GSC Biological and Pharmaceutical Sciences
eISSN: 2581-3250 CODEN (USA): GBPSC2
Cross Ref DOI: 10.30574/gscbps
Journal homepage: https://gsconlinepress.com/journals/gscbps/

(RESEARCH ARTICLE)

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Critical factors for the rehabilitation of Hann Bay (Senegal, West Africa): Solutions for sustainable development

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GSC Biological and Pharmaceutical Sciences, 2024, 27(01), 165–173

Publication history: Received on 24 February 2024; revised on 07 April 2024; accepted on 10 April 2024

Article DOI: https://doi.org/10.30574/gscbps.2024.27.1.0118

Abstract

The advanced degradation of Hann Bay (Dakar, Senegal) has reached highly elevated levels, with serious environmental, health, and social consequences. Thus, this study focused on the determinants for rehabilitating Hann Bay and proposed solutions for sustainable development. The target area is currently home to 500,000 inhabitants and hundreds of industrial units, with virtually no suitable wastewater treatment systems. Socio-economic surveys and three rounds of effluent sampling were carried out between 2020 and 2022 at eleven sites in Hann-Bel Air, Dalifort Foirail, Thiaroye sur mer, Sicap Mbao, and Mbao. The study showed increased physicochemical, biological, and bacterial pollution of the heavily contaminated wastewater along the bay. The analytical results of the samples collected for the three series show that almost all sampling points exceed the limit value for TSS (50mg/l) and COD (200mg/l). This indicates that physicochemical and organic pollution are still present in the bay, causing fish to escape into the open sea. BOD measurements are also above the standard (N05-061; 80 mg/l) for series 1 and 2, showing an alteration in bay conditions. Analysis of the microbiological quality of the water in terms of oils and fats showed values well above the current standard (NS 05-061, 20-50 mg/l), which explains the frequent fish kills at the Hann marinas, Hann pêcheurs, and Cité ISRA sites. The same situation was observed in samples of fecal coliforms (CFU/100ml), helminth eggs (eggs/L), nitrogen, phosphorus, zinc, and lead at values outside the norm.

Through socio-economic surveys of the populations and workers in the industrial units, the recommended solutions focus on protection and prevention measures, enforcement of regulations, communication and awareness-raising, equipment acquisition, and monitoring and surveillance to rehabilitate the bay.

Keywords: Pollution; Physical-chemical; Biological; Bacterial; Wastewater; Hann Bay; Senegal

1. Introduction

The Hann Bay target zone, located south of the Cape Verde peninsula and east of the city of Dakar, stretches for around 17 km and is bounded to the north by the old Rufisque road, to the south by Hann Bay, to the west by the base and to the east by the village of Petit Mbao. In Senegal, the issue of pollution in Hann Bay has been a central concern for the government and various stakeholders for decades. The Bay of Hann, which used to be very busy, generates massive quantities of domestic wastewater (100,000m3), which enters the natural environment without treatment (Mbeguere, 2002). As a result, industrial plants that used to be located far from the urban center are now close to residential areas because of the potential nuisance their operation could cause. On the other hand, solid demographic pressure enormously impacts the quality of domestic wastewater discharged. Hann Bay, as indicated by (Gill & Meloche, 2012). Today, Hann Bay is significantly degraded, with wastewater from neighborhoods being disposed of in septic tanks on

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public roads and no adequate collective sanitation system in place (Ndao, 2012). This pollution of beaches and seawater has scared off tourists, bathers, and potential investors.

The enormous discharges are via the stormwater Canals (Canal V and VI), which have been diverted from their primary role: SOGREAH study - 2012 (on the bay's most polluting industries).

Marine pollution could be one of the causes of fish scarcity: Diop (2014), and the sources of pollution are diverse: hydrocarbon discharges, cargo emptying, industrial discharges, domestic wastewater, and household refuse.

This study is, therefore, intended to contribute to solving these problems. In this sense, it could enable stakeholders to control the area's degradation better and drastically reduce the consequences of pollution for sustainable development.

2. Materials and methods

2.1. Presentation of the study area

The central communities affected by the deterioration of the bay (Hann-Bel Air, Dalifort Foirail, Thiaroye sur mer, Sicap Mbao, and Mbao) have grown in size. Due to a lack of sanitary infrastructure and adequate wastewater collection and disposal systems (connection to the stormwater network of Canals 5 and 6), the local population dumps solid and liquid waste on the beach or in the bay. Due to a lack of sanitary infrastructure and an inadequate system for collecting and disposing of wastewater (connected to the rainwater network of Canals 5 and 6) and household refuse, residents, are dumping their solid and liquid waste on the beach or in the bay. Field surveys reveal that the Hann-Mbao study area comprises several municipalities, households, and various human activities that generate pollution through direct or clandestine discharges into the bay or pits. This has negative ecological, health, and visual impacts, with adverse consequences for sustainable bay management.

2.2. Presentation of sampling sites

2.2.1. Sampling was carried out at eleven sites along the Bay of Hann

Canal 6: Canal 6 (4 km long), originally designed to collect rainwater, now drains wastewater mixed with household and other waste from Colobane to Hann Bay. Residents, industrialists, fishermen, merchants, and unauthorized connections generate this pollution.

The bay's blue color is altered in this area by pollution from Canal 6. It turns brown due to organic suspended solids, mineral-suspended solids such as sediment and residue, and dissolved organic matter.

ISRA Canal drains blackish wastewater from the port (it contains hydrocarbons), which is discharged untreated into Hann Bay.

- Port Mole 10: Wastewater transported by stormwater networks ends up at the outlets of the Dakar autonomous port.
- Port Mole east side: The lack of a complete pretreatment system for industrial wastewater exacerbates oil and grease discharges.
- Fishing Pier Canal: This Canal drains domestic and industrial wastewater from Hann
- Wallo gui Canal: This Canal drains untreated wastewater from Hann's municipalities and industrial companies connected directly to it.
- Dalifort Canal/ADM project: At the Dalifort Canal (ADM project), we have a stormwater drainage network mixed with wastewater. This blackish wastewater is collected in the commune and discharged into the ocean. The Dalifort-Fora Canal is open-air, and distinct types of solid waste are stored in the open air close to the Canal.
- SOGAS Canal: During our field studies, we observed bloody discharges through the SOGAS Canals on the bay. This company specializes in animal slaughtering. It is a significant contributor to pollution in the bay. SOGAS does not currently have the appropriate equipment for processing animal blood.

Thiaroye sur Mer Industrial Waste Canal/ICS: This Canal, designed to collect rainwater, has turned black with various wastewater from the SENTA tanneries. Added to this are the industrial and domestic units clandestinely connected to the Canals, intended initially to evacuate rainwater at these points.

Canal V: The Canal V watershed is part of the area known as Corniche Ouest. It is characterized by significant commercial and industrial activity.

Canal V receives a large quantity of effluent from sewers and industry.

The existence of a vast number of illegal connections to the stormwater drainage networks hampers the smooth operation of Canal V.

- SAR Canal: On the SAR Canalside, pipelines are present, but discharges are hundreds of meters from the shore.
- Petit Mbao basin: In the vicinity of the future Petit Mbao wastewater treatment plant, massive quantities of untreated wastewater from LINDA wicks are being discharged into a basin.

2.3. Sampling, analysis and equipment

Three sampling campaigns (October 15, 2020, September 7, 2021, and February 21, 2022) were carried out on the following sites: Canal 6 (Hann Marinas), Canal Cite isra (Hann Bel Air, Cite isra), Port - mole 10, Port- mole 10 – east (Hann-bel air), Fishing quay Canal (Hann pêcheurs), Wallo gui Canal, (Hann pêcheurs) Adm project Canal (Dalifort), Soga's Canal (Dalifort), Industrial discharge Canal (Thiaroye sur mer), Sar Canal (MBAO), Petit Mbao basin (Petit M bao).

The samples were sent directly to the Analysis and Testing Laboratory of the Polytechnic Graduate School (ESP) in Dakar to avoid any deterioration or contamination, and the analyses were carried out immediately.

In particular, effluent samples were placed in vials and kept in a cool box in a dark, cold place before being transported to the laboratory.

The materials and equipment used for sampling are :

- Latex gloves
- A bucket to draw water
- Plastic bottles to collect water.
- A felt-tip pen to mark and number bottles according to the sampling point
- A bag to hold all sampling materials

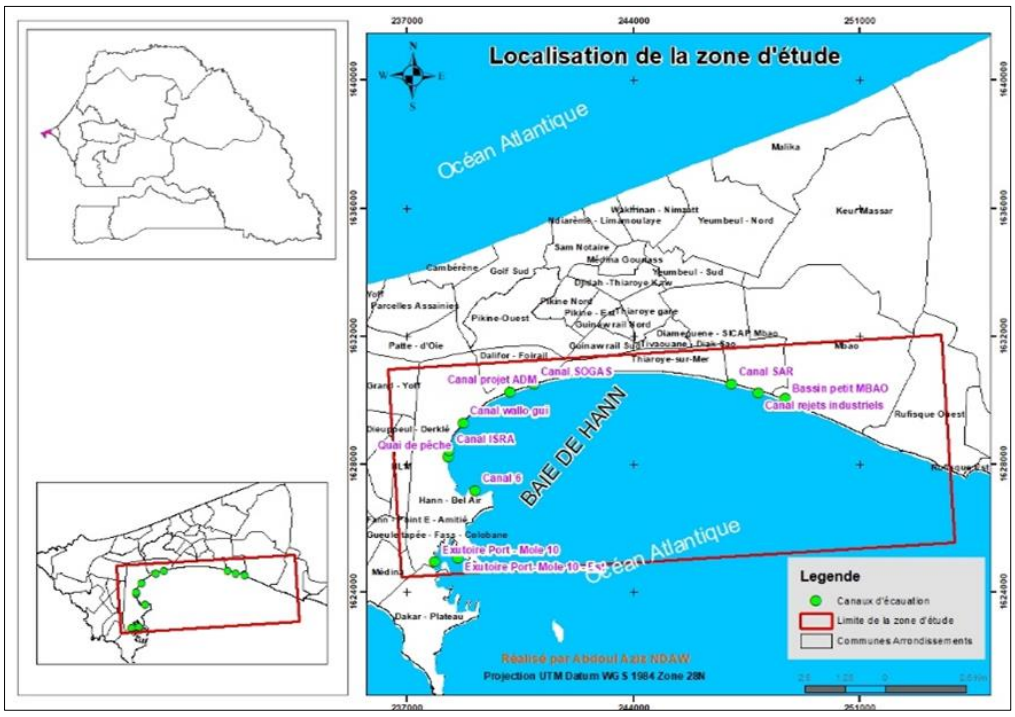

Figure 1 Location of effluent sampling sites

3. Results and discussion

3.1. Contamination and alkalinity of wastewater collected at the Petit Mbao basin site

PH compliance was noted for all series 1 and 2 samples (October 15, 2020, and February 21, 2022), except for the Petit Mbao basin, which reached a PH = 9.40 during campaign 2, far exceeding the threshold and accepted regulations (6-9).

Surveys and field visits have shown that clandestine industrialists and networks are causing this contamination. They discharge wastewater directly and untreated into a basin in Petit Mbao, just a few meters from the site planned for the future wastewater treatment plant. Consequently, the peak noted in series 2 shows that between 2020 and 2022, there will be some alkalinity in the wastewater, with negative consequences for the environment (pH=9.40).

Therefore, it is vital to maintain wastewater within the pH range of 6 to 9 to keep microorganisms alive and healthy and preserve the natural environment after discharge.

Table 1 PH results for series 1 and 2 (October 15, 2020, and February 21, 2022)

	RESULTS	
	PH-Series 1	**PH-Series 2**
Period / **Sampling points (samples)**	**10/15/2020**	**02/212022**
Bassin Petit Mbao Step Mèche Linda	7	9.40

3.2. Apparent pollution at the Canal 6 site

Table 2 shows the excessive presence of suspended solids (SS) during the various sampling campaigns, far exceeding the standards set in Senegal. This increases water turbidity and leads to a sharp drop in transparency, reducing light penetration, photosynthetic production, and dissolved oxygen. Levels vary depending on the sampling point, but almost all are well above the TSS limit value (NS 05-061/50mg/l) and do not meet the acceptability threshold. These results align with those of the ARTELIA group (2011), which do not comply with the standard for the TSS parameter at this sampling site.

Canal 6 TSS levels are very high, reaching 1740 mg/L for series 3. This is due to the high quantity of suspended solids in the bay's waters (water very rich in insoluble particles), which results in very high turbidity (hyper-turbid water). This causes a sharp drop in transparency, leading to a reduction in photosynthetic production and dissolved oxygen.

At Canal 6, a bar screen was installed in 2019 by environmentalists from the target area to stop solid waste, allow normal wastewater discharge, and minimize TSS.

This effort is insufficient because while the bar screen stops some waste at Canal 6, most are discharged directly onto the beach and into the bay. Also, the small businesses along the bay contribute to primary pollution by discarding paper and plastic packaging, tins, and unsold fish, which shows the level of degradation of the beach.

This apparent and visual pollution, with its strong odors, is caused by domestic wastewater (physical, organic, chemical, biological), made up of black water and grey water (washing-up, bathing...) and industrial wastewater, discharged directly and deliberately into the sea without prior treatment via Canal VI.) and industrial wastewater, discharged directly and deliberately into the sea without prior treatment via the VI Canal. It presents a severe health risk.

On the other hand, the results table shows a very high overall TSS at the SOGAS outlet for series 1, 2, and 3. They range from 780 to 18270, far exceeding the standards set in Senegal. This is due to suspended solids in the wastewater and very high turbidity, resulting in organic pollution due to high organic content.

In addition, we note visual pollution and strong odors in this part of the bay, which receives polluted water from SOGAS.

Finally, the same observation was made in the Petit Mbao basin, with apparent pollution (primary pollution) from industry and households along the bay and high TSS, resulting in cloudy water and reduced photosynthetic production.

TSS is also very high in the small MBAO basin for series 1, 2, and 3. It ranges from 780 to 18270, far exceeding the standards set in Senegal.

Table 2 TSS results (mg/l) for series 1, 2, and 3 (October 15, 2020, September 7, 2021, and February 21, 2022)

	RESULTS		
	TSS (mg/l)-Series1	**TSS (mg/l)-PH-Series 2**	**TSS (mg/l)-PH-Series 3**
Period / **Sampling points (samples)**	**10/15/2020**	**09/07/2021**	**02/212022**
Canal 6	40	14	1740
Sogas Canal	4840	780	18270
Bassin Petit Mbao Step Mèche Linda	5440	504	10716

3.3. Strong increase in organic pollution at all sampling sites

Campaigns 1, 2, and 3 showed high COD results (indicated as a measure of the chemical pollution of a discharge by the organic and oxidizable inorganic matter present in the bay water) at all sampling points in the bay water) for all sampling points and did not comply with regulatory standards and thresholds, reaching as high as 81600 mg /l for SOGAS (see Table 3). It should be noted that these enormous COD values correspond to a high organic matter content (secondary pollution). The increase in this form of pollution disrupts the bay's self-cleansing role. This is all the carbon waste from the food industry (the food of choice for microorganisms in the water).

This is due to an increased pollutant load and a large quantity of sludge. There is a lack of oxygen and organic matter throughout the bay.

For series 1, COD does not meet the tolerance threshold set by the standards [NS 05-061 - 200 mg/l] in waters sampled along the bay, and there is a relatively significant exceedance of the limit value, up to 13200mg/l for SOGAS (table 3).

This is due to the large quantity of sludge, with a considerable increase in the pollutant load of wastewater at several points, resulting in a high concentration of organic matter. For series 2, the situation is the same as for series 1 (table 3), i.e., it does not comply with the standards in the waters sampled along the bay. The limit value (200mg/l) exceeds all sampling points, reaching 81600mg/l at SOGAS.

When the environment is depleted of oxygen by organic matter, they seek it in the dissolved sulfates, which they reduce to sulfide, released in hydrogen sulfide, generating a rotten-egg odor that proves fatal for aquatic life.

As a result, we can speak of an oxygen shortage throughout this part of the bay, especially at points located at the Petit Mbao basin, ICS, and SOGAS, with high values reaching 52800 mg/l, 34800 mg/l and 84600 mg/l.

Knowing that oxygen is essential to life, we must wonder about the future of this body of water in this part of the bay.

Today, coastal pollution makes swimming practically impossible, except for particular enthusiasts or those unaware of the state of the bay, who run the risk of infection.

The same is valid for mole 10 and Canal SAR, with very high COD levels: 4,380 mg/l and 1,824 mg/l, exceeding the standards set in Senegal.

There is also the risk of an oil spill from the SAR pipeline in this part of Hann Bay.

Overall, COD exceeded regulatory standards and thresholds by a wide margin for all series. This is due to increased pollutant load and a large quantity of sludge. Oxygen is lacking, and organic matter is high all along the bay, leading to environmental degradation and fish escaping to the open sea.

Table 3 COD results for series 1, 2, and 3

	RESULTS		
	TSS (mg/l)-Series1	**COD (mg/l)-Series 2**	**COD (mg/l)-Series 3**
Period / Sampling points (samples)	**10/15/2020**	**09/07/2021**	**02/212022**
Canal Sar output	1804.8	1824	1785.6
ICS Canal	3264	34800	720
Sogas Canal	13200	81600	11040
Mole 10 outlet	1190.4	2544	4320

3.4. Organic pollution due to high BOD5 levels along the bay

For campaigns 1 and 2, BOD standards were exceeded at almost all sampling points (threshold N05-061 80 mg/l). This degree of water pollution is significant, showing an alteration of the bay caused by non-biodegradable organic matter. The presence of these pollutants and the scarcity of nutrients lead to pronounced degradation of the environment and the flight of fish into the open sea. These results align with those obtained in 2011 by ARTELIA, with a BOD5 discharge rate of 667 Kg/d.

BOD (the number of oxygen microorganisms (bacteria) required to decompose or fully oxidize to partially) is also high in the Petit Bar pond for series 1 and 2. It is between 160 and 240 mg/l, exceeding the standards set in Senegal. The ICS MBAO discharge results obtained by ARTELIA (2011) align with and even exceed those obtained in the area at the Petit Mbao Basin discharge point.

According to Table 4, BOD is non-compliant at the fishing pier for series 1 and 2, exceeding 300mg/l. This discharge point collects wastewater from septic tanks and fishing businesses. According to the ARTELIA study (2011), CONDAK alone discharges 210mg/l BOD/D, which aligns with the above results.

This pollution can be seen from the shore along the entire bay length and inland for the first 200 meters. Along the bay, organic pollution due to a high organic matter content and a scarcity of nutrients has led to pronounced environmental degradation.

As a result, the physicochemical results for the waters of Hann Bay are heavily contaminated.

Table 4 BOD results (mg/l) for series 1 and 2 (September 7, 2021, and February 21, 2022)

	RESULTS	
	COD (mg/l)-Series 3	**COD (mg/l)-Series 3**
Period / Sampling points (samples)	**09/07/2021**	**02/212022**
Canal Fishing wharf	340	320
Sogas Canal	550	950
Bassin Petit Mbao Step Mèche Linda	160	240

3.5. Increase in biological pollution at Port and SAR sites due to high bacterial load

The results of oil and grease sampling (mg/l) carried out at the target points (Port and SAR) show that concentrations (527.5 mg/l at Pier 10 at the Port and 1318.7 mg/l) at SAR exceed the tolerance threshold set by the standard [NS 05-061] (see table 5). These results far exceed the 1983 DEEC results(source: BRGM/DEEC, 1986) at the SAR sampling point (43.2 mg/l). This confirms the development of pollution over the past thirty years, with the presence of pollutants and grease from SAR refining, hydrocarbon discharges at the port, and grease from SONACOS.

Lastly, the proliferation of oils, greases, and hydrocarbons reduces exchanges between the atmosphere and the sea, leading to a shortage of oxygen essential to the sea.

Table 5 Analysis report extract (mg/l)

Parameters	Port mole 10	SAR	Canal ISRA	Canal Fishing wharf	Canal 6	SOGAS	Standards NS 05-061
Oils and fats (mg/l)	527.5	1318.7	-	-	-	-	20-50

3.6. Eutrophication due to high nitrogen and phosphorus values at several sampling sites

Table 6 shows that the nitrogen and phosphorus values obtained at SOGAS, the fishing pier, and Petit Mbao do not comply with the standard.

For nitrogen, we note a significant exceedance of up to 1008 mg/l at the SOGAS Canal and 330 mg/l at the fishing pier. For phosphorus, all samples exceeded the regulatory threshold by a wide margin at the SOGAS Canal, reaching 71.33 mg/l and petit bao.

As a result, algae and plankton growth and proliferation are increased in some parts of the bay. This phenomenon of fertilization and overgrowth, known as eutrophication, is increasingly observed in the bay. These results align with the ARTELIA report (2011), which exceeded and reached the SOGAS point: 312 kg/d nitrogen and 33 kg/d phosphorus.

Table 6 Extract test results (mg/L)

	Canal Fishing wharf	Bassin petit Mbao - Mèche Linda etc.	Canal 6	Canal SAR	Sogas Canal	ICS Canal
Nitrogen	330.4	67.2	56	162.4	1008	56
Phosphorus	18.19	34.48	15.05	2.34	71.33	13.24

3.7. Zinc and lead accumulation in marine vegetation

All sampling points exceed the permitted lead standard (0.038 mg/kg) (see Table 7). This can have harmful effects on the environment.

The SOGAS Canal and Petit Mbao basin reached high values for lead (2.66mg/l) and (1.18mg/l), above the norm. Canal 6 and SAR also exceed the standard with 0.94mg/l and 0.94mg/l, respectively (see Table 7). This elevated level of lead pollution can be seen all along the bay. Lead also accumulates in marine vegetation, making the fish chain more dangerous. The increased oxygen consumption also contributes to global warming and seawater saturation with CO2 through photosynthesis. Similarly, for zinc, all the effluents sampled were well above the threshold set by the August 9, 2006, decree (o, 276mg/l), resulting in high toxicity along the bay, which can cause damage and inhibit metabolic processes. Table 7 shows that exceedance is very high for the SAR Canals (2.79 mg/l) and 6 (2.7 mg/l). These results agree with those of Madame Louise Aminata Sagna THIAW, in her 2019 dissertation entitled: "Assessment of the bioaccumulation of trace metal elements (pb, cu...) in Hann Bay", which reveals that the development of industrial activities and the establishment of habitats along the shoreline have increased pressure on the coastal marine environment, which is contaminated in some places. It also states that " heavy metals in the bay result from causes linked to human activities.

Lastly, Hann Bay is severely affected by weak currents, which prevent pollutants from being sufficiently dispersed.

Table 7 Extract test results (mg/l)

	Canal Fishing wharf	Bassin petit Mbao - Mèche Linda etc.	Canal 6	Canal SAR	Sogas Canal	ICS Canal
Zinc	2.24	2.28	2.70	2.79	2.43	0.90
Lead	0.86	1.18	0.94	0.94	2.66	0.71

4. Conclusion

The results obtained show very high concentrations at almost all sampling sites along Hann Bay and non-compliance for nearly all physicochemical parameters and the metals and hydrocarbons tested (BOD et al., oils and greases, nitrogen, zinc, lead).metals and hydrocarbons (BOD et al., oils and greases, nitrogen, zinc, lead), with levels well above the permitted limit value.

The elevated effluent levels sampled revealed the danger posed by the bay, which comprises areas unsuitable for bathing and landing fish products.

Finally, industrial, domestic, and hydrocarbon pollution (transport and transit of hydrocarbons and dead oils in the port) have become uncontrollable. This is why, according to ARTELIA (2011) (SOGREAH report), which predicted 0 BOD, COD, and TSS discharges in 2020 once the infrastructure was in place, this forecast has not been achieved, as the pollution control equipment is not yet operational.

This diverse and persistent pollution impacts the availability of fishery resources and the employment of young people. Natural factors mainly cause it, such as the coastline retreat, industrial wastewater discharges, illegal connections, uncontrolled discharges by local populations, and solid waste dumping.

Therefore, acting as quickly as possible and applying effective treatments to restore the bay is necessary.

The following recommended solutions are general, regulatory, and technical, and their implementation will enable sustainable development of the target area:

- Regular monitoring of water quality
- Raising awareness among all stakeholders: government, industry, local communities, partners and the scientific community;
- Revise the outdated "polluter pays" agreement and get stakeholders to sign it;
- Raise awareness of the environmental code voted in 2023 for practical application and compliance with housing construction standards;
- Set up exceptional protection standards for Hann Bay by state decree, such as a marine protected area where the waters are protected in the municipalities of Hann and Mbao;
- Control and monitor the quality of domestic and industrial wastewater through regular sampling and prohibit beaches from bathing;
- Identify connections made to the stormwater network or directly to the sea;
- Set up simple, rapid, and effective mechanisms for financial or technical assistance and support for pre-treatment systems, with an effective monitoring system.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest is to be disclosed.

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