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# Influence of different Wastewater Treatment Processes on the rate and characteristics of MPs released from WWTPs in Fiji, South Pacific

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## Abstract

The global effects of MP (MP) pollution on the environment are concerning, and they are exacerbated by the multiple sources of pollution in aquatic environments such as urban runoff, waste mismanagement, industrial pollution, and so on. South pacific islands host a large diversity of aquatic flora and fauna and given its ecological significance it is necessary to identify the sources of MP pollution in the region. To date, very little attention has been given to identify whether effluents from wastewater treatment plants (WWTP) are acting as a significant source of MP in the South Pacific region and its countries. Therefore, the present study analyzed and compared the treatment methods and fate of MPs in the country's two main WWTPs: 1) the Kinoya WWTP (simple secondary clarifier and trickling filter) and 2) Natabua WWTP (secondary pond treatment system). Sampling locations were based on the different treatment stages, and samples were collected from each stage of treatment before effluents were released into the ocean. Kinoya WWTP had an average of 3.45 ± 0.3 particles/L in the inlet stage and released an average of 0.3 ± 0.26 particles/L of MP through the outlet with 91% removal efficiency (RE) with an output equivalent of 4500 particles per day. The initial stage of treatment from the anaerobic pond outlet at Natabua had an average of 2.9 ± 1.05 particles/L, and the maturation outlet had an average of 0.53 ± 0.42 particles/L, a removal efficiency of 81% and thus an output equivalent of 4558 particles/L of MP. Polymer analysis under FTIR confirmed that cellophane or semi-synthetic cellulose and polypropylene were common polymers in the final effluent in Kinoya WWTP, and Natabua plant has cellophane or semi-synthetic cellulose, polypropylene and polyethylene were observed as common polymers. Although there are numerous study that have compared wastewater treatment processes, this is the first study in Fiji that investigates the efficiency of the two methods of water treatment process in the context of microplastic pollution and emphasizes the effectiveness of the treatment stages in determining the concentration of MP released into the ocean.

**Keywords** Wastewater treatment, Plastic pollution, Secondary water treatment, MP fate, MP

## Introduction

Plastic waste has increased dramatically over the years, with an average of 23 million metric tons in 2016, estimated to have reached up to 53 million metric tons per year by 2030 [9, 16]. As a result, plastic debris is increasingly becoming a global issue due to its ubiquitous presence in the marine environment [13]. The fragmentation of plastic in the environment are studies in its different sizes as samples which are mega-plastic, usually are > 1 m

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in size; then macro-plastic which are < 1 m, and meso-plastic which are < 2.5 cm [38, 68]. The size of plastic fragments which have created a buzz of concern are termed as microplastic (MPs) and these are < 5 mm in size. MPs enter water bodies via primary and secondary sources [13]. Moreover, MP are categorized as primary and secondary MPs whereby the primary MPs enter the ocean via runoffs from the mainland and consist of manufactured raw materials such as synthetic textiles, marine coatings, marine coatings, and virgin plastics debris, whereas secondary MPs are the result of the breakdown of meso and macro-plastics into smaller particles [7, 39]. In addition, its is found that an average concentration of MP ranging from 0.001 – 140 particle/m$^3$ are found in aquatic environment and average range of 0.2 – 8766 particle/m$^3$ are found in coastal environments and marine ecosystems in other parts of the world [68]. An average range of 2.2 particles/L are found in the Pacific Ocean in pooled locations and despite being lesser than the global average, it is still considered high when compared to a densely populated areas such as San Francisco (California, U.S.) with 0.086 particles/L [24]. The presence of MP in high concentration has threatened the biodiversity of the marine ecosystem and over long-term create risks for its biota [68]. Accruing number of researches have displayed higher interaction of MP with marine organisms, via ingestion pathway and its spread across different trophic levels e.g. from zooplanktons to fish [24]. MP exposure to fish and marine organisms poses the risk of entanglement, abrasion, reduced nutrient assimilations, reductive dysfunction, and mortality [42, 48]. MPs are also sources of associated harmful environmental contaminants particularly oxidizing species such metals that are adsorbed on MP surface due to their high surface area [56]. These chemicals also comprised of persistent organic pollutants (POPs), polycyclic aromatic hydrocarbons (PAHs), Per- and Polyfluorinated Substances (PFAS), etc. which can bioaccumulated in the bodies of aquatic organisms and undergo biomagnification along the food chain [31, 49]. Reports have continually elaborated risks of MPs to humans from frequently consumed food contaminated with micro and nano plastics and such food are fish, shellfish, salt, and beer [8, 62, 71]. To synthesize possible control on impacts of MP on the environment it is critical to consolidate knowledge and understanding of potential sources that contribute to the pollution of aquatic ecosystems and then design solutions to mitigate the issue.

One of the major entry points of MP to marine environments is via WWTP which is a growing concern for marine organisms and humans [26, 65, 66]. Literature indicates that despite multiple stages of treatment in a plant, MP are still identified in the effluent which ultimately are released to aquatic environment [5, 17, 58, 64, 66]. Archetypally, studies show that the removal efficiency of most WWTP are 95% effective and a considerable number of MPs usually ends up as sludge, but a fraction of its treated effluent discharged to the ocean still yields a concerning number of MPs into the ocean [26]. For example, a WWTP in Northern Italy discharges 400,000,000 L of wastewater per day with approximately 160,000,000 MPs, indicating the magnitude MP that are being released globally into aquatic environments [47]. Previous studies in have also observed trends regarding microplastics association with wastewater contaminants such as pharmaceuticals, illicit drugs, and heavy metals with serious health issues possible from exposure to these contaminants [18, 22, 47]. Different types and shapes of MPs have institute the stages of WWTPs, from microbeads and glitter [51] to cosmetics and fibers from synthetic textiles [55]. In an alternative study, out of all the analyzed MPs, 51% of the samples were in the form of films in shape, and the common polymer found was polyester [43]. WWTPs may receive large number of MPs depending on the design of the treatment process, as well as the industrial activity and population [64]. However, most wastewater treatment systems in developing countries such as South Pacific countries have not prioritized designs to focus on fates of MPs within stages of treatment. In population, Fiji is the second largest among pacific island countries in terms of population with an estimation of 884,887 and it shares with other pacific island countries that faces challenges of territorial fragmentation, remoteness from major markets with a small economy [35]. Fiji's economy relies on tourism which accounts for about 32% of the county's gross domestic product (GDP) in 2019 and this is a greater part of the sector which increases accommodation and food services in urban and resorts areas in Fiji [1]. The recent COVID-19 pandemic sees Fiji's economy contracted by 0.4% in 2019 and this have affected a lot of sectors apart from tourism particularly capital projects for upgrading waste management infrastructure [1]. Small Island Developing States (SIDS) like Fiji urgently need to develop waste management systems as the environmental conditions in many areas are threatening the health and natural resources [50]. This research is probably the first in Fiji to compare the treatment methods of wastewater particularly focusing on fate of MPs, although, there are numerous researches done in the past years on similar subject, globally. Apart from urban waste water, sources of waste in Fiji include resorts, hospitals, villages, commercial businesses, agricultural runoffs, and household waste from laundry, kitchens, showers, and sink water [67]. Wastewater in Fiji are managed under the Water Authority of Fiji (W.A.F.), established in 2010 which is operated from four main offices in Viti Levu Island [25, 37]. The two selected WWTP sites that are investigated for this research, Kinoya and Natabua treatment plants, are not as advanced as most plants in a developed neighboring country such as Australia. (Table S1). This means that their capacity can only be compared to small regional areas such as the Hunter region in NSW, studied by [59, 72]. But not with Sydney that caters for 1.2 million population. This is the first study to comprehensively focus on fate of MP in Fiji with the following objectives: 1) understanding the fate and transport of MPs in wastewater treatment processes from Fiji's selected WWTPs, 2) providing a particle size distribution of MPs at the various stages of the wastewater treatment, and 3) experimentally identifying the MP removal efficiency of the treatment facilities and released concentration into the freshwater/marine ecosystem.

## Material and methods

### Selection of sampling locations

In 2017, the Bureau of Statistics in Fiji recorded Fijis population as 884,887 and with land area of about 18,273 km$^2$, its population density 46 per km$^2$ and survey have seen major shift of population from rural to urban areas [69]. Two of the major urban areas in Fiji are located on the main land of Viti Levu island and these are Suva (capital of Fiji) and Lautoka (Fig S1). Suva is populated with 30% of the overall population of Fiji, which is about 268,468 people which are assumed to be connected to Kinoya WWTP with wastewater volume usage of 200 L/capita/day (Fig. S2) [52]. Lautoka area have about 8% of the overall population of Fiji and recent survey by the Water Authority of Fiji determined that about 53,034 people are connected to the Natabua WWTP (Fig. S3) [37]. Fiji's Bureau of Statistics recorded that there are about 3568 registered business in Suva in which the top three activities are; 43% of the business are in wholesale and retail trade, 9.8% in accommodation and food services and about 7.8% in manufacturing [29]. On the other hand, the Lautoka area have about 1341 registered business in which the top three categories are; 45% in wholesale and retail trade, 10% in accommodation and food services and about 7.9% in transport and storage activities [29]. The socio-economic status and activities on both locations have provided basis for initial understating of the magnitude of wastewater and plastic sources that are linked to the WWTP that caters for the area. On these grounds, the two locations, Suva and Lautoka were selected with its responsible WWTP's which are Kinoya (Suva) and Natabua (Lauoka).

### Kinoya WWTP

The Kinoya plant is located between Suva City and Nasinu Town and it follows a typical conventional sewer treatment process (Fig. 1, top). The influent flows through the screening stage, where most floating debris, such as plastic, is removed, and then through the grit removal system before the water is settled in the primary settling tank. This is where the Influent was taken. Undigested particles are separated at this stage, and primary sludge is formed. The wastewater is then transferred to the Trickling Filter. It undergoes biological treatment when it flows in thin layers over the aerobic layer of 'biofilm,' allowing absorption of dissolved solids [54]. The wastes then move to the secondary clarifiers before being pumped out into the ocean (blue arrow at the end shown in Fig. 1). The outfall pipeline runs approximately 2.4 km from the treatment plant to Laucala bay [37]. A population of about 243,795 people are catered by the Kinoya WWTP with wastewater volume usage of 200 L/capita/day (Fig. S2) [52].

### Natabua WWTP

The Natabua treatment process of wastewater undergoes primary and secondary treatment (Fig. 1, bottom). The influent is pumped into the treatment ponds, termed as termed the 'lagoon process', which consists of the anaerobic pond, facultative pond, and maturation pond, before the treated water is pumped outside. The anaerobic pond is about 2 m deep, the organic loads and oxygen uptake is high. The anaerobic digestion process is more intense at temperatures above 15 °C [41]. The facultative pond is distributed into two, the Primary facultative pond (which receives raw wastewater) and the Secondary facultative pond (which receives particle-free sewage). A facultative wastewater pond has two zones, an upper aerobic layer overlying a low anaerobic zone where anaerobic and facultative bacterium slowly stabilize the organic material [30]. A population of about 35,000 households in the Natabua WWTP (Fig. S3).

### Sampling method

The method is an extension of our published study [59], Samples collected from Kinoya WWTP (Suva) were taken from the following points; inlet pond (KS1), clarifier pond (KS2), Filtration pond (KS3), and outlet pond (KS4) using 10 L plastic buckets. They were collected two times per treatment stage, thus total sample volumes of 80 L. The samples were digested overnight using 40 ml of Fenton's reagent (0.05 M $FeSO_4.7H_2O$ and 30% $H_2O_2$). Wastewater samples were then filtered onto a series of stainless-steel mesh sieves and thoroughly examined to identify any plastic particles.

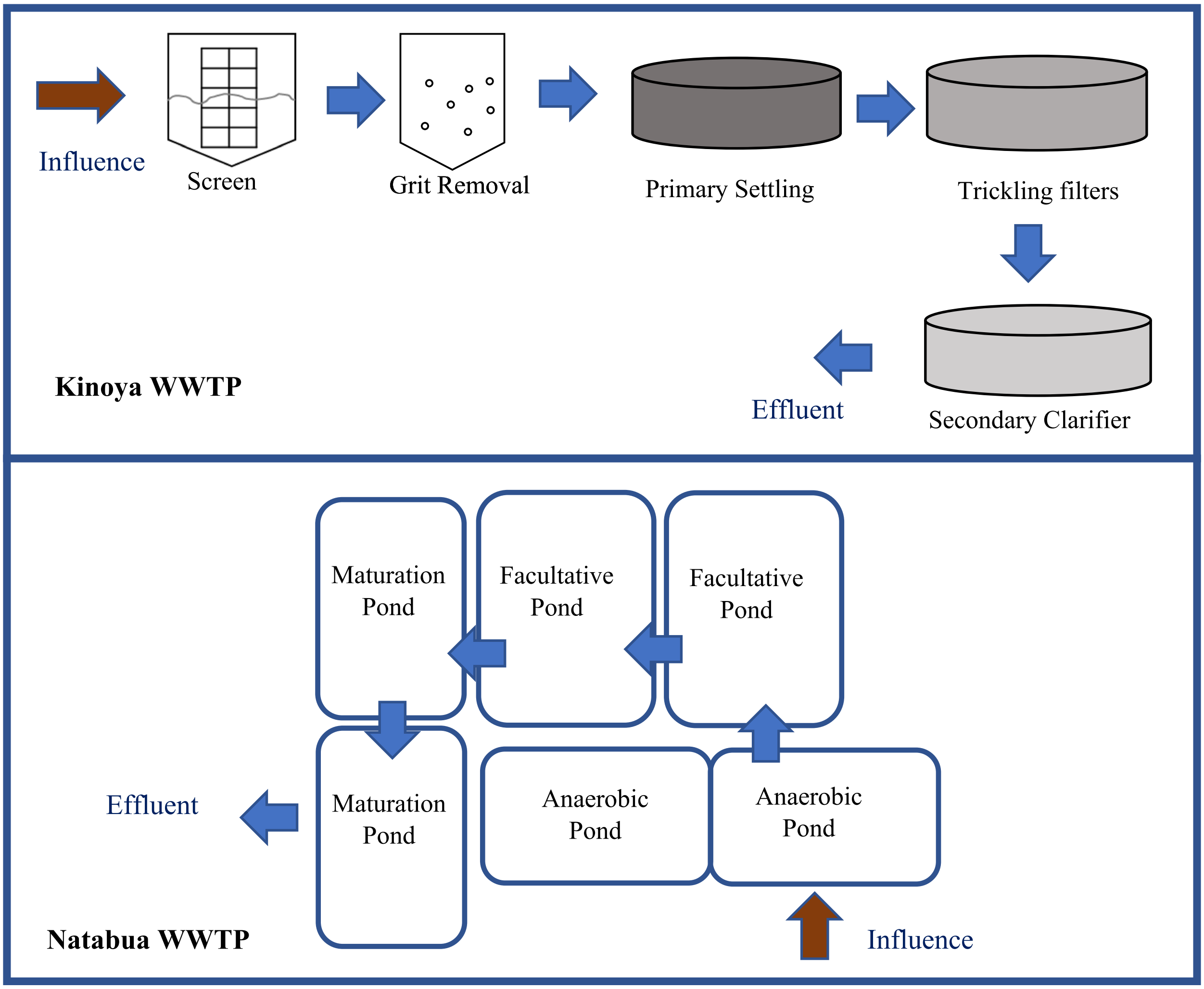

**Fig. 1** The wastewater treatment process in Kinoya and Natabua WWTPs. Kinoya wastewater system (top) uses a comparatively advanced treatment system and Natabua (bottom) uses a pond treatment system

Wastewater collected from Natabua was done from the following treatment ponds: anaerobic pond (NS1); facultative pond (NS2); maturation pond from the outlet sampling points (NS3) using 10 L plastic buckets. Samples were collected twice per treatment stage and thus the total sample volumes were 60 L. Upon visualization, the presence of macro-sized plastics and debris and floating micro debris, likely resulting from the fragmentation in the anaerobic pond was found. In this study, the facultative pond illustrated the change in the number and type of plastic waste and helped provide interesting information on wastewater treatment within the anaerobic and facultative stages.

### Method validation

An experiment was performed to validate MP extraction and test the recovery rate of different types of MP from wastewater as reported by [59]. With 1 L glass jars, duplicate samples of Inlet, Clarifier, Filter, and outlet were spiked with 10 MP fragments of PE and PVC ranging from 2 to 1 mm in size and about 1 g of PET particles. The samples were digested overnight using 40 ml Fenton's reagent (0.05 M $FeSO_4.7H_2O$ and 30% $H_2O_2$). After digestion, the samples were filtered through a series of stainless-steel sieves of 2 mm, 250 µm, and 125 µm. Rose bengal solution of 0.2 mg/mL was applied to each sieve to allow it to stain for five minutes at room temperature and then rinsed with deionized water. MPs of similar characteristics to background samples were identified and extracted, and the recovery rates for the MPs were calculated using the following formula:

$$\text{MPs recovery rate}(\%) = \frac{\text{Number of MPs}}{\text{Number of MPs spiked in wastewater}} \times 100$$

### MP extraction

Each 10 L sample was mixed with Fenton's reagent and left to incubate at room temperature overnight. Following incubation, the samples were filtered through decreasing-sized sieves of 2 mm, 250 µm, and 125 µm for both WWTPs (Kinoya and Natabua) samples. Extra filtration sieves sizes were also executed for both sites to complement their different type of treatments and expected plastic sizes; Natabua WWTP – 16 mm, 8 mm; Kinoya WWTP—53 µm. For characterization, suspected MPs were visually observed for their shape and color [39]. The MP was then rinsed with Mili-Q water before it was ready for polymer type analysis. The polymer identification was carried out using the Attenuated Total Reflectance Fourier Transform Infrared spectroscopy (ATR-FTIR) analysis (Spectrum Two Perkin-Elmer FTIR Spectrometer, Japan). The percent Removal Efficiency (RE%) for each WWTP was calculated using the concentrations of MPs counted for influent (C.MP, infl) and effluent (C.MP, effl) (Eq. (1):

$$\text{Removal Efficiency (RE) } (\%) = \frac{C_{MP,infl} - C_{MP,effl}}{C_{MP,infl}} \times 100 \quad (1)$$

### Statistical approach

A one-way analysis (ANOVA) of variance was performed, treatment vs. treatment, using the Fischer method at a 95% confidence interval to evaluate the significant differences in MP concentration between the different treatment steps for the two major treatment plants (Natabua: Anaerobic, Facultative, Maturation), (Kinoya: Inlet, Clarifier, Filtrate, Outlet). The Datatab software, statistical calculator was used for the analyses.

## Results

### MPs in KINOYA Wastewater

Characterization of the samples from Kinoya WWTP using the ATR-FTIR determined that from the total MP particles collected, 21% were from the inlet, 31% from the clarifier, 19% from the filter, and 29% from the outlet. In quantifying the number of MPs through the processing stages at Kinoya, 3.45 ± 0.3 particles/L in the inlet stage was reduced to 2.4 ± 0.39 particles/L after the clarifier. These was then reduced to 1.33 ± 0.25 particles/L after the filter and 0.3 ± 0.26 particles/L in the outlet (Fig. 2). With a 95% confidence interval, it is observed there are significant differences between all stages in terms of the contents of MP's removal from inlet to clarifier ($p < 0.01$), clarifier, and filter ($p < 0.01$) and between filter and outlet ($p < 0.01$).

The pie chart (Fig. 3A) shows MP sizes of 2 mm mainly captured at the inlet stage (67%), followed by 5 mm MP (33%). The shapes of MP dominating this sample were fragments and fibers (both at 44%), and FTIR analysis of the MPs determined that most were made of cellophane and polyester in this stage. Samples taken and filtered

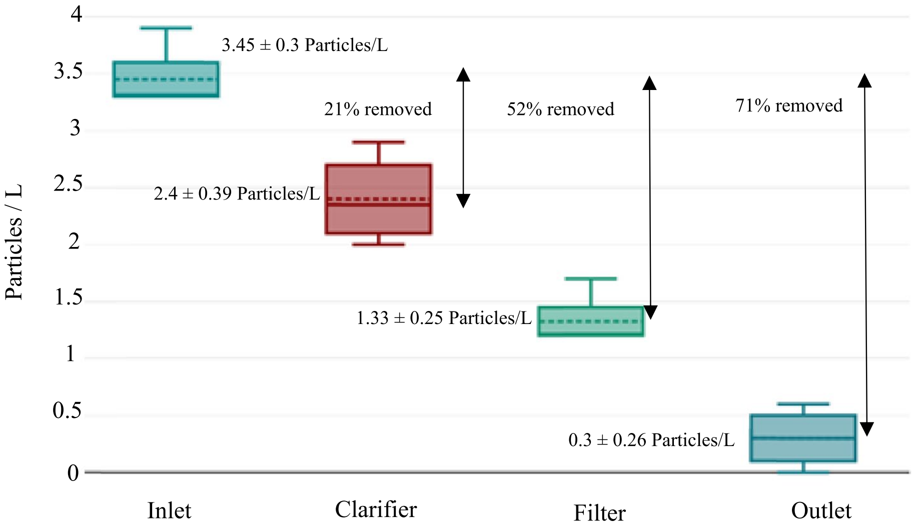

**Fig. 2** Mean number of MPs/L captured on the four different treatment steps at Kinoya WWTP with the boxplot showing the mean concentration (mean ± SD) with its significant differences

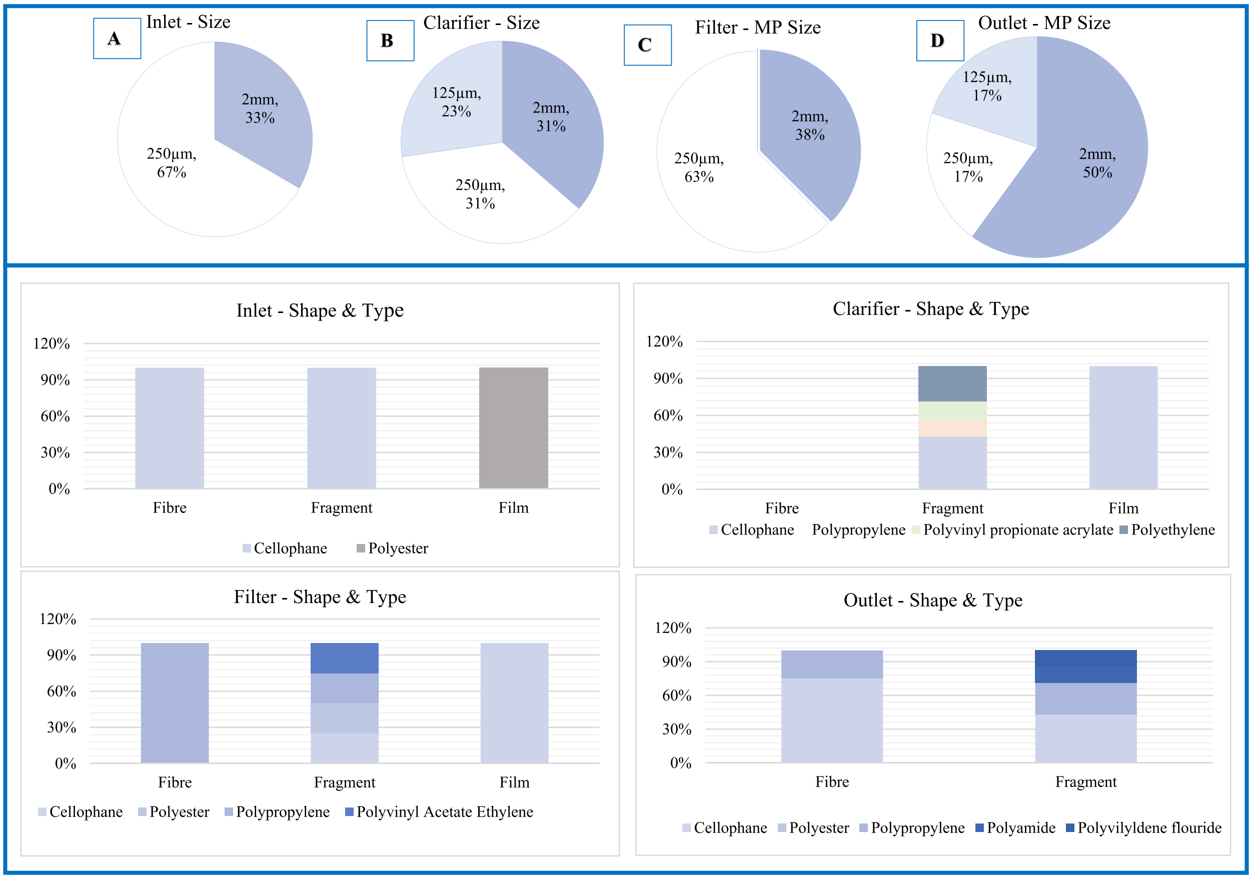

**Fig. 3** The pie chart shows the different percentage of sizes of MP's captured from the different stages of treatment in Kinoya WWTP and the percentages of different types of shapes captured in the bar graphs

from the clarifier stage (Fig. 3B) captured high percentages of MP sizes of 5 mm (31%) and 850 µm (31%) shaped mainly of fragments and in films (62% and 38%). The type of MP determined in this stage was mostly cellophane polyethylene, including polypropylene and polyvinyl propionate acrylate. The filter stage sample, as shown in Fig. 3C captured more percentage of 2 mm MPs (63%) followed by 5 mm MPs at 38% in most of these MP are in the fragment (63%).

These MPs were mostly made of cellophane, polypropylene, polyester, and polyvinyl acetate-ethylene. The end sample at the outlet stage commonly entraps MP of sizes 5 mm with an amount of 50% in which most shapes of these entrapped MPs are in fragments (Fig. 3D). Interestingly, FTIR analysis of this stage shows that most of these MPs are made of cellophane, polypropylene, polyamide, and polyvinylidene fluoride. The ratio changes after the clarifier stage with (62%) fragments and (38%) films, and then after the filter stage, the ratios were (63%) fragments, (25%) films, and (13%) fibers. A greater volume of fragments (67%) followed by fibers (33%) was measured at the output stage. The abundance of polymers (Table 1) observed in the influent have a high amount of cellophane at 0.80 particles/L, followed by polyester at 0.10 particles/L. The clarifier sample has a high percentage of cellophane (0.80 particles/L) followed by polyethylene with 0.20 particles/L and then polypropylene and polyvinyl propionate acrylate, both ranging at 0.10 particles/L. Analysis of the sample from the filter stage shows a high concentration of cellophane at 0.30 particles/L, followed by 0.20 particles/L polyethylene and then 0.10 particles/L polyester and polyvinyl Acetate Ethylene (MP observed at Kinoya (Fig S4).

### MP's in Natabua wastewater

ATR-FTIR characterization of MP suspected samples from Natabua WWTP confirmed 65% obtained from anaerobic stage, 27% from the facultative stage and 4% from the maturation outlet stage were of plastic material. Quantification of the total number of MPs collected through wastewater processing stages at Natabua displayed that an average 2.9 ± 1.05 particles/L were collected at the anaerobic pond which were then reduced to 1.3 ± 0.43 particles/L after flowing through facultative

**Table 1** The table shows the types of polymer captured from the Kinoya WWTP and identified using the ATR-FTIR. The first section of the table shows the percentage (%) of each type of MP from a stage and the next section describes the number of MP per 10L sample

| MP—Type of Polymer | Inlet | Clarifier | Filter | Outlet | Inlet MP/10L | Clarifier MP/10L | Filter MP/10L | Outlet MP/10L |
|---|---|---|---|---|---|---|---|---|
| Cellophane | 89% | 62% | 38% | 67% | 0.80 | 0.80 | 0.30 | 0.80 |
| Polyester | 11% | - | 13% | - | 0.10 | - | 0.10 | - |
| Polypropylene | - | 8% | 25% | 25% | - | 0.10 | 0.20 | 0.30 |
| Polyvinyl propionate acrylate | - | 8% | - | - | - | 0.10 | - | - |
| Polyethylene | - | 8% | - | - | - | 0.20 | - | - |
| Polyvinyl propionate acrylate | - | - | - | - | - | - | - | - |
| Polyvinyl Acetate Ethylene | - | - | 13% | - | - | - | 0.10 | - |
| Polyester | - | - | - | - | - | - | - | - |
| Polyamide | - | - | - | 8% | - | - | - | 0.10 |
| Polyvinylidene fluoride | - | - | - | 8% | - | - | - | 0.10 |

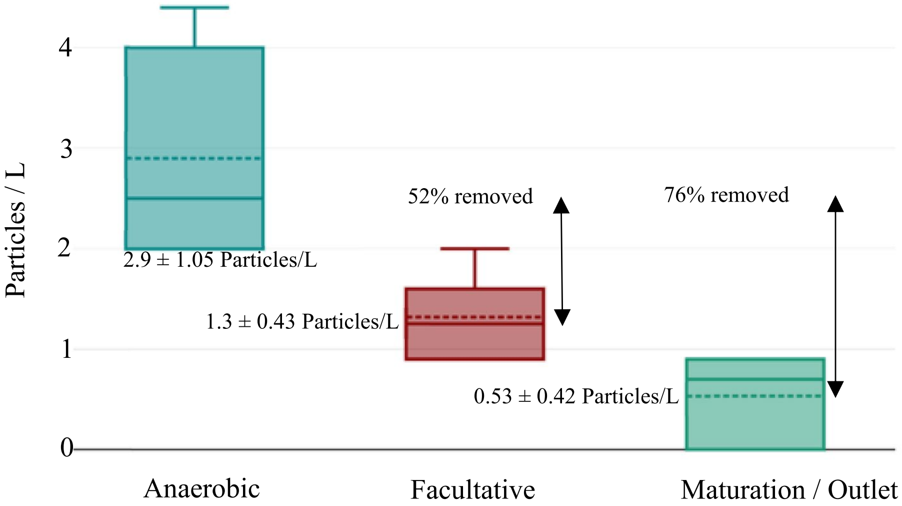

**Fig. 4** The mean number of MPs/L captured on the three different treatment stages at Natabua WWTP. Boxplot shows the mean concentration (mean ± SD) with its significant differences

pond and then further reduced to 0.53 ± 0.42 particles/L after the maturation outlet stage (Fig. 4). The graph shows a 76% greater reduction in the content of MPs from the anaerobic to maturation outlet stage than after the facultative stage of about 65%. With 95% confidence interval, the analysis shows significant difference in the MPs content removed between anaerobic and facultative stage and similarly between anaerobic and maturation outlet stage. There is no significant difference of MPs removed between the facultative and maturation outlet stage. The pie charts in Fig. 5A shows that samples collected and filtered at the anaerobic stage captured more percentage of 2 mm sized MPs (58%) followed by the 250 µm sizes at 8%. About 50% of MPs collected were in shapes of film, followed by 35% fragments and 8% fibers. Some of the common types of polymers observed were polyethylene, polyethylacrylate, and cellophane.

The determined polymers at this stage were cellophane, polyethylene, and polyester. The maturation outlet stage (Fig. 5C) sample shows dominating amount 125 µm (45%) over 250 µm MP sizes at 45% and then 18% of 2 mm MPs. More percentage of these shapes were in fragment forms at 64% and then film shapes at 2 mm. Polymers observed from this final stage were polyethylene, cellophane, and polypropylene. Details of different polymers found at the various treatment stages at natabua WWTP are in Table 2). The anaerobic stage has cellophane at 23%, followed by polyethylene at 19% and then polyethylacrylate at 10%. The facultative stage shows a high concentration of polyethylene (38%) followed by polyester (23%) and then polypropylene (15%). The maturation outlet stage was found to have cellophane (33%) and polyethylene (33%) similarly high in concentration, followed by polypropylene (17%) and polymethacrylate (17%).

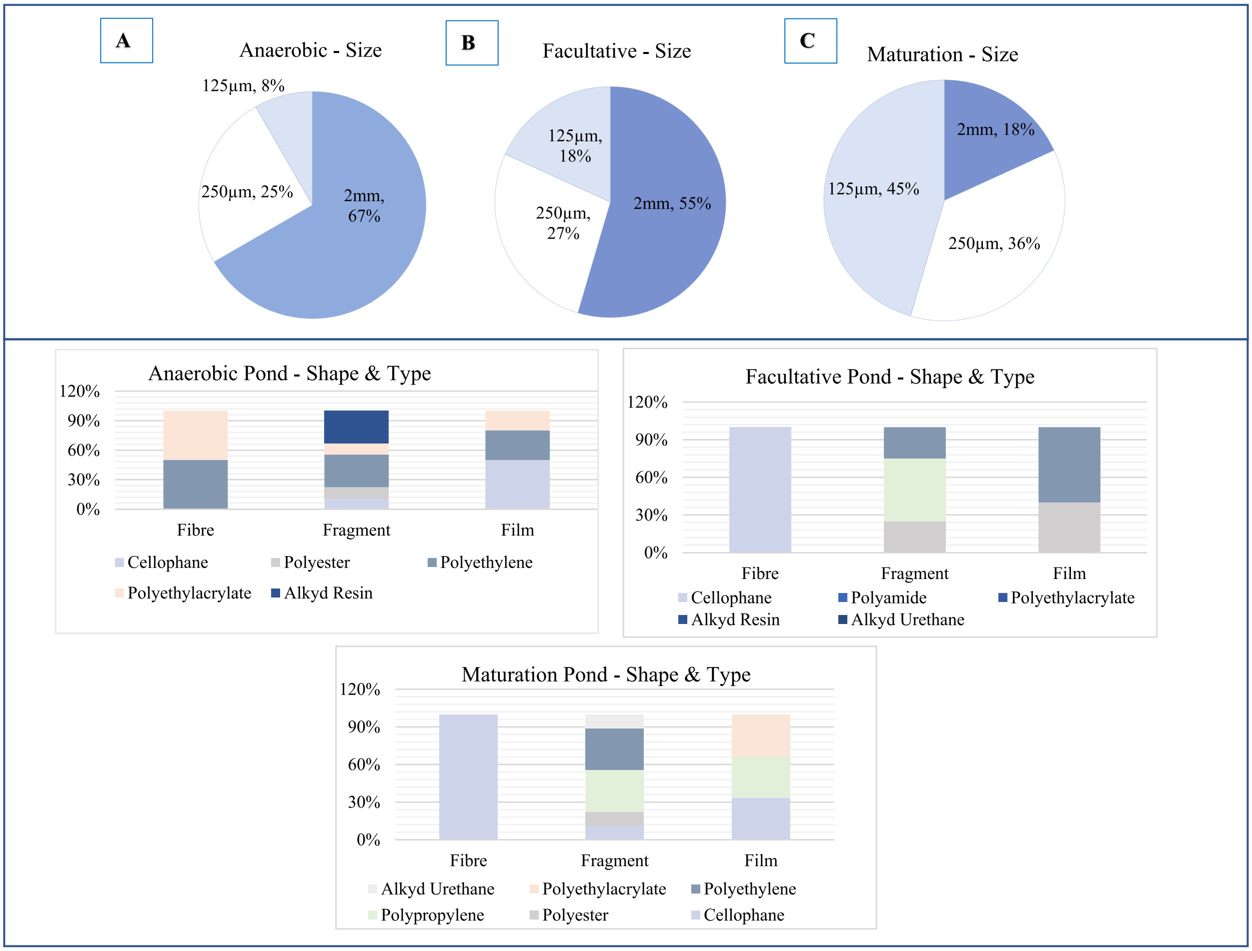

**Fig. 5** The pie chart shows the different percentage of sizes of MP's captured from the different stages of treatment in Natabua Wastewater Treatment Plant

**Table 2** The table shows the types of polymer captured from the Natabua WWTP and identified using the ATR-FTIR. The first section of the table shows the percentage (%) of each type of MP from a stage and the next section describes the number of MP per 10L sample

| MP—Type of Polymer | Anaerobic | Facultative | Maturation Outlet | Anaerobic MP/10L | Facultative MP/10L | Maturation Outlet MP/10L |
|---|---|---|---|---|---|---|
| Cellophane | 23% | 10% | 33% | 0.70 | 0.10 | 0.50 |
| Polyester | 3% | 23% | - | 0.10 | 0.30 | - |
| Polypropylene | - | 15% | 17% | - | 0.20 | 0.10 |
| Polyvinyl propionate acrylate | - | - | - | - | - | - |
| Polyethylene | 19% | 38% | 33% | 0.60 | 0.50 | 0.20 |
| Polyvinyl Acetate Ethylene | - | - | - | - | - | - |
| Polyester | 3% | - | - | 0.10 | - | - |
| Polyamide | - | - | - | - | - | - |
| Polyvinylidene fluoride | - | - | - | - | - | - |
| Polyethylacrylate | 10% | - | 17% | 0.30 | - | 0.10 |
| Alkyd Resin | 6% | - | - | 0.2 | - | - |
| Alkyd Urethane | - | 8% | - | - | 0.1 | - |

**Table 3** Comparison of the plants location, population, connected households and anthropogenic activities

| WWTP | Geographical Location | Population of Location | Total Households | Top Business Industries | References |
|---|---|---|---|---|---|
| Natabua | Lautoka, Fiji | 71,573 | 15,611 | 1.Wholesale and retail trade; repair of motor vehicles<br>2. Accommodation and food services<br>3. Education | (Fiji Bureau of Statictics, 2017) |
| Kinoya | Suva, Fiji | 243,795 | 51,470 | 1.Wholesale and retail trade; repair of motor vehicles<br>2. Accommodation and food services<br>3. Manufacturing | (Fiji Bureau of Statictics, 2017) |

## Discussion

The characteristics of the MP and the quantity observed from the two distinct WWTPs portrays the different influences that contributes to the result. Such influences are the method and technological system of the treatment and geographical location of the plants and its anthropological factors. Information displayed in Table 3 from the Fiji's Bureau of Statistics depicts a total of 51,470 households are connected to Kinoya treatment plant whereas 15,611 households are connected Natabua treatment plant.

### Kinoya WWTP: size distribution and types of polymers in stages of treatment

The size distribution analysis shows that most MPs entrapped at the inlet stage falls between ranges of 2 mm and 250 μm and the concentration of MP decreased as expected (Fig. 6). This range of MP sizes (2 mm – 250 μm) was majorly present in all stages of treatment whereas the smallest size (125 μm) was commonly abundant at the clarifier and outlet stage only. A critical finding in this aspect were the types of polymer found at the different stages of treatment. Few of these polymers were present in samples from all stages, such as cellophane, polyester, polypropylene, and polyethylene (Table 1). These polymers may have originated from various consumer products such as flat PP strings, plastic bottles, construction and household materials. Cellophane, interestingly, has been historically used predominantly as a food packing material and its presence may represent an increase in plastic alternative materials used in the area. Further, the influent taken after the screening area were expected to have less to no macro floating debris including plastics after passing the screening stage [54]. This stage contains many settable undissolved particles that may have been interpreted by the presence of fiber, fragments, and

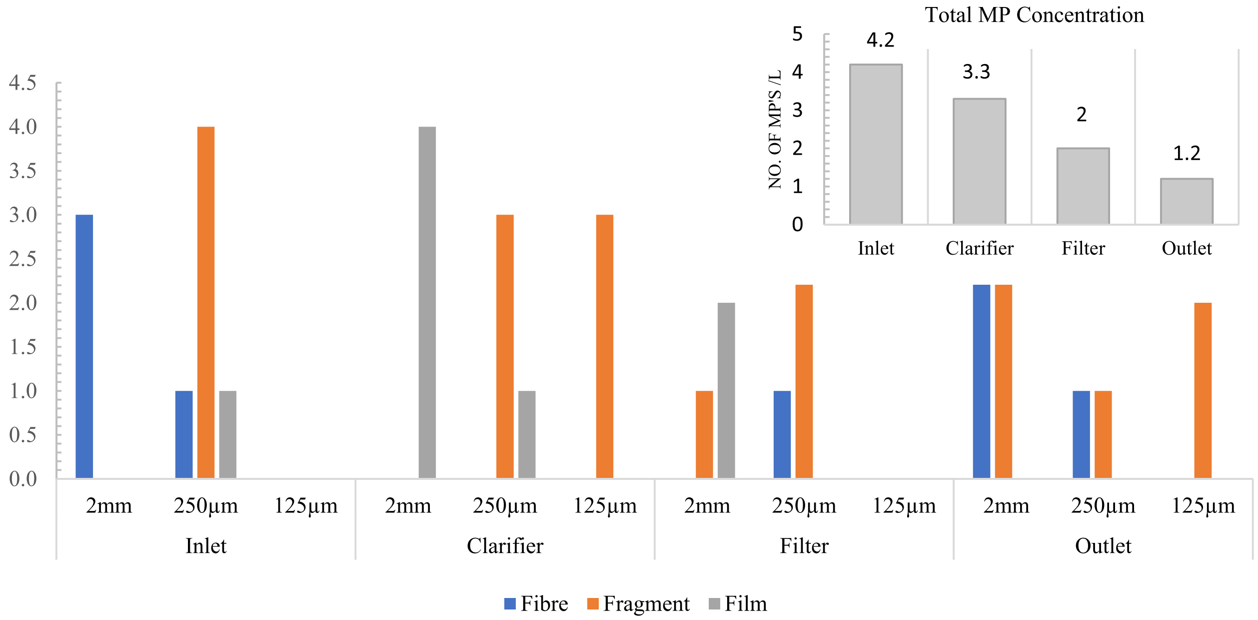

**Fig. 6** Size distribution. Microplastic concentration at Kinoya WWTP in sequential treatment stages

a few films. Apart from the higher number of connected households to the Kinoya plant, the surrounding area are accommodated with top business industries from such as wholesale and retailers and accommodation and food services.

Fragments with average sizes of 250 µm were primarily observed in this stage in which 89% of it were cellophane. Recent articles confirmed that cellophane identification from FTIR can be representative of semi-synthetic cellulose or cellulose triacetate (CTA or TAC) and paper (lignocellulosic fibers) [19, 44, 57]. Wastewater sample from clarifier considered to be extracted after the grit chamber, has separated many settleable un-dissolved particles at this stage. Sludge is also collected at this point which gain settled or trapped MP. The result shows the dominance of fragment and film-shaped ’ dominance with sizes 2 mm and 250 µm (Fig. 4B). Again, cellophane (62%) dominates the sample with the highest number of cellophane particles from the Suva area. Samples extracted from the filter possess fiber, fragment, and film shapes, but MP sizes are 2 mm, 250 µm, and none 125 µm. This stage involves a trickling filter filled entirely with lava slag and gravel packing material. The influent water is spread on top by the rotary distributor arm [54]. The typed of polymer observed in this stage were cellophane (38%), polypropylene (25%), and polyester (13%). As extracted from the thickener settling tank, the effluent contains supernatant water classified as treated enough to be discharged to the sea located 1.5 km from the shoreline. Figure 7 shows that the effluent dominated by fragment and fiber shaped MP were present in all sizes of 2 mm, 250 µm, and 125 µm MPs and apparently will be the scenario of what is directed to the sea. Cellophane and polypropylene dominated the types of MP that is discharged out. The FTIR characterization process also indicates the presence of other polymers such as Polyvinyl Acetate ethylene, and Polyvinylidene fluoride, plasticizers, and polyamide, also known as Nylon, which is used for materials such as silk, rubber, and latex [40]. Apart from littering issues, the Suva area is densely industrialized with plastic packaging industries as well as piping factory outlets which may have contributed to such resulting pollutants. A research on the surrounding area found that the most abundant plastics were plastic bags and food containers, and PET- bottles [53] which in its macro sizes will be filtered in the screening stage, where most floating debris are removed, and then flows through the grit removal system before the water is settled in the primary settling tank. The influents from Kinoya were taken after these screening systems which can remove such macro sizes and alter the type of MP samples during the experiment.

## Natabua WWTP: size distribution and types of polymers in stages of treatment

The Natabua WWTP, a natural pond process, is a system designed for wastewater treatment to diminish organic content and remove pathogens from wastewater. This shows the dynamic process of this natural wastewater treatment where the biodegradation rate is high, and wastewater stabilizes within a few days [61]. From the size distribution analysis (Fig. 7), the anaerobic pond, as the initial pond of treatment, sees the presence of all three ranges of sizes of MPs (2 mm, 250 µm, and 125 µm), which may in a way describes the process of biodegradation causing plastic fragmentation and, in this case, mostly in fragment and film shapes [4]. The types of polymers captured in this stage were cellophane and polyethylene. Polyethylene as stated that

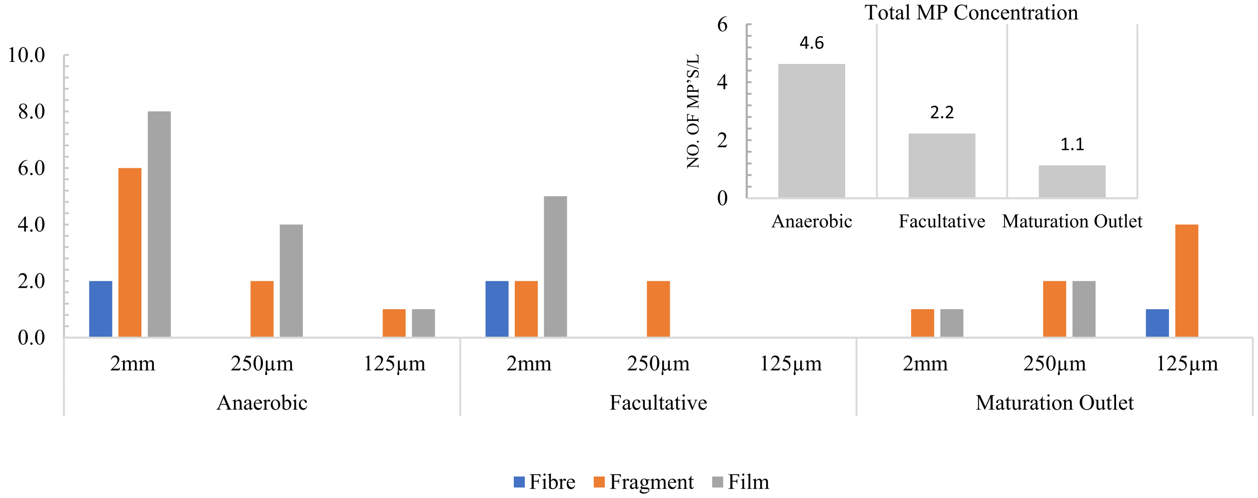

**Fig. 7** Size distribution. Microplastic concentration at Natabua WWTP in sequential treatment stages

under the biodegradation process its fragmentation has been caused by insects such as the rice weevil (*Sitophilus oryzae*), and the cigarette beetle (*Lasioderma serricorne*) [60] and as well as from bacterium isolated from the guts of waxworms called Bacillus sp. YP1 [70]. The Natabua WWTP is located within a metropolitan vicinity and is vulnerable to receiving high amounts of plastics-related products. Considering the common usage of cellophane bags and packaging, the outcome of the percentage of cellophane is relatable. The facultative sample filtrates have MPs sizes of 2 mm and 250 µm and are dominated by fragment and film, high polyethylene, and then polyester. Polyester, a material with excellent durability and abrasion resistance, is mainly used for clothing, rope, and upholstery [60]. About seven clothing and textile industries within the Lautoka vicinity can be the source of these MPs [27]. The maturation effluent shows all the filtered sizes (2 mm, 250 µm, and 125 µm) MPs presence, and this is a scenario of an outfall to the sea which is about 2 km offshore. The type of polymers escaping from the outfall at Natabua (Table 2), shows that cellophane and polyethylene dominate, followed by polypropylene and poly-ethyl-acrylate. Polypropylene is a thermoplastic polymer widely used for packaging consumer products and plastic parts for various industries [20]. Natabua being surrounded by numerous local manufacturing industries and highly populated may have been a source of such an outcome [34]. Poly-ethyl-acrylate is an addictive used in the production of polymers such as resins and plastic. In this case, it could be accessed from the nearby industries in the Lautoka vicinity [11]. Considering health impacts, poly-ethyl-acrylate has been carcinogenic in the long terms impact as well as causes respiratory issues [6].

#### Cellophane

Cellophane has been historically used predominantly as a food packing material but its presence in wastewater samples may also be confused with cellulose which are also identified as cellophane upon FTIR reads. Interestingly, most polymer samples collected from different treatment process in Kinoya and Natabua, identified by FTIR were dominated by cellophane. Previous articles on wastewater have also identified such dominating cellophane reads and have had further analyzed to distinguish whether such polymer ID of cellophane is a representative of semi-synthetic cellulose or natural cellulose. The differentiation can be identified by color, chemical or most commonly the spectra bands. Hence, inconsideration of such articles, cellophanes identified from the two treatment plants were differentiated with their absorbance spectra bands. The article mentioned that absorbance graphs showing semi-synthetic cellulose samples had band at 1735 and 1052 $cm^{-1}$ compared to natural that didn't have band at 1735 $cm^{-1}$ [14]. Thus, based on such statement, the FTIR absorbance graphs for cellophane samples from both treatment plants were analyzed and all were confirmed to be semi-synthetic cellulose. Consequently, it is assumed that incursion of high amount of cellophane or semi-synthetic cellulose in such case will be related to the use of semi synthetic fibers called viscose or rayons, which are fibers made from natural cellulose such as wood or wood product such as paper pulp [63]. Past articles investigation on source of cellulose in aquatic environment or waste water system have labelled municipal waste water treatment plants and industries such as pulp and paper mill wastewater to be major contributors of cellulose [21, 45]. From municipal waste water, toilet papers are the primary contributor which disintegrates whilst piping transfer and later ends in WWTP process in the form of linear cellulose [45]. The population density in urban areas as such can be the source of high usage of toilet paper, thus higher amount of cellulose breakdown and number of semi-synthetic cellulose which were read as cellophane in the collected samples.

#### Removal efficiency and average total MP

The Removal Efficiency (RE) for the KINOYA process (surface water) considering inlet (3.45 ± 0.3 particles/L) to outlet (0.3 ± 0.26 particles/L) was 91%. A recent study conducted on the coastal areas in Suva determined the concentration of MPs on surface water at Laucala Bay at 0.09 ± 0.02 particles/L in Kinoya outfall contributed the most [28]. The determined effluent concentration eventually depicts that Kinoya WWTP in treating about 15,000 Liters of wastewater per day with its outfall to the ocean, may leave a daily content of 41,400 MPs through influent and releases an average of 4,500 MP/day as effluent. Compared to a similar set-up of treatment but one of the biggest WWTP in northern Italy, its RE is 84% with the treatment of about 400,000,000 L wastewater/day and the potential release of MPs to the receiving aquatic system would be approximately 160,000,000 particles/L displaying polyesters (35%) as a communal polymer [12, 47]. The Kinoya WWTP mainly has cellophane (67%) and propylene (25%) from its outlet, which partly reveals the discharge MP content.

The Removal Efficiency (RE) at the Natabua process (surface water) from the anaerobic 2.9 ± 1.05 particles/L) to maturation outlet (0.53 ± 0.42 particles/L) is 81%. The Natabua WWTP treats 8,600 L of wastewater daily in dry weather [37]. Considering this volume of influent, the plant will receive a content of 24,940 MPs per day, and about 4,558 MPs are released to the ocean as effluent from the mean value of 0.53 ± 0.42 particles/L, which is more than the volume that is released from the Kinoya (RE of 91%) sewage treatment process in Suva. With additions to the effluents, the combined coastline of 6,112 km in Fiji was recorded to have a daily generation of about 168.4 tons of plastic waste (2014) and which an estimated 135 tons enter our marine environment due to mismanagement [23, 53]. A comparison of the MP removal efficiency of WWTP used in the study and Countries with similar percent of removal is provided in Table 4.

### Wastewater treatment methods of Kinoya and Natabua WWTPs

The different treatment methods from the two WWTPs play different roles in the fates of MPs, and this is shown in the removal efficiency (RE) of its treatment systems. Kinoya plant itself in its primary treatment stage has a Grit chamber system in which MPs are removed mainly from surface skimming and sedimentation [15, 46]. Wipes, PE packaging, cigarette buds, and other macro size units are removed in this section. The RE past the grit system in Kinoya is 21% and it is approximately as close as the grit treatment demonstrated from a WWT process in South Korea with 57%–64% [32]. However, high efficient removal was still shown in waste water treatment system in Cartagena, Spain at 74% [10].

On the other hand, the initial stage of treatment at Natabua WWTP (anaerobic pond system) has a natural method of breaking down debris such as plastic with the control of temperature, pH, and retention time [3]. With its main functions in breaking down organic matter, effective temperature naturally sourced from sunlight will effectively break down such debris, depositing sludge at the bottom of the pond and decomposing it anaerobically [33]. Using natural ponds in dry tropical parts of Fiji, such as Lautoka is considered a good choice due to the required amount of sunlight. Studies stated that climate change has also played a role in such waste water treatment system due to changing temperatures in tropical areas, as higher temperature means higher removal and energy efficiency [33]. The findings are otherwise, with Kinoya showing greater removal efficiency. The volume of MPs released from Natabua WWTP is greater than Kinoya pondering the total input volume for both sites. The Kinoya waste water treatment systems are built with stages that are equipped with superior technological treatment designs that of Natabua such as the clarifier and filter stages. The clarifier promotes the solid settlement of waste before biological treatment, and it is where most of the floating solids are skimmed off the surface [22]. Studies have stated that an exceptional amount of MP is removed from this stage either by sedimentation or flotation [22]. The percentage removed (RE) from the clarifier stage is 39%, whereas the filter removal efficiency is 40%. Trickling filter, under the secondary treatment in WWTPs reduce the residuals suspended and dissolved solids, and it can remove MPs through entrapment in solid flocs [36].

Alternatively, the final two stages at Natabua (facultative and maturation pond) portray a natural or traditional treatment method. The facultative pond including the maturation pond provides biological treatment where facultative bacteria breaks down organic matter. For removal of MPs, retention time is a favorable factor with a minimum detention time of 30 days [30]. The longer contact time of MPs in the pond will increase surface biofilm coating on the MPs and thus modify the relative density causing it to settle on the floor (sludge) instead of being an effluent to the next stage or the environment [66]. This outcome is feasible considering the removal percentage at Natabua facultative and maturation pond, which increases from 52 to 76% before the outlet. This will still be an issue to the environment with poor sludge management which is a much larger contaminant of such MPs.

## Conclusion

This study explored wastewater treatment system and the removal of MP based on the two-different methods at Natabua and Kinoya WWTPs. The fate of MPs in such a treatment system depends on each stage in the system, which in this case shows a difference of 10% in Removal Efficiency (RE). In contrast, Kinoya shows a much more impactful system. Overall, the removal efficiency of both treatment plants is high and appreciated in the financial capability of the responsible authority and the country itself. For Natabau WWTP, it is evident that sludge will be the basis of MP accumulation from the wastewater

**Table 4** Effluent removal capacity for WWTP from developed countries with almost similar percentage achieved

| No | Country | Type of Treatment Plant | Capacity (ML/day) | Effluent (MP/L) | Removal Efficiency % | Reference |
|---|---|---|---|---|---|---|
| 1 | Turkey | Primary, Secondary | 43 | 0.9 | 78 | (Akarsu et al., 2020) [2] |
| 2 | Australia (Hunter Region, NSW) | Secondary | 48 | 2.76 | 76.6 | (Raju et al., 2020) [59] |
| 3 | USA (Mount Pleasant) | Primary, Secondary | 22.7 | 2.50 | 97.6 | (Conley et al., 2019) [22] |

settlement; hence it is another gap that is yet to be determined with ways to improve its management. The estimated number of MPs excreted to the ocean (Kinoya—of 4,500 MPs per day, Natabua—4,558 MPs per day) should be an environmental concern particularly in its capability to associates other environmental pollutants. It may produce an average of 1.3 million MPs on the surrounding shores in Fiji in a year. It is also critical to be aware of the type polymers commonly present in each location. This will provide -based information for more research on the fate of these polymers in terms of their associated pollutants, access to marine organisms, and the cycle back to human health system. Common polymers from both treatment sites were cellophane, polypropylene, and polyethylene which may have been sourced from various mismanagement of waste from aspects of commercial activities waste, industries waste, tourisms waste, and most importantly, the culture of pollution is a factor. Fiji has banned single-used plastic. However, there are still multiple sources of cellophane and polyethylene contributing factors. In summary, the assessment of the WWTPs and investigation of the efficiency of the processes in this study has provided an opportunity to determine the general capability and efficiency of its treatment stages in removing MPs and lay a platform for innovative ideas on improving the technologies to remove MP's effectively. It will also pave the pathway of information about the average contribution of MP by two major WWTPs in Fiji to the ocean.

### Abbreviations

| | |
|---|---|
| MPs | MPs |
| PE | Polyethylene |
| PP | Polypropylene |
| PS | Polystyrene |
| POPs | Persistence Organic Pollutants |

## Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s43591-023-00068-0.

**Additional file 1: Table S1.** Wastewater treatment plants in Fiji and their capacity WWTP. **Fig S1.** Viti Levu Island map of Fiji showing locations of Natabua WWTP in Lautoka and Kinoya WWTP in Suva. **Fig S2.** The wastewater service area of Kinoya, Suva. Source: JICA Survey Team reported with Fiji Water Authority (Japan International Cooperation Agency(JICA), 2020). **Fig. S3.** The wastewater service area of Lautoka. Source: JICA Survey Team reported with Fiji Water Authority (Japan International Cooperation Agency(JICA), 2020). **Fig S4.** The display of part of microplastic samples shown were commonly observed at Kinoya (A) and Natabua (B) WWTPs. Kinoya samples, as shown at A, were mainly PE and cellophane and the Natabua samples have PP and PP, which include a straw. **Fig. S5.** The graph shows the absorbance of cellophane identifies polymers from the two WWTP with similar bands at 1735 cm$^{-1}$. This is based from past findings which indicates the bend readings for semi-synthetic cellulose compared to natural cellulose (Bradshaw *et al.*, 2020).

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### Authors' contributions

Malelili Naulivou Rokomatu conducted the underlying research, investigations, analysis and writing; Geetika Bhagwat-Russell edited, reviewed and proof read the manuscript; Logeshwaran Panneerselvan edited the graphics and proofread the manuscript; Subash Raju assisted with setting up the sampling and analysis method; Viliame Savou assisted in sampling at the WWTPs and laboratory analysis; Timaima Waqainabete assisted in microplastic sampling at the WWTPs and Thavamani Palanisami conceptualized the idea and supervised the work.

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### Availability of data and materials

The raw data supporting the conclusions of this article are available from the authors on reasonable request due to the request by the Water Authority of Fiji which owns the WWTPs used for the syudy.

## Declarations

### Ethics approval consent to participate

Not applicable.

### Consent for publication

All authors have read the final draft of the article and approved to publish it in Environmental Science and Pollution Research.

### Competing interests

The authors declare no competing interests.

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