Agriculture Drainage Affects River Water Quality

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ABSTRACT

The acidic level of the freshwater is a major concern to water treatment plant operators. Extremely acidic freshwater could affect the operation of the treatment plant in many ways. The cost to neutralisation the water would increase and treatment scheduling would be more complicated. This paper reports the influence of agricultural drainage on river water quality in Bekok river system in Johor, Malaysia. The river is the sole source of freshwater supply to two water treatment plants located at the downstream reach of the river. Three water quality parameters, i.e. pH, Iron and Ammonia-N, were used as an indication parameter. Water samples collected from 16 different river reaches along the 20-km river were analysed. A significant decrease in pH was found near the water intake point, where most of the drained areas are located. The study also found that in general, the quality of the river water was better during low flow condition (non-rainy days) compared to high flow (rainy days). Multiple regression analysis showed that pH was significantly related to Iron and Ammonia contents.

Keywords : *Agricultural drainage, water quality, river, watershed*

INTRODUCTION

Stream water contamination from non-point source pollution has been a current issue in river system management of agricultural country [10]. This is particularly true when part of the river reach has to flow through an agricultural area where intensive farming activities are located. Literature had shown that the use of various type of agricultural chemicals [3] and the modification of the riverbank lands through the construction of intensive drainage infrastructure contributed to the degradation of surface water quality in the adjacent streams. The acidity level in the stream as collectively indicated by the pH values would provide a general scenario of these phenomena.

The acidic level in a river system is of paramount important if the river is to be used as source of public water supply. For instance, according to the World Health Organization [14] and the Malaysian Water Association [7] water supply guidelines standard (Table 1), the highly acidic water of pH less than 3 would incur a tremendous treatment cost in terms of neutralizing agent (liming materials) before the water could publicly be used [4]. A further reduction in pH value would cause the operation of the treatment plant to be delayed because the raw water may become toxic and unsuitable for drinking purposes.

Under natural conditions, rivers convey surface and sub-surface water from the higher point to the lower part of the watershed and eventually reaches the sea. The river system would include the riverbanks or flood plain of the catchment area that is hydrological and hydraulically important. When an integrated water resources development is planned within the river basin, alterations to the physical aspect of the watershed characteristics are expected. For example, if a watershed is to be used as a source for raw water supply to a treatment plant, a dam has to be built to store the surface water. Similarly, if agricultural crop has to be grown inside the watershed area, drainage canals along the flood plain or waterlogged area have to be built to enable crop to be grown and to avoid flooding [5]. Agricultural drainage, for instance, would change the ecosystem or the physical and chemical behaviors of the soil to some extent. For example, the pre-matured or young alluvium soils like those found along the riverbanks are generally sensitive to the changes in their horizon development [11].

Table 1 : Recommended/Acceptable physical water quality criteria

Parameter	Raw Water Quality	Drinking Water Quality
Total coliform	5000 count/l	0
Turbidity	1000 NTU	5
Color	300 Hazen	15
pH	5.5-9.0	6.5-9.0
(Sources: Twort et al. 1985; MWA, 1994)		

Though the general environmental impact of land use changes on the overall river regime is clearly understood [12; 2] little is known on the effect of the changes in soil ecosystem on the quality of the receiving river, under the tropical Malaysian conditions. Understanding the impact of soil drainage on the stream water quality is important particularly if the river is to be used for domestic purposes. This is especially true where most of Malaysian River systems being used for domestic raw water supply flow through agricultural areas where soil drainage activities are taking place.

The purpose of this study was to investigate the impact of agricultural soil drainage taking place along the riverbanks on the receiving water quality. More specifically, this study looked into the effects of soil oxidation processes occurring during drainage canalization works on the acidity of the surface water. The study was accomplished through water quality survey at the certain reaches of the river.

The study of the effect of agricultural drainage on the receiving water quality was conducted based on the following hypotheses;

- The naturally acidic soil in the catchment was the main contributing factor to the high acidity of the Bekok River.
- The land development along the river system through the

construction of an intensive field drainage system for agricultural purposes has accelerated the acidification process of the soil.

MATERIALS AND METHODS

The Study Site

This study was carried out in Bekok River System in Johor, Malaysia (103° 00' 00" E, 2° 05' 00" N). The river is one of the major fresh water sources to the domestic water supply in Batu Pahat. The river basin covers more than 100km^2 with the major river flowing down all the way from the upstream to the downstream portion where intensive multiple crops (vegetables, banana and oil palm) farming is practiced along the flood plain. Water treatment plants are located at the downstream reach of the river. These treatment plants depend solely on the raw water supply from the Bekok River. Thus the river quality will directly impact the performance of these water treatment plants.

Figure 1 is the study site showing the watershed and the river system, the agricultural drainage and the location of the water treatment plants. **Figure 2(a)** is the topographic map of the study catchment showing the general landform of the watershed. A significant portion of the area belongs to low lying areas (area of less than 4m from mean sea level). The area along the riverbanks was generally flat with shallow water table and flood prone in nature. From the conservation point of views, these areas can be considered as part of buffer zone or flood plain of the river system.

Figure 2(b) shows the landuse pattern of the study catchment. Intensive farming activities are taking place in these areas because of easy and direct access to the water supply. A mixed agriculture (seasonal crops such as corn and vegetables and perennial crops such as palm oil and bananas) is being practised in almost all parts of the area. Because of the low-lying areas, open drainage canals of 1.2 meter deep at 400 meters interval were constructed up to field level to avoid crops from flooding. The soil types of these areas are considered as young river-alluvial and potentially acidic with substantial percentage belong to peat soil.

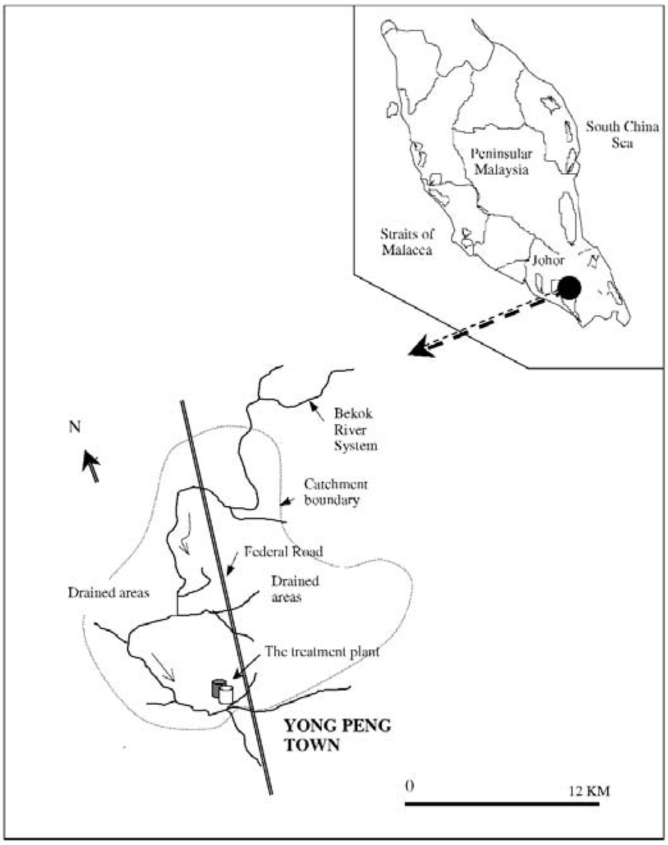

Figure 1 : The study location showing the river system and the water treatment plant

Water Sampling Points

A series of water quality sampling was conducted during relatively low flow (dry condition) and high flow (wet condition). Water samples were taken six times within seven months. The rainfall data prior to the survey was used to indicate relatively dry or wet days. In addition, antecedent rainfall values usually indicate the soil moisture status, thus the leaching potential of the groundwater runoff.

The selection of the sampling stations was according to the distant from the water treatment plants, along the main river as well as at the discharge points of the drainage canals. Sixteen sampling stations of about 0.5-0.75km apart were identified **(Figure 2 (c))**. Fifteen water quality parameters were measured and analyzed. However only three of them i.e. pH, NH_3-N and ferrous are detailed in this paper. pH was also measured in one of the drainage block (so called suspected point source area) to determine the acid level of that particular drained field area. As shown in **Figure 2(d)**, the chosen drainage block was provided with proper drainage facilities, up to the field level.

RESULTS AND DISCUSSION

Soil and Water Acidification Processes

Soil acidification process can possibly occur through three different mechanisms. The first is through soil weathering process [12], the second, through the process of the oxidation of pyrite substances in soil, and third through the accumulation residual of agricultural fertilizers [6]. While the soil weathering is a natural process and is beyond human control, the other two mechanisms are simply man-made.

Soil weathering is a natural soil formation process. The interaction between mineral (mica) element contained in the soil particles and the H^+ of the rain water could cause the soil to be more acidic. The mechanism is difficult to control unless a non-acidic rain is warranted. The polluted rain water caused by industrial urban activities are generally the main contributing factors for acidic rain.

The second mechanism is closely related to man-made activities. The oxidation of FeS_2 in the soil was due to the decomposition of pyrite material or sulfate of the soil. The oxidation process would cause a serious soil acidification particularly when the pyrite exposed to oxygen (air). Eventually, such process would produce ferric ion and ferric hydroxide and the soil became more and more acidic [9]. In relation to this, the construction of agricultural drainage system in low-lying areas of the river basin would lower the water table of these areas.

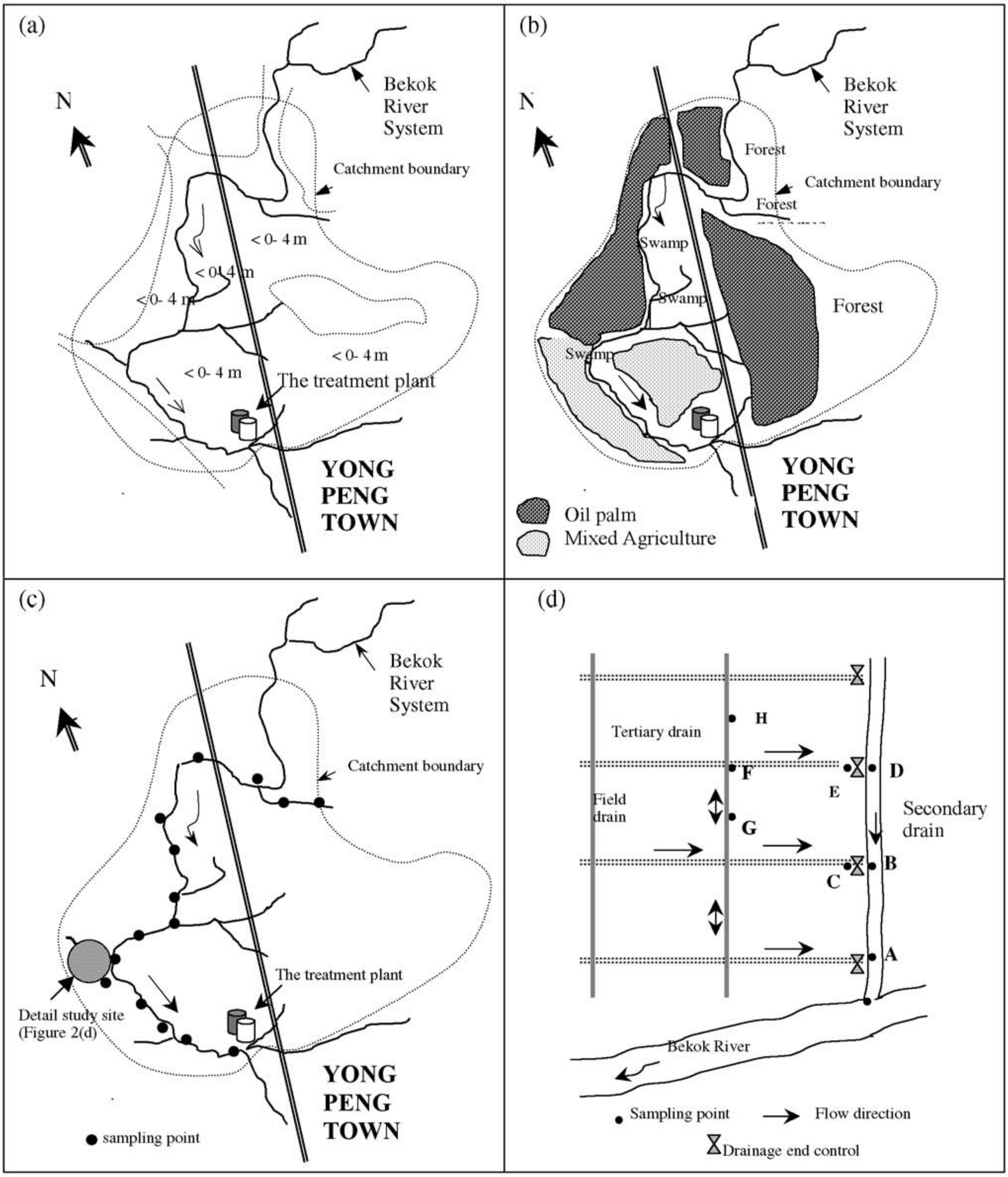

Figure 2 : (a) Topographic feature (b) Agricultural land-use (c) Water quality sampling points (d) Drainage system at block level

Consequently, more soil surface of the basin would be exposed to the air and this will accelerate the soil oxidation process. As illustrated in **Figure 3**, with the help of rainfall, the oxidized pyrite element will infiltrate and accumulate into the soil profile (particularly at horizon A of the soil), before it being leached to the river mouth through the subsurface flow processes.

The Soil Acidity

Many tropical soils especially those located along the river belong to potentially acidic soils. These soils are considered as young soils where weathering and formation process are still occurring. To verify the acidity level, the soil *pH* was determined. The result of the test is given in Table 2. The average *pH* is below 4.0 which can be categorized as acidic soil.

WATER QUALITY OF THE BEKOK RIVER

pH

The *pH* of surface water could indicate the general pattern of the acid level of the river. In a more scientific form *pH* represents

Table 2. The soil pH in the Bekok Catchment

Sampling Point	Soil depth (cm)	pH 1	2	3	Average
A	0-15	3.58	3.60	3.60	3.59
	15-30	3.82	3.92	3.84	3.86
	30-45	3.45	3.50	3.47	3.47
B	0-15	3.75	3.57	3.53	3.62
	15-30	3.51	3.57	3.48	3.62
	30-45	2.92	2.90	2.90	2.91

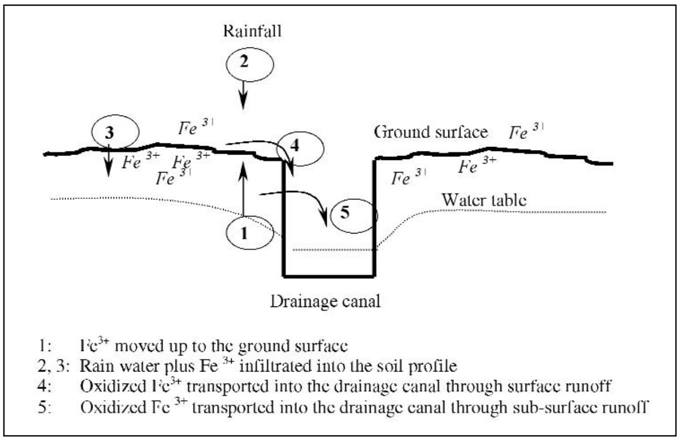

Figure 3. The mechanism of Fe^{3+} transport from the ground surface and soil profile to the drainage canal

the hydrogen ion (H^+) contents in water. **Figure 4(a)** shows the mean *pH* of the Bekok River during relatively dry and wet days.

During the wet condition with relatively high flow, the surface water was generally more acidic compared to that of during dry period. During the rainy days the soil is wet and may be saturated. Under such soil conditions the leaching process is likely to happen more rapidly. Thus the transfer of the soluble ion through subsurface drainage from the soil profile into the drainage canals and subsequently into the river system is more obvious [4]. On the other hand, during dry days where the soil profile is relatively dry, the leaching process occurs at minimum rate.

The *pH* value of water can be significantly affected by its temperature. However, under the running water condition, a direct relationship between *pH* and surface water temperature is not obvious. The observed surface water temperature during the wet days was generally lower compared to that of dry period. The average measured stream water temperature was between 27-29°C and 29-31°C for wet and dry days respectively. This is to be expected because during wet days the river flow is higher. Thus the surface water temperature tended to decrease as the water became more aerated. Under such situation the tendency of the hydrogen ion to be neutralized is tended to be higher resulting in higher *pH* values.

NH_3-N and Fe^2+

Concentration of NH_3-N and ferrous (Fe^2+) of the Bekok River under different weather conditions are depicted in **Figures 4(b)** and (c). While the acid level in the surface water is collectively indicated by their *pH* values, the ammonia and ferrous levels would give some indication on the amount of the residual agricultural materials transported into the river. The *N* content, for instance, would indicate the amount of nitrogen fertilizer leakage into the surface water [13] while the Fe^2+ would represent other toxic elements in the soil profile. As for hydrogen ions, these toxic ions are potentially get leached into the river system along with subsurface runoff.

Comparatively, the observed *N* values are within an acceptable guidelines [7] for raw water supply of 0.5 mg/l or lower. However the *Fe* content of the surface water was found higher than that proposed in the guidelines. The recommended acceptable value for *Fe* for raw water supply is 1.0 mg/l or lower. To explain these *N* and *Fe* contents in the Bekok River, it can be proposed that the Bekok River is still free from *N* contamination but not *Fe*. The high level of *Fe* in the surface water is expected as a result of soil acidification process through soil drainage activities in the area.

Other water quality parameters

The present level of other water quality parameter of the river system under study are as follow; *BOD<1.0 mg/l, COD<50 mg/l, Phosphorous<0.5 mg/l, Manganese<0.2 mg/l, Suspended Solids<3.0 mg/l* and *Total Coliform <3.0 count/100 ml*. The results obtained suggest that the river under study is still free of heavy metal contamination. This is expected as the entire river basin is categorized as an agricultural watershed with fully vegetated.

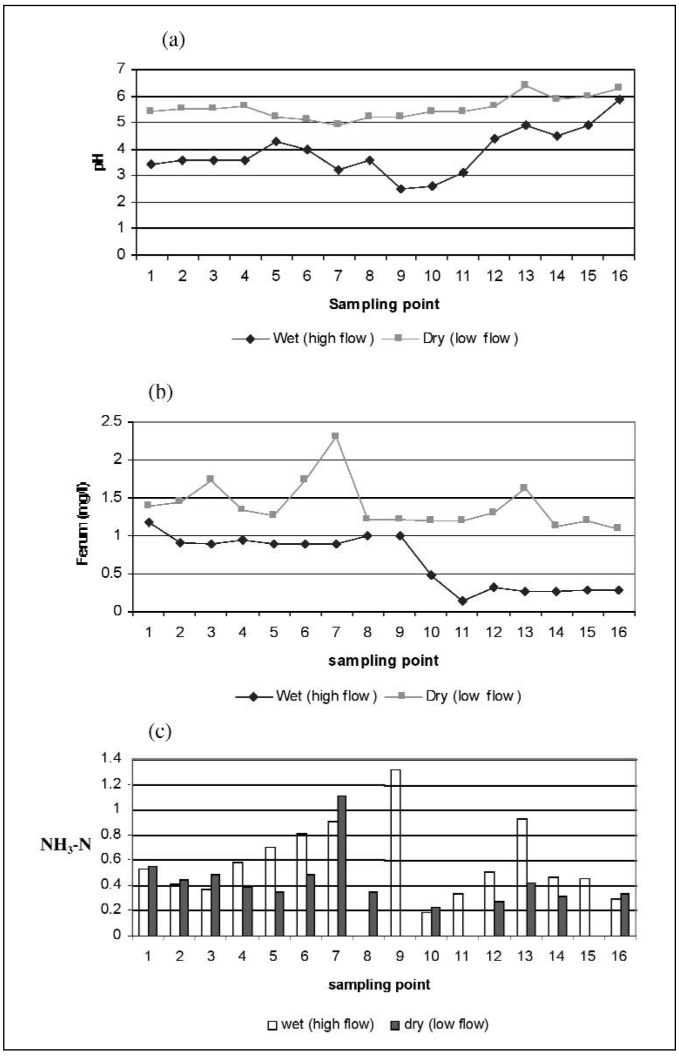

Figure 4 : Means of (a) ph (b) Fe (c) NH_3-N, along Bekok River

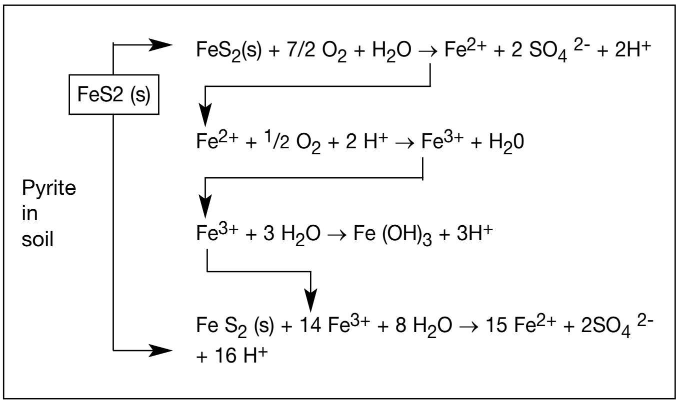

Figure 5. Acidification process of soil by oxidation of pyrite causing the release of free H^+ [1]

Water quality during low and high flow

Figure 4(a) shows the mean *pH* values of the Bekok River during low and high flows. Overall, it is observed that during the high flow, the *pH* value was lower than that during low flow. In other words, the river was more polluted during high flow. This finding is in accordance to the basic principle of non-point sources pollution problem in surface water. In a large agricultural catchment, pollution from nonpoint sources by phosphorus, agricultural organics and some heavy metals is detrimental to the river system. Unlike in urban rivers of point sources problem, the most severe impact for nonpoint sources problem occurred during or following a storm event [9]. Naturally, during the rainy days the soil is wet and may reach near saturated level. The accumulation of the free hydrogen ions in the drained agricultural areas can be explained as follow. The construction of drainage canals in an area of potentially acidic soil will expose more soil surface area. This would further expose the pyrite layer to the air and enhance oxidation process. Consequently, this will increase the amount of hydrogen ion in the soil layer. As illustrated in the chemical reaction in **Figure 5**, further oxidation of Fe^{3+} and FeS_2 through various stages of redox reaction in the soil [1] would end-up with a low soil *pH*. The ions present in the soil profile are then transported into the drainage canal through surface runoff and leaching process as rainwater percolates through the soil profile. In addition, under the gravity flow drainage, surface water in the drains carrying acidic element will eventually flow into the river system. The accumulated *H* ions from various parts of the catchment areas into the river system will eventually decrease the *pH* level of the surface water.

Nevertheless, it would depend on various factors such as sampling timing and techniques as well as the hydro-geographical characteristics of the catchment.

Water quality variation along the river reach

A further analysis was made to examine the variation in the water quality at different river reach. Using the same data, the water quality parameter was regressed against the distance from the intake point, and the results are tabulated in **Table 3**.

From the table, during the low flow only *pH* values was significantly correlated to the distant from the water intake. The coefficient of determination, r^2 of more than 48 percent indicated a moderately strong relationship between *pH* values and the distance from the intake point. A similar trend was found during the high flow but at a lower initial (intercept) value.

In both cases, the regressions also show that the pH values decreased directly with the distance, *L*. In other words, the river is more acidic toward the lower reaches of the river, close to the water treatment plant intake. This finding is expected as more drained areas be found in the lower part of the catchment. Shallow rooted crops such as vegetables are grown in the locality and these crops require an extensive and efficient drainage system. Unlike in the lower part, the upstream parts of the catchment remain undrained and covered by secondary forest and tree crops.

The correlation analysis between *Fe* and the distance from the water intake, *L*, also gave a good relationship during the high flow. The correlation coefficient of more than 71 percent indicated a strong relationship between *iron-Fe* content and the distance from the intake point. This finding provides a further support to the hypothesis that the hydrogen ion accumulated in the soil profile is more rapidly leached into the river during the high flow.

A multiple regression analysis between *pH* as the dependent variable against NH_3-N and *Fe* as independent shows a good relationship. The best fitted model was $pH = 4.669 + 0.959\ Fe - 1.851\ NH_3\text{-}N$. The p-values in the ANOVA table is less than 0.01 indicating that there is a statistically significant relation between variables at the 99% confidence level. The physical meaning to this analysis could be that *Fe* and NH_3-N contents in the surface water contributed significantly to the *pH* value. **Table 4** presents the statistical output from cross-correlation analysis between those three water quality parameters. It is clear that pH is highly dependent on its *Fe* and NH_3-N level, while NH_3-N and *Fe* are not significantly correlated.

Water quality in the suspected point source area

To investigate further the effect of agricultural drainage on the receiving surface water, a more detail field investigation was carried out in one of the drained areas. This area was chosen as the authors suspected that it was the pollution point source of the Bekok River. As shown in **Figure 2(d)**, eight sampling points within the area representing different level of drained water were selected. Table 5 summarized the results of the observation.

The results show that the *pH* level of the surface water increase, as it gets closer to the river. In general, the acidity level of the surface water was in the following order; *pH* at field drain (*pH 3.3*) < at tertiary drain (*pH 3.5-3.7*) < at the secondary drain (*pH> 4.0*). For instance the pH values at points inside the field drain i.e. points G and H, were extremely acidic as compared to those at points near the drainage outlets of points C and F. This phenomenon could be explained using the principle of dilution or decaying factor of the dissolved chemicals in the running surface water system. It seems that the *pH* values is positively correlated with the distance from the pollution point source.

Field observations found that areas along 0.5 to 1.0 km from the riverbank were naturally flooded. Owing to the direct contact with the running water (river), these areas are considered the flood plain or riparian zones of the river system. The riparian or flood

Table 3 : Summary of the simple linear regression analysis

Flow	Parameter	Regression equation	r^2	P
Low flow				
	Fe	$Fe = 1.5713 - 0.0205\,L$	16.01	P >0.1 *
	NH_3-*N*	$NH_3\text{-}N = 0.5243 - 0.0113\,L$	10.01	P >0.1 *
High flow	*pH*	$pH = 3.0876 + 0.094\ 1\,L$	41.16	P <0.01 **
	Fe	$Fe = 1.0756 - 0.0486\,L$	71.51	P <0.01 **
	NH_3-*N*	$NH_3\text{-}N = 0.6417 - 0.0068\,L$	2.07	P >0.10 *

L = distance from the intake point in Km; ** significant , * not significant

Table 4 : Correlations analysis of the pH, Fe and NH_3-N

		pH	*Fe*	NH_3-*N*
pH	Pearson Correlation	1.000	**.391***	**-.439***
		.	.027	.012
	N	32	32	32
Fe	Pearson Correlation	**.391***	1.000	.097
		.027	.	.599
	N	32	32	32
NH_3-*N*	Pearson Correlation	**-.439***	.097	1.000
		.012	.599	.
	N	32	32	32

* Correlation is significant at $P \leq 0.05$

Table 5 : Observed pH values in one of the suspected point source area

Sampling point *	*pH*	Specific location
A	4.7	At the intersection point between secondary drain and main river
B	4.4	At the intersection point between secondary drain and tertiary drain
C	3.5	At the tertiary drainage outlet box
D	4.7	Same as point B
E	3.5	Same as point C
F	3.7	At the inner site of the tertiary drain
G	3.3	In the field drain
H	3.3	In the field drain

* Referring to **Figure 2(d)**

Note: – The secondary drain is one of the straightened natural Bekok River tributaries
– The drainage block is provided with an intensive drainage network and covered with mixed crop, mainly banana and Oil palm

plain of a river system is an important part of the physical and biological structure of a healthy river [10]; [13]. Therefore, conservation of these areas is necessary toward a healthier river. The physical structure of these areas is particularly important in agricultural areas where riparian zones can act as nutrient filters between fields and surface waters.

CONCLUSIONS AND RECOMMENDATION

In agricultural watersheds the surface waters generally receive a substantial amount of drainage water from the soil horizon. Field studies have been conducted to investigate the agricultural drainage-surface water interaction. The following conclusion and recommendation could be drawn. The acidity of the river under investigation was generally quite low. The *pH* values at certain reach of the river were somewhat affected by the soil drainage activities. The oxidation process associated with the drainage activities could have been taken place along the riverbank. The high *Fe* contents in the surface water could be taken as another evidence. Soluble ion in the soil profile resulted from the soil oxidation process could have been transported into the river system thus it caused the surface water to be more acidic. The NH_3-*N* content is relatively small.

This study was simply based on spot water quality samplings and was not according to a proper dynamic modeling design. Therefore, further research is needed to further verify the soil drainage-surface water quality relationship in the study basin. A long-term monitoring of stream water chemistry in relation to the land use change, particularly at the flood plain area of the catchment is essential. It would provide useful information towards an integrated river basin management in the long run. To be more specific, knowing the changes in soil chemistry of the flood plain area over time would be able to predict the long-term effects of soil chemical changes on important water quality parameters of the receiving water. Such research work is more urgent in catchment areas where their river systems are being utilized for freshwater supply to the domestic water treatment plant.

The findings of the study clearly show that the stream water quality had been affected by land drainage activities of the catchment. Several recommendations are made as part of stream water quality protection program.

- Establishing riprarian zone of the catchment: the riprarian zone is an important interface between the surroundings agricultural land and the stream ecosystem. The riprarian zone controls the interaction between the stream and the surroundings. Besides functioning as nutrient filters and buffer zones between surface waters and agricultural land these zones are important areas for floras and faunas.
- Establishing cropping zone: Crop zoning or right selection of crop to be grown at the stream terrestrials would be able to minimize the acidification processes of agricultural land. If only flood tolerant crop such as aquatic-type of crops are grown, no intensive drainage system is required. As a result, the water table drawdown and soil surface exposure could be minimized and eventually the release of the hydrogen ions in the soil profile can be reduced.
- Soil liming: liming the drained agricultural areas could be another immediate measure to reduce acidity level of the soil, thus the river. Though it would give immediate effect, it requires higher cost and it should be considered as an emergency correcting measure.

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