The observed total suspended solids (TSS) yield a year after forest harvesting in hill dipterocarp forest of Peninsular Malaysia

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Abstract. The management of forested catchment areas has become important as water originates from upper catchment is the main source of raw water supply for the downstream users. The purpose of this study is to determine the total suspended solids (TSS) in the river system that are affected by conventional forest harvesting practices in Peninsular Malaysia. The study sites were located at Jengai Forest Reserve in Dungun, Terengganu. The commercial forest logging was implemented in the Compartment 44 and compartment 60 as control catchment. Kerak and Angka River catchments are in compartment 44 while, Jera River catchment is in compartment 60. Forest harvesting operation started in November 2016 and ended in October 2017 with tree cutting activities from May 2017 to September 2017. Observation of rainfall from June 2017 to December 2018 and observation of TSS for a one-year period after logging completed from November 2017 to October 2018. As shown by the Kerak River catchment, the TSS started to increase from November 2017 to January 2018 with TSS 5.8 times higher, followed by 15.4 times higher from February to April 2018 and 10 times higher from May to October 2018 compared to undisturbed catchment. These findings are important for forest managers to understand the effects of forest canopy opening to river water quality and as a guideline in the management of forest production for timbers in this country.

Keywords: Forest harvesting; hill dipterocarp forest; water quality; suspended solid.

1. Introduction

Forests play an important role in the hydrological cycle that influences the amount of water available and regulate surface and ground water flows. The most important contribution of the forest is to maintain high water quality of the river. The forest and water managers are facing a challenge in maximising the wide range of forest benefits without detrimental to water resources and ecosystem function. Selected logging practice in Malaysia has started in 1978 and it has moved from lowland forest to hill dipterocarp forests. The terrain and river slope are steeper in hill forest and as such the impact of forest harvesting to water quality is predicted to be higher. Hence, in this study, the observation on total suspended solids (TSS) was conducted for one-year period after forest harvesting operation completed in hill dipterocarp forest. The objective is to determine the TSS yields pattern within a year with influence of rainfall. The four activities involved in the logging operation are the construction of skid, tree cutting, log skidding and log hauling to the temporary landing yard. Bulldozer and excavator are the machine normally used in commercial forest harvesting.
2. Material and methods

2.1 Study site
The study was conducted in compartments 44 and 60 at Jengai Forest Reserve in Dungun, Terengganu (Figure 1). It is situated at latitude 4.58565 and longitude 103.11850 with elevation ranging from 100 to 570 m.a.s.l. Forest logging was conducted in compartment 44, while compartment 60 remained unlogged as control catchment. The area of compartment 44 is 416.5 ha and compartment 60 is 398 ha. Kerak and Angka Rivers are the two catchments identified in compartment 44 and Jera River is in compartment 60. The three catchments are located at the upper streams with Jera River catchment is the biggest, followed by Kerak River and Angka River catchments. The three catchments have similar river density per hectare. The topography is described as undulating to hilly with the slope reach up to 50° (Table 1). The soil consists of Beserah and Renggam series. The soil texture properties are coarse sandy loam to gravelly coarse sandy clay. It is categorised as deep and good drainage of soil that shows high infiltration rate and water retention will not have occurred. The vegetation is typical of hill dipterocarp forest consisting of three-layered canopy; upper, middle and lower layers.

![Figure 1](image-url)  
*Figure 1. Locations of Kerak and Angka River catchments in compartment 44, while Jera River catchment in compartment 60.*

| Catchment  | Elevation (m) | Slope (°) | Area (ha) | River length (m) | River density (mha⁻¹) |
|------------|--------------|-----------|-----------|------------------|----------------------|
| Kerak River| 170 – 492    | 0 – 54.4° | 304       | 10,901           | 35.9                 |
| Angka River| 100 – 498    | 0 – 57.9° | 287       | 10,274           | 35.8                 |
| Jera River | 118 – 576    | 0 – 58.7° | 370       | 13,097           | 35.4                 |

2.2 Data observation
Forest harvesting operation started in November 2016 and ended in October 2017 but, the data collection was conducted from May 2017 to September 2018 (16 months). Total suspended solids are fine
particulate matter that remains in suspension in streamflow. It contains organic and non-organic particles. TSS is the measurement of actual weight of the particulate matter for a given volume of water (mg l⁻¹). The multistage water samplers were set-up at each catchment outlet with the intention to collect water during storm events. Small holes were drilled at the upper part at each of the plastic bottle sampler. Six bottles were vertically tied to a pole made from steel and then the pole was planted into the riverbed with the holes facing the flows. The samples were collected on biweekly basis. Based on the sediment concentration determined from dry weight method analysis (mg l⁻¹), the sediment yield was calculated by multiplying with a volume of surface runoff (litre) and expressed in ton/ha/year.

Rainfall (P) was observed automatically using tipping bucket rain gauge; SEBA hydrometrie model RG 60–3 (0.5 mm/tips) for the two compartments. The locations are outside the catchments to avoid the dense forest canopy cover. The data were recorded every 30 minutes.

3. Results and discussion

The rainfall pattern can be divided into three categories as shown by the data recorded from June 2017 to December 2018 at the two stations. High rainfall from November to January, low rainfall from February to April and moderate from May to October. Compartment (Compt.) 60 received less rain than compt. 44. The total rainfall in compt. 44 for the second half of 2017 was 3242 mm, while in 2018 was 3882 mm (Figure 2). The total rainfall in compt. 60 for the second half of 2017 was 2908 mm, while in 2018 was 3602 mm (Figure 3).

![Figure 2. The monthly rainfall distribution in compartment 44.](image-url)

![Figure 3. The monthly rainfall distribution in compartment 60.](image-url)
Water yields (Q) increased in the first year after forest was logged in Kerak River catchment (Figure 4). The daily discharge double mass curve shows that the increment was higher in northeast monsoon and reduced to the original state as it approaches the dry season. The Q in Jera River catchment ranges from 34,135 to 53,097 m$^3$ha$^{-1}$month$^{-1}$ and the Q in Kerak River catchment ranges from 2,586 to 97,470 m$^3$ha$^{-1}$month$^{-1}$ and it was assumed that the sedimentation rates follow the water volume determined that is involved the stormflow events.

![Double Mass Curve of Discharge (Q)
(July 2017 – September 2018)](image)

**Figure 4.** The cumulative estimated water yields for one-year period after forest logging operation completed.

The amount of TSS calculated from the total sediments captured by the water samplers was closely related to rainfall seasons (Table 2). The TSS rates for the periods of November 2017–January 2018 were higher than February–April 2018 and May–October 2018. The TSS determined at River Jera catchment was ranged 0.02–125.0 ton ha$^{-1}$, 0–393 ton ha$^{-1}$ at Kerak River catchment and 0–30.0 ton ha$^{-1}$ at Angka River catchment. Basically, TSS is less than 1.0 ton ha$^{-1}$ from February to October at Jera river catchment but fluctuated at the other two catchments. The observation at Angka River catchment started in December 2017 and TSS was found lesser from Jera River catchment from December 2017 to February 2018. Even though the tree cutting was conducted after the monsoon, the effects on TSS were seen from March 2018 onwards. TSS in Angka River catchment was 0.9 to 35.3 times higher than in Jera River catchment from March to September 2018.

| Date of samplings | Jera River (ton ha$^{-1}$) | Kerak River (ton ha$^{-1}$) | Angka River (ton ha$^{-1}$) |
|-------------------|---------------------------|-----------------------------|-----------------------------|
| 8/11/2017         | 1.2                       | 23.07                       | -                           |
| 22/11/2017        | 1.43                      | 35.29                       | -                           |
| 6/12/2017         | 19.82                     | n.a.                        | n.a.                        |
| 19/12/2017        | 4.36                      | 93.41*                      | 20.82*                      |
| 23/1/2018         | 124.89                    | n.a.                        | n.a.                        |
| 7/2/2018          | 0.24                      | 137.28*                     | 30.06*                      |
| 7/3/2018          | 0.14                      | 2.22                        | 1.26                        |
| 22/3/2018         | 0.02                      | 0.35                        | 0.37                        |
| 18/4/2018         | 0.03                      | 0.4                         | 0.32                        |
| 1/5/2018          | 0.24                      | 0.11                        | 0.48                        |
Table 3. The average TSS divided into three phases of rainfall availability and increment of TSS in logged catchments with reference to control catchment.

| Time frame       | Jera River (ton/ha⁻¹) | Kerak River (ton/ha⁻¹) | Angka River (ton/ha⁻¹) |
|------------------|------------------------|------------------------|------------------------|
| Nov 2017–Jan 2018| 25.32                  | 147.26 (5.8x)          | 25.44 (1.0x)           |
| Feb–Apr 2018     | 0.0866                 | 12.05 (15.4x)          | 0.61 (7.0x)            |
| May–Oct 2018     | 0.5213                 | 5.383 (10x)            | 6.23 (11x)             |
| Total            | 25.93                  | 164.7                  | 32.27                  |

The average TSS calculated within the time frame indicated that a total of 25.9 ton/ha⁻¹yr⁻¹ TSS was delivered from Jera River; as control catchment while, TSS of 164.7 and 32.3 ton/ha⁻¹yr⁻¹ were delivered from Kerak River and Angka River catchments respectively; as logged catchments (Table 3). In terms of increment, TSS in Kerak River catchment increases 5.8 times higher than Jera River catchment during northeast monsoon, 15.5 times higher during dry season and 10 times higher during southwest monsoon. The sediment yield is expected to be reduced through years as the forest surface recovers. The situation in Angka River will be seen significantly in the following year as the forest logging operation was continued after rainy season.

Based on the TSS values determined between Jera River and Kerak River catchments, the minimum value of TSS determined that affect the water quality by the forest logging operation is 1.2 ton/ha⁻¹ that is the value obtained in November 2017. The threshold value for soil erosion under tropical forest recommended by UNESCO for is 1.0 ton/ha⁻¹yr⁻¹. A study by [1,2] conducted in a small watershed (28.4 ha) at Jengka experimental basin reported that the suspended sediment yield increase of 1.77 ton/ha⁻¹yr⁻¹ in the first year after logging completed determine from the TSS comparison before and after logging operation. The suspended sediment back to original state after on the fourth year after forest logging completed. It is difficult to compare the results with previous studies as the catchment area, location, method of observation and analysis on sedimentation were different.

The availability of TSS in the river system is influenced by the physical characteristics of the catchment, vegetation density and climate condition. As for the forest logging operation, the tree fell near to the river bank will effect water quality more when rain occurs. The construction of logging and skidding roads play the most important roles in determining the sediment concentration in the river system. Soil erosion on logging and skidding roads had been reported by [3,4,5]. The location of river systems from the construction of logging roads and skid trails in the forest logging area influence the intensity of degradation to water quality. In hill forest, not only the topography is steep but also the
extremely steep slope at one side of the river bank. The road construction at the ridges will eventually lead the eroded soil down hills and into the river system.

4. Conclusions
This study shows that forest logging operation in hill dipterocarp forest affects the total suspended solids extremely during monsoon while, minor effect in the month that less rainfall just in a year period after forest logging operation completed.

5. References
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