Ecological Engineering Approach as a Sustainable Solution for Wastewater and Surface Water Issues in Rural Areas of Bario, Sarawak, Malaysia

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Abstract. This study is initiated with the aim of providing solutions for an effective wastewater management in Bario, a remote area situated in the middle of thick forest, close to Sarawak-Kalimantan border, with the only access is either by 55-minutes flying with 16-seat twin otter plane or 14-hour drive on 4WD vehicles using logging trail. Wastewater samples were collected at eight sites all over Bario and analyzed for pH, DO, BOD, COD, TSS, Ammonia NH₃-N and E.Coli. The results have highlighted a crucial issue, that is, open ditch and rivers posed high COD and highly contaminated with NH₃-N and E.Coli. The primary source of NH₃-N and E.Coli were believed to be originating from human excretion due to the leaking septic tank. Therefore, we proposed solutions that will be targeting all three stages of wastewater management system of Bario. Firstly, the 200 L makeshift drum barrel that were being used as septic tank need to be replaced with a proper septic tank. Secondly, in order to make the open ditch becoming self-treating, it needs to be sparsely planted with vegetation (i.e. water lilies) that can absorb the nutrient from the wastewater as well as increasing the aesthetic of the ditch. Thirdly, we proposed a constructed wetland as a treatment system for the wastewater before being released into the river. Conclusively, as the sewage is treated in septic tanks, and the greywater is treated using wetland, Bario has huge potential to facilitate more sustainable, economical and effective decentralized wastewater management system.

1. Introduction
In recent years, with rapid social-economic development, environmental conditions are dramatically changing in developing and undeveloped countries. Due to its rural characteristics, the limited infrastructure facilities that are provided are often inadequate, with the large part of the region are still waiting for proper sanitation system, or are aiming to improve the efficiency of the existing facilities [1, 2]. As of 2015, approximately 2.4 billion people, primarily in sub-Saharan Africa and south Asia, are lacking access to proper sanitation [3].
Considering the technical and economical limitations in developing and undeveloped countries, decentralized wastewater management systems appears to be the most logical solutions [4, 5]. Other than able to tackle sustainability issues and promoting water, bio-energy and nutrient recycling, these facilities are the best option for areas where construction of a centralized wastewater management system is not considered economically and technically viable [6]. Moreover, by switching into a smaller, localized and decentralized system, it will be the most financially sound solution, as the major cost of the decentralization will only absorbed by the treatment technology, in contrast to the centralization option, with bigger proportions come from the sewerage collection system [7]. As additional advantage, decentralized system is generally compact and poses flexible operating conditions with high aesthetic values [8].

2. Experimental

2.1. Sampling site

Bario is a remote area of Sarawak situated on the Kelabit Highlands, at an altitude of 3,500 feet above sea level, with an area of 3,850 km². It is located in the middle of thick forest, close to the Sarawak-Kalimantan border, with the only access is either by 55-minutes flight with 16-seater twin otter plane or 14-hour drive on four wheel drive (4WD) using logging trail. Bario community consists of 6,000 people of 13 to 16 villages with a small number of roads connecting among them. It is bordered by Tamabu range of mountains at the west and Apo Duat mountains at the east. Average daily temperature in Bario ranges from 14 - 26°C with an average annual rainfall of 2,000 mm. Bario is drained by four small streams, namely, Remapoh, Arur Laab, Arur Dalan and Merarui rivers, with one to four metres in width, which converge into Dapor river. Bario rivers also form the headwater of Limbang, Kuba-an, Libun, and Dapor rivers, with Libun and Dapor rivers being the important tributaries for the Tutoh and Ulu Baram rivers.

Due to its remoteness, the limited infrastructure facilities that are provided are often inadequate, therefore resulting in a poor and often deteriorating environment. Electricity generated through solar panels was just implemented in less than 5 years while drinking water treatment facilities are still under construction, expected to be in operation in 2021. As for sanitation system, no plan seems to be in place as it is now. Currently, the sewage was discharged into steel drum barrels with 200 L capacity that after years of usage, became corroded, and leaked out into the ditch. While the greywater was directly discharged into the ditch, making the ditch functioning as an open sewer system, before being released untreated into Merarui River. Additionally, they were at least two sites along the ditch and Dapor River that were known as the wallowing spots for wild and domesticated buffalos. At one time, as many as 10 domesticated buffalos were found wallowing at a site along the ditch and as many as 100 wild buffalos were found wallowing at a site along the Dapor River. These buffalos were the primary inception of the animal feces that goes into the ditch and Dapor River.

In Bario, they are two main indigenous tribes inhabited the area. The main tribe Kelabit inhabited the town and small villages scattered around the town. Whereas the Penan tribe inhabited the jungle along the perimeter of Bario. Penan is a nomadic indigenous people that tend to build their settlement deep in the jungle. But now, as they have been exposed to the outside world, they tend to build their houses at the edge of the jungle close to the village, so that they could send their kids to the school while the parents work at the paddy field owned by Bario residents. It is also safe to assume that Penan was inclined to build their houses close to the river as the river will serve as their primary water resources. However, at the same time, they will also build outhouse toilet in the same river, in this case, Arur Dalan River, hence, contaminating the river with human excretion.

In Bario, the main economic activities depend heavily on rice cultivation with paddy field concentrated in the middle of Bario. All four streams (Remapoh, Arur Laab, Arur Dalan and Merarui rivers) as well as the ditch flowed through the paddy field, thus, making them prone to the non-point
source of fertilizers used during the paddy planting. Therefore, as all three small streams (Remapoh, Arur Laab, Arur Dalan) and the ditch will merge into Merario River, before converged into Dapor River, it becomes imperative to investigate the quality of the surface water used as a main source of the water supply for Bario.

2.2. Water quality sampling procedures
Surface water samples were collected at eight sampling points all around Bario (figure 1). The samples were analyzed for pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Ammonia (NH$_3$-N) and E.Coli. pH and Dissolved Oxygen (DO) were measured with HANA Instrument Portable Water Sampler. While Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Ammonia (NH$_3$-N) and E.Coli were analyzed in accordance to APHA Standard Method [9].

3. Results and Discussions

3.1. Water quality of Bario’s surface water
In reference to Malaysia’s Department of Environment (DOE) Water Quality Index (WQI), all parameters were within class I, II and III except for BOD, COD and NH$_3$-N in the samples from the ditch (table 1). High COD content, with concentrations ranged from 79.7 to 243.1 mg/L, indicated that the water was highly polluted with both oxidizable organic and inorganic pollutants. Furthermore, it can also be seen that the highest COD were observed in water samples from the ditch, suggesting the dominant impact of organic sources. This assumption was held true as the ditch flows through the town of Bario, the main source of organic constituents in the water. As for BOD, high concentration of 6.51 to 8.04 mg/L implied that organic matter that needs oxygen while decaying or breaking down were coming from biological sources such as sewage, plant and animal matter (table 1). High NH$_3$-N concentrations, ranged from 0.91 – 0.98 mg/L, were also observed in water samples from the ditch (table 1). As the ditch flow through the town, it was believed that BOD and NH$_3$-N were originated from human excretion due to the leaking septic tank. Nevertheless, as the ditch was also flow through the paddy field, fertilizer runoff might also become a possible source for NH$_3$-N [10]. However, considering high E.Coli content of all samples (table 1), it was affirmed that human and animals excretion were the dominant sources that contaminate the water and not the fertilizer runoff [11].
Figure 1. The location of sampling points in Bario.
Table 1. Water quality of surface water and open ditch in Bario according to WQI proposed by Department of Environment (DOE), Malaysia.

|                      | pH  | TSS mg/L | DO mg/L | BOD mg/L | COD mg/L | NH3-N mg/L | E.Coli CFU/100 mL | WQI Class |
|----------------------|-----|----------|---------|----------|----------|-------------|------------------|-----------|
| D1 – Ditch (at Kg. Bario Asal) | 5.83 | 62.07    | 4.68    | 6.51     | 203.9    | 0.91        | 500              | III       |
| D2 – Ditch (at local shop) | 5.74 | 60.04    | 4.91    | 6.92     | 243.1    | 0.98        | 700              | III       |
| D3 – Ditch (at residents housing) | 5.82 | 64.79    | 4.94    | 6.64     | 223.1    | 0.91        | 800              | III       |
| AD1 - Arur Dalan River (upstream) | 7.09 | 1.72     | 6.93    | 7.92     | 79.7     | 0.26        | 430              | III       |
| AD2 - Arur Dalan River (downstream) | 6.53 | 3.54     | 6.49    | 7.91     | 80.1     | 0.58        | 620              | III       |
| MR1 - Merarui River (upstream) | 6.78 | 4.39     | 5.52    | 8.04     | 126.9    | 0.39        | 540              | III       |
| MR2 - Merarui River (downstream) | 6.34 | 17.27    | 5.01    | 7.81     | 174.8    | 0.58        | 750              | III       |
| DR1 - Dapor River | 6.48 | 47.68    | 5.61    | 7.48     | 176.7    | 0.66        | 805              | III       |

WQI is calculated based on 6 parameters, namely, pH, TSS, DO, BOD, COD and NH3-N.

* The parameters were classified as class IV.

* The parameters were classified as class V.

In overall, according to DOE WQI, all water samples demonstrated water quality within class III (moderate), with the following order in term of its quality from best to worse, Arur Dalan River > Merarui River > Dapor River > Ditch (table 1). Arur Dalan River flowed mostly through the jungle and only small stretch of it flowed through the town of Bario, thus, explaining its better quality. Unlike Arur Dalan River, the ditch, Merarui River and Dapor River were all flowed through the Bario town. Of all these, the ditch exhibited the lowest water quality as it was the point where all the untreated and leaking sewage started to get into the surface water. On the other hand, Sg. Dapor held a slightly better quality than its tributary of Sg Merarui, primarily because it is relatively bigger and deeper than Sg. Merarui, hence having greater diluting capacity. In general, the water may possibly be used for water supply though extensive treatment is crucially required.

In general, the results have highlighted a crucial issue, that is, ditch and rivers posed high organic content (i.e. COD and BOD) and highly contaminated with ammonia (i.e. NH3-N) and pathogen (i.e E.Coli). The primary source of these contaminants were believed to be originating from human excretion due to the leaking septic tank. High content of ammonia, other than causing eutrophication to the surrounding surface water, will pose huge technical implications to the water treatment plant operation. High ammonia content will make the chlorine disinfection process becomes ineffective. The disinfection system will need more chlorine as the chlorine will first need to react with all available ammonia before it can starts disinfecting the pathogen. Therefore, the identification of a suitable wastewater treatment system to treat these contaminants, especially ammonia, has become a crucial issue.
3.2. Ecological engineering approach as a sustainable solution for wastewater and surface water issues in Bario

In corresponding to the highlighted issues, we proposed solutions that will be targeting all three stages of wastewater management system of Bario. First, the 200 L drum barrel that were being used as makeshift septic tank need to be replaced with a proper septic tank. Second, in order to make the ditch becoming self-treating, it needs to be sparsely planted with vegetation (i.e. water lilies) that can absorb the nutrient from the wastewater as well as increasing the aesthetic of the ditch. Third, we proposed a constructed wetland as a treatment for the wastewater before being released into the river. Apparently, ecological engineering solutions (i.e. vegetated ditch and wetland) are the most appropriate treatment system for rural areas because of numerous reasons. Firstly, these two engineering solutions are excellent in removing nutrients especially NH$_3$-N, as the vegetation will absorb the nutrient from the wastewater. They are also fairly good in removing pathogen like E.Coli as the root system of the vegetation will serve as a filter and a harbor for the pathogen to attach themselves to. Secondly, residents of Bario are all paddy planters. They are experts in planting paddy, managing an irrigated paddy field and handling piping and channelling. Therefore, they have all the skills needed to maintain a wetland by themselves. Thirdly, these two engineering solutions require low and easy maintenance routine. Once the vegetation has growing steadily, the only maintenance needed is pruning the vegetation every couple of months. It is very critical not to allow the vegetation decay in the ditch and wetland as the decaying vegetation will release the nutrients from the plant back into the water [12]. Additionally, the solutions have a very high aesthetic value and will enrich the biodiversity of the surrounding area. Fourthly, these engineering solutions are the perfect example of a self-reliance and decentralized solution for wastewater management in rural areas like Bario. Apparently, in order for any technical systems to work successfully in rural areas, it has to be self-reliance.

4. Conclusions

In conclusion, as the sewage will be treated in septic tanks, and greywater and surface water in the ditch will be treated using vegetated ditch and wetland, Bario has huge potential to facilitate more sustainable, economical and effective decentralized wastewater management system.

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