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Pollution assessment around a big city in West Africa reveals high concentrations of microplastics and microbiologic contamination

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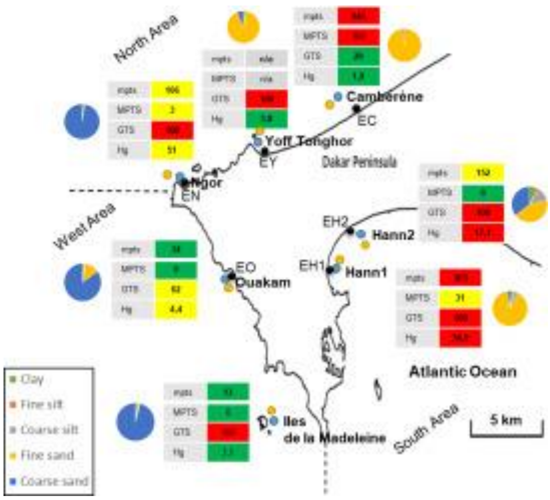
Abstract :

Marine pollution around West African big cities is of major concerns. Nevertheless, few attempts have been performed so far particularly on microplastic assessment. We had led first survey targeting microplastic in West African coastal waters (2016); and evaluated on the same sites microbiological contamination as well as marine sediment toxicity and mercury content. Thus, neuston marine water samples were collected over Dakar a highly populated West African city. The average abundance was around 258 954 microplastic particles per km 2 and 37 442 for macroplastics (MP). One station, downstream from the major wastewater plant, contained high abundance of microplastic particles of over 945 000 and 190 000 macroplastics. The offshore station had a lower abundance of microplastics and MP. It was observed that the stations found with highest level of microbiological pollution were related to highest microplastics abundance and the presence of major effluents, suggesting wastewaters inputs and microbiological pollution favoured by microplastics and macroplastics as vector. No correlation was observed between microplastics and/or macroplastics and sediment toxicity neither Hg level, which appear low in all studied sites. However, high level of ecotoxicity were often found near effluents. Such results are a first step within the framework of encouraging awareness and actions in West Africa.

Graphical abstract



Highlights

► A first assessment of microplastic pollution performed over West African continental shelf waters. ► High levels of organic matter limit the assessment of microplastics through classical approaches. ► Dakar city contributes to high level of plastic pollution in the ocean, possibly rafting microbiological contaminants, including *E. coli*. ► High spatial variability of marine pollution around Dakar city. ► High ecotoxicity of the marine sediment not related to Hg level.

Keywords : Plastic pollution ; Marine litter ; Vibrio ; Mercury Marine sediment ; Senegal

1. Introduction

In West Africa, most municipal and industrial wastewater is discharged onto the coast with little or no treatment, increasing the risks to public health. Less than 10% of African urban areas have wastewater collection systems. As a result, only a tiny fraction of wastewater is treated (World Bank, 2012). Marine pollution threatens the health of fish, which are an essential resource in West Africa and a primary source of protein for coastal populations. This pollution reduces the yield of fisheries by degrading the natural habitat, increasing egg mortality and reducing egg quality. Plastic debris inflicts significant damage on the African coastline: it threatens the survival of marine species that swallow it or become trapped in it, threatens human health, increases the risk of flooding (by clogging drainage infrastructure), and reduces the region's attractiveness to tourists.

An increasing number of studies reveals microplastic pollution of the world ocean (Adamopoulou et al., 2021) and their various impacts (Tallec et al., 2018; Hale et al., 2020; Galgani and Loiselle, 2021). Microplastics can be divided into two categories: primary microplastics (industrial production, or fibers shed from clothes and other textiles) and secondary microplastics, which are the result of the degradation macroplastics in the environment, which are broken down into smaller and smaller fragments by the action of sunlight, natural mechanical forces and other factors (GESAMP, 2010). At the level of individual organisms, impacts of microplastics are numerous and affect the entire marine food chain (Lehel and Murphy, 2021). Once ingested, these microplastics can either clog the digestive system, or simply pass through it (Wang et al. 2020). However, smaller particles, such as nanoplastics, will also be able to pass through the digestive membranes and migrate into the circulatory system and even in other organs (GESAMP, 2010). The impact of microplastics on in the environment and marine organisms is still not well known and several questions currently arise: intrinsic dangers of microplastics, adsorption properties of microplastics (vector of chemical and biological contaminants from PCBs/polychlorinated biphenyls to heavy metals like, Hg, and Vibrio (Galgani et al., 2020). The impacts of plastic debris (macroplastic) are ecological, economics and social (Galgani et al. 2010; Maximenko et al. 2019); in West Africa their impacts on tourism, sanitation and fishing are the most reported until now. Nevertheless, there are few studies led in African waters (Sparks and Immelman, 2020; Alimi et al., 2021). The number 14 (Life below water, SDG14) of the sustainable development goals (SDG) of the United Nations explicitly targets the assessment of microplastics in water. Based on that, the African countries are also expected to assess the density of microplastics in their exclusive economic zone (EEZ).

Senegal is part of this story and requires an initial assessment, most particularly after its recent decision to ban the use of plastic bags in 2020 (JO, 2020). In Senegal, like in Dakar, small scale fisheries activities (Diankha et al., 2017) are of essential socio–economics importance and a key employment sectors in the country (Ba et al., 2017). The surrounding seawaters are highly productive areas (Diogoul et al., 2021), particularly for small pelagic fishes (Ba et al., 2016; Thiaw et al., 2017; Baldé et al., 2019). Studies conducted by Ndour et al (2018) at the surface water level (0 - 25 m) on zooplankton abundance in the Senegal and Guinea zones show a predominance of copepods (68.5%) out of 19 zooplankton groups identified. Analysis of relative abundance by zone showed a predominance of copepods representing 71.7% in the northern zone and 65.4% in the southern zone. The abundance of almost all other groups was low (<5%), with the exception of gastropod groups in the northern zone (9.7%) and pteropods (10.4%) and ostracods (7.4%) in the southern zone. Concerning Ichthyoplankton, Ndour et al (2018) identified eggs and larvae of 29 fish families of which the most dominant are the following: Clupeidae (35.8%), Myctophidae (14.3%), Carangidae (9.6%) and Scombridae (9.3%). The abundance of the other families identified did not exceed 6.5%. Analysis of the relative abundance of larvae in each zone showed the dominance of Clupeidae (43.2%), followed by Myctophidae (21.5%) and Gadidae (7.4%) in the waters of the northern zone. In the waters of the southern zone, the ichthyoplankton was also dominated by Clupeidae larvae (28.3%), followed by Carangidae (16.0%) and Scombridae (15.7%). Therefore, the importance of assessing marine pollution is obvious but is seldom performed. Recent study have stress the potential impact on fish particularly on their larvae (Wang et al. 2020).

Big cities have been found to provide high density of microplastics in their wastewaters (Franco et al., 2021) and several ways to measure them exist, including by direct measurement (Galgani et al., 2013), indirect assessment through oceanic models (Gago et al., 2015), or using bioindicators (Matsuguma et al., 2017). While modelling levels up uncertainty (Worsfold et al., 2019), we decided to use a direct approach to assess microplastics pollution in the vicinity of the Senegalese Dakar city (West Africa). This assessment also include ecotoxicological bioassays, harmful bacteria, often associated with plastic pollution (Kirstein et al., 2016) and marine sediment analysis. The primary goal of this study was to provide a first assessment of the presence of microplastics and macroplastics in surface waters in the region, in a context of new law rationalizing plastic use in West Africa. The second objective was to evaluate the microbiological contamination (*e.g.* enterococci, Vibrio). The microbiological analysis allows to get a large picture of marine population for the various sites studied and check potential interaction or relation. The third objective concerns the chemical quality in relation to the mercury content and to assess the ecotoxicological quality of marine sediments. These will allow to provide an original overview of the marine pollution around an emblematic west African big city.

2. Material and Method

2.1. Study location

The study area is the city of Dakar located on the Cap-Vert peninsula in Senegal, West Africa (Fig. 1), with a population over one million inhabitants and over 2.4 million people in the greater metropolitan area of Dakar Region, spread on 84 km².

Seven coastal sites according to their location around the peninsula were selected for sampling purposes covering the North, South and West coast of the Peninsula. All the sampling sites were carried out near the coast (maximum distance from the coast < 500 m), except one done offshore. The national park of the "Iles de la Madeleine" (islands). Located more offshore (> 2 000 m) than the six others did it was selected at the least exposed presumed site (Fig. 1). One site, Cambérène is under the influence of the presence of a sewage discharge effluent (< 0.5 km from the sampling site (Fig. 1, Table 1)). The national park of the "Iles de la Madeleine" (islands), was selected as the least exposed site, located more offshore than the six others did (Fig. 1).

2.2. Data collection

2.2.1. Microplastics and macroplastics

All the seven sites to collect surface samples of microplastics and macroplastics were performed using a small craft on June 6th, 2016 in straight line at 2 knots during 20 minutes. An adapted Bongo net of 200 µm mesh size with trawl pole mounted on the left rear side of the boat was used. The Bongo net of 1.15 meter diameter (*e.g.* Habtes et al., 2014) was kept stable on the surface by three ropes hooked to a spinnaker pole that holds the net on the windward side of the boat. And indeed high density plastics will be less concerned in this quantification. Samples were put in numbered labelled glass bottles for post processing in the laboratory.

2.2.2. Microbiology

Enumeration of *E. coli* and enterococci was conducted for each site (Fig. 1). 500 mL of surface water were also collected in sterile polypropylene bottle. Two surface additional water samples were collected at each site, in sterile 1-liter glass bottles, for the detection of presence of *Salmonella* and harmful *Vibrio* sp., respectively. All the samples were kept in cooler with ice blocks before further processing within 24h at the laboratory facility.

2.2.3. Physicochemical parameters, Marine sediment and climatic conditions

Meteorological conditions were quiet during the sampling operations (06/06/2016): swell 1,4 - 1,6 m from East and wind at 5 - 12 knots from East/North-East. The distance travelled by the boat was recorded by a Global Position System (GPS) and local depth reported using a manual and hull mounted echosounders. Physico-chemical parameters (temperature, salinity dissolved oxygen and pH) were recorded in surface (20 cm depth) at each station. An Ekman grab was used to collect the sediment. Sediment samples for sizing were dried at room temperature and classified into five categories: clay, fine silt, coarse silt, fine sand and coarse sand (Guevara-Riba et al., 2004). The sediment samples used for the *Magellana gigas* bioassay (Galgani et al., 2009; Brehmer et al., 2011) and inorganic mercury quantification were kept cool (4°C) before analysis.

3. Data analysis

3.1. Microplastics and macroplastics

Six samples on seven collected were considered (Cambérène, Ngor, Ouakam, Iles de la Madeleine, Hann1 and Hann2). Yoff Tonghor was not considered, due to an overload of biological component particles (*i.e.* macro-zooplankton, see Supplementary A). Counting of microplastics was done at IFREMER laboratory (La Seyne-sur-Mer, France). While laboratory contamination mainly relate to the presence of fibers and very small microplastics, the work presented provides information on larger microplastic contamination. Protocols are adapted to measure particles of 330µm - 5mm, after sieving, to fit with the EU guidelines for regular monitoring, an approach that is widely recognized (Galgani et al., 2013; GESAMP, 2019), with the advantage of avoiding contamination by smaller particles. The quantification of micro and macroplastics is carried out in accordance with the GESAMP 2019 guide which uses the needle to confirm microplastics. Each sample was decanted after shaking in a 1-liter graduated test tube for 12 hours. Agitation allowed the dissociation of the different particles present in the sample. After sedimentation of the plankton (floating plastics are lighter), the supernatant, which contained the microplastics, was sieved (5 mm and 300 µm mesh) and rinsed extensively with distilled water. A mineral salt can be dissolved in the collected seawater to increase the density of the water and float the plastic fragments (Andrady, 2011). Microplastics were poured into two Petri dishes listed <5 mm (named 'microplastics) and > 5 mm (so called macroplastics,) with small amount of water, possibly scraping the surface of the sieve with a spatula when the remaining quantity was large. After removing plant debris and large plankton organisms from the pliers, the Petri dish was placed on a graph paper. All materials used have been cleaned beforehand to avoid contamination with microplastics. Using a magnifying glass, verification of the size and counting of microplastics in each box was done. Particles were counted and stored for subsequent weight measurement. After counting, the contents of the Petri dishes were divided into two dishes (microparticles and macroparticles) and placed in an oven at 50°C for 24 hours to weigh. The contents were then stored for further physico-chemical analysis. In this study, the identification (nature and colour) of microplastics and macroplastics was not carried out. The number of microplastics and macroplastics and their weight were related to the sampling surface and expressed as number of items per km².

3.2. Microbiology

The microbiological analyses consisted *E. coli* and enterococci counts. The detection methods NF EN ISO 9308-1/A1 for *E. coli* and NF EN ISO 7899-2 for enterococci were used with both detection limits at <15 CFU·100 mL^{-1} *Salmonella* detection was done according to the method described in NF EN ISO 19250.

For the molecular detection by polymerase chain reaction (PCR) of harmful *Vibrio* sp., 500 mL of surface water was filtered through 0.22 µm polycarbonate membrane filters. Then, filters were individually immersed in 20 mL enriched culture medium of Alkaline Peptone Water (AKP) at pH=8.6 at 37°C for 24 hours. Then, total DNA was extracted and molecular primers (utox-F, vptox-R, vvtox-R, vctox-R according to Bauer and Rørvik, 2007) for harmful *Vibrio* sp. were used to detect the presence of *Vibrio. cholerae*, *Vibrio. parahaemolyticus*, and *Vibrio. vulnificus*. Subsequently, all *Vibrio. cholerae*-positive broths were tested with specific primers to target the pandemic serogroup O1 (O1 rfb) or O139 (O139 rfb) according to Hoshino et al., (1998) and the cholera toxin sub-unit A (ctxA) according to Shirai et al., (1991) and Nandi et al., (2000).

3.3. Marine Sediment: granulometry, mercury content and global toxicity

Two proxies of marine pollution were used to characterize each site. The evaluation of Global Toxicity of Sediments (GTS) was performed using a bioassay, as measured using the larval development of the oyster *Magellana gigas* (His et al., 1999; Galgani et al., 2009; Brehmer et al., 2013). Direct Mercury Analyzer (DMA, Automatic Mercury Analyzer, type DMA-80) was used for estimating the mercury content of 0.1 g sediment samples without prior pre-treatment, i.e., without removal of methylmercury (MeHg) by organic extraction (Maggi et al., 2009). Finally, the granulometry of sediment samples was measured, providing percentages of clay, fine silt, coarse silt, fine and coarse sand (Guevara-Riba et al., 2004). Before measuring the particle size, the organic matter was destroyed by adding 30% hydrogen peroxide at 150°C for 1 hour and the organo-mineral cements are disintegrated by adding a solution of sodium pyrophosphate solution for 2 h at room temperature. The sediments were then placed in a 10 cm long extension tube to determine the fall time of the clays and fine clays/silt. The samples were taken from the sponge before the fall times of the clays and clays/silt using the Robinson pipette (Brousse and Arnaud-Fassetta 2011). The sampled volumes were then poured into a tared capsule and dried at 105 °C for 24 h. After drying, the masses of clays and silts were measured. The fractions of coarse silt, fine sand and coarse sand were evaluated by sieving.

Granulometry, a parameter influencing the distribution, mobility and bioavailability of sedimentary pollutants, is essential information in the study of pollution in this matrix of the marine environment. Various studies showed that pollutants such as heavy metals and polyaromatic hydrocarbons with low water solubility (high molecular weight), in comparison with more water soluble polyaromatic hydrocarbons, tend to be preferentially fixed to the fine particles of sediments. The mobility and bioavailability of these pollutants decrease with the increase of this fine fraction of the sediments (Raoux and Garrigues 1993). Coarse particles (fine and coarse sands) are less cohesive and have a small contact surface with the pollutants, which reduces the fixation of these pollutants (*i.e.* Heavy metals) in the sediments (Geffard 2001; Le Hir 2008).

3.4. Statistical analysis

We tested the linear relationship between the quantity of microplastics or macroplastics and the bacterial count of *E. coli* or enterococci. The purpose of this test was to check whether abundance of plastic particles is linked to microbiological contamination. The relationship between microplastics and macroplastics was tested, as well. The residuals distribution of the models was plotted and visually inspected. All statistical calculations were carried out using the statistical software "R" version 4.1.1 (R Core, 2021).

4. Results

4.1. Micro and macro plastics

Results revealed very high concentrations of microplastics, reaching 945 607 microplastics km^{-2} and 159 g km^{-2} at Cambérène, but lower values in the other sites at Ngor (106 203 microplastics km^{-2} and 11 g km^{-2}), Hann1 (303 059 microplastics km^{-2} and 60 g km^{-2}) and Hann2 (152 038 microplastics km^{-2} and 15 g km^{-2}) (Table 2). The lowest densities of microplastics were observed in Ouakam (34 236 microplastics km^{-2} and 6 g km^{-2}) and Iles de la Madeleine (12 641 microplastics km^{-2} and 2 g km^{-2}) on the West coast of the peninsula. The concentrations obtained for macroplastics presented a pattern similar to the one of microplastics, with higher concentrations at Cambérène (189 995 macroplastics km^{-2}), Hann1 (31 302 macroplastics km^{-2}), and a lower level Ngor (3 354 macroplastics km^{-2}). Even no macroplastics was recorded on both West coast site. The corresponding weights were high at Cambérène (328 g km^{-2}) and Hann1 (250 g km^{-2}), and weak at Ngor (6 g km^{-2}). Mean values (n = 6) were measured at 258 964 microplastics km^{-2} and 42 g km^{-2} for microplastics and 37 442 macroplastics km^{-2} and 97 g km^{-2} for MP.

4.2. Microbiology

For five over seven sites, enumeration of *E. coli* ranged from 3.10^3 to 1.10^4 CFU per 100 mL and for 4 over 7 sites, enumeration of enterococci from $1.8.10^2$ to $1.7.10^3$ CFU per 100 mL (Table 2; Fig. 2). *Salmonella* was detected only in Cambérène where the effluent of the major sewage treatment plant is present. *V. cholerae* was identified in a single site (Hann 1) and not detected in all the subsequent analyses, corresponded to a non-toxigenic non-O1/non-O139 *V. cholerae. V. parahaemolyticus* was also detected in one site, Yoff Tonghor. None of the samples was positive for *V. vulnificus.* Last, Cambérène the station with highest microplastics and macroplastics, was the only site where *Salmonella* presence was observed.

4.3. Physicochemical parameters, mercury content and global toxicity

All sites were characterized by the granulometry of sediment and basic physicochemical parameters (Table 2). Seawater salinity and temperature were similar in all sites with a slight temperature decrease in Cambérène, the most offshore location (~0.5 km from the coast) from the six coastal stations. All sampling sites were above anoxic level and well-oxygenated and maximum Δ_{pH} = 0.5 with a mean around 8.1. However, more heterogeneity was found for marine sediment grain sizes among sites. Ngor, Ouakam and Iles de la Madeleine were mainly composed of coarse sand while Cambérène, Yoff Tonghor, Hann1 and 2 were mainly composed of fine sand. Hann1 and 2 presenting the finest granulometry (clays, fine silts and coarse silts) of all sites.

The mercury contents in the sediments were globally low except in the southern part, with a 7 times higher level found at Hann1, close to an effluent (Table 2). Collected sediments presented a high level of toxicity, all sites displayed 100% of abnormal larvae according to the larval *M. gigas* embryo test, except at Cambérène, and Ouakam, where 29.5 and 61.9 % of abnormal larvae were measured (Table 2).

4.4. Statistical analysis

Positive and significant linear relationship between the microplastics and macroplastics was found (Fig. 2 and Supplementary B, Model 1). Same observation was done between the microplastics or macroplastics and count of *E. coli* CFU (Supplementary B, Model 2 and 3, respectively), indicating a higher concentration of *E. coli* with an increase of the concentration of microplastics or macroplastics. However, relationships between enterococci and microplastics or macroplastics were not significant. The linear regression on microplastics, macroplastics and *E. coli* aimed to verify whether abundance was linked to microbiological contamination. Although this statistical test did not necessarily imply a cause-and-effect relationship. All the plotted residuals looked random with absence of clear patterns and distributions were centered on 0. It should be noted that the distance between the sampling point and the effluent outlet, in addition to maritime agitation, can influence the consistency of the results. The greater the distance, the more microplastics and bacteria are dispersed in the water. This can be observed at the Cambérène site with a distance of 474 m to the effluent outlet and the presence of a wastewater treatment plant. It is nevertheless important to point out that the insufficient number of sites makes the statistical test hardly representative.

5. Discussion

In absence of river in the Cap-Vert peninsula, and without evidence of abandoned or last derelict fishing gear at sea (Matsuoka et al., 2005), this study suggests that the presence of microplastics relates either to the direct dumping of domestic and industrial effluents, or to the inputs from the remote effluent from Dakar city. The variability of microplastics and macroplastics can be explained by the nature and the flows from effluents (Table 1) and the phenomenon of currents and upwelling. In addition to the behaviours of populations in urban areas that often release waste into the environment (Tavares et al., 2020) can play a role as tangible evidence (Adam et al., 2020). In Waste Water Treatment plants, microplastics are often concentrated, and most of them released in the water system, as in Cambérène. As in Hann bay, they may be also originate from the spilling of waste and plastic items directly in the effluent discharge site (Bettarel et al., 2008), doubtless aggravated by coastal water retention in the south coast (isolation of Hann Bay from ocean current flows) (Ndoye et al., 2017). Direct dumping at sea of plastic waste in an effluent is a common scheme occurring also in the fishermen village of Ngor (Supplementary C), while it cannot occur in the remote Iles de la Madeleine or in Ouakam, located far from effluents and inhabitants. Note that the coasts of Ouakam, Ile de la Madeleine, Hann1 and Hann2 are influenced by ocean currents. The physical shape of the Dakar peninsula (Fig. 1) distances these sites from the currents observed in the Atlantic. Average values obtained around the Dakar Peninsula are higher than those measured in 2013 and 2014 in Spain (North West Iberian upwelling system) and Cantabrian Sea (Gago et al., 2015). It is also above the levels reported by Nel and Froneman (2015) in South Africa, by Eriksen et al., (2013), in northern Spain (Gago et al., 2015) and even in the Mediterranean Sea, which *e.g.* average levels found at 116 000 microplastics km^{-2} with a maximum of 360 000 microplastics km^{-2} (Collignon et al., 2012) In contrast, very high amounts (64 million microplastics per km^2) have been observed in the Mediterranean Sea (van der Hal et al., 2017). The comparison of the present microplastics results with others shown the high heterogeneity as in South Africa but on smaller geographical extend (Table 3). Even if the Northeast vector component of the wind during the sampling could increase the retention of microplastics and macroplastics at the coast on North and West Coasts, the Dakar peninsula contribution (with an average of ~260 000 microplastics km²) can be considered as high.

High values of *E. coli* were systematically associated with high values of microplastics (Cambérène and Hann1) (Fig. 2). The microplastics and macroplastics around Dakar peninsula appear statistically linked to microbiological contamination of *E. coli* via effluent release. It also reinforce the hypothesis that microplastics and macroplastics can be highly suspected to be vector of microbiological contaminants which colonized them (Kirstein et al., 2016). At the Ouakam and Ile de la Madeleine sites, the no-detection of bacteria and the low presence of microplastics suggest the presence of other factors for microbial proliferation than microplastics. In terms of ecosystems, microplastics and macroplastics provide a new habitat for many species at sea, including many microorganisms, bacteria, viruses, fungi, microalgae like diatoms. These species will quickly colonize plastic waste at sea, by attaching themselves to it and even developing (Du et al., 2022). Since plastics are persistent and highly mobile materials, they will have the capacity to transport these species over large scales of space and time, the so-called “raft” effect (Galgani et al., 2020). Recent observation of harmful algal bloom in this area (Brehmer et al., 2021), which occur alternatively on the North and South coast of the peninsula, could be transported by microplastics and macroplastics and should be investigated.

The high level of microplastics and macroplastics in Cambérène corresponds to the low level of Hg and the lower GTS, which could be the effect of the wastewater treatment plant: concentration of microplastics (Kazour et al., 2019) and decrease of Hg discharges to water (Balogh and Nollet, 2008). Moreover, for this station, the microbiological pollution was as high as the microplastics level. This link between microplastics concentrations and microbiological pollution (*E. coli* and enterococci) was also observed at the Ngor, Hann1 and Hann2 sites. Furthermore, the stations with the lowest concentrations of microplastics (Iles de la Madeleine and Ouakam) were also the lowest in terms of microbiological pollution (*E. coli* and enterococci). A direct correlation between Hg and overall sediment toxicity was not observed between the different sites. Finally, as expected, the overall toxicity of the sediments, such as their Hg content, appeared to be unrelated to the microplastic concentration as well as the microbiological level in the upper part of the water column.

We have not found in the literature Hg measurement in Senegalese marine sediment. All Hg levels were below the reference levels established for dredged sediments (Geffard, 2001) and the Canadian criteria for assessing the quality of marine sediments (Environment Canada, 2007). Despite these low Hg levels, the high variability observed between sites proves that there was indeed anthropogenic pollution. This observed variability could be attributed, in part, to the granulometry, linked to local currents. The southern coast (Hann1 and Hann2) contained much more fine fractions than the other sites (low swell and current favouring sedimentation) (Gueye et al., 2017; Almar et al., 2019). Various studies show that pollutants such as heavy metals and Polycyclic aromatic hydrocarbons (PAHs) with low water solubility (high molecular weight), in comparison with more water-soluble PAHs, tend to be preferentially fixed to the fine particles of sediments. The mobility and bioavailability of these pollutants decrease with the increase of this fine fraction of the sediments (Raoux and Garrigues 1993). Coarse particles (fine and coarse sands) are less cohesive and have a small contact surface with the pollutants, which reduces the fixation of these pollutants (*i.e.* heavy metal) in the sediments (Geffard 2001; Le Hir 2008). The Global sediment toxicity (GST) (*e.g.* Brehmer et al., 2013) observed between sites was characteristic of the nature and intensity of the pollution: treated wastewater discharges at Cambérène, Ngor (average flow), untreated urban and industrial wastewater discharges at Hann1 and 2, wreckage at Iles de la Madeleine, high anthropogenic activity at

Yoff Tonghor and domestic wastewater discharges at Ouakam (Table 1). Granulometry could provide additional information (link between GST and granulometry) if the samples had been diluted for GTS, which would have made it possible to discriminate the most toxic sites.

While the main limitation of the study is the small number of samples, it may support larger-scale harmonisation and a better comparison at regional, continental and global scales. Plastic ingestion by marine organisms have not been considered in the present study and can underestimate the microplastics and macroplastics assessment as mentionned by Markic et al. (2020) Plastic is a compound of synthetic organic polymers obtained by the polymerization of monomers extracted from oil or gas. There are several types of plastics, up to 200 families of which the most abundant are polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyethylene terephthalate (PET), nylon and acrylonitrile butadiene styrene (ABS) (GESAMP, 2010). Obviously, the nature of the microplastics should be identified using *e.g.*, FTIR and Raman spectroscopy (Kumar et al., 2021). At this stage, it must be perceived as a starting point for Senegal (where plastic bags were partially banned in 2015) and more generally North-Western Africa where most of main cities are coastal.

Thirty-five other African countries banned or ruled on the use of plastic bag, even if implementation remains often an issue. Awareness is a key challenge in West Africa. Nevertheless, as part of the Ocean Decade programme SGD14.1.1, we advocate for capacity building and training to support the implementation of monitoring. Our results show the importance of microplastics contamination and may raise attention for policy makers. Being the first in Western Africa, our study provides scientific and technical basis for the monitoring of microplastics, supporting the implementation of monitoring, reduction measures, education, and more generally regional initiatives such as the Abidjan Convention. At sub regional level, it enters in the framework of the sub regional fisheries commission (SRFC), understanding that both microplastics and macroplastics are a cause of concern for resources and affect the fisheries sector (Nash, 1992, Gregory, 2009). Finally, it may favour the involvement of civil society, through participative sciences, together with policy makers and environmental managers.

6. Conclusions

Mercury levels in the Dakar city sediments were generally low. Nevertheless, the sediments shown high level of ecotoxicity, we do not found the source of this ecotoxicity, that call for a wider screening. The microbiological results (on *E. coli*, enterococci, salmonella, *Vibrio*) show that most of the sites do not comply with bathing water quality. That could also prevent aquaculture activities around the city. The analysis of microplastics reveals high concentrations and densities in general and very high near effluent of wastewater plant. Such level can trigger impact on fish larvae but deeper studies are required before to statute on this point. Macroplastics as microplatitics densities shown a high spatial variability, probably due to the complexity of oceanic current near the coast and the peninsula geographical configuration. Positive and significant linear relationship between the microplastics and macroplastics was found. Same observation was done between the microplastics or macroplastics and count of *E. coli* CFU. This supports the hypothesis that microplastics are a vector of microbiological pollution. The presence of effluents all along the coast of Dakar city required an urgent need of sanitation to preserve marine habitat as recreational areas and to give people the right to enjoy a healthy environment. Future more detailed studies will be conducted on the link between microplastics and bacterial parameters.

7. Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Legend

Figures

Fig. 1. Sampling sites around the Cap-Vert peninsula, Senegal, West Africa. The Cap-Vert Peninsula were divided in three main area: North, West and South (dotted lines). Considering X as the first letter of the sampling site, all sites were identified on the map by (i) the position of microplastic sampling (NX), (ii) the position of the nearest wastewater effluent (EX), and (iii) the position of water and sediment sampling (site name). EC = Effluent Cambérène, NY = Net Yoff Tonghor, EY = Effluent Yoff Tonghor, FN = Net Ngor, EN = Effluent Ngor, FO = Net Ouakam, EO = Effluent Ouakam, FM = Net Madeleines, FH1 = Net Hann1, EH1 = Effluent Hann1, FH2 = Net Hann2 and EH2 = Effluent Hann2. Statistical pie chart characterizes the sediment granulometry in percentage for all site (clay, fine and coarse silt, fine and coarse sand).

Fig. 2. Graphic of coastal microplastics (mp, <5 mm) and macroplatics (MP, > 5mm) abundance and density (g km²) around the peninsula of Dakar city. On second axis the *Escherichia coli* and enterococci in CFU/100mL.

Tables

Table 1: Sampling site detail: Station name, around the peninsula of the Cap-Vert, their distance (in meter) “to the nearest effluent and the coast (D_{efflu}, D_{coast}), their local depth, the distances and areas sampled for microplastics (D_{microp}, $Area_{micropl}$). All stations are georeferenced (GPS, DD: Decimal degrees). Type of pollution, effluent flow (H: high, M: medium and L: low), and type of bottom are indicative (S: sand; R: reef).

Table 2. Coastal microplastics (mp, <5 mm) and macroplastics (MP, > 5 mm) abundance (km^{-2}) and density (g km^{-2}) around the North, West and South parts of the peninsula of Cap-Vert (Dakar city). For microbiological results A: Absence; P: presence. *Escherichia coli* and Enterococci are in CFU/100mL and for Salmonella, *Vibrio cholera*, *V. parahaemolyticus*, *V. vulnificus* only “A” Absence or “P” presence (in grey) is notified. Marine sediment granulometry in proposition (%) of clay, fine silt, coarse silt, fine sand and coarse sand. GTS : Global Toxicity of Sediments (% of abnormal larvae) ; Hg : mercury content (in µg kg^{-1}) in the marine sediment. Physicochemical parameters in each studied site.

Table 3. Comparison of microplastics abundance in surface waters found in the present study around the Cap-Vert peninsula throughout various studies led in Africa, Europe and the United States of America.

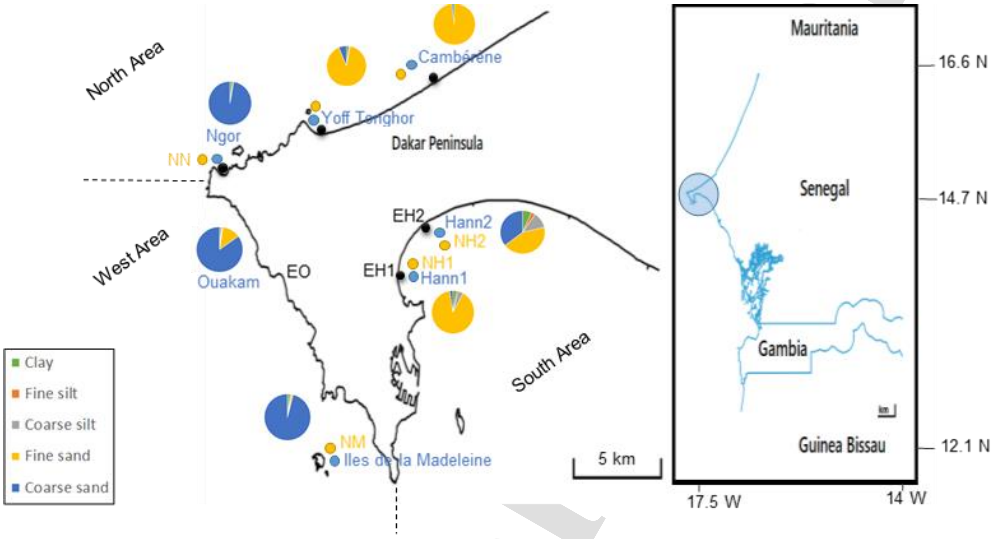
North Area
Cambérène
Yoff Tonghor
Ngor
NN
Dakar Peninsula
West Area
Ouakam
EO
EH2
Hann2
NH2
EH1
NH1
Hann1
South Area
NM
Iles de la Madeleine
5 km
Clay
Fine silt
Coarse silt
Fine sand
Coarse sand
Mauritania
16.6 N
Senegal
14.7 N
Gambia
Guinea Bissau
12.1 N
17.5 W
14 W

Figure 1

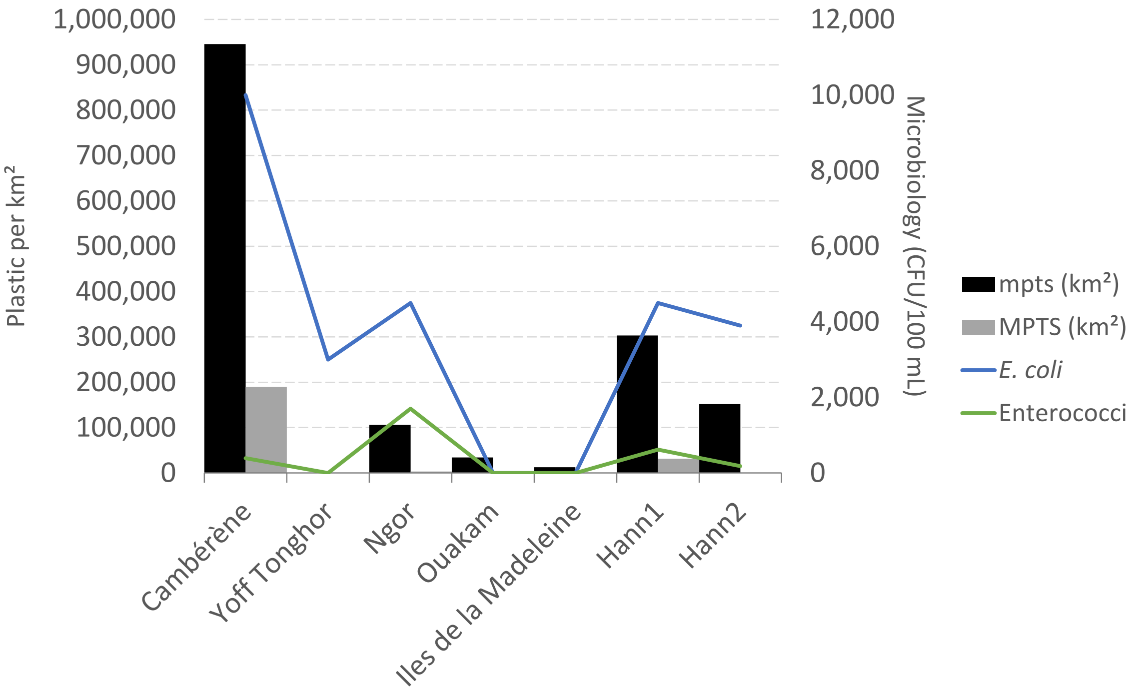

Figure2 (with mpts = microplastics and MPTS = macroplastics)

Table 1

Station name	D_{efflu} (m)	D_{coast} (m)	Depth (m)	$D_{micropl}$ (m)	$Area_{micropl}$ (m^2)	GPS Lat. North, Long. West	Type of pollution	Effluent flow	Nature of the bottom
Cambérène	474	447	7.3	769	916	14.771338, -17.431724	Wastewater plant effluent	H	S
Yoff Tonghor	143	122	2.2	630	725	14.766937, -17.478672	Wastewater Fishing landing place	M	R
Ngor	102	84	3.0	778	895	14.748700, -17.520144	Wastewater	M	R
Ouakam	104	89	4.3	950	1 092	14.713744, -17.491012	Wastewater	L	R
Iles de la Madeleine	2 868	2 200	6.0	963	1 107	14.653854, -17.468710	Shipwreck	n/a	R
Hann1	76	62	1.9	611	703	14.677953, -17.460680	Wastewater	H	S
Hann2	161	505	4.0	778	895	14.714914, -17.430293	Wastewater	H	S

Table 2

Peninsula of Cap-Vert	Site	microplastics		macroplastics		*Escherichia coli* (CFU/100 mL)	Enterococci (CFU/100 mL)	Salmonella	*Vibrio cholerae*	*V. parahaemolyticus*	*V. vulnificus*	Clay (%)	Fine silt (%)	Coarse silt (%)	Fine sand (%)	Coarse sand (%)	GTS (%)	Hg (µg kg^{-1})	T (°C)	pH	Sal (psu)	O_2 (mg L^{-1})
		km^{-2}	g km^{-2}	km^{-2}	g km^{-2}																	
North	Cambérène	945 607	159	189 995	328	10 000	390	P	A	A	A	2.0	0.7	0.2	95.3	1.8	29.5	1.9	19.0	8.50	33.9	6.93
	Yoff Tonghor	n/a	n/a	n/a	n/a	3 000	< 15	A	A	P	A	1.8	0.9	0.3	90.7	6.3	100	3.8	21.3	8.09	33.3	6.44
	Ngor	106 203	11	3 354	6	4 500	1 700	A	A	A	A	1.8	0.9	0.0	0.1	97.2	100	5.1	21.4	7.96	33.9	6.23
West	Ouakam	34 236	6	0	0	<15	< 15	A	A	A	A	1.2	0.7	0.5	12.7	84.9	61.9	4.4	21.9	7.99	33.9	5.71
	Iles de la Madeleine	12 641	2	0	0	<15	< 15	A	A	A	A	1.8	0.9	0.3	1.0	96.0	100	3.5	22.4	8.02	33.8	5.20
South	Hann1	303 059	60	31 302	250	4 500	620	A	P	A	A	2.8	1.3	3.9	89.6	2.4	100	34.9	22.3	8.13	34.0	4.99
	Hann2	152 038	15	0	0	3 900	180	A	A	A	A	6.7	2.9	11.8	43.1	35.5	100	17.1	22.6	7.96	33.7	3.73

Table 3

Country / sea / lake	Area	mp km^{-2}	References
South Africa	South western cape province	257 000 000	(Alimi et al., 2021)
Iberia	NW Iberia upwelling system	980 000	(Gago et al., 2015)
Senegal	Cambérène	945 607	Present study
Cantabria	Cantabrian Sea	407 000	(Gago et al., 2015)
Senegal	Hann 1	303 059	Present study
South Africa	Kwa Zulou-Natal	280 000	(Alimi et al., 2021)
Senegal	Peninsula of Cap-Vert (Dakar)	258 954	Average present study
Senegal	Hann 2	152 038	Present study
Europa	North Western Mediterranean	110 000	(Collignon et al., 2012)
Senegal	Ngor	106 203	Present study
Usa	Laurentian Great Lake	43 000	(Eriksen et al., 2013)
Senegal	Ouakam	34 236	Present study
Senegal	Iles de la Madeleine	12 641	Present study
South Africa	South-eastern major bays	11 000	(Alimi et al., 2021)
Greece	Corfu Gulf	9 800	(Adamopoulou et al., 2021)
Mediterranean	North Lonian Sea	5 600	(Adamopoulou et al., 2021)
Kenya	Naivasha	3 640	(Alimi et al., 2021)
Greece	Corfu Gulf	2 800	(Adamopoulou et al., 2021)
Mediterranean	North Lonian Sea	2 200	(Adamopoulou et al., 2021)
Greece	Inner Saronikos Gulf	1 100	(Adamopoulou et al., 2021)
Greece	Inner Saronikos Gulf	600	(Adamopoulou et al., 2021)

Conflict of Interest

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.