# Fecal Coliform Reduction Management in Manila Bay Bathing Beaches: A Case Study in the Philippines

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## Abstract

Manila Bay is considered as one of the best locations to experience sunset, visitation for relaxation, and a place for gathering. However, the constant draining and dump coming from different industrial sectors has developed to a bay which constitutes to high level of pollutions. The need to address the issue with regards to water body pollution has been underexplored. The paper investigates several fecal coliform reduction methods: the use of secondary and tertiary treatments like sand filtration and UV disinfection processes bolstering activated sludge processes, membrane bioreactor technology systems, and intermittent filtering. The following methods were examined to resolve Manila Bay's Bathing Beaches' high fecal coliform levels. The use of intermittent filtering with the filter media of unsorted sand yielded the highest reduction rate of 6.3 $\log_{10}$ compared to common activated sludge processes averaging only 0.38 $\log_{10}$. The mitigation of the bays could potentially reduce ecological and environmental problems. Food, water, and energy are primary concerns for a country's sustainability. With the involvement of pollution, the rise of capital scarcity would be evident which would reduce businesses, development, livelihood, and eventually the quality of life. The need to promote and mitigate water of bodies such as bays is therefore highly important for management. Thus, policymakers and government sectors may take this into consideration for promotion and conservation of natural resources.

## Keywords
Fecal coliform, Manila Bay, reduction methods, sustainability, environmental management

## 1. Introduction
Manila Bay is often touted as one of the most significant water bodies of the Philippines. Manila Bay is located in the western part of Luzon bounded by Cavite and Metro Manila on the east, Bulacan and Pampanga on the north, and Bataan on the west and northwest. The Manila bay's Southern part opens to the South China Sea. Spanning 190 kilometers, the bay drains about 17,000 km$^2$ of watershed area constituting 26 catchments. The bay's northern part is especially susceptible to lahar (a rapidly flowing mudflow of rock debris that originates from volcano slopes) discharges. The western coast receives discharges from Bataan watersheds and the bay's Eastern side receives river flow originating from Cavite and Bulacan. However, the focus of this study will be on the eastern coast, being susceptible to polluted runoffs coming from the Pasig River – a product of industry effluent mismanagement. It is also important to note that sediment rates from Cavite and Manila were consistently high which heavily suggest these areas act as sinks of sediments and collect bay pollutants (Jacinto et al. 2006).

Manila Bay is considered as one of the best locations to experience sunset, visitation for relaxation, and a place for gathering. However, the constant draining and dump coming from different industrial sectors has developed to a bay which constitutes to high level of pollutions (Moaje, 2022). To which, the recent protocol to help mitigate the bay and developing the "Miami" Bay feel for tourist was implemented (Moaje, 2022). Despite the increase plans to promote the preservation of the shore area, the bay itself was not properly conserved. Recently, tests from the Department of Environment and Natural Resources (DENR) presented high level of coliforms which creates pathogens leaving the water unsafe for usage. Thus, the need to assess the management of Manila Bay should be explored for consumers, tourists, and the economic development of the country.

### 1.1 Review of Parameters

When examining means of evaluating water quality, there are two primary parameters that dictate such factors. The first parameter concerns any organic produce primarily nutrient concentrations, dissolved oxygen, and total suspended solids. This parameter ensures algal growth is monitored, preventing organisms from suffering from eutrophication or hypoxia from the lack of dissolved oxygen. Meanwhile, algal build up and high total suspended solid concentrations prevent plants from being able to obtain sunlight. Thus, poor organic produce conditions are intrinsically linked to a diminishing fish and plant population. The second group of indicators which primarily impact human wellbeing rather than ecosystem wellbeing will be the focal point of this paper. These indicators include heavy metals, pesticides, and fecal coliform levels. Heavy metals such as mercury impact human well-being through bioaccumulation, harming humans upon the consumption of such biota. The prevalence of pesticides follows a similar trend as heavy metals as both have impacted the food chain multilaterally. These effluents are associated with being toxic and having potential carcinogenic effects. The pH level is not considered as significant a parameter as seawater is able to re-buffer the water's pH levels.

### 1.2 Objectives of the Study

The main focus of the current study examined the Manila Bay through is fecal coliform. Fecal coliform levels are especially critical for the Department of the Environment and Natural Resources' Class SB categorized water bodies. This Class B presents itself as being a recreational water class intended for primary contact recreation: namely, bathing, swimming skin diving, etc. The Manila Bay Bathing Beaches have notoriously had improper management of fecal coliform levels, despite fecal coliform significantly impacting the quality of bathing beaches. Specifically, coliform bacteria may cause serious illnesses such as gastroenteritis and diarrhea. These coliform bacteria typically derive from untreated sewage and septic tanks. However, the fecal coliform subgroup of these bacteria can be specifically defined as the members of the total coliform group that come from the intestinal gut of warm-blooded animals (Seo et al. 2019). Fecal coliform is most evaluated through sanitary or disease-related parameters. Fecal coliform contamination in sands of educational facilities and parks in Seoul accurately reflect the common concerns that crop up when evaluating human relationship to bacterial infection. Specifically, the paper alludes to a child's tendency to hand-mouth contact. The fecal coliform group has always served as a benchmark for contamination in soil and pathogenic organisms in drinking water. In large water bodies, fecal coliform indicates recent pollution. Conversely, the presence of the intermediate-aerogenes cloacae (IAC) group increases upon a decrease in fecal coliform. To summarize, "when evaluating bacterial pathogens, the coliform group is a reliable indicator of the adequacy of treatment but when indicating pollution in drinking water supply systems, the coliform group is a better indicator than specific fecal coliform organisms" (Kabler et al. 1960).

## 2. Literature Review

### 2.1 Primary, Secondary and Tertiary Treatments Identified Using Enzymatic Methods

Enzymatic methods are suitable prospects for methods used to decrease fecal coliform levels. George et al. (2007) indicated specifically that sand filtration succeeded by UV disinfection were shown to eliminate these microorganisms. Studies measure fecal coliform abundance in plate counts on selective medium and rapid β-D-glucuronidase (GLUase)- based assays. Specifically, the production of the β-D-glucuronidase enzyme indicates the presence of fecal coliform in aquatic environments. The addition of the fluorogenic substrate, 4-methylumbelliferyl-β-D-glucuronide, triggers enzymatic activity resulting in the production of a fluorescent product: the yield of this product was measured through spectrofluorometry. A combination of factors such as having a colder closed environment, in the study's case refrigerated raw sewage, slightly increased the yield of fecal coliform levels. Furthermore, treating wastewater resulted in no fecal coliform fluctuation over time. Contrasting this finding to raw wastewater, fluctuations occurred over five sampling campaigns. When loads of untreated wastewater containing fecal coliform enter wastewater treatment plant facilities, the increase in the load of fecal coliform was shown to be directly correlated with the size of the entering population (George et al. 2007).

When evaluating water quality, discussing primary, second, and tertiary treatment processes are necessary. Broadly speaking, primary treatment of wastewater involves sedimentation processes where solid waste, such as total suspended solids, are isolated from aqueous bodies. Secondary treatment processes highlight the use of oxidation to purify wastewater which can be achieved through a variety of means such as biofiltration which filters additional sediments through trickling filters and aeration which aerates mixtures of wastewater and microorganism solutions. Further, tertiary wastewater treatment involves the use of chemical processes such as activated carbon which involves trapping pollutants as water enters the carbon's pores. It maximizes surface area to create chemical reactions that remove phosphate or nitride substrates which are present in E coli and coliform groups. The various secondary and tertiary treatment processes tested resulted in comprehensive data on coliform reduction levels given a certain method. It was found that the method of activated sludge, sand filtration, and disinfection and lagooning, which uses gravity to naturally biologically balance the intended waterbody, were among the most efficient methods. Specifically, the methods resulted in a normal discharge rate of only 3000m$^3$/day and 14m$^3$/day respectively with inhabitant-equivalents capacity of 20,000 and 90 respectively. Overall, they result in reduction of fecal coliform levels of 4 and 5.4 $\log_{10}$, respectively. In the first method discussed, sand filtration comprised 0.78 log10 of this decrease, and UV rays for 2.91 $\log_{10}$. Interestingly, discharge rates and population count can be further decreased through high retention times. Thus, factors that can increase the retention time of sludge such as the aforementioned cooler temperatures and suspended solid concentration in sludge can contribute to increase this time.

Naturally, the efficiency of GLUase production used to detect the presence of fecal coliform decreased. It is also important to note the importance of supplementing the activated sludge process with filtration and disinfection processes. This is because treatments involving activated sludge processes can yield significantly higher nominal discharge rates at 2,100,000m$^3$/day, resulting in an inhabitant's capacity of 7,000,000. Regarding disinfection processes, the use of ultraviolet rays is considered a great alternative to chlorination processes. Despite it being responsible for much of the fecal coliform removal rate, it seems awkward how its GLUase activity, a measure of fecal coliform presence, did not reduce. However, such contradiction occurs because UV radiation inactivates the microorganisms that carry the GLUase process. Thus, this validates the effectiveness of UV in reducing fecal coliform until the present (Emerick et al. 1997; George et al. 2007). To summarize, if only primary treatment practices are implemented, only 29% of culturable fecal coliform levels are reduced while the number can be raised to 60% by implementing the highly efficient secondary and tertiary treatment practices (George et al. 2007).

## 2.2 Membrane bioreactor technology

A more unconventional means of reducing fecal coliform levels involves the use of membrane bioreactor technology (MBR). The MBR system has seen a lot of success through its removal of fecal coliforms and up to 5.8 $\log_{10}$ removal of coliphages, which are simply indicators that monitor fecal contamination in water bodies. The system's high removal rates of coliphages regardless of coliphage concentration makes the system's implementation promising.

Membrane bioreactors involve processes where a perm-selective membrane is incorporated with a suspended growth bioreactor. The membrane is typically used as a filter that's oriented towards isolating solid materials. According to Zhang and Farahbakhsh (2007), nominal pore sizes of membranes were between 0.04 and 0.1 µm. Theoretically, the pore size was optimal as fecal coliform bacteria spanned a diameter between 0.6 and 1.2 µm, so no particles would completely penetrate the membranes. This was also justified practically as no fecal coliforms were found in the permeate samples. However, due to the greater size of coliphages, coliphages would be detected in the permeate due to their inability to seep through the MBR's pores (Figure 1). Thus, this difference in pore size compared to fecal coliform bacteria makes coliphage more ideal for an MBS system since some of them may be able to pass through the membrane pores (Côté et al 1997; Zhang and Farahbakhsh, 2007). When employing the MBR system, it is important to refrain from maintenance cleaning directly before use of the system as it removes the cake layer responsible for enhancing the removal of bacteriophages. However, the paper showcases instance where maintenance cleaning does not clearly impact fecal coliform levels.

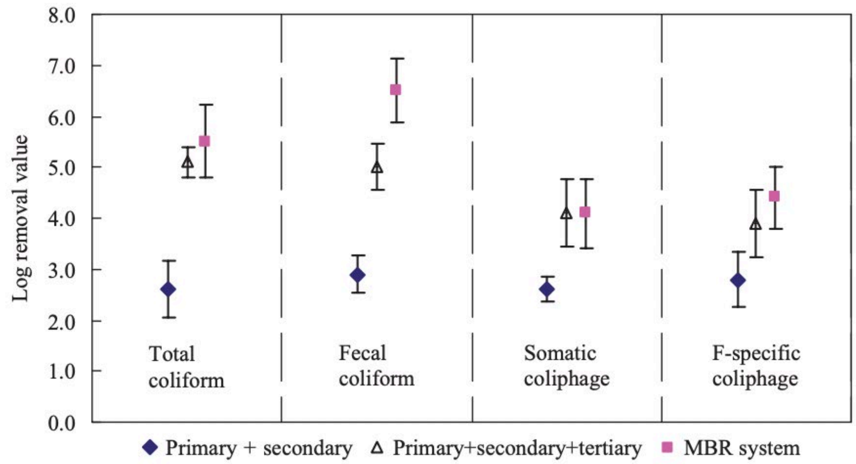


Figure 1. Comparison of Fecal Coliform Removal Values Between Primary, Secondary and Tertiary Processes and Membrane Bioreactor Technology Systems (Zhang et al. 2007)

Overall, the removal of coliphages ranged from 3.1 to 5.8 logs and 3.3 to 5.7 logs, respectively. This value was greater than that of the previously-mentioned primary, secondary, and tertiary treatment processes by more than 1 log unit, but the uncertainty for the MBR system was greater to the extent that its minimum value is roughly equal to that of the other method. The MBR method can be argued to be more beneficial to reducing fecal coliforms since it eliminates the need to do secondary and tertiary treatments, namely filtration and disinfection processes potentially making this method more cost-effective. The MBR's more streamline system and need for fewer steps makes it an ideal prospect for limiting the budget needed for fecal coliform reduction processes (Zhang et al. 2007).

### 2.3 Intermittent filtration

There is an emphasis on grain sizes in any filtration processes. Specifically, it is significant enough to affect the reduction rates of fecal coliform by more than three areas of magnitude. Thus, the use of fine grain sizes such as unsorted sand in filtration methods is heavily advised. Adaptations to particle size and loading rates can alter retention time and consequently, the bacteria's path upon passing through filter media (Stevik et al. 1979). Higher retention time is necessary to maximize the interaction between the percolating wastewater and the porous medium (Huysman et al. 1993).

Furthermore, other factors such as filter temperature and physical flow conditions affect the efficiency of the filter system (Gold et al. 1991). The paper investigated the use of different filters, but the removal efficiency was relatively high regardless of the filter used ranging from $\log_{10}2.9$ to $\log_{10}6.3$. However, the filter media used played a significant role in the effectiveness of the filtration method, where the use of unsorted sand had an effect of more than three orders of magnitude compared to 0-4mm thickness of lightweight aggregates. Filter media that creates a slow-moving wetter front is preferred as the rate of removal is greatest in the top layer of filters due to there being better oxygen conditions and smaller pore size caused by biological clogging. The hydraulic sorptivity of unsorted sand allows a steady-state unsaturated flow throughout the whole filter volume. This improves retention time: like the use of activated sludge, higher retention times increased the removal of fecal coliform in unsaturated, aerobic filters. Like primary treatments, the fastest moving fraction of the sludge contributes to the bacterial transport through the columns. Applying the same emphasis on retention times, pressure dosed filters saw greater fecal coliform reduction methods than gravity dosed filters. Gravity dosed systems resulted in a nonuniform distribution of the flow. Contrasting this with pressure dosed systems, they have decreased in flow velocity and a less thick water film due to higher average sorption head. Overall, the maximum remove efficiency of $\log_{10}6.3$ in intermittent filtering makes it the most ideal method compared to membrane bioreactor technology and primary, secondary and tertiary treatment (Ausland et al. 2002).

## 3. Data Analysis

According to the DENR Administrative Order (DAO) number 34, the fecal coliform critical level is 200MPN/100ml and this was later revised August 2016 to the fecal coliform Class SB standard being 100MPN/100ml which fosters the Most Probable Number technique in evaluating effluent concentrations (Table 1). It is a method that estimates the number of bacteria in a water sample. Despite this widely used technique, external factors such as sunlight intensity can distort the actual yield of fecal coliform (Kim et al. 2014).

Table 1. Annual geomean results of the analysis for fecal coliform in bathing beaches within Manila Bay Region

| Station name | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | |
|---|---|---|---|---|---|---|---|
| | | | | | | 1st Qtr | 2nd Qtr |
| 1. Navotas | 4,235,582,437 | 4,819,459 | 331,027 | 259,067 | 1,068,214 | 917,675 | 126,647 |
| 2. Luneta | 378,708,915 | 150,023 | 92,378 | 128,860 | 17,959 | 117,427 | 15,767 |
| 3. CCP | 85,160,676 | 255,076 | 61,211 | 702,229 | 225,433 | 164,949 | 25,907 |
| 4. MOA | 229,098,575 | 304,002 | 118,0097 | 720,665 | 1,147,700 | 973,996 | 272,164 |
| 5. PEATC | 28,549,438 | 85,543 | 9,967 | 121,219 | 164,761 | 209,659 | 10,604 |
| 6. Brgy Wawa | 3,951 | 2,814 | 5,242 | 8,216 | 3,954 | 6,712 | 851 |
| 7. Villa Leonora | 22,030 | 4,868 | 10,246 | 14,413 | 2,636 | 5,400 | 685 |
| 8. Villa Carmen | 2,288 | 795 | 1,046 | 2,872 | 971 | 99 | 570 |
| 9. Mattel | 1,665 | 501 | 780 | 1,453 | 1,019 | 8 | 276 |
| 10. Bacoor | 173,876 | 4,710 | 11,923 | 12,070 | 2,380 | 105,845 | 307,486 |
| 11. Lido Beach | 2,420 | 7,295 | 3,173 | 2,810 | 1,662 | 3,238 | 404 |
| 12. Villamar Beach | 3,271 | 1,973 | 5,161 | 2,224 | 1,887 | 2,767 | 214 |
| 13. Mount Sea (San Isidro Beach) | 18,425 | 17,418 | 41,269 | 9,848 | * | * | 170 |
| 14. Celebrity Beach | 20,615 | 18,545 | 24,441 | 9,036 | 5,255 | 1,911 | 314 |
| 15. Garden Coast Beach | 1,309 | 2,149 | 2,693 | 725 | 919 | 143 | 481 |
| 16. Coasta Eugenia Beach | 1,011 | 3,167 | 2,770 | 2,369 | 1,972 | 322 | 1,252 |
| 17. Villa Criselda Beach | 2,329 | 3,316 | 2,818 | 3,357 | 2,034 | 378 | 1,041 |
| 18. Antonio's hideaway | 951 | 432 | 251 | 896 | 667 | 199 | 782 |
| 19. Dalaroy's Resort | 737 | 905 | 111 | 28 | 105 | 57 | 100 |
| Note: DAO 2016-08 water quality standard for fecal coliform Class SB is 100MPN/100mL | | | | | | | |

Spanning 2017 to 2022, there have only been a few instances where coliform standards were satisfied. There was an anomalous 2020 fecal coliform level of Dalaroy's Resort 28MPN/100ml that subscribed to the DAO standard followed by the first quarter of the 2022 fecal coliform levels of Villa Leonara, Villa Carmen, and Dalaroy's Resort satisfying the standard with 99MPN/100ml, 8MPN/100ml, and 57MPN/100ml, respectively. In the second quarter, Dalaroy's Resort's fecal coliform levels increased to 100MPN/100ml which is considered within the standard advised by the DAO. However, it is important to consider that these results may have been affected by the reduced number of people using bathing beaches due to the pandemic.

## 4. Conclusion and Recommendations

Thus, implementing these changes may help mitigate Manila Bay's Bathing Beaches' fecal coliform levels. The use of refrigerated wastewater systems to cool the system's temperature can be implemented but are rather costly. Furthermore, parameters must be instilled to restrict raw wastewater from entering plants such as the use of sand to further sift through pollutants. This links to the use of UV disinfection coupled with sand filtration, which can serve as the secondary and tertiary treatment processes of fecal coliform reduction levels with a typical primary treatment. Also, the conventional use of activated sludge seemed inferior to many other treatment processes such as lagooning. If intermittent filtering processes are favored, the filter media used is crucial in maximizing the time of moving wetter front, which impart increased retention time just as pressure dosed systems did. Thus, future studies scrutinizing the implementation of intermittent filtering using unsorted sands within the context of a tropical, heavily-urbanized bay can be examined. This may help determine if the effectiveness of unsorted sand as a filter media is unaffected by the Manila Bay climate or its water conditions.

The mitigation of the bays could potentially reduce ecological and environmental problems. Since bays in general are a crucial natural landscape, the promotion and conservation of it is highly important. This body of water can efficiently consume shortwave radiation through evaporation; which is crucial for hot condition climate. Since the body of water help in mitigating urban environment and balance the climate effect, the need to manage its condition, health, and overall status should be considered for the benefit of the community. Food, water, and energy are primary concerns for a country's sustainability (Spielberg et al. 2017). It has been indicated that natural capital would be the most expensive resources our current generation have. With the involvement of pollution, the rise of capital scarcity would be evident which would reduce businesses, development, livelihood, and eventually the quality of life. The need to promote and mitigate water of bodies such as bays is therefore highly important for management. Thus, policymakers and government sectors may take this into consideration for promotion and conservation of natural resources.

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