Application of GIS for water quality monitoring in the aquaculture impacted Rawang sub-basin of the Selangor river, Malaysia

N D Hettige¹-³, H Rohasliney⁎¹, Z H B Ashaari¹, A B A Kutty² and N R B Jamil¹

¹Faculty of Forestry and Environment, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia
²School of Environmental & Natural Resource Sciences, University Kebangsaan Malaysia, 43600 UKM, Bangi Selangor, Malaysia.
³Environmental Studies Division, National Aquatic Resource Research and Development Agency (NARA), Crow Island, Colombo 15, Sri Lanka.

⁎Corresponding author’s email: rohasliney@upm.edu.my

Abstract. Freshwater aquaculture is a prominent activity in Rawang sub-basin of the Selangor River. Despite the importance good water quality in daily life, there is limited study on the impact of aquaculture activities on water quality. This paper discusses water quality parameter status (pH, dissolved oxygen (DO), ammoniacal nitrogen, turbidity, total suspended solids (TSS), chemical oxygen demand (COD) and biochemical oxygen demand (BOD)) based on Water Quality Index (WQI) in the aquaculture-impacted Rawang sub-basin of Selangor River and develops the Inverse Distance Weighted (IDW) maps showing water quality status by using GIS (ArcGIS 10.2.1 software) in order to identify the potential aquaculture impacted sites. Seven river sampling sites were selected including Guntong (SR1), Guntong’s tributaries (SR2/control), Kuang (SR3 and SR7), Gong (SR4), Buaya (SR5), and Serendah (SR6) using random sampling techniques based on accessibility and proximity to aquaculture farms. Seven water quality parameters were recorded and analysed on a bi-monthly basis. Results revealed that Guntong, Kuang, Buaya and Serendah rivers had moderate water quality, whereas Gong River was significantly polluted. The control river recorded clean water quality status. One-way analysis of variance (ANOVA) showed that there were significant differences in all measured water quality parameters among sampling sites (P<0.05).

1. Introduction
Malaysia, along with the rest of the world, has seen very rapid growth in the field of agroindustry in general and in aquaculture in particular. In order to meet the rising demand from an ever-increasing global population, aquaculture must continue to grow and develop as it is considered to be a crucial food source in the 21st century [1]. Total aquaculture production in Malaysia reached approximately 150,000 tons in the year 2000 followed by rapid increases over the last decade according to the United Nations’ Food and Agriculture Organization (FAO) [1]. Yusoff [2] reported that plans are in place to further promote aquaculture as a vital driver of national growth and subsequently as an important
mainstay of Malaysia’s economy. Aquaculture activities allows the nation and its population as a whole to reap the benefits of economic growth. Freshwater aquaculture is not new in Malaysia as it has been conducted in Malaysia since 1920 [3]. It has been mainly conducted in the major rivers such as Selangor, Pahang, Santubong and Selang Sibu rivers. However, it needs to be considered that untreated discharges from aquaculture farming activities could cause potential detrimental impacts to the water quality and aquatic organisms to the nearby rivers [1] - [4].

To date, GIS has been widely applied in many areas as a spatial analysis tool especially for [5] water quality studies [6]. Presently, the number of studies on the impacts to water quality due to aquaculture farming activities in Malaysia is very limited. Thus, this study was conducted to fill and improve upon this research gap. The first objective was to monitoring of water quality status (pH, dissolved oxygen (DO), turbidity, ammoniacal nitrogen, total suspended solids (TSS), chemical oxygen demand (COD) and biochemical oxygen demand (BOD)) according to the Water Quality Index (WQI) in the aquaculture-impacted Rawaung sub-basin of Selangor River. The second objective was to develop the Inverse Distance Weighted (IDW) maps showing water quality status by using ArcGIS 10.2.1 software in order to identify the possible aquaculture impacted sites.

2. Materials and Methods
2.1. Study Site
The samples were Selangor River is one of the major rivers in Selangor and it covers approximately 25% of the state [7]. It originates in the foothills of Fraser’s Hill and flows through the Kuala Selangor, Hulu Selangor and Gombak districts. It finally meets the sea at the Straits of Malacca. It comprises 10 sub-basins based on hydrological boundaries [8]. The Rawang sub-basin is one of the important sub-basins of the Selangor River with prominent inland farm aquaculture practices [9].

2.2. Research Design
This study was conducted in aquaculture-impacted rivers in the Rawang sub-basin of Selangor River beginning from April 2019 to February 2020 on a bimonthly basis.

![Figure 1. Map of the Malaysia Peninsular, Selangor River and the study area’s selected sampling sites](image)
In total, seven sampling sites were selected by using a random sampling technique and based on its accessibility. Among the sampling sites, six were chosen based on their proximity to aquaculture farms. The control site (SR2), which is located near to a forested area, there were no aquaculture farms upstream. The sampling sites were numbered and coded as follows: SR1 (Guntong River), SR2 (Guntong River’s tributaries), SR3 (Kuang River), SR4 (Gong River), SR5 (Buaya River), SR6 (Serendah River) and SR7 (Kuang River). The aforementioned sites’ approximate proximity to aquaculture farms was as follows; SR1 and SR3 (downstream 200m), SR4 and SR5 (downstream 20m), SR6 (downstream 400m) and finally SR7 (downstream 400m).

2.3. Water Quality Analysis

During the sampling phase, three replicate samples were collected from each site for the purpose of physicochemical water quality analysis (N = 7 sampling sites × 6 sampling trips × 3 replicates = 126 individual samples per river basin). Dissolved oxygen (DO), turbidity and pH were measured in-situ by using the following equipment: dissolved oxygen (DO) meter (YSI 52, USA), turbidity meter (HACH 2100 P) and pH meter (Thermo Scientific Orion 3-Star). All of the said portable meters were calibrated accurately before use. Collected water samples were transported to the laboratory at 4°C for subsequent laboratory analysis. Chemical oxygen demand (COD) and ammoniacal nitrogen testing were performed using a DR 2800 spectrophotometer [10] while biochemical oxygen demand (BOD) was measured using a BOD meter. Total suspended solids (TSS) was quantified using the standard method [11]. Water quality data were compared to the WQI classification of National Water Quality Standards (NWQS) for Malaysia developed by the [12]. Furthermore, the WQI was calculated by incorporating the DO, pH, BOD, COD, ammoniacal nitrogen and TSS parameter in the following equation:

$$\text{WQI} = 0.22 * \text{S}_{\text{DO}} + 0.19 * \text{S}_{\text{BOD}} + 0.16 * \text{S}_{\text{COD}} + 0.15 * \text{S}_{\text{AN}} + 0.16 * \text{S}_{\text{SS}} + 0.12 * \text{S}_{\text{pH}}$$

whereby S\text{DO} represents Sub-index DO (% saturation), S\text{BOD} is Sub-index BOD, S\text{COD} is Sub-index COD, S\text{AN} is Sub-index NH3-N, S\text{SS} is Sub-index SS and S\text{pH} is Sub-index pH. However, this method is not sufficiently enough to assessment of stream water quality status [13] because it did not include many other important water quality parameters [14] such as phosphate and nitrates.

2.4. GIS Analysis

Spatial analysis was conducted using the ArcGIS 10.2.1 software to determine the variation of water quality. Interpolation using Inverse Distance Weighted (IDW) technique commonly used to create distribution of water quality data. Buffer 200m was created within river bank as an expansion to observe the distribution of water quality parameters namely DO, BOD, COD, ammoniacal nitrogen and WQI. The data were collected from seven sampling stations along selected river. Results of interpolation of every parameter were finally reclassified into standard range classes provided by DOE.

3. Results and Discussion

Average water quality parameters of sampling sites were graphically presented using GIS interpolation maps.

3.1. DO

DO is essential parameter of any aquatic ecosystem because it is an indication of the degree of the health. The Rawang sub-basin is categorized between Class II to Class III with average DO concentration ranged from 3.11 mg/L to 6.41 mg/L (Figure 2). Buaya (SR5) and Gong (SR4) rivers were categorized different water quality classes although there were located approximately the same distance from the aquaculture effluent discharge point. Because the obtained DO concentration values suggest that the auto purification capacity of these two sites are different. The auto purification capacity of water bodies are predicated upon natural factors, namely velocity, depth, discharge and temperature [15]. Buaya River has higher discharge (0.061 m3/s) as compared to Gong River (0.041 m3/s), hence
its auto purification capacity is also enhanced. Depleted DO concentrations were recorded at points (Gong River, SR4) which are nearest to the waste discharge points of aquaculture farms. This could be ascribed to high concentrations of degradable organic and inorganic matter that originates from aquaculture farms [16].

![Digitized map of variation of DO concentration in the selected sampling site](image)

**Figure 2.** Digitized map of variation of DO concentration in the selected sampling site

When considering the average DO concentrations during the study period, it is evident that the Serendah River (SR6) and Kuang River (SR7) both have a recovering water quality status compared to the aquaculture-impacted sites based on the oxygen sag curve theory. The fact that these sampling sites are denoted as having the same water quality status as the control site (SR2) further validates this. Additionally, one-way ANOVA indicated that there was a significant difference between sampling sites with regards to their DO concentrations (p<0.05).

DO is one of the parameters for observation of organic contamination [17]. Many authors have found that the water quality of the Rawang sub-basin has been impacted by organic pollution. As an example, the water quality of the Rawang sub-basin has been designated as poor due to its DO concentration [18]. They suggested that the low DO concentration is due to organic pollution of the surrounding area. In addition, Chowdhury et. al. [7] found a significant decrease of DO concentration in the main canal of the Selangor River where it connects to the Rawang sub-basin. However, based on a previous study on the variation in water quality at the Bestari Jaya Aquaculture Pond and the Selangor River in June and July 2012, Idris et. al. [19] found that DO is higher at the fish farm than at the discharge point of the river. They suggested that this variation is attributed to the use of water quality-improving materials such as highly soluble salts.

### 3.2. BOD

The Rawang sub-basin is categorized between Class II to Class IV except for control site (Class I) with BOD concentration ranged from 0.54 mg/L to 6.49 mg/L (Figure 3). In terms of water quality classification based on BOD, the Buaya (SR5) and Gong (SR4) rivers were categorized as having different water quality classes even though they had the same proximity to the aquaculture farm outlet. The reason for this could be attributed to differences in the auto-purification capacity of these sites, similar to the changes in water quality classes based on DO. The control site possessed a good water quality status compared to other sampling sites because it is located near to a forested area. Also, water quality classification based on BOD, both the Serendah (SR6) and Kuang (SR7) rivers were in the same classes. This was because these sites were situated at approximately the same distance from the aquaculture farm outlet. Therefore, the finding suggests that water quality of Kuang River (SR7) and
Serendah River (SR6) were improving. Based on a study conducted at the Fornelo and Inha Rivers of Portugal, BOD reverts to normal values for feeding water approximately 2–3 kilometers downstream from the point of effluent discharge [20]. This was also proven with low BOD concentrations recorded at the sampling points of Kuang River (SR7) and Serendah River (SR6) were located further downstream from the aquaculture farm effluent discharge point as compared to the other sampling sites.

The previous study in the Selangor River conducted by Othman et al. [18], high BOD concentrations were found in the Rawang sub-basin as compared to the upstream and downstream sampling sites of the main River of the Selangor. Additionally, Chowdhury et al. [7] found the highest concentrations of BOD Selangor River was at the sampling site where the Rawang sub-basin connect the Selangor River. Based on the findings from preceding studies, it could be concluded that organic contamination is present around the study area and that it originates from land-based aquaculture farming activities which is relevant to the current study. According to the Selangor River Basin Management Plan 2007–2012, aquaculture activities are a contributing factor to pollution loads amounting to 10.5 t BOD per day to the main river and its tributaries [13].

One-way ANOVA testing confirmed the presence of a significant difference between sampling sites (p<0.05). It has been reported by Pulatsu et al. [21] that the effects of fish farm effluent on the BOD levels of the receiving water have been found to be significant. Increased TSS values are one of the main factors contributing to the high BOD levels because organic matter is trapped by suspended particles [13]. Higher feeding levels increases the production of organic matter from the farm either as uneaten feed or feces and will lead to a significant increase in BOD of the receiving water body [22].

3.3. COD
Similarly to DO and BOD, the organic matter content of the water could also be measured by concentration of COD [23]. Aquaculture produces effluents which have high loads of organic matter [24]. This study showed that, minimum average COD concentration was 0.06 mg/L while maximum average concentration was 44.44 mg/L within the sub-basin and it categorized between Class II and Class III except for Control site (Class I) (Figure 4). The obtained results revealed that based on their COD levels, water quality was improving in the Serendah (SR6) and Kuang (SR7) rivers which were located further away from the aquaculture farming site. The reason is similar to the variations in DO and BOD in these two locations. However, the Buaya (SR5) and Gong (SR4) rivers were categorized as Class III. These two locations had the same approximate proximity to the aquaculture farm’s effluent discharge point.
Similar to the other water quality parameters, one-way ANOVA showed that there were significant differences in COD among the sampling sites. Some of the river tributaries within the Rawang sub-basin have been classified as Class III and Class IV based on their COD concentrations [7]. However, the said author mentioned that this was due to the point and non-point sources created from industrialization and urbanization of the area. Khoon [25] conducted a study on water quality status in the Selangor River based on water quality data collected from the Department of Environment (DOE). In that study, the water quality status at the Rantau Panjang DOE monitoring station, which is situated in the main river of the Selangor River downstream of the Rawang sub-basin, was categorized as Class IV based on COD levels.

3.4 Ammoniacal Nitrogen

Based on the WQI classification guideline of ammoniacal nitrogen in NWQS of Malaysia, Rawang sub-basin was under the category between Class III to Class IV with the concentration ranged from 0.39 mg/L to 1.77 mg/L (Figure 5). It is evident that all sampling sites located downstream from the effluent discharge point of aquaculture farms were classified under the same water quality classification. Generally, the ammonia concentration in the aquaculture farms is higher because of the feeds used to accelerate fish growth. Ammonia could also originate from effluents discharged into nearby water bodies from the said aquaculture farms. Ammoniacal nitrogen is mainly derived from the excretory products of fish metabolism and that of feed components [26]-[27]- [28]. Kawasaki et. al.[29] found that main Selangor River has categorised as Class III with ammonia concentration according to the NWQS guideline. Higher concentration (0.01 to 4.01 mg/L) of ammoniacal nitrogen also recorded in Rawang sub-basin [18]. By performing one-way ANOVA, it was found that a statistically significant difference exists in the ammoniacal nitrogen levels of the various sampling sites (p<0.05).

Based on the Kawasaki et. al. [29] aquaculture activities are one of the major sources of nutrient pollution in the Selangor River. Their findings revealed that waste originating from aquaculture farms caused nutrient levels at two sampling sites to be elevated. Also, the range of total dissolved nitrogen, total dissolved phosphorus and the ammonia concentrations recorded were measured at 0.51 - 13.4 mg N/L, 0.004 - 0.370 mg P/L and 0.01 - 0.98 mg N/L respectively. Based on analysis done on water samples collected downstream from the Selangor River and also at shrimp farm and aquaculture farm ponds, Kawasaki et. al. [1] reported higher nutrient concentrations in the aquaculture ponds compared to the river due to the fact that feeds are supplied to the former instead of the latter. However, higher concentrations of ammonia were measured in the river as compared to the aquaculture ponds. Eutrophication was also observed in the ponds due to the presence and growth of phytoplankton. Ammonia in water is typically utilized by some phytoplankton for their growth. The said authors
concluded that this could be because of lower ammonia concentrations in the ponds relative to in the river.

Figure 5. Digitized average ammonical - nitrogen in the sampling site

3.5 pH
Kuang River (SR7) recorded the highest average pH values (6.77 ± 0.90) among other sampling sites. Nevertheless, the Buaya River (SR5) exhibited the lowest pH values (6.07 ± 0.35). Based on the WQI based NWQS for Malaysia, the average pH values for all sampling sites puts them in the Class II classification (pH 6-7). pH is a representation of the ionic contamination of water. Based on the results obtained, it could be concluded that ionic components can be released from the materials that bring about organic contamination such as ammonia, phosphate and nitrate. The water solubility of those irons increase at lower pH. According to the study findings, aquaculture farming activities are the point source for the release of organic materials.

The biological oxidation of organic matter creates electrons and it also creates other important compounds simultaneously such as acetate. The oxidation of acetate often produces free hydrogen and hydroxyl ions in water [30]. Therefore, this type of process could lead to pH fluctuations in the water. Furthermore, Chea et. al. [31] stated that a reduction in pH levels could be the result of organic matter decomposition. The control site (SR2) exhibited low average pH values (6.39 ± 0.24) because, based on Hamid et. al. [32] and Ward [33], headwaters are more likely to have lower acid neutralizing capacity in comparison to larger streams that drain the watershed. One-way ANOVA showed a significant difference in pH values between the sampling sites (p<0.05).

3.6. TSS and Turbidity
The average value for TSS at the control sampling site was measured to be 10.78 ± 7.34 mg/L. That is lesser than the TSS values obtained at every sampling site that are located near to aquaculture farms across all sampling trips. Analysis using one-way ANOVA showed a significant difference of obtained TSS and turbidity values among sampling sites (p<0.05). According to the WQI based NWQS of Malaysia, average TSS of all sampling sites were classified as Class III (50-150 mg/L) water quality status excluding Control site (Class I).

One-way ANOVA showed a significant difference in pH values between the sampling sites (p<0.05). The minimum TSS was 10.78 mg/L whereas maximum was 111.58 mg/L. Similarly, the lowest turbidity was observed at the Control River (85.91±83.73 NTU). However, there was no standards limits for the turbidity in WQI based NWQS to classified classes. The presence of organic matter could be one of the reasons for the high turbidity observed [34]. Additionally, it has been found that fish farm effluent has higher TSS values than the farm inflow at fish farms in the Esen Stream, Turkey [35].
3.7 WQI

WQI is useful in assessing the suitability of river waters for a variety of uses such as agriculture, aquaculture, and domestic use [36]. Based on the calculated WQI values (Figure 6), the Guntong River tributary where the control sampling site is situated is categorized as clean water quality, meanwhile Guntong, Kuang, Buaya, Serendah and Kuang rivers exhibited a status of being moderately polluted. The Guntong River tributary (SR2) showed a Class I classification compared to its counterparts. This could be attributed to it being located near to a forest area and the fact that there were no aquaculture farms upstream from it (Table 1).

During a previous survey conducted around the aquaculture farms located along the main canal of the Selangor River, Daniel & Kawasaki [37] found many aquaculture farms released wastewater without proper treatment. Chowdhury et. al. [7] concluded that special attention is required to affect an improvement in water quality within this sub-basin of the Selangor River. Following the WQI based NWQS for Malaysian rivers, the water quality of the Rawang sub-basin was found to be in the class IV category from the study conducted by Chowdhury et. al. [7].

Table 1. Summary of the water quality classification based on the WQI and water classes

| Sampling sites          | SIDO | SIBOD | SICOD | SIAN | SISS | SIpH | WQI | Water classes | Classification  |
|-------------------------|------|-------|-------|------|------|------|-----|---------------|----------------|
| Guntong River (SR1)     | 63.35| 84.60 | 60.56 | 47.18| 47.64| 95.34| 66  | III           | Slightly polluted |
| Guntong River tributary (SR2) | 88.29| 98.14 | 99.03 | 87.67| 91.29| 95.28| 93  | I             | Clean           |
| Kuang River (SR3)       | 56.92| 80.32 | 58.89 | 36.67| 50.46| 97.31| 62  | III           | Slightly polluted |
| Gong River (SR4)        | 40.97| 75.21 | 52.09 | 33.24| 54.99| 88.25| 58  | IV            | Polluted        |
| Buaya River (SR5)       | 79.13| 86.73 | 66.07 | 42.23| 58.66| 86.91| 73  | III           | Slightly polluted |
| Serendah River (SR6)    | 85.50| 91.40 | 71.85 | 71.42| 63.55| 95.98| 80  | II            | Slightly polluted |
| Kuang River (SR7)       | 75.63| 88.54 | 70.23 | 42.90| 55.40| 93.40| 71  | III           | Slightly polluted |

Where: SIDO: Sub-index for DO, SIBOD: Sub-index for BOD, SICOD: Sub-index for COD, SIAN: Sub-index for ammonical nitrogen, SISS: Sub-index for suspended solids, SIpH: Sub-index for pH, WQI: Water Quality Index

Figure 6. Digitized classification of WQI at selected sampling sites, Rawang sub-basin, Selangor
This study found that Gong River (SR4) is classified as a polluted river. However, based on the monthly variations of each parameter, the very low DO concentration was found in this river. In efforts to identify the more problematic parameters and where remedial measures could be introduced on the basis of priority on river sections, calculating the sub-indexes for individual water quality parameters was useful [36]. Subsequently, the sub-index value was calculated for each parameter. Based on the calculated sub-index values, it is evident that compared to other locations, a low value of SIDO was observed here. Because this section of the river receives waste directly from the aquaculture effluent discharge and it was also observed during the sampling visits.

Also, based on the equation, sub-index of DO increases with the increase in concentration while for others it decreases at different rates [38]. The sub-index classification for BOD, the control sampling site was designated as having a clean water quality status while a polluted water quality status was given for the Gong River. However, other sampling sites were denoted as having a slightly polluted condition. Low WQI values are engendered by the presence of the pollutant NH3-N, as noted by the previous researchers [38]. According to the same authors and the same study, the sub-index decreases swiftly with an increase in the concentration of NH3-N; this despite the fact that the NH3-N sub-index only accounting for 15% of the overall equation.

4. Conclusions
Based on the calculated WQI values, Guntong, Kuang, Buaya, Serendah and Kuang rivers are denoted as moderately polluted while Gong River is categorized as polluted. On the contrary, the Guntong River tributary was found have a clean water quality status. This study showed that the developed IDW maps with indicating the water quality status can support in identifying the potential aquaculture impacted sites along the river.

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