Type of the Paper (Baseline Records of Contamination Levels)

Filling in the knowledge gap: Observing MacroPlastic litter in South Africa's rivers

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Received: date; Accepted: date; Published: date

Abstract: Only 12% of the world's published plastic research includes references to Africa despite it being a significant contributor to the global plastic waste and mismanagement problem (~88.5% of Africa's plastic waste is mismanaged). Ocean plastics are transported from land by rivers to the sea. However, source contextualization is complex. Many African rivers predominantly run alongside human settlements that host informal waste dumpsites. In this study a simple cost effective, easily deployed, consistent and replicable survey methodology was employed. The study quantified macroplastic in three rivers discharging into Algoa Bay, South Africa. The results indicated that industrial Swartkops and metropolitan Baakens Rivers both illustrate moderate plastic pollution (>3000 plastic particles/day), with the relatively natural Sundays River to showing minimal evidence of river macro plastic (<100 plastic particles/day). The types of plastic were noted using the RIMMEL app (premier African implementation), enabling proportional comparison of different plastic litter types to be completed.

Keywords: macro-plastic; South Africa; river monitoring; RIMMEL app; visual monitoring

Highlights:

- Many rivers in significant plastic pollution contributing countries are unsurveyed

- RIMMEL provides a simple, consistent method to quantify river macroplastic
- Provision of the first plastic counts for 3 Port Elizabeth rivers, South Africa

Rivers are a widely acknowledged source of oceanic plastic pollution. Studies of oceanic plastic pollution have resulted in a social and political drive to quantify, characterize and invoke action to prevent marine plastic pollution. As a result, in the past decade, a growing number of studies have been undertaken to quantify river macro, meso and micro plastic being washed to the sea. There is a growing knowledge of rivers' contribution to this marine plastic waste, but knowledge and data gaps exist, especially in lower socio-economic areas, challenging community and environmental locations.

The growing body of knowledge on river macroplastic pollution initially focused on European and north American/Canadian rivers. More recently, studies extended to consider Asian rivers, and several of the top 100 world largest rivers (by discharge) have been analyzed, including Yangtze and Danube rivers (Milliman and Farnsworth, 2013). However, to date very little is reported on river plastic pollution in the African continent (Nel and Froneman, 2015; Ryan, 1988), with studies undertaken on the Vaal River (Bouwman et al., 2018), Gauteng Rivers (Bouwman et al., 2018), Crocodile River (Umlauf, 2019), estuary surface and sediment (KwaZulu-Natal) (Naidoo et al., 2015), marine waters and coastal environs (Nel and Froneman, 2015; Ryan, 1988; Ryan et al., 2018).

Africa is a significant contributor to the global plastic waste and mismanagement problem. Of the estimated 80Mt plastic mismanaged globally in 2015, approximately 21% occurred in Africa (Lebreton and Andrady, 2019). Approximately 88.5% of Africa's plastic waste is mismanaged, above the global average of 47% (Lebreton and Andrady, 2019). There is the potential for a proportion of this waste to enter the river network and be transported to the surrounding marine environment. However, there are few quantitative plastic pollution studies completed across Africa and therefore a knowledge gap and lack of baseline information. A review of published literature (Google Scholar) highlights this, with 12% of all published papers or research on macro, meso and micro plastic including consideration of Africa, and only 11% of plastic pollution studies include a reference to Africa and rivers.

Many field methodologies have been used to quantify river plastic pollution at a macro to micro scale. These include a variety of drag nets (neuston, mantra and other nets) being towed behind boats or hung in place within a river flow, water sampling (water collection and sieving/filtration and microplastic counting) (Barrows, 2017; Liedermann et al., 2018; Mai et al., 2018; Priyanka and Udayashankara, 2018), and visual counts (using basic visual recognition and applications on computers/tablets/phones) (Golumbeanu et al., 2017; González-Fernández and Hanke, 2017; González et al., 2016; Jambeck and Johnsen, 2015; Zettler et al., 2017). Macroplastic (>2.5cm) in rivers is easily visible, identified often as plastic in its' original form (e.g. bags, bottles) (Blettler et al., 2017; Lee et al., 2015). Macroplastic is visible in river flow if the observer is standing close to the water (≤10m) and the plastic is in large pieces (Crosti et al., 2018; González-Fernández and Hanke, 2017). Mesoplastic (5mm-2.5cm) is less easily visible in river flow but can be identified when using a net or river sample method to collect the plastic in the river flow (detailed in supplementary information). Microplastic (1µm-5mm) is very difficult to identify visually in moving river flow and requires physical sampling (water sampling/net plastic collection) and analysis (Hurley et al., 2018a; Li et al., 2018).

The European Commission Joint Research Centre (EC JRC) is one of several research networks created to address the knowledge gap in plastic pollution (marine and/or freshwater). Within this network, the RIMMEL project has created the JRC Floating Litter Monitoring Application (RIMMEL app) (EC JRC et al., 2016; González-Fernández and Hanke, 2017). This app, to be used on a tablet or mobile phone, provides a GPS and time stamped record of plastic identified, and importantly identifies not only its type, but also the size of the plastic found. The data collected by RIMMEL is standardized due to the applicants' data collection methodology and is in use across 36 scientific institutes, authorities and organizations in 17 (primarily European and Mediterranean) countries. The RIMMEL app is European Commission supported, widely accepted data collection tool and was designed for global river plastic pollution data collection.

Physical field monitoring of three rivers in the Port Elizabeth (South Africa) area was undertaken during the summer of 2019 (January – March). Port Elizabeth is located in the Eastern Cape and forms part of the Nelson Mandela Bay Metropolitan Municipality, the second largest metropolitan district in South Africa. The major port city of Port Elizabeth is comprised of a strong economic, cultural and financial center, affluent urban development area (surrounding Baakens River) and intense industrial area and inland township community (surrounding Swartkops River). Surrounding Port Elizabeth city are natural wilderness spaces including Addo Elephant National Park (to the north east and adjacent to the Sundays River). Visual recording following the RIMMEL app methodology (Castro-Jiménez et al., 2019a; Crosti et al., 2018; González-Fernández and Hanke, 2017; Schirinzi et al., 2020; Schöneich-Argent et al., 2020) in conjunction with complementary river sample collection in each river was undertaken at three monitoring locations on three major rivers near Port Elizabeth (see supplementary information for further details). It is also acknowledged that tablets, large screen phones or field computers may not always be available in resource limited research departments or safe to use in certain areas. A paper version of the RIMMEL app specifically for the recording of plastic pollution was therefore created and tested alongside the tablet RIMMEL app. This was done to ensure that, in areas where using tablets is unsafe, or for monitoring teams without access to tablet or mobile technology necessary to run the app, the visual monitoring could still be completed.

The three rivers (Figure 1) were selected as they provided an overview of the Port Elizabeth river conditions, from intensely industrialized, modified and polluted to relatively natural and undeveloped. A tabulated summary of the study river's characteristics is provided in the supplementary material.

Figure 1. Port Elizabeth river sampling sites, and their contributing catchments.

The Swartkops River extends ~134km with a catchment area of >1360km^2 (Figure 2). Prior to industrialization of this catchment, the Swartkops Estuary was identified and qualified as a RAMSAR (wetland of international importance) site (1980's), however this qualification has since been downgraded due to pollution and modification of the salt pans/salt industry use of the estuary (BirdLife International, 2002). The Swartkops River runs through urbanized and industrial regions of Port Elizabeth (Binning and Baird, 2001). It is the most heavily industrialized river in Port Elizabeth and was selected to represent a high anthropogenic impacted river. Plastic waste mitigation strategies implemented in the Swartkops River such as drain outlet baskets have since been deployed at the Motherwell Township, however down river is at risk of storm water runoff, flood events, and strong winds depositing plastic waste from the informal dumpsites and townships closer to the Swartkops River mouth. The Zwartkops Conservancy, an education and conservation NPO, also actively undertakes litter cleanup campaigns across the lower sections of this catchment, collecting 14,700 bags in 2017 and 14,400 in 2018 (50L bags, ~6kg/bag). During the January and February period of this studies field work, the Zwartkops Conservancy collected 1317 and 1165 bags of litter from the lower Swartkops Estuary area. There are also multiple stationary litter traps along several of the semi-canalized tributaries to this river, upstream from the monitoring location. These are infrequently emptied (~quarterly) and are constructed to detain approximately 5-7m^3 of litter including plastic.

Figure 2. Wyle "Colour" Bridge sampling location on the Swartkops River.

Sampling was undertaken at the 'Colour Bridge', a road bridge located 5km from the estuary river mouth. The river is both fluvial and tidal at this location. Monitoring was completed in the thalweg of the flow (near central location on the bridge) during peak outflow (the 3rd and 4th hours after the top of the tide).

The Sundays river is a long (>250km) meandering river with very little urban development or industrialization along its banks. The river has not been canalized, and for a portion of its lower reach it flows through/alongside the Addo Elephant National Reserve (game reserve). The river is the largest and most natural in the Port Elizabeth area, with the river estuary/mouth and surrounding sand dune area under conservancy management (nature reserve) (Figure 3).

Figure 3. Old Main Road Bridge sampling location on the Sundays River

The monitoring location was on a disused road bridge located 11km upstream from the river mouth. The location is influenced by both tidal and fluvial flow. The central thalweg was monitored in the same manner as the Swartkops River, during the strongest discharge period of the outgoing tidal period (a downstream flow condition influencing the discharge rate at the bridge).

The Baakens River is a highly modified urban river that flows through the Baakens Valley and central Port Elizabeth urban area. The lower section of this river has been canalized, and the upper reaches are within a riverine parkland area. The rivers tributaries collect storm water from much of the high socio-economic urban areas of Port Elizabeth and the Walmer golf course.

Figure 4. Footbridge sampling location on the Baakens River.

The field monitoring was undertaken on a small pedestrian bridge in the lower reach of the Baakens River (Figure 4). The location was 1km from the river mouth but above the tidal influence on this river (the river bed rises above the tidal influence approximately 500m from the river mouth). At the monitoring location, the river has been artificially straightened. It is grassed on the southern bank (an artificial flood plain) and planted with reeds on the northern bank. The river is narrow (<3m wide) and shallow (<2m deep, average daily flow) but has a gravel or concreted bed and is relatively fast flowing (compared to the Swartkops and Sundays Rivers).

The visual macroplastic monitoring methodology designed and previously pilot tested by EU JRC (Crosti et al., 2018; González-Fernández and Hanke, 2017; González et al., 2016) was adopted for this research. At each location and during each monitoring period, one person visually monitored and recorded macroplastic moving down the river using the RIMMEL app and a second person completed the same task using a paper version of the RIMMEL app (available in the supplementary information). The two visual plastic ‘spotters’ worked in isolation and did not confer or support each other in sighting or identification of the plastic particles.

To undertake the visual assessment of macroplastic transported down the monitored rivers, the monitoring location upstream from the river mouth (with fluvial flow) was selected where a vantage point centered over the river was available (e.g. a bridge, preferably ≤ 10m above the water surface). To complete the visual monitoring, the ‘spotter’ stood in the selected monitoring point on the bridge, looking upstream, and recorded all plastic that moved under the bridge within a designated ‘observation track’ over the monitoring period (Figure 5).

Figure 5. Visual observation track and monitoring location selection used to collect RIMMEL app data (Sundays River Old Main Road Bridge example). Modified from Figure 1 in (González-Fernández and Hanke, 2017).

The visual monitoring point was specific to the location, aimed to provide a representative observation track for each river (e.g. from river bank to river center). Baakens River width at the monitoring location was small, < 3m, therefore the entire width of this river was included in the observation track. The Sundays River is wide (85m) and the bridge elevation is at the upper limit appropriate for visual plastic identification. The observation track was therefore limited to 10m and spanned from the center of the river back towards the river bank. The Swartkops River is also relatively wide (110m), but the bridge is ~4m above the water surface and has a comparatively slow flow velocity (<0.4 m/s). The observation track for the Swartkops River at the Colour Bridge of 15m was selected. A minimum of 7 individual monitoring surveys were completed at each of the river monitoring locations during the January-March period of 2019.

The RIMMEL app has a GPS location macro, enabling automatic latitude and longitude recording if the device (e.g. tablet) has a GPS. For the paper version of the RIMMEL and devices without GPS enabled, the location can be identified using a handheld GPS or though geographic information systems (e.g. ESRI or google maps/google earth). The app also requires the observer elevation and observation track to be noted, alongside the river width and flow velocity.

The flow velocity is ideally monitored using a calibrated flow meter. However, where such equipment is unavailable, the float method can be used to estimate river flow velocity and calculate discharge. To undertake the float method test, collect a piece of natural detritus such as a stick. At the upstream edge of the bridge, release the stick into the central flow of the river. Monitor the time taken for the stick to pass beneath the bridge (a known and measured width). The flow velocity can then be estimated (time (sec)/distance (m)) multiplied by a friction correction (Harrelson et al., 1994)). The float method test needs to be repeated multiple times to improve the accuracy in measurement, and needs to be completed a minimum of three times during the 2 hour monitoring period (start, 1hr, end). To accompany the flow test information, cross section survey of the river was completed to determine the flow, depth, area and the elevation of the bridge above the water surface (Figure 2Figure 3Figure 4).

The average plastic particle count/day was calculated from all monitoring periods (n=7) following the methodology specified in (Crosti et al., 2018; EC JRC et al., 2016; González-Fernández and Hanke, 2017; van Emmerik et al., 2018). Representative daily plastic particle counts were calculated using the reported relative daily discharge for the three rivers and the recorded flow during the monitoring periods. These values were then extrapolated to provide an indication of the potential annual plastic particle flow down these rivers at the monitoring locations (Figure 6).

Figure 6. The count of meso and macroplastic transported down the monitored rivers from RIMMEL and complementary visual counts completed at the monitoring location. Figure 8a presents the relative daily counts of plastic particles for the monitoring locations; Figure 8b extrapolates these results to a tentative estimate of the possible annual, non-flood plastic particle discharge.

Initial analysis indicated that Swartkops and Baakens rivers both illustrate moderate plastic pollution (>3000 plastic particles/day), with the relatively natural Sundays River showing minimal evidence of macro and meso plastic in the river water (<1000 plastic particles/day). All rivers illustrated the presence of meso plastic as well as macro plastic. The Baakens River was noted to present a larger proportion of macroplastic relative to the Swartkops and Sundays Rivers. However, the upstream area of the Swartkops River is supported by plastic cleanup activities (Zwartkops Conservancy pers comm, Dale Clayton 31st March 2019). The Zwartkops Conservancy collected over 2480 bags of litter from the banks of the Swartkops River. If no litter collection had occurred during the monitoring period, it is suggested that the quantity of macro plastic recorded for the Swartkops River would be notably greater. The 'Swartkops without cleanup' values illustrated in Figure show the potential increase in macro plastic conveyed down the Swartkops River if only 1 piece of plastic waste from each of the 2482(~6kg each) litter bags was transported by the river.

The types of plastic were recorded using the RIMMEL app, enabling proportional comparison of different plastic litter types to be completed. The plastic identified in the Sundays Rivers was small (~5cm in size) and brightly colored, however the determination of the plastic origin (e.g. food wrapper, plastic bag etc.) was not always clear (as the particles were often fragments of the original plastic product) and therefore a greater number of identified plastic particles were classified as ‘plastic pieces’ to prevent incorrect logging of plastic type.

Figure 7. Proportion of plastic by type

The majority of identifiable macroplastic was found to be plastic packaging and food wrappers/packaging. There were a greater number of plastic bags and foam pieces (from packaging and construction) found in the Swartkops River, than the Sundays or Baakens Rivers. The Baakens River presented a larger quantity of plastic sheeting or film (from packaging).

The macro and mesoplastic particle sizes ranged from ~5mm to >50cm. The larger proportion of collected plastic falls within the mesoplastic category (FigureFigure). Of the macro plastic counted, the plastic particles were generally at the smaller end of the size range. Similar to previously published studies on plastic particle size, the particle size found in the monitored rivers follows the (exponentially) increasing trend, showing greater particle counts as the particle size range decreases (Cai et al., 2017; Gasperi et al., 2018; Schymanski et al., 2018). The results suggest that the quantity of mesoplastic pollution is approximately twice that of the macroplastic pollution in the monitored rivers.

Figure 8. Particle size of monitored plastic

The plastic monitoring published for South Africa coastal waters (macro, meso, and microplastic counts) ranges from ~200 up to >300,000 plastic particles/m^3 (Bouwman et al., 2018; Naidoo et al., 2015; Nel and Froneman, 2015; Verster et al., 2017), with highly urbanized and developed catchment rivers showing up to 56 MP/L (Bouwman et al., 2018). The quantity of macro- and mesoplastic identified in three rivers within this study show significantly lower quantities of plastic compared to sampled South African coastal waters. However, it is important to note that the size range considered in this study is limited to 5mm and therefore does not include microplastic particles (microplastics are included in many of the aforementioned studies). It is also acknowledged that the results reported in this study are a first insight into the plastic quantities in the monitored rivers and that a longitudinal study is necessary to ensure all environmental conditions and seasons are included in the monitoring to provide greater accuracy in the generalized plastic river discharge estimates.

The field monitoring results have been compared to the global published data of plastic in freshwater (with the inclusion of standard samples for wastewater and drinking water for reference). The monitored rivers illustrate plastic quantities in the 30th and 35th percentile of the published plastic quantities (Figure). Initial monitored plastic quantities from the three monitored rivers suggest these rivers to convey plastic pollution to the ocean, but that they are not among the most polluted rivers monitored and reported to date.

Figure 9. Comparative plastic quantity (MP/m^3) from the Port Elizabeth field study, reported MP quantities from rivers around the world and representative waters (receiving bays, wastewater and drinking water) (Anderson et al., 2017; Baldwin et al., 2016; Bouwman et al., 2018; Castro-Jiménez et al., 2019b; Cheung et al., 2018; Dris et al., 2015; Faure et al., 2015; Fischer et al., 2016; Free et al., 2014; Gasperi et al., 2014; Hurley et al., 2018b; Kosuth et al., 2018; Lima et al., 2014; Mani et al., 2015; Mason et al., 2016; Mccormick et al., 2014; Moore et al., 2011; Rech et al., 2015; Sadri and Thompson, 2014; Schymanski et al., 2018; Su et al., 2016; Tibbetts et al., 2018; van der Wal et al., 2015; Vermaire et al., 2017; Wang et al., 2017; Zhao et al., 2015). The three field study rivers are highlighted in black. The location of the freshwater plastic sample locations reported (blue) and from this study (black) are presented in the map inset. It is noted that the results tentatively compared here are not representative of a set size range of plastic particle or piece, but are provided for an initial indicative consideration.

Further studies though South Africa and Africa in general are needed to help address the research gap in river plastic pollution transported to the oceans, but this study provides a first step towards addressing this knowledge gap. The RIMMEL app and complementary visual counting is effective in monitoring macro- and mesoplastic respectively in these small to moderate sized rivers in locations where advanced monitoring methods are not available and provides data consistent and comparable to that collected and reported in Europe and other countries. It is noted that due to the success of this survey in Port Elizabeth, This protocol has been adopted by a 7 African research groups of the West Indian Ocean Marian Science Association (WIOMSA in conjunction with the African Waste Network). The research teams, from (Kenya, Madagascar, Mauritius, Mozambique, Seychelles, Tanzania) have formed a trans-Africa research consortium who will monitor river plastic pollution using these survey techniques over the next 2 years. This is a strong inroad to addressing the knowledge gap in African river plastic pollution and the quantity of surface river plastic being conveyed to the oceans and marine environment.

Supplementary Materials: All data discussed in this paper is available within the manuscript.

Author Contributions: K Moss, D Allen and S Allen conceptualized the research project. K Moss, D Allen and S Allen undertook the field monitoring, data analysis and manuscript writing. D González-Fernández designed the RIMMEL app and provided the analytical support to the RIMMEL data.

Funding: This research was funded through the Association of Commonwealth Universities (ACU) Fellowship awarded to S Allen. The African Waste Network hosted the ACU fellow. EU JRC funded the development of the RIMMEL app. Additional support was provided by the Leverhulme Trust (ECF-2019-306).

Acknowledgments: This research was supported by the University of Strathclyde’s Department of Civil and Environmental Engineering, WESP, the Commonwealth Blue Charter Fellowship (ACU), the African Waste Network and Nelson Mandela University as well as the University of Cadiz.

Conflicts of Interest: The authors declare no conflict of interest.

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Figures and tables

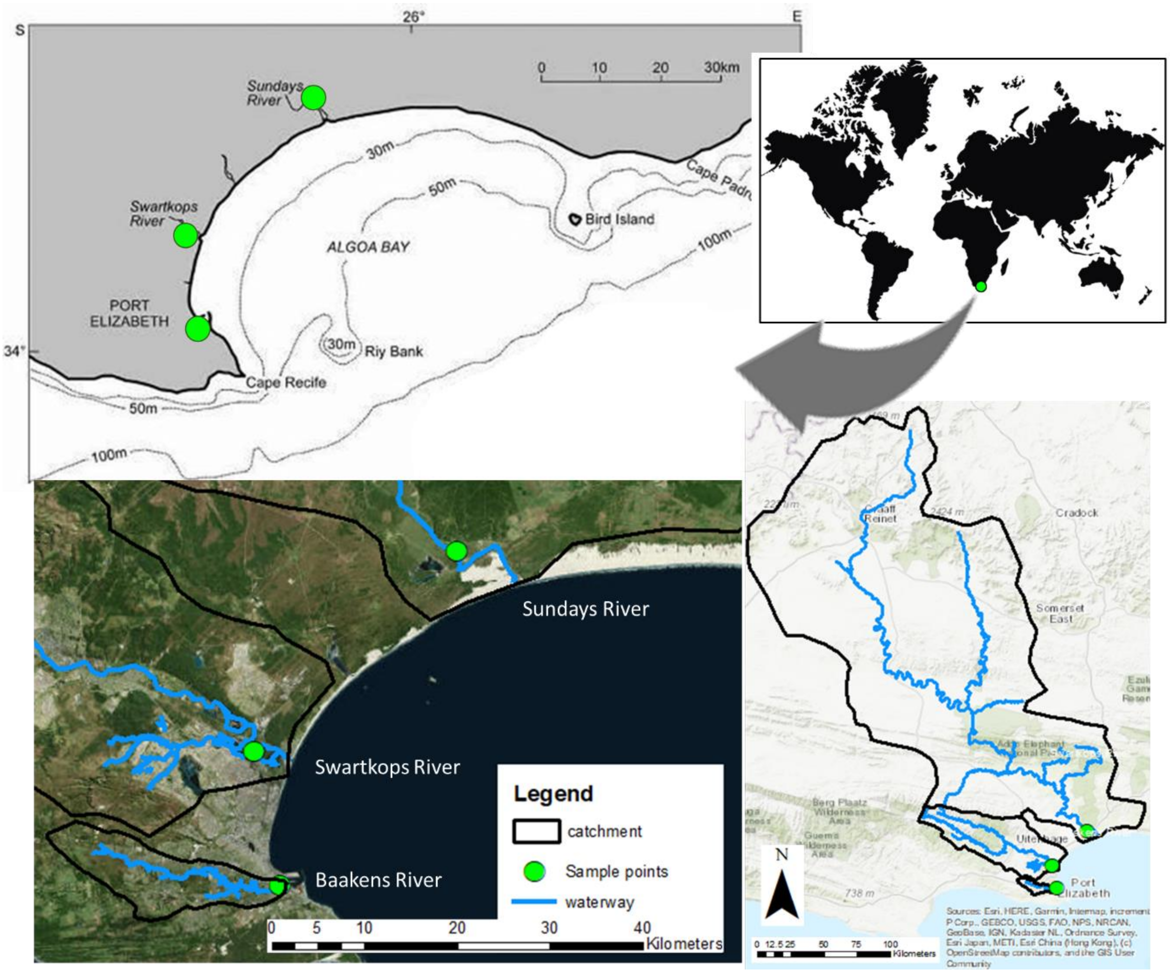

Figure 1. Port Elizabeth river sampling sites, and their contributing catchments.

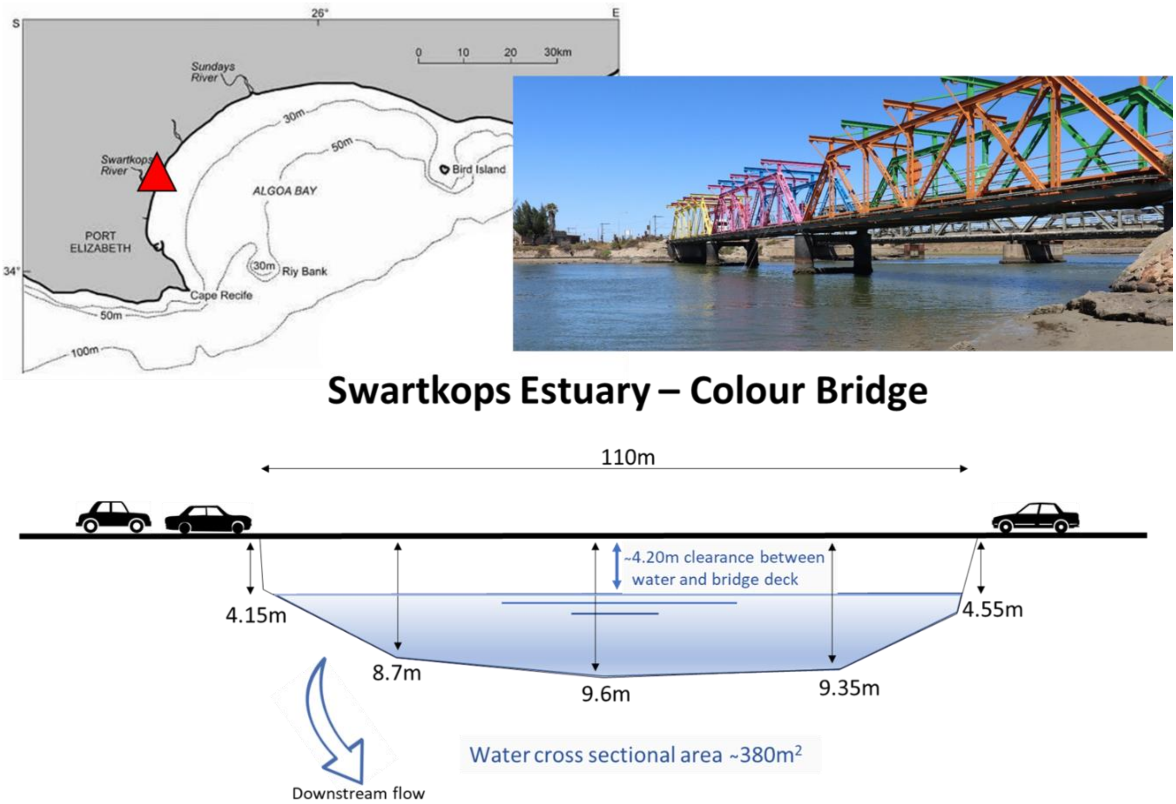

Figure 2. Wyle "Colour" Bridge sampling location on the Swartkops River.

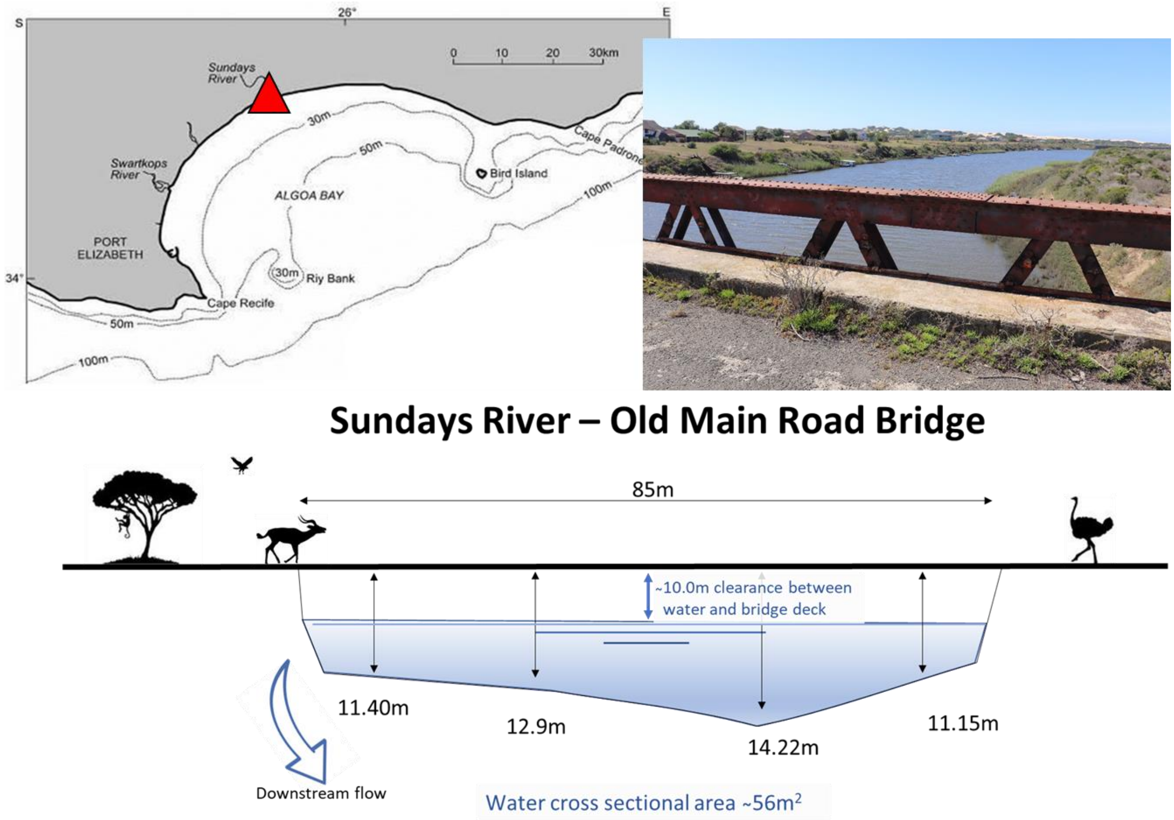

Figure 3. Old Main Road Bridge sampling location on the Sundays River

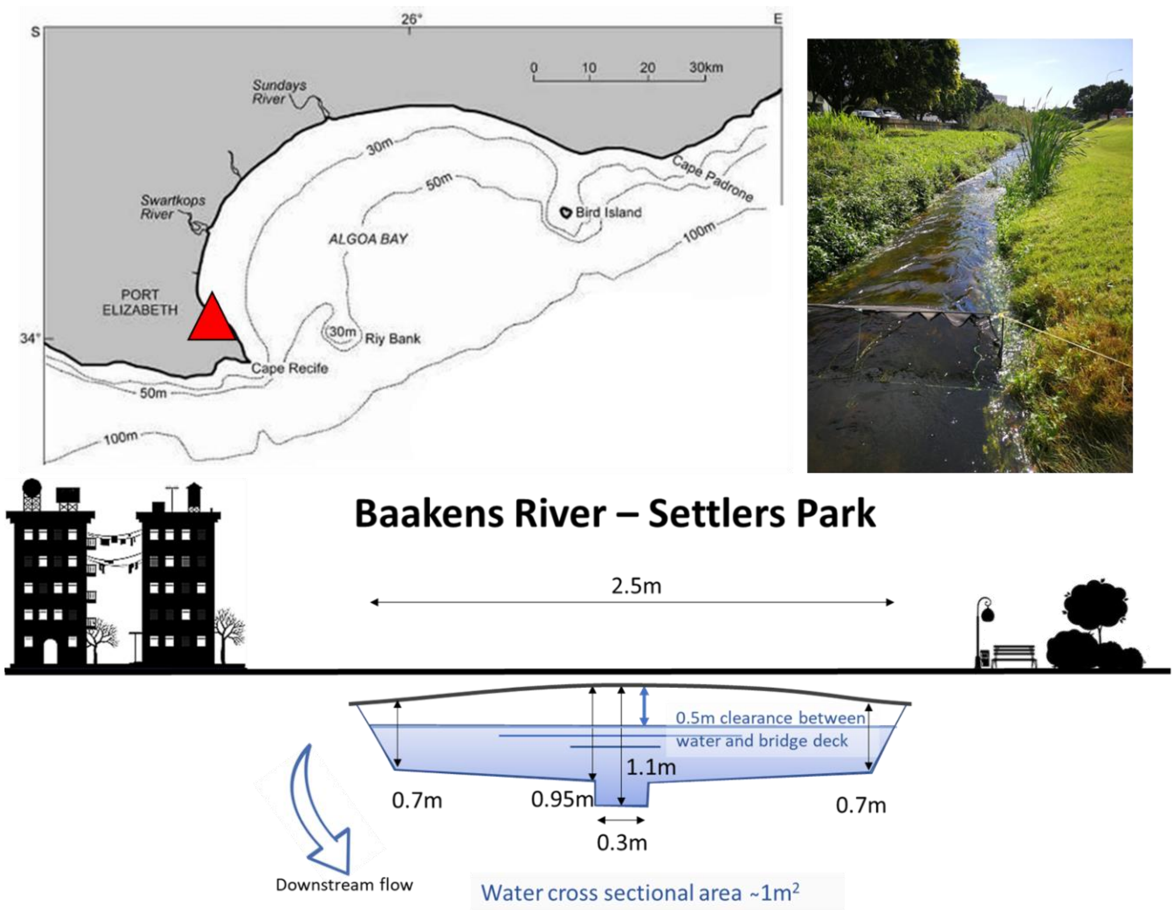

Figure 4. Footbridge sampling location on the Baakens River.

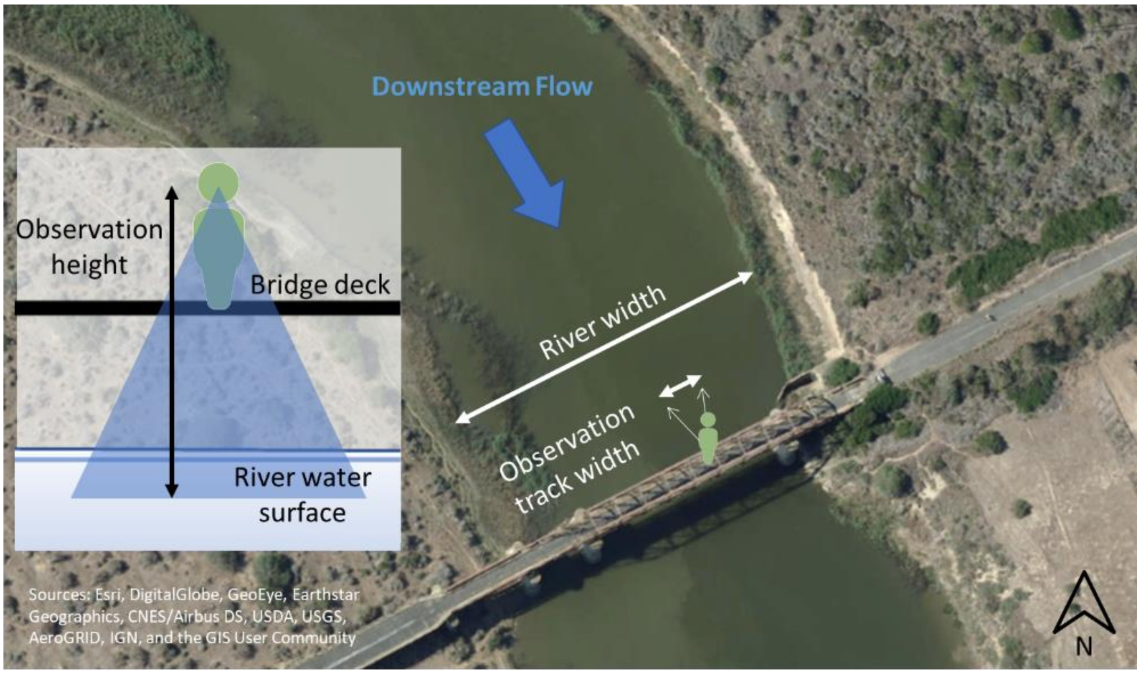

Figure 5. Visual observation track and monitoring location selection used to collect RIMMEL app data (Sundays River Old Main Road Bridge example). Modified from Figure 1 in (González-Fernández and Hanke, 2017).

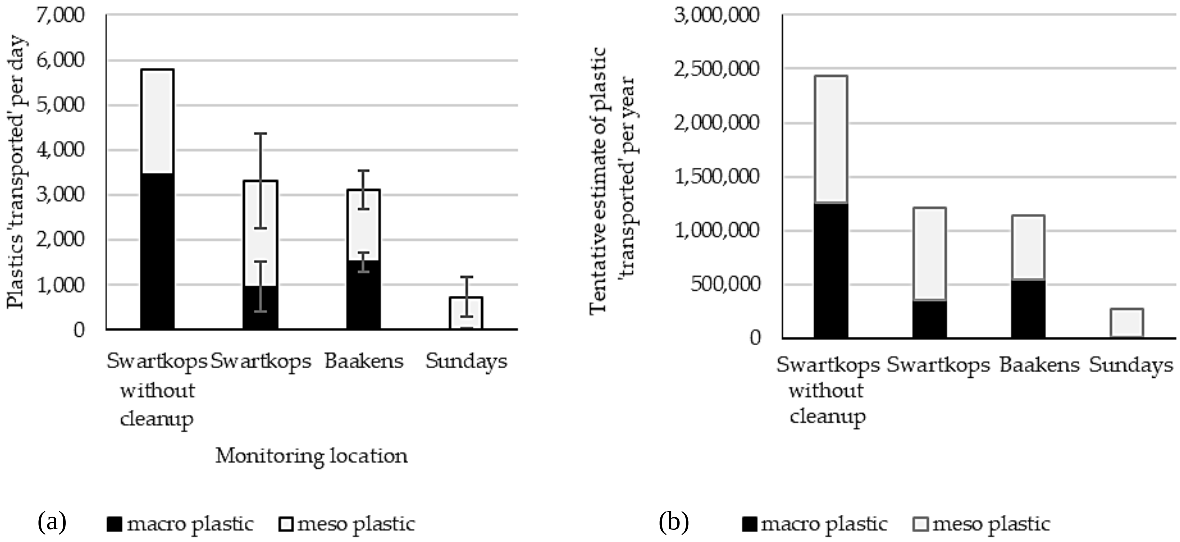

Figure 6. The count of meso and macroplastic transported down the monitored rivers from visual counts completed at the monitoring location. Figure 5a presents the relative daily counts of plastic particles for the monitoring locations; Figure 5b extrapolates these results to a tentative estimate of the possible annual, non-flood plastic particle discharge.

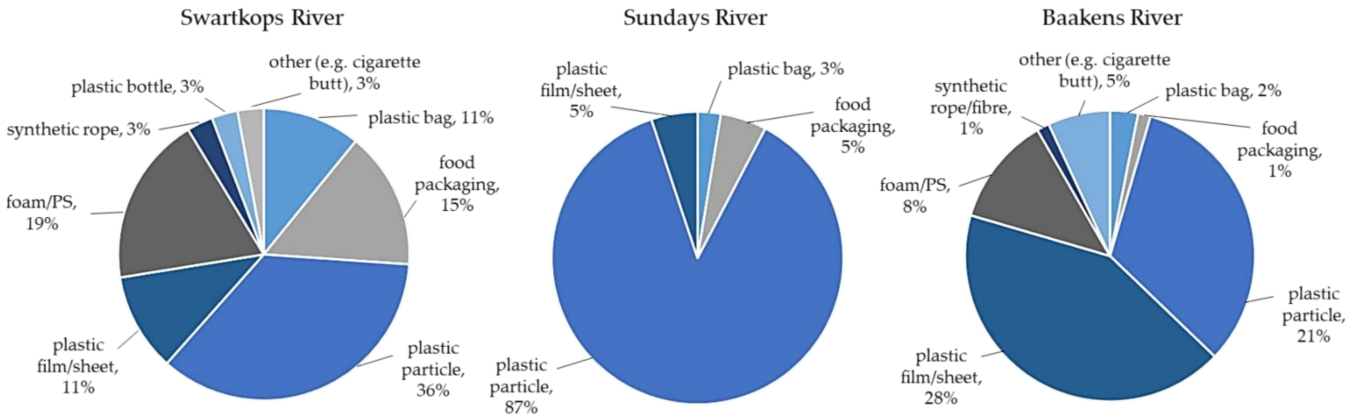

Figure 7. Proportion of plastic by type

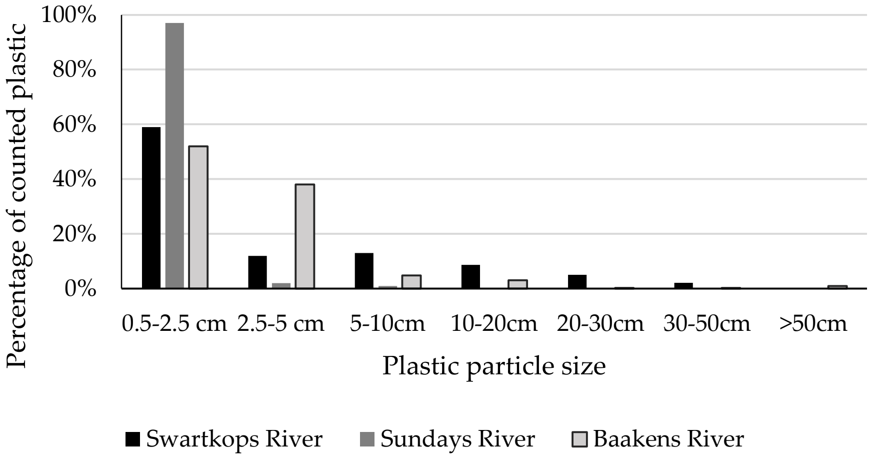

Figure 8. Particle size of monitored plastic

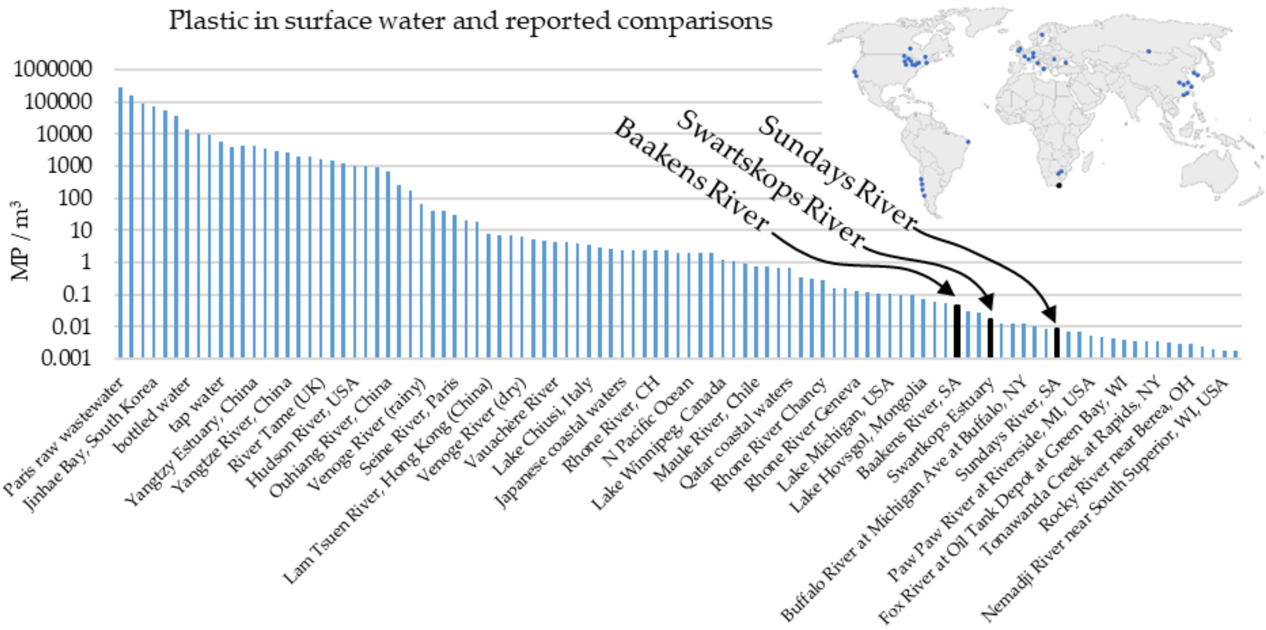

Figure 9. Comparative plastic quantity (MP/m^3) from the Port Elizabeth field study, reported MP quantities from rivers around the world and representative waters (receiving bays, wastewater and drinking water) (Anderson et al., 2017; Baldwin et al., 2016; Bouwman et al., 2018; Castro-Jiménez et al., 2019b; Cheung et al., 2018; Dris et al., 2015; Faure et al., 2015; Fischer et al., 2016; Free et al., 2014; Gasperi et al., 2014; Hurley

et al., 2018b; Kosuth et al., 2018; Lima et al., 2014; Mani et al., 2015; Mason et al., 2016; Mccormick et al., 2014; Moore et al., 2011; Rech et al., 2015; Sadri and Thompson, 2014; Schymanski et al., 2018; Su et al., 2016; Tibbetts et al., 2018; van der Wal et al., 2015; Vermaire et al., 2017; Wang et al., 2017; Zhao et al., 2015). The three field study rivers are highlighted in black. The location of the freshwater plastic sample locations reported (blue) and from this study (black) are presented in the map inset.