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MODELING IMPACT OF ANIMAL FARMING ON WATER QUALITY OF SERIN RIVER

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DECLARATION

No portion of the work referred to this dissertation has been submitted in support of an application for another degree of qualification of this or any other university of institution of higher learning.

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List of Abbreviations

Ac	element cross-sectional area (m^2)
BOD	biochemical oxygen demand
BOD_5	5-day biochemical oxygen demand
Ca	Calsium
CBOD	Carbonaceous BOD
Cd	Cadmium
CO_2	Carbon dioxide
Cr	Chromium
Cu	Copper
DOA	Department of Agriculture
DO	dissolved oxygen
E.coli	*Escherichia coli*
GPS	Geographical Positioning System
Hg	Mercury
HNO_3	Nitric acid
H_2O	Water
INWQS	Interim National Water Quality Standard
JKR	Jabatan Kerja Raya
N	Nitrogen
NaOH	Sodium hydroxide
NH_3	Ammonia
NH_3-N	Ammonia-nitrogen
NH_4^+	Ammonium
NO_2^-	Nitrite
NO_3^-	Nitrate
NO_3^--N	Nitrate-nitrogen
NREB	Natural Resources Environment Board
O_2	Oxygen
Org-N	Organic-nitrogen
P	Phosphorus
Pb	Lead
PO_4^{3-}	Phosphate
QUAL2E	Enhanced Stream Water Quality Model
QUAL2K	Modernized version of QUAL2E
SRP	Reactive Phosphorus
TKN	Total Kjeldahl Nitrogen
TWDB	Texas Water Development Board
U.S. EPA	United States Environmental Protection Agency
VBA	Visual Basic for Applications
WHO	World Health Organization
Zn	Zinc

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Modeling Impact of Animal Farming on Water Quality of Serin River

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ABSTRACT

Serin River is polluted as a result of effluents disharged from pig farms. Wastewaters from animal farming with high contents of organic matter and nutrient had has destructive consequences on river system. Hence, the objectives of this study were to determine water quality of Serin River and to construct QUAL2K model in order to better understanding the water quality issues in Serin River. The calibrated and validated QUAL2K model using field data from January to March 2009 was used to predict the future water quality of Serin River. Results of analysis indicated that the tributary that received pig farm effluent has significantly higher mean concentration ammonia-nitrogen (NH_3-N) of 2.61 mg/L, organic-nitrogen (Org-N) of 0.96 mg/L and total Kjeldahl nitrogen (TKN) of 3.56 mg/L. This tributary also has the highest average value of copper (Cu) and lowest dissolved oxygen (DO) concentrations. Results of prediction indicated BOD_5 and NH_3-N concentrations of receiving river and rivers adjacent to or downstreams of it exceeded Class II based on INWQS if wastewaters discharged directly into the river without treatment. The recommended maximum permitted values of temperature, pH, BOD_5 and NH_3-N were ≤ 50°C, ≥ 5, ≤ 100 mg/L and ≤ 2 mg/L respectively. If the treated wastewaters were being discharged into river, BOD_5 and NH_3-N concentrations of receiving river and stations adjacent to or downstreams of it were classified into Class II. The suggested temperature, pH, BOD_5 and NH_3-N values were ≤ 35°C, ≥ 5, ≤ 100 mg/L and ≤ 5 mg/L respectively. It is recommended that further studies be conducted on assessment of water quality by using such models to ensure long-term sustainability of river.

Keywords: water quality, animal farming, pig farming, QUAL2K.

ABSTRAK

Sungai Serin telah dicemari efluen yang dialirkan daripada lading khinzir. Pelepasan efluen dari ladang penternakan dengan kandungan bahan organik dan nutrien yang tinggi merupakan impak besar terhadap sistem sungai. Maka, tujuan kajian ini ialah menentukan kualiti air Sungai Serin dan mengaplikasikan model QUAL2K untuk memahami kualiti air Sungai Serin secara lebih lanjut. QUAL2K model yang telah ditentukur dan disah menggunakan data kajian dari Januari hingga Mac 2009 digunakan untuk menilaikan kualiti air Sungai Serin pada masa yang akan datang. Keputusan kajian ini mendapati bahawa anak sungai yang menerima efluen daripada ladang khinzir mengandungi purata nilai nitrogen-ammonia (NH_3-N), 2.61 mg/L, nitrogen-organik (Org-N), 0.96 mg/L, dan jumlah nitrogen- Kjeldahl (TKN), 3.56 mg/L yang lebih tinggi secara signifikan di samping nilai oksigen terlarut (DO) yang terendah secara signifikan. Anak sungai tersebut juga mempunyai jumlah purata kuprum (Cu) yang tertinggi. Berdasarkan keputusan ramalan, jumlah permintaan oksigen biokimia (BOD_5) dan NH_3-N bagi sungai yang menerima efluen dan sungai bersebelahan atau terletak di hulu sungai melebihi Kelas II menuruti Piawai Kualiti Air Kebangsaan Interim Malaysia, jikalau air sisa itu dialirkan ke dalam sungai secara terus tanpa pengurusan. Nilai suhu, pH, BOD_5 dan NH_3-N yang dicadangkan ialah ≤ 50°C, ≥ 5, ≤ 100 mg/L dan ≤ 2 mg/L masing-masing. Jikalau air sisa yang telah diurus dialirkan ke dalam sungai, jumlah BOD_5 dan NH_3-N oleh bagi sungai yang menerima efluen dan sungai bersebelahan atau terletak di hulu sungai diklasifikasikan Kelas II. Bagi efluen yang telah diuruskan, nilai suhu, pH, BOD_5 dan NH_3-N yang dicadangkan ialah ≤ 35°C, ≥ 5, ≤ 100 mg/L dan ≤ 5 mg/L masing-masing. Adalah dicadangkan supaya kajian lanjutan dijalankan berkaitan dengan penilaian kualiti air dengan mengaplikasikan model matematik untuk memastikan kepelbagaian gunaan air sungai.

Kata kunci: kualiti air, ladang ternakan, ladang khinzir, QUAL2K.

1. INTRODUCTION

In Malaysia, one of the industries severely injurious to water quality is the pig industry (Kinson *et al.*, 2001). Animal farming is an important industry in Sarawak, especially pig farming (Ainon *et al.*, 2005). Based on the statistics of pig population reported by the Department of Agriculture Sarawak (DOA, 2002), 22% of the country's pig population was in Sarawak (Ling *et al.*, 2006). With the introduction of confinement facilities, presently livestock and poultry farms gaining in popularity pose a challenging environmental problem (Ainon *et al.*, 2005; Ritter and Shirmohammadi, 2001). Whenever the farms are being cleaned, the faeces of animal would normally be washed into nearby rivers/streams or waterways (Chadwick *et al.*, 2002). According to Ainon *et al.* (2005), it was estimated that 28% of river basins in Malaysia were polluted with sewage and animal farm wastewater. It reported a small river in Serian Sarawak, Rayang River, had been declared a "dead river" as a result of pollution by nearby animal farming. Thus, the water quality of rivers/streams had atrociously downgraded and long term pollution not only may awfully affect the aquatic ecosystem, but also the environment surrounding. Some factors that deteriorate water quality of rivers/streams include introduction of organic matter and nutrients, such as nitrogen (N) and phosphorus (P), depletion of dissolved oxygen (DO), and increase in temperature (Ritter and Shirmohammadi, 2001).

Because of the complex nature of nonpoint source pollution, the development of detection and abatement techniques, water quality modeling, a supporting tool for aquatic assessment is required. It is noteworthy the most complex and sophisticated model may not necessarily be the most useful model (Fan and Wang, 2008). In this study, a modernized version of the

Enhanced Stream Water Quality Model (QUAL2E), QUAL2K will be applied. QUAL2K is chosen due to its popularity and ease of application. Similar to QUAL2E, QUAL2K is a comprehensive and versatile stream water quality model that can simulates up to fifteen water quality constituents in any combination desired by the user (Brown and Barnwell, 1987). However, it is proved to display better agreement with field measurements than QUAL2E (Fan & Wang, 2008; Hassain, 2007; Park and Lee, 2002). Fan and Wang (2008) also suggested that QUAL2K is a very useful tool in analyzing, further understanding water quality problems and resolving water quality issues in a river. If it had been calibrated and verified cautiously with accurate input especially some of the most sensitive parameters, it can not only model the actual (present) scenario of the quality but can also predict future quality conditions (Gardner *et al.*, 2007).

Referring to Ling *et al.* (2006), some animal farms discharged the effluents into one of the tributary of Serin River. This has changed its water quality in terms of biochemical oxygen demand (BOD), ammonia nitrogen (NH_3-N), reactive phosphorus (SRP), *Escherichia coli* (*E. coli*) concentrations and DO when compared to other tributary which did not receive animal farm effluent. Therefore, in this study, the objectives are to determine water quality of Serin River with the aim of evaluating the impact of waste effluent from animal farming on water quality as well as to forecast water quality of Serin River in the future. Water quality parameters studied included temperature, pH, DO, BOD_5, NH_3-N, nitrate nitrogen (NO_3^--N), organic nitrogen (Org-N), total Kjeldahl nitrogen (TKN), as well as heavy metals such as Copper (Cu), Cadmium (Cd) and Chromium (Cr). To achieve the objective, the following steps were taken:

- A water quality modeling of Serin River was developed using QUAL2K as the framework.
- The Serin River QUAL2K model was calibrated to the average observed hydrological and field data of 4th January, 17th January, 19th February and 13th March 2009.
- The Serin River QUAL2K model was validated to the average observed hydrological and field data of 10th January and 6th February 2009.
- The calibrated and validated model was used to predict water quality of Serin River in the future.

2. LITERATURE REVIEW

2.1 Animal Farming in Sarawak

In Sarawak, animal farming is an important livestock industry. There are 154 commercial farms in Sarawak with an estimated standing animal population of approximately 460,000. The industry generates about RM50 million revenue a year. In order to protect against river pollution, the Natural Resources Environment Board (NREB), Control of Livestock Pollution Rules have enforced a rule such that animal farms with more than 100 animals must build more than one oxidation ponds of appropriate size and depth depending on the animal population (Ainon *et al.*, 2005; Ling *et al.*, 2007).

Kinson *et al.* (2001) reported that a mature pig produces three times the waste a person does. An average weight of 150 kg mature pig would excrete approximately 21.1 kg/animal/day of solid material and 15.9 litres/ animal/ day of liquids. This figure is also agreed by a study conducted in Taiwan which suggested that each pig produce an estimated of 20 litres/day of wastewater (Sheen *et al.*, 1994). In our tropical country, pigs are usually bathed twice daily (Ainon *et al.*, 2005). In other words, there are tonnes of wastewater produced by pigs per day in addition to the wastewater taken during routine cleaning and bathing of pigs. According to a study conducted in Serian, Sarawak, there were two pig farms being operated for 10 years with 8,000 pigs and 800 pigs respectively (Ainon *et al.*, 2005). Hence, an approximate amount of 176,000 litres of wastewater generated each day. If the installed oxidation ponds do not function properly due to the fact that unsuitable size and thus over-loaded, leakage and poor planning, the receiving rivers/streams/watercourses would seriously polluted (Kinson *et al.*, 2001).

In Sarawak, a few pig farms located along Serin River located at old Kuching-Serian Road. This river plays an vital role as drinking water sources (Ling *et al.*, 2008).Water quality analysis indicated that discharges of these farms have caused deleterious effect on water quality of receiving tributary and its downstream ranging from high BOD, NH_3-N, SRP and *E. coli* concentrations to decreased DO. Most of its water quality fell short of Class II category in accordance with the Interim National Water Quality Standard (INWQS) whilst DO and NH_3-N levels were not suitable for aquatic life (Ling *et al.*, 2006).

2.2 Waste Effluents from Animal Farming

2.2.1 Definition of Animal Wastes/Manures

According to Chadwick and Chen (2002), waste/manure is defined as animal excretory products, that is, faeces and urine that are deposited in buildings or on collection yards and then require handling. There are three types of waste/manure depend on their physical nature.

"Solid manure" is a heterogeneous mixture of dung, urine and bedding material. Poultry manures may be produced in the absence of bedding. Typically, solid manures have higher dry matter content than slurries and are stacked in heaps until there is a chance for spreading (Chadwick and Chen, 2002).

"Slurries" are relatively uniform mixes of dung and urine produced by cattle and pigs kept in buildings with slatted floors or scraped passages in the absence of bedding material. Slurries can be pumped to storage tanks before being spread by a number of different application techniques (Chadwick and Chen, 2002).

"Dirty water" is described as a product of cattle-farms and is a dilute effluent with low nutrient content. It comprises dairy parlour washings and yard runoff, however, it can also contain silage effluent and some animal excreta. It is produced in large quantities and generally gives rise to disposal problem (Chadwick and Chen, 2002).

2.2.2 Animal Wastes and the Environment

Animal wastes can affect surface water through several possible pathways, such as direct discharges to surface waters, transported over the surface of agricultural land, feedlots and barnyards to nearby lakes and streams, spills and other dry-weather discharges as well as leakages or overflows from poorly constructed manure storage and treatment systems (Burkholder et al., 2007; Copeland, 2008; Ritter and Shirmohammadi, 2001). According to Copeland (2008), the release of waste from animal feedlots to surface water, groundwater, soil, and air is associated with a wide range of human health and ecological impacts and contributes to the degradation of the nation's surface waters.

The primary pollutants associated with animal wastes are nutrients (particularly N and P), organic matter, solids, pathogens, and odorous/volatile compounds. Besides, animal waste contains salts and trace elements, and to a lesser extent, antibiotics, pesticides, and hormones (Copeland, 2008).

2.2.3 Chemistry of Animal Wastes

According to Ainon *et al.* (2005), raw manure is up to 100 times more toxic than raw municipal sewage. The organic material contained in manure, slurries, silage effluents, waste milk or vegetable washings enters a water course directly without proper treatments, can broken down by microorganisms in the water. The equation involved is (Ritter and Shirmohammadi, 2001):

$$\text{Organic matter} + \text{microorganisms} + \underset{\text{Oxygen}}{O_2} \rightarrow \underset{\text{Carbon Dioxide}}{CO_2} + \underset{\text{Water}}{H_2O} + \text{more organisms}$$

The organic matter is used as an energy source for synthesis of new cell material, and the microorganisms use the oxygen in the water to break down the organic matter. As a result, in severe cases of contamination, aquatic life can be killed through oxygen starvation rather than direct poisoning (Ritter and Shirmohammadi, 2001).

2.3 Water Quality Impacts

2.3.1 pH

pH is a measure of hydrogen ion activity in a water sample. It plays an important role in chemical and biological activities in natural waters attributed to it can affect the concentration or activity of other constituents present directly or indirectly. The maximally permitted range of pH for aquatic life especially fish depends upon many other factors for instances temperature, DO and various of anions and cations present (Kinson *et al.*, 2001). In general, pH values of less than 7 is caused by the end products of organic waste stabilization occurring in the rivers/streams such as carbon dioxide and organic acids, and thus an acidic condition created (Ainon *et al.*, 2005). Nevertheless, a pH range of 6.5-9.0 with no change greater than 0.5 units outside the natural seasonal maximum or minimum is protective of freshwater, aquatic life and is considered harmless to fish (Kinson *et al.*, 2001).

2.3.2 Temperature

The increase or decrease of water temperature affects chemical and biological rates which are temperature dependent (Drolc and Koncan, 1996). Usually, temperature is inversely correlated with DO level. This can be found in the work by Drolc and Koncan (1996) which suggested that the main reason for significant decrease in DO concentration occurs during low flow period which coincides with high temperature.

The temperature of water also depends on the weather condition (Ling *et al.*, 2006). As water temperature exceeds 30°C, a suppression of all benthic organisms can be expected. Generally, a change of about 5°C can significantly alter the balance and health of an aquatic environment. Sudden drops in temperature can be harmful, but usually an increase in temperature will cause more damage than a decrease (Nathanson, 1986).

2.3.3 DO

Discharge of organic, degradable wastewater into flowing water results in a decrease in concentration of DO. Two major causes for oxygen deficit: metabolism of pollutants by microorganisms (biodegradation) and chemical oxidation of reduced pollutants (Drolc and Koncan, 1996). In other words, bacteria will use up the DO very rapidly if there is too much organic material in the water (Nathanson, 1986). Besides, DO will decline when O_2 is consumed during respiration of plants, algae and phytoplankton in the water (Drolc and Koncan, 1996).

The concentration of DO is also affected by factors such as flow of the river, presence of sources of organic pollution, and assimilative capacity of the river. As aforementioned, changes in water temperature also have a significant effect on DO concentrations. Low DO indicates poor water quality and thus would have difficulty in sustaining balanced ecosystem. Usually, low DO concentrations are found to be near to the point of pollutant discharge (Farah *et al.*, 2008). This may caused high fish mortality, odours and aesthetically unpleasant condition (Kannel *et al.*, 2007; Syamsilidik and Santoso, 2001). On the other hand, the factors which are beneficial for DO concentration are atmospheric reaeration and production of DO due to photosynthesis (Drolc and Koncan, 1996). Generally, 5 mg/L of DO content is considered as the lower limit for a water body to be healthy and falls within an acceptable concentration for aquatic life (Syamsilidik and Santoso, 2001).

2.3.4 BOD

BOD can be used as an indirect measure of the total amount of biodegradable organics in the water. The more organic material there is in the water, the higher the consumption of O_2, therefore, the higher the value of BOD. Hence, the more polluted a river with organic matters, the higher the level of BOD (Nathanson, 1986).

A study conducted in Taiwan reported that BOD is the most important contaminant for analysis. It further stated that domestic sewage has been identified as the most significant source of BOD pollution whereas the wastewater from swine farms is the least significant source (Sheen *et al.*, 1994). Moreover, according to a report done by DOE, in 2006, 22 river basins in Malaysia were categorized being polluted by BOD. High BOD was contributed largely by untreated or partially treated sewage and discharges from agro-based and manufacturing industries. The estimated BOD loading contributed by pig farms was 213,215 kg/day, consisting 4.58% of total BOD load discharged throughout Malaysia (DOE, 2006).

Usually, standards for effluent discharge will vary depending upon the condition of receiving water. In a slow moving stream, a BOD_5 of 5 mg/L may be enough to produce deoxygenation, which results in anaerobic conditions. On the other hand, a fast flowing stream such as mountain stream may have the capacity to assimilate an effluent with a BOD of 50 mg/L without deteriorating its water quality in term of DO (Kinson *et al.*, 2001).

2.3.5 Nutrients

2.3.5.1 Nitrogen

Nitrogen is an essential nutrient to both plants and animals, being a vital component of amino acids, proteins and nucleic acids (Hatch *et al.*, 2002). A previous study indicated that river water became significantly polluted by nutrients, especially N while flowing through dairy farming areas (Woli *et al.*, 2004). Hence, it can be concluded that livestock wastewater contains high concentrations of inorganic and organic nitrogen compounds as well as other nutrients (Cho *et al.*, 2000; Ling *et al.*, 2006). Therefore, where intensive livestock farming does occur, pollution from excess inorganic forms of N that are 'reactive' is a serious problem (Hatch *et al.*, 2002). Organic matter contains Org-N converted to such various nitrogen products as ammonia (NH_3), ammonium ion (NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^-) during the nitrification and denitrification process. World Health Organization (WHO) recommends that drinking water should not contain more than 50 mg NO_3/L (Kinson *et al.*, 2001). Fish are sensitive to ammonia and nonionic ammonia concentration as low as 0.2 mg N/L may prove toxic to fish and other aquatic life particularly at high pH (Ritter and Shirmohammadi, 2001).

2.3.5.2 Phosphorus

P in nature exists mainly as phosphate (PO_4^{3-}) but in water may occur in several forms, including soluble SRP and total P (Kinson *et al.*, 2001). P can enter water from sewage or agricultural runoff containing fertilizers and animal wastes (Nathanson, 1986). PO_4^{3-} in wastes is primary sources of excess amounts of nutrients in water (Kinson *et al.*, 2001). N and P are constituents of animal manure with a considerable potential to pollute the environment by eutrophication of surface water. An increase in the nutrient status of the water lead to rapid growth of algae and other vegetation, depletion of DO, increased turbidity, and a degradation of water quality (Ritter & Shirmohammadi, 2001).

2.3.6 Heavy Metals

Heavy metals are among the most common environmental pollutants contributed by natural sources and mainly anthropogenic activities, whereby industrial and urban wastes are disposed into water bodies (Abbas *et al.*, 2008). Some heavy metals, for instances, Cu and Zn, are essential nutrients and minerals required for livestock growth and reproduction (Li *et al.*, 2005; Vries *et al.*, 2002). However, such elements are often present in animal feed in concentration far higher than necessary for animal health (Vries *et al.*, 2002). As a result, the dairy livestock may restrict undesired accumulation of these heavy metals in tissues by adaptation of absorption and excretion leading to an increase in the heavy metal contents of manure (Li *et al.*, 2005). When leached to surface water, the concentrations of metals and