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THE EFFECT OF CONSTRUCTED MARINE OUTFALL ON WATER QUALITY AT BATU FERINGGHI COASTAL AREA

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Abstract

It has been a long time that Batu Feringghi Beach has attracted tourists and visitors from local and overseas. In early February 2014, the beach was polluted and said to highly contain *Escherichia coli* in the seawater. To resolve this problem, the Malaysia Drainage and Irrigation Department have built two marine outfalls for two rivers, Sungai Batu Feringghi and Sungai Satu, as drainage up to 120 meters from the head of the river to the open sea. This research was to conduct a study on the water quality especially the pathogen microorganism content before and after the marine outfall was constructed and installed. The samples of water were taken from the same three locations (LP1, LP2 and LP3) before and after the marine outfall was built for parameter total coliform, fecal coliform and *E. coli*. Total coliform at LP1, LP2 and LP3 were 1535, 989 and 1507 MPN/100 mL, respectively. The contents of fecal coliform and *E. coli* at LP1, LP2 and LP3 were 279, 292 and 346 MPN/100 mL, and 23, 20 and 46 MPN/100 mL, respectively. The removal efficiencies for total coliform, fecal coliform and *E. coli* were 95.8%, 98.7% and 31.9% at LPI, 98.8%, 96.7% and 59.2% at LP2, and 99.8%, 99.4% and 93.9% at LP3, respectively, giving evidence that marine outfall is one of the approaches that can be used to reduce the content of pathogenic microorganisms, particularly in coastal areas used for recreation. This study has also highlighted the importance of the contamination issue for pathogenic microorganisms and opened the eyes of the authority and government bodies to establish the release limit of these parameters in the existing environmental law.

INTRODUCTION

Pathogenic organisms are a group of bacteria, protozoa, helminths and viruses. These pathogens can exist at very low concentrations in water and wastewater; thus it is difficult to identify and analyze them. Therefore, microbiological water and wastewater analysis are commonly referred to as indicators of microorganisms [1]. For many years, fecal coliform has been used and this parameter is still used in many countries as a standard measure for fecal contamination [2]. Also, since the early 1900s, coliform and fecal coliform bacteria have been used as drinking water indicators for fecal contamination [3]. Although the mere presence of fecal coliforms in water bodies does not necessarily pose immediate health risks, the idea is that their presence may also indicate the potential for more dangerous pathogens found in fecal species, including viruses [4].

Typhoid, shigellosis, cholera and amoebiasis diseases are some of epidemics in the early history of different countries due to pathogenic bacteria. It was then determined that sewage/wastewater was the primary source of these pathogenic bacteria [5]. Pathogenic bacteria presence in sewage/wastewater may be coming from people and animals that are infected with or carrying a particular infectious disease. In sewage, the pathogenic organism can be divided into four broad categories of bacteria, protozoa, helminth, and viruses. Bacteria like fecal coliform (*Escherichia coli*) typically causes gastrointestinal infections such as paratyphoid fever, typhoid, cholera, dysentery, and diarrhea. These gram negative bacteria [6] are highly infectious and they are the cause for thousands of deaths every year especially in poor sanitation countries [7].

Sources for pathogenic bacteria are from point sources and non-point sources. Point sources include sewage treatment plant, hotel and factories while non–point sources are river sedimentation, improper toilet connections, illegal food outlets, laundry and car wash services. It is very difficult to determine the relative contribution of nonpoint and point sources to the bacterial content of surface water. This is due to the complex nature of the bacterial sources of the watershed and there are many factors that influence the sustainability of the pathogens when they are released into the environment and open water pond. The wastewater can be traced back to the original pipe which is the source of the starting point for the discharge. This could be the biggest potential source for human infected by bacteria. Non-point sources of pollution can be from various points such as large amount of water from widespread and impermeable soils, substandard septic systems, and open deposition of animal feces [8]. Although raw sewage often carries huge amount and a big variety and types of fecal micro-organisms (with also human pathogens), the effort to reduce the bacteriological contamination in wastewater is not a priority as for this time. The release limit for pathogenic microorganism parameters is also not included in the current legislation in Malaysia in particular. Thus, this matter must be taken into consideration seriously since the possibility of the human exposure to sewage or other concern that might be related to sewage is high [9].

Over the past decades, many scientists have focused their attention on using natural systems to remove pharmaceuticals, micro-organisms, organic matter, and personal care products in wastewater/sewage [10-13]. Furthermore, the selection of pathogen/ fecal coliform treatment technology depends on apparent low building costs, minimal operational and maintenance needs [14]. Disinfection refers to the selective destruction of organisms causing disease from sewage effluent. Disinfection techniques may be physical, chemical, or radiation. Chlorination, ultraviolet (UV) and ozone oxidation are common forms of disinfection available for wastewater applications. Therefore, it is important to investigate the possible treatment to minimize pollution that cause by fecal coliform in wastewater discharge especially in Malaysia.

Marine outfall is a structure for disposal system from the wastewater/sewage treatment plant to the disposal location [15]. An effective marine outfall is designed in such a way to ensure that sewage is diluted properly and dispersed efficiently and will not pollute recreation areas. The dilution process of wastewater into the sea has three phases, which are near-field, far-field and long-term flushing processes. Usually, the outfall network consists of pipes or tubes, diffusers, and ports on the diffuser, to ensure complete sewage dilution without any concerns for the marine environment. A jet buoyancy dispersion model is used in the design of the marine outfall to ensure that dilution of photogenes and fecal coliform complies with the marine standard [16].

At the beginning of February 2014, a report on contamination in the coastal region of Batu Feringghi was published by Berita Harian [17], that revealed the water had been transformed to dark and black colour due to pollution and was found to contain *E. coli* bacteria. In addition, the condition in the estuary of Batu Feringghi river was contaminated with black water with rotten odors. This incident has affected the image of Batu Feringghi beach as a popular tourist destination for both domestic and international tourists. **Figure 1(a)** shows the coastal area of Batu Feringghi during the occurence. To overcome this problem, the Department of Irrigation and Drainage Malaysia had built two marine outfalls at Sungai Batu Feringghi (**Figure 1(b)**) and Sungai Satu to drain water from both rivers to the middle of the sea at 120 m away from the beach. **Figure 2** shows the marine outfalls in both rivers which are completely constructed and installed on 22^{nd} of December 2016.

Even though there are a lot of research of pathogenic microorganism elimination in wastewater but the method using a marine outfall seems limited especially in Malaysia. The main objective of this research is to determine the effectiveness of marine outfall in minimizing the pollution of pathogenic microorganisms in Batu Feringghi coastal areas for recreational activities. The data obtained could be used to carry out further research as pathogenic microorganism pollution in the government's main concern to enforce water pollution legislation in future.

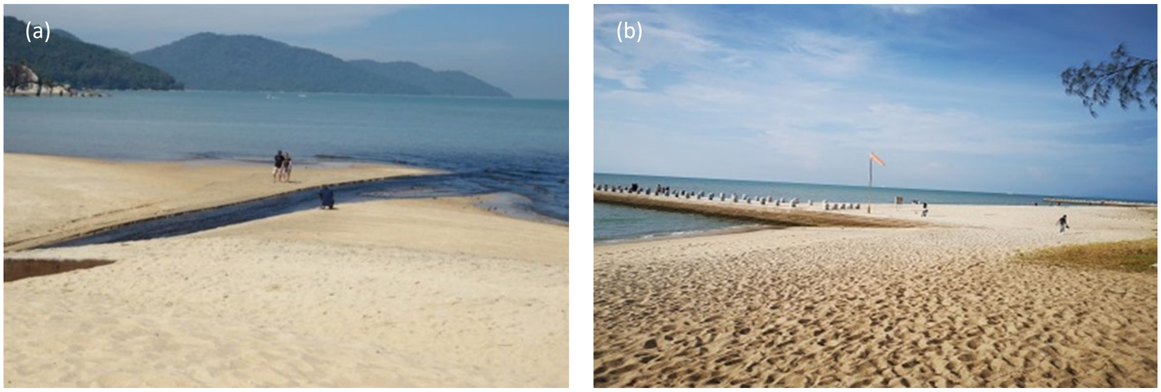


Figure 1. (a) The coastal area of Batu Feringghi in 2014 and (b) an marine outfall in Batu Feringghi coastal area

Figure 2. The location of marine water sampling locations in Pantai Batu Feringghi [LP1= Sampling location 1; LP2= Sampling location 2; LP3= Sampling location 3) relative to the marine outfalls].

MATERIALS AND METHODS

Water Sampling Location

Marine water samples were collected at the three locations (LP1, LP2 and LP3) as shown in **Figure 2**. Samples were taken several series on different days in the same three locations before and after the construction of the marine outfalls. The distance between the three sampling sites with the coastline is 100 m and the sample was collected at high tide where the salinity reading was about 30-35 ppt to ensure the perfect mixing of water at the three sampling locations. For all the parameters, 14 water samples per location were taken at LP1, LP2 and LP3 from 15th to 28th February 2014 before the marine outfalls were constructed and 19 samples per location from 19th July 2017 to 11th December 2020 after the installation of the marine outfalls.

Sampling Equipment

The equipment needed was more for marine water sampling equipment. Multiprobe and Sonde equipment for in-situ measurements were in good condition and calibrated before taking the measurement. The GPS device was carried over every time during sampling for latitude and longitude readings and to ensures that samples were taken in the correct location. Personal Protective Equipment (PPE) such as safety jackets, safety shoes, rubber gloves, etc. were provided and worn during sampling.

In-Situ Sampling Method

The GPS device was linked to the YSI Multi Parameter Sonde Device so that the location reading can be recorded in the Sonde device automatically. Then, the YSI Multi Parameter Sonde Device was set or entered date, time and location correctly. In the location of sampling, multiprobe devices were inserted in the sea water with a depth of between 30 cm to 100 cm from the water surface. The probe was left in water at least 10 min. The readings of the physical parameters in-situ, i.e., pH, temperature (T), dissolved oxygen (DO), turbidity, conductivity and salinity were then taken when the readings on the multiprobe screen were already stable. The sensors on the multiprobe device were rinsed with distilled water after each sampling location, and then kept in accordance with the procedure set by the multiprobe device manufacturer.

Ex–Situ Water Sampling

Samples were taken using a Van Dorn Sampler device. For water samples taken from the sea by boat, the samples were taken from the direction of the boat, following the direction of the wind and far from the boat engine. The Van Dorn Sampler was rinsed with sample water to prevent contamination of the water sample taken. Water samples were taken after Van Dorn had been sunk at a level between 30-100 cm below the water level. The water samples were packed in the 'Sterile Whirl Pack' bag and placed in the cool box to maintain the temperature below 10°C. After completing the sampling work, the Van Dorn sampler was rinsed using distilled water. All the water samples were submitted to the laboratory in less than 24 hours. The collection and handling of samples were in accordance with the standard procedures established by the American Public Health Association (APHA) [18, 19].

Water Sample Analysis

All samples collected at the sampling locations were sent directly to the laboratories on the same day for analysis. All the standard procedure method used by the laboratory for the analysis of the sample was based on a method developed by the American Public Health Association (APHA 23rd Edition) [18].

Data Analysis

The analysis data collected from the laboratories will be recorded and further processed. The data will be analyzed using statistical methods of t-Test using Excel 2021 (Microsoft Coporation, US).

RESULTS AND DISCUSSION

Physicochemical Parameters In-Situ Monitoring

The physicochemical parameters (pH, T, DO, turbidity, conductivity and salinity) were monitored before and after the marine outfall for all the three sampling locations (**Table 1**). All the values were the mean SD for LP1, LP2 and LP3 (*n*=3). From the results, it can be concluded that the values for all parameters were having similar values between each sampling locations with no significant different between before and after the marine outfall except for turbidity. The pH parameter is an indicator of the acidity or alkalinity of water and each organism has its own suitable pH range for growth and survival. For coliform bacteria, the survival rate is 7.5 % in acidic environments and 66.11 % in alkaline environments [20]. For recreational use of seawater, the appropriate pH value should be between 6.5 and 8.3. The average pH readings before marine outfall installed was 7.96, while the average pH after use of the marine outfall is 8.10, indicating that all three locations are alkaline and are suitable for the survival of coliform bacteria.

Table 1: Physicochemical characterization before and after the marine outfall for LP1, LP2 and LP3.

Parameter	Concentration	
	Before	After
pH	7.96 ± 0.078	8.10 ± 0.000
T (˚C)	30.2 ± 0.0850	30.2 ± 0.085
DO (mg/L)	6.52 ± 0.116	6.41 ± 0.060
Turbidity (NTU)	19.7 ± 0.991	11.6 ± 0.801
Conductivity (mS/cm)	49.5 ± 1.67	47.5 ± 0.037
Salinity (ppt)	31.0 ± 0.435	30.7 ± 0.031

The temperature of the water depends on the weather, sunlight and wave conditions at that time. Temperature also changes with the seasons [21], with this parameter is widely recognized as an important control factor in the influence of bacterial growth. On average, bacterial growth is ideal when the temperature of the water is above 15°C. The average water temperature before and after marine outfall installed were at 30.2℃, revealing that the temperature at all the three locations is suitable for the growth of coliform bacteria.

The values of DO are low at low tide since during this time, the mixing of air and water on the surface was less due to very little wave movement. This oxygen content also depends on temperature, salinity of seawater and atmospheric pressure. DO in water will decrease when temperature or salinity increases [22]. This DO content also affects the biological, microbiological and chemical processes in marine waters. DO increases as the content of the coliform bacteria decreases. The average DO before marine outfall installed was at 6.52 mg/L, while the average water temperature after use of the marine outfall was at 6.41 mg/L. This dissolved oxygen reading in all the three locations is above 5 mg/L and is suitable for marine life, fisheries, coral reefs, recreation and mariculture as stated in Marine Water Quality Criteria and Standards (MWQCS) for Malaysia [23].

Turbidity parameters are more likely to be associated and contribute more to the concentration of total coliforms [24]. The turbidity readings are often directly proportional to the coliform bacteria content [25]. The average turbidity before marine outfall installed was at 19.7 NTU, while the average turbidity after use of the marine outfall is 11.6 NTU, showing that the turbidity reading before was higher than the one after installation of the marine outfall. Therefore, the decreasing turbidity after the use of marine outfall indirectly shows that the reducing concentration of the coliform bacteria.

The electrical conductivity of marine water is a very stable value unless there are significant changes when there is a dilution factor of either natural or human water runoff. Electrical conductivity has a positive relationship, which is directly proportional to the coliform bacteria. As electrical conductivity increases, the coliform bacteria content also increases [26]. The average conductivities before and after the marine outfall installation were 49.5 and 47.5 mS/cm, respectively. The lower conductivity reading after installation of the marine outfall could be an indication for decreasing value for the concentration of the coliform bacteria revealing the effectiveness of the use of the marine outfall.

Salinity is the amount of inorganic salt which is soluble in water. This parameter is an important for ecological factor that influences the biota and marine organisms, particularly the osmotic function of the organism itself. Salinity also has a positive relationship, which is directly proportional to the coliform bacteria. As salinity increases, the contents of coliform bacteria also increase [26]. However as can be seen from **Table 1,** the salinity in the three places, before and after the marine outfall is not much different because they are within the same area and also might be due to insignificant volume of discharge sewage compared to the seawater volume. The trend of salinity is almost similar the trend of electrical conductivity in which the readings before and after the marine outfall application are not significantly different and both of them are positively correlated to the coliform bacteria content.

Previous research was conducted by [27] in Western Channel, Penang. The location of the Western Channel is near Batu Feringhi coastal area. The fecal coliform (FC) concentrations in the Western Channel (straits from Jelutong to George Town) consistently vary within the range 103–105 MPN/100 mL depending on the distances from the sewage outfall. The mean FC concentrations are shown in **Table 2** [27]. One option in [27] involves building a long-submerged outfall to convey primary treated sewage for disposal. The peak FC density would reach 12,000 MPN/100 mL, decreasing to 600 and 300 MPN/100 mL.

Table 2: Mean fecal coliform (FC) concentration in Penang Straits in Western Channel Area [27].

Sampling Station	FC Concentration (MPN/100 ml)
A	1.1×10^3
B	2.5×10^2
C	3.8×10^2
D	5.9×10^2
E	3.2×10^2
F	4.3×10^2
G	4.6×10^2
H	2.6×10^3
I	1.6×10^3
J	2.6×10^2
K	2.2×10^2
L	9.1×10

From another research in Taiwan [28], there are three marine outfall systems called Da-Lin-Pu (DLP), Chuna-Chou (CC), and Tso-Ying (TY). All of the systems are located in the south of Taiwan along the 20 km long coastline of Kaohsiung City. The DLP and TY systems were discharging industrial wastewaters, while the sewage produced from Kaohsiung City with a population of 1.4 million was discharged into the ocean through the CC marine outfall system. The lengths of the DLP, CC and TY outfall pipes are 3350, 3000 and 5045 m. The average total coliform in wastewater to be discharged from DLP, CC and TY were 1.4×10^6 MPN/100 mL, 4.3×10^6 MPN/100 mL and 1.5×10^6 MPN/100 mL, respectively. After the application of the marine outfall, the reading of total coliform of the oceanic area of these three outfall fields were in the average of 790 MPN/100 mL. In addition, the average number of E. coli in the primarily treated sewage from Kaohsiung was reported to be about 6,700,000 CFU/100 mL. According to the general design criteria of ocean outfall systems, the sewage is diluted at least 100 times on the surface of sea, then the number of the bacteria decreased to 67,000 CFU/100 mL when the sewage plume was raised up to the surface of sea-water [29].

Total Coliform, Fecal Coliforms and *E. coli* Concentration

Figure 3 demonstrates the results of laboratory analysis of total coliform content in LP1, LP2 and LP3. The Total coliform contents before the marine outfalls were built in LP1, LP2 and LP3 were 36,516, 77,601 and 2,212 MPN/100 mL. While the average content of Total coliform after use of the marine outfall is 1,535, 989 and 1,507 MPN/100mL for LP1, LP2 and LP3 respectively. **Figure 4** shows the results of laboratory analysis of fecal coliform content in LP1, LP2 and LP3. The average fecal coliform contents before the marine outfall installation were 22,274, 8,841 and 847 MPN/100 mL for respective LP1, LP2 and LP3 locations. While the average contents of fecal coliform after the construction of the marine outfall were 279, 292 and 346 MPN/100 mL for LP1, LP2 and LP3 respectively. **Figure 5** shows the results of laboratory analysis of *E. coli* content in LP1, LP2 and LP3. The average *E coli* contents before and after the marine outfall was built were 14,250, LP2 is 3,374 and 759 MPN/100 mL, and 23, 20 and 46 MPN/100 mL for LP1, LP2 and LP3 respectively.

Referring to **Figure 3-5**, the average contents of total coliform, fecal coliform and *E. coli* in Batu Feringghi Coastal Area prior to the marine outfall installation are high at LP1 and begin to decrease at LP2 and LP3. This is due to the location of the LP3 sampling which is further away from the source of pollution, that is from Sungai Batu Feringgi, Sungai Satu and Sungai Emas due to the liquidity and mixing process by the seawater.

The sources of coliform pollution came from Sungai Batu Feringghi, Sungai Satu and Sungai Mas. Referring to [30], the concentration of E. coli in Sungai Batu Feringghi was between 16,000 CFU/100 mL to 900 CFU/100 mL. Furthermore, localized trapping can also be observed towards the west of Sg. Mas. This is likely attributed to the orientation of Sg. Mas river mouth, which approaches the coastline at an oblique angle such that its discharge opposes the northeasterly longshore current, hence prohibiting crossing of the constituents at the water front. More specifically, it was found that the concentrations trapped in this location is much higher, at up to 41.8%, 74.1%, 76.1% and 59.5%, respectively, compared to the weighted initial concentration from the three rivers. This suggests that both advection and dispersion are hindered at this location, and pollutants may potentially cause severe beach pollution [31].

After the construction of the two marine outfalls, the average total coliform, fecal coliform and *E. coli* content of the Batu Feringghi coastal area at LP3 was higher than that of LP2 and LP1, since only Sungai Batu Feringghi and the Sungai Satu have been installed with marine outfalls. Furthermore, The location of LP3 is closer to Sungai Emas compared to Sungai Satu and Sungai Batu Feringghi. In addition, there are many other point sources that do not have a good sewage treatment system, such as private residences, beach restaurants and camps that release sewage without proper treatment in the LP3 area.

Based on the Marine Water Quality Criteria and Standards (MWQCS) for Malaysia [23], the limit for the fecal coliform parameter is 100 MPN/100 mL for recreational activities in primary contact. With the average content of fecal coliform after the use of marine outfall at LP1, LP2 and LP3 were 279, 292 and 346 MPN/100 mL, then water recreational activities with a primary contact such as swimming are not suitable in this area.

Comparing the results of the sample analysis before and after the use of the marine outfall, on overall, the average contents of total coliform, fecal coliform and *E. coli* decreased in LP1, LP2 and LP3 after the installation. The removal efficiency performance of the parameter is determined by comparing the average parameter before and after the marine outfall installation. **Figure 6(a)** illustrates the total coliform removal efficiencies at LP1, LP2 and LP3 were 95.8%, 98.7% and 31.9%, respectively, when the values before and after installation are compared. Based on t-test, the change in content for average total coliform parameter in LP1 and LP2 before and after construction of marine tunnels is significant (p<0.05) while at LP3, the average values for total coliform and after the installation are insignificantly different (p>0.05). The fecal coliform removal efficiencies after the construction pf marine outfalls at LP1, LP2 and LP3 were 98.8%, 96.7% and 59.2%, respectively (**Figure 6(b)**). Based on a t-test analysis, the change in average content of fecal coliform parameter at LP2 before and after construction of marine tunnels is significant (p<0.05) while at LP1 and LP3, it shows no significant difference (p>0.05). For *E. coli*, the removal efficiencies at LP1, LP2 and LP3 after the application of marine outfalls were 99.8%, 99.4% and 93.9%, respectively, as depicted in **Figure 6(c)**. The change in average content for *E. coli* parameter at LP2 and LP3 before and after the construction of marine outfalls is significant (p<0.05) whilst it insignificant (p>0.05) at LP1.

Removal efficiencies for total coliform, fecal coliform and *E. coli* indicate more than 90% when applying the marine outfalls, particularly at LP1 and LP2 which are located closely to the source of pollution at Sungai Batu Feringghi, Sungai Satu and Sungai Emas. Based on the findings, it reveals that the installation of marine outfalls has given effective and significant removals of total coliform, fecal coliform and *E. coli*, thus protecting public recreation areas, in particular Bukit Feringghi, from pollution. However, the fecal coliform readings after the marine outfall installation is still beyond the limit of 100 MPN/100 mL as stated in MWCQS. Thus, it is suggested to include emission standards for fecal coliform into the Malaysia environmental regulations including the sewage treatment system with a capacity of 20000 PE below to ensure that all sources of potential fecal coliform pollution in rivers and seas are properly treated before their discharges to the environment.

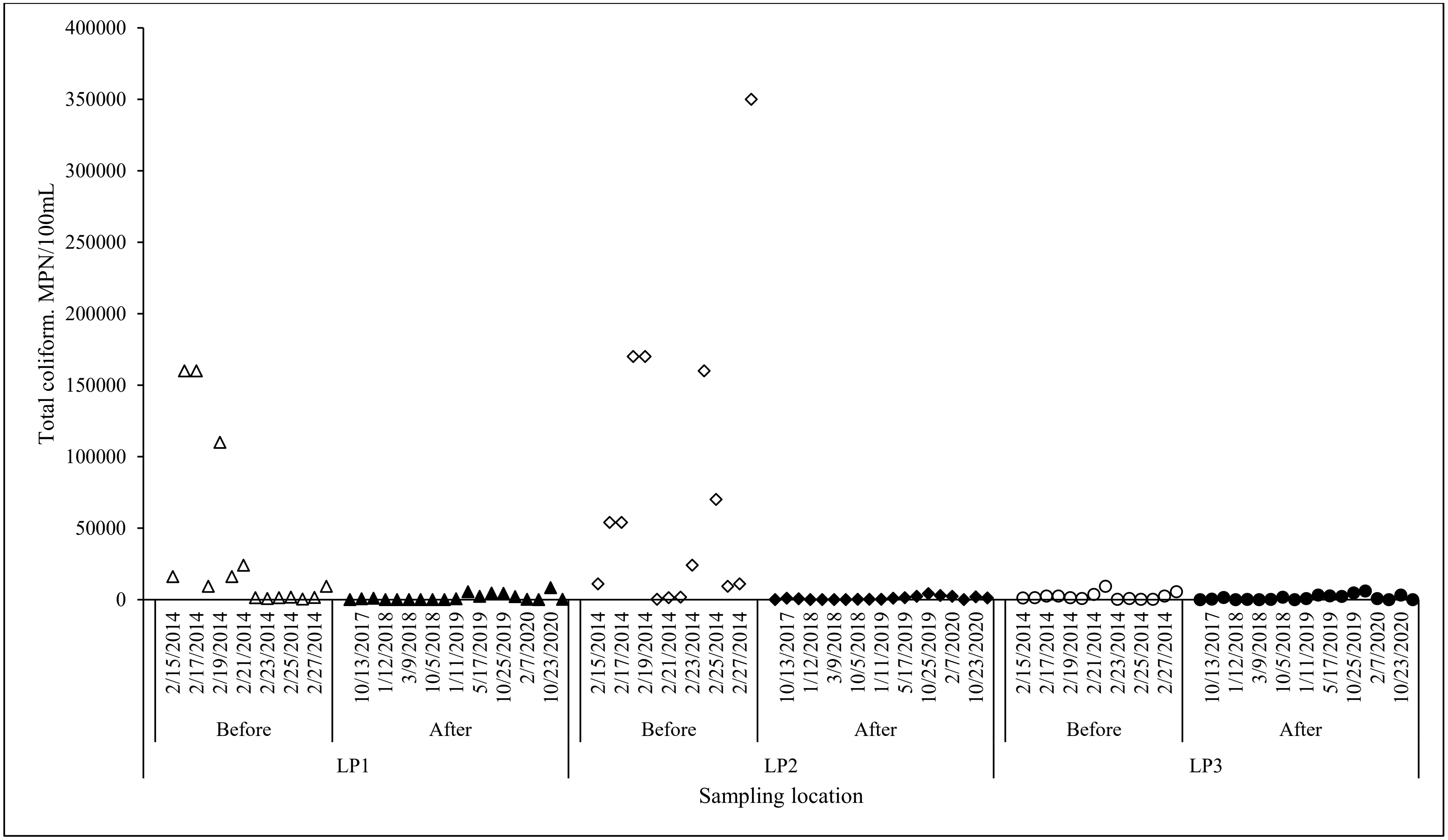


Figure 3. Total coliform concentration at all three locations.

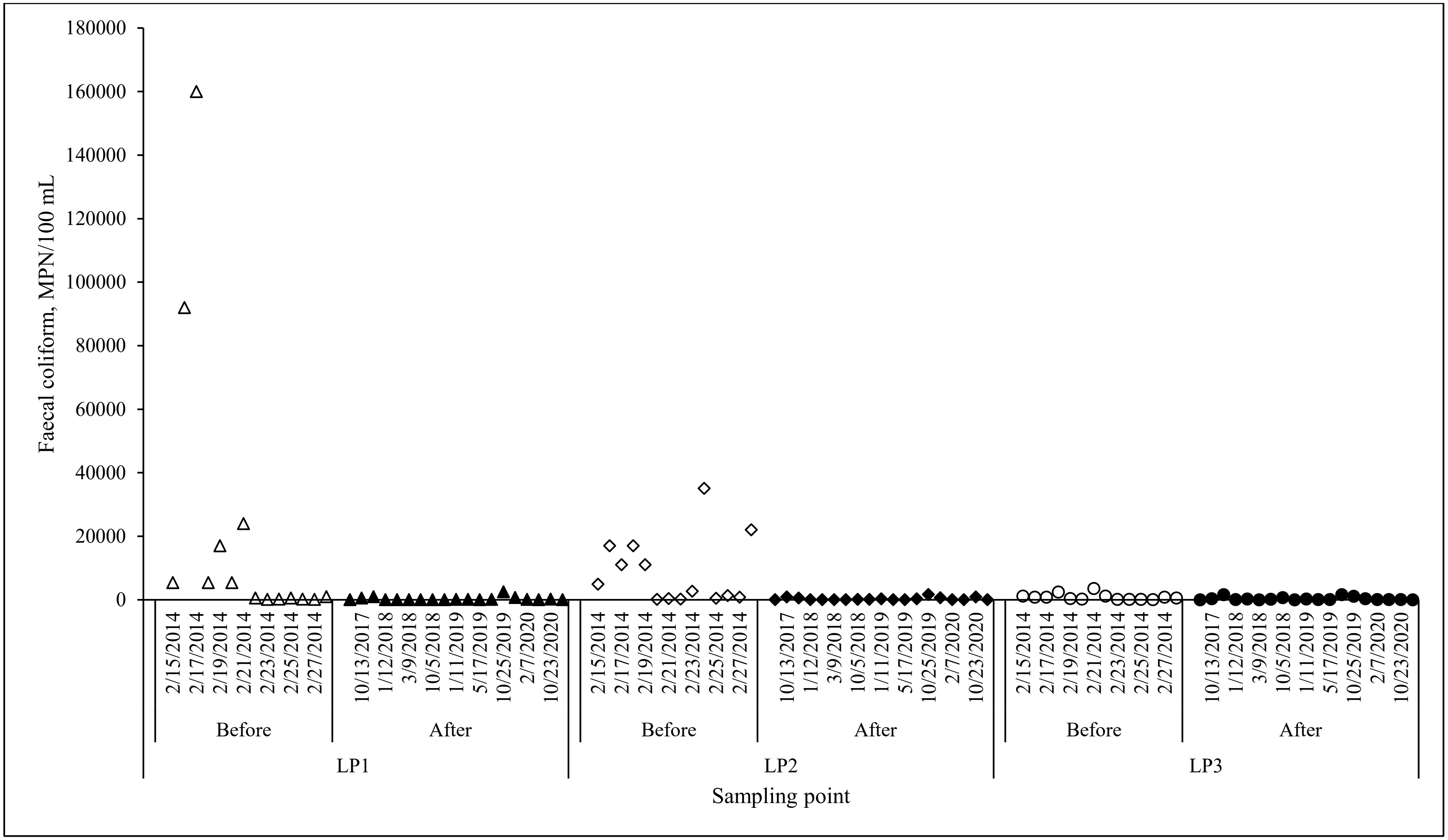


Figure 4. Fecal coliform concentration at all three locations.

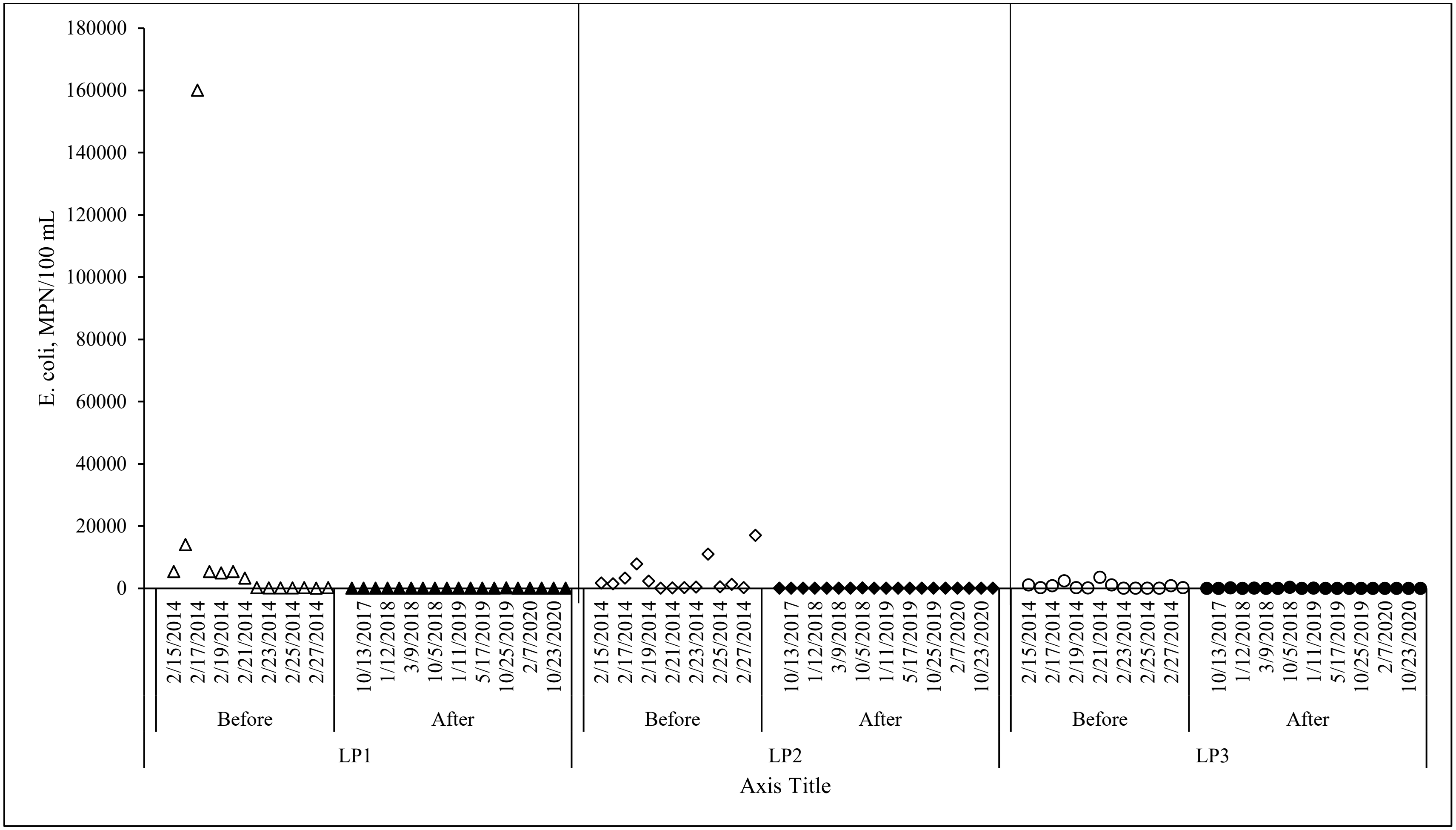
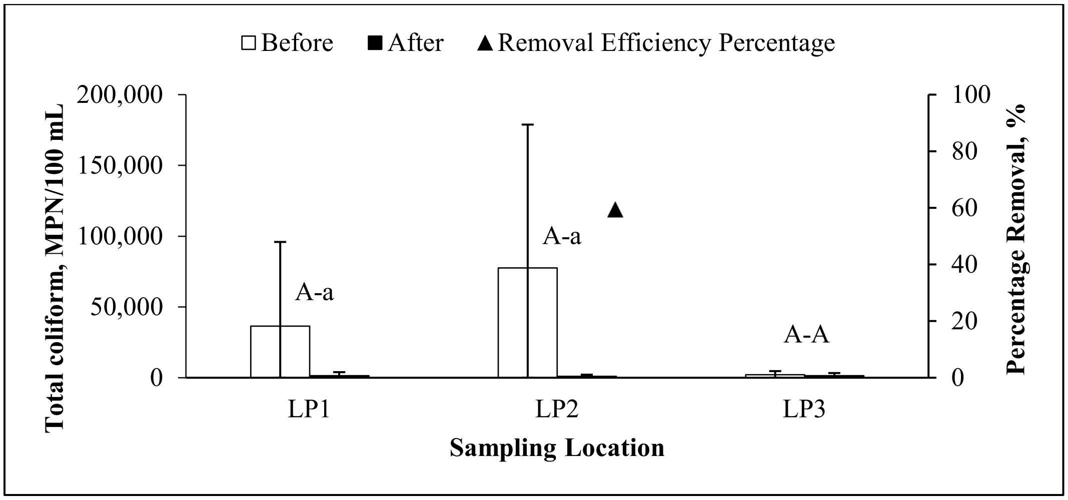
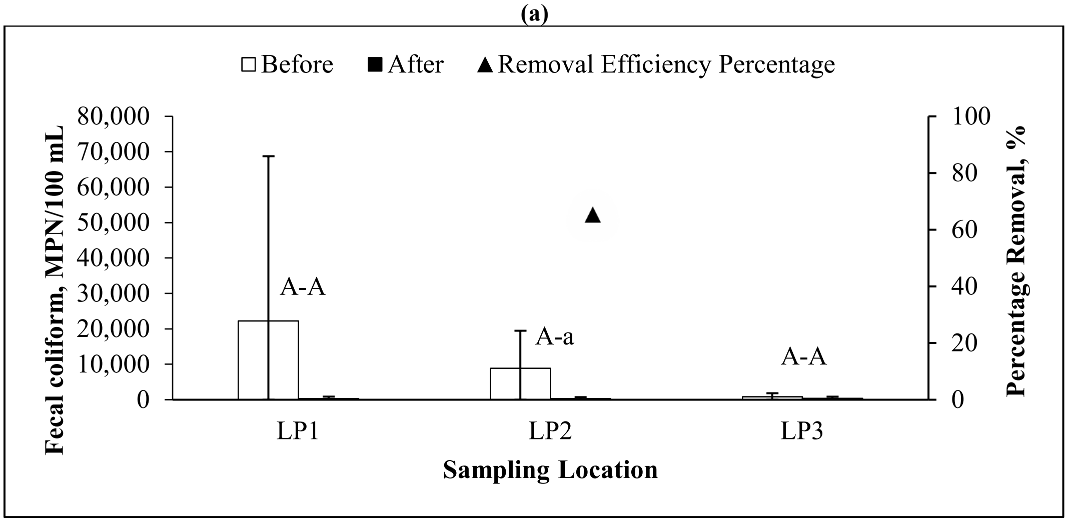


Figure 5. *E. coli* concentration at all three locations.



(a)



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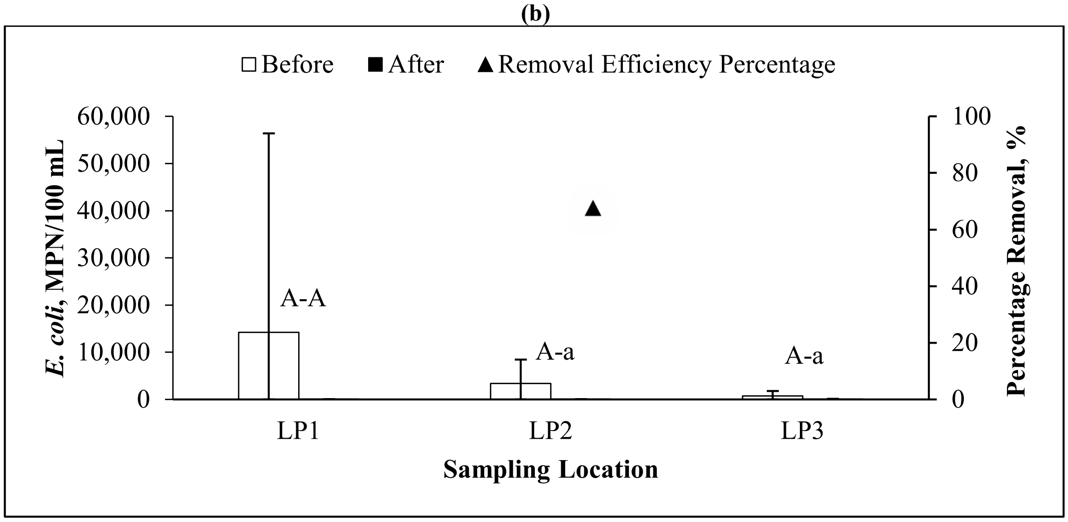

(c)

Figure 6. The average value before and after the marine outfall installation and its removal efficiencies at LP1, LP2 and LP3 for (a) total coliform, (b) fecal coliform, and (c) E. coli, respectively (A-a letter represents a statistically significant difference at $p<0.05$ for the average content of total coliform between before and after construction of marine outfalls).

CONCLUSION

Based on the results of the water quality analysis, the average content of total coliform, fecal coliform and *E. coli* had reduced significantly after the use of the marine outfalls, giving evidence that the application of marine outfall approach is very effective in reducing with microorganisms pollution in seawater, particularly in public recreation areas. However, referring to the National Standard for Natural Recreational Water Quality for prime parameters, and the average content of fecal coliform obtained from this study, water recreation activities with primary contact, such as swimming, are not suitable in Batu Feringghi coastal area since its fecal coliform is still beyond the limit (100 MPN/100 mL). The emission standards for fecal coliform parameters need to be incorporated into Malaysia environmental regulations to ensure that all sources of potential fecal coliform pollution in rivers and seas are completely treated before discharge. More studies on the effects of pathogenic bacteria should be carried out in tourist-focused rivers and seas for human safeguards. Appropriate methods including effective operation cost methods should be studied to treat pathogenic bacteria especially in the sewage treatment system with a capacity of 20000 PE, that can solve the issue of fecal coliform contamination in terms of loading which it should not be resolved by the dilution of the river.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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