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Biochemical Oxygen Demand, Nitrogen, Phosphorus and Navigational Carrying Capacities of Bengoh Reservoir for Potential Aquaculture and Recreational Developments

Esther Lik Yee Law[1*], Puong Ling Law[2]

[1]Faculty of Engineering, Computing and Science,
Swinburne University of Technology, Jalan Simpang Tiga, 93350 Kuching, Sarawak, MALAYSIA

[2]Department of Civil Engineering, Faculty of Engineering,
Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, MALAYSIA

*Corresponding Author

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Abstract: This paper quantifies the biochemical oxygen demand (BOD), nitrogen (N), phosphorus (P) and navigational carrying capacities of Bengoh Reservoir for potential fish cage culture and recreational developments. The pollutant degradation coefficients (*k*) and pollutant carrying capacities (tons/day) of the reservoir were determined. The computed pollutant degradation coefficients were primarily based on the hydrological information of the catchment, hydraulic and operational details of the dam, and the targeted water quality standards of the river-connected Bengoh Reservoir. The maximum allowable pollutant loading rate (tons/year) defines the reservoir's maximum Waste Assimilative Capacity (WAC) on specific pollutants (BOD, N and P), while in compliance to the targeted benchmark with the receivable pollutant loadings. It was found that the current BOD, TN and TP loading rates are 0.308 ton/day, 0.119 ton/day and 0.114 ton/day, respectively. To comply with Class I Standards of the National Water Quality Standards of Malaysia (NWQSM), the Maximum Allowable Loading Rates of BOD can be as high as 92.24 tons/day as compared to the current loading rate of 0.308 ton/day, maximum TN loading of 116.63 tons/day versus current 0.119 ton/day, and maximum TP loading at 125.54 tons/day versus current 0.114 ton/day. It was also found that the maximum number 218 cages (225 fish/cage) of Tilapia would be allowed in Bengoh Reservoir so as to comply with Class I of NWQSM. Based on the peak level of the reservoir recreational types of use in demand and the mix of public and private access, the navigational carrying capacity of the reservoir was estimated to be about 130 boats.

Keywords: Pollutant loading rates, degradation coefficient, carrying capacities, aquaculture, navigational.

1. Introduction

In Sarawak, some of the major hydroelectric power (HEP) and water supply reservoirs include the Bakun HEP Reservoir, Murum HEP Reservoir, Batang Ai HEP Reservoir, Bengoh Reservoir, and Assyakirin Reservoir. Those inland freshwater reservoirs are endowed with immense commercial potential for water-based developments such as cage aquaculture, recreational, eco-tourism projects. An example of one of the most successful reservoir water-based development projects in Sarawak is the Tilapia Cage Culture Development Project at Batang Ai HEP reservoir by focusing only on the cage culture of Tilapia fish. As of December 2017, the number of cages of Tilapia cage culture at Batang Ai Reservoir approved by Jabatan Pertanian Sarawak, Unit Penguatkuasa Dan Pelesenan, Bahagian Perikanan

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**Corresponding author: tatalaw@gmail.com*

Darat, Jalan Dusun Off Jalan Ong Tiang Swee, 93200 Kuching, Sarawak recorded a total of 11,406 cages and 9,073 cages are currently in operation, all for the culture of Tilapia [1]. The estimated average production rate of Tilapia fish is approximately 1,100 tons/year, while the biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrogen (N) and phosphorus (P) levels of the reservoir are maintained well within the Class IIA Limits of the National Water Quality Standards of Malaysia (NWQSM) [1]. However, prior to the implementation of any additional or new development in the reservoir or catchment, it is of paramount important that the key pollutant degradation rates and maximum allowable pollutant loading rates be determined in order to maintain the targeted water quality.

1.1 Fish Cage Culture – Potential Impacts on Water Quality

Water-based development of a reservoir always brings about negative impacts on the water quality and cage aquaculture is of no exception. Cage aquaculture is generally associated with high organic loadings, excessive nutrient discharge, high demand of dissolved oxygen and production of chemical waste. Sediments are often deposited from feed waste (uneaten food and undigested food from fish by-product) and insoluble compound (dead fish). The potential increase in total nitrogen (TN) and total phosphorus (TP) would contribute nutrient enrichment. Accumulation of organic sediment and enrichment of nutrient in the water source enhance the production of aerobic bacteria in the water that elevate dissolved metabolic wastes and biochemical oxygen demand (BOD) in the water. Chemical waste and mineral supplements from the fish feed may also impact the water quality. In order to ensure the sustainability of the cage aquaculture environment, key management strategies such as site selection, fallowing of site, evaluation of environment capacity, governmental regulations and codes of practice are essential to keep the concentration of several pollutants at the prescription level.

1.1.1 Sediment

Sediments beneath the cages are frequently subject to high organic loadings from waste feed and bio-deposits (faeces) from fish [2]. Studies [3]-[6] show that the bottom area below the cages could experience 2-20 times higher sedimentation rate than a reference area. High levels of organic enrichment observed beneath the cages would result in moderate impact within 50-m radius around the cages with respect to the levels of organic carbon, total carbon, total sulphur, sulphide, redox potential, total phosphorous and total nitrogen [4], [7]. Sara et al. [8] used stable isotope analysis for carbon and nitrogen and they found that an oligotrophic area, at 25m depth and a mean current of 10-12cm/sec, the influence of carbon and nitrogen from farming waste could be detected within 1-km radius of the cage. The bio-deposits can have definite effects on sediment chemistry and macrobenthic invertebrates, as an increase in total volatile solids (TVS) and free sulphides in sediment is anticipated in the immediate vicinity of the cage farms [2]. The environmental impacts of waste feed and bio-deposits would be significantly minimized if the fish farms can fallow for a period of weeks or even years to allow the conditions to return to normal [2]. The water quality can be significantly improved by introducing oxygen injection system for cage farms [9], or to reduce fish density, regulate feeding, increase water exchange rate by installing current generators or to choose a well-flushed site [2].

1.1.2 Dead fish as a waste

Mortality often takes place in all types of cage culture. On average, the cage culture fish mortality rate can be as high as 10% as reported by [10]. The mortality rate of cage fishing can be attributed to an array of common factors that are preventable. Generally, dead fish must be removed from the cages daily by adopting proper procedure, even though dead fish is not estimated to be a problem to sediment enrichment [11], [12].

1.1.3 Nitrogen (N) and phosphorus (P)

Significant proportion of the phosphorous in the feed is released into the environment (66-88% in marine salmon cage); estimated that for 1kg of salmon produced, 7.8-12.2g of phosphorous are released into the marine environment [13]-[17]. Ammonia and ammonium are the most common types of nitrogen (N) waste that may include 65-90% of total nitrogen loss in fish, and the total nitrogen loss in cage culture ranges from 72% to 79% of total input, Ruohonen [15] estimated that for 1kg of Atlantic salmon produced, 53.4g of nitrogen are released into the environment; and Storebakken et al. [16] found that nitrogen loss in Atlantic salmon amounts to 54% of total nitrogen intake and 82% of the waste was excreted in soluble form. The released nutrients would be consumed by algae and the production depends on the location and time of the algae [11], [12]. Brooks and Mahnkan [11], [12] found that algal production in areas with dense fish population showed insignificant increase in algal production in marine coastal waters. Other studies on the impacts of open marine waters from a Scottish loch with a large fish farm with very restricted water exchange to the open sea also show no evidence of measurable effects on phytoplankton density [6]. Feed loss can be significantly reduced, and thus the nutrients by the use of hydro-acoustics and video techniques, which detects the loss of feed [18], [19].

1.1.4 Hydrogen sulfide (H2S) and dissolved oxygen (DO)

Accumulation of organic sediment tends to produce ammonia and hydrogen sulphide gases when oxygen is depleted, and the gas can be reduced rapidly by oxygen, diffusion and sufficient mixing in water column.

Comparatively low dissolved oxygen levels have rarely been reported to be a problem in cage culture marine waters, whereby ambient dissolved oxygen could decrease by 0.3mg/L [20]. However, Brooks and Mahnken [11], [12] reported as much as 2mg/L decrease in dissolved oxygen (DO) level in water passing through a large, poorly flushed cage farm. At high temperatures and peak biomass (fish) in the cages, the DO concentrations can reach critically low levels [21]. The DO concentrations can be significantly improved by introducing oxygen injection system for cage farms [9]. Other strategies are to reduce the number of cages in the area, reduce fish density, regulate feeding, increase water exchange rate by installing current generators [2].

1.1.5 Chemical waste and chemotherapeutants

Minerals and pigments are sometimes incorporated into the feed, and chemicals use in cage construction materials may include stabilizers, plasticizers, ultraviolet absorbents and antifoulants [18]. To fight disease or to reduce fish mortality rate, disinfectants and chemotherapeutants (such as the antibacterial, antifungal and the antiparasitic compounds) may be used to control pathogens and chemotherapeutants [18], [22], [2]. Significant reduction in the use of antibiotics can be achieved through selection of more favourable sites or localities and better management practices [2].

1.1.6 Copper (Cu) and zinc (Zn)

Zinc (Zn) is an essential trace element for fish nutrition and is added to the feeds, as part of the mineral supplement that could be deposited in the sediment [18], [23], [11]. The sulphide in the sediment combines with both zinc and copper (Cu) to reduce their bioavailability to non-toxic levels. However, zinc level may return to its background level during chemical remediation, leaving no evidence of a long-term build-up while being converted to a more bio-available form [10], [11]. Besides, accumulation of copper in sediments can be significantly reduced by washing cage nets on land [11], [12]. Solberg et al. [24] found that the use of copper-coating on either within or around the net-pens would not affect the quality of the seafood products.

1.2 Navigational carrying capacity of reservoir

To calculate the navigational carrying capacity of reservoir for recreational purposes, it is necessary to integrate reservoir's uses and goals with respect to its characteristics. The navigational carrying capacity of reservoir can be determined once the peak level of recreational use, the types of use in demand, and mix of public and private access. The observation on the activities at various times during wet and dry seasons, including the number of boats on the reservoir, type of each boat (fishing, high-speed, personal, commercial, non-commercial, etc.). Moreover, the boat's approximate speeds; stationary, no wake, or wake-producing speed should be recorded. Usually, once the activities are captured at several points in time, it should provide a reasonably accurate picture of actual us age, and thus the navigational carrying capacity of reservoir.

2. Materials and Methods

2.1 Bengoh Reservoir and catchment land use

The Bengoh Reservoir has a maximum reservoir coverage area of approximately 8.77 km^2 at full supply level of 80.0 mLSD [25]. The reservoir is located approximately 2.2 km west of Kampung Bengoh and about 1.2 km upstream from its confluence with Sungai Semadang. The catchment size of Sungai Sarawak Kiri is about 633 km^2 [25]. The Bengoh Catchment measures approximately 127 km^2 about one quarter the size of the Sungai Sarawak Kiri catchment (Fig. 1). The Bengoh Catchment hydrology and Bengoh Reservoir details are summarized in Table 1 [25].

Fig. 1 shows the catchment land use characteristics of the Bengoh catchment [25]. The hills forests of the upper Bengoh Range are intact, but its adjacent lowland forests have been extensively cleared, mainly for shifting cultivation. A large part of the basin is now either farmland, secondary or regenerated forest or barren grounds. The shifting cultivation is widely practiced in the catchment by the local people. Hill paddy and other mixed crops, such as tapioca and maize are cultivated on the hill slopes. After one or two cycles of crops, the farmers move on to clear another plot of land, leaving the other plot under bush fallow. This system of farming eventually uses up a large area of land, thus explaining the sizeable area of land affected by shifting cultivation. There is minimal cultivation activity to the upper range of Bengoh Range; however, the hill forest to the south west of the catchment area had been logged selectively and under regeneration. The land use patterns/distribution of the area within the Bengoh Catchment mainly consists of shifting cultivation area (approximately 62%). It was estimated that approximately 22% consist of primary forest and another 14% regenerated forest [25].

2.2 Pollutant Degradation Coefficients and Pollutant Carrying Capacities

The pollutant degradation coefficient, k is also known as reaction coefficient (day^{-1} or d^{-1}), which can be defined as the assimilative capacity of a water body or reservoir with respect to a particular pollutant. The pollutant degradation coefficient, k is known based on the estimated current load (CL), tons/year from water-based and land-based activities, it is possible to estimate the amount of future load (FL), tons/year of that particular pollutant. The following expressions describe both the allocation of additional or allowable future load (tons/year), and the allocation of reducing future load (tons/year) in order to achieve the endpoint or maximum concentration level (MCL) of that particular pollutant [26].

Table 1 - Hydrology and reservoir

Hydrology of Bengoh Catchment		
Catchment Area	127	km^2
Mean Annual Rainfall	3990	mm
Mean Annual Inflow	284	Mm^3/yr
Flood Peak Flows:		
- 5 years	320	m^3/s
- 10 years	365	m^3/s
- 20 years	400	m^3/s
Design Flood Inflow – PMF	2420	m^3/s
Bengoh Reservoir		
Full Supply Level	80.0	m LSD
Max. Design Flood Level	85.2	m LSD
Min. Normal Operating Level	55.0	m LSD
Storage at (NRL)	144.1	Mm^3
Active storage (above 55.0)	130.2	Mm^3
Reservoir Area (at FSL)	8.77	km^2
Reservoir Area (at max. Flood)	10.5	km^2

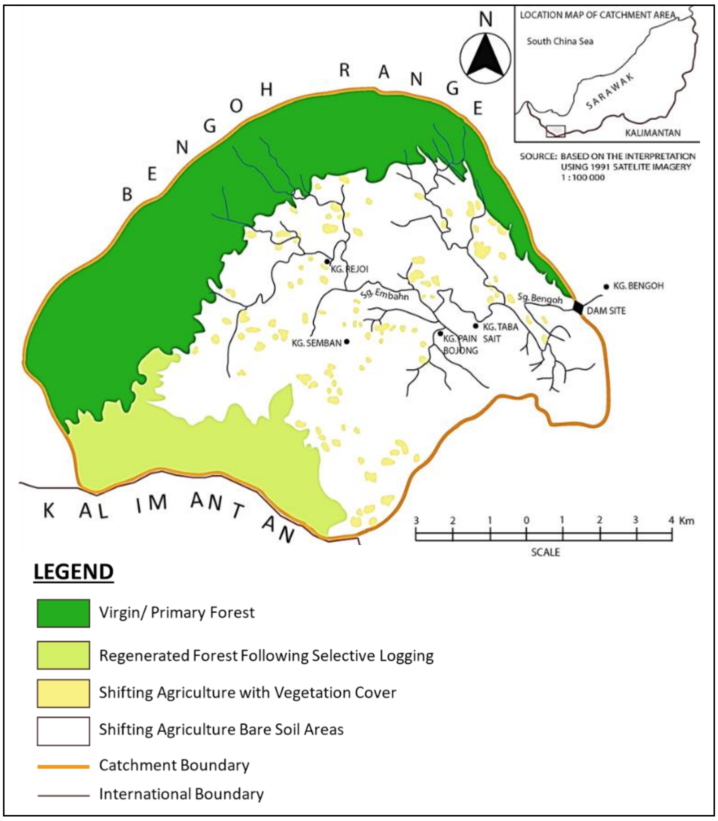

Fig. 1 - Locality and land use of Bengoh Catchment (1.2418° N, 110.2417° E)

$$CL \pm FL = MCL \tag{1}$$

In Eq. (2), pollutant degradation coefficient, *k* is determined based on the fraction of soluble pollutant remaining, where S is the actual water quality concentration and S_0 is the estimated water quality concentration, which the estimation is based on the pollutant loading rates [27], [28].

$$\frac{S}{S_0} = \frac{1}{(1 + k\theta)} \tag{2}$$

where, S/S_0 = Fraction of soluble pollutant remaining, k = Reaction rate coefficient, d^{-1}, θ = Hydraulic detention time, d Q = Flowrate, m^3/d.

The degradation rates of the BOD, N and P are affected by the reservoir and surrounding temperature. Therefore, it is essential to consider the temperature coefficient, as shown in Eq. (3), to identify the pollutant degradation coefficients [29].

$$\frac{k_T}{k_{20}} = \varnothing^{(T-20)} \tag{3}$$

where, k_T = Pollutant degradation coefficient at T℃, d^{-1}, k_{20} = Pollutant degradation coefficient at 20℃, d^{-1}, $\varnothing$ = Temperature-activity coefficient, T = Temperature, ℃.

The maximum allowable pollutant carrying capacity of Bengoh Reservoir can be determined by quantitative computational methods as shown in Eq. (4) and Eq. (5). The pollutant loading characteristics can be assumed to be steady-state loading in a completely mixed reservoir. The upper bound first estimate of the steady-state response to the pollutant loading into the reservoir would be expressed as followed [26]:

$$\text{Maximum Concentration Level (mg/L)} = \frac{W}{Q} \tag{4}$$

where, W = Estimated steady-state pollutant loading into reservoir, kg/yr, Q = Flowrate, m^3/d.

It is noteworthy that the amount of pollutant loading while meeting the maximum concentration level (MCL) would vary substantially from season-to-season, or even day-to-day, as a function of rainfall amount, catchment runoff rate, reservoir volume/detention time, time related types-and-scales of land-based activities and so on. For reservoir with equilibrium of multi-year average inflowing water and outflowing water, it is desirable to adopt the uniform mixture model to calculate the pollutant carrying capacity. Based on the material balance equation, the pollutant carrying capacity of a river-connected reservoir can be expressed as [30]:

$$W_L = (C_s - C_0)V + kC_sV + C_sq_{out} \tag{5}$$

where, W_L = Pollutant carrying capacity of reservoir, kg/yr, C_s = Water quality target concentration (NQWSM Class I), mg/L, C_o = Actual reservoir water quality concentration, mg/L, V = Average storage capacity of reservoir, m^3, q_{out} = Outflow rate of reservoir, m^3/yr, k = Pollutant degradation coefficient, d^{-1}.

2.3 Navigational Carrying Capacity

To determine the navigational or recreational carrying capacity of a reservoir, "Watercraft Census" were used to find out about the peak level of recreational use, types of use in demand, and mix of public and private access [31].

The census includes the observations at various times during wet and dry seasons. Observers counted the number of boats on the reservoir, type of each boat (transportation – people and tourists, fishing, high-speed, personal, commercial, non-commercial, etc.). The boat's approximate speed-stationary, no wake, or wake-producing speed were also recorded. In this study, a census that captures activity at several points in time shall provide a reasonably accurate picture of actual us age, and thus the navigational carrying capacity of Bengoh Reservoir. To calculate the navigational carrying capacity of the reservoir, it is required to integrate reservoir uses and goals with respect to reservoir characteristics.

Table 2 shows some of the useful reference figure related to the optimum boating density suggested by a group of researchers [32]-[36]. The estimated total reservoir surface area is approximately 8.77 km^2 (about 880 ha). In this case, with respect to Bengoh Reservoir surface area usage distribution, it would be rather conservative to allocate 10% (88 ha) as wake zone, while the remaining 90% (792 ha) of the gross reservoir surface area can be utilized for navigational purposes.

3. Results and Discussion

3.1 Current Loading Rates of BOD, TN and TP

In this research, the Class I designations of the National Water Quality Standards of Malaysia (NWQSM) was adopted as the Waste Assimilative Capacity (WAC) benchmark or target. To estimate the pollutant losses in the surface runoffs, the catchment was categorized into six categories: settlements (population equivalent), reservoir (water body), primary forest, regenerated forest, shifting agriculture and pepper/rubber/sundry cultivation (Table 3). The integrated pollutant losses of the individual categories in the surface runoffs (kg/ha.yr) of the BOD, TN and TP losses in Bengoh Catchment amount to approximately 0.308 ton/day, 0.119 ton/day and 0.114 ton/day, respectively while the levels of BOD, TN and TP fall well within the Class I Standards of NWQSM (Table 4).

Table 2 - Suggested optimum boating density

References	Boating Uses	Suggested Density *(Acres per Boat)*
[32]	All uses combined – Cass Lake	5 - 9
	All uses combined – Orchard Lake	4 - 9
	All uses combined – Union Lake	6 - 11
[33]	Water-skiing & all other uses	40
	Water-skiing only	15 - 20
[34]	Water-skiing & motorboat cruising	20
	Fishing	10
	Canoeing, kayaking, sailing	8
	All uses combined	10
[35]	All boating activities	25
[36]	All motorized uses	30

Table 3 - Estimation BOD, TN and TP losses in surface runoff

Population/ Land Use	Area (ha)	Estimated Pollutant Losses in Surface Runoff (kg/ha.yr)			References
		BOD	TN	TP	
Settlements	1000 PE	14.6	0.755	0.715	[37], [38]
Reservoir	877	2 - 3	3.50	0.15	[39]
Primary forest	2,794	2 - 3	3.50	0.15	[40], [39]
Regenerated forest	1,778	2 - 3	3.50	0.15	
Shifting agriculture	7,620	10	2.93	3.60	[41], [42], [39]
Pepper/ Rubber/ Sundry	508	10	2.26	24.51	[43], [39]

Table 4 - Estimated current BOD, TN and TP loading rates

Population/ Land Use	Current Pollutant Loading Rates (kg/yr)		
	BOD	TN	TP
Settlements	14,600.00	755.00	715.00
Reservoir	2,631.00	3,069.50	131.55
Primary forest	8,382.00	9,779.00	419.10
Regenerated forest	5,334.00	6,223.00	266.70
Shifting agriculture	76,200.00	22,326.60	27,432.00
Pepper/ Rubber/ Sundry	5,080.00	1,148.08	12,451.08
Total (kg/yr)	112,227.00	43,301.18	41,415.43
Total (tons/day)	0.308	0.119	0.114

3.2 Reservoir Pollutant Degradation Coefficient and Carrying Capacities

Based on Eq. (1) to Eq. (3), the pollutant degradation coefficients (day^{-1}) and maximum allowable pollutant loading rates (tons/day) of Bengoh Reservoir were computed and determined as shown in Table 5. It is shown that the degradation coefficients of BOD, TN and TP of the reservoir are 0.0025 d^{-1}, 0.0028 d^{-1} and 0.0132 d^{-1}, respectively. Once the functional hydrological information of the catchment, the hydraulic and operational details of the dam, and the targeted water quality parameters of the river-connected Bengoh Reservoir were known, the maximum allowable loading rates (tons/day) of the specific pollutants can be determined. As shown in Table 5, it is shown that the

Maximum Allowable Loading Rates of BOD can be as high as 92.24 tons/day as compared to the current loading rate of 0.308 ton/day; maximum TN loading at 116.63 tons/day versus current 0.119 ton/day, and maximum TP loading at 125.54 tons/day versus current 0.114 ton/day. As indicated, the Bengoh Catchment and thus the Bengoh Reservoir are in a state of almost pristine environment, and currently with negligibly low pollutant loading rates.

Table 5 - Degradation coefficient and maximum allowable loading rates of BOD, TN and TP

Pollutant	BOD	TN	TP
Degradation Coefficient, *k* at 25°C (day^{-1})	0.0025	0.0028	0.0132
Current Pollutant Loading Rates (tons/day)	0.308	0.119	0.114
Maximum Allowable Pollutant Loading (tons/day)	92.240	116.630	125.540
Allowable Additional Loading Rates to comply with Class I NWQSM (tons/day)	91.930	116.510	125.430

3.3 Excess Pollutant Loading Rates

To quantitively determine the maximum allowable amount of caged Tilapia culture in Bengoh Reservoir, the mass balance of organics and nutrients for Tilapia fish must be readily available. Based on the data gathered during the joint study conducted by Universiti Malaysia Sarawak (UNIMAS) and Universiti Teknologi Malaysia (UTM) in 2017, Mass Balance of Organics and Nutrients of a Salmon Cage Farm Supplied with High Energy Feed [44], and field survey data on Batang Ai Tilapia cage culture conducted in June 2018, a “Modified Mass Balance of Organics and Nutrients for Tilapia” (Fig. 2) was developed for the estimation of additional amount of fish farming in Bengoh Reservoir.

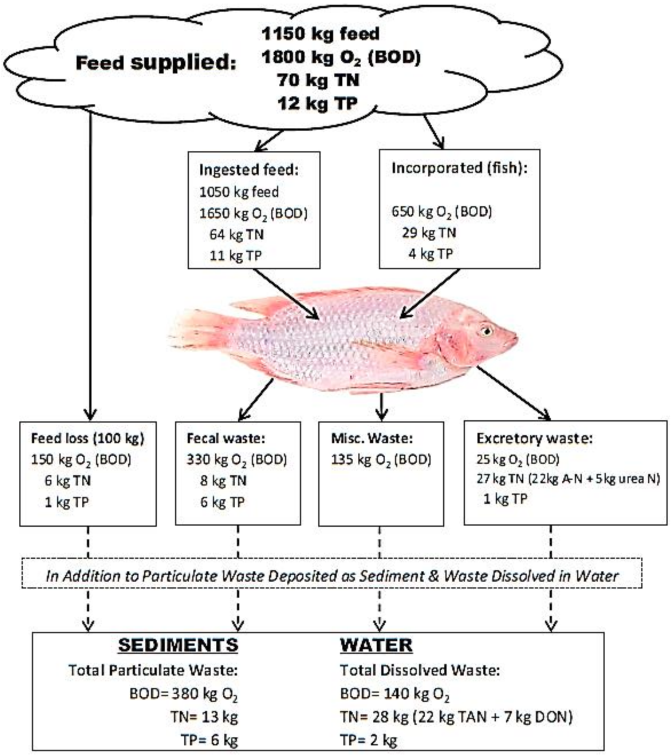

Fig. 2 - Modified mass balance of organics and nutrients of tilapia cage culture

The key information adopted for the development of the Modified Mass Balance of Organics and Nutrients for Tilapia (Fig. 2) are outlined in the following paragraphs. The data gathered from Batang Ai cage fishing farm showed that for every 1 kg of fish produced, there would be about 20kg of waste generated from the fish feed and faeces [45]. Study outcomes also showed that the Feed Consumption Ratio (FCR) = 1.15 with an estimated Feed Loss = 9%, Feed Consumption: Protein = 38%, Fats = 34%, Carbohydrate = 12%, 11g P/kg Energy, Energy = 24MJ/kg [9], [44]. Of a total 70kg of total nitrogen (TN), 41% would be incorporated in the fish, 40% dissolved in water and 18-19% being deposited in the sediment [32]. From a total amount of 12kg total phosphorous (TP), 33% would be retained by the fish, 16% dissolved in water and 50% solids settled/deposited as sediment. Approximately 16-25% of TP would dissolve in water, while 50% or more would be deposited in the sediment.

In this study, it was found that the allowable additional loading rates of BOD, TN and TP would be 91.93 tons/day, 116.51 tons/day and 125.43 tons/day, respectively. Thus, should the Tilapia fishing farm be introduced to Bengoh Reservoir while maintaining Class I Standards of NWQSM, it was estimated that the maximum allowable number of cages would be approximately 218 cages, whereby each cage is expected to house approximately 225 fishes.

Table 6 - Allowable additional loading rates and allowable number of cages

Aspects	BOD	TN	TP
Allowable Additional Loading Rates (tons/day)	91.93	116.51	125.43
Feed per pollutant factor (ton feed per ton pollutant/day)	1.565	0.06	0.010
Feed consumption in 150 days (ton/150days)	58.74	1,913.14	12,060.58
Average daily feed consumption (ton/day)	0.392	12.75	80.40
Daily feed consumption of a fish (g/fish.day)	8.00	8.00	8.00
Estimated Allowable Number of fish	49,000	1,593,750	10,050,000
Allowable Number of Cages (225 Fish/ Cages)		218	

Note: Estimations based on field survey data gathered in Jan 2020:
Average Daily Feed Consumption = 8.00 kg/1000 Fish
Average Weight (Biomass) per Fish = 400g = 0.40 kg
Average Number of Days to Produce 400g/fish = 150 days

3.4 Navigational Carrying Capacity

To determine the navigational carrying capacity, one of the universal most widely used methods is to divide the usable surface by the optimum boating density. In this study, the total reservoir surface area was estimated to be about 880 hectares having 792 hectares (90% of total reservoir surface area) usable surface area. Table 7 below illustrates the estimation of navigational capacity of Bengoh Reservoir. It is estimated to be approximately 130 boats. However, the navigational carrying capacity on usable surface area of the reservoir may require adjustments in view of the presence of multiple boat sizes, uses, and irregular shoreline.

Table 7 - Estimated navigational carrying capacity

Aspects	Reservoir Navigational and Usage Characteristics	References
Reservoir-Use Mix	50% Idle Speed/Stationary 50% Fast-Moving uses	[31]
Optimum Boating Density	(0.5×10 acres/boat) + (0.5×20 acres/boat) = 15 acres/boat	[32, [33], [34], [35], [36]
Useable Reservoir Area	792 hectares ≈ 1,957 ac	-
Navigational Carrying Capacity	1,957 ac/15 ac per boat = 130 boats	-

4. Conclusions

From this study, the primary conclusions drawn are described in the following paragraphs. The estimated current loadings are 0.308 ton/day of BOD, 0.119 ton/day of TP and 0.114 ton/day of TN. To maintain the targeted Class I Standards of NWQSM, the Maximum Allowable Loading Rates of BOD, TN and TP are 92.24 tons/day, 116.63 tons/day and 125.54 tons/day, respectively. With respect to water-based cage aquaculture development whereby each case would house about 225 Tilapia, the maximum allowable number was estimated to be 218 cages. The navigational carrying capacity of Bengoh Reservoir was estimated to be approximately 130 boats prior to adjustments by comparing with the navigational carrying capacity for the actual level of use.

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