Journal of Engineering Science and Technology
Vol. 14, No. 3 (2019) 1289 – 1300

ASSESSMENT OF PHOSPHORUS LOAD IN WATER RIVER USING SUBSTANCE FLOW ANALYSIS (SFA) METHODS

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Abstract

The excellent performance of Substance Flow Analysis (SFA) technique in river water quality assessment is widely acknowledged. Thus, this study is conducted to test the ability of SFA technique to be assimilated in the Malaysian context. The phosphorus flow along Kuala Selangor River sub-Basin (KSRsB) has been investigated for a period of one year throughout 2017. The results of the analysis showed that the highest phosphorus load was in the midstream part, which was 43% compared with the upstream and downstream parts, which were 31% and 26%, respectively. The findings revealed that phosphate-based fertilizers containing Nitrogen-Phosphorus-Potash (NPK) used in oil palm plantations, amounting to 4.5 kton P/yr in total, contributed the highest phosphorus load. As a conclusion, decision makers to strategize novel methods and plans in improving the river's water quality can use the results.

Keywords: Kuala Selangor, Phosphorus (P), River, Substance flow analysis (SFA),

1. Introduction

Phosphorus (P) is a unique element that has molecule-forming characteristic, which is used to store and produce energy in the forms of Adenosine Triphosphate (ATP) and Acid Detergent Fibre (ADF) [1] Phosphorus behaviour in water body has been studied in depth because its excessive presence may cause algae proliferation and eutrophication, which subsequently disturbs the human food chain [2]. The presence of phosphorus in water is divided into two forms, organic phosphorus like food wastes and human faecal matters and inorganic phosphorus like synthetic detergent, which have a potential of giving out different values of nutrient release in the water body [3]. The presence of high phosphorus concentration in water body may paralyse the human immune system and causes a chronic effect on the aquatic life [4]. Therefore, river phosphorus content, particularly in Malaysia, must be controlled to conform to the standard set by the Department of Environment of Malaysia, which is under 0.2 mg per litre [5].

In river water quality management, the nutrient with phosphorus flow has been widely studied and the ability of Substance Flow Analysis (SFA) technique to assist stakeholders in providing decision support has clearly been proven [6-8]. Studies by Jiang et al. [9] and Montangero and Belevi [10] managed to test the SFA technique and use it to display the readings and current trends of phosphorus balance in water body metabolism. The quasi-dynamic generic model developed from the SFA results is able to present the phosphorus loss occurring in the hydrospheric anthropogenic system.

Water pollution issued such as eutrophication has provided a clearer summary of the course guideline for future action [11]. The adaptation of the SFA approach using phosphorus parameter is able to save sampling cost and express novelty in smart control of nutrient management by adopting the research findings rather than risking global health. This method can also be used in other Southeast Asian countries.

Study area description investigated the phosphorus movement along Kuala Selangor River sub-Basin (KSRsB). The selected parameter, phosphorus, was studied using the SFA technique that is based on mass balance principle according to the law of mass conservation [12]. The objectives of this study were to introduce Substance Flow Analysis (SFA) approach in measuring the phosphorus flow, develop a nutrient model for Kuala Selangor River Basin, and suggest mitigation steps to effectively solve the nutrient pollution problem.

2. Methods

2.1. Geographical setting

The location selected for the study is the Kuala Selangor River sub-Basin (KSRsB) due to several negative arguments raised in recent years on the quality level of its water. Jaafar et al. [13] reported that based on the water quality index, the downstream of the Selangor River has been polluted to the extent that intensive water treatment is required. Moreover, Wan Juliana et al. [14] reiterated in their study that the Kuala Selangor river mouth is experiencing serious pollution because the effluents from factories, farms, houses, and cities have mostly polluted the upstream waters released into the ocean. Among the specific cause identified was diesel oil spill [15].

KSRsB, which is located in Selangor, has a length of 134 km and spread across nine districts and 55 parishes. It covers areas such as pit swamp forests, forest farms, terrestrial forests, oil palms, paddy fields, cash crops plantations (rubber, coffee, cocoa, and coconut), weeds, old mines, empty lands, villages, and cities.

Kuala Selangor has a consistent temperature of between 21°C and 32°C, high humidity, and a total annual rainfall of around 2670 mm. Almost 181,502 hectares or 23% of land in Kuala Selangor is made up of pit soil and the rest are mineral soil. Among the tourist's attractions, spots in Kuala Selangor River include Kg. Kuantan, Kg. Belimbing and Taman Alam (Fig. 1) [16].

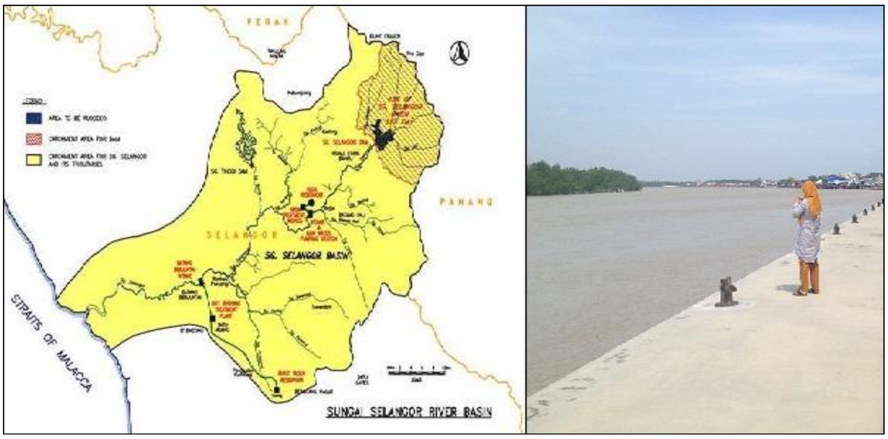

Fig. 1. Location of research in Kuala Selangor River Basin (KSRsB), Malaysia (Map source: Selangor State Department).

2.2. SFA methodology

This study only considered activities that contribute to phosphorus movement into the river water body. Detailed observation on the river bottom was not the focus of this research. Next, the SFA nutrient model was developed to present the complexity of a river basin system.

SFA technique introduced by Walker et al. [17] was used to study the flow of relevant parameter along the KSRsB. The three basic SFA steps involved were a) System analysis, b) Model approach, c) Data gathering and compilation.

2.2.1. System analysis

Table 1 shows the SFA analysis system, which consists of 8 subsystems and 42 flows to complete the phosphorus compound balance in KSRsB metabolism.

Each developed subsystem was based on the current activity scenarios that were considered dominant in triggering the phosphorus movement into the river water body.

2.2.2. Model approach

There were five equation models that were formulated and considered to be the fundamentals in the development of an SFA model. Generally, the relationship between dependent variable y (parameter: mass) and independent variable x (coefficient: P) can be explained as a functional relationship, as follows:

$$\sum \text{Input\_P} = \sum \text{Output\_P} + \sum \text{stock\_P-increases} - \sum \text{stock\_P-releases} \quad (1)$$

When equation (1) was statistically analysed, there were four equations, which covered the input, output, net accumulation, as well as stock components, and they were stated as follows:

- Total $\text{Input\_}_{\text{P-KSRsB}} = \sum \text{Input\_P}$ [S1ax +S2bx +S3cx +S4dx + S5ex +S6fx+ S7gx +S8hx] (2)
- Total $\text{Output\_}_{\text{P-KSRsB}} = \sum \text{Output\_P}$ [S1a-x +S2b-x +S3c-x +S4d-x + S5e-x +S6f-x-x+ S7g-x +S8h-x] (3)
- (Total_$\text{Net_}_{\text{P-KSRsB}}$ = Total $\text{Input\_}_{\text{P-KSRsB}}$ = Total $\text{Output\_}_{\text{P-KSRsB}}$ (4)

Table 1. System Analysis for Kuala Selangor River sub-Basin (KSRsB).

Point of sampling area	Description	Process/goods
Upstream KSRsB	S1: Rice cultivation	3 inputs: 3ax [fertilizer, rain, irrigation], 2 outputs: 2-ax [yield, runoff]
	S2: Poultry	2 inputs: 2bx [feedstuff, water], 3 output: 3b-x [market product, manure, water loss]
	S3: Fruit Valley	3 inputs: 3cx [fertilizer, rain, irrigation], 2 outputs: 2cx [yield, drainage]
Midstream KSRsB	S4:Field crops and vegetables	3 inputs: 3dx [fertilizer, rain, irrigation], 2 outputs: 2d-x [yield, runoff]
	S5: Oil Palm Plantation	3 input: 3ex [fertilizer, rain, irrigation], 2 outputs: 2e-x [yield, drainage]
	S6: Duck Farming	2 inputs: 2fx [feed, water], 3 outputs: 3f-x [yield, manure, water discharge]
Downstream KSRsB	S7: Household	3 inputs: 3gx [foodstuff, water, detergent], 2 outputs: 2g-x [household wastewater (Hh Ww), Wastewater sewer system]
	S8: Industry	2 inputs: 2hx [material, water], 4 outputs: 4g-x [industrial Wastewater, effluent, runoff, sludge]

Note: x refers to positive input flow of P in each subsystem, -x refers to negative output flow of P in each subsystem.

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- Total $\text{Input\_}_{\text{P-KSRsB}} = \sum \text{Input\_P}$ [S1ax +S2bx +S3cx +S4dx + S5ex

+S6fx+ S7gx +S8hx] (2)

- Total Output_$_{P\text{-}KSRsB}$ = ∑Output_P [S1a-x +S2b-x +S3c-x +S4d-x + S5e-x +S6f-x-x+ S7g-x +S8h-x] (3)
- (Total_Net_$_{P\text{-}KSRsB}$ = Total Input_$_{P\text{-}KSRsB}$ = Total Output_$_{P\text{-}KSRsB}$ (4)

2.2.3. Data gathering and compilation

The analysis done in this stage is very crucial in SFA application because the data accuracy and ability in developing the model framework rely on the SFA inventory data. The three aspects of data taken into account were characteristics of data, data on SFA, and data compilation. Because the aim of the study is to analyse the input and output of phosphorus into and from KSRsB, the three data characteristics involved were solid (e.g., foods, manure, fertilisers), liquid (e.g., wastewater, urine, rain), and gases (e.g., sulphur dioxide). The data on SFA includes the literature review, visits and interviews with farmers, entrepreneurs, Majlis Daerah Kuala Selangor (MDKS) authorities, residents, and based on writers' own estimates'. This study did not involve in-situ sampling. Various local and international references have been used to complete the phosphorus coefficient parameter according to each field. The phosphorus coefficient data, together with the uncertainty data for each case are shown in Table 2.

Table 2. Variable values, uncertainties and probability distribution for KSRsB system.

Variable	Mean value	Unit	Uncertainty range	Probability distribution
***a*1/-1: Rice cultivation**	510	ton/yr	±45	Uniform
***b*1/-1: Poultry**	2775	ton/yr	±50	Uniform
***c*1/-1: Fruit valley**	878.93	ton/yr	±45	Uniform
***d*1/-1: Fields crop and vegetables**	392.58	ton/yr	±45	Uniform
***e*1/-1: Oil palm plantation**	5815	ton/yr	±45	Uniform
***f*1/-1: Duck farming**	7.3515	ton/yr	±25	Uniform
***g*1/-1: Household**	778.2	ton/yr	±60	Uniform
***h*1/-1: Industry**	469	ton/yr	±60	Uniform

Analysis of uncertainty was also included in this study. The arrangement of data was an important step prior to the integration of quantitative data into the system model using the STAN 2.5 software. The adaptation of data regarding the generation of mass volumes, sources of data, and quantity of indicators involved the calculation of material flow.

3. Results and Discussion

3.1. SFA model for phosphorus load

The development of a phosphorus SFA model for KSRsB in the year 2017 was based on the analysis of the balance sheet shown in Fig. 2. The detailed explanation of phosphorus load was categorized into several stations namely: a. Downstream for Selangor River, Ayer Hitam River and Sembah River, b. Midstream for Kuang River, Gong River, Serendah River and Rawang River, and c. Up-stream for Guntung River, Kerling River, Buloh River. Generally, the accumulation rate of phosphorus load was highest at the midstream station with a surplus value of 23% with 6.2 kton P/yr, followed by the upstream station with 11% with 4.4 kton P/yr surplus value.

The lowest phosphorus accumulation value, which was 2% with 3.7 kton P/yr, was observed at the downstream station. Based on the observation, the average reading of phosphorus element load accumulation was relatively higher upstream moving towards midstream because of the large- scale oil palm plantation found in this region.

Other sources that influenced the pattern of phosphorus load accumulation were untreated municipal wastewater, domestic sewage, and industrial sewage. The increase in human activities in this area due to ecotourism, such as firefly sighting at the midstream of KSRsB, has pretty much caused a minor change of about 1% in the phosphorus load accumulation.

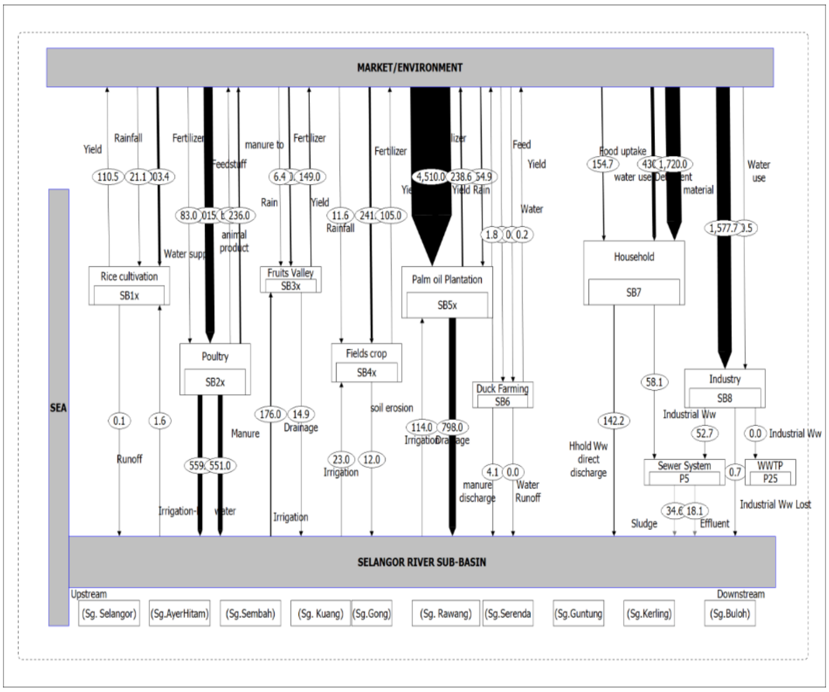


Fig. 2. SFA Model for phosphorus load in Kuala Selangor River sub-Basin, 2017.

3.2. Case study of KSRSB assumption

The summary of results related to phosphorus load accumulation according to each activity is presented in Table 3. The estimated overall net phosphorus load for KSRsB in 2017 was 14395 ton P/yr.

The comparison between all four phosphorus pools presented in Table 3 shows that farming was responsible for 49% of the phosphorus load, followed by human activities 31%, husbandry 19%, and nature 1%. The results showed that plantation activities (oil palm, paddy, and fruits) contributed 43% with 391.3 ton P/yr of phosphorus flow loss, which was the largest phosphorus loss into KSRsB due to the intensive use of fertiliser in crop production.

Table 3. Annual inputs of phosphorus (ton P/yr) and percentage of total load attributed to different sources to KSRsB.

Phosphorus pool resources	This study	Percentage (%)
Farming		
Rice cultivation		
Fruit valley	437	49
Field crops and vegetables	537	
Field crops and vegetables	393	
Oil palm plantation	5815	
Husbandry		
Animal feedlot	2776	19
Duck farming	7	
Human activities		
Household	2728	31
Industries	1694	
Environment	< 1	
Atmospheric deposition	< 0.9	0
Rock weathering	< 0.5	
Mining	0	
Total	14395	100

Table 4 shows the total phosphorus loss based on the type of crops in Kuala Selangor district. With about 90.1% of phosphorus loss happened due in agricultural soil, oil palm planting was clearly the main contributor of phosphorus loss. This is followed by paddy cultivation in Tanjung Karang with 7.4% phosphorus loss. These phosphorus losses can be avoided by practising sustainable environmental policy in these sectors.

Table 4. Annual phosphorus loss from soil in Kuala Selangor district (2017).

Crop	Area sown (ha)[a]	P loss in range (kg/ha)[b]	Average for total P loss from agro-soil (ton P/yr)
Paddy	5589	4-20	67.1
Oil palm	41000	10-30	820.0
Coconut	4500	1-4	11.3
Rubber	300	10-20	4.5
Fruits	1700	1-4	4.3
Other crops	1070	1-4	2.7
Total	**54159**		**909.9**

Sources: a = RT MDKS study (2017), b = Chen (1985); Devendra (1996); Hassan and Devendra (1992).

As shown in Fig. 3, there are two types of flows that determined the total phosphorus balance in KSRsB metabolism namely input flow and output flow. The results showed an annual phosphorus input flow of about 7334 ton P/yr and an annual phosphorus output flow of 4323 ton P/yr, with the annual net balance of 3011 ton P/yr. Referring to the linear graph in Fig. 3, the phosphorus entrance into KSRsB metabolism was at a constant rate, except for a sudden increase at the middle point range because of the intensive phosphate nutrient usage in the agricultural system. On the contrary, the graph for phosphorus output from KSRsB metabolism was not constant. The momentum experienced random changes at the delta point. It is clear that plantation, aquaculture, and husbandry activities have a heavy influence on the water pollution within KSRsB.

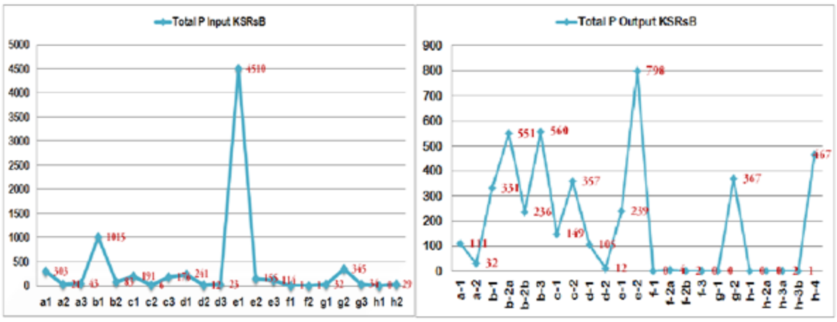
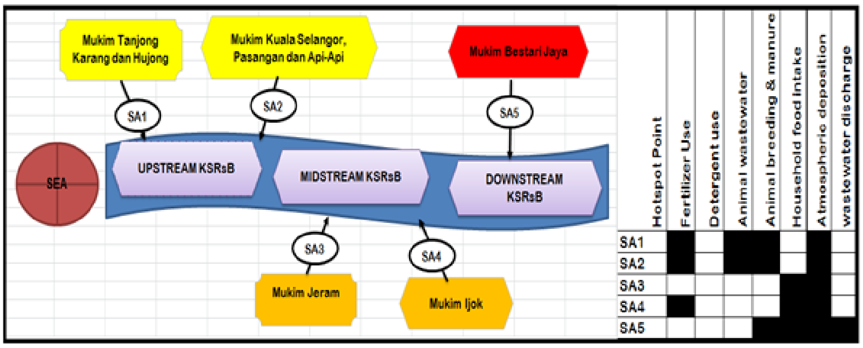


Fig. 3. Input and output of P load (ton P/yr) in KSRsB in 2017.

3.3. KSRsB's phosphorus flow remediation suggestion

To tackle the issue of high phosphorus loss in KSRsB, several restorations and prevention steps suitable for each hotspot are needed (Fig. 4). Intensive usage of fertiliser in agricultural activities, non-diet phosphorus intake in feedlot farming, as well as booming economic activities in SA1 and SA2 are among the main factors that influence the phosphorus accumulation in KSRsB. Most of the agricultural activities in this area use an excessive amount of chemical fertilisers exceeding the plants' actual requirements. Hence, Best Management Practices (BMP) is the best option to mitigate the phosphorus loss into the water body [17].



Notes: SA= Scenario Alternatives, 1….5=Hotspot area

Fig. 4. Proposed option to reduce phosphorus loads in KSRsB, Selangor.

Ecotourism, husbandry, and farming in SA2 and SA3 also contribute to the increase of phosphorus load accumulation in this area. From observation made during sampling and information obtained from the locals, the majority of the organic waste from household and livestock are released into the nearby river directly without going through any treatment system. Therefore, the most ideal option to recover the phosphorus loss into the stream is by changing human behaviour in terms of practising a safer and cleaner organic wastes disposal. In addition, the recovery of human faecal wastes, household food wastes, and animal excreta can be considered through the application of advanced technologies (urine separation, waste and wastewater recycling, as well as compost toilet development [18] and by having a centralised treatment centre. However, the presence of mangrove forests along KSRsB has pretty much acted as a buffer zone to prevent phosphorus from flowing directly into the water body in KSRsB. The mangrove species such as *Rhizophora mucronata*, *Sonnerata alba*, *Ceriops tagal* and *Avicennia marina* acted as vegetated buffer zones between agricultural land and surface waters have proved to be effective filters for sediments and sediment-bound nutrients [19].

Meanwhile, SA4 and SA5 are packed with settlements and factories (Table 3). The increase in phosphorus accumulation in these areas indicates that the rate of phosphorus recycled by households is very low of 13.7%. Therefore, the effort to recycle organic wastes into compost must be doubled in order to prevent phosphorus loss through leaching [20]. This study also discovered a very high dependency on detergent cleaner feed materials that contain phosphate. According to the Department of Environment [21], the banning of phosphates in both laundry and automatic dishwasher detergents in Malaysia is zero. Hence, reducing the usage of phosphate-based detergents by replacing them with phosphorus-free detergents may prevent the eutrophication problem in KSRsB. In addition, the local authorities are encouraged to build a waste and wastewater treatment centre in this area. A more comprehensive local law enforcement in controlling illegal wastes disposal activities such as burning, aboveground wastes accumulation, and wastes dumping into the river may also reduce the nutrient release into the environment.

3.4. Uncertainty involved in analysis

Based on this study, there are several aspects that can be improved by future studies in order to obtain results that are more accurate. First, the selection of boundary or scope of the research that only involved phosphorus movement in a river sub-basin. In actuality, the collection of phosphorus data could be expanded to a larger kilometre radius in order to truly identify the cause of phosphorus pollution in the area being studied. Secondly, the time allocated for this study was only for one year, which is 2017. Thus, there may be an error in this research in terms of its inability to estimate river's existing phosphorus content. Third, some of the pool reservoirs that are considered significant in the production of phosphorus were ignored in this study, such as landfill, wastewater treatment plant, trade with import and export activities, household system, and industries. Fourth, the change in the concentration of phosphorus coefficient in every sample also affected the accuracy of data calculation in this study. As shown in Table 2, the different estimated variation values obtained from the uncertainty analysis for the annual phosphorus load in KSRsB was acknowledged. Most of the information regarding phosphorus concentration was obtained from foreign references due to the lack of such information from local references. The most obvious drawback of this study was the difficulty in obtaining valid information. More time should be allocated to obtain information that is more accurate from various resources operators.

4. Conclusions

This study managed to prove the successful implementation of the SFA method in investigating phosphorus nutrient flow and develop an SFA model framework in KSRsB. It is concluded that not many environmental policy decision makers in Malaysia are using the SFA method to increase river water management effectiveness, not to mention the local community in the area being studied. There are also environmental consultants that are not even aware of the existence of the SFA technique. This study has provided an insight into the movement of phosphorus input, output, and stock in the KSRsB metabolism. Apart from that, these findings can be used by local authorities to develop immediate measures in water body monitoring activities. This study has also revealed low-level nutrient recycling efficiency. Overall, SFA is an effective method to increase the efficiency of water body management. It is hoped that the application of this method, which does not require high sampling cost or expensive technologies, will be assimilated in other areas. However, more intensive and detailed studies are required and more data need to be analysed in order to convince the local decision makers on the effectiveness of using SFA technique in enhancing the productivity of water resources management in Malaysia.

Acknowledgement

Thank you to the government agencies such as the Department of Statistic for providing sufficient data for this study. MOSTI, IPPP research grant from University of Malaya and UMT TAPE 2017/2018: Vote 55123 for funding the researcher’s entire study in Phosphorus Evaluation in Research Study.

Nomenclatures

*a*1	Total of NPK fertilizer input for rice cultivation
*a*2	Total of rainfall input for area study
*a*3	Total of water input for paddy irrigation
*b*1	Total of feedstuff input for poultry farming
*b*2	Total of water input for poultry farming
*c*1	Total of fertilizer input for fruit cultivation
*c*2	Total of rainfall input for fruit valley area
*c*3	Total of water input for fruit valley irrigation
*d*1	Total of NPK fertilizer input for field crops and vegetables
*d*2	Total of rainfall input field crops and vegetable area
*e*1	Total of NPK fertilizer input for palm oil plantation cultivation
*e*2	Total of rainfall input for palm oil plantation area
*e*3	Total of water input for palm oil irrigation area
*f*1	Total of feedstuff input for duck farming
*f*2	Total of water input for duck farming
*g*1	Total of food uptake input for household consumption
*g*2	Total of water usage input for household consumption
*g*3	Total of detergent input for household’s laundry activities
*h*1	Total of material input for industries production
*h*2	Total of water usage input for industries consumption
a-1	Total of yield output for rice cultivation

a-2	Total of drainage output for water discharge
b-1	Total of Market product output for poultry yield
b-2*a*	Total of Manure discharge output for poultry
b-2*b*	Total of Manure to compost output for market product
b-3	Total of Water discharge output for drainage
c-1	Total of yield output for fruit production
c-2	Total of drainage output from fruit activities
d-1	Total of yield output for field crops and vegetables
d-2	Total of drainage output water discharge for crop harvesting
e-1	Total of yield output for palm oil plantation cultivation
e-2	Total of drainage output for palm oil plantation cultivation
f-1	Total of yield output for duck farming
f-2*a*	Total of manure discharge output for duck farming
f-2*b*	Total of manure output for compost production
f-3	Total of water discharge output for duck farming
g-1	Total of wastewater lost output to wastewater treatment plant
g-2	Total of wastewater output for household usage
h-1	Total of industrial wastewater output for treatment
h-2*a*	Total of industrial wastewater output for sewer system treatment
h-3*a*	Total of sludge output from industrial activities
h-3*b*	Total of effluent output for industrial consumption
h-4	Total of wastewater runoff output for industrial activities

Abbreviations

KSRsB	Kuala Selangor River sub Basin
SFA	Substance Flow Analysis

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