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Impact of catchment development on water quality in Bakong river basin

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Abstract

This study looks into the impacts of catchment development on water quality of Bakong River by focusing on field surveys and analytical study such as water quality analysis, aquatic resources surveys, and agricultural development. It is found that large scale land conversion renders the receiving stream waters constantly silted and polluted by the agrochemical residues making the water unfit for human consumption. The undisturbed peat swamp areas in the middle and lower stretches of the catchment are the sources of constant supply of dissolved organics and inorganics and there is no technically and economically viable measures that can control the influx of dissolved organic leachates. It is also concluded that there is an urgent need to integrate land and water use elements in Bakong River watershed development plan.

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Keywords: Water distribution network, Shuffled complex evolution, optimization, nodal demands.

1. Introduction

An effective management strategy for state and national river water requires a comprehensive database on the status of river water characteristics, on changes and trends of land use within the catchment, and an understanding on what these changes mean to the water users. Without such information, the management would merely be reactive in nature, i.e. attending to river water problems only after they become critical, with potential adverse manifestations on the channel profile, aquatic resources and public health.

The Bakong river in the Miri District, Sarawak, Malaysia has been identified as a major source of future water supply for the rapidly growing Miri township. Although the expected supply from the Bakong river is seen as sustainable in terms of quantity, the long term sustainability of its water quality is rather uncertain in view of present and future developments within the catchment. This paper presents the findings of a study, commissioned by the Malaysian Department of Environment (DOE), for the purpose of establishing 'baseline' information on the Bakong river basin, particularly regarding water quality, hydrology and the present and future land and water use trends in the catchment.

The Bakong catchment, *ca.* 1,600 km^2 in size, is a sub-catchment of Baram river in the northern region of Sarawak (Fig. 1). The Bakong River has its source in the Niah-Jelalong Permanent Forest Reserve on the southwest perimeter of the catchment. The river chainage is *ca.* 120 km and the width of the catchment in the middle section is *ca.* 32 km. An 80 million liters/day capacity water intake system is presently under construction at a location at the lower end of the Bakong catchment.

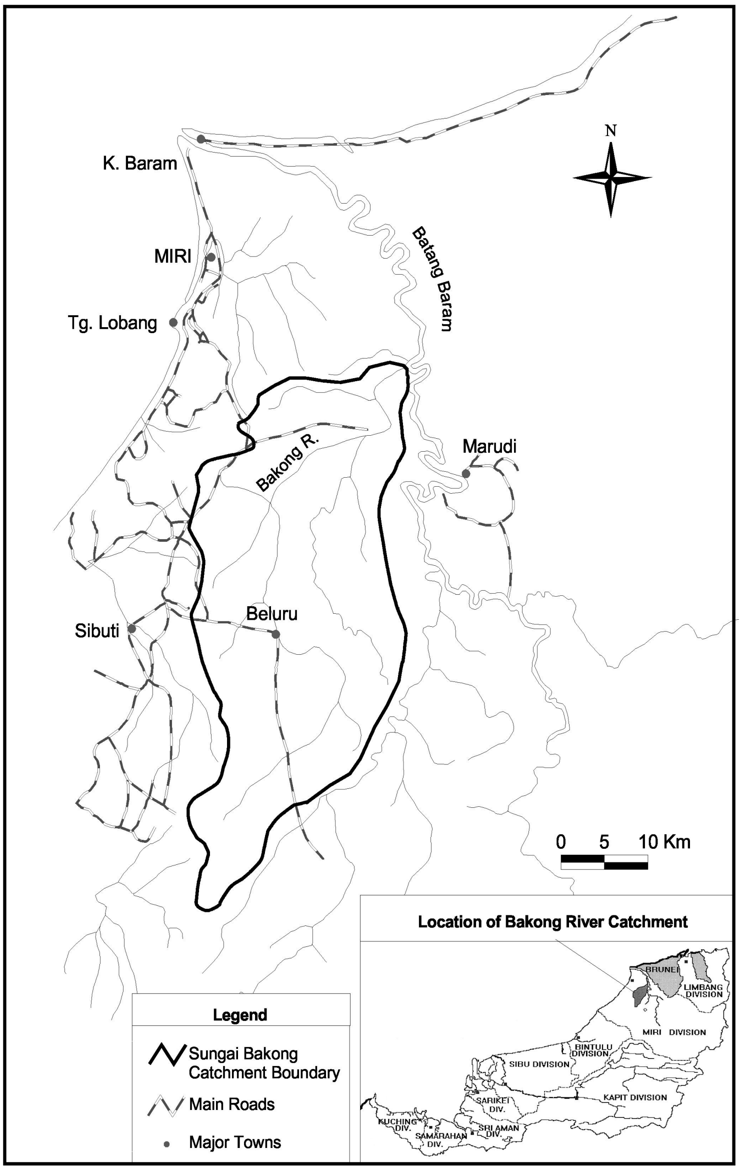

Fig. 1. Bakong river catchment and the context area in Sarawak

2. Methodology

Data on climatic conditions, vegetation cover, population, agriculture land use, topography and geological features of the Bakong catchment were obtained from the relevant government agencies in Sarawak, primarily the Drainage and Irrigation Department, Agriculture Department and the Public Works Department. Field verification of the land use features, hydrological and aquatic resource surveys, and samplings of soil and water were carried out between April and November 1997.

2.1 Hydrological surveys

Channel geometric characteristics of the Bakong River were profiled through measurement of the elevation and cross-section at 12 locations along the main Bakong River and its major tributaries (Fig. 2). To complement the available rainfall, evaporation, flow, and other surface meteorological data, a continuous data logger (pressure sensor probe) for gauging the water level was established at Pekan Bakong, located approximately in the mid-section of the river stretch.

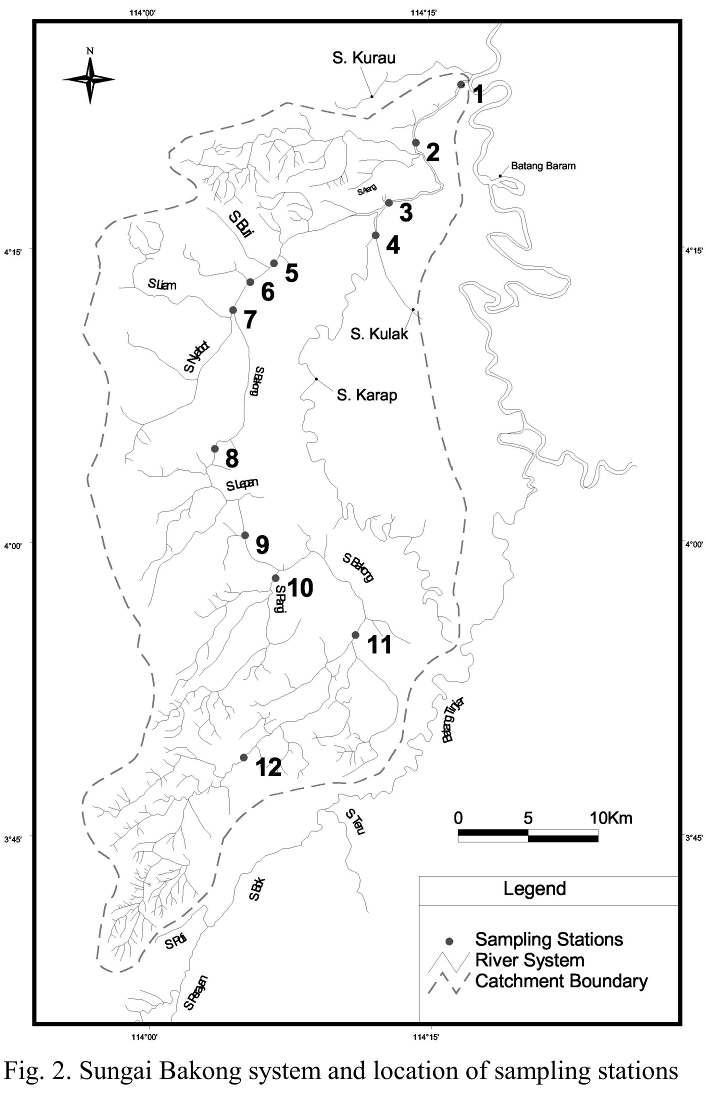

Fig. 2. Sungai Bakong system and location of sampling stations

2.2 Water and sediment sampling

Water and sediment samplings were carried out at the same 12 locations used for the hydrological survey. Water samplings were carried out from a boat at mid-depths at the third points. Composite samples (from the two spot samples) were made for each sampling location and samples were preserved according to the ISO5667/1 Guidance for Water Quality Sampling. A total of 4 to 10 samples were obtained at each sampling station during three sampling trips. In-situ water quality data samplings for non-conservative and non-preservable parameters (temperature, pH, dissolved oxygen, turbidity, conductivity and odour) were determined on-site using a Hydrolab® Surveyor MK-II. Within the tidal reaches, samplings were carried out during both half-way floodings and ebbings in order to capture variation in the water quality due to the tidal influence. A grab sampler was used for the sampling of the riverbed sediment.

2.3 Water and sediment analysis

Non-conservative water quality parameters such as biochemical oxygen demand (BOD), nutrients, and coliforms were analysed within 8 hours at the field laboratory. Standard Methods (APHA, 1996) were used in the quantitative analyses of metals, chemical oxygen demand (COD), BOD (3-day, 30^o), nutrients (nitrate, ammonia, and phosphate), hardness, total suspended solids, and sedimentary organics and pesticide residues. Total coliform and *E. coli* counts were determined using the Paqualab filtration method. Extraction of sedimentary residual pesticides was confined to the organochlorine component as this fraction is more resistant to degradation. Extraction method used for the pesticide residue was according to that described by Cochrane et al. (1994) and the organochlorines were analysed using a capillary ECD-GC (HP Model 5986). Crude humic acid contents of the sediment were determined by alkaline extraction followed by acid precipitation of the humic acids. Humic acids in water were extracted according to the method described by Thurman and Malcolm (1981) and reported as a total combination of pure humic and fulvic acids. For the present purpose, the results of water analyses are tabulated into four sets of data clusters: upstream (Stations 10, 11 and 12), upper middle stretch (Stations 7, 8 and 9), lower middle stretch (Stations 3, 4, 5 and 6) and downstream stations (Station 1 and 2) (Table 1).

2.4 Aquatic resource study

Fish samples were collected using gill nets of different mesh size. Cast nets were also used at shallow pools and tributaries of the river. Approximately 10 throws of the cast nets were made at each of the eight selected sampling locations. All individuals caught were fixed in 10% formalin and preserved in 70% ethanol. The fish were measured and preserved, and were identified following the descriptions by Mohsin and Ambak (1983), Inger and Chin (1990) and Kottelat *et al.* (1993). Fishermen and local inhabitants were interviewed, and surveys on fish landing at the Beluru Fish Market were also carried out. Samplings of plankton and chlorophyll-a were carried out at all 12 water sampling stations along the Bakong river and its tributaries.

3. Results and discussion

3.1 Water quality

The water quality data for the Bakong River, covering both wet and dry seasons, are presented in Table 1. The field observations and the results of water analysis clearly

Table 1
Results of water quality and sediment analyses for the Bakong River

Parameters	Lower Reaches (n=6)	Lower Middle Reaches (n= 10)	Upper Middle Reaches (n=6)	Upper Reaches (n= 4)
pH	4.3 ± 0.3	4.5 ± 0.6	5.5 ± 0.7	5.5 ± 0.8
Temp (^{o}C)	28.3 ± 0.8	27.7 ± 0.8	27.0 ± 0.3	26.1 ±0.2
Turbidity (NTU)	59.0 ± 22.2	69.7 ± 35.7	198.3 ± 203.3	205.6 ± 36.4
Conductivity (uS/cm)	59.5 ± 4.4	63.6 ± 6.2	59.0 ± 9.0	52.5 ± 10.2
Apparent Color (Pt-Co)	665 ± 263	970 ± 459	1397 ± 767	1404 ± 443
True Color (Pt-Co)	537 ± 101	426 ± 215	194 ± 110	144 ± 97
Redox (mV)	465 ± 3	577 ± 50	517 ± 20	520 ± 26
DO (mg/L)	0.34 ± 0.14	1.21 ±0.87	3.67 ± 2.60	4.79 ± 1.27
BOD_5 (mg/L)	3.40 ± 2.29	2.43 ± 1.55	2.45 ± 0.30	2.67 ± 0.60
COD (mg/L)	83.3 ± 29.8	82.7 ± 26.1	67.5 ± 14.4	46.7 ± 23.8
TSS (mg/L)	93.0 ± 152.0	30.6 ± 36.9	88.0 ± 87.4	113.5 ± 27.0
TDS (mg/L)	143.5 ± 16.3	153.6 ± 32.1	127.0 ± 6.9	79.0 ± 43.8
Hardness (mg/L Ca)	16.7 ± 2.1	18.7 ± 3.8	17.7 ± 3.1	19.1 ± 4.4
Oil & Grease (mg/L)	5.6 ± 2.8	4.6 ± 2.7	4.0 ± 1.4	3.6 ± 5.1
T. Coliform (cfu/100ml)	773 ± 61	812 ± 127	720 ± 140	820 ± 28
E.Coli (cfu/100 ml)	550 ±212	568 ± 170	427 ± 103	575 ± 21
Nutrients				
Nitrate-N (mg/L)	0.01 ±0.02	n.d.	0.02 ± 0.04	0.03 ± 0.02
Ammonia-N (mg/L)	1.13 ± 0.52	0.99 ± 0.40	0.55 ± 0.14	0.37 ± 0.46
Phosphate (mg/L)	0.35 ± 0.10	0.37 ± 0.13	0.34 ± 0.11	0.35 ± 0.15
Dissolved Metals. (mg/L)				
As	0.30 ± 0.09	0.28 ± 0.08	0.25 ± 0.17	0.04 ± 0.05
Cd	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.00	0.01 ± 0.01
Cu	0.03 ± 0.01	0.03 ± 0.01	0.02 ± 0.000	0.02 ± 0.00
Fe	1.52 ± 0.89	1.27 ± 0.28	0.55 ± 0.15	0.70 ± 0.35
Pb	0.28 ± 0.03	0.34 ± 0.03	0.41 ± 0.01	0.39 ±0.01
Mn	0.06 ± 0.01	0.08 ± 0.04	0.09 ± 0.09	0.08 ±0.04
Ni	0.07 ± 0.01	0.07 ± 0.01	0.06 ± 0.01	0.04 ± 0.01
Total organics in sediment (% dry w/w)	8.5±2.8	17.9±6.5	11.3±0.8	4.6±2.5
Crude humic acid in sediment (% dry w/w)	0.25±0.12	2.17±0.15	1.24±0.26	0.10±0.03
Humic and fulvic acids in water (mg/L)$^{(*)}$	n.a.	47.9	1.7	n.a.

Note: n.d. – not detected; n.a. – not analysed; (*) – results for single confirmatory analysis, corrected and based on pure humic and fulvic acids extracts. The large standard deviations in the data is due to the variation in the water quality within the segment of the river as well as the seasonal variation (the rainy and dry seasons).

show that the water quality of the Bakong is significantly affected by high levels of suspended colloids and peat materials. This is probably the result of combined input of runoffs from the predominantly swamp forest area and erosion from the disturbed headwater areas.

Based on the limited data gathered, the water quality indices computed using the 6-key parameter formula adopted by DOE showed that all the locations in middle and lower stretches of the Bakong river fall within the ‘very polluted’ category, primarily due to the natural abundance of peat leachates (dissolved organics as reflected by the high values of COD) and poor reaeration of water (low dissolved oxygen levels) due to the sluggish flow in this tidal zone. The water quality at the upstream station cluster fall into the ‘slightly polluted’ category, attributable primarily to the silted runoff from the disturbance in this part of the catchment. Input of other anthropogenic pollutants was insignificant except for the bacteria associated with sanitary waste discharges. The level of sedimentary organochlorine pesticides was found to be relatively low, reflecting their limited application in the subsistence farming activities of the villagers along the river corridors.

Analyses of humic acids in water samples obtained from Stations 5 and 9 revealed a phenomenon whereby the level of dissolved humic acids at the downstream station is significantly reduced by natural precipitation (visually verified and also reflected in the high total organics and crude humic acid contents of the sediment). This precipitation is induced probably by the relatively high discharge of iron and manganese from the decaying vegetation along the marshy Karap River, a major tributary in the lower Bakong. Humic substances are known to precipitate upon chelation by metals such as calcium, manganese and iron. Although this phenomenon may appear to be in favour of the Bakong water as a raw source of drinking water, further investigation is currently ongoing to verify and better understand the factors and variability of the conditions involved.

The management of river water quality in Malaysia is guided by the DOE Interim Water Quality Standards (INWQS). INWQS specifies the water quality criteria or limits of five classes of water sources in accordance to the highest attainable designated use or uses in each class. The present study revealed that the water quality at the proposed new intake on the Bakong river marginally satisfies the minimum acceptable standard of Class III water as defined by INWQS, i.e., suitable for water supply purposes only after extensive or advanced treatment.

3.2 Aquatic resources

A total of 10 families of fish represented by 15 genera and 22 species were caught from the main Bakong river and its tributaries. Analyses based on the number individual fish caught showed that approximately 62% were represented by the Anabantoidei. Although the fresh water habitat of Southeast Asia is dominated by Cyprinid fish (Zakaria, 1994), the fish composition in the Bakong river system were mainly dominated by the Anabantoids. The family Helastomatidae was also dominant in all habitats and made up 33% of the total number of fish caught. Some of the tributaries were important breeding and nursery grounds for commercially valuable fishes such as *Wallango* sp. (tapah), *Channa* sp. (snake head) and *Clarias* sp. (catfish).

The fish faunal composition in the Bakong river system is dominated by species that are relatively tolerant to low oxygen, highly acidic water and organic rich water. Most of the fish species have an accessory breathing organ that allows them to breath the ambient air and to live in oxygen poor water. This capability is demonstrated by the families Anabantidae, Belontiidae, Bagridae, Channidae, Helastomatidae, Notopteridae, Osphrenomidae and Siluridae. The family Channidae such as *Channa micropeltes, C. striata, C. melosoma* and *C. lutius* are especially adaptable to polluted and acidic water (Lee and Ng, 1994).

Results from the present study showed that the river contained a relatively low density of phytoplankton. This could be due to the dystrophic conditions where the water is rich in organic material, low oxygen concentration and poor light penetration. The zooplankton distribution in the study area is also poor, with only six genera recorded compared to, for example, 16 genera in Lake Kenyir (Chuah, 1993). Physical changes in the aquatic environment due to forest operations, including land conversion to agriculture, may exert a tremendous pressure on the population and diversity of aquatic organisms.

3.3 Agriculture development

An evaluation on agriculture capabilities of the study area revealed that over 50% of land within the Bakong catchment belong to Class 5, i.e., land areas with such severe limitations in their original state that agricultural use is not feasible. Lands belonging to this category, characterised by low soil fertility, high water table, flooding, deep accumulation of raw acid peat and low bulk density, are found largely in the lower and middle parts of the Bakong catchment.

Another class of equally unfavourable soils (in the context of agricultural capability) is found largely in the hilly headwater areas of the Bakong catchment. This Class represents about 10% of the total catchment area. Thus, the total area that can be utilised, with or without limitations, for agriculture development is only about 30% of the catchment area. Currently, the major activities in Bakong are domestic based agriculture with an increasing presence of plantation based agricultural development. Most of the development is for oil palm plantations. They are found mostly in the upper reaches of Nyabor, Pangi and the main stream of Bakong. To date, a total of approximately 46 000 hectares of land within the catchment of Bakong has been allocated for oil palm plantation.

3.4 Threats to water resource

Field surveys and analytical study indicated that there are four primary sources of pollutants presently affecting and potentially capable of further deteriorating the water quality of the Bakong River:

The silted surface runoff from land conversion activities, including the construction of major and minor access roads and tracks into the forested area to facilitate timber extraction, terracing works, and usage and maintenance of the dirt roads and tracks. A study conducted elsewhere in Malaysia (DID 1989) showed that forest conversion to oil palm plantation resulted in a 2.5-fold increase in the runoff to rainfall (Q/P) ratio, initial soil losses of up to 800% (though recovered after about two years), and significant increases in the levels of conductivity, calcium and magnesium in downstream water.

Operation and maintenance activities of the oil palm plantations which include manuring/ fertilising, pest control and processing of palm oil. Although the impact of these activities is still not quite clear, there is a long-term potential of increase in the nutrient and pesticide loadings in the downstream waterways. On nutrient loss for instance, a study by Foong (1993) indicated that N, P, K and Mg are continually leached even when the palms are in the matured state.

Peat swamp runoff and leachates. The study has established a significant level of humic and other dissolved organic compounds originating from the peat swamps and marshland in the middle and lower Bakong catchment. These naturally derived dissolved organics are potential precursors to hazardous chemicals, such as trihalomethanes (THMs) and other chlorinated organics, that may be formed during the normal water treatment procedures (Peter and Perry; 1980). The potential health risks associated with these disinfection by-products are well documented (Fielding and Jorth, 1986; Bull and Kopfler, 1991).

Biological contaminants associated with untreated sewage, particularly those from the longhouses and other settlements along the river. The occasionally observed elevations in the counts of *E. coli* and total coliform indicate potential water quality and epidemiological problems locally as well as at the proposed raw water intake point downstream.

4. Conclusions

Almost all the agriculture-capable land in the study area has already been or is being actively developed into oil palm plantation. It is concluded that such large scale land conversion renders the receiving stream waters constantly silted and polluted by the agrochemical residues making the water unfit for human consumption. As reflected in the results of water analyses, the mostly undisturbed swamp areas in the middle and lower stretches of the catchment are the sources of constant supply of dissolved organics and inorganics, such as humic substances, iron and manganese leaching out from the submerged and decomposing vegetation of the swamp forest.

Even though riverbank settlements and plantation activities are the major anthropogenic water pollution sources, the nature of the downstream biophysical environment suggests no technically and economically viable measures that can control the influx of dissolved organic leachates from the peat swamp forest. It is concluded that there is an urgent need to integrate land and water use elements in Bakong River watershed development plan.

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