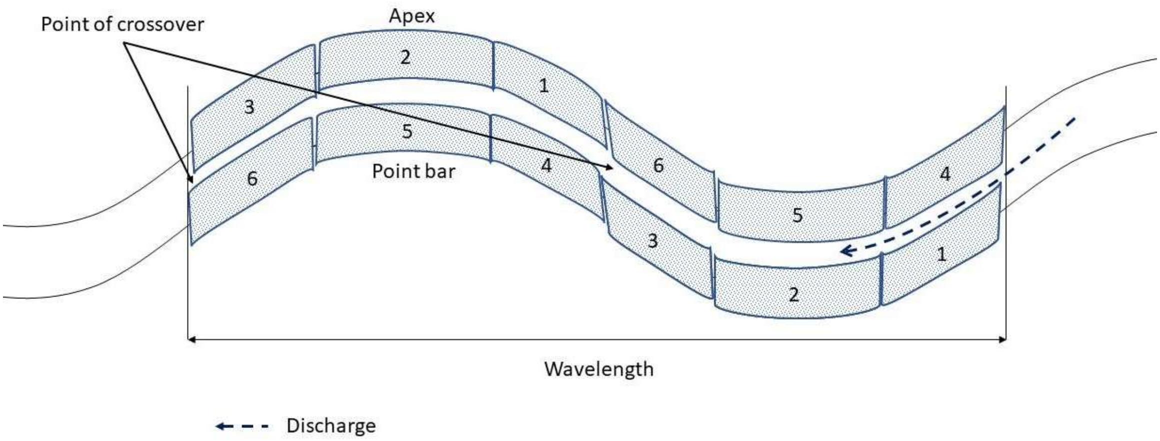

Figure 9. Visualisation of the division of the groyne field areas at the riverbanks over the wavelength in a meandering river starting at the point of crossover and containing one inside and one outside bend.

4. Results

4.1 Spatial and temporal distribution of sanitary wet wipes

There was a significant difference in the concentration of sanitary wipes found between the north and south bank ($\chi^2(1) = 277.5$, $p < .000$) as well as between the inside and outside bend ($\chi^2(1) = 18.34$, $p = .03$). Higher concentrations of wipes were found on the southern banks and in the inside bends. No interaction effect was found (figure 10).

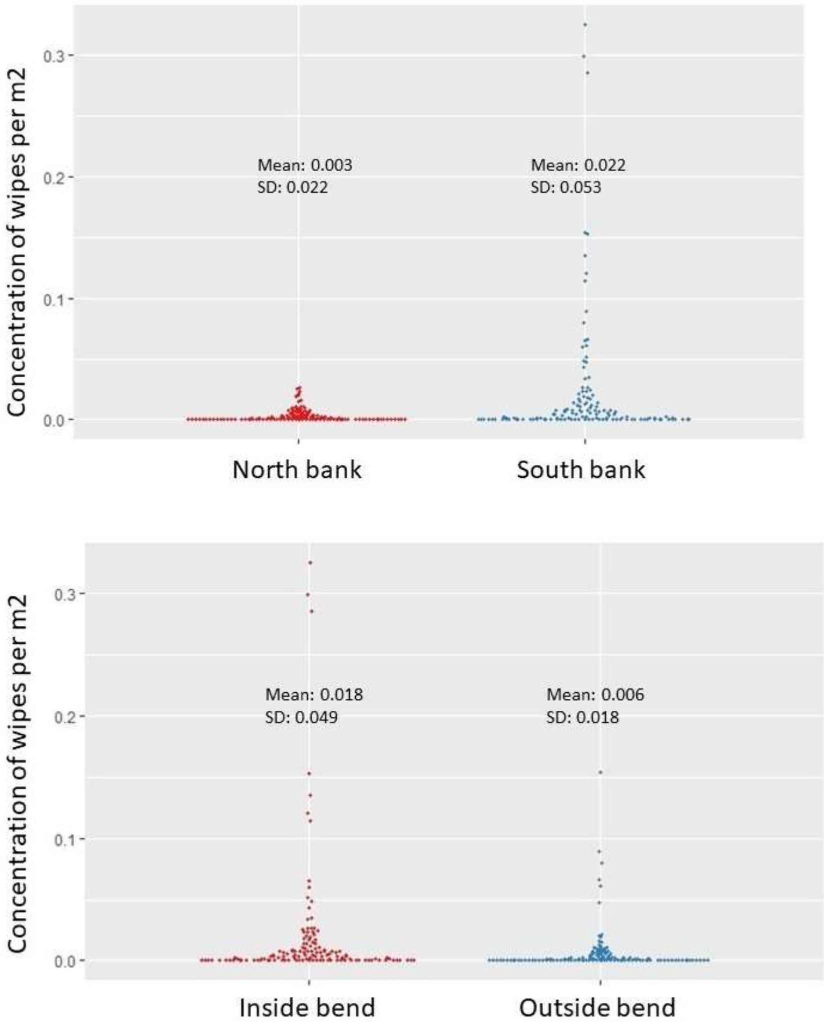

Figure 10. Beeswarm jitter plot of the distribution in concentration of sanitary wipes and the effect of the bank side and bend type. The top figure displays the difference in concentration between the north and south bank and the bottom figure the difference between the inside and outside bend.

Within a groyne field, vegetation ($\chi^2(2) = 47.56$, $p = .001$), substrate ($\chi^2(2) = 244.70$, $p < .000$) and groyne field part ($\chi^2(1) = 124.77$, $p < .000$) all have a significant effect on the concentration of sanitary wipes. No interaction effect was found meaning that the two variables do not influence each other (figure 11).

Tukey post hoc tests revealed a significant difference in concentration wet wipes between no vegetation and vegetation ($p < .01$), between sand and stones ($p < .000$), sand and clay ($p < .000$), between pebbles and stones ($p < .000$), between pebbles and clay ($p < .000$), between stones and clay ($p < .000$), between the downstream and middle part of a groyne field ($p < .000$) and between the downstream and upstream part of a groyne field ($p < .000$). It appeared that higher concentrations of sanitary wet wipes are located at a vegetated riverbank rather than those with no vegetation or grass. Also, it seemed that the presence of stones and the downstream position within a groyne field generated the highest concentration of wet wipes (figure 11).

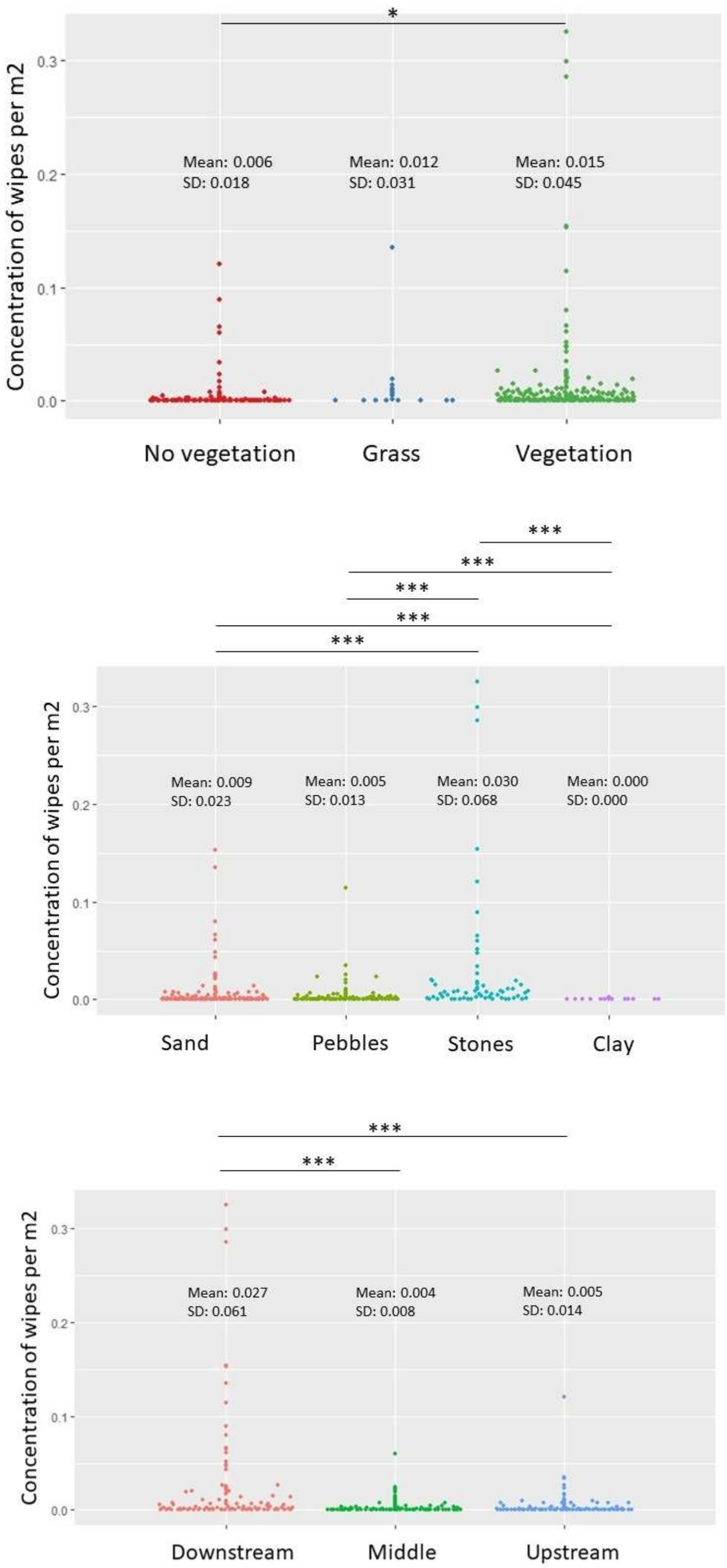

*Figure 11. Beeswarm jitter plots of the distribution in concentration of sanitary wipes within a groyne field and the effect of vegetation type, substrate and location in groyne field. The top figure displays the difference in concentration between the vegetation types, the second figure the difference between the substrates and the last figure the differences between the locations. * p < .01, ** p < .001, *** p < .000.*

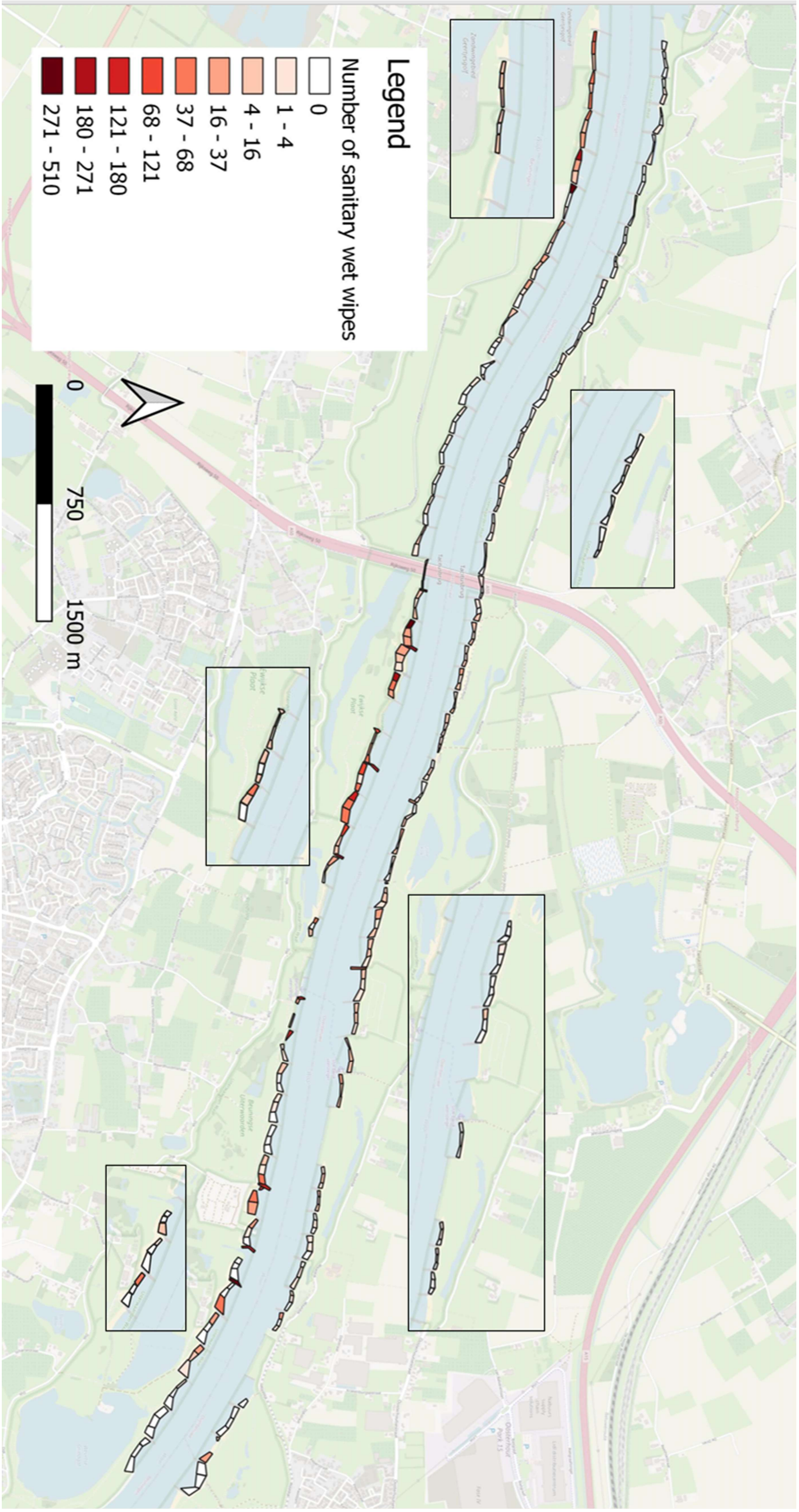

Figure 12. The spatial distribution of sanitary wet wipes in the first and second count. Displayed are the areas measured that cover an approximate third of a groyne field and the absolute number of sanitary wet wipes it counted. The counts of the areas that were covered a second time are displayed in the boxes next to those areas.

By visualising the concentrations of sanitary wet wipes within the river's wavelength, the highest concentrations of wet wipes seem to be in the inside bend plus upstream of the inside bend (figure 13).

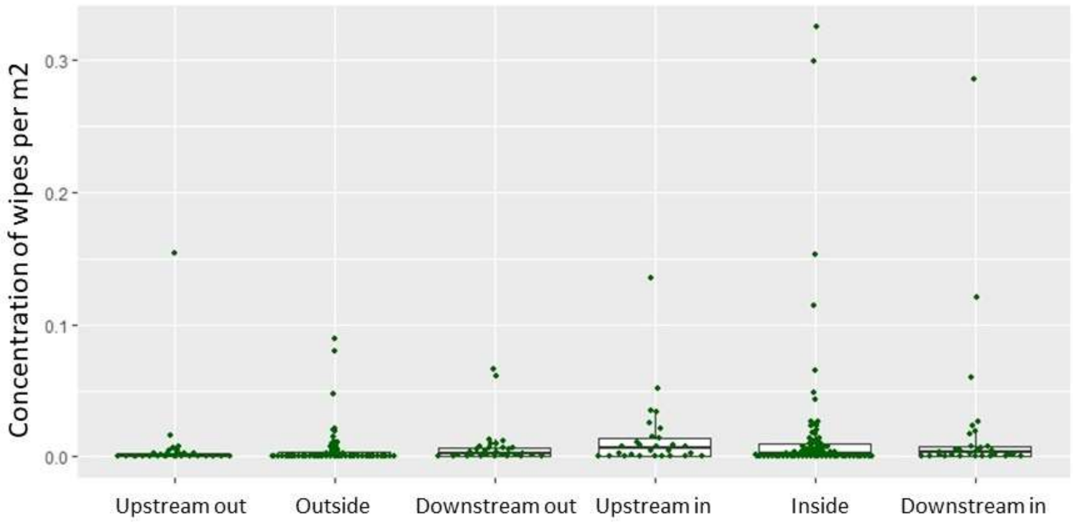

Figure 13. The distribution of the number of sanitary wet wipes over the wavelength of a river bend. The figure shows the means of the concentration of wipes per m2 at different parts in the wavelength.

Furthermore, no distinct pattern can be observed when looking at the temporal distribution of sanitary wet wipes (figure 14).

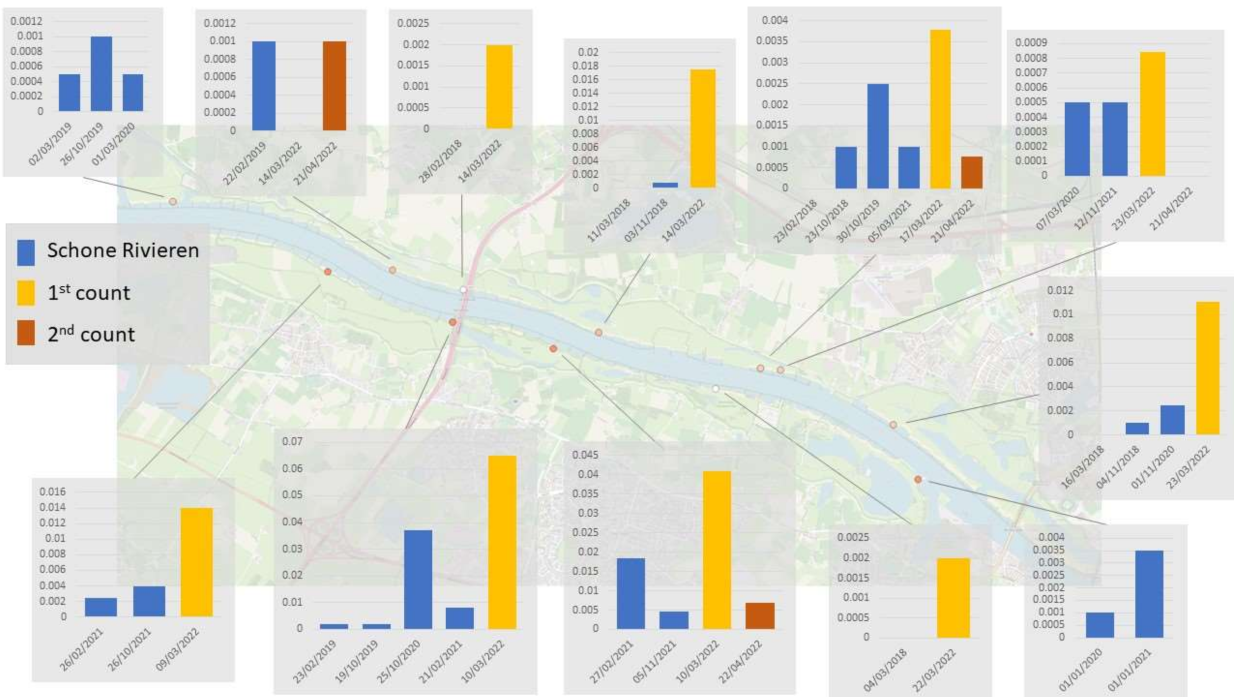

Figure 14. The concentration of sanitary wet wipes counted on various locations within the study area over time. The bars each represent a count of which the date is displayed on the x-axis and on the y-axis the concentration of wipes. Data of previous counts is derived from the Schone Rivieren initiative's database.

4.2 Sewage overflows

In the last five years, there have been 1 to 3 recorded overflows per year at the overflow that diverts from drainage area De Biezen (table 2). Sensors located inside of the overflow at the threshold are only able to give an estimate of the volume (m^3) that overflows. Due to the possible occurrence of a malfunctioning sensor these are not always correct. Before the first count of this study (7 to 25 March), two small discharge pulses have been recorded on 6 and 20 February and before the second count (21 and 22 April) one on 15 April. This information is obtained upon request from the Nijmegen municipality. The other municipalities adjacent to (Beuningen en Overbetuwe) or upstream of (Cuijk, Heumen, Berg en Dal and Mook en Middelaar) the study area that responded (Beuningen, Cuijk, Heumen and Berg en Dal) all claim to have no overflows discharging on the Waal (overview in appendix B). Waterschap was approached as well but did not respond.

Table 2. Past recordings of discharge pulses in overflow 'de oude haven' diverted from pumping station De Biezen.

Year	*Date (dd/mm)*	*Approximate volume (m^3)*
2017	30/03	7604
	28/06	1370
2018	30/04	1009
	29/05	2750
	30/10	612
2019	20/02	*NA*
	01/04	*NA*
	11/11	*NA*
2020	07/01	1143
2021	13/07	2268
	10/09	533
	27/09	*NA*
2022	06/02	773
	20/02	678
	15/04	15

5. Discussion

5.1 Explaining the spatial and temporal distributions

Higher concentrations of sanitary wet wipes were located at the inside bends compared to the outside bends, vegetated areas contain higher concentrations of wipes than those with grass or no vegetation, and the downstream parts of a groyne field contain higher concentrations of wipes than the other parts. These results can be explained by looking at several hydrological factors and how they influence sediment transport patterns as they appear to be similar. A higher concentration wipes at the inside of a bend corresponds to sediment dynamics on which the helical flow that occurs in a bend causes erosion at the outside of a bend and deposition at the inside of a bend (Berendsen, 1996, p. 187; Kasvi et al., 2017; Donovan et al., 2021). The helical flow might affect the sanitary wet wipes in the same way. By visualising the distribution over the wavelength of a bend, the wipes seem to concentrate at the beginning of the inside bend and the inside bend itself. This corresponds with deposition patterns of meandering river containing mild bends and low discharge levels (Berendsen, 1996, p. 187) and is thus supporting evidence of the influence of the helical flow on the distribution of sanitary wet wipes. An explanation for the higher concentration at the downstream part of a groyne field can be the way water flows in between groynes where it is diverted from the main channel and enters the groyne field at the downstream groyne (ten Brinke & Scheifes, 2004). This flow can take wipes to the downstream part of the groyne field where they are deposited.

As previous research already mentions, vegetation and underground or substrate influences the transport of plastic, dependent on a plastic's properties (Al-Zawaidah Ravazzolo & Friedrich, 2021; Van Emmerik et al., 2020). This study provides new knowledge on the effect of vegetation and substrate on specifically sanitary wet wipes. The difference between the north and southern bank corresponds with previous research that found more sedimentation on the southern banks of the Waal (Sorber, 1997). However, this was explained by sediment grain size and influx of discharge and therefore, one can still speculate about several explanations which will be elaborated in the following paragraphs.

5.2 Drawbacks and uncertainties

5.2.1 Temporal and spatial difficulties

The main implication of this study is the lack of temporal data and larger scale spatial data. The study only provides results based on one measurement and is therefore unable to detect temporal differences or to include temporal differences such as seasonality. Vegetation flourishes differently in winter than in summer and discharge and water levels are different as well. Moreover, there are different effects of recreational factors throughout the year. In summer, the study area is expected to be used for more recreational purposes, which might lead to different outcomes.

This study only considered a few hydrological factors but in reality, more factors influence the transport dynamics of sanitary wet wipes and this process is therefore much more complex (Roebroek et al., 2021; Al-Zawaidah, Ravazzolo & Friedrich, 2021). For example, Roebroek et al. (2021) tried to explain the variation of plastic litter on the riverbanks of the Rhine and branches by the hydrometeorological factors precipitation surface runoff, wind and river flow. They found that sanitary wet wipes, sanitary pads and cotton buds are positively correlated with wind speed and negatively with precipitation.

This might be an explanation for the difference between the number of wipes found at the north and south bank. The prevailing wind current in the Netherlands is a western/southwestern wind which means for the south bank that it comes from land. One can therefore speculate that perhaps the wipes partially come from land and end up at the riverbanks where they get stuck in vegetation. However, if the wind had more influence, one would expect a more evenly distribution of the wipes along the riverbank. This is not the case since the larger number of wipes is found on the inside bend and/or on the downstream part of a groyne field. An interaction effect of both wind and hydrological factors could be a possible explanation for this.

Another possibility is the influence of navigation ships that are passing over the Waal. Previous research shows that heavier ships cause stronger currents (ten Brinke, 2003). Since the heavier ships, which carry goods inland, travel on the south side of the channel, the south banks experience stronger currents. This is known to lead to more erosion of sediments which means fewer wipes at the south bank instead of more, assuming the wipes follow similar patterns to that of sediments. Alternatively, sanitary wipes have different transport dynamics than sediments and are affected differently by factors such as shipping vessels and vegetation. Stronger currents could also stimulate the exchange dynamics and cause wipes to be drawn in which leads to accumulation of it at the south side of the channel. The difference between the banks can also be influenced by a possible source nearby, located on the south side of the river. Based on previous research that suggested a link between urban sewages and sanitary waste (Morrit et al., 2014; Vierwind & Lhoest, 2021), Nijmegen could potentially be a source of sanitary wipes as it is located south of the river. However, at this stage this remains only speculative as it is yet unclear how far the wipes have travelled and the possibility exists they originate from Germany or even Switzerland.

5.2.2 The sampling approach

A considerate difference between the Schone Rivieren initiative's data and this study's data is found. The Schone Rivieren data mainly found cotton buds that gave rise to the identification of so-called sanitary hotspots. Contrarily, no cotton buds were spotted during this study, however, the focus was not cotton buds and some might be overlooked by the samplers. Moreover, some areas counted more sanitary wipes than previous years. Previous research pointed out that transport dynamics are dependent on plastic's properties (Van Emmerik et al., 2020) and therefore, the difference in categorial and number of items could be explained by the physical difference of cotton buds and sanitary wet wipes. The same factors are likely to influence their transport differently. Furthermore, Collas et al. (2021) suggested the influence of covid-19 on the increase of sanitary wet wipes. Similarly, the legislative act that banned SUPs could lead to a decrease in the number of cotton buds whereas sanitary wet wipes are not considered in this category.

Considering the sampling approach, Roebroek et al. (2021) showed that on average volunteers find 10% less sanitary waste items but that in general, there is no significant bias meaning that voluntary data is reliable and citizen science a valuable way of conducting research. Based on this, one could conclude an actual difference in categorial items and number thereof. However, this is debatable considering the fact that (i) sanitary wet wipes are frequently poorly visible because they are buried with sand, wrapped around or entangled in roots or other vegetation (figure 16), making them not easily detectable for the voluntary's eye. Also, (ii) in the presence of 200+ wipes, cleaning up is time and labour-intensive and the chance exists volunteers' thoroughness decreases. Nevertheless, the difference can still be reality since cleaning areas differ in location within a groyne field (sometimes upstream, sometimes downstream). In conclusion, the Schone Rivieren data contains widely varying factors which make it difficult to provide a representative overview of the patterns of sanitary wet wipes spatially and temporally. This present study's method is more precise but on the other hand labour-intensive.

Figure 16. Pictures showing the possible difficulty of detecting sanitary wet wipes when, from left to right, wrapped around the roots of a shrub, covered with sand, or entangled with vegetation.

5.2.3 Nijmegen's sewage system as a possible source

The previous study of Vierwind (2021) identified an 83% share in weight of sanitary wet wipes of the total amount of waste derived from a sewage overflow in Soest. According to Arthur Nijhof, who manages Nijmegen's sewage system, this large share seems to correspond with Nijmegen's sewage system. The pumping stations are cleaned two times a year and observations of the waste suggest it mainly consists of sanitary wipes or textile-like material. Some overflow sewages that discharge on terrestrial area in ponds are closed off with a railing to prevent children from entering. These often need cleaning after the occurrence of an overflow and much of the waste that the discharge pulse contained ends up in nature where it remains (figure 17). This way, sanitary waste from the sewages is unintentionally filtered out of the sewage system and ends up in nature elsewhere before it reaches the Waal. The chance exists that it returns to the sewages by factors such as rain, wind or transported by animals, or that it transports in a similar way over land to rivers. Unfortunately, this study was therefore unable to make an estimate of the number of wipes that discharges from the sewages into the Waal. The study's findings thus cannot link Nijmegen's sewage system to the sanitary waste on the riverbanks of the Waal downstream of Nijmegen. However, based on the information on the Nijmegen sewage system in combination with previous research, we can strongly assume that at least part of the sanitary wet wipes in the Waal originates from the sewages.

Figure 17. Overflow Gebroeders Koenraad park in Nijmegen. a) The overflow end after an overflow; b) the overflow end after cleaning; c) waste that remains in the park after an overflow event.

Several studies stated that there is a strong link between the presence of a sewage overflow and sanitary waste downstream of it by localized sanitary hotspots highlighted in the Schone Rivieren data (Vierwind & Lhoest, 2021; Boonstra & de Winter, 2021). It is difficult to say whether this study's findings can support this. First because the criteria that are used to define a sanitary hotspot (Boonstra et al., 2021), do not apply to this study's data. They identified sanitary hotspots when they contained over 35 cotton buds and 8% of the items by count were sanitary waste meaning there are no sanitary hotspots in this study's study area due to the absence of cotton buds. The definition of a sanitary hotspot should be reconsidered after this study. Second, due to a lack of continuous spatial and temporal data about the concentration of wet wipes, this study's data cannot be compared to the concentration of sanitary wipes upstream of Nijmegen, when the city's sewage overflows are considered as a source.

5.3 Outlook

5.3.1 Recommendations for future research

This study's new insights contribute to developing an overview of the current problem by looking at the spatial distribution of wipes and a suggested possible source. By proposing that sanitary wet wipes follow similar patterns as that of sediment, estimations can be made about their transport patterns and consequently where they would accumulate. By continuing collecting data and monitoring riverine plastic, the goal of acquiring a holistic overview in both space and time of the problem can be achieved from which transport dynamics can be discovered. This could contribute to making damage assessments by predicting or estimating economic or ecological losses. However, many factors are involved on which only a few are to uched upon in this study. The transport dynamics of sanitary wet wipes is much more complex and might also change the natural dynamics of its environment. Therefore, much further research is necessary.

Because the results of the study can only be partially explained by sediment dynamics, it is plausible that sanitary wipes are influenced by other factors and have different transport dynamics than sediments. Previous research already suggested that macroplastics should be considered as a new type of sediment particle (Liro et al., 2020) accompanied by its unique interactions with environmental factors and influences. Although there are plenty studies on the interaction of vegetation, fauna or instream wood on the riverbeds (Al-Zawaidah, Ravazzolo & Friedrich, 2021), a gap in research exists on the impact of macroplastics on riverbed and riverine structures. Certain concentrations of sanitary wet wipes or other riverine waste in general could lead to altered hydrodynamics of a river or sediment dynamics. Consequently, adjustment of existing hydrological models that are based on plastic-free environments might be necessary.

The next step in investigating the source of sanitary wet wipes is monitoring the overflows that discharge directly into the Waal. Without capturing the actual content of such overflow, it remains unclear how much sanitary waste found on the riverbanks of the Waal originates from the sewage systems of Nijmegen. Only with long-term consistent and regular monitoring of sanitary waste on the riverbanks of the Waal in combination with the monitoring of the overflow contents that directly discharge on the Waal, one might be able to observe correlated patterns. Parallel to this study was the study of Mandy Rus (2022) that researched plastic in the water column near Lobith located in a bend using kornets. Lobith is located upstream of Nijmegen and right by the border of Germany, indicating that all sanitary wipes must originate from there. Her main findings were that most sanitary wipes were found at the inside bend, which corresponds to this study and previous studies, and on the riverbed rather than floating or in the middle of the river column. Interestingly, a constant absolute flow of sanitary wipes was found, regardless of the discharge. Using this knowledge, in combination with findings of this study, furthermore, it is necessary to research the spatial distribution of sanitary wet wipes upstream of Nijmegen, using this study's methodology, for comparison. This way more knowledge about the influence of Nijmegen's sewage system is gained. If concentrations are similar, Germany can be considered an important source. In that case, it is recommended to cooperate with all countries inside the catchment area in researching the source. Additionally, the influence of river bends and navigation ships are assessed differently since river bends are sharper upstream of Nijmegen and navigation ships pass through by cutting corners therefore as well.

Although most sample methods are simple and can easily be conducted by any citizen, the comparison of available data on a large scale is often complicated. Monitoring methods can vary largely leading to different outcomes, as is demonstrated in this study. For this reason, Al-Zawaidah et al. (2021) have proposed a framework based on four key elements that should remain constant: (1) space (scale, sampling area and structure), (2) time (duration, structure, frequency, and period), (3) observers, and (4) plastic categorization (categories and size range). This study, therefore, proposes to evaluate voluntary monitoring approaches by incorporating this study's new information while focussing on these four elements. Moreover, the efficiency of clean ups can be increased by targeting the inside bends for example.

5.3.2 Policy recommendations

Considering the number of sanitary wet wipes found in this study, they should be regarded as a significant problem. Not only for the environment but for infrastructure systems such as sewages as well. More awareness should be created about the abundance of sanitary wet wipes in our environment and the impacts they have on it. This can be done through campaigns or posters/notes inside sanitary areas reminding people that they wipes contain plastics and should not be flushed. Currently, sanitary wet wipes are not considered a SUP but should be included to prohibit the production and reduce the use of sanitary wet wipes.

6. Conclusion

This study provides new insights into the transport dynamics of sanitary wet wipes by visualising their spatial distribution at the riverbanks of the Waal. In the study area, the inside bends of the river contain higher concentrations of wipes than the outside bend and the southern bank contains a higher concentration of wipes than the north bank. Furthermore, vegetation type, substrate and location within a groyne field all influence the concentration wipes. Higher concentrations of wipes were found in the presence of vegetation such as shrubs and trees compared to areas with grass or no vegetation. Higher concentrations were found when the substrate contains stones rather than sand, pebbles or clay, and the downstream part of a groyne field contains a higher concentration of wipes then the middle or upstream parts.

Furthermore, this study could not directly link the sewage overflows of Nijmegen to the concentration of wipes at the riverbanks of the Waal downstream of Nijmegen.

Finally, the study's results contribute to the plastic monitoring plan of the Dutch rivers and reveal new knowledge gaps on which future research can be based. Currently, there are no policies that specifically regard sanitary wet wipes or riverine sanitary waste in general but gaining knowledge through the monitoring program will help develop mitigation measures and develop policy.

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Appendix A

Table 1. The absolute number of sanitary wet wipes of the first and second count displayed next to each other. Field numbers start counting on the west side, moving to east. The groyne field is divided into the downstream (1), middle (2) and upstream (3) part. The bank side is south (S) or north (N). Dominant vegetation type and substrate are displayed as well.

Field	*Part*	*Number of wipes 1st count*	*Number of wipes 2nd count*	*Bank side*	*Vegetation type*	*Substrate*
1	Upstream	0		N	No	Clay
1	Downstream	78	13	S	No	Stones
1	Middle	40	5	S	Vegetation	Sand
1	Upstream	7	5	S	Vegetation	Stones
2	Downstream	0		N	No	Stones
2	Middle	0		N	No	Stones
2	Upstream	0		N	Grass	Pebbles
2	Downstream	68	6	S	Vegetation	Sand
2	Middle	10	0	S	Vegetation	Sand
2	Upstream	48	11	S	Vegetation	Sand
3	Downstream	0		N	No	Stones
3	Middle	1		N	No	Stones
3	Upstream	1		N	No	Sand
3	Downstream	55		S	Vegetation	Sand
3	Middle	8		S	Vegetation	Sand
3	Upstream	19		S	Vegetation	Sand
4	Downstream	0		N	No	Pebbles
4	Middle	0		N	No	Stones
4	Upstream	3		N	No	Stones
4	Downstream	271		S	Vegetation	Sand
4	Middle	24		S	Vegetation	Sand
4	Upstream	5		S	Vegetation	Sand
5	Downstream	0		N	No	Sand
5	Middle	0		N	Vegetation	Sand
5	Upstream	2		N	Vegetation	Sand
5	Downstream	501		S	Vegetation	Stones
5	Middle	0		S	Vegetation	Sand
5	Upstream	1		S	Vegetation	Sand
6	Downstream	0		N	No	Clay
6	Middle	0		N	No	Clay
6	Upstream	0		N	Vegetation	Sand
6	Downstream	21		S	Vegetation	Stones
6	Middle	6		S	No	Stones
6	Upstream	1		S	Vegetation	Sand
7	Downstream	0		N	No	Clay
7	Middle	0		N	No	Clay
7	Upstream	0		N	No	Clay
7	Downstream	22		S	Vegetation	Stones
7	Middle	11		S	Vegetation	Pebbles
7	Upstream	1		S	Vegetation	Pebbles
8	Downstream	0		N	Vegetation	Clay
8	Middle	0		N	Vegetation	Clay
8	Upstream	0		N	Vegetation	Clay
8	Downstream	24		S	Grass	Sand
8	Middle	1		S	Vegetation	Sand
8	Upstream	0		S	No	Sand
9	Downstream	1		N	No	Stones
9	Middle	1		N	Vegetation	Stones

9	Upstream	0		N	Vegetation	Pebbles
9	Downstream	9		S	Vegetation	Stones
9	Middle	0		S	Vegetation	Stones
9	Upstream	1		S	Vegetation	Stones
10	Downstream	2		N	Vegetation	Pebbles
10	Middle	0		N	Vegetation	Pebbles
10	Upstream	0		N	Vegetation	Pebbles
10	Downstream	1		S	Vegetation	Sand
10	Middle	0		S	Vegetation	Sand
10	Upstream	0		S	Vegetation	Sand
11	Downstream	0		N	No	Pebbles
11	Middle	1		N	Vegetation	Pebbles
11	Upstream	0		N	Vegetation	Pebbles
11	Downstream	26		S	No	Stones
11	Middle	0		S	Grass	Sand
11	Upstream	3		S	Grass	Stones
12	Downstream	0		N	Vegetation	Pebbles
12	Middle	3		N	Vegetation	Pebbles
12	Upstream	0		N	Vegetation	Pebbles
12	Downstream	2		S	Vegetation	Sand
12	Middle	0		S	Vegetation	Sand
12	Upstream	0		S	Vegetation	Sand
13	Downstream	4		N	Vegetation	Pebbles
13	Middle	0		N	Vegetation	Pebbles
13	Upstream	2		N	Vegetation	Pebbles
13	Downstream	3		S	Vegetation	Sand
13	Middle	0		S	No	Pebbles
13	Upstream	0		S	No	Pebbles
14	Downstream	2		N	No	Pebbles
14	Middle	0		N	No	Pebbles
14	Upstream	0		N	No	Pebbles
14	Downstream	2		S	Vegetation	Stones
14	Middle	0		S	No	Pebbles
14	Upstream	0		S	No	Pebbles
15	Downstream	0	0	N	Vegetation	Pebbles
15	Middle	0	1	N	Vegetation	Pebbles
15	Upstream	0	0	N	No	Pebbles
15	Downstream	1		S	No	Sand
15	Middle	0		S	Grass	Sand
15	Upstream	0		S	Grass	Sand
16	Downstream	4	1	N	Vegetation	Pebbles
16	Middle	0	0	N	Vegetation	Pebbles
16	Upstream	1	0	N	Vegetation	Pebbles
16	Downstream	2		S	No	Clay
16	Middle	3		S	No	Sand
16	Upstream	0		S	No	Sand
17	Downstream	0	0	N	Vegetation	Pebbles
17	Middle	0	0	N	Vegetation	Pebbles
17	Upstream	5	0	N	Vegetation	Pebbles
17	Downstream	5		S	Grass	Stones
17	Middle	5		S	No	Sand
17	Upstream	2		S	Vegetation	Sand
18	Downstream	2	0	N	Vegetation	Pebbles
18	Middle	0	0	N	Vegetation	Pebbles
18	Upstream	1	0	N	Vegetation	Pebbles
18	Downstream	8		S	No	Stones
18	Middle	35		S	No	Stones
18	Upstream	55		S	No	Stones
19	Downstream	0		N	No	Pebbles

19	Middle	1		N	Vegetation	Sand
19	Upstream	0		N	Vegetation	Sand
19	Downstream	6		S	No	Sand
19	Middle	3		S	Vegetation	Sand
19	Upstream	10		S	Vegetation	Stones
20	Downstream	2		N	Vegetation	Sand
20	Middle	0		N	Vegetation	Sand
20	Upstream	0		N	Vegetation	Sand
20	Downstream	495		S	Vegetation	Stones
20	Middle	33		S	Vegetation	Sand
20	Upstream	23		S	No	Sand
21	Downstream	3		N	No	Stones
21	Middle	0		N	No	Stones
21	Upstream	2		N	No	Sand
21	Downstream	26		S	No	Stones
21	Middle	15		S	Grass	Sand
21	Upstream	4		S	No	Pebbles
22	Downstream	2		N	Vegetation	Sand
22	Middle	0		N	No	Sand
22	Upstream	5		N	Vegetation	Sand
22	Downstream	204		S	Vegetation	Pebbles
22	Middle	48		S	Vegetation	Pebbles
22	Upstream	24		S	No	Pebbles
23	Downstream	9		N	Vegetation	Sand
23	Middle	1		N	Vegetation	Sand
23	Upstream	7		N	Vegetation	Sand
24	Downstream	1		N	Vegetation	Sand
24	Middle	1		N	Vegetation	Sand
24	Upstream	6		N	Vegetation	Sand
24	Downstream	89	9	S	Grass	Sand
24	Middle	9	0	S	Grass	Stones
24	Middle	21	1	S	Vegetation	Sand
24	Upstream	38	15	S	Vegetation	Pebbles
25	Downstream	19		N	Vegetation	Pebbles
25	Middle	1		N	Vegetation	Pebbles
25	Upstream	6		N	Vegetation	Pebbles
25	Downstream	121	8	S	Vegetation	Stones
25	Middle	3	0	S	No	Sand
25	Upstream	46	5	S	No	Stones
26	Downstream	4		N	Vegetation	Stones
26	Middle	2		N	Vegetation	Stones
26	Upstream	6		N	Vegetation	Stones
26	Downstream	149	42	S	Vegetation	Sand
26	Middle	39	8	S	Vegetation	Sand
26	Upstream	51	0	S	Vegetation	Sand
27	Downstream	7		N	Vegetation	Pebbles
27	Middle	2		N	Vegetation	Pebbles
27	Upstream	1		N	Vegetation	Pebbles
27	Downstream	99		S	Vegetation	Sand
27	Middle	6		S	Grass	Sand
27	Upstream	8		S	Vegetation	Stones
28	Downstream	3		N	No	Stones
28	Middle	5		N	Vegetation	Stones
28	Upstream	2		N	Vegetation	Stones
28	Downstream	20		S	Vegetation	Stones
28	Middle	0		S	No	Clay
28	Upstream	0		S	No	Clay
29	Downstream	0		N	No	Sand
29	Middle	10		N	Vegetation	Sand

29	Upstream	2		N	No	Stones
29	Downstream	55		S	Vegetation	Sand
29	Middle	0		S	No	Sand
29	Upstream	8		S	Vegetation	Sand
30	Downstream	0		N	Vegetation	Sand
30	Middle	0		N	No	Sand
30	Upstream	3		N	No	Sand
30	Upstream	22		S	Vegetation	Stones
30	Downstream	7		S	No	Stones
31	Downstream	0		N	No	Sand
31	Middle	2		N	No	Sand
31	Upstream	14		N	Vegetation	Stones
31	Downstream	163		S	Vegetation	Stones
31	Middle	4		S	Vegetation	Stones
31	Upstream	2		S	Vegetation	Stones
32	Downstream	27		N	Vegetation	Stones
32	Middle	2		N	No	Pebbles
32	Upstream	6		N	No	Stones
32	Downstream	5		S	No	Stones
32	Middle	0		S	Vegetation	Sand
32	Upstream	0		S	Vegetation	Sand
33	Downstream	3		N	Vegetation	Pebbles
33	Middle	1		N	No	Pebbles
33	Upstream	0		N	No	Pebbles
33	Downstream	3		S	No	Stones
33	Middle	1		S	Vegetation	Sand
33	Upstream	0		S	Vegetation	Sand
34	Downstream	4		N	No	Pebbles
34	Middle	6	0	N	Vegetation	Pebbles
34	Middle	6	0	N	No	Pebbles
34	Upstream	1	0	N	Vegetation	Pebbles
34	Downstream	0		S	No	Pebbles
34	Middle	0		S	No	Pebbles
34	Upstream	0		S	No	Pebbles
35	Downstream	18	1	N	Vegetation	Pebbles
35	Middle	4	0	N	Vegetation	Pebbles
35	Upstream	6	0	N	Vegetation	Pebbles
35	Downstream	14		S	Vegetation	Sand
35	Middle	4		S	Grass	Sand
35	Upstream	54		S	Vegetation	Sand
36	Downstream	11	0	N	Vegetation	Pebbles
36	Middle	5	0	N	No	Pebbles
36	Upstream	3	0	N	No	Pebbles
36	Downstream	107		S	Vegetation	Stones
36	Middle	60		S	Vegetation	Stones
36	Upstream	18		S	Vegetation	Sand
37	Downstream	11		N	Vegetation	Pebbles
37	Middle	3		N	Vegetation	Pebbles
37	Upstream	1		N	Vegetation	Pebbles
37	Downstream	37	5	S	Vegetation	Sand
37	Middle	3	0	S	Vegetation	Sand
37	Upstream	0	0	S	Vegetation	Sand
38	Downstream	16		N	Vegetation	Pebbles
38	Middle	5		N	Vegetation	Pebbles
38	Upstream	1		N	Vegetation	Pebbles
38	Downstream	0	0	S	Grass	Sand
38	Middle	0	0	S	Grass	Sand
38	Upstream	0	6	S	No	Stones
39	Downstream	7		N	Vegetation	Stones

39	Middle	11		N	Vegetation	Pebbles
39	Upstream	9		N	Vegetation	Pebbles
39	Downstream	0	0	S	Grass	Sand
39	Middle	0	0	S	Grass	Sand
39	Upstream	58	56	S	No	Stones
40	Downstream	29	0	N	Vegetation	Pebbles
40	Middle	9	0	N	Vegetation	Stones
40	Upstream	8	0	N	Vegetation	Sand
40	Downstream	31	0	S	Vegetation	Stones
40	Middle	0	0	S	Vegetation	Stones
40	Upstream	0	0	S	Vegetation	Sand
41	Downstream	1	1	N	Grass	Sand
41	Middle	7	1	N	Vegetation	Pebbles
41	Upstream	2	0	N	Vegetation	Pebbles
41	Downstream	36		S	Vegetation	Stones
41	Middle	13		S	Vegetation	Sand
41	Upstream	1		S	Vegetation	Stones
42	Downstream	6	1	N	Vegetation	Pebbles
42	Middle	2	0	N	Vegetation	Pebbles
42	Upstream	5	0	N	Vegetation	Pebbles
42	Downstream	1		S	No	Clay
42	Middle	0		S	No	Clay
42	Upstream	0		S	No	Pebbles
43	Downstream	0	0	N	No	Pebbles
43	Middle	1	0	N	Vegetation	Sand
43	Upstream	0	0	N	Vegetation	Sand
43	Downstream	0		S	No	Pebbles
43	Middle	0		S	No	Pebbles
43	Upstream	0		S	No	Pebbles
44	Downstream	1		N	No	Pebbles
44	Middle	4		N	Vegetation	Pebbles
44	Upstream	0		N	Vegetation	Pebbles
44	Downstream	0		S	No	Sand
44	Middle	0		S	No	Sand
44	Upstream	0		S	No	Sand
45	Downstream	0		N	No	Pebbles
45	Middle	1		N	Vegetation	Pebbles
45	Upstream	0		N	Vegetation	Pebbles
46	Downstream	2		N	Vegetation	Pebbles
46	Middle	2		N	Vegetation	Pebbles
46	Upstream	1		N	Vegetation	Sand
47	Downstream	19		N	Vegetation	Sand
47	Middle	0		N	No	Sand
47	Upstream	1		N	No	Sand
48	Upstream	0		N	No	Pebbles
49	Downstream	0		N	No	Stones
49	Middle	0		N	No	Sand
49	Upstream	0		N	Vegetation	Sand
50	Downstream	7		N	Grass	Stones
50	Upstream	25		N	Grass	Pebbles
51	Downstream	0		N	Vegetation	Sand
51	Middle	0		N	Vegetation	Sand
51	Upstream	0		N	Vegetation	Sand

Appendix B

Table 2. Overview of the communication regarding their sewage systems, overflow locations and the overflow data of the municipalities adjacent to the Waal or Maas-Waalkanaal

Municipality	***Called***	***Emailed***	***Answered by municipalities***	***Overflows***	***Locations***	***Overflow data***
Heumen	No	Yes	Yes	3	Locations are soley on surface waters such as ponds and not directly on the rivers	Yes from 2017 tm 2022
Cuijk	Yes	Yes	Yes	They could only provide old information that was already shared with the study of Vierwind & Lhoest	Locations are solely on surface waters such as ponds and not directly on the rivers	No
Beuningen	Yes	Yes	Yes	On waterways that discharge on the Maas instead of the Waal	Did not ask further	
Berg en Dal	Yes	Yes	Yes	Non directly on the Waal		
Mook en middelaar	No	Yes	No			
Nijmegen	No	Yes	Yes	Nijmegen shared a map with all overflow locations	Oude haven/kanaalstraat	Yes, data from 2017 to 2022
Overbetuwe	Yes, answered straight away they have no overflows directly on the Waal	Yes, to ask whether they could share the data they have of other overflows	No			
Waterschap rivierenland	Yes	Yes	No			