Circular economy approach for wastewater treatment farming in Bangpakong River basin

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Abstract. Bangpakong River is one of river basins that faced the pollution problem in Thailand. This river is located in the downstream of central plain of Thailand and flows into the sea at the gulf of Thailand. Water quality problems in the last decade of this river basin are appeared from the low water quality index with evidences such as dead of fish, black color of water, low Dissolved Oxygen (DO) concentrations, high organics and nutrients concentrations, high contaminated of coliform bacteria. All wastewater is controlled by the environmental law. Only wastewater from agriculture part is not yet properly managed. The objective of this study was to quantify the mass and material flows in agricultural farms such as pig, fish and prawn farms. Circular economy concept as reuse of wastewater in agricultural farms was approached in scenario. Surveys, questionnaires and water samplings were taken for farms. Information and mass flows within the farms were analyzed. This study found that the main source of pollution from these farms mostly resulted from the effluent of wastewater in term of Biological Oxygen Demand (BOD) and Total Nitrogen (TN) loads, were discharged into the environment. The hot spot areas were canals which flow to the river. Mass flows in pig farm revealed that BOD and TN loads to the environment were 90, and 120 tons/year. In which, calculated thresholds were 30 and 60 tons/year for BOD and TN. Similar results also found from aquaculture farms which contributes BOD and TN loads of 187 and 77 tons/year for fish farms and 156 and 84 tons for prawn farms. In this study, calculated reuse as circular economy approach about 50\% of farm wastewater to agricultural field could provide the key role of BOD and TN reduction to the environment, and meeting the threshold level.

Keyword: Circular economy; Farming; Material flow analysis; Waste reuse;

1. Introduction
In Thailand, agricultural activities such as pig, fish and prawn farming are growing every year. Pig production grew by over 10 Million pigs in year 2018 [1]. Pig farm is one of bigger polluter for the degradation of ground and surface water. High concentration of organics and nutrients in wastewater are presented in the BOD and COD concentrations of higher than 2,000 and 3,000 mg/L and, TN concentration of higher than 400 mg/L [2]. For aquaculture product, Thailand was one of the top 20 countries that had the aquaculture products of more than 2.3 Million tons/year [3]. Generally,
treatment plants of agricultural activities are based on pond system. The benefit of pond system is the simple structure, earthen pond, and easily operation and maintenance. However, it requires huge area in order to meet effluent standard. Reuse of wastewater from farms has been practiced worldwide as there are the resources for Nitrogen (N), Phosphorus (P) and Potassium (K). It was the concerns to use the wastewater as it contained other pollutants such as heavy metal and pathogens. Previous study reported that loading rates for effluent application were generally determined by N concentration and limited to 150 – 200 kg N ha⁻¹ [4]. Natural treatment system, constructed wetland, is becoming the technology used for agriculture and aquaculture wastewater treatment [5]. However, the treatment needs excessive land. Circular economy was referred to AgroCycle which aimed to reduce waste while also making best uses of the wastes producing by using economically viable processes and procedures to increase their value [6]. Circular economy means to reuse and recycling of materials which earlier considered as waste and later becomes a resource. Reuse and recycling could be the treatment option in farms. Irrigation of wastewater in both untreated and treated forms was practiced in many countries for crops and tree plantation as summarized in the previous study [7]. The objective of this study was to compare existing and reuse scenario of material flows from pig, fish and prawn farms in Bangpakong River with specific of 1 km-offset from the river in order to propose the circular economy concept or the reuse of waste instead of the investment for the extra treatment to meet the effluent standard.

2. Methodology

2.1. Study area
Bangpakong River is one of examples that faced the pollution problem in Thailand. This river is located downstream river located in the central pain of Thailand and flows into the sea at the gulf of Thailand. Regarding pig farms, there were 393 farms, which registered on Chachoengsao Provincial Livestock Office. All pig farms are distributed over 11 districts and it was found the high prevalence in Phanom Sarakham (139 farms), Sanam Chai Khet (81 farms), Tha Takiap (53 farms) districts, respectively. For aquatic farms (5,975 farms), governmental agencies reported that in Chachoengsao province consist of 1) medium and small size of fish farm, which cultivating freshwater and saltwater and 2) medium and small size of prawn farms. Most of aquatic farms in Chachoengsao were high prevalence in Bang Khla (1,576 farms), Ban Pho (1,036 farms), and Mueang Chachoengsao (959 farms) districts.

2.1.1. Questionnaire design and assessment. Survey and questionnaires focus on the activity of pig, fish and prawn farms, which related to the water use, pollution emission, environmental management and the consumptions of chemical substances. Two sets of questionnaires were designed included set I: pig farms and set II: aquatic farms (fish and prawn).

2.1.2. Boundary and farms selection. Study farms in Bangpakong River basin was selected by geographic information system (GIS) via the ArcMap application. Data of farm location was obtained from Chachoengsao Provincial Livestock Office, Department of Livestock Development, Ministry of Agriculture and Cooperatives, and Chachoengsao Provincial Fisheries Office, Department of Fisheries, Ministry of Agriculture and Cooperatives. Selected farms were set within the 1 km-offset from the river. This was based on the hypothesis of non-point sources distribution into the river.

2.2. Material flow analysis
Mass balance processes were generated from the observed data and review information. BOD and TN loads were focused for calculation of material flows resulted to the discharged loads to environment or river. Water samplings from farms were conducted in order to confirm the concentrations of BOD and
TN in pig, fish and prawn farm, especially at the catching period. BOD and TN loads were compared between present and the threshold scenarios.

Figure 1. Selection of study areas (a) pig farms (b) fish and prawn farms.
3. Results and discussion
This paper shows results from surveys, questionnaires, samplings, calculation in 2 parts: 1) details of farms and pollution sources, and 2) pollution loads.

3.1. Number of farms and pollution sources

3.1.1. Number of farms. In this study area, results from GIS tool could express number of farms in Figure 1. There are 62, 64 and 270 farms of pig, fish and prawn farms located in the boundary system of 1 km-offset from river. The questionnaires were conducted at these farms. Fish and prawn farming are the main agricultural activities.

Pollution sources. In Table 1, Pig farms (100.0%) were operated by the opened systems. 40.0% of survey farms had cultivation area <500 m² and 36.7% larger than 1,000 m². The average number of pigs in farms included 13 boars, 431 sows, 245 swine and 632 piglets. Both fish and prawn were cultivated in earthen ponds (100.0%). Average area of fish farm (37,983 m²) was larger than prawn farm (8,901 m²). Farmer in prawn farms used 130 kg of baby prawn/pond for start cultivation. Both aquatic farms had 1-2 ponds/farm for cultivation. Fish farms were cultured based on fresh water with various types of fishes such as tilapia (Oreochromis niloticus), Thai carp (Barbonymus gonionotus), seven-striped carp (Probarbus jullieni) and fish polyculture. Farmers in fish farms were cultured for 1 cycle/year, each cycle were in range 8-12 month. Normal case had productivity with average value for 14.2 tons/cycle, while abnormal case such as disease and weather were change the productivity decreased to 1.7 tons/cycle. Farmer in prawn farms cultured giant malaysian prawn (Macrobrachium dacqueti) and pacific white shrimp (Litopenaeus vannamei) with 3 cycle/year (3 month/cycle). The average value of productivity between normal and abnormal case were slightly different, approximately 0.5 tons/cycle. Both aquatic farms classified as household affairs, 100.0% and 97.2% for fish and prawn farms, respectively. Most of business duration of fish farms were in range 1-5 years (76.1%) and >10 years was found in prawn farms (61.3%).

Table 1. Information of the target farm management.

| Questions                  | Pig farms | Fish farms | Prawn farms |
|---------------------------|-----------|------------|-------------|
| Operation system          | Opened system 100.0% | Earthen pond 100.0% | Earthen pond 100.0% |
| Number of farms           | 62        | 64         | 270         |
| Farm area                 | <500 m² 40.0% | 37,983 m² (average) | 8,901 m² (average) |
| No. of animals (average)  | 13 Boars 431 Sows 245 Swine 632 Piglets | 147,261 fry/pond | 1.25 million baby prawn/pond |
| Cultivation (average)     | Boars: 3.5 years 1 pond 67.4% 1 pond 40.1% | 2 ponds 28.3% 2 ponds 49.3% | 9.8 month/cycle 3 month/cycle |
|                           | Sows: 2.6 years | 9.8 month/cycle | 3 month/cycle |
|                           | Swine: 5.2 months | 1 cycle/year | 3 cycle/year |
|                           | Piglets: 1.4 months |           |             |

Solid waste management in aquatic farms included: sludge/sediment from ponds and waste materials such as drug/vitamins bottles, syringes and feeding bags are shown in Table 2. In fish farm, 23.9% of fish farm were used sludge/sediment to made earthen dyke of ponds. Fish farms 19.6% were preparation of pond for new cultivation period. Farmer were dry ponds for 30 days (21.7%) and 7 days (19.6%). Suggested that, 76.1% of farm no sludge/sediments management due to most of fish farms classified as natural farming. Focused on prawn farms, 85.2% of farms had sludge and sediment
management, most of them were managed every 2 years (53.5%) and 3 years (30.3%). The 71.1% of prawn farms were preparation of pond for new cultivation period.

Table 2. Information of resource usage and environmental management.

| Questions                              | Pig farms                      | Fish farms                     | Prawn farms                    |
|----------------------------------------|--------------------------------|--------------------------------|--------------------------------|
| Water consumption                      | Ground water 48.8%             | Water supply 51.6%             | Water supply 94.4%             |
|                                        | Water supply 37.2%             | Irrigation canal 48.4%         | Ground water 2.8%              |
|                                        |                                |                                | Rain water 2.8%                |
| Amount of waste water                  | 10 L/d/pig                     | 3700 m³/1600m³/crop            | 2700 m³/1600m³/crop            |
| Wastewater management                  | Yes 51.2%                      | No 100.0%                      | No 100.0%                      |
|                                        | No 48.8%                       |                                |                                |
| Wastewater treatment systems           | Biogas 44.8%                   | -                              | -                              |
|                                        | Aeration pond 17.2%            |                                |                                |
|                                        | Stabilization pond 10.3%       |                                |                                |
| Wastewater monitoring                  | Yes 46.5%                      | No 100.0%                      | No 100.0%                      |
|                                        | No 53.5%                       |                                |                                |
| Discharge of wastewater                | Pond in farm 39.5%             | Public drainage                | Public drainage                |
|                                        | Public drainage 37.2%          | 100.0%                         | 100.0%                         |
|                                        | Surface water 14.0%            |                                |                                |
| Solid waste management                 | Pig manure                     | Sludge/sediment                | Sludge/sediment                |
|                                        | Fish feed 37.2%                | Earthen dyke 23.9%             | Yes 85.2%                      |
|                                        | Compost 23.3%                  | No 76.1%                       | No 9.9%                        |
|                                        | Sold 18.6%                     |                                |                                |
|                                        | Collection area 11.6%           |                                |                                |
|                                        | Biogas 9.3%                    |                                |                                |

3.2. Pollution loads

3.2.1. Pollution loads in farms. Treatment of wastewater from farms is mostly the pond system. From surveys, the treatment plants in many farms failed due to no maintenance such as the removes of sediment or sludge. Concentrations of BOD and TN from observed farms are expressed in Table 3. Results of BOD and TN concentrations in pig farms are higher than the threshold standard. Due to the small size of farm, farms do not have enough capacity to treat wastewater. Meanwhile, BOD and TN concentrations from fish and prawn farms are not much different to effluent standard. In practice, the treatment of fish and prawn farms by leaving water in pond for a month could help the self-purification of water.

Table 3. Amount of wastewater and concentrations of BOD and TN.

| Farm | Total wastewater (m³/d) | BOD effluent concentrations (mg/L) | BOD of threshold level (mg/L) | TN effluent concentrations (mg/L) | TN of threshold level (mg/L) |
|------|------------------------|------------------------------------|-------------------------------|-----------------------------------|-----------------------------|
| Pig  | 819                    | 300*                               | 100                           | 400*                              | 200                         |
| Fish | 15,116                 | 17**                               | 20                            | 11**                              | 4                           |
| Prawn| 32,954                 | 13**                               | 20                            | 7**                               | 4                           |

*After treatment
** After catching
3.2.2. Pollution loads to Bangpakong River and threshold scenario. Related to flows and concentrations of BOD and TN, loads are calculated and shown in Table 4. BOD loads from fish and prawn farms are much higher than load from pig farm. Even the concentration is not high the huge amount of water use in aquatic pond can contribute the enormous loads. However, TN loads from all farm types are higher than the threshold loads. This present condition shows “poor” practice of local farm which the environmental managements still do not meet the standard regulation. Water will later discharge to the river basin. In previous study, N loads from pig farm to Thachin River basin was 1100 t N/year and 920 t N/year from direct discharged and overflow from waste stabilization pond [8]. It is a crucial research to know how the farms would treat wastewater in order to meet the standard.

Table 4. Loading from study areas.

|                  | Load from present scenario | Load from threshold scenario |
|------------------|---------------------------|----------------------------|
|                  | Pig farm | Fish farm | Prawn farm | Pig farm | Fish farm | Prawn farm |
| BOD load (tons/year) | 90   | 187   | 156 | 30 | 220 | 240 |
| TN load (tons/year)    | 120   | 77   | 84 | 60 | 44 | 48 |

3.2.3. Pollution loads from circular economy approach. Based on results from present scenario and threshold scenario, pig farms contributed BOD and TN loads more than the threshold values. Two possibilities to reduce the BOD and TN loads are improving the treatment plants of pig farms and the reuse of wastewater from pig farms for agricultural field. In both improvements, it may need more areas or equipment. From calculation, if the farms can reuse about 50% of wastewater to agricultural field, the BOD and TN loads to the environment will be reduced to the loads of threshold level. From the results of fish and prawn farms study, the BOD and TN loads of present scenario were slightly different to the threshold. Therefore, the treatment at sources may be the better solution for these farms as the huge volume of wastewater. This solution is also suggested from governmental agency [9] to leave wastewater in the pond after catching for self-purification. In the final stage, removing of the sludge and drying of pond are proposed.

4. Conclusion
Pollution loads from livestock and aquatic culture are currently the main parts that made the deterioration of water quality in Bangpakong River. In small size of farms, the treatments are inadequate and resulting the effluent quality beyond the standard level. Expansion of treatment capacity would need large investment. Reuse of wastewater for agricultural field nearby is an option that could help reduce the pollution loads discharging from farms. This study found that reuse of 50% wastewater can achieve threshold level of pollution loads. To successfully manage the wastewater discharging to the river basin, the circular economy approach policy could be a promising mechanism.

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