Plastic Discharge in Bali's Rivers

Research into Bali's plastic polluted rivers and designs of suitable collection structures for rivers to mitigate the plastic discharge into the ocean

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Civil Engineering Consultancy Project | CIE4061-09

by

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August 14, 2019

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Project duration: April 28, 2019 – June 30, 2019

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Preface and acknowledgements

This report is written as part of the course CIE4061-09 Civil Engineering Consultancy Project. The purpose of this course is to perform a Civil Engineering consultancy project with a multidisciplinary group of students. The project started with a search for students willing to continue on the Pantai Project started by another group of students in September 2018. The Pantai Project aims to tackle the plastic waste problem on Bali. The name Pantai Project reflects this goals as Pantai means ”beach” in the Indonesian language Bahasa.

During the project we received support from different individuals and companies involved, which was a great contribution to the project.

First of all, we would like to thank our supervisors Prof. dr. ir. S. Aarninkhof and Dr. ir. P. Taneja for their support and feedback during the project.

Furthermore, we would like to thank The Ocean Cleanup for the equipment and guidance for performing the river measurements. Without their help the measurements would have been less successful.

Also the local organisations involved have helped us a lot during our research on Bali. Without their knowledge and information we would not have been able to identify and describe the local waste policies and systems that well. Therefore, we would like to thank I Gede Hendrawan (Ph.D Marine Sciences at Udayana University), Paola Cannucciari (Senior Program Manager at EcoBali) and Emma Sparrow (Founder of OceanMimic).

Finally, we would like to give a special thanks to R. de Klerk, J. Memelink, E. van Utenhove, T. van Welsenes and S. van Wijland, who started the Pantai Project last year. They were always available for questions and supported us during the project.

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Delft, July 2019

Partners

THE OCEAN CLEANUP TU Delft Global Initiative

Local support

PUSAT UNGGULAN PARIWISATA UNIVERSITAS UDAYANA ecoBali OCEANMIMIC

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Abstract

Indonesia is one of the largest ocean pollutants in the world in terms of plastic emissions. The country has many tourist areas, including the island of Bali, which is the main tourist hub. The plastic problem is large around and on Bali, which has negative consequences for both the environment and the tourism sector. NGOs and the government are trying to tackle the plastic problem, with an increasing effort in the last few years. This research project has been set up to determine which regions and rivers in Bali discharge the most plastic and therefore pollute the ocean the most, and to design a river structure to mitigate plastic emissions to the ocean.

For this study, 31 rivers in eight different regions were measured and analysed. All rivers were measured by visual observation, a trawl or a combination of the two. The flow velocity and the width were measured for each river. By means of the average weight of one piece of plastic, the plastic flux could be obtained. The river embankments were systematically assessed for each river. In addition, the wind speed was also measured for each river.

The three most polluting rivers of the island are all in different regions. These three rivers will be the most effective to tackle in order to reduce the plastic discharge to the ocean. The study shows that when a river flows through a densely populated area, the river is more polluted, as is the case with the three most polluted rivers.

Through a MCA, two effective waste catchment structures were eventually found for the two types of rivers on the island, which are rivers with and without navigation. The structures will remove the plastic from the rivers. The structure for the river that can be closed is the Trash Trap, see figure 6.8, and for the river that cannot be closed is the Sea Defence Structure.

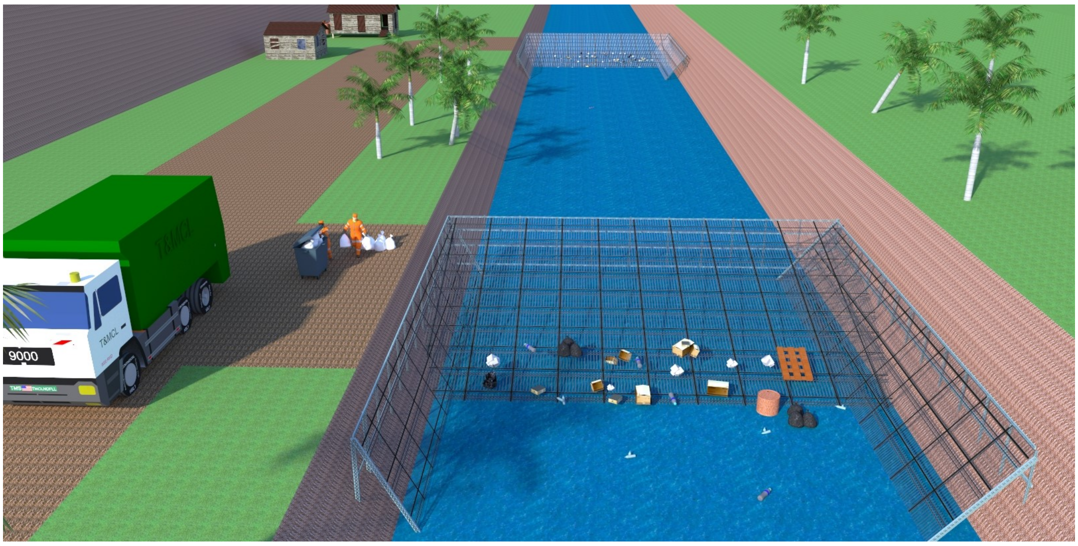


Figure 3: Front view of two trash trap structures in a river

1 Introduction

Plastics in the marine environment have become a major concern around the world. Plastics persevere in oceans and have adverse consequences to the marine life and potentially human health [Dris et al., 2015]. Although plastics break down into smaller parts in the ocean, they do not dissolve completely. As fish presume that the plastic particles is food and consume them, they enter our food chain [Boerger et al., 2010]. One of the biggest marine polluters is Indonesia, which uses 9.8 billion plastic bags per year [Lamb, 2018]. In 2017 the government of Bali, Indonesia's biggest tourist hub, declared a 'garbage emergency' because of the increasing amount of plastics on the beaches [Oliphant, 2017]. Currently, however, the plastic problem in Bali does not show any signs of stopping. The single-use plastic ban, which took effect on the 21st of December, 2018, when the Governor of the island, Wayan Koster, signed the policy, said to decrease Bali's marine plastics by 70% by the end of 2019. Nonetheless, the current situation does not show any sign of change. This is, probably, mostly due to a six month grace period of the ban. Currently, this period is still active and all over the island plastic bags are still distributed. The island seems far from ready to enforce the ban completely.

1.1. Research gap

This study continues on the work of the first Pantai Project, who studied the plastic problem on Bali in 2018. Their conclusion was that the plastic, which pollutes the famous tourist beaches of the island, originates from the many rivers on the island. Their recommendation was that more study needed to be done into which rivers and/or regencies discharge the most plastic, in order to be able to tackle the problem more effective [van Utenhove et al., 2018]. Furthermore, Gede Hendrawan, PhD Marine and Coastal environment of the Udayana University, is currently performing an extensive research regarding the plastic pollution on Bali. In a interview with G. Hendrawan (appendix C.1) he explained that he researched the plastic discharge in rivers in the west of Bali, in the dry season of 2014. In addition, he measured the pollution on the embankments of nine rivers, one in each regency, in the dry season of 2018. This research will be published in July 2019. These previous studies mainly focused on the west part of Bali and did not research the differences between the regencies with respect to the plastic discharge in the rivers and where the rivers were most polluted. Therefore, this research will close this gap by researching the plastic discharge in rivers in every regency. In order to increase the reliability of the research, a large share of the total amount of rivers on Bali will be measured. If it is known which rivers and what type of rivers are most polluted, more specific measures can be taken to mitigate the plastic pollution in the rivers. One of these measures is the placement of a waste catchment structure in a river. This is a measure that could be implemented on relatively short term, which is important because of the urgency of the situation as described at the start of this chapter. Depending on the plastic discharge of a river and the kind of regency it is located in, different waste catchment structures can be applicable. Therefore this research also aims to determine for which rivers in Bali these structures can be most effective and what specific type could be implemented for the different rivers.

1.2. Objective and research questions

The objective of this study is to close the research gap by determining which rivers and regencies on Bali have the highest plastic discharge and which solutions there are to reduce the flow of plastic in the rivers, before it flows into the ocean and onto Bali's beaches. Based on this objective the following research question is formulated:

'Which rivers and regencies on Bali have the highest plastic discharge and which structures are most suitable to reduce the plastic flow of the rivers into the ocean and onto the shores of Bali?'

To help answer the research question, the following sub-questions are formulated:

- How is (plastic)waste handled in Bali and which measures are already in place to mitigate the problem?
- How does plastic end up in the rivers?
- Which measures can be implemented to prevent plastic entering the environment?
- What is the plastic flow of the different rivers and regencies?
- What is the degree of pollution of the embankments of the different rivers and regencies?
- Does the wind(velocity) have an influence on the plastic pollution of the rivers and embankments?
- Is there a correlation between socio-demographics (population density, income, tourism, education and religion) and the plastic flow in the rivers?
- Which waste catchment structures are currently available and which are most suited to be implemented in rivers to retain the waste flow, before entering the ocean?

The first three sub-questions give insight into the current state of the waste handling system in Bali, how waste can end up in the rivers and what measures are already taken and which could be taken to mitigate the plastic problem. It is important to know this to be able to give suitable recommendations to improve the situation on Bali. The fourth and fifth sub-questions are necessary to answer, in order to compare the rivers in the different regencies with each other and to determine which rivers are the most polluted. The sixth sub-question helps to determine if the wind is a factor when (larger) models are made, which determine the plastic flow in rivers. By answering the seventh sub-question it will become clear if the socio-demographics of a regency have an influence on the degree of pollution of the rivers within the regency. If there is a correlation, the differences between the degree of pollution within the regencies could be explained. Furthermore, if it's known if certain socio-demographics causes a higher degree of plastic pollution, more specific measures can be taken which are focused on the groups with these specific socio-demographic characteristics. This can help to determine which (non measured) rivers are potentially polluting. The final sub-question will provide insight in which waste catchment structures are currently available and which structures are most suitable in different rivers. This insight is necessary to find the most suitable structures for the rivers in Bali. When the answers to these sub-questions are determined, the main research question can be answered.

1.3. Research method

These sub-questions will be answered by measuring 28 rivers located in different regencies of the island. The rivers will be measured by visual observation (i.e. counting the floating plastic particles) and with the use of a trawl. This will be discussed in more detail in chapter 4. In addition, data of three other rivers is provided by another TU Delft group, performing plastic flow measurements on Bali in the same period. In total, data from 31 rivers, located in eight different regencies on the island, is obtained and analysed.

Based on the data, different possible solutions for the government of Bali, to mitigate the plastic problem, are proposed. Possible solutions are, for example, constructing structures in rivers to intercept and collect the plastics in the rivers before they reach the ocean, expanding waste collection services or gasification of waste.

These measures could help reduce the amount of plastics in the ocean and on the beaches of Bali, which will be beneficial for the marine life, potential human health, and tourism. However, these measures can often come with high costs and could lead to social resistance. In order to take this into account, the proposed possible solutions in this paper will be analysed by means of the 'Multi criteria analysis'. This will be discussed in more detail in Chapter 4.

1.4. Structure of the report

In chapter 2, the existing literature on plastics in the marine environment and possible measures are examined. Next, measures are discussed to prevent (plastic) waste entering the environment. Thirdly, the methodology on how to measure the rivers and to evaluate possible measures is explained. In the ensuing chapters, 5 and 6, the results of the measurements and possible structures in the rivers will be discussed. The discussion, conclusion and recommendations conclude the report.

2
Literature

In this chapter the existing literature on the handling of waste on Bali, plastics in rivers, implemented and planned measures, and socio-demographic factors that possibly influence the plastic discharge in rivers, are discussed.

2.1. Handling of waste on Bali

In this section, different ways in which waste is handled on Bali will be described. The research of van Utenhove et al. [2018] identified six main transportation streams of waste after it leaves the households, hotels, businesses etc. Firstly, there is waste which is not collected, but often incinerated or dumped in the environment, for example, in rivers and onto riverbanks [Tang, 2004]. Furthermore, waste can also be collected. Waste can be collected by governmental organisations that bring it to TPST facilities (which is an Indonesian abbreviation for integrated waste treatment facility) and TPST3R facilities (with 3R standing for reuse, recycle and reduce) or by non-governmental organisations (NGO's). Finally, people can dispose their waste at, so called waste banks. Each of these streams will be discussed in more detail in the following subsections.

2.1.1. Uncollected waste

Waste collection is an important component of waste handling, but is often a weak link [MacRaea and Rodic, 2015]. Wilson et al. [2012] state that in developing countries, the rate of waste collection is often as low as 45%. In Bali 60% of the total waste output is collected [Erviani, 2019a]. In the more rural areas, the inhabitants are more traditional and handle a large part of their waste themselves. This is also because the government is not able to collect waste in the entire regency. In these areas the chief of a community determines in which way the waste is handled [van Utenhove et al., 2018]. These people often have the waste mindset from when everything was still organic, and could be disposed of in nature without a problem. Therefore, most uncollected waste is dumped in nature or incinerated [Tang, 2004].

The incineration of waste in Bali happens often by consumers themselves, which is mainly done close to their own houses. This waste is often burned at low temperatures which leads to an incomplete combustion of waste. As a result many dangerous toxins could be released, which can lead to smaller reproductive organs in children [Staessen et al., 2001]. Furthermore, it increases the risk of (house)fires. Therefore, in many countries incineration of waste is banned. However, in Indonesia incineration it is still a common way to handle unwanted waste.

Unfortunately, illegal dumping of waste in nature is also still common in Indonesia [Tang, 2004]. Research has shown that low-value plastics have a higher probability to end up in nature than high-value plastics. High-value plastics are more likely to be collected from disposal sites and resold. Low-value plastics are a significant contributor to plastic in the ocean, since 80% of plastic waste has low residual value [Conservancy and McKinsey, 2015].

The waste is often dumped in natural areas close to rivers. The waste that is dumped in rivers or along riverbanks will largely end up in the ocean which happens mainly during rainy season when the large amount of rainfall causes the waste on the riverbanks to be carried away by the flow of the river. The plastics in the waste either end up in the ocean, where it breaks down into smaller particles and enters the food chain [Boerger et al., 2010], or it can end up at the beaches of Bali again.

These types of own waste handling happens mainly if people do not have access to a proper collection systems. In these areas, there are also some small sorted waste dumps, as shown in figure 2.1a, to prevent that people throw it in the ocean.

(a) Sorted waste dump

(b) Waste collection by truck

Figure 2.1: Different waste handling methods

2.1.2. Collected waste

Waste can also be handled in a more regulated way. As mentioned in subsection 2.1.1 is waste collection is an important component of waste handling, but is often a weak link. There are several different stakeholders who play a role regarding the waste collection in Bali. Both governmental organisations as well as non-governmental organisations (NGO's) collect waste. Both will be discussed separately.

Governmental organisations

In Bali, the regencies are responsible for their own waste management. Each regency has a DLHK, which is a governmental environmental agency, which manages the TPST and TPST3R facilities.

Waste that is picked up and brought to a TPST facility will, regardless of the type of waste, be transported in large quantities to a landfill. In Badung waste is for example collected twice a week by trucks. This is shown in figure 2.1b. Over the entirety of Indonesia, 69% of all produced waste ends up in landfills, 24% keeps polluting the ecosystem and only 7% is recycled [Bahraini, 2019]. This gives an indication of the magnitude of the different streams of waste on Indonesia, although the situation in Bali might differ from the other islands. However, most landfills are reaching, or already have reached, their full capacity, due to the large quantity of waste brought to them, daily.

The biggest landfill on Bali, the Suwung landfill in Denpasar, is, despite its surface of 32,4 hectares, close to its full capacity. Other landfills that already reached their capacity, such as the landfill of Gianyar, transport their waste also to the Suwung landfill as backup [BaliPost, 2018]. Meanwhile, the landfill in Gianyar is being transformed into an integrated urban waste management (TPSTP) facility. At this facility, the waste is sorted. The organic waste will be composted and the remaining waste will be transported to the Suwung landfill. The fact that the landfills reach their capacity indicates that people are willing to dispose their trash in an environmental friendly manner. However, the landfills, thus, cannot keep up with the islands waste output and will soon all be full.

The waste that is collected at TPST3R facilities will, in contrast to regular TPST facilities where only the organic waste is separated from the waste, be sorted for plastic too. After the sorting, the recyclables will be brought to Java, non-recyclables will be brought to a landfill and organic waste will be composted. The government founded these facilities to stimulate recycling and circular economy through the 3R approach; reuse, recycle and reduce. Hazardous waste should be reused for the same purpose and valuable components within waste should either be recycled to produce the same or a different product or they should be recovered [Damanhure, 2017].

Since each regency has a different budget for waste management, the quality of the waste management system strongly differs per regency. The Tabanan regency has, for example, eleven TPST3R facilities. However, only two facilities are managed properly. The TPST3R Bantas Village facility and the TPST3R Jatiluwih Village are active facilities where the waste is being processed and sorted to fertilizers. The other nine TPST3R facilities only transport and eliminate waste, without real waste management [NusaBali, 2018]. In addition, there are large differences in the number of garbage trucks owned by the regency's DLHK. While Denpasar has 46 trucks to collect waste in an area of 127 m^2 with 638.548 inhabitants, for example, Gianyar has only 16 garbage trucks for an area of 368 m^2 and 492.757 inhabitants [GianyarKab, 2015]. Because of this, only 411 m^3 of the total 1500 m^3 of waste generated per day in Gianyar could be transported to the landfill.

Non-governmental organisations

As mentioned in the beginning of subsection 2.1.2, there are also non-governmental organisations (NGO's) that handle waste on Bali. These NGO's are active in some regencies and offer waste management possibilities. One of those NGO's is EcoBali. EcoBali offers collection services for households, offices and businesses. For a fee that starts at 115.000 IDR per month (8 USD) they pick up waste based on the customers' needs (i.e. bin size and collection frequency) [EcoBali, n.d.]. However, for most people on Bali this is very expensive. The minimum wage in the Badung regency for 2019 is 2.7 million IDR per month, which is about 190 USD [WageIndicator, n.d.].

In addition, there are so called 'middlemen' active as NGO's. These middlemen buy recyclables, which are mainly PET bottles and caps, from individuals, after which they transport and sell it to large recycling facilities on Java [van den Berg et al., n.d.]. This helps to mitigate the waste problem, because individuals have a financial incentive to properly handle their recyclable waste and collect recyclables from the waste dumped in nature. For some people collecting the used recyclables and selling it to middlemen is their main source of income. These people are called 'waste pickers' [van den Berg et al., n.d.]. However, the other types of waste that are not recyclables, will either degrade or stay in the environment for decades.

Finally, due to the large amount of plastics on the beaches and in the ocean, more and more NGO's are established to tackle the waste problem on Bali. These organisations fight for example the use, sale and production of plastic bags. One example of such an organisation is 'BYE BYE PLASTIC', which is established by two local children. In a creative way, e.g. by means of flash mobs, festivals and beach clean-ups they try to increase public awareness on the effects of plastic and promote alternative environmental friendly bags [Hernanto, 2017].

Currently, beach cleanups are organised regularly by different organisations. Ocean Mimic, which is also a NGO, organises weekly beach clean-ups. At these clean-ups, plastic is picked-up from the beaches, for one hour. Thereafter, the collected plastic is weighed and noted. Finally, the waste is sorted and properly handled based on the type of waste by EcoBali.

Waste Banks

Lastly, there is a new emerging concept, called a waste bank, which can be established by both governmental and non-governmental organisations. A waste bank is a facility where inhabitants of Bali can bring their waste. They can open up an account at their local waste bank. Each deposits with non-organic solid waste is weighed and given a monetary value, based on rates set by waste collectors. This value is saved in the account and can be withdrawn at any time, like a regular bank [Salim, 2013]. At the waste bank, the waste is sorted and can be recycled or reused [Nugroho, 2018]. The Ministry of Environment of Indonesia promotes these initiatives as the new strategic program [Temesirecycling, n.d.]. Both non-organic and organic household waste creates economic value after the sorting activities. The non-organic household waste will be recycled and the organic household waste will be composted [Nugroho, 2018]. This concept is subject to a rapid growth. Many companies in Indonesia even made waste banks a part of their corporate social responsibility. According to the Ministry of Environment, Indonesia had 1,195 waste banks in 58 districts and cities employing 106,000 workers in 2013. By 2014 the Ministry has set a target to develop waste banks in 250 cities across Indonesia with an amount of 25 in each city. It was estimated that by the end of 2015 about 5% of the population would be served by 15,000 waste banks. With this rapid growth Indonesia will be heading towards an actual revolution in waste management and the result will be a significant contribution to recycling [Temesirecycling, n.d.]. That the waste bank is currently still emerging is shown by the goal of the government of Jembrana, who wants every village to have its own waste bank in 2019 Berkarya [2018].

One example of a waste bank in the regency of Badung is the previously mentioned EcoBali. In addition to the collection services that EcoBali offers, it also act as a waste bank. Its waste bank is suitable for communities and businesses that generate large amounts of recyclable items, which EcoBali will collect if the amount is more than one full truck load [EcoBali, n.d.]. However, also individuals can bring their smaller amounts of recyclable items to this facility.

2.2. Plastic in rivers

Most plastic that ends up in the ocean comes from land-based sources. This is partially caused by land-based inputs from coastal populations and partially by inland populations trough riverine systems. A study by Schmidt et al. [2017] showed that 88-95 percent of the global plastic waste in the ocean is transported by the top ten most polluting rivers. Recent research by Lebreton et al. [2017] found that 86% of the global input of plastic into the oceans, through riverine systems, comes from Asian countries. This is mainly caused by a high-population density, a relatively large amount of mismanaged plastic waste and periods of heavy rainfalls. The research of van Utenhove et al. [2018] showed that also in Bali most of the plastic on the beaches and in the oceans is contributed by the rivers on the island. The plastics end up in the rivers by direct dumping in rivers, dumping on embankments, and as a result of wind [Dris et al., 2015].

Dumping of waste

The Ocean Conservancy, together with McKinsey Center for Business and Environment, performed a research into how plastic ends up in the ocean [Conservancy and McKinsey, 2015]. The research focused on five countries, which are China, Indonesia, The Philippines, Thailand, and Vietnam. They mention that, while uncollected waste was certainly the major contributor, another driver of this problem is leakage from underdeveloped collection systems. About 75% of land-sourced ocean plastic comes from uncollected waste or litter, whilst the remainder comes from gaps in the collection system itself. The interview with G. Hendrawan (appx. C.1) showed that this is indeed the case in Bali and that there are defects in the existing waste collection systems. When the transport of waste is not sufficiently regulated, garbage truck drivers have little incentive to follow the rules. To avoid paying tipping fees at landfills, save time and reduce fuel expenses, some drivers of waste transport will shift to illegal dumping. Next to that, collection systems, in the five focus countries, still make a lot of use of informal dump sites. These informal dump sites are large piles of waste that have little or no infrastructure in place to control leakage to the ocean.

The waste which is dumped directly into the river will be carried away by the flow of the river in the direction of the ocean. However, plastic does not necessarily enter a river directly, but is often dumped near the river and on the embankments. Then the waste first accumulates on the river banks and will be swept away with a large run-off event after large rainfalls. Due to Bali's geographical location, it is subjected to two different seasons over a year. A rainy season and a dry season. During the dry season, the discharge and the water level is lower than in the rainy season. In the rainy season, the (plastic) pollution on the embankments, which will have accumulated over the dry season, will be swept away downstream, into the ocean and onto the beaches. This phenomenon is a mayor contribution to the plastic problem on Bali. Especially, in the beginning of the rainy season when the first major rain showers occur the discharge increases. This can be seen in Figure 2.2, where the amount of collected waste of beach clean-ups is given.

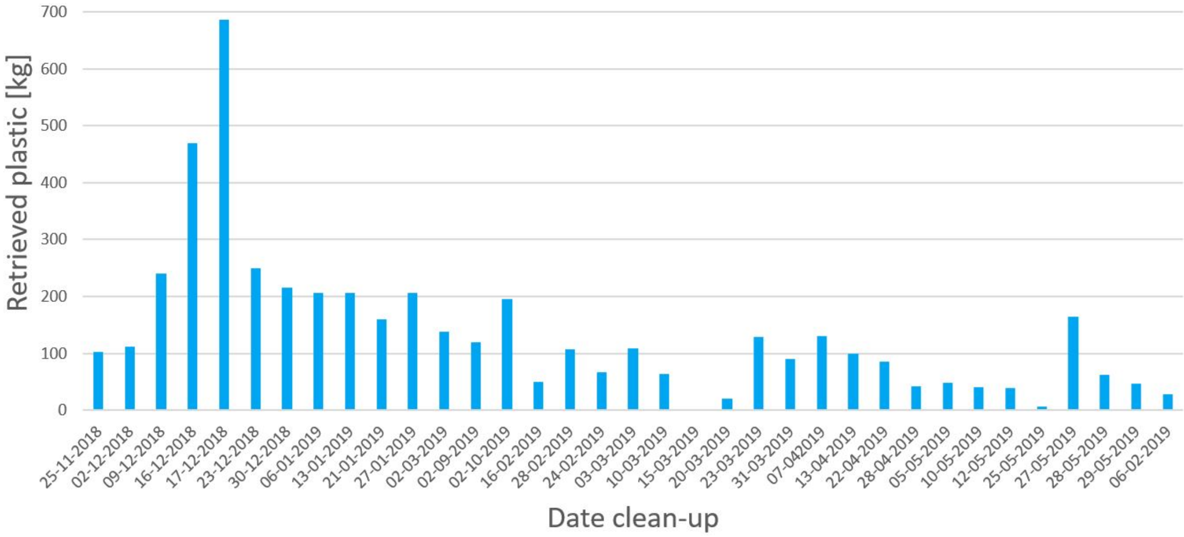


Figure 2.2: Plastic collected from beaches [kg] (source: Ocean Mimic)

Figure 2.2 shows a clear spike in December, at the start of the rainy season. Whilst this data is only from one beach, in one hour, and is depended on the amount of volunteers, who participated in the clean-up, it clearly shows how bad the situating can be, and how large the peak discharges can be.

That being said, little to no research into the plastic on the embankments has been done. Although, at the time this report is being written, G. Hendrawan, PhD. from the Udayana University of Bali, is publishing a paper about the plastic pollution on the embankments of the rivers on Bali.

The effect of wind

Another factor, which can play a role regarding the plastic discharge in rivers, is the wind velocity. As (plastic) waste is thrown onto the streets and into nature, it gets transported by wind. Due to the wind and gravity, the litter eventually ends up in the most low lying part of the area. This can either be ditches, where water is running through, which ends up in rivers, or in rivers directly. Although this correlation is mentioned in papers, little research into the correlation between wind velocity and plastic discharge in rivers is done, and no data can be found about the matter.

2.3. Implemented and planned measures

In this section the already implemented and planned measures to mitigate the waste problem are discussed. Here, a distinction is made between the measures taken or planned by the Indonesian government and NGO's.

2.3.1. Indonesian Government

In this section the measures will be described that the Indonesian government is planning to implement to reduce plastic waste in the environment. According to the interviews with P. Cannucciari of EcoBali (appx. C.2 and G. Hendrawan (appx. C.1), the Indonesian government has become more active in recognising and mitigating the plastic waste problem over the past years. The effort of the national government comes forward with the recent ban on single use plastic [Times, 2018]. The new policy was signed on December 21 2018 and carries a six-month start-up period. The ban includes shopping bags, styrofoam and plastic straws. Because Indonesia realizes the harmful threats of plastic waste on the ocean and environment, the government has developed a national plan of action regarding marine plastic debris for the years 2017 to 2025 [of the Republic of Indonesia, 2018]. The Indonesian government mentioned three key aspects in handling marine plastic debris in Indonesia:

1. Coordination between institutions that are responsible for waste management.
2. Application of technology to control plastic debris, including the application of science-based management.
3. A focus on advancing societal efforts to reduce, recycle and reuse plastic debris.

The national plan of action consists of five main pillars. The first pillar is to improve behavioural change. Especially for long-term solutions, behavioural change is very important. Due to the large number of stakeholders spread out in all regions, stakeholder awareness and involvement should lead to an efficient and effective contribution. The focus is on collaborations amongst ministries for inclusion of non-government stakeholders and cross-sector collaborations nation wide. The second pillar is the reduction of land-based leakage. This pillar consists of the encouragement of research and production of alternative materials to plastic use, in order to restrain new plastic production. Reducing ocean-based leakage is the third pillar. This entails monitoring and collecting the plastic debris from the ocean and the improvement of environmental awareness through education, while also improving waste management facilities in ports, small islands and coastal areas. The fourth pillar is to reduce plastic production and use. The Action Plan is designed to encourage manufacturers of plastic to use recycled plastics as input materials as much as possible, while at the same time producing more biodegradable plastics. The fifth, and last, pillar is to enhance funding mechanisms, policy reform and law enforcement. This includes the establishment of a standard procedure for marine waste management and waste management infrastructure improvements.

Next to the five main pillars, the national plan of action describes five strategy programs at different levels. The action plan at the local government level includes the river authority to filter the plastic waste from the rivers. Several action programs at this level include the strengthening of human and financial resources, infrastructure management and change of behaviour. Developing integrated coastal waste management projects is also at this level. The action plan at national level includes promoting change within the society. Another focus at this level is rearranging agencies who take care of upstream landfills related to plastic waste. For implementation at national level, the government strives, among others, for stakeholder awareness, implementation of paid plastic bag policy and strengthening regulation on plastic debris management in seaport, shipping and fishing lines. Next to the local and national level, the government also has strategies on international level, on industrial sector level and on academics and community service organization level. The described main pillars and strategy programs aim to achieve the final goal for reducing marine plastic debris by 70% in 2025.

2.3.2. Non-Governmental Organisations

In this section an overview is provided of implemented solutions by parties other than the government, since the government is not the only party taking measures to mitigate the plastic problem. The creation of plastic waste is an activity that involves all levels of society. Furthermore, it is not the case that there is one single organisation that is responsible for waste prevention and management and not one single organisation can solve the issues of waste by itself. Because the plastic waste problem affects everyone, multiple initiatives arise that originate from the different societal levels. The research conducted by Kandziora et al. [2019] concluded the importance of networks to prevent and reduce plastic pollution in the ocean. They state that by following a common vision and a collective systematic approach, marine debris networks are capable of creating synergies between all relevant stakeholders. This will result in a flow reduction of waste into our oceans. In conclusion, networks are key to achieving the Sustainable Development Goals of the United Nations. An initiative that is responding to the mentioned importance of networks is the Indonesian Waste Platform (IWP). The IWP, aims to induce collaboration across geographies, sectors and communities, making it possible for government, business and civil society to work together and contribute to Indonesia's National Plan of Action on Marine Debris, which is described in section 2.3.1. The IWP aims to foster connectivity and collaboration, for which IWP is presenting itself as the hub of Indonesia's ocean plastic and waste management community and as a neutral entity that allows transparent sharing and inclusiveness. Next to that, IWP organises national symposia and peer-to-peer capacity building. Finally, the IWP leads innovative projects on the ground, by leading projects where there are clear gaps in the existing stakeholder landscape [IWP, n.d.].

Next to the national level, a large number of initiatives exists on the island of Bali at local level. An example is the Bali Beach Clean Up (BBCU) program by Coca-Cola Amatil Indonesia and Quiksilver Indonesia. The initiative has created 78 job opportunities for local communities to clean up 9,7 km shoreline everyday throughout Bali's five iconic beaches: Kuta, Legian, Seminyak, Jimbaran, and Kedonganan. The underlying principle behind the program is that corporations have a role to help protect the environment while at the same time can create economic opportunities [Hernanto, 2017].

The Klungkung regency, which is one of the smaller regencies in Bali, is taking measures to improve the sustainability of its waste management system. The regency is processing its waste differently than the other regencies. It was the first to close the landfill, called Sente landfill, at the end of the year 2017. The landfill has been transformed to a revolutionary waste management program called TOSS, which stands for Temporary Waste Management Site. The waste is directly processed to briquettes and pellets, which can be used as fuel Tribun-Bali [2018].

2.4. Socio-demographic factors

In this section, different characteristics (i.e. income, tourism, education, religion, population density, landfills and waste collection) of the regencies on the island will be discussed based on a literature study. For each characteristic a map will be made that shows the differences between the regencies. In chapter 5, these maps will be compared with the maps showing the measurement results in order to determine possible relationships. Figure 2.3 shows the different regencies on the island. In the next subsections, the different characteristics will be discussed successively.

Figure 2.3: Overview of Bali's regencies

2.4.1. Income level

The income level of a regency has an effect on the waste generated in that regency, as an increasing income level leads to an increase in the generation of food, paper, plastic, metal and glass waste [Grover and Singh, 2014]. It is a common observation that with an increase of economic growth the generation of waste grows equally. Individuals with a higher income consume more than lower-income ones, which results is a higher waste generation [Grover and Singh, 2014]. A study of Medina [2002] shows that there is also a positive correlation between a community's income and the amount of solid waste that is generated.

On the other hand, should higher-income communities or individuals have more possibilities to collect, transport and dispose the waste. In low-income communities with poor waste collection, the residents tend to dump their waste in e.g. the nearest river or burn it. For Third World countries waste management accounts for 30-50% of the municipal operational budgets [Medina, 2002]. Despite the high costs for the municipalities, only a small part of the waste is collected. In Bali on average only 60% of the waste is collected [Erviani, 2019a]. For the disposal of waste, this is often worse. In Asian cities 90% of the waste ends up in open dumps [Medina, 2002].

To determine the level of income of Bali's regencies, three economic measures are used, the regional income and expenditure (APBD), the original local government revenue (PAD) and the general allocation fund (DAU). In table B.3, for each regency the values of these three measures are shown. Below, each measure will be discussed briefly.

- The regional income and expenditure budget (APBD) is the annual financial plan of regional governments in Indonesia, approved by the regional people's representation council. The APBD is determined by regional regulations and covers a period starting from January 1 to December 31 [Wikipedia, n.d.].
- The Original Local Government Revenue (PAD), is income from sources within the area of a particular region, collected under applicable law. The PAD is part of the APBD [Wikipedia, n.d.].
- The General Allocation Fund (DAU) is a sum of funds to be allocated each year by the central government of Indonesia as a development fund to each autonomous region (province, regency or city). The DAU is also part of the APBD [Wikipedia, n.d.].

The data in B.3 shows that in 2018, Badung was the regency with the highest APBD and PAD, which was about 408 million and 355 million euro, respectively. Therefore, this regency received the lowest DAU compared to the other regencies, about 21 million euro. The regency with the lowest APBD in 2018 was Klungkung, with about 68 million euro. However, Klungkung did not receive the largest DAU. This was Buleleng, with about 60 million euro. Figure 2.4 shows the income level of the different regencies based on the APBD.

2.4.2. Tourism

Bali is the leading tourist destination in Indonesia [Sutawa, 2012]. In the year 2018 a total of 6.070.473 people visited Bali. This is more than double the amount of visitors of Bali in 2012, which was 2.892.019 visitors [Bali Government Tourist Office, 2019]. This shows that the number of tourists have been growing rapidly in the past few years.

Tourism is closely related to the income level described in subsection 2.4.1. Up to 80% of Bali's income is derived from tourism [Cole, 2012]. Although the growth in tourism increases the welfare of people working in the tourism sector, it is estimated that about 85% of the tourism economy is in hands of non-Balinese [Cole, 2012]. The growing tourism has also negative effects [Sutawa, 2012]. As discussed in 2.4, this will result in higher waste generation due to an increase in consumption [Grover and Singh, 2014]. Furthermore, the growing tourism also affects the land use and culture. Because of the growing tourism, agricultural lands are changing into to hotels, restaurants, etc. In 2015, compared to 2014, this resulted in a 3,7% decrease in paddy production area [Knoema, n.d.]. This decrease affects the welfare of people working in the agricultural sector.

The tourism also affects the culture on Bali. The positive effect that it can revive the culture. On the

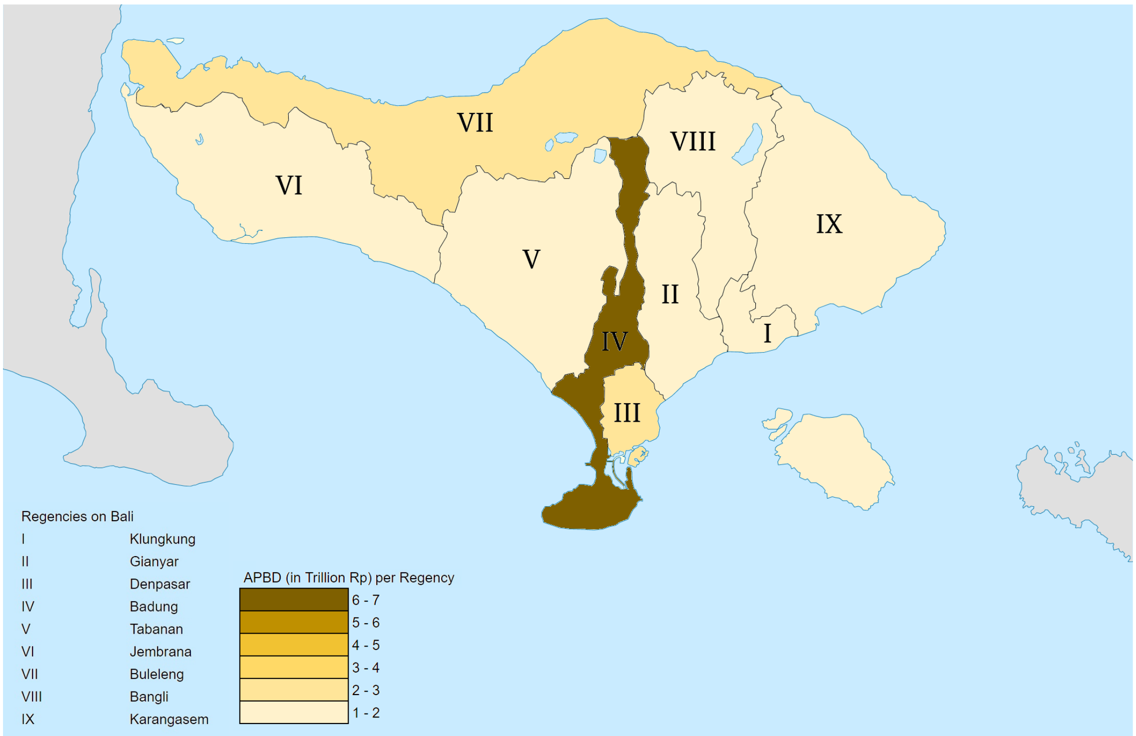


Figure 2.4: Income level of regencies

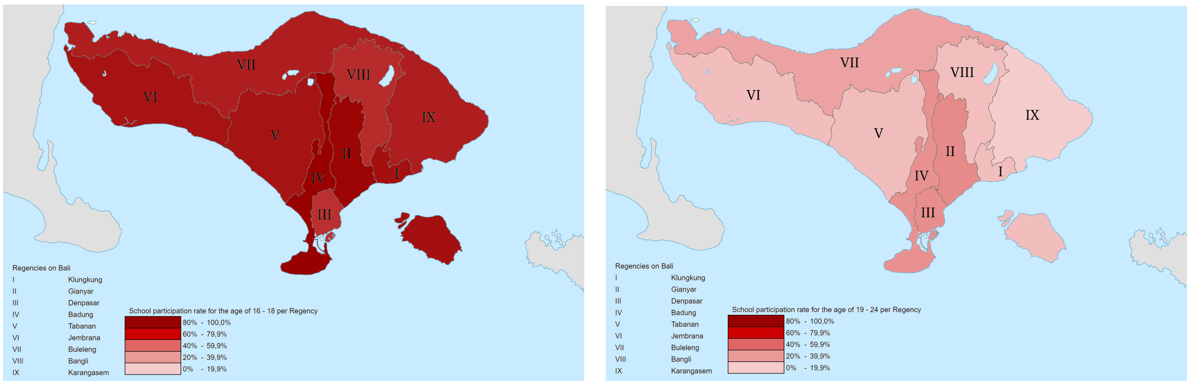
other hand, tourist visiting some part of the culture leads to mass production, commercialization and material orientation, which results in distortion of the culture [Sutawa, 2012]. To reduce the negative impacts, religious and academic leaders give education about the effects of tourism. In addition, the government limits tourism businesses, such as pubs and discotheques, that tend to spread negative impact towards the community, by strict regulations. Finally, Sutawa [2012] describes that empowerment and involvement of the community in the tourism development is key for sustainable tourism development, which preserves the island's culture and nature.

The area with the most tourism on Bali is the South of Bali, it is the busiest and most developed area. The main tourist locations are Kuta, Legian, Seminyak, Canggu, Sanur and Nusa Dua, which are all located on the coast. This area also inclused Denpasar and the Ngurah Rai airport. Most of these locations are part of the Badung regency. In 2015 a survey of the Indonesian Hotel and Restaurant Association (PHRI-Bali) counted 130.000 hotel rooms, of which 98.000 room are located in the regency of Badung [Kristianto, 2016]. Outside of the South there are only 2 large tourist locations, which are Ubud (Central Bali) and Lovina (North Bali). In chapter 5, these busy tourist areas will be compared with the more quiet areas, such as West Bali, based on the measured plastic discharge in the rivers. Because tourism is closely related to the income level, the map of income level will be used for the analysis of tourism.

2.4.3. Education

Education activities regarding the environment provide a platform on which a community begins to apply the knowledge needed to improve [Fredrick et al., 2018]. To be able to achieve a change in waste management behaviour, education about the increasing amount of waste generation that it is related to personal behaviour is essential. It is crucial to raise greater awareness about personal responsibility. When households realize they generate too much waste, it could be a motivation to reduce waste. Furthermore, the communication on how to minimise the waste and why it needs to be minimised is essential Minelgaitė and Liobikienė [2019]. A suitable medium for this communication is education in schools. Therefore, children and young adults are more likely to learn about the risks of waste in the environment and about proper ways of handling waste when they go to school and have an education.

Education and change of attitude are interwoven. Attitude may not be only changed by education however. Knowledge on a topic increases and people could change attitudes, but that the step to improve behaviour depends on a complex set of social and psychological factors. While knowledge of an issue is critical, it is often not sufficient to cause action [Fredrick et al., 2018]. The school participation rate per regency in Bali is presented in table B.4 and in figures 2.5a and 2.5b



(a) School participation rates, ages 16 - 18, per regency (b) School participation rates, ages 19 - 24, per regency

Figure 2.5: Religion maps

2.4.4. Religion

Bali is a multi-religious island. The predominant religion is Hinduism, plus Muslim, Christian and Buddhist minorities (see appx. B.2). With about 93% Hindus, Bali is the only Hindu island of Indonesia [Hayes, 2008]. This is also shown in Figure 2.6. The regency where Hindus are most dominant is Bangli (see Figure 2.7a). In this regency 98.6% of the inhabitants are Hindu (see appx. B.2). This regency is the only regency not adjacent to the coast. Although this regency is relatively large with 490 km^2, it is the third most thinly populated regency with only 264.945 inhabitants (see appx. B.1). Therefore, rivers in this regency are not measured, as most villages tend to lay at the coast. The regency with the second highest percentage of Hindus (98.4%) is Gianyar. Gianyar is a much smaller regency with respect to area size. However, the population is almost twice as large (see appx. B.1). In this regency, three rivers are measured.

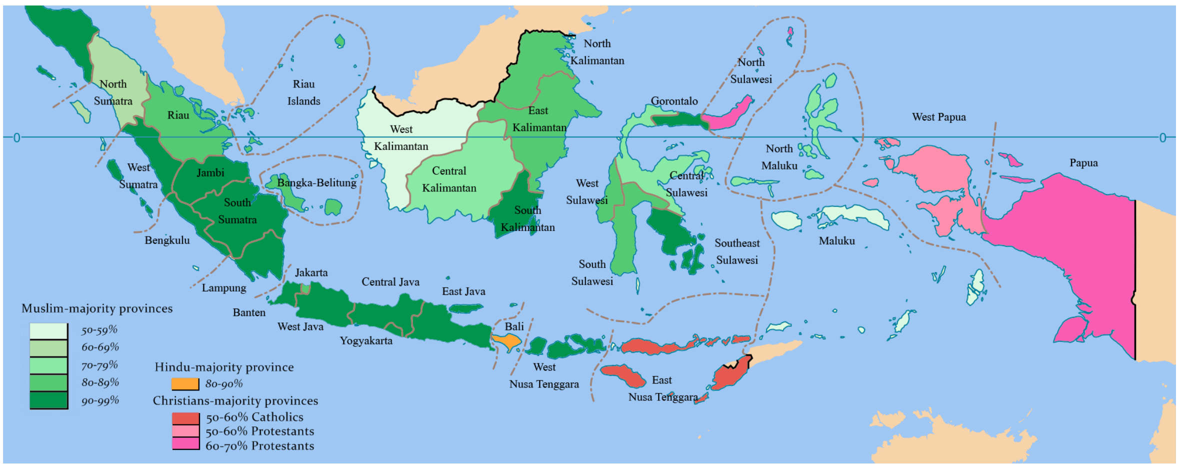
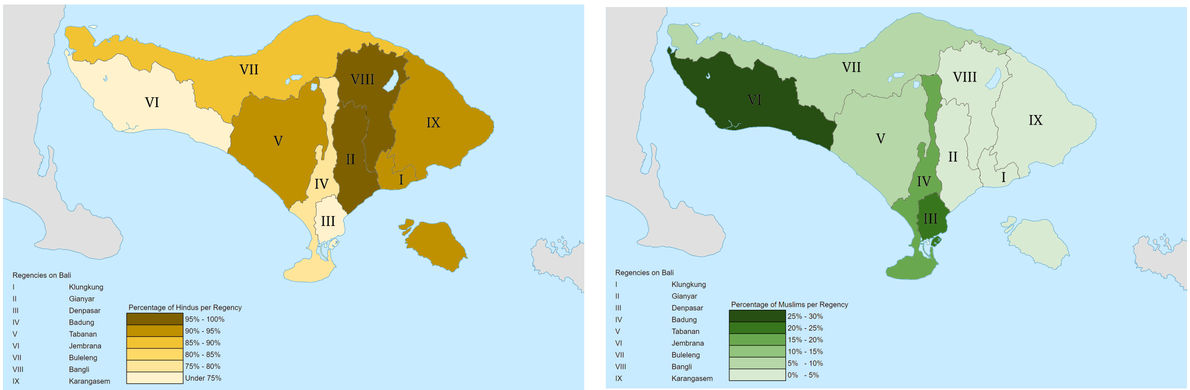


Figure 2.6: Overview of religions in Indonesia

The regency with the lowest number of Hindus is Denpasar. In Denpasar 64.0% is Hindu, 24.3% Muslim, 7.4% Christian and 2.4% Buddhist (see appx. B.2). Denpasar is the regency with the smallest area (128 km^2). However, it is regency with the second largest number of inhabitants (638,548 inhabitants) (see appx. B.1). Denpasar has the largest share of Christians and Buddhist, but not Muslims.

In Denpasar two rivers are measured. The regency with the highest share of Muslims is Jembrana, namely 26.6% (see appx. B.2). In Jembrana the Islamic faith is most noticeable because of the many mosques in the area. In this regency eight rivers are measured. Figure 2.7b shows that Denpasar and Jembrana are the two dominant regencies for Muslims.



(a) Hindus

(b) Muslims

Figure 2.7: Religion maps

It is difficult to determine if the division of religion in the regencies have an effect on the plastic discharge. However, existing literature shows that religion could have an effect on the attitude and behaviour towards sustainability. James [2009] describes that the Eastern religions (i.e. Buddhism and Hinduism) believe that God is in and through everything, including nature. Hinduism is known for its close relationship with nature. It emphasizes the communion between human and nature and respect for the environment [Alam, n.d.]. The Western religions (i.e. Christianity and Islam) on the other hand believe that God created nature and that God and humans are superior to nature. Therefore, Western religions should be less inclined to be more sustainable and are more willing to alter nature [Sarre, 1995]. The studies of Eckberg and Blocker [1989] and Wolkomir et al. [1997] confirm this with Christians showing less sustainable behaviour than people from other religions. This shows that religion could have an effect on the plastic discharge.

However, the lower tendency towards sustainability is the same for Muslims, and specifically in Indonesia, is not studied yet. The Islamic culture, on the contrary, is also emphasizing the importance of being in harmony with nature. From the 6000 verses in the Holy Quran, 500 of them are about natural phenomena [Dehlvi, 2016]. In addition, the Islamic community in Indonesia is making effort to reduce the plastic problem in Indonesia. In 2018 the country's two largest Islamic organisations, Nahdlatul Ulama (NU) and Muhammadiyah, joined the Government's challenge to reduce plastic waste in Indonesia. Together the organisations have about 100 million followers. The leaders will visit prayer groups in Indonesia to preach about the severity of the plastic problem. Herewith, they can reach followers down to village level [Lamb, 2018]. Minton et al. [2015] describes that although religion does not exclusively predict sustainable attitudes and behaviors, an understanding of religion does provide insight into a more holistic view of sustainability. Therefore, religion could be an important demographic factor that needs to be considered.

2.4.5. Population density

Grover and Singh [2014] states that family size and income are the most significant factors determining the quantity of solid waste from household consumption. The generation of residential waste increases with increasing family size. Therefore, regencies with a large population generate more waste compared to those with a smaller population. Although in most urban areas around the world waste collection rates are higher than in rural areas, the high levels of waste density in urban areas can overburden existing waste management systems. When this is not accompanied by the development of sufficient waste management infrastructure, it can create a huge gap in waste coverage [Conservancy and McKinsey, 2015]. In table B.1 the population density of each regency in 2017 is shown. This is also represented in figure 2.8. Denpasar is the regency with the highest population density, which is 4997 inhabitants per km^2. However, it is not the regency with the largest total population. This is Buleleng, which has a population of 814.356 inhabitants and an area size of 1365 km^2. Denpasar has 638.548 inhabitants and an area size of only 128 km^2. Therefore, it has the highest population density.

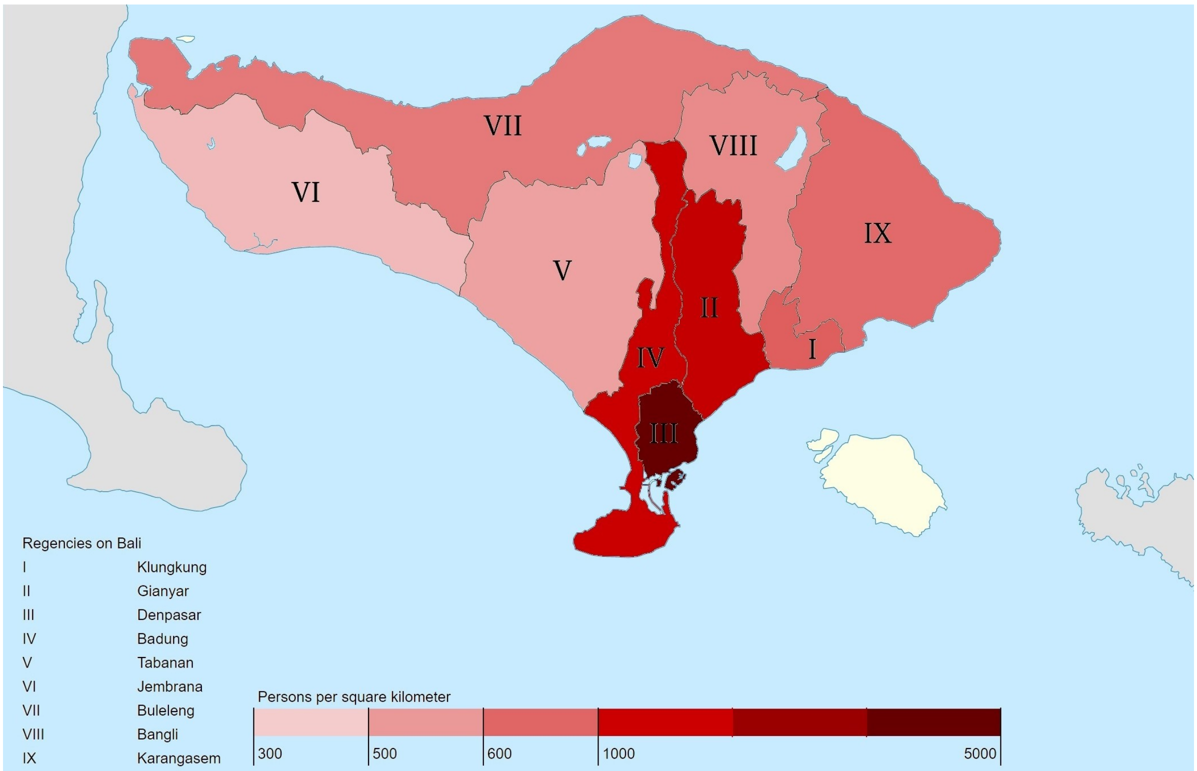


Figure 2.8: population density

2.4.6. Landfills

According to the interview with G. Hendrawan (appx. C.1) every regency in Bali has its own landfill except for Badung. Badung uses the landfill in the Denpasar regency, which is the biggest landfill on Bali. However, since some of the regencies have a relative large surface, the landfill might not be close to some parts of the regencies. This is for example the case with Badung where the distance between the coastline and the north is very large. G. Hendrawan mentioned in the interview (appx. C.1) that in these cases it happens that the trucks that pickup the waste from households etc. dump it at illegal dumping sites because they find the landfill too far away. In figure 2.9 the location of the landfills in each regency is shown.

Figure 2.9: Landfill locations

3

Mitigating measures

In this chapter different measures will be discussed to mitigate the plastic waste problem. The planned measures by the national government and some implemented measures by local partners are already discussed in chapter 2. This chapter will elaborate on this by providing an overview of other possible measures which are not implemented on Bali, but are proposed in literature. Finally, a comparison will be provided of the measures.

3.1. Waste sorting

According to G. Hendrawan (appx. C.1) it is very important that regulations will be implemented to make sure that waste is sorted properly at the source, such as at households and restaurants. Next to regulations, educating people also plays an important role. The inhabitants have to be aware of the different types of waste, how to separate them and what happens if they do not. It is very important that the government simultaneously provides a good infrastructure to collect the waste, thus it does not get mixed up again after being separated, which happens often at the moment. By manually sorting waste, the high-residual-value waste can be extracted for recycling and a significant portion of low-value plastic can be converted to refuse-derived fuel. The conversion of waste to energy will be further discussed in section 3.5.

3.2. Tourist tax

Authorities on Bali are currently considering to introduce a tourist tax of ten United States Dollar for overseas visitors. The idea is that the revenue of this tax will be used for programs that help to preserve the environment and culture of Bali [Guardian, 2019]. According to Hendrawan (appendix C.1) such a tax could be really useful, if the collected money is actually used to mitigate the plastic waste problem. The money could, for example, be used to provide a proper infrastructure for waste management and to educate the inhabitants of Bali. If the money is used for the right purposes, it is not expected that it will cause a decline in tourist numbers. The authorities are still debating about what will be the best way to collect the tax. It could either be added to the airline ticket price or paid at a special counter at the airport. However, both options receive some resistance. The International Air Transport Association argues that adding the tax to airline tickets is not in line with the Chicago Convention, whereas the general manager of Ngurah Rai International Airport thinks a special counter at the airport would decrease the service level of the airport [Erviani, 2019b]. An increased price of the visa can be the middle course.

3.3. Expansion of waste collection services and increase collection rates

A proposed solution by The Ocean Conservancy & McKinsey Center for Business and Environment [2015] is to expand the existing collection services and increase waste collection rates. This solution is specifically effective for Indonesia, which will drive up collection rates that were below 30%. Driving up collection rates means more pick-up locations, which causes the need for more transport. Transport is however the most expensive management activity regarding municipal solid waste management in developing countries [Ferronato et al., 2019]. This makes this solution more difficult to implement.

3.4. Closing leakage points within collection system

Another solution proposed by The Ocean Conservancy and McKinsey [2015] is to close the leakage points within the collection system which are mentioned in section 2.2. The avoidance of leakage within the transportation part of the collection system requires a much more transparent tender process, that encourages competition between bidders of the transport service. To be able to ensure that service providers abide by the criteria determined in the tender process, better performance management is required. This includes waste-container tracking, with the help of GPS for example, to ensure that transporters complete their designated route with their full load of waste, rather than dumping it illegally. Payment should be based upon measurable performance and dumping fines should be enforced more consistently and effectively. For the prevention of leakage from dump sites there are relatively simple, fast and inexpensive measures that have been shown to decrease this leakage to a significant extend. Creating a perimeter around the dump and its access road is an example mentioned that can help define the size of the dump. This makes it possible to perform basic shaping, compacting of the waste and periodic covering of the waste layers with soil [Conservancy and McKinsey, 2015].

3.5. Conversion of waste

This section describes the concept of Enhanced Landfill Mining (ELFM) as a measure to process waste in a sustainable way. ELFM intends to place landfilling of waste in a sustainable context. It includes the process of recovering energy in the form of electricity or heat from waste. There is an environmental disadvantage to ELFM, including the emissions of pollutants and greenhouse gases. To reduce the content of pollutants in the products generated and in the emissions to air, water and soil, special abatement technologies need to be used. These special technologies make this measure more costly, which makes it more difficult to implement. Another aspect that needs to be considered before implementation is the economic feasibility of ELFM. This highly depends on the development of innovative technologies that guarantee an efficient waste to energy conversion. However, a lack of data about the energy efficiency makes it difficult to compare these technologies with conventional technologies, since energy efficiency is an important system indicator for this comparison. The lack of data makes it difficult to decide on the most suitable new technology for implementation [Bosmans et al., 2013].

There are multiple existing processes of converting waste to energy. Regarding municipal solid waste, the main available conversion technologies include incineration and gasification. Opinions differ about the sustainability of incineration. Waste incineration can be an environmentally friendly method if it is combined with energy recovery, control of emissions and an appropriate waste disposal method [Bosmans et al., 2013]. Next to that, incineration can include recycling of materials. Technologies are available to inactivate incineration residues before disposal. There are innovative attempts to recover metals from these residues. This is opening up new possibilities for alternative collection schemes for several waste components. For this reason, waste to energy is on the way of becoming an important tool for material recycling and resource conservation [Brunner and Rechberger, 2015]. The other main available conversion technology is gasification. Gasification is the partial oxidation of organic substances to produce syngas (synthesis gas). This syngas can be used as a feedstock for the chemical industry or as a fuel for efficient production of electricity and/or heat [Bosmans et al., 2013]. Gasification can process very large quantities of mixed waste with relatively little pretreatment or sorting [Conservancy and McKinsey, 2015]. One of the important advantages of gasification is that the syngas can be cleaned of contaminants prior to its use [GSTC, n.d.].

3.6. Waste catchment structures

Another type of solution that could be implemented is to place more catchment structures in the rivers, in order to trap the waste that is flowing through the rivers. Currently there are two of these structures in place in Bali. Gede Hendrawan mentioned in the interview (appendix C.1) that these structures are very useful with respect to preventing the waste to enter the oceans. It would therefore be beneficial if these structures are implemented in more rivers and in more regencies. Furthermore, this is a solution that could be implemented on relative short notice. The situation in Bali regarding the amount of waste ending up in the rivers, ocean and beaches is very urgent and therefore effective measures should be taken as soon as possible. A lot of measures involve changing behaviour or the effectiveness of the measure is uncertain. Since the placement of catchment structures in rivers can be implemented on relative short notice and is effective in preventing the waste to enter the ocean, this solution will be further researched and discussed more elaborately in chapter 6.

3.7. Overview proposed measures

Table 3.1 provides an overview of the previously mentioned measures to prevent the plastic from ending up in the environment. For each measure the advantages and disadvantages regarding implementation are given. The Ocean Conservancy together with McKinsey [2015] examined some of these measures and concluded four measures as the most effective for Indonesia, in terms of net benefit and ease of implementation. These measures are to expand collection services and increase waste collection rates, closing leakage points within collection system, gasification and finally to manually sort waste to extract the high-residual-value waste for recycling and convert a significant portion of low-value plastic to refuse-derived fuel.

Table 3.1: Comparison measures

Measure	Advantages	Disadvantages
Waste sorting	This measure is mitigating the problem at the source. This will be specifically effective in the long-term.	A change in behaviour is required, which leads to a long period before results.
Tourist tax	The extra income for the regencies will contribute to the ease of implementing the other mentioned measures. Very cost efficient.	Not in line with the Chicago Convention and an expected decrease in the service level of Ngurah Rai International Airport.
Expand collection services and increase waste collection rates	Effective, since collection rates in Indonesia are very low at the moment.	High transportation costs required.
Closing leakage points within collection system	No new infrastructure is required, only improvement. This makes this measure less costly.	Cooperation of service providers is required for successful implementation.
Conversion of waste	A sustainable way of waste processing, while producing energy.	Environmental disadvantages, including the emissions of pollutants and greenhouse gases.
Waste catchment structures	Short-term solution and very effective.	High implementation costs.

4

Methodology

This chapter will describe which rivers were measured, why they were selected and how the data was obtained from the rivers. The plastic discharge was either obtained by means of a trawl or via visual observation. In addition, it will be explained how the other parameters, related to the river, have been obtained.

4.1. Measured rivers

Bali consists of eight different regencies, and the capital city of Denpasar. As Denpasar is considered an administrative capital, with its own boundaries, it can also be considered as an administrative division. This results in nine different areas, henceforth named regencies, which are shown in figure 2.3.

To determine which rivers discharge the most plastic onto the beaches and into the ocean, measurements are performed in rivers located in the different regencies of the island. It was decided to measure the rivers close to the river mouth, as most of the bridges are located at the coast and the amount of plastics will be the highest close to the river mouth.

The measurement locations are shown in figure 4.1. The locations are predetermined based on literature and with the use of Google Maps. From literature is obtained which rivers are already studied and are considered as possible problem areas. Google Maps is used to determine if the river is suitable for measuring and what the best measurement location is along the river. First, it is determined if the location is safe to perform measurements. Many possible locations are close to busy roads with only little space on the sides. These locations are tried to prevent. Furthermore, the size of the river is determined. In the dry season many rivers are empty. These rivers are excluded. Also it is determined if the rivers pass villages or other populated areas, which may lead to a higher plastic discharge. In the next section will be discussed how the rivers are measured and which data is retrieved.

As the decision was made only to measure rivers near the coast, no measurements were taken in the Bangli regency (VIII Fig. 2.3), as this regency is landlocked. Due to the fact that most people on the island live at the coast, this regency is sparsely populated and not considered as a relevant area, as can be seen from figure 2.8. Although rivers flow through the regency, it can be assumed that the majority of the plastics in the rivers originates from the regencies which enclose the mentioned regency, near the shore. As obtaining names of the rivers proved to be very difficult, the decision was made to number the measured rivers. A map of the measured rivers can be seen in Figure 4.1. The measurement locations of the rivers are given in table A.1 in appendix A.2. As can be seen from figure 4.1, little to no rivers were measured in the Karangasem regency and on the southern peninsula of Uluwatu. This was due to geographical reasons, areas with steep slopes and high cliffs, respectively, were found here. Which resulted in rivers with zero discharge in the former case, or a total absence of rivers in the latter case.

Figure 4.1: Overview of the measured rivers

4.2. River data

This section explains how the measurements were performed and how the data from the rivers was obtained. The rivers have either been measured with a trawl, by visual observation or a combination of the two. The trawl has been used in rivers that met the minimum depth requirement of 73 cm due to the dimensions of the trawl. If the river was too shallow, or no plastics appeared to be flowing, a visual observation was chosen.

4.2.1. Trawl

The trawl used for the measurements is the trawl designed by The Ocean Cleanup. The trawl is a consistent way of measuring plastic waste in rivers, provided that it is applied correctly. The top of the trawl floats on the surface of the river, with the frame attached. The water will flow through the net, and the waste will remain in the net. The frame has an outer dimension of 73 x 73 cm and therefore 73 cm is the minimum depth restriction of the river to be able to use the trawl. The inner dimensions of the frame is 65 x 65 cm. This is therefore the surface through which the water flows with plastic and through which the plastic is captured by the net. The mesh size of the net is 30 x 30 mm. Plastic particles smaller than these dimensions can not be captured by the trawl.

4.2.2. Visual observation

Visual observation was applied to rivers when the waterlevel was too shallow to use the trawl, when the bridge above the river was too high or when the flow velocity was zero. In addition, visual observation was applied at places where the trawl could not be used, such as at a river mouth.

On a bridge

During the visual observations on the bridge, the river was divided in two halves to prevent confusion during counting. At each observation, counting was done by two researchers on the left side and two researchers on the right side. When in doubt, there was contact between the two groups to make sure that a piece of plastic was not counted twice. Counting was always done at the upstream side of the river on the bridge, as there was more time to determine if the object was plastic, organic or something else.

At every river for which a visual observation was applied, counting was done for a period of fifteen minutes. Thereafter the observations from both sides were added up to obtain the plastic discharge of the entire river for that period. To achieve a reliable outcome, four visual observations were carried out, after which an average plastic discharge could be found.

At river mouth

Since a trawl can not be used at a river mouth, it has been decided to perform visual observation within a two-meter strip along the side of the river. The number of pieces of plastic floating through the two-meter strip, along the entire width of the river, was counted. For visual observations at a river mouth, counting was also done for a period of fifteen minutes. These observation were performed four times as well, in order to obtain a reliable average on the plastic discharge of the river.

4.2.3. Embankments

In addition to the plastic discharge, we also looked at the pollution on the embankments. This was done by counting the amount of pieces per square meter. Pictures were taken of the embankments to double check the results afterwards. As some rivers had very high concentrations of pollution on one area, and almost no pollution on other areas, such as river 18 (Appendix A.1), an average was taken. Per river was looked at a total of $10 - 20\ m^2$, after which an average per square meter was taken. The results, then, were ordered in categories ranging from zero to five, with a particular range of pieces per square meter assigned to each category:

- Category 0: 0 pieces per m^2
- Category 1: 1-5 pieces per m^2
- Category 2: 5-10 pieces per m^2
- Category 3: 10-15 pieces per m^2
- Category 4: 15-25 pieces per m^2
- Category 5: 25+ pieces per m^2

4.3. River parameters

In this section, a description is given of how the river parameters were measured, in order to calculate the discharge of the river. This is needed to extrapolate the trawl results to the entire river. The discharge is calculated by multiplying the flow velocity, times the average depth, times the width of the river.

4.3.1. Flow velocity

The flow velocity is determined in a conventional manner, without the use of measuring equipment. As most bridges were too high, the equipment could not reach the water level. Furthermore, debris flowing in the river could possibly come into contact with the equipment, which could damage it. To achieve a reliable value of the flow velocity, the following steps have been taken for each measured river.

First, the width of the bridge is measured with a tape measure. After that the flow velocity is measured. This is done by releasing a piece of wood, noted by the entire team, into the river, upstream of the bridge. If the piece of wood was directly below the upstream part of the bridge, the time measurement was started, using a stopwatch. The time measurement was then stopped when the piece of wood was directly below the downstream side of the bridge. The previous steps were performed four times for each river. After this, an average of the four measurements was taken to determine a reliable flow velocity.

For the rivers where the measurements were made at the river mouth, a different way of determining the flow velocity was used. Here, it was examined how long it took for a piece of plastic to float along a previously set length. These measurements were performed by determining a length along the river of four meters with a tape measure, and by using a stopwatch to keep track of time. The observations, again, were performed four times. By taking an average of the four measurements, an accurate value of the flow velocity was obtained. As the flow contracts at bridges due to the pillars of a bridge, the flow velocity increases. However, the area through which the water flows, thus decreases. The measured discharge at the river will therefore be the same for the entire river.

4.3.2. River width

For determining the width of the rivers, two types of measurements were done. Mainly by using the measuring tape, and secondly by using the measuring function of Google Maps. The latter was done at river mouths and when the river was too wide to use the measuring tape. As the discharge of the river on Google Maps may be different at the point of time the satellite photo was taken, the width of the river may be different too. To validate the width measured on Google Maps, an estimation of the actual river width was made, which was then compared to the width of Google Maps.

4.3.3. River depth

The depth of the rivers was simply measured by using a long rope and a rock. The length of the rope underwater was then noted to determine the depth. This was done on several locations over the length of the bridge. Then, the average of the results was taken, which was used as the average depth. A rectangular river cross section is thus assumed.

4.3.4. Average weight of a piece of plastic

In order to compare the trawl results (measured in plastic flux: kg/h) with the visual observation results (measured in plastic flow: pcs/h), the average weight of a piece of plastic is required. After a trawl session, the total weight of the obtained plastic was determined. After that, the amount of plastic pieces was counted. This was done after every session, for four rivers. This work was done by Van den Haak [2019] and resulted in an average plastic piece weight of 0.027 grams.

4.3.5. Wind velocity

Lastly, the wind velocity at the locations was measured. This was done to determine if there is a correlation between the wind velocity and, either, the plastic discharge or the embankment pollution. For this, a wind velocity gauge was used. This gauge had a range of $30\ m/s$ and an accuracy of 5%.

4.4. Multi-criteria analysis

Once the plastic discharge of the different rivers across Bali is determined, customised solutions can be developed to capture the plastic in these rivers. In order to thoroughly evaluate these solutions, a multi-criteria analysis (MCA) will be performed. The MCA is a method based on the evaluation of a number of alternatives with respect to a number of criteria. The criteria can be quantitative or qualitative. The variety of importance of the different criteria can be considered by assigning weights to every criterion Jacquet-Lagrèze and Siskos [2001]. Different decision makers might value the criteria involved differently. For determining the weights of the criteria, assumptions will be made based on the experiences during the measurements on Bali. The weights will be assigned from the point of view of the regencies since the regencies will have to make the decision to implement these structures and have to use a part of their budget for doing so. A higher weight will be assigned to criteria that seem important from their point of view and lower weights to criteria that seem less important. The results of the MCA can be used by the decision making authority, regency officials in this case, for making a decision with respect to implementing these type of structures.

4.5. Interviewing

Because the research is conducted in Bali, it allows for the local population to be involved in the research. Their involvement is considered by means of interviews. The interviews with local partners will provide insight into the behaviour, attitudes and motivations of local inhabitants that cannot be found in literature. Interviewing also allows for better understanding of the topic from the perspective of the participants [Rosenthal, 2016]. Two interviews are conducted with local partners. One interview is performed with Gede Hendrawan, PhD Marine and Coastal environment of the Udayana University. The second interview is performed with Paola Cannucciari, the Senior Program Manager at a local waste collecting company called EcoBali Recycling. Furthermore, information and data is obtained from Ocean Mimic. Ocean Mimic organises weekly beach cleanups throughout Bali.

5

Results measurements

In this chapter, the results of the measurements are provided and discussed. First, in Table 5.1, the overall results are depicted. Then the plastic discharge of the rivers, the plastics on the embankments and lastly the results of the wind velocity measurements are discussed. Further details about all the measured rivers, including pictures, can be found in appendix A.

Table 5.1: Results of the measurements

River	$[\#]$	1	2	3	4	5	6	7	8
Means	–	Visual	Visual	Visual	Trawl	Visual	Visual	Visual	Visual
Plastic flow	$[pcs/h]$	51	31	22	341	1	1	109	1
Plastic flux	$[kg/h]$	1.4	0.8	0.6	9.1	0.0	0.0	2.9	0.0
Embankments	$[pcs/m^2]$	7	13	22	6	0	6	8	2
Discharge	$[m^3/s]$	4.5	0.8	2.3	104.8	6.5	1.7	2.3	8.1
Wind velocity	$[m/s]$	2.7	1.3	2.1	0.8	0.0	0.4	0.5	1.5
River	$[\#]$	9	10	11	12	13	14	15	16
Means	–	Visual	Visual	Visual	Trawl	Visual	Trawl	Trawl	Trawl
Plastic flow	$[pcs/h]$	1	0	7	1	11	21	33	316
Plastic flux	$[kg/h]$	0.0	0.0	0.2	0.0	0.3	0.6	0.9	8.4
Embankments	$[pcs/m^2]$	9	14	7	6	16	N/A[1]	N/A[1]	N/A[1]
Discharge	$[m^3/h]$	0.9	0.2	2.7	3.6	6.2	0.5	0.5	0.9
Wind velocity	$[m/s]$	2.2	0.5	0.3	0.4	1.1	N/A[1]	N/A[1]	N/A[1]
River	$[\#]$	17	18	19	20	21	22	23	24
Means	–	Visual	Visual	Visual	Visual	Visual	Visual	Visual	Visual
Plastic flow	$[pcs/h]$	154	21	62	83	0	0	5	21
Plastic flux	$[kg/h]$	4.1	0.6	1.7	2.2	0.0	0.0	0.1	0.6
Embankments	$[pcs/m^2]$	10	23	9	8	8	3	0	33
Discharge	$[m^3/h]$	42	10.5	0.3	7.9	3.6	0	0.5	0.3
Wind velocity	$[m/s]$	1.3	1.4	0.9	1.8	2.9	1.1	1.0	0.9
River	$[\#]$	25	26	27	28	29	30	31	Avg.
Means	–	Visual	Visual	Visual	Visual	Visual	Visual	Visual	-
Plastic flow	$[pcs/h]$	16	7	72	3	301	10	14	55.3
Plastic flux	$[kg/h]$	0.4	0.2	1.9	0.1	8.0	0.3	0.4	1.5
Embankments	$[pcs/m^2]$	31	14	5	17	23	38	0	21.1
Discharge	$[m^3/s]$	0.3	0.1	0.9	0	32.6	0.3	0.1	7.9
Wind velocity	$[m/s]$	0.9	1.9	0.2	0.3	3.9	0.3	1.3	1.2

[1]Results from the bachelor students, no data available

5.1. Plastic discharge of Bali's rivers

The results of the plastic discharge of the rivers will be discussed in several subsections. First, the overall results of the rivers will be discussed. Thereafter, the results will be compared with the socio-demographics factors discussed in chapter 2.4.

5.1.1. Overall results

The plastic discharge of the rivers are quite equal over the island, as can be seen in figure 5.1. There are three rivers which stand out from the rest. These are rivers 4, 16 and 29, with a plastic discharge of 341, 316 and 301 pieces per hour, respectively. These rivers flow through, or end up in highly populated areas, which may explain the result. As example, river 16, originates high up in the Bandung regency (IV) and thus has quite a large catchment area, with many inhabitants, before ending up in the Denpasar regency (III). After the three rivers which discharge the most plastic, there are three which discharge between 83 and 154 pcs/h. These are rivers 7, 17 and 20. From Table 5.1 follows that the average discharge of a river is 55.3 pcs/h.

If we neglect the outlier regency $VIII$ from table 5.2 (as it is landlocked), we can see a range of plastic discharge. The average pollution is 63.1 pcs/h per regency. The most polluting regency is the Denpensar (capital) regency (III), with the highest average plastic discharge per river. The least polluting regency is the eastern regency of Karangasam (IX). The highest total plastic discharge is measured in the Jembrana regency (VI). However, it needs to be considered that in this regency 8 rivers are measured while in most of the other regencies only 1 or 2. This makes comparing regencies based on the total plastic flow and drawing conclusions regarding the average plastic discharge more difficult. What does stand out is that the Tabanan regency (V) discharges, on average over five rivers, four pieces per hour, whilst the neighbouring regencies discharge between seven and eleven times that amount. From the six most polluting rivers, two end up in the Jembrana regency (VI), two in the Denpasar regency (III), one in the Klungkung regency and the last in the Buleleng regency (VII).

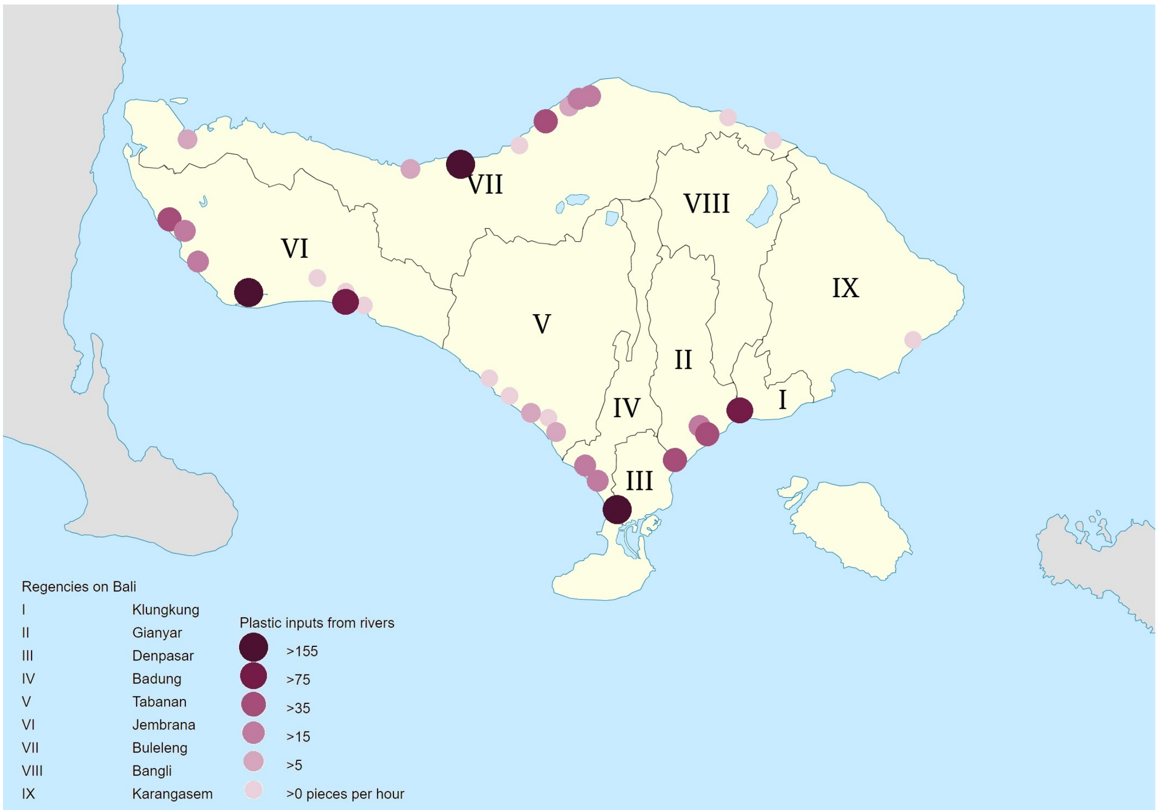


Figure 5.1: Plastic discharge of the measured rivers on Bali

Table 5.2: Plastic discharge of the rivers per region

Regency number	I	II	III	IV	V	VI	VII	$VIII$[1]	IX	Avg.
Number of rivers	1	2	2	2	5	8	10	0	1	31
Avg. plastic flow $[pcs/h]$	83.0	41.5	235.0	27.0	4	69.6	44.9	0	0	63.1
Total plastic flow $[pcs/h]$	83.0	83.0	470	54	20	556.8	449	0	0	245.1

[1]Landlocked regency

5.1.2. Plastic discharge rivers versus the socio-demographics

In this subsection each of the socio-demographic factors will be discussed based on the measurement results.

Income level

The APBD is the annual financial plan of the regional governments which include the income and expenditure budget. In figure 5.2 is shown what the budget of each regency is and a part of this budget should be used for waste management within the regency. As can be seen some regencies have a much higher budget and could therefore also spend more money on proper waste management. Badung, Denpasar and Buleleng have the highest budget. However, some of the most polluted rivers flow through these areas. This could be caused by the fact that the richer the regency, the more people have to spend. The amount of waste that is generated in these areas could therefore also become higher. As a result a larger amount of plastic could end up in the rivers despite the better waste management in these areas.

On the other hand, Jembrana, Klungkung and Gianyar have a much smaller budget and the rivers in these regencies are mildly to highly polluted. This could partially be caused by poor waste management in these regencies. However, the Tabanan regency also has a small budget but the rivers within this area seem not very polluted. Since there is no clear link between the the budget and the extent to which the rivers are polluted for each regency, it cannot be concluded that a higher budget automatically leads to less polluted rivers or a smaller budget to more polluted rivers. It is likely that other factors also play a role in the extent to which rivers are polluted.

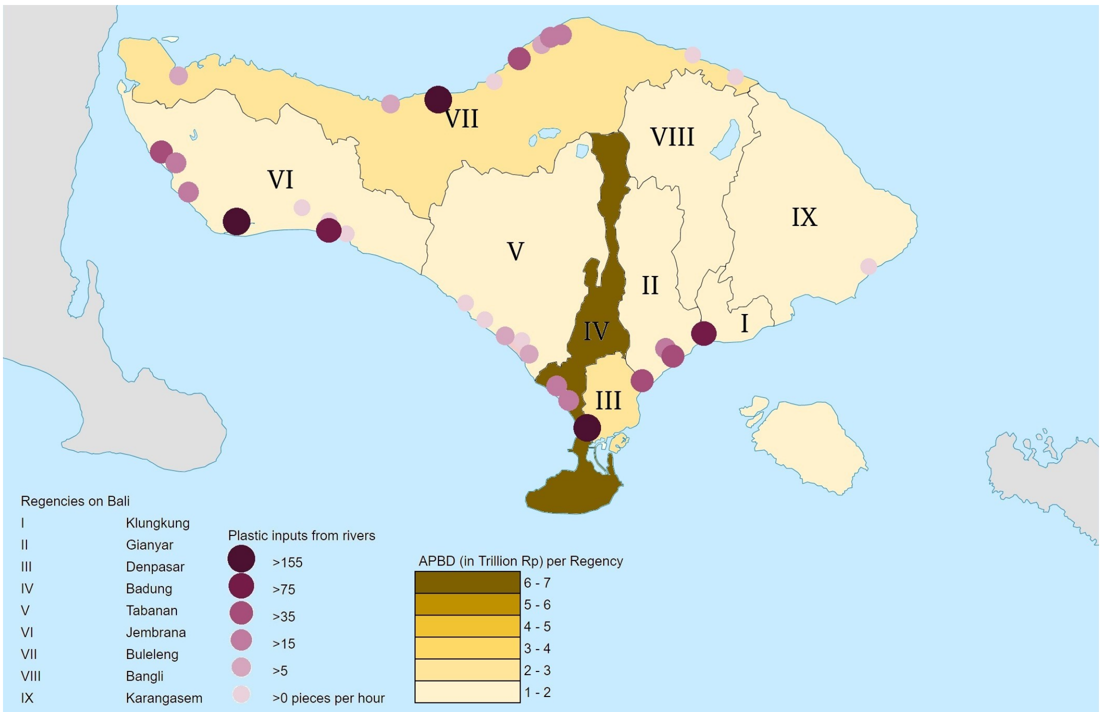


Figure 5.2: Overview of APBD and plastic discharge

Education

In figure 5.3, the school participation for the age group 19 to 24 is compared with the plastic discharge. For the age group 16 to 18, one can find similar school participation in each of the 9 regencies and therefore the school participation of this age group is not compared with the plastic discharge. From tables B.1 and B.4, it can be seen that the top three regencies in terms of school participation for the age group 19 to 24 are also located in the three most densely populated areas, namely Denpasar, Gianyar and Bandung. When the data of these three regencies is compared with the plastic discharge in the rivers, it seems to have a negative effect on each other. However, if one looks at the entire island, the opposite seems to be concluded, as can be seen that in a regency with a low school participation such as Jembrana, many highly polluted rivers occur. Therefore, a clear link cannot be seen between school participation and the plastic discharge.

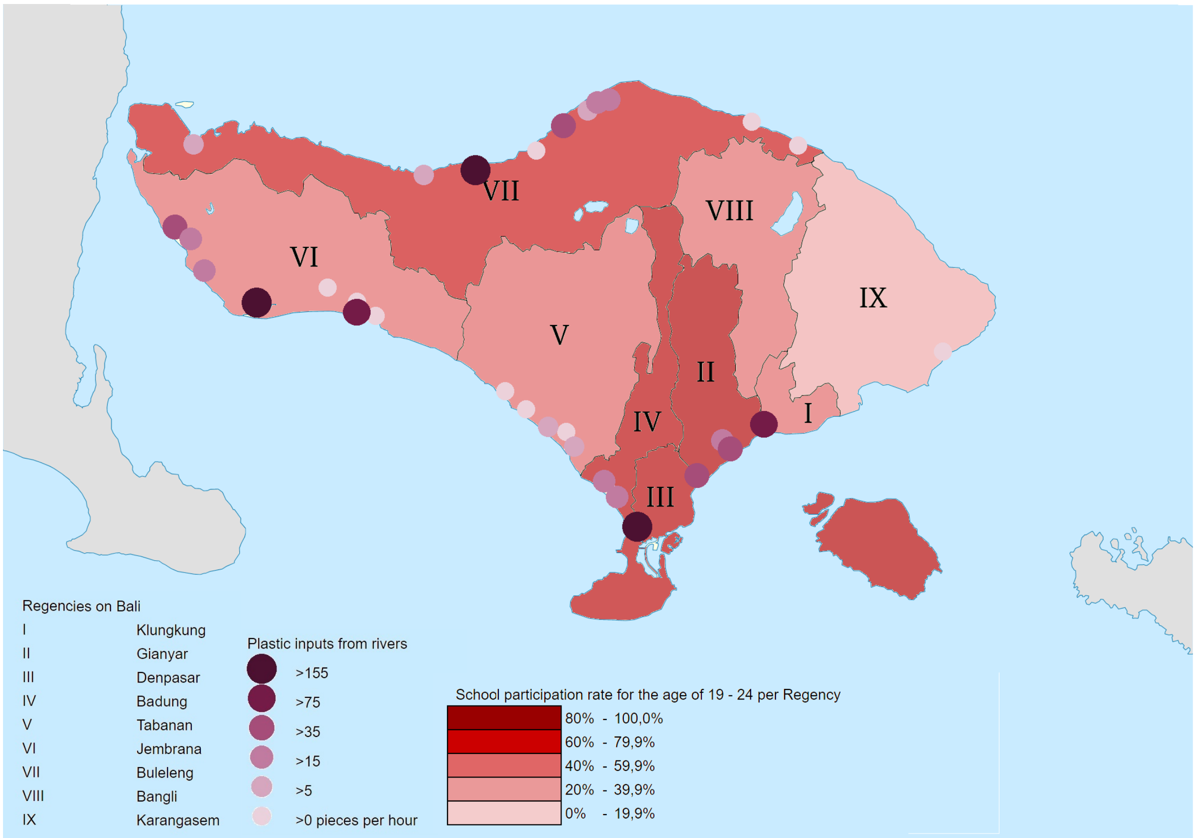


Figure 5.3: Overview of 19-24 age school participation with plastic discharge

Religions

Figures 5.4 and 5.5 show the percentage of the Hindu and Muslim population respectively in Bali's regencies. In both figures, the occurrence of both religions are compared with the plastic discharge in the rivers. As can be seen in figure 5.4, no link can be directly seen between Hinduism and plastic discharge. The same applies to figure 5.5, no link can be seen between the occurrence of Muslims and an increased plastic discharge.

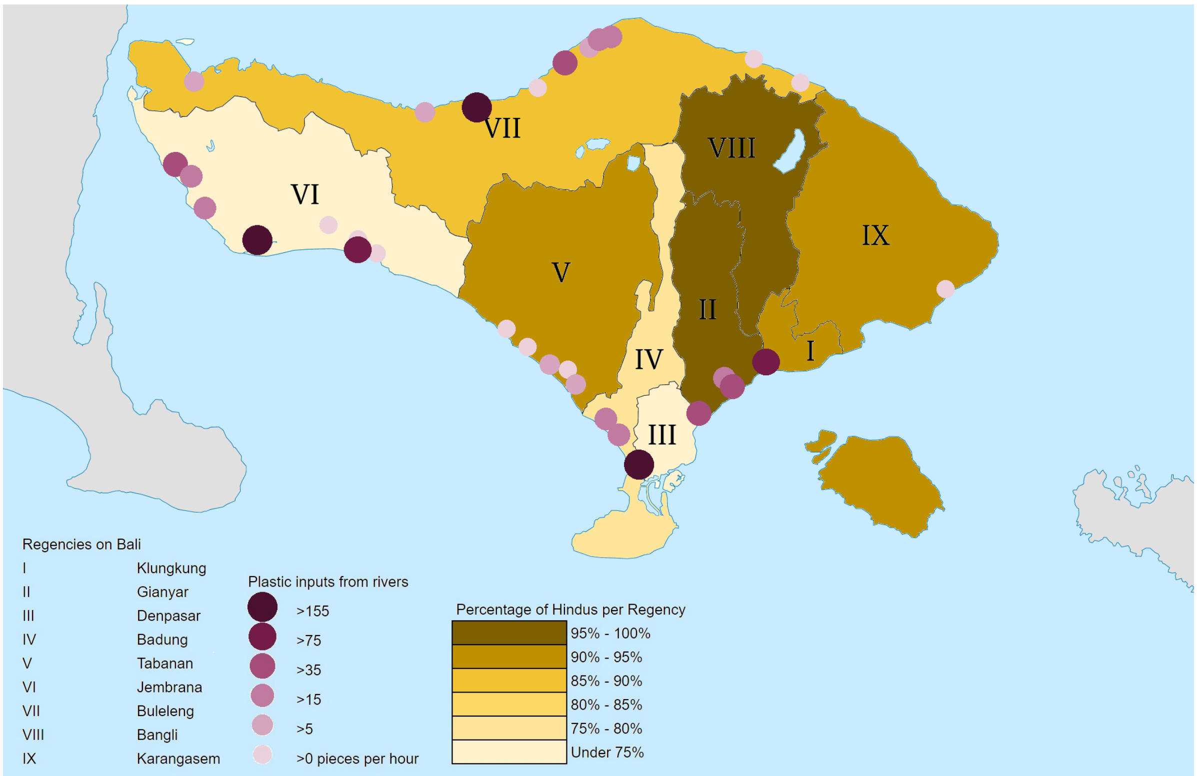


Figure 5.4: Overview of Hindu with plastic discharge

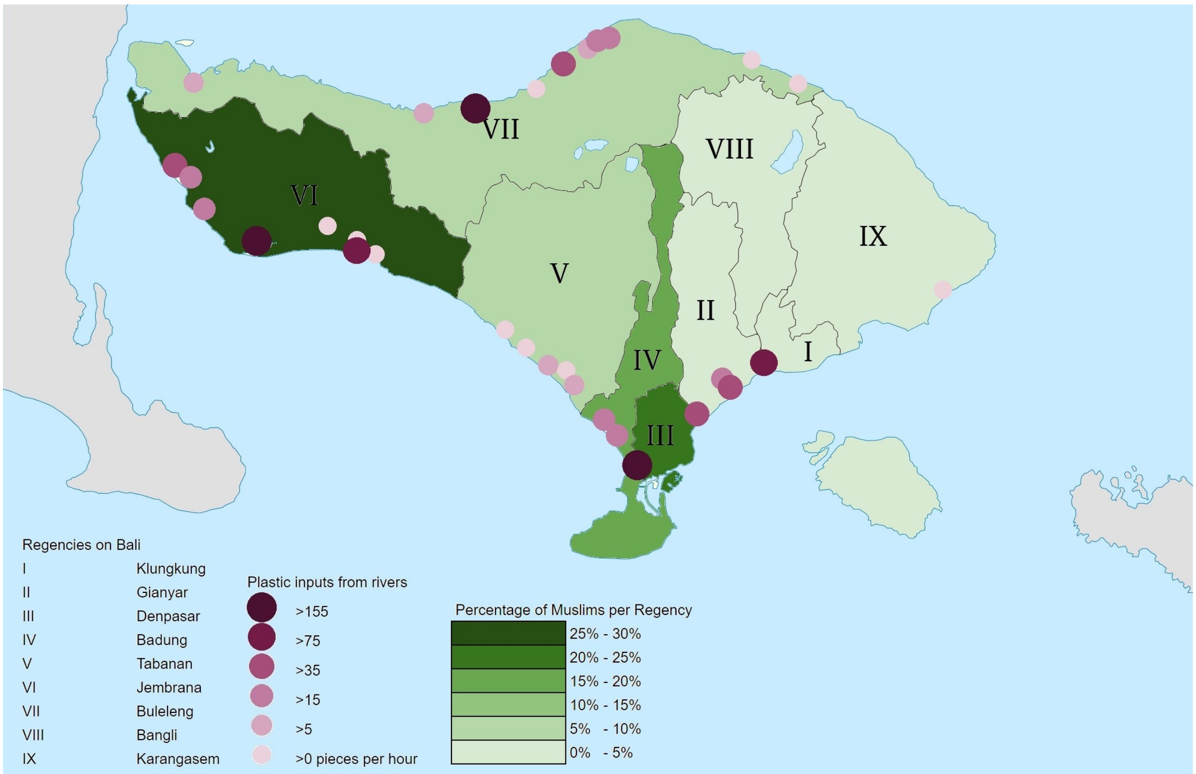


Figure 5.5: Overview of Muslim with plastic discharge

Landfills

Figure 5.6 shows the locations of the landfills of each regency with a star. As mentioned before, each regency only has one landfill, with the exception of Badung which uses the landfill located in Denpasar. Two of the most polluted rivers that are measured, rivers 16 and 29 in respectively Denpsar and Buleleng originate deep inland. The areas where these rivers flow through are relatively far away from the landfills of these regencies. It is therefore possible that waste is dumped in these rivers by trucks from pick-up services in the areas inland. However, another of the most polluted rivers, river 4 in Jembrana, flows relatively close to the landfill. It would therefore be expected that waste is not dumped here by trucks for which the landfill is too far away and the river might thus be less polluted. The high amount of waste in this river could however be explained by other factors such as that it flows through a very densely populated area. A clear link between the most polluted rivers and the location of the landfill within a regency can thus not be found.

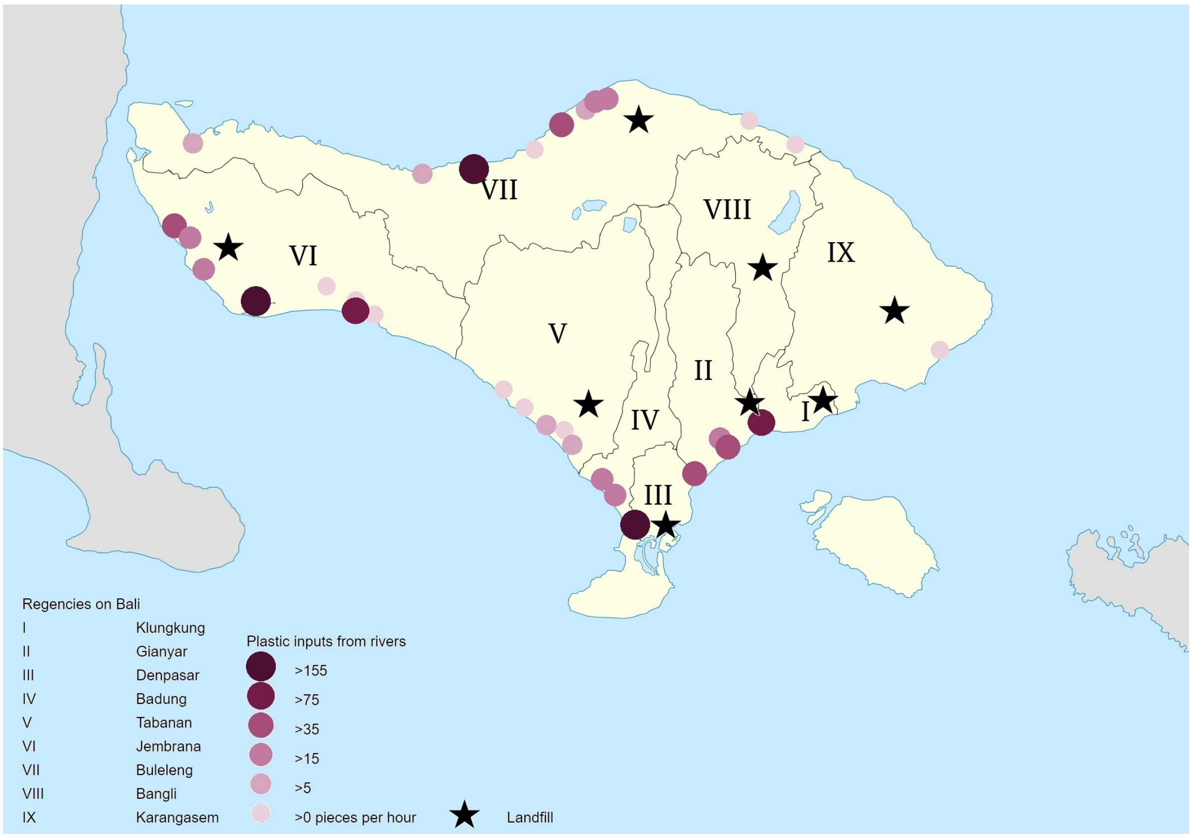


Figure 5.6: Overview of landfills and plastic discharge

Population density

Figure 5.7, shows the population density with the plastic discharge in the measured rivers. Denpasar, the capital of Bali, has the highest population density. In addition, Gianyar and Bandung are also very densely populated areas. Highly polluted rivers are found in these three regions. Because an average population density over the complete regency has been taken, it is not immediately clear that there is a connection between plastic discharge and population density. However, from our observations it can be stated that the more polluted rivers are in densely populated areas. For example, river 4 is heavily polluted because it flows through the city of Negara and river 29 because of the city of Bubunan.

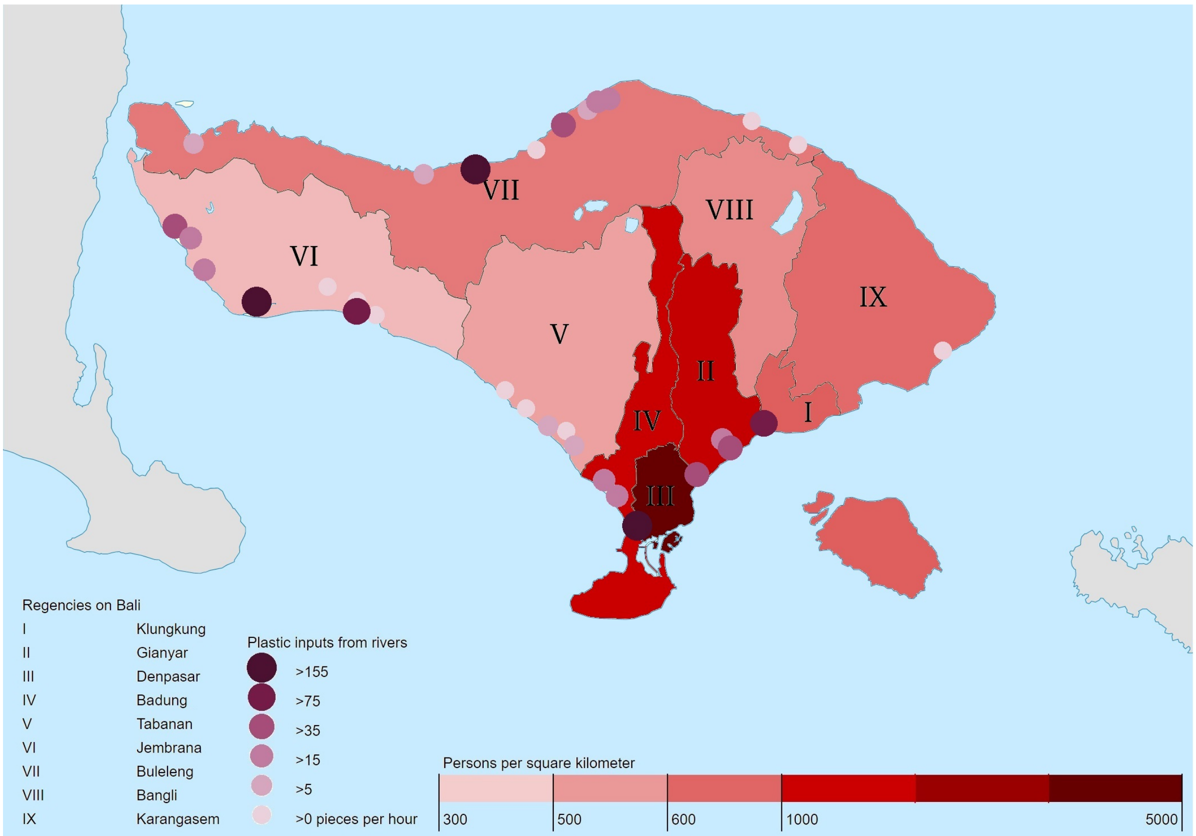


Figure 5.7: Overview of population density with plastic discharge

5.2. Embankments

5.2.1. General

Figure 5.8 shows the categories of the embankments of the measured rivers. Unfortunately, there are no results from the Bandung and Denpasar regency, as there the measurements were taken by the Bachelor group who did not look at the embankment pollution. In addition, as said regencies are densely populated (see Fig. 2.8), the rivers are canalised, with near vertical walls, thus no plastics can get stuck on the embankments. As can be seen, the Buleleng regency has the most polluted embankments, followed by the Gianyar and Tabanan regencies. This can be explained by the lack of waste management service in the regencies. In the other regencies the pollution is more or less equal.

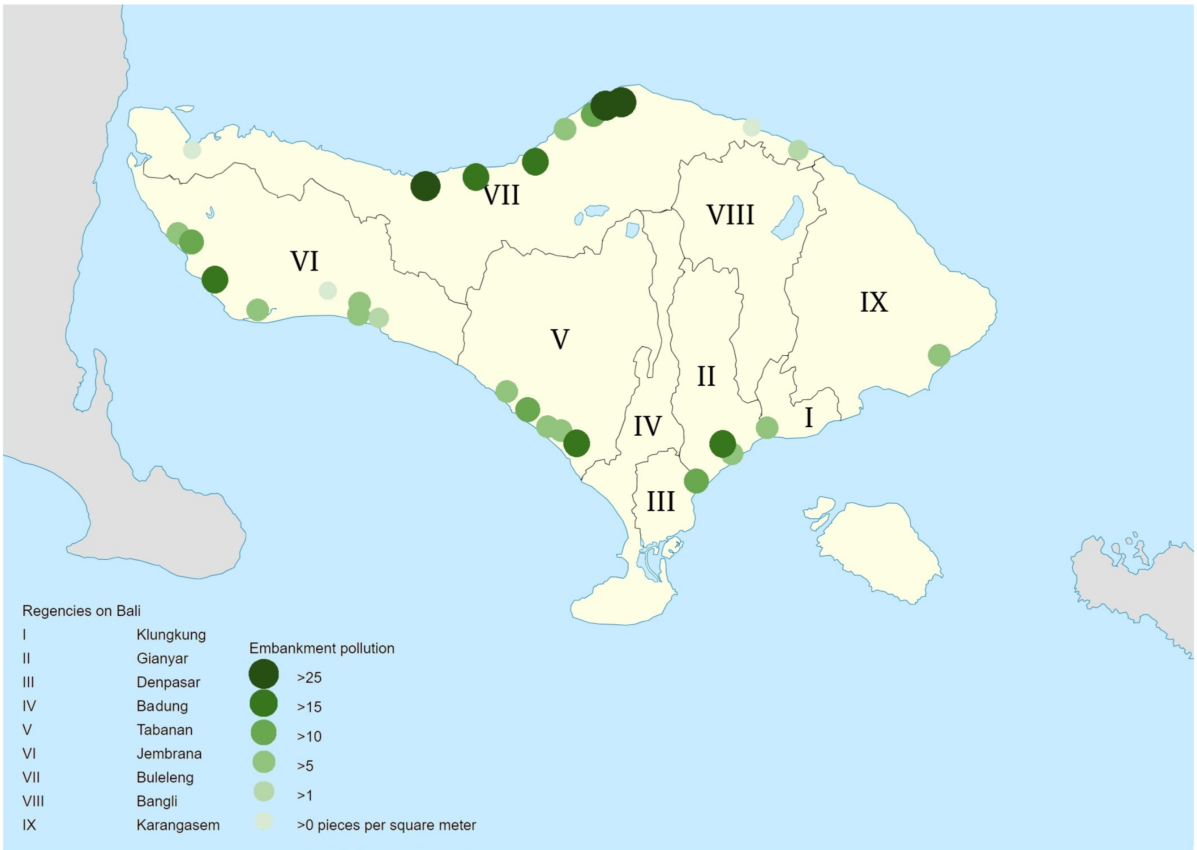


Figure 5.8: Plastic pollution embankments

However, these results should be handled with care. Although, bridges are the main spot of dumping plastic on the embankments, these measurements were taken on a single, local, part of the rivers. Upstream or downstream of the locations, either at a different bridge or at the embankments, a total different result can be found.

5.2.2. Comparison embankment pollution landfills

Figure 5.9 shows the location of the landfills of each regency with a star. Each regency has only one landfill, expect for the Bandung regency which uses the landfill in Denpasar. Although rivers 24 and 25 are close to a landfill, both rivers have highly contaminated embankments. The same applies to rivers 3 and 13. According to the figure 5.9 that comes from the data and literature, it seems that as the distance to the landfill decreases, the embankments become more polluted. One reason for this might be that waste is dumped illegally into the riverbanks and in the nature from the trash trucks, but this cannot be said with certainty.

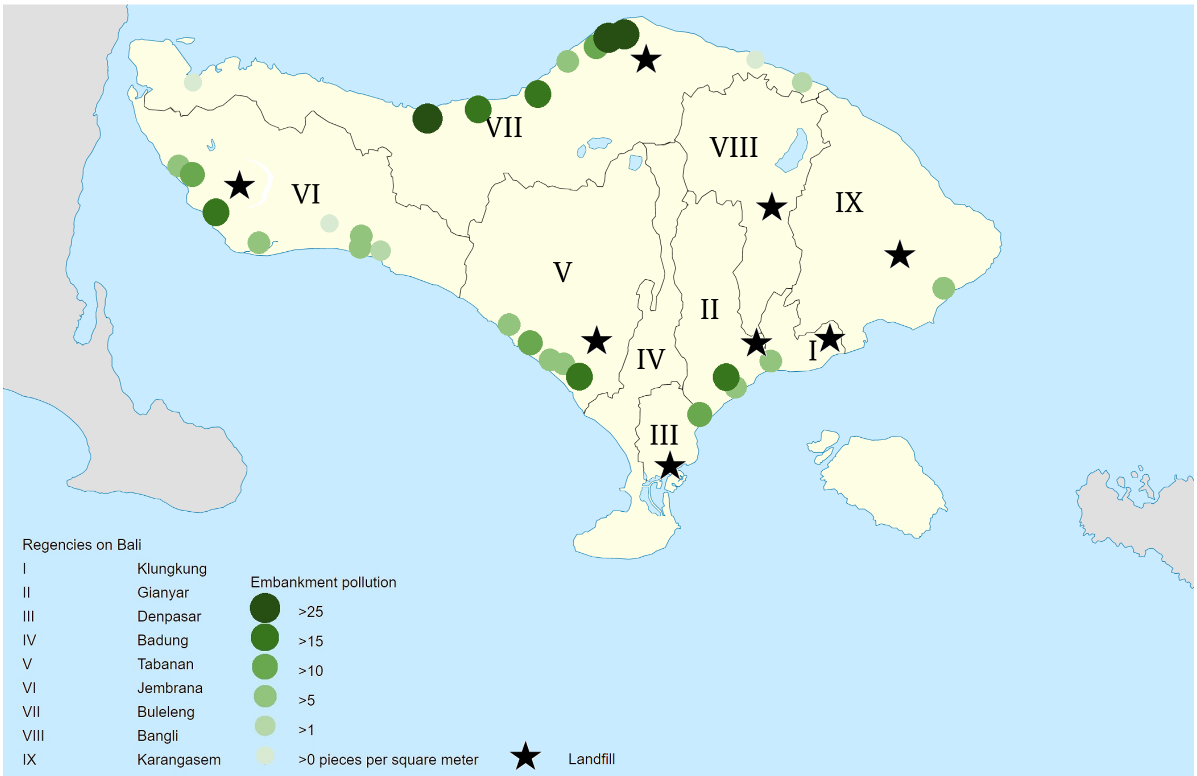
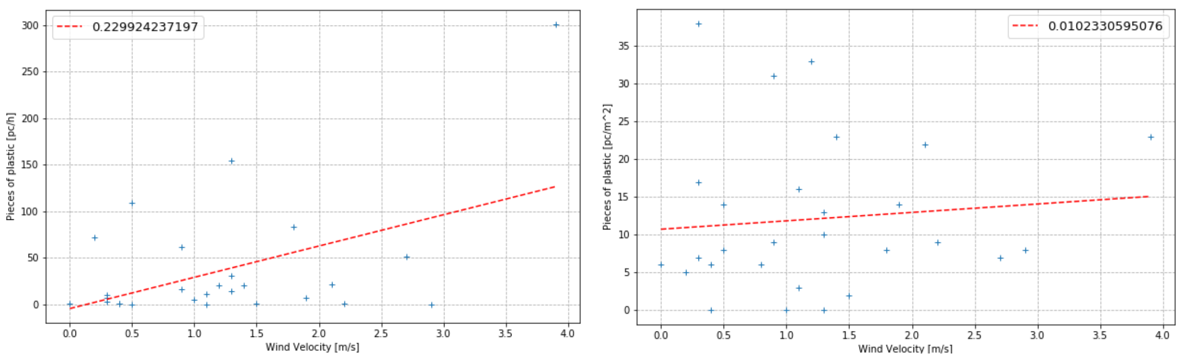


Figure 5.9: Landfills compare with embankments

5.3. Wind velocity

To analyse if the wind velocity has an influence on the plastic discharge of the rivers, we measured the wind velocity at the rivers. As the used the plastic flow from three rivers from the bachelor group, no data of the wind velocity is available for rivers 14, 15 and 16. In Figure 5.10a, the wind velocity is plotted against the plastic discharge of the rivers. The coefficient of determination, R^2, is found at 0.23, if the outlier of the only trawled river is removed. This (somewhat biast) result, still shows that the correlation is very small.

In addition, the correlation between the wind velocity and the embankment pollution is researched. As wind moves the plastic debris to the rivers, one can expect that, if the wind velocity increases, the amount of plastic on the embankments also increases. However, following this logic, the plastic debris could then end up in the river directly. Figure 5.10b show the results of the wind velocity vs the embankment pollution. Again, the coefficient of determination, R^2, is very low, at 0.010.



(a) Wind velocity vs plastic discharge

(b) Wind velocity vs embankment pollution

Figure 5.10: Results wind velocity measurements

From the results of Figures 5.10a and 5.10b, it can be concluded that no correlation can be found between neither the wind velocity and the plastic pollution, nor the wind velocity and the embankment pollution, on Bali. This can be explained by the fact that most of Bali is covered by forests, and thus at the location of the measurements, there are large palm trees blocking the wind. The wind velocity was therefore quite low, and always close to $1\ m/s$. For other, larger, rivers, such as the lower Rhine, where there are less trees nearby, the results may differ.

6

River clean-up solutions

Chapter 3 proposes several solutions to mitigate the plastic problem on Bali. However, these are mostly long term solutions. A short term solution that is proven to be effective is therefore looked at in more detail, namely river clean-up solutions. These solutions help to prevent the plastic from entering the oceans through the rivers. With the plastic discharge across the different regencies now known from chapter 5, customised solutions can be developed for different rivers and regencies. From the results in chapter 5.1 it can be concluded that two types of rivers need to be tackled. Namely, rivers with navigation and rivers without navigation. River 4 in the Jembrana regency is a wide estuary with navigation, which means that a closed water structure cannot be implemented in this river. The other, smaller, rivers have little to no shipping. In these rivers, closed water structures are possible to implement.

6.1. Structures

To mitigate the plastic discharge from the rivers into the ocean, it is necessary to have structures in the polluting rivers to capture the waste flow. Although structures are already present in some rivers, they have little effect on a clean ocean around Bali. According to the interview with G. Hendrawan (appx. C.1), the advantage of the existing structures found on the island is that they cover the complete width of the river, and as a result, a large amount plastic is withheld and collected. After researching possible structures, a list of potential structures is made. These structures can be found in table 6.1 and table 6.2. The structures are placed in different tables for different categories, namely open rivers and closed rivers. Open rivers are rivers where navigation needs to be possible and closed rivers are rivers without navigation. The existing structures are also included in the possible solutions. Because the problem in the rivers is very large and action must be taken in the short term, the structures in the concept phase or development phase will not be included in this study. Below, the structures, as found in tables 6.1 and 6.2, will be briefly explained.

Table 6.1: Closed water structures

Structures	Name	Website
Str. 1	Existing structure	-
Str. 2	Recycled island/Bandalong Litter Trap	www.bandalong.com
Str. 3	Mr. Trash Wheel	www.baltimorewaterfront.com
Str. 4	Shoreliner	www.tauw.nl
Str. 5	Drainage nets	www.boredpanda.com/drainage-nets-catching-trash-kwinana-city/
Str. 6	Trash trap	www.anacostiaws.org/

Table 6.2: Open water structures

Structures	Name	Website
Str. 2	Recycled island/Bandalong Litter Trap	www.bandalong.com
Str. 4	Shoreliner	www.tauw.nl
Str. 7	SEADS	www.impakter.com/seads/
Str. 8	Trash Skimmer Vessel	www.apexenvirocare.com.au/dredging-sales/mud-cat-trash-skimmer-vessels.html

6.1.1. Closed river structures

Most rivers on the island do not experience any navigation. They can, thus, be closed off completely by a structure, which is the most effective solution to mitigate the plastic problem in the rivers. Several structures are found for this type of river, and are discussed below.

Existing structures

Currently, there are two structures in place in Bali to catch plastic and other waste in the rivers. One is located in the Mati river and one in the Badung river, in the Denpasar and Badung regency, respectively. These structures cover the entire width of the river and can be opened in the case of high (debris) discharges, during the rainy season. The structure in Denpasar (fig. 6.1) has a complicated design, while the structure in Badung is simpler, though still expensive. Therefore, only Badung and Denpasar can currently afford to built these kind of structures in the rivers, as mentioned by G. Hendrawan in the interview (appx. C.1). Although these structures seem quite robust, both are out of commission for some years now, and do not show any sings off being repaired [DenPost, 2016].

The first existing structure (fig. 6.1), works by catching the trash onto the metal 'fences'. The debris, then, is transported upward, and dropped onto a conveyor belt, which runs along the entire width. This conveyor belt ends-up at a garbage container, where the trash is collected. The structure is located in river 16, which had a plastic discharge of $300+\ pcs/h$. In addition, several nets are placed along the river to catch the waste flow. The second existing structure (fig. 6.2) works in a similar way, without the automated trash removal system. It collects the debris on the metal 'fences', however, these fences are not automatically cleared, it needs to be done by hand.

As the second existing structure is similar to another, ensuing structure, it will be left out. Henceforth the first existing structure is simply referred to as the existing structure.

Figure 6.1: Existing structure 1 on river Tukad Mati (source:maps.google.com)

Figure 6.2: Existing structure 2 on Bangdung (source:maps.google.com)

Bandalong Litter Trap or Recycled Island

The Bandalong Litter trap is a smart solution to collect floating waste in the rivers. As can be seen in figure 6.3a, waste is directed to the device via the floating arms that are connected to the quay. The trash is trapped by a one-way gate. If the waste is in the device, it will be held until the waste is collected. This solution is suitable for rivers and streams wider than 2 meters. The Bandalong Litter Trap works silently and does not need any mechanical assistance. Another benefit is that it does not cause any upstream flooding. This design is similar to that of the Recycled Island, and is therefore named synonymously in this paper.

This structure can also be used as an open water structure. However, the arms need to be removed and the structure must be attached to the river bottom, so that the device cannot move due to the water flow. In this way navigation is not hindered by the structure, because they can sail around it. The effectiveness of the structure does decrease however.

(a) Bandalong Litter Trap

(b) Mr. Trash Wheel

Figure 6.3: Floating device structures

Mr. Trash Wheel

Mr. Trash Wheel (fig. 6.3b) is a structure that has been implemented in the harbour of Baltimore since 2016. It uses the natural flow and solar power to collect the trash. Using (plastic) floating arms, it collects the trash in front of the structure, much as the previous structure. However, the difference is that Mr. Trash Wheel uses solar power and the river current to elevate the trash into a (higher) container. It can therefore collect more trash than the Bandalong Litter Trap, before having to be emptied.

Shoreliner

The Shoreliner (fig. 6.4a) is quite similar to the Bandalong Litter Trap. It also has arms which float on the water in order to collect the trash into the structure at water level. The main difference is that the arms of this structure are, normally, longer. They extend much further to the sides of water bodies. They are, thus, especially helpful for areas where trash can get stuck between plants and in mangrove forests.

(a) Shoreliner

(b) Example of a drainage net system

Figure 6.4: Debris catchment structures

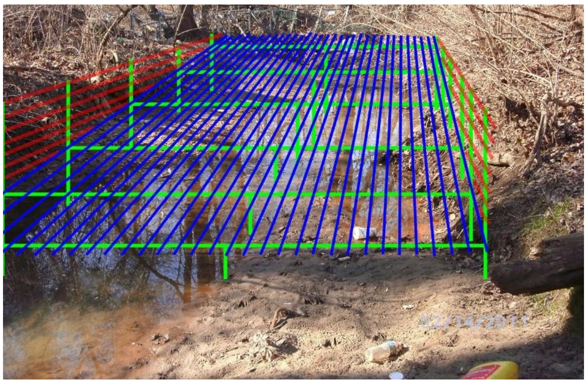
Drainage nets

Drainage nets (fig. 6.4b) are placed around holes of concrete structures, which completely close-off a river. The discharge, then, has to flow entirely through the structures and through the nets, thereby collecting trash. When the nets are full, they either can be opened on the back-side, or taken off completely, to collect the trash. During peak events, this can happen quite quickly. As a consequence an enormous strain can occur on the nets and the nets can tear off. Another drawback is the mesh size of the nets. If taken too small, the water discharge cannot flow through the accumulated trash anymore. If taken too large, smaller particles, such as straws, can just flow through the nets, and end up in the oceans.

Trash trap

The Trash Trap (fig. 6.5a and 6.5b) has a simple design, similar to the second existing structure in the Badung river. However, this structure also has the advantage that the sides are closed off. This prevents any debris falling off, off the sides. The main structure is placed under a small, upward sloping, angle. This ensures that if there is a larger discharge, there is enough space on the structure to spread out the debris. In addition, this creates more space for the water to flow through. This helps to prevent that the debris will block the water flow and create upstream floods. The structure still has to be made robust, to withstand the large forces that peak discharges can offer. If it is known that the river has a large trash discharge, it can simply made longer, with higher side fences to accommodate the higher debris discharge. When it is full, though, it has to be emptied manually.

(a) Trash Trap



(b) Trash Trap

Figure 6.5: Debris catchment structures

6.1.2. Open water structures

Rivers that do experience navigation cannot be closed of completely. Open water structures are therefore required.

SEADS

The Sea Defence Structure (SEADS) is an interesting structure, as it does cover the complete width of the river, but does not cut it off completely, thus navigation is not hindered. By using two or more, partly overlapping, walls, which are placed diagonally in the river, trash will end up in a trash catchment area (upper right section of fig. 6.6). This catchment area can even be automated to completely make the structure autonomous.

As this structure might be implemented in a tidal river, the waste can flow into two different directions, during the different tidal phases. The structure can handle this by the implementation of two catchment areas on the opposing sides of the river and structure. The structure can also be opened in case of emergency situations [Dalmonte, 2018]. The structure has one drawback, not only does it capture the drifting trash, it also entraps the sediment flowing in the river. Maintenance dredging will probably need to be done and downstream erosion can be expected.

Figure 6.6: Sea Defence Structure (SEADS) (source:www.seadefencesolutions.com)

Trash Skimming Vessel

The trash skimming vessel is essentially the same as Mr. Trash Wheel, with the exception that it moves about in the harbour or river. It is piloted by one or more persons, who navigate the vessel towards the trash. The trash is, then, scooped up with a conveyor belt, into a container. These vessels are widely used around the globe and can handle larger objects, such as logs and tires [M.C.I., 2018]. Due to the on water mobility and over land transportability, the vessel can be implemented on several locations, when needed most.

(a) Mud Cat skimming vessel

(b) Qingzhou Julong Envir. Tech. skimming vessel

Figure 6.7: Skimming vessels

6.2. Multi-Criteria Analysis

In order to give advise about which structures from the selection can be best implemented in the rivers, it was decided to use a multi-criteria analysis (MCA). The criteria are given a factor on a scale from 1 to 5. A factor of 1 being the lowest score and a factor of 5 the highest. In total, six criteria are used to analyse the different structures. The decision to use these six criteria is made from the importance found from literature study and observations during the project. These six criteria will each have a certain weight, as some can be more important than others. As mentioned in section 4.4 the weights are conducted from the point of view of the regencies. The total weight of all criteria will add up to one. These criteria, and their weight, will be briefly discussed below, after that the outcomes of the MCA will be discussed.

6.2.1. Criteria

Installation costs - weight: 0.15

As the regencies do not get any money from the Indonesian government to pay for the structures, they need to finance them themselves. Most of the income of the regencies comes from tourism, thus some regencies, as the Denpasar and Badung regencies, have more money to spend. However, some of the most polluting rivers are in the more remote regencies, where tourism is far less, which means they have less money to spend on the problem. Therefore, the installation costs of a structure, which include the material and fabrication costs, is an important factor. A weight of 0.15 is assigned to this criteria.

Active/passive - weight 0.1

This criterion is about if the structure can operate autonomous or needs constant human guidance. Most of the structures do not require much specialisation, other than collecting the trash from the structures. Some structures do require more specialisation, as the existing structures and Mr. Trash Wheel. As manual labour is relatively cheap in Indonesia, this criterion has a weight of 0.1.

Durability - weight: 0.2

The durability is defined by the tendency to break down and by the repair costs. Some structures have many moving parts that can get damaged. These moving parts can be expensive to repair and may need a specialised labourer to come in and repair the structure. This can lead to downtime or even, when it does not get repaired, to a structure which does not work at all. Therefore this criterion has a weight of 0.2.

Versatile - weight: 0.1

If a structure can be easily implemented in different rivers, without having to do many modifications to the design or components, the costs of a structure can be significantly less. Therefore, it is looked at if a structure is widely applicable, as regencies can buy them in bulk and only a few people have to be educated on how they work. This is opposed to regencies having to buy different structures to suit their different rivers.

Peak discharge - weight: 0.2

Most of the pollution on the beaches comes during the rainy seasons, as the majority of the trash, which has accumulated on the embankments during the dry season, goes downstream at once. This was made clear by figure 2.2, where in December values of up to $680\ kg$ were found on one beach in a single day. Therefore it is important that the structure is able to withstand these peak (pollution) discharges. If the structure cannot handle the high discharge, or even fails completely, it receives a lower mark for this criterion. As the peak discharge gives the highest nuisance, the criterion receives a weight of 0.2.

Effectiveness - weight: 0.2

Lastly, it is looked at if a structure collects the waste over the entire depth, as some structures only collect the waste which floats on the river. Some waste will, then, still discharge in the ocean and on the beaches. As this does not mitigate the entire problem, the effectiveness of a structure is quite low. Therefore, this criterion receives a weight of 0.2.

6.2.2. Results MCA closed river

First, we look at the structures which can be implemented in the rivers that can be closed off completely, which is the vast majority of the rivers on Bali. See table 6.1 for their respective names and websites. In table 6.3, the results of the MCA are given. The reasoning behind the grading will be explained below.

Table 6.3: Results MCA - closed river

Criteria	Weight	Existing Str.	Bandalong Trap	Trash Wheel	Shoreliner	Drainage nets	Trash Trap
Installation costs	0.2	1	4	2	3	2	5
Active/passive	0.1	5	4	4	4	3	3
Durability	0.2	2	4	2	4	2	3
Versatile	0.1	2	5	5	5	3	4
Peak discharge	0.2	4	1	2	1	1	4
Effectiveness	0.2	4	2	3	2	5	4
Total score	1	2.9	3.1	2.4	2.9	2.6	3.9

Installation costs

The existing structure scores the lowest, as it is by far the most expensive solution. It has many moving parts which have to be specifically designed for the structure. The Bandalong Litter Trap and the Shoreliner do not have any moving parts, they are merely floating containers with arms to catch the trash. Mr. Trash Wheel does have moving parts, thus scores lower than the previous two. For the drainage nets, concrete structures have to be build first in the rivers. As they have to be dimensioned for the peak discharges, they need to be quite large. The Trash Trap consists merely of steel rods, woven together as rebar, which is a very inexpensive solution and therefore scores best.

Active/passive

The existing structure may need one person who checks the current discharge of the river and the trash. The angle of the structure, then, can be adjusted accordingly. The rest of the structure, including the trash removal, is autonomous and therefore scores high. The Bandalong Trash Trap, the Shoreliner and Mr. Trash Wheel score quite high, as the trash just flows naturally into the structure. However, they score lower than the existing structure, as the traps are fairly small, and the trash has to be removed by crane, thus some personnel is needed. With the Trash Trap the trash flows also naturally into the drainage nets and onto the structure. However, it also still needs personnel to remove the trash.

Durability

For durability the existing structure scores low. The design seems to be quite sturdy, however, the structure has been out of operation for three years now and is apparently too expensive to repair. The Bandalong Litter Trap and the Shoreliner are, as mentioned above, sturdy, steel containers, which are hard to break and less expensive to repair. Mr. Trash Wheel has many moving parts, which can break easily and can be expensive to repair, and thus scores low. The drainage nets can rupture if they come in contact with sharp objects. Since they have to be made by hand, they can be expensive to repair. The Trash Trap has a robust design, and since it consists mostly of metal rods, it is relatively cheap to repair.

Versatile

With all its moving parts and sections, which have to be designed individually for different widths of rivers, the existing structure is not versatile, however, the design can be adjusted. To implement the Bandalong Trash Trap, the Shoreliner and Mr. Trash Wheel in different rivers, only the dimensions of the arms have to be adjusted, which can be cheaply done. The structures themselves do not have to undergo any alterations. The drainage nets and the Trash Trap do have to be adjusted for different widths of rivers, and their respective discharges. However, due to the simple design of the Trash Trap, it is cheap to do. The sizes of the drainage nets' concrete casings differ per river.

Peak discharge

The existing structure cannot handle the peak discharges. This is made clear by the ability to lift the trash retainment sections out of the water, as not to hinder the flow. That being said, the floating structures certainly cannot handle the peak discharges this island has to offer, the trash storage capacity of Mr. Trash Wheel, however, is larger than the other two, and therefore scores a bit higher. Only if the drainage nets are dimensioned to the peak discharge, they could withstand the force the water and the trash has to offer, however, this would mean using very expensive materials. If the Trash Trap is designed accordingly, it could withhold the peak discharges.

Effectiveness

This criterion is about the effectiveness of the structures over the width and depth of the structure, over the river. The existing structure covers the entire depth and width, however, as mentioned before, the retainment sections can be lifted out of the water when the discharge gets to high. The floating structures, obviously, do not cover the entire depth of the rivers, thus score low. As the entire discharge has to flow through the drainage nets, it scores the highest. The Trash Trap does cover the entire depth, only if a river overflows, and goes outside its normal boundaries, the structure is less effective.

6.2.3. Results MCA open river

As some rivers on Bali cannot be closed off completely, such as the tidal river 4, structures are compared which still leave space for shipping. However, some structures will be discussed which are also included in the section where the river is closed off completely. Small changes will be made to those structures, which can be read in section 6.1.1. In Table 6.2, the results of the MCA are depicted for the rivers which needs to stay open for shipping.

Table 6.4: Results MCA - open river

Criteria	Weight	Bandalong Trap	Shoreliner	SEADS	Trash Skimming Vessel
Installation costs	0.2	4	4	2	2
Active/passive	0.1	4	4	5	1
Durability	0.2	4	4	4	2
Versatile	0.1	5	5	3	5
Peak discharge	0.2	1	1	4	1
Effectiveness	0.2	2	2	5	2
Total score	1	3.1	3.1	3.8	2.0

Installation costs

For the open river structures, both Bandalong Litter Trap and Shoreliner scores the best. The Shoreliner is a relatively simple structure compared to the other three structures, as seen as the structure does not consist of any moving parts. Both structures will be cheaper if ordered in bulk. The SEADS structure is more expensive, as seen as concrete structures needs to be built in de river. A trash skimmer vessel is an expensive piece of equipment to clean the river.

Active/passive

SEADS scores the best for this criteria, as seen as there will be a continuously waste stream leaving the river to recycle the waste. Therefore, nobody will have to be present at this structure. Both Bandalong Litter Trap and Shoreliner score again the same. These structures sometimes need to be checked to see if the bin is full. The Trash Skimmer scores poorly because it is necessary to have someone operate the device. If no one is available, no plastic will be taken from the river.

Durability

The Bandalong Trash Trap and the Shoreliner are rigid steel containers that are hard to break and not expensive to repair. Because the SEADS is relatively simple and mainly consists of a concrete structure, this structure will last a long time as long as the concrete is of good quality. Because the Trash Skimmer Vessel consists of many moving parts, because the machine has to move through the river, causes a high probability that the machine can break. This makes this machine scores low.

Versatile

Bandalong Litter Trap, Shoreliner and Trash Skimmer vessel score very well, because it will not have to be designed per river. However, the Bandalong Litter Trap will have to be adjusted, because the arms cannot be attached to the quay, but will have to be anchored to the river bottom. SEADS will have to be redesigned for every river, since every quay is different and every river has a different width.

Peak discharge

Because the Bandalong Trap and Shoreliner cannot cope well with large plastic discharge, these structures scores low. The waste bins of both structures will filled up very quickly. Because it is not convenient if several vessels sail on the river, little plastic will be extracted from the river if there is a peak discharge. For this reason, the Trash Skimming vessel also scores low for peak discharge. Only SEADS score well, among other things that a continuous drain of plastic and waste has been realized in the design of this structure.

Effectiveness

This criterion is about the effectiveness of the structures over the width and depth of the structure, over the river. SEADS covers the entire depth and width, for this reason this structure scores highest. The floating structures, All floating structures score low, since they basically only clean up the surface of the river, and only a small part compared to the full river width.

6.2.4. Conclusion of structures

From table 6.3 and 6.4, an advise can be derived about which structures are most suitable to be implemented in the rivers on Bali. For the rivers which can be closed off completely, the Trash Trap would be the best structure, which consists of metal bars and rods, under a slope, where the trash accumulates on top, and the water can flow through. This simple and versatile design, can be implemented in all rivers, with a low price tag. Thus even the regions where there is less income of the tourism tax, the structure can still be a very good solution to mitigate the plastic problem.

For the rivers which cannot be closed off, the best solution of the MCA is much more expensive. For the open rivers, the Sea Defence Solution (SEADS) seems to be the best structure. This is due to the fact that it does cover the entire river width, and its depth, but does not closes it off for navigation. It also uses the flow of the river to naturally collect the trash, for both ebb and flood flow. Thus trash in both flow directions can be caught.

6.3. Redesign of Trash Trap

Although, the Trash Trap scores the highest in the MCA for the closed rivers, it is advised to alter the design of the structure. This has two reasons, firstly the peak discharge and secondly the effectiveness of catching smaller plastic pieces. As the design stands now, even if strengthened, it will probably fail under peak discharges. This because the mesh size chosen to withhold the debris flowing in the river. If a small mesh size is chosen, a lot of debris is withheld by the structure, increasing the strain on the structure. If a larger mesh size is chosen, the strain will be less, and thus the structure has a higher chance of surviving peak discharges. However, this brings us to the second problem, the effectiveness of catching the smaller plastic pieces. If a larger mesh size is used, more plastic pieces will flow through and still end up in the ocean. What is proposed is to build two, or more, Trash Traps, in series, per river. Each structure will have a smaller mesh size, starting upstream. This results in less strain on the structure(s), because the debris load on the structures will be divided over the structures, and the ability to still catch the smaller plastics. Two renders have been made of a fictitious river with the Trash Traps. They can be found below in figures 6.8 and 6.9.

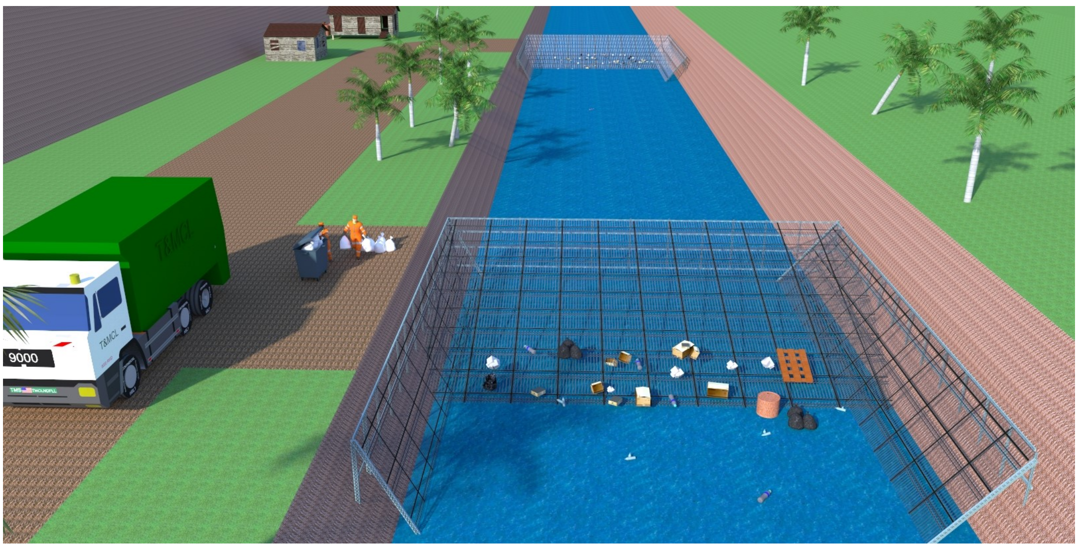


Figure 6.8: Front view of two trash trap structures in a river

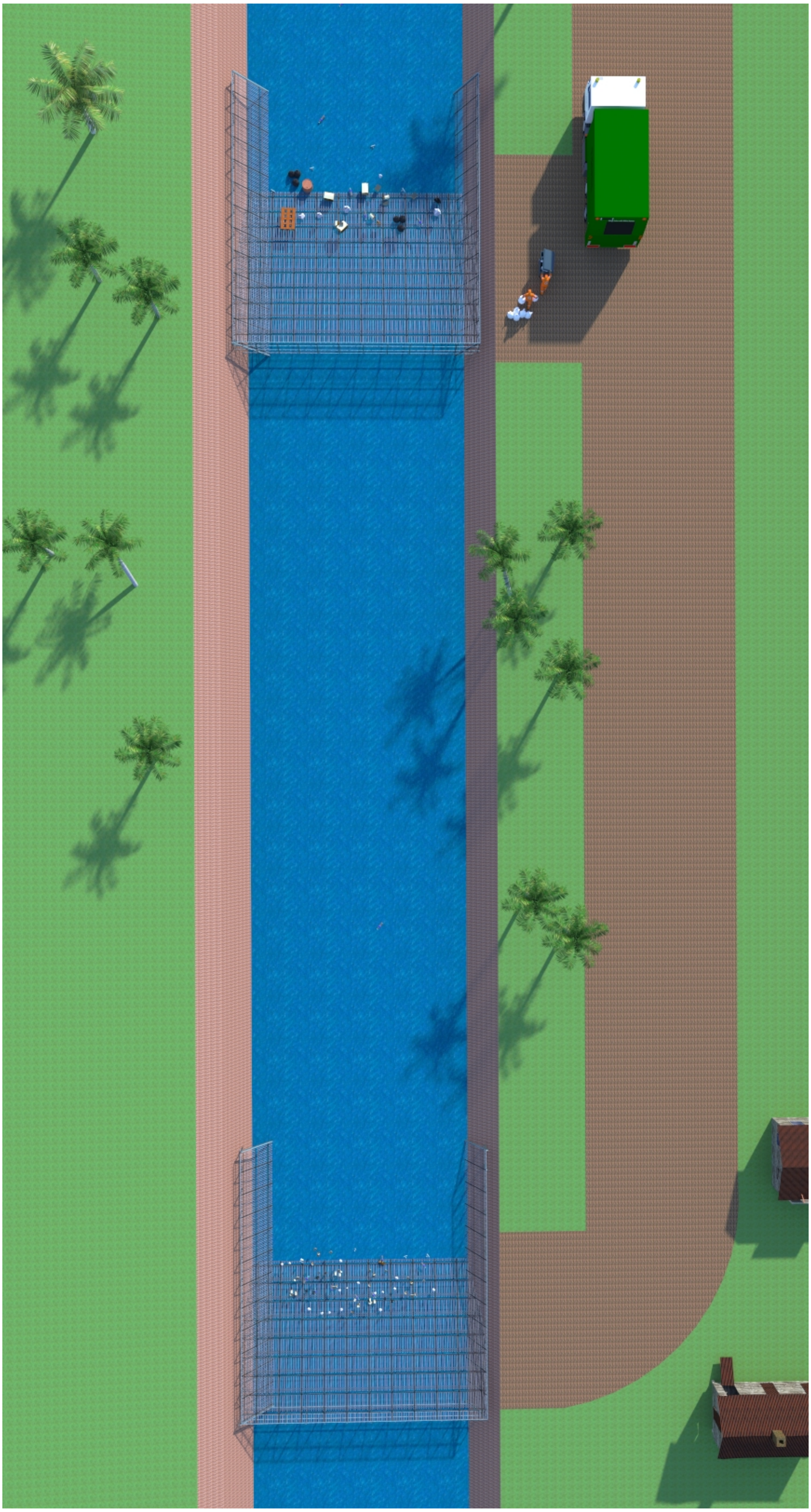


Figure 6.9: Top view of two trash trap structures

7

Discussion

During the visual observations, plastic particles were counted in the rivers that would not be caught by the trawl. As a result, the actual weight per plastic particle will be lower than that assumed weight in our study. As the measurements of the trawled rivers were all converted from kg per hour into pieces per hour, the actual results of those rivers may differ. In addition, even though the wet weight of the plastic pieces was taken, for the average weight, results may differ. If, for instance, a plastic bag was caught, which has some water in it, it gives skewed results.

The measurements were taken during the dry season. This had as an outcome that some rivers were completely dry, which results in zero plastic flow. However, if the measurements are done during the rainy season, they should be done at exactly the same time, at all the locations. This is needed because if the measurements are done at different times, the results will differ due to different precipitations, which results in dissimilar discharges. This will result in two problems, the first is a higher waterlevel. A higher waterlevel means that pollution, located higher on the embankments, is now also reached, and will be swept away. The second problem is the flow velocity. An increase in flow velocity means that, per time unit, more particles will flow past the measuring point, than during a smaller flow velocity.

The plastic discharge per regency, can be looked at in two ways. The average plastic discharge over the amount of measured rivers, or the total plastic discharge of the rivers, per regency. The problem here is that some regencies have more measured rivers than others. As example, in the Karangasem regency, only one measurement was done, which had a plastic flow of zero. On the other hand, the Denpasar regency, with only two measured rivers, has the highest average plastic discharge and the second highest total plastic discharge. This shows that a small number of measured rivers does not necessarily means a smaller plastic discharge. The reason some regencies have fewer measured rivers, is because the rivers were not selected on regencies. Only afterwards was looked through which regencies, the rivers flow. In addition, some rivers are used as borders for regencies, thus making it more difficult to allocate a river to a particular regency.

It is hard to directly draw conclusions from the embankment pollution. The amount plastic which flows through the rivers, will be relatively the same over a particular stretch. However, the plastics on the embankments are static, and may differ over a certain stretch. This means that the embankment polluting can differ up- or downstream of the measurement location. It was observed that most of the embankment pollution occurs at bridged, at it is the most accessible way to reach a river. This means that where the data was obtained, most of the pollution should develop. However, findings may differ at different bridges, along the same river.

The results of the the multi-criteria analysis are largely dependent on the weights that are assigned to the different criteria. The weights of the different criteria were determined based on expectations. Basing the weights on the opinion of the actual decision-maker, in this case the Regency, could lead to different and more correct results of the MCA.

8 Conclusion

In chapter 1, eight sub-question were stated and the research question was formulated. In this chapter, these questions will be answered, after which the main question can be answered.

8.1. Sub-questions

First, the sub-questions as stated in the introduction will be resolved one by one.

How is (plastic)waste handled in Bali and which measures are already in place to mitigate the problem?

The waste in Bali is handled in multiple different ways. If there is no access to a suitable collection system most waste will either be incinerated by consumers themselves, dumped along rivers or riverbanks or dumped somewhere else in nature. In some areas trucks will pick up the waste and bring it to a TPST or TPST3R facility which are managed by the regional government of each regency. At a TPST facility mixed waste is gathered after which all waste will be transported to a landfill. At a TPST3R facility the waste is sorted and based on the type of waste either recycled, composted or brought to a landfill. Furthermore, there are different NGO's active on Bali which provide their own services to pick-up and handle the waste. Finally, the inhabitants of Bali can also bring their waste to a waste bank where the waste with economic value will be recycled or reused.

Multiple measures are already implemented to reduce the amount of waste that is dumped at rivers, riverbanks and in nature and to mitigate the plastic problem. In December 2018 the government put a ban in place regarding single use plastic to reduce the amount of plastic on the island. Next to that, the government has developed a clear national plan of action regarding marine plastic debris for the years 2017 to 2025. Furthermore, in 2015 the Indonesian Waste Platform (IWP) was founded to induce collaboration between the government, businesses and civil society. This is necessary to mitigate this problem since all these parties have to cooperate to achieve a reduction of mishandled waste. Finally, there are a lot of local initiatives on Bali to involve local communities in cleaning up the beaches.

How does the plastic end up in the rivers?

Plastic can end up in the rivers in multiple ways. Waste, including plastic, can be dumped in the rivers directly by inhabitants of Bali. The waste can also be dumped onto riverbanks where it accumulates mainly during dry season due to the low water levels of the rivers. In the rainy season it can then end up in the rivers due to run-off after heavy rainfall. Finally, plastic can end up in the rivers due to transport by wind. When plastic is thrown in nature the wind and gravity can cause the plastic to be transported to the most low lying part of the area which is often a river.

Which measures can be implemented to prevent plastic entering the environment?

Different measures have been discussed to prevent plastic from ending up in the environment. New regulations can be developed to ensure that waste is sorted properly at the source. This measure requires a simultaneous improvement in waste collecting infrastructure by the government, where the separated waste does not get mixed up again. The government can also implement a tourist tax for funding the measures to mitigate the plastic waste problem. Current resistance of this measure should be mitigated before implementing this measure. Another measure is to expand the existing collection services and increase waste collection rates. The high transportation costs that come along with this measure make this more difficult to implement. The closing of leakage points within the existing collection system is another measure that is expected to be efficient in Bali, since the current collecting system shows multiple points that can be improved. The improvement of current landfills in Bali is also a suggested measure. Landfills can be made sustainable by implementing the Enhanced Landfill Mining concept. It includes the recovery of energy from waste. This measure is however only sustainable if the emissions are controlled. The final measure is to expand the number of catchment structures in Bali, which are currently only two structures. All these measures have advantages and disadvantages, which need to be sufficiently considered before implementation.

What is the plastic flow of the different rivers and regencies?

As the island of Bali has over 50 rivers, not all of them have been given names. It was decided to number the measured rivers, of which a map has been made (see Fig. 8.1). Here, they will be referred to with their respective number. A table of coordinates per river can be found in Appendix A.2.

Figure 8.1: Overview of the measured rivers

Three rivers on Bali have a plastic discharge of more than 300 plastic pieces per hour. This is almost six times as much as the average measured river on Bali, which discharges 55 pcs/h. These are rivers 4, 16 and 29, which have a plastic flow of 341, 316 and 301 pcs/h respectively. Therefore, these rivers should be tackled first. What stands out is that these three rivers are all located in different parts of

Bali. What they have in common, though, is that they all flow through densely populated areas. Four other rivers have a plastic discharge between the 60 and 160 pcs/h and the rest of the rivers have a plastic discharge below the average of 55 pcs/h.

For the regencies, conclusions are harder to be drawn, as the results differ based on how one looks at the measurements. As some regencies have more (measured) rivers, their total plastic discharge can differ from regencies with fewer (measured) rivers. If the average plastic discharge over the number of measured rivers is taken, the Denpasar regency is the most polluting. It has an average flow of 235 pcs/h, per river. However, if the total plastic discharge, of the measured rivers of each regency is calculated, the Jembrana regency has the highest discharge, which has a discharge of 556.6 pcs/h, followed by the Denpasar and Buleleng regency, with plastic discharges of 470 and 449 pcs/h.

What is the degree of pollution of the embankments of the different rivers and regencies?

As during peak discharge events, the (plastic) pollution on the embankments of rivers will be swept away into the ocean, it is important to look at which rivers have polluted embankments. However, these measurements were done on one location of the rivers so the results may vary upstream or downstream of the measurement locations. Therefore, the results should be handled with care.

There are three rivers with an embankment pollution higher than 30 plastic pieces per square meter. These are rivers 24, 25 and 30. These three rivers are located in the Buleleng regency, which is, therefore, also the regency with the highest embankment pollution.

Does the wind velocity have an influence on the plastic pollution of the rivers and embankments?

This sub-question helps to identify if the wind factor must be included when larger models are made. If the wind velocity versus the plastic discharge and versus the embankment pollution is plotted, coefficients of determination, R^2, of 0.230 and 0.010 are found, respectively. It can therefore be concluded that there is no correlation between the wind velocity and the plastic discharge or the embankment pollution, of the rivers on Bali. These results can be limited for the rivers on Bali, as they tend to be surrounded by large trees, thus blocking the wind.

Is there a correlation between socio-demographics (income, education, religions, landfills, population density) and the plastic flow in the rivers?

There are no clear links found based on the obtained data between any of the socio-demographics of a regency and the plastic discharge in the rivers of that regency. With respect to the income level of a regency it appeared that some of the most polluted rivers were located in the regencies with the highest income which is not in line with the expectations. Therefore it seems likely that other factors also play a role such as that people in these regencies have more to spend and therefore might also consume more plastic. With respect to education level a similar pattern can be found. Within three of the four regencies with the highest education level also three of the most polluted rivers are located, while it was expected that a higher education level within a regency could lead to less polluted rivers. With respect to religion some regencies with a high level of either Muslims or Hindu had a lot of polluted rivers while others did not. Therefore it seems that religion does not have a clear relationship with plastic discharge in rivers. With respect to landfills there are two regencies, Badung and Denpasar, in which rivers flow that originate far north in the regency while the landfill is located in the south. Therefore it could be that the high level of pollution in the rivers in these regencies are caused by the fact that trucks who pick up waste in the north side of the regency dump it in the rivers because the landfill is too far away. However, this pattern was not found in every regency so it can not be said with certainty that the proximity of a landfill to the rest of the regency causes a higher level of pollution within the rivers. With respect to population density it is found that the regencies with the highest population density also have some of the most polluted rivers. However, the regency with the lowest population density also has a large amount of pollution within the rivers and therefore it can not be concluded with certainty that a high population density causes a high level of pollution within the rivers.

Which structure is most suited to be implemented in rivers to retain the waste flow, before entering the ocean?

There are two types of rivers on Bali, one that has no navigation on it and one where navigation needs to be possible. This means that for the first type of river, the river can be closed off completely by a structure. For the second type, the river cannot be closed off completely, thus two types of structures are needed for the rivers on Bali.

Following a multi-criteria analysis, it can be concluded that a Trash Trap structure is the most advisable structure to implement in the first type of river. For the second type, which needs to stay open for navigation, the Sea Defence Structure (SEADS) has the highest score. To cope with the peak discharges, during the (start of) the rainy season on Bali, it is advised to build two, or more, Trash Traps. These should be placed in series, with decreasing mesh size, to prevent total blockage of the rivers. In this manner, smaller plastic pieces can be caught, before entering the ocean.

8.2. Research question

With the help of the previous answered sub-questions, the research question can now be answered.

'Which rivers and regencies on Bali have the highest plastic discharge and which structures are most suitable, to reduce plastic flow of the rivers, on the shores of Bali and into the ocean?'

Rivers 4, 16 and 29, which end up in the villages of Negara, Denpasar and Bubunan, respectively, are the most polluted rivers on Bali. On average, per measured river, the Denpasar regency has the highest plastic discharge. However, if one looks at the total plastic discharge, the Jembrana regency has the highest discharge, with the Denpasar regency having the second highest discharge.

There are two different types of rivers for which structures must be designed to catch the plastic that flows through the rivers and prevent it from entering the ocean. For each type of river, one design is selected. The most suitable structures to implement are Trash Traps, in rivers which may be closed off for navigation, and Sea Defence Structures (SEADS), when rivers cannot be closed off for navigation. For the Trash Traps, it is advised to place multiple in series, in a river, with decreasing mesh size, in order to prevent blockages and flooding during peak discharges. Both structures can be widely applicable over the different rivers of Bali, as redesign is relatively simple and cheap to do.

9

Recommendations

Lastly, recommendations are given over improvements and where further research can focus on. This includes smaller scale recommendations, about the project and more general recommendations about the entire plastic problem.

As the island of Bali has over 50 (large) rivers, not all of the 50 rivers have been researched. This was partly because of the ample discharge in the rivers and partly because of a shortage of time. In addition, smaller streams were also encountered, which were dry, but were polluted too. All the rivers and smaller streams on Bali that have not been measured within this research should still be investigated to give a more complete overview.

This brings us two the second recommendation, data during the rainy season and the beginning thereof. As some rivers, and streams especially, had a low discharge or were completely dry, it is advised to do additional measurements during the rainy season. This brings, however, additional problems, as the discharge in the rivers will differ due to different intensities of precipitation events. All rivers, then, should be measured at the same time, but even then, there will be a difference in discharge, as some are longer, thus will take a longer time for the peak flow to reach the coast.

Furthermore, that there is an increase in the plastic discharge, at the beginning of the rainy season, is known. However, it is not known how much this is per river. A single river should be measured, over the course of a year, to see the difference in plastic discharge. This should also help to dimension the structures, who have to withstand the peak discharges.

The results of the wind velocity versus the plastic discharge and the embankment pollution cannot be extrapolated for use in European countries, where rivers flow through a more open environment. On Bali, the rivers tend to flow trough wooded areas, thus reducing the wind velocity. Therefore, more research needs to be done on the influence of wind velocity on the plastic flow, in open areas.

A future group could start to design a structure and implement it. Where this paper provides a good set-up for what kind of structures can be implemented, a more extensive design should be made. This should include strength and strain calculations and a construction plan. Then, a structure should be implemented and monitored to see if the structure works correctly.

These structures only catch the (macro) plastics. Not much in known about the micro plastics. On these type of plastics, bacteria can nestle and grow, which can be harmful for the environment. Therefore, a study must be done to look at how much micro plastics are discharged on the rivers and how contaminated they are.

What was encountered, during the project but also beforehand, is that there are a lot of initiatives to tackle the plastic problem, but there is little to no communication between the initiatives. We encountered companies who were essentially doing the same, but did not know of each other. In essence, unnecessary duplication of effort is done. A platform should be created where companies and initiatives can find each other and see what everyone is doing. This can either be on an international scale or a national scale. In addition, a data bank should be created where initiatives, companies and universities could share their data about the plastic problem. This should prevent that the same research is done twice and that solutions can be found in a more effective way.

As Bali is just one of the 16.000 islands of the Indonesia archipelago, other island should be looked at as well. However, if a structure is designed and successfully tested on Bali, it can be implemented on other islands, without having to do measurements beforehand. Peak discharges can play an important role, however, and therefore should be looked at.

Lastly, the problem should be better tackled at the source. Where building a structure in rivers to prevent the plastic entering the ocean is already better than collecting plastic from the beaches, it should really be prevented that plastic enters the environment at all. On one hand, there is a part of the population who throws trash in rivers, on the other hand, there is another part who collects it from the beaches. This is very impractical, and shows what the fundamental problem is. People upstream do not see what problem they create downstream, whilst people downstream essentially act as private trash collecting companies. People upstream should be better educated of the problems they create downstream. However, the problem is not their fault entirely, most of the regencies do not offer waste management systems in every part of the regency, especially in the higher laying villages. The province of Bali should coordinate a island wide waste management system, where regencies pay fees based on their income, making it affordable for every regency.

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A

Appendix I: Rivers

A.1. Measured rivers

To determine which rivers discharge the most plastic onto the beaches and into the ocean measurements are performed in rivers located across Bali. Figure A.1 shows the different locations of measured the rivers. From this figure follows that the measured rivers are located in many different areas of the island. Hereby, the different areas can be compared based on the measured plastic discharge and certain demographic factors. In total 31 rivers are measured. Below each measurement locations will be described successively.

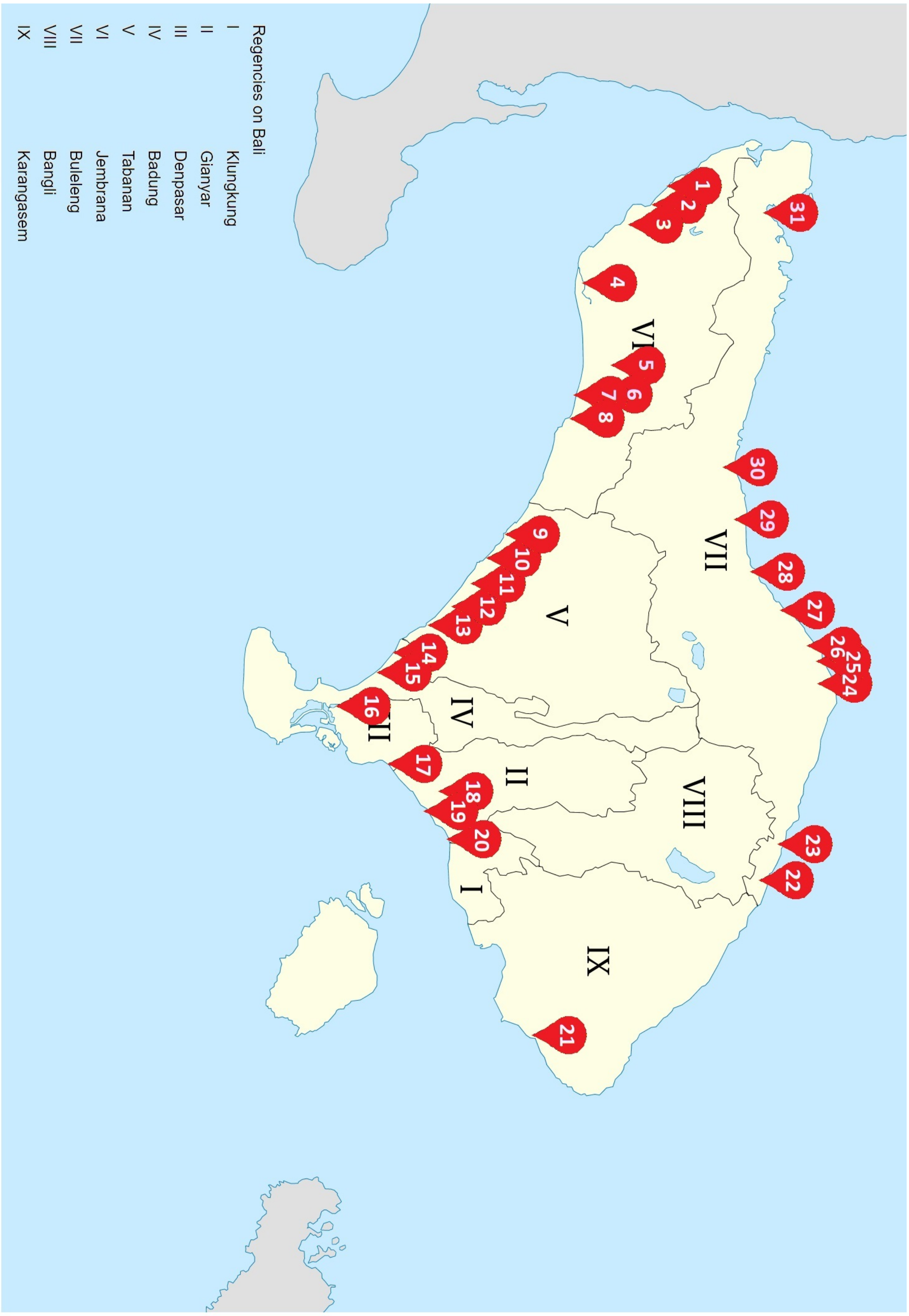

Figure A.1: Overview of the measured rivers

River 1

River 1 is located in the regency of Jembrana, which is located in the West of Bali. The measurement location was remote and there were no residence of roads next to the river. The measurement location is in this case where the rivers flows into the ocean. The measurements were performed a bit more inland to exclude the tides of the ocean towards inland. Although the river was relatively deep, visual measurements were performed due to the absence of a bridge. Figures A.2a and A.2b represent the location of measurement.

(a) View of River 1 towards the ocean

(b) View of River 1 towards inland

Figure A.2: View of River 1

River 2

River 2 is located in the regency of Jembrana, which is located in the West of Bali. The measurement location was on a bridge which was part of the main road from East to West Bali. There was a lot of traffic on this road. Due to little space on the bridge and unsafe conditions, only visual observations were performed. In addition, the water was shallow and there was almost no flow. Figures A.3a and A.3b represent the measurement location.

(a) View of River 2 towards the ocean

(b) View of River 2 towards inland

Figure A.3: View of River 2

River 3

River 3 is located in the regency of Jembrana, which is located in the West of Bali. The measurement location was remote and near the river mouth. There was no bridge in this area to perform the measurements. Therefore, only visual counting was performed. Figures A.4a and A.4b represent the measurement location.

(a) View of River 3 towards the ocean

(b) View of River 3 towards inland

Figure A.4: View of River 3

River 4

River 4 is located in the regency of Jembrana, which is located in the West of Bali. The measurement location was in an area with mangrove forests. There was a big bridge with little traffic passing it. The river was very wide and deep. Furthermore, there was a high flow velocity. Therefore, it was possible to perform trawl measurements. Figures A.5a and A.5b represent the measurement location.

(a) View of River 4 towards the ocean

(b) View of River 4 towards inland with the trawl

Figure A.5: View of River 4

River 5

River 5 is located in the regency of Jembrana, which is located in the West of Bali. The measurement location was in a relatively quiet area with small villages. There was a small bridge with some traffic passing it. The river was relatively wide and the flow velocity was relatively high. However, the rivers was not very deep. Therefore, it was not suitable for performing trawl measurements. Figures A.6a and A.6b represent the measurement location.

(a) View of River 5 towards the ocean

(b) View of River 5 towards inland

Figure A.6: View of River 5

River 6

River 6 is located in the regency of Jembrana, which is located in the West of Bali. The measurement location was in an remote area. However, there was a small shop at the corner of the bridge next to the river. The bridge was relatively small and little traffic was passing it. The river was very wide. However, the river was shallow and the flow velocity was relatively low. Therefore, it was not possible to perform trawl measurements. Figures A.7a and A.7b represent the measurement location. In figure A.7a there are two locals building a small weir in the river.

(a) View of River 6 towards the ocean

(b) View of River 6 towards inland

Figure A.7: View of River 6

River 7

River 7 is located in the regency of Jembrana, which is located in the West of Bali. The measurement location was in an remote area close to the river mouth. Figure A.8a shows the river mouth. Figure A.8b shows the large river towards inland. At the river mouth there was a side channel, which also ends at the river mouth. This side channel is shown in figure A.9. Both the river and channel were deep and had a relatively high flow velocity. However, there was no bridge at this measurement location. Therefore, only visual measurements were performed. Unlike the river, the channel flows past several villages. Because of this is it decided to measure the channel. Figures A.8a, A.8b and A.9 represent the measurement location.

(a) View of River 7 towards the ocean

(b) View of River 7 towards inland

Figure A.8: View of River 7

Figure A.9: View of the side channel

River 8

River 8 is located in the regency of Jembrana, which is located in the West of Bali. The measurement location was in an remote area. There were some residence close to the river. The bridge was relatively small and little traffic was passing it. The river had a relatively high flow velocity. However, the river was relatively shallow. Therefore, it was not possible to perform trawl measurements. Figures A.10a and A.10b represent the measurement location. From the river view towards the ocean no photo was taken. Therefore, figure A.10a is a screenshot from Google Maps.

(a) View of River 8 towards the ocean

(b) View of River 8 towards inland

Figure A.10: View of River 8

River 9

River 9 is located in the regency of Tabanan, which is located in the South of Bali. The measurement location was in a busy area. There was a bridge at the location. However, the bridge is part of the main road from East to West Bali. Therefore, was not safe to perform trawl measurements at this location. Figures A.11a and A.11b represent the measurement location.

(a) View of River 9 towards the ocean

(b) View of River 9 towards inland

Figure A.11: View of River 9

River 10

River 10 is located in the regency of Jembrana, which is located in the West of Bali. The measurement location was in an remote area. There were some residence close to the river. The bridge very small and primitive. No traffic was passing it. In addition, the river was very shallow and the flow velocity was low. Therefore, it was not possible to perform trawl measurements. At this measurement location it was striking that there was a lot of plastic on the embankments of the river. The river here was clearly used to dump plastics. The figures of A.12 represent the measurement location.

(a) View of River 10 towards the ocean

(b) View of River 10 towards inland

(c) View of bridge

(d) View of river embankment

Figure A.12: View of River 10

River 11

River 11 is located in the regency of Jembrana, which is located in the West of Bali. The measurement location was in an remote area. The bridge was relatively small and little traffic was passing it. The river had a low flow velocity. Therefore, it was not possible to perform trawl measurements. At this measurement location it was striking that on the embankments of the river many small piles of plastics were burned. Figures A.13a and A.13b represent the measurement location.

(a) View of River 11 towards the ocean

(b) View of River 11 towards inland

Figure A.13: View of River 11

River 12

River 12 is located in the regency of Jembrana, which is located in the West of Bali. The measurement location was in an remote area. The bridge was relatively small and little traffic was passing it. The river had a low flow velocity. Therefore, it was not possible to perform trawl measurements. At this measurement location it was striking that on the embankments of the river many small piles of plastics were burned. Figures A.14a and A.14b represent the measurement location.

(a) View of River 12 towards the ocean

(b) View of River 12 towards inland

Figure A.14: View of River 12

River 13

River 13 is located in the regency of Jembrana, which is located in the West of Bali. The measurement location was in a relatively busy area. There was a bridge at the measurement location. The river had a low flow velocity. Therefore, it was not possible to perform trawl measurements. At this measurement location it was striking that on the embankments of the river were large piles of plastics, like shown in A.15d. There were also piles of burned plastics, like shown in figure A.15c. Figures A.15a and A.15b represent the measurement location.

(a) View of River 13 towards the ocean

(b) View of River 13 towards inland

(c) View of river embankment

(d) View of river embankment

Figure A.15: View of River 13

River 14

River 14 is located in the regency of Badung, which is located in the South of Bali. The measurement location was suitable for trawl measurements. These measurements were performed by Pantai bachelor students. Figures A.16a and A.16b represent the measurement location. There was no picture taken of the river towards inland. Therefore, Google Maps is used to retrieve figure A.16b.

(a) View of River 14 towards the ocean

(b) View of River 14 towards inland

Figure A.16: View of River 14

River 15

River 15 is located in the regency of Badung, which is located in the South of Bali. The measurement location was suitable for trawl measurements. These measurements were performed by Pantai bachelor students. Figures A.17a and A.17b represent the measurement location.

(a) View of River 15 towards the ocean

(b) View of River 15 towards inland

Figure A.17: View of River 15

River 16

River 16 is located in the regency of Badung, which is located in the South of Bali. The measurement location was suitable for trawl measurements. These measurements were performed by Pantai bachelor students. Figures A.18a and A.18b represent the measurement location.

(a) View of River 16 towards the ocean

(b) View of River 16 towards inland

Figure A.18: View of River 16

River 17

River 17 is located in the regency of Denpasar, which is located in the South of Bali. The measurement location was in peaceful area with few residence and close to the river mouth. The river was very wide and deep. However, there was no bridge on the main river. Therefore, visual measurements were performed. There was also a side channel ending up at the river mouth. This side channel is shown in A.20a. FigureA.20b shows a special stone bin, which is used to burn plastics. Multiple of these bins were along the river. Figures A.19a and A.19b represent the measurement location.

(a) View of River 17 towards the ocean

(b) View of River 17 towards inland

Figure A.19: View of River 17

(a) View of side channel

(b) View of bin for burning plastics

Figure A.20: View of River 17

River 18

River 18 is located in the regency of Ubud, which is located in the South of Bali. The measurement location was in an remote area. The bridge was relatively small and much traffic was passing it. Therefore, it was not safe to perform trawl measurements. At this measurement location it was striking that on one part of the embankments, next to the bridge, trash was dumped in a very high concentration, and on the other part of the bridge, offers were laid by the locals for the river spirits. Figures A.21a and A.21b represent the measurement location.

(a) View of River 18 towards the ocean

(b) View of River 18 towards inland

Figure A.21: View of River 18

River 19

River 19 is located in the regency of Ubud, which is located in the South of Bali. The measurement location was in a small surf village at the coast. The bridge was relatively small and little traffic was passing it. The river was relatively deep. However, the flow velocity was low. Therefore, it was not possible to perform trawl measurements. Figures A.22a and A.22b represent the measurement location.

(a) View of River 19 towards the ocean

(b) View of River 19 towards inland

Figure A.22: View of River 19

River 20

River 20 is located in the regency of Klungkung, which is located in the South East of Bali. The measurement location was is a relatively quiet neighbourhood with some villa's. The location was close to the ocean. There was no bridge at the location. Therefore, it was not possible to perform trawl measurements. Figures A.23a and A.23b represent the measurement location.

(a) View of River 20 towards the ocean

(b) View of River 20 towards inland

Figure A.23: View of River 20

River 21

River 21 is located in the regency of Karangasem, which is located in the East of Bali. The measurement location was near a small village. There was a bridge at the measurement location with little traffic passing it. The flow velocity was also relatively high. However, the river was very shallow. Therefore, it was not possible to perform trawl measurements. Figures A.24a and A.24b represent the measurement location.

(a) View of River 21 towards the ocean

(b) View of River 21 towards inland

Figure A.24: View of River 21

River 22

River 22 is located in the regency of Buleleng, which is located in the North of Bali. The measurement location was along the Northern main road from East to West Bali. There was a large bridge at the location. However, a lot of traffic was passing it. In addition the river was very shallow. Therefore, it was not possible to perform trawl measurements. Unfortunately, there are no pictures taken at this location. Figures A.25a and A.25b are retrieved from Google Maps and represent the measurement location.

(a) View of River 22 towards the ocean

(b) View of River 22 towards inland

Figure A.25: View of River 22

River 23

River 23 is located in the regency of Buleleng, which is located in the North of Bali. The measurement location was along the Northern main road from East to West Bali. There was a large bridge at the location. However, a lot of traffic was passing it. In addition the river was very shallow. Therefore, it was not possible to perform trawl measurements. Unfortunately, there are no pictures taken at this location. Figures A.26a and A.26b are retrieved from Google Maps and represent the measurement location.

(a) View of River 23 towards the ocean

(b) View of River 23 towards inland

Figure A.26: View of River 23

River 24

River 24 is located in the regency of Buleleng, which is located in the North of Bali. The measurement location was in a densely populated area. There was a bridge at the measurement location with a lot of traffic passing it. The river was very shallow. Therefore, it was not possible to perform trawl measurements. At this location is was striking that there was a lot of plastics on the embankments. Figures A.27a and A.27b represent the measurement location.

(a) View of River 24 towards the ocean

(b) View of River 24 towards inland

Figure A.27: View of River 24

Figure A.28: View of the embankment

River 25

River 25 is located in the regency of Buleleng, which is located in the North of Bali. The measurement location was in a densely populated area. There was a bridge at the measurement location with a lot of traffic passing it. The river was very shallow. Therefore, it was not possible to perform trawl measurements. At this measurement location it was striking that there was a certain crops farm in the river. During the measurements the farmer was constantly picking the plastics out of his crops. While on the other side of the bridge an older woman dropped her garbage bag in the river. Figures A.29c and A.29d give a good indication on the amounts of plastics in the river. Figures A.29a and A.29b represent the measurement location.

(a) View of River 25 towards the ocean

(b) View of River 25 towards inland

(c) View of plastics in the river

(d) View of plastics in the river

Figure A.29: View of River 25

River 26

River 26 is located in the regency of Buleleng, which is located in the North of Bali. The measurement location was in a densely populated area. There was a bridge at the measurement location with a lot of traffic passing it. The river was very shallow. Therefore, it was not possible to perform trawl measurements. At this measurement location it was striking that although this river is more closely to the big city of Singaraja compared to river 24 and 25, there was less plastic in the rivers. Figures A.30a and A.30b represent the measurement location.

(a) View of River 26 towards the ocean

(b) View of River 26 towards inland

Figure A.30: View of River 26

River 27

River 27 is located in the regency of Buleleng, which is located in the North of Bali. The measurement location was in the city of Singaraja, a densely populated city. There was a bridge at the measurement location with a lot of traffic passing it. The river was relatively deep. However, the flow velocity was very low. Therefore, it was not possible to perform trawl measurements. Figures A.31a and A.31b represent the measurement location.

(a) View of River 27 towards the ocean

(b) View of River 27 towards inland

Figure A.31: View of River 27

River 28

River 28 is located in the regency of Buleleng, which is located in the North of Bali. The measurement location was in Lovina, a densely populated city. There was a bridge at the measurement location with a lot of traffic passing it. The river was relatively shallow and there was little flow. Therefore, it was not possible to perform trawl measurements. Figures A.32a and A.32b represent the measurement location.

(a) View of River 28 towards the ocean

(b) View of River 28 towards inland

Figure A.32: View of River 28

River 29

River 29 is located in the regency of Buleleng, which is located in the North of Bali. The measurement location was in Lovina, a densely populated city. There was a bridge at the measurement location with a lot of traffic passing it. The river was relatively shallow and there was little flow. Therefore, it was not possible to perform trawl measurements. Figures A.33a and A.33b represent the measurement location.

(a) View of River 29 towards the ocean

(b) View of River 29 towards inland

Figure A.33: View of River 29

River 30

River 30 is located in the regency of Buleleng, which is located in the North of Bali. The measurement location was in a quiet area with small villages. There was a bridge at the measurement location with a lot of traffic passing it, because it was the main road from East to West Bali. The river was very shallow and there was little/no flow. Therefore, it was not possible to perform trawl measurements. Figures A.34a and A.34b represent the measurement location.

(a) View of River 30 towards the ocean

(b) View of River 30 towards inland

Figure A.34: View of River 30

River 31

River 31 is located in the regency of Buleleng, which is located in the North West of Bali. The measurement location was in a quiet area close to the West Bali National Park. There was a bridge at the measurement location with a lot of traffic passing it. The river was very shallow and there was little/no flow. Therefore, it was not possible to perform trawl measurements. Figures A.35a and A.35b represent the measurement location. There was no picture taken of the view of the river towards inland. Therefore, Google Maps is used to retrieve figure A.35b.

(a) View of River 31 towards the ocean

(b) View of River 31 towards inland

Figure A.35: View of River 31

A.2. Locations

Table A.1: Location of the measurements, in latitude and longitude coordinates

River	1	2	3	4	5	6	7
Latitude	-8.27812	-8.29873	-8.33353	-8.39518	-8.35105	-8.38284	-8.39818
Longitude	114.48876	114.51428	114.52335	114.62803	114.71821	114.75161	114.75208
River	8	9	10	11	12	13	14
Latitude	-8.39751	-8.4989	-8.53005	-8.55828	-8.56659	-8.58342	-8.65235
Longitude	114.78524	114.96782	115.00388	115.04349	115.07284	115.08541	115.12507
River	15	16	17	18	19	20	21
Latitude	-8.66989	-8.72076	-8.65439	-8.60099	-8.60811	-8.57308	-8.46229
Longitude	115.14341	115.18695	115.26653	115.29911	115.32259	115.37105	115.62628
River	22	23	24	25	26	27	28
Latitude	-8.1528	-8.12731	-8.07983	-8.08485	-8.09211	-8.11651	-8.16622
Longitude	115.4162	115.34577	115.16336	115.13713	115.11915	115.07678	115.01608
River	29	30	31				
Latitude	-8.19287	-8.19951	-8.15536				
Longitude	114.93232	114.87179	114.52609				

B

Appendix II: Regencies

B.1. Geographic data

Table B.1: Regency data [Negeri, K.D., 2017]

Regency	Total Area (km^2)	Total Population (2017)	Population Density
Badung	418,62	468.346	1118,785533
Bangli	490,71	264.945	539,921746
Buleleng	1.364,73	814.356	596,7158339
Gianyar	368	492.757	1339,013587
Jembrana	841,8	323.211	383,9522452
Karangasem	839,54	545.389	649,6283679
Klungkung	315	215.852	685,2444444
Tabanan	1.013,88	466.647	460,2586105
Denpasar	127,78	638.548	4997,245265

B.2. Demographic data

Table B.2: Religion data [Statistik, B.P., 2016]

Regency	Hinduism	Islam	Protestantism	Catholicism	Buddhism	Confucianism	Lain-lain
Badung	76,35%	17,50%	3,39%	1,88%	0,45%	0,22%	
Bangli	98,59%	1,01%	0,10%	0,03%	0,05%		0.22%
Buleleng	89,97%	8,79%	0,50%	0,23%	0,50%	0,01%	
Gianyar	98,38%	0,94%	0,14%	0,07%	0,47%		
Jembrana	71,21%	26,60%	1,10%	0,71%	0,29%		
Karangasem	94,97%	4,79%	0,11%	0,05%	0,08%		
Klungkung	94,38%	4,21%	0,60%	0,09%	0,72%		
Tabanan	92,69%	5,72%	0,66%	0,45%	0,48%		
Denpasar	65,95%	24,33%	4,95%	2,39%	2,35%	0,03%	

B.3. Economic data

Table B.3: Economic data updated on May 4, 2018 [Iswaril, 2017]

Regency	APBD (Rp)	PAD (Rp)	DAU (Rp)
Badung	6.567.483.603.537	5.700.510.789.575	330.336.650.000
Bangli	1.118.895.723.344	120.500.000.000	559.867.699.000
Buleleng	2.124.617.361.711	371.366.874.000	965.435.235.000
Gianyar	1.926.241.277.262	695.786.110.666	693.573.732.000
Jembrana	1.114.793.253.249	128.271.931.580	552.643.376.000
Karangasem	1.561.878.043.098	234.000.000.000	729.378.991.000
Klungkung	1.094.682.989.901	152.478.228.437	530.371.681.000
Tabanan	1.891.138.654.520	409.183.800.000	811.768.631.000
Denpasar	2.040.573.867.675	808.925.879.427	650.169.150.000

B.4. Educational data

Table B.4: School participation rate per age categorie in 2018 [BPS, 2019]

Regency	7-12 years	13-15 years	16-18 years	19-24 years
Badung	99,71	100	92,07	32,88
Bangli	99,02	95,57	74,64	14,62
Buleleng	100	94,43	80,08	25,94
Gianyar	99,78	99,47	90,17	35,70
Jembrana	99,41	99,24	84,37	14,79
Karangasem	99,35	96,48	80,11	8,54
Klungkung	99,21	97,58	85,69	14,93
Tabanan	98,96	98,55	84,45	15,31
Denpasar	99,62	99,17	73,10	34,24
Bali province	99,56	97,92	82,35	27,24

C

Appendix III: Interviews

C.1. Interview Gede Hendrawan

Institution	Udayana University
Date	May 7th, 2019
Interviewers	Annemiek van Marsbergen & Sophie Brooijmans
Interviewee	Gede Hendrawan, Ph.D
Location	Faculty of Marine Science and Fisheries, Jl. Raya Kampus Unud, Jimbaran, Kuta Sel., Kabupaten Badung, Bali, Indonesia

Respondent: I did the same kind of research before, using a net also. But we fixed it across the whole width of the river with a mesh size of 2.5 centimetre. Because we wanted to have the plastic larger than 2.5 cm and less than 30 cm. This is macro debris. Larger than 30 cm is large debris and smaller than 2.5 cm is micro and meso debris. So that's why we use a trap with size 2.5 cm to 30 cm. We could trap debris larger than 30 cm. At that time we measured the plastic passing through the net for one hour. We then measured nine rivers in the west of Bali. I selected the rivers as like the main rivers. We got the data from Bali local government with the flow rate. We did the measurement in 2014 for three months during June, July and August, so dry period. During the measurements in July I think, one day we measured the debris in Jembrana regency and at that time it was raining and then we couldn't trap because the flooding was very high so we just counted the debris. We also measured the flow rate with a current meter and also measured the depth of the water. Actually the idea is not to only measure the debris coming from the river. We wanted to make a numerical model how the river is getting the debris into the ocean. We use this data as input for a numerical model. This was the main goal. I think at that time we had not enough data because we only did one hour in one river.

Interviewers: How many times should you suggest to measure a river?

Respondent: For dry season actually not so many garbage will be flowing into the river because the garbage mostly exist in the river bank because some people just throw it in the river bank and this doesn't flow into the river. Especially for the garbage that is the big plastic will sink into the bottom of the river because the rivers are not so deep here so that will be trapped and doesn't flow. This was a problem we found then.

Respondent: In 2017 we tried another methodology by using Csir methodology to measure the garbage in the river bank. We selected the locations from downstream to upstream. We selected this by random sampling the transects by 3 km each station and then at each station we did on the right and left side of the river bank. On each side we did a line transect and we did at least three line transects at each side and a maximum of six at each side. The distance of each transect is about 15 meter. If we have six or five locations in one river, downstream and upstream, we have at least 6 to 36 transects for one river.

Interviewers: Did you think the measurement in 2017 worked better than what you did in 2014?

Respondent: I think so, when we are doing the transect method is better when we measure during dry season. But on the rainy season using the net is maybe better. So last time, 2014, when we measured during dry season it was not so much garbage we collected because the flow is very low and of course we collected some data but in one hour we collected not so much garbage.

Interviewers: So maybe we could also look at river banks?

Respondent: Yes I think for dry season. Because the people by the river just throw garbage on the river bank and that will flow in the river during rainy season.

Interviewers: Did you publish the data from your research?

Respondent: We just finished the manuscript.

Interviewers: But the research from 2014?

Respondent: Also not yet published because we still try to compare our data now between 2014 and 2017. We just finished collecting the data. Our team that did measurements for the garbage in the river bank just finished last Sunday. Now our team is completing the data for the rivers. Also we measured from the households how many garbage is produced by the household every day and this is completed last month. We also measured garbage in the city, performed an inland survey and we also did interviews. The last measurement of the riverbanks is performed in all, nine, regencies in Bali. We interviewed 700 people. Inland survey for the city of 53 location. We measured 9 rivers in Bali. And we surveyed about 250 households in Bali. This is all within only one research.

Interviewers: But the nine rivers are just in the south west area?

Respondent: No we measured in all regencies in Bali. So we have eight regencies that are facing the ocean. We selected a river in all of these and added one river for control so nine in total.

Interviewers: Did you see big differences between the rivers regarding debris and plastic?

Respondent: We did a survey September last year within the metropolitan city (4 river names). Interestingly there are some differences. Ayung river is used by some rafting operators and is therefore more clean than other rivers in Denpasar. Also in Denpasar for example, if a river is passing through dense population it is a very dirty river so that is a different characteristic. At least different river usage for some people, we can clearly distinguish different characteristics like tourism activity or river passing through city.

Interviewers: Are there also regencies with better waste collection systems or better waste handling so less ends up on the river bank and is handled in a more proper way?

Respondent: Waste management is not so different within regencies. But in Badung and Denpasar, which are big cities and also tourism destinations, they have more money. But there are still problems in the rivers. For example the Mati river that is going through dense population, still has many garbage in the river. So the waste management is still a problem. There are similar problems in small cities in for example the west of Bali. Waste management is not supported by enough money. We don't have good waste infrastructure and management. Actually there should be sanitary landfills but they are still open dumping. Even the biggest landfill in Denpasar is open dumping. They are improving the management since last year but there are still some problems. And also our team was trying to identify illegal dumping in rivers in the last survey. They took a photo and marked the location by GPS and in that way tried to map the illegal dumping.

Interviewers: From December they did a ban on single use plastic, do you see differences? Do these kind of measures from the government help?

Respondent: We cannot measure how different it is right now, but at least now every supermarket doesn't provide plastic bags anymore. Legally it will be less plastic bags in the rivers. But we will see because we already collected data in February to this April and this is actually a baseline you can use. There are two new regulations. The first was implemented in December 2018 by Denpasar city. And the second is regulation by province level (governor of Bali) and this regulation will cover all regencies of Bali and effectively will be fully implemented in June this year.

Interviewers: Yes because there is like a 6 months transition period right?

Respondent: Yes it will be effectively implemented this June. So we tried to gather baseline data before it is fully implemented. Then we need an evaluation after a year or two years. So then we can get the difference. As long as this regulation is still implemented because some organisations are against this regulation like the plastic organisations. They don't agree with this regulation because they can sell less plastic. But as long as this regulation is implemented I think you can see the difference. Because on our work we also tried to ask some people how effective this regulation will be reducing plastic in the daily life of people. And they agree with this and follow this regulation they said.

Interviewers: We also saw that they are maybe thinking about doing a tourist tax. What do you think about that?

Respondent: I heard this last year or couple of years before. Some idea is to take a tax for tourism but this is still on discussion.

Interviewers: Do you think something like this would be a good idea or that it doesn't help much?

Respondent: I think the most important thing is consistency. When the tax is used for this problem I think it will be useful. But sometimes they use it for other things. If the government uses this tax for handling the waste problem I think it will be very useful. So as far as I know the government provides the funding from the regency income less than 1% to this problem, which is very low. If we get more money from the tax it can be very useful. At least providing a proper infrastructure for waste management and also education.

Interviewers: How does the waste management in Bali exactly works right now?

Respondent: Most of them that is like for the big cities like Denpasar and Badung are already providing garbage services and bring it to the landfill. Only this. So only bringing it to the landfill and not recycling or anything. But I think since 5 years a waste bank is operated in Denpasar and also waste pickers collect plastic and then they sell it to the recycling place in Denpasar. Not actually recycling but they are processing the plastic to small pieces of plastic and then bring it to Java and recycle it. 70% of waste from the households is organic material. But we have no good place to compost it. They just bring it to the landfill and dump it over there. Last 2014 or 15 our government tried to process the organic waste to energy. But we still have a problem because it is still mixed. So the sorting from the source is very very important and regulation needs to be implemented for the sorting process at the households.

Interviewers: Yes that they already sort the garbage at the households and it can be collected separately?

Respondent: Yes separation at the households, providing proper infrastructure, provide trucks that will pick up the garbage from the households and then determine which garbage will go to the waste energy, which garbage will be recycled, something like that. First we need to educate the people to sort the garbage in their own household and then simultaneously the government needs to provide proper infrastructure. You cannot do it partially. After sorting by household and then mix it in the truck is not good. That is what happens now.

Interviewers: So some people sort it at the households but it still ends up mixed?

Respondent: Yes.

Interviewers: So has the government not enough money to do it now correctly or is there another issue?

Respondent: Yes so waste is not the number one priority but when this waste problem will disturb our tourism activity it will be a priority. So that's why our government now has this within their top five of priorities. I hope very soon it will be handled by the government.

Interviewers: When do you think you will publish the data you measured?

Respondent: Our work will be presented on June 20th in government office. We invited around 300 people of all regencies and Jakarta. It is like baseline data from us. Maybe we can invite two of you. Remind me close to the date about this. Maybe one or two of you.

Interviewers: Yes would be great! Maybe we are actually doing the same rivers so then we could maybe compare it. (although we measure a little bit earlier in the year.)

Interviewers: Do you know any existing structures in the rivers in Bali, is this used a lot here in Bali, do they have these structures?

Respondent: Yes in Denpasar and Badung there are trash traps in the Mati river and Badung river. As far as I know there are two big traps in the big rivers. They are very big and across the whole width of the river.

Interviewers: Is this effective? That it catches the plastic before it gets in the ocean?

Respondent: Yes without this it would be more dirty. But since I don't have data before I can't compare but of course it will reduce plastic downstream. But during the rainy season and big floods the structures will be opened.

Interviewers: Do you think they should implement this more in Bali?

Respondent: I suggested this to the government. It will be effective to reduce garbage into the ocean but it's very expensive that is why only Denpasar city and Badung can buy this. The other regencies can't afford it. So I asked Badung regency to support other regencies because it's very rich. Because Badung will receive more garbage in Kuta beach if other regencies don't have these structures. And then the tourism activity in Badung will be disturbed so that's why I asked Badung regency to support other regencies so then they will support to reduce plastic onto Kuta beach. Because last year we also had Badung regency to assess the recycling place in Badung regency and they have much money. They also supported some other regencies but I don't know for what. But I said to them please support them for this traps.

Interviewers: What is the biggest reason the plastic ends up in the ocean? Do people everywhere just throw it in the river or is it more in like the northern regencies that they throw it more in the rivers or is it the same?

Respondent: In the questionnaire of last week we have interviewed 200 people close to the river. Not so many respondents said they just throw garbage into the river, maybe 20% of them. But when our team tried to find the illegal dumping in the river we still find many illegal dumping the river. Similar with other locations. Not only in the river but also far away from the rivers. Actually the regulation to prevent illegal dumping is very difficult to implement. Sometimes people throw it in the night time. They feel like at least the garbage doesn't stay in their own house.

Interviewers: Do also businesses and companies dump it in the river?

Respondent: The private garbage services who pick the garbage from the households. Some of the trucks also dump it in the river sometimes. For example the north of Badung is far away from the landfill then they are trying to look for a location to dump it. One regency has to have one landfill. Only Badung regency doesn't have a landfill. Since last year they are planning to make a grand design of waste management in Badung and maybe they will also make a landfill. So only Badung doesn't have a landfill.

Interviewers: Then do the trucks in Badung bring it to a other regencies?

Respondent: They bring it to the biggest landfill in Sew???? But the area of Badung from coastline to the North is far away. So some of the trucks when it is far they just dump in.

Interviewers: So they can't just go to another regency and dump it there?

Respondent: No.

Interviewers: So maybe if you built an extra landfill in that part?

Respondent: I don't know because they are now still making plan to maybe have a landfill in Badung. When last year I had Badung to assess the sorting place (TPST) we also discussed with them that from this data they will make the grand design for waste management.

Interviewers: If we have all the data maybe we could exchange data?

Respondent: So every river you will measure for 1 time or more? And 1 hour or more?

Interviewers: We thought half an hour but maybe based on what you said an hour. Do you think the discharge of plastic changes in the morning and evening periods?

Respondent: For the dry season I don't think it will be different. If you have time and take a video of the measurement that would be nice.

Interviewers: How many times do you think you should measure 1 river?

Respondent: 3 days I think is better. If you can also doing it in the morning, noon time etc.

Interviewers: Do you think the plastic discharge differs between days?

Respondent: I think for the dry season there will not be so much difference. Because as I said before our rivers are not so deep. Then the garbage will be trapped by the stones if it's thrown in the river. Then it will take very long to get downstream because it is trapped. Will you operate the trawl in the downstream?

Interviewers: Yes. We also need a bridge etc.

Respondent: Yes for when we measured the river banks we also needed a bridge to access the locations. Also sometimes when it is dry season and you put a trawl you will most certain hit the bottom.

Interviewers: Yes maybe we will also just count it if it's too shallow for the trawl we will just do visual observations.

Respondent: Yes we also did that last time because it was impossible to operate the net and then we just did counting from the surface. We compared data from net and counting the surface. Are you only doing west of Bali?

Interviewers: No we actually wanted to do more regions to see if there is a difference between these places. You also performed measurements in the North right?

Respondent: Yes. There are only 3 big rivers over there.

Interviewers: Maybe if your data will be published end of June we can compare.

Respondent: Yes because we have different methodologies, like we have measured on the river banks, we can compare. In 2014 I just did rivers in west of Bali and 2017 on whole island.

Interviewers: If you got the data and time to visit us here it would be nice to discuss it. Between the 8th and 20th.

C.2. Interview Paola Cannucciari - EcoBali

Institution	Eco-Bali Recycling
Date	May 6th, 2019
Interviewers	Annemiek van Marsbergen & Sophie Brooijmans
Interviewee	Paola Cannucciari (Senior Program Manager Eco-Bali Recycling)
Location	Eco-Bali Recycling, Badung regency, Bali, Indonesia

Interviewers: Is EcoBali the only waste collector or are there more companies like ecoBali in Bali or does the government also collect waste?

Respondent: We are the only company in the area that collect waste that already is sorted. The others are just collecting waste that is mixed, nobody is doing anything even the government. Nobody is sorting at the houses, except our clients. We do have a pre sorting system. For the organic waste we have composting systems we are able to provide to clients that are interested. And we have been doing this since 2006, actually a little bit before that. At the beginning we didn't have a sorting facility but we have one since 2010, so this is our second location. We collect waste that is pre-sorted and than bring it here, than it is sorted again. In specific categories and from categories it goes directly in the recycling. And only the residu goes into the landfill.

Interviewers: Is their only one landfill on the Island and is it government regulated?

Respondent: Each regency has there own one. Except Badung and city of Denpasar, they are actually together. They have one landfill, which is the one in Sarangan. This has been our main thing but if we look into our mission it is working towards zero waste in nature and to landfill basically. So we are looking for continuous solutions for different packages, because the waste and organic waste that is present for us is mostly coming from so called domestic waste, so we are not dealing with industrial waste. Because there are no industries here in Bali. And so we are looking into finding odd solutions in order to increase the number of recyclables or categories of recyclables to decrease the residu to the landfill. That's the way we work. In order to achieve this and then we also create partnerships with brandowners like Danone and Body Shop to get their support. On top of this we have programs for schools. We have been activating at pretty big networks of waste banks as well. And recently we ought to do work with the government, a proper actual partnership.

Interviewers: And the government is willing to help you?

Respondent: The government is not helping, it is working together. The supporters are enabling us to do the work under their program. Our system is a bit more refined than what they have. At the waste banks for example we work together, they have been asking us to take care of that on their behalf.

Interviewers: So you are seeing that the government is willing to help with the problem?

Respondent: Recently yes. Not fully getting there, but yes. We can't say like in the past that they are doing nothing, we can't say that anymore. They are not there yet, but they definitely have any rule with a strategy.

Interviewers: they also have a ban on single use plastic, do you see that that is working? We have read that producers and businesses have 6 months to replace items with alternative materials, so do you already see a change?

Respondent: Yes. definitely. I mean all the supermarkets and all that. You don't get a plastic bag, it is a successful thing to do. We hope it stays like that.

Interviewers: We have also read that authorities in Bali are planning to implement a Tax for tourism of 10 dollar? What do you know about the tax and do you think it will help?

Respondent: No. I don't know from which department it is coming from. It is not what we are involved into. It is more an idea that is travelling around for a couple of years.

Interviewers: Which rivers/areas on Bali do you think have the most plastic discharge? What are possible areas where the plastic origins?

Respondent: I cannot tell you which is the one that discharges the most plastic. I can tell you that virtually every river discharges a lot of waste. Each year during rainy season definitely.

Interviewers: Are there certain areas on the island that are known to discharge the most?

Respondent: As far as I know all of them actually bring plastic and every single river discharges plastic, as long as there is enough population.

Interviewers: All the regions have different systems for waste collection right?

Respondent: Yes, but in the end of the day they are all very similar and they are all avoiding the fact that people are used to throw the waste into the river or in bins that during the rainy season actually gets washed up there. There is no big difference between the regencies. They are all similar.

Interviewers: do you operate on the whole island?

Respondent: It's too far away, so only the southern part. We are up to Ubud, we are up to outside Denpasar and all the way down to Nusa Dua and Uluwatu and Canggu. Big area.

Interviewers: In the other areas there is not a company like yours so then the government has to collect it?

Respondent: Yes but also the government has to collect on our area. We don't have the means to cover the whole area, our portion is very small. Our service is based on product demand. So it's not that we are covering full areas. In terms of massive impact it might not be easy to calculate.

Interviewers: Do you see that your price is too high for certain households?

Respondent: That's the reason why we go to the waste banks, for the others that are not willing to pay that kind of money. It is important that they pay that kind of money, otherwise it is unsustainable. We don't have the government to subsidies. Our service is at realistic costs. And for the community, that's the reason why we work with the waste bank.

Interviewers: Do you see that a lot of people don't want to pay for it?

Respondent: It's a niche thing. A lot people think they shouldn't pay that much.

Interviewers: When they don't pay for it, what do they usually do with their waste?

Respondent: They either choose another collector or they collect with the government or they throw it in the back of their house or they burn it. Whatever.

Interviewers: Is there one service that is used the most among the services that you offer?

Respondent: Yes. The two-bin system is the one that is used the most. The composting system is still of lower numbers, because people are afraid that it smells or that it attracts vermin and all that. So we are still trying to convince people that it is actually the best way to go.

Interviewers: But overall you have a lot of clients?

Respondent: We have more than 1300 clients.

Interviewers: Are these clients households?

Respondent: Like mixed with businesses.

Interviewers: Is this here your own sorting and material recovery facility (MRF)?

Respondent: Yes. Everything that we collect comes here. It is separated in here and then it is all dealt with in here. We don't have another facility.

Interviewers: And then you look for the recyclables?

Respondent: We collect the recyclables and then we sell it to factories. Factories in Java, that is where it goes.

Interviewers: We have read that there are no real large facilities on Bali, right?

Respondent: Not even a small one.

Interviewers: So everything goes to Java?

Respondent: Yes.

Interviewers: Do you think that that is a good way or should they also have a facility in Bali?

Respondent: In Bali it is very expensive, since it is a touristic place. Also because ones you put together factories that actually need to deal with single items, the flow of material that you are able to catch might be not enough on (what comes from) the island. It means that you need to collect way more, so it is not a successful business. There was one company in Bali that was collecting and transforming plastic bags and they moved to Java.

Interviewers: Do you know any existing structures that capture plastic in rivers (used by authorities)?

Respondent: There are a few grids around the rivers but they are mostly open. You would be much better of talking to the government about this. I think there is a push from the central government to start people looking into this direction, with regard to plastic waste in the sea and rivers. Some of the rivers have been improved here. There is a department that has a whole programme about that. There is a push from more central to the lower level.