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The Geochemical Properties of Rural Rivers: The case of River Oni in Efon Alaaye Area of Central Western Nigeria

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Abstract

The geochemical properties of River Oni which passes close to Efon Alaaye and supplies it and nearby settlements with potable water are presented in this paper especially in view of potential pollution of the river from urban influences. The river with seasonal discharge varying from 4 l/s to 104 l/s had suspended sediment load ranging from 125 mg/l to 835 mg/l and solute load ranging from 13 mg/l to 581 mg/l. pH ranged from 6.6 to 7.5, electrical conductivity from 66.7 to 73.4 mS/cm, and alkalinity from 19 mg/l to 29 mg/l. The dominance pattern of the analysed ions was $Ca^{2+} > Mg^{2+} > K^+ > NO_3^- > PO_4^{3-}$. The first two were derived mainly from atmospheric fall out and weathered rocks, while the last three derived mainly from fertilizer residues from the farms. As the concentrations of these elements are still below the WHO safety level, there is need to prevent a decline in the river water quality.

Introduction

Efon Alaaye is the largest and the most populated town in the Efon Local Government Area of Ekiti State in Nigeria. Situated between steep-sided and intensively cultivated North-South trending ridges, the town is located just south of latitude 7°40'N and approximately on longitude 4°55'E (Fig. 1). Efon Alaaye and the neighbouring towns like Ilesa and Aramoko had enjoyed pipe-borne water supply early (in the 1950s) from the Oni River. However, the water supply scheme was short-lived due to upstream erosion and total silting of the reservoir. Efon Alaaye is currently one of the areas with serious erosion problems in south western Nigeria (Jeje, 1988, 2005).

These problems notwithstanding, River Oni is still the source of water supply to the people of Efon Alaaye and Ilesa and its environs. A considerable stretch of the river flows by and receives surface runoff and sewage from the town. Given the population being supported by this river

and the likelihood of its being polluted through urban influence, a study of the geochemical characteristics of the river water was considered relevant. This paper thus describes the solute and particulate matter transported by the Oni River at Efon Alaaye.

Physical Setting

The Oni River originates along a line of weakness in a North-South trending quartzite ridge, at an elevation of about 650m a.s.l. near Obake Village. It takes a northerly course, descending 215m downhill within a distance of 4km. Thereafter, it follows a westerly course on a relatively flat slope round the town before flowing parallel to the Old Efon-Erinmo Road for about 2.5 km. (Fig. 1). The river subsequently flows into the Osun River, one of

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the regional rivers in south western Nigeria. A survey of slope profiles determined at locations across the river shows that the lower valley slope units are concave to rectilinear while the upper slope units are convex. Based on 40 measurements of the valley slope profiles, the valley-side slopes on the average subtend an angle of 25°. Steep channel reaches consist of a series of bedrock riffles separated by bedrock – floored pools which are veneered by sediment. Table 1 shows some physical characteristics of the catchment and the main river channel.

The catchment (5.5km²) is underlain by quartzite and quartz-schist of the Efon Psammite Formation belonging to the Precambrian Basement Complex (de Swardt, 1953; Smyth & Montgomery, 1962). The course of the river is structurally controlled by N-S trending joints and faults (Fig. 1). Numerous small springs in the head-water area and seepages along joint and foliation planes supply a modest base flow even in the dry season. The drainage pattern is characterised by short 1st-order streams which take source from amphitheatre – like depressions in the rocks.

Soils within the Oni catchment vary from the shallow gravelly soils on the upper and middle slopes (the Okemessi/Efon Series) to the sandy hill wash soils toward the valley floor. This topographic sequence more or less determines the agricultural land use pattern.

Much of the natural cover of tropical rain-forest has been destroyed as a result of cultivation, urbanisation and road construction. Large patches of degraded forest are now confined to the gravelly soils on the upper slope units. The more common land cover is a re-growth dominated by fallow species particularly, *Chromolaena odorata*, which is broken into patches by farms. Over 80% of the people are farmers. Due to limited agricultural land, the available land is intensively exploited resulting in reduced fallow period (2-4 years). Annual crops such as rice, yam, and maize are cultivated on the lower hill slope units. Cultivation currently includes application of fertilizers (superphosphate, N P K, nitrate of ammonia, and sulphate of ammonia). Bush burning is pronounced, resulting in a significant percentage of the catchment being devoid of vegetal cover by the end of the dry season.

The mean annual rainfall is about 1400mm, and the rainy season lasts from April to November. Rainfall distribution is bimodal (July and September/

October). High intensity storm events occur at the beginning and towards the end of the rainy season.

Instrumentation and Methods

A water level recorder and a check staff gauge were installed at the catchment out fall (about 4 km from the source). The stage records were converted into discharge using a rating equation determined from discharge rating measurements carried out using a mini OTT current meter. Rainfall was measured using a Hellman rainfall recorder. For suspended sediment concentration, water samples were collected daily with the aid of a depth integrating sampler constructed from 500 ml plastic bottles and provided with appropriate inlet and outlet tubes (cf. Gregory and Walling, 1971). During storm events, sampling was carried out on the rising and falling stages of the hydrograph at more frequent (>10 minutes) intervals. In a period of 15 months between 1985 and 1986, a total of 820 samples were obtained, 300 for daily low flows and 520 for storm events. The suspended sediment concentration (mg/l) was determined in the laboratory by filtering 200ml water samples using Whatman Glass Fibre Circles (GFC; 0.45mm) and vacuum pump assembly, oven drying, cooling in desiccators and weighing the suspended sediment residue together with the filter pad.

Annual suspended sediment yield and annual solute yield were obtained using the suspended sediment and solute load rating curves and daily mean discharges (see Walling, 1978; Ogunkoya and Jeje, 1987).

Temperature, pH and electrical conductivity of the water were determined during collection of samples, using a mercury thermometer, a Cambridge pH meter and an electrical conductivity meter (mS/cm) respectively.

Stream water samples obtained weekly were analysed for some chemical elements that may reflect the local agricultural practices. Thus, calcium (Ca²⁺), magnesium (Mg²⁺) and potassium (K⁺) concentrations expressed in mg/l were determined by atomic absorption spectrophotometer using a Perkin Elmer Model 303 double-beam instrument. Phosphate and nitrate were determined using an Automatic Technicon Auto Analyser II. Laboratory analyses were carried out at the Institute of Ecology, Obafemi Awolowo University, Ile-Ife, incorporating quality control (AQC) procedure (multiple determinations on select samples in each batch) with appropriate precision requirement (<5% c.v.).

Result

Discharge

The river shows marked seasonal variation in water discharge with the mean rainy season values varying from 29 l/s to 104 l/s; and the dry season values ranging between 4 l/s and 29 l/s. The highest daily discharge value of 104 l/s occurred in the first week of September, 1986 (see figure 2).

Oni exhibits a flow pattern involving quick response to storm events but with relatively high base flows (Figure 3). This latter may be due to the high infiltration capacity of the soils in the catchment, particularly, the non-urban surfaces (Jeje, 1981, 1988).

Temperature

Stream temperature ranged between a mean of 26°C in the rainy season and a mean of 27°C in the dry season. There was a slight difference between river water temperature under forest shade and that in the open. Average water temperature under forest shade was 25.1°C while that of the unshaded section was 27.3°C.

Sediment/Solute Yield

During the 15 months of monitoring, the river transported significant quantities of suspended sediment on 10 occasions. These were during large storm events that elicited peak discharges in excess of 50 l/s. The value of suspended sediment concentration during these storm events ranged between 125 mg/l and 835 mg/l with a mean of 222 mg/l and standard deviation of ± 102 mg/l. A maximum concentration of 835 mg/l was measured from a sample obtained during the first major flood in May, 1985. Generally, the highest concentrations were recorded at the beginning of the rainy season, in April and May. These months also had the highest sediment yields. The lag between peak suspended sediment concentration and peak discharge in the Oni River was probably due to mass mobilization of sediment from Efon Alaaye and the exposed farmlands in the drainage basin at the beginning of the rainy season (see Figure 4).

Analysis of variance showed that there was a significant difference between the dry season and rainy season suspended sediment loads. The dry season sediment concentration varied from 2.1 mg/l to 28.5 mg/l with a mean of 16.5 mg/l.

Solute concentration (total dissolved load) ranged between 13 mg/l and 581 mg/l with a mean of 56 mg/l and a standard deviation of 44 mg/l. The dry season solute concentrations were relatively high and near constant at 31 mg/l to 77 mg/l with an average of 61 mg/l, while the rainy season concentrations were mainly relatively low at 13 to 22 mg/l. A few samples however, had very high solute concentrations (with high K^+ , NO_3^- and PO_4-P during the rainy season). This was probably related to the leaching of fertilizer and chemical residues from cocoa and other farms at the upper part of the basin.

pH Streamwater

The river pH ranged from 6.6 to 7.50. The highest values were recorded during the dry season between December and March when stream flow was sustained by base flow. pH values, were generally depressed and constant during the rainy season. Repeated sampling through storm flow periods indicated that pH did not change markedly with discharge during individual storms.

Conductivity

Electrical conductivity ranged between 66.7 and 73.4 mS/cm (25°C) with a mean of 67.2 mS/cm. As observed for the pH, the highest values occurred during the dry season and the lowest during the rainy season. The least monthly variation (66.4 to 68.3 mS/cm) occurred during the rainy season.

Alkalinity

Alkalinity was also higher in the dry season than in the rainy season except in June 1985 when high values were recorded. The lowest alkalinity of 19 mg/l was recorded in September while the highest value of 29 mg/l was obtained in January, 1986.

Major Ionic Constituents

Table 2 shows the values of the ionic constituents of the water samples while Table 3 shows the concentrations in equivalent weight units (meq/l). Of the ions determined, the dominance pattern of the solute species was $Ca^{2+} > Mg^{2+} > K^+ > NO_3^- > PO_4-P$ (see Table 3). Calcium concentration varied from 5.1 mg/l to 8.8 mg/l with a mean of 7.6 mg/l. Maximum concentration occurred in the dry season and the mean concentration levels for the two seasons of the year were significantly different (ANOVA $\alpha = 0.05$).

Mg²⁺ levels in stream water ranged between 1.6 and 6.6 mg/l with an annual mean and standard deviation values of 5.1 mg/l and 1.1. mg/l, respectively. No pronounced seasonal variation was observed.

Potassium (K⁺) values ranged between 0.6 and 3.5 mg/l with the lowest values occurring during the dry season. The values probably reflect the relative immobility of K⁺ and the fact that K⁺ is taken up by the biomass.

The nitrate and phosphate contents in stream water were low but higher than those reported for some rivers in the area by Ogunkoya and Adejuwon (1991). Most of the dry season samples have nitrate concentration ranging from 0.03 to 0.08 mg/l with an average of 0.05 mg/l. Some high values were however recorded for the rainy season. Phosphate values ranged between 0.16 mg/l and 2.20 mg/l with concentrations between 0.3 and 2.2 mg/l during the rainy season.

Discussion

Due to the nature of the relief, the percentage area of the catchment covered by farmland and urban structures (see Table 1), and the proximity of Efon Alaaye to the catchment outfall, stream flow response to rainfall is rapid. This causes significant contrasts in water and sediment discharge on a day to day, and on storm runoff period basis. Thus at low flows, especially during the dry season, stream water was clear and had very low suspended sediment concentration (<3 mg/l). Instantaneous suspended sediment load increased with the onset of the rainy season and more so during storm runoff events (see Figure2)

The annual suspended sediment yield (5.1t/ km²/yr) and the instantaneous suspended sediment load of River Oni appear similar though lower to values reported for similar sized catchments under similar environmental conditions, (including catchment geology), in south western Nigeria (see Ogunkoya and Jeje, 1987) and elsewhere in the humid tropics (see Slaymaker, 1975). Ogunkoya and Jeje (1987) reported yields of between 11.9 and 25.1t/ km²/yr (catchment area : 2.0 - 9.5km²; relief ratio: 0.08 - 0.14). Slaymaker (1975) on catchments in the tropical rain forest environment of eastern Australia (catchment area: 12.0km² - 20.0km²) reported yields ranging from 11.4 t/km²/y to 22.3 t/ km²/yr. It may thus appear that the level of anthropogenic influence in the River Oni catchment

was yet insignificant, as at the time of study. For instance one of the catchments reported by Ogunkoya and Jeje (1987), River Opapa (area 2.0km²; relief ratio: 0.14; suspended sediment yield : 25.1t/km²/yr) had 59% of its area under agricultural land use and with a poorly paved road virtually abutting the river channel along a steep slope. On the other hand, another catchment, River Etiokun (area:18.8km²), reported by these same authors, having 86% of its area under forests, had suspended sediment yield of 1.2 t/km²/yr.

However, the location of the poorly developed (unpaved roads and drains, and poorly landscaped residential areas) but expanding town (Efon Alaaye) on the flank of a ridge and near the catchment out fall, and also the initiation of significant gullying within the town (see Jeje,1996) may promote disproportionate increases in suspended sediment yield.

River Oni had a mean pH value of 6.8 which is consistent with those reported by Ogunkoya (1986) for rivers draining quartzite and quartz-schist south and south east of the Oni catchment. Also the electrical conductivity of the river is similar to those reported by Ogunkoya (1986) for similar sized catchments draining quartzite in south western Nigeria. Higher values of electrical conductivity and total alkalinity during the dry season are due to the limited water available for dilution during this season as compared to the rainy season. Thus for instance, the value of conductivity decreased, from 72.6 mS/ cm in April to 66.6 mS/ cm in July 1985 with a noticeable increase during the August break. It decreased again in September through November 1985 before increasing again till the end of the dry season. Egborge (1971) and Adebisi (1981) respectively made similar observations in Osun and Ogun Rivers of South Western Nigeria.

The low concentration of dissolved ions in the stream waters is attributable to the relatively low solubility and low base saturation of the underlying quartzite rock. Except for potassium, the mean concentrations of individual ions tend to be slightly higher in the dry than in the rainy season even though no distinct seasonal trend in relation to magnesium Mg⁺ was observed. The values of nitrate NO₃⁻, Phosphate PO₄⁻P and potassium K⁺ in Oni River, appear high when compared with those reported by Egborge (1971). Appreciable nitrate and phosphate concentrations were obtained in July, September and October, 1985 with mean monthly values of 4.3 mg/

1, 3.6 mg/l and 3.2 mg/l, respectively. The low solute yield in the dry season is due to the limited stream flow and therefore, limited mobilization of solutes from the catchment. Fertilizer (super phosphate, N P K, nitrate of ammonia and sulphate of ammonia) leached from farms at the Obahe end of the basin, might have promoted the observed NO_3^- and PO_4P concentrations. In spite of the elevated NO_3^- and PO_4P load, the annual solute yield of 14.3 t/km^2 , is not dissimilar to what obtains within the region (see Ogunkoya and Jeje 1987).

Conclusion

Although more work needs to be done to determine the detailed effect of anthropologic factors in sediment generation and transport within the River Oni catchment, it appears that the main source of suspended sediments transported by the River Oni is the built up parts of the basin. The urban area is poorly developed and is built on steep slopes. The observations with regard to the low solute load and ionic concentrations of the river are consistent with observations from similar sized drainage basins underlain by quartzite in central western Nigeria. However some observed high values of potassium, and phosphate during the rainy season is probably associated with agricultural activities.

Although the concentration of these elements in Oni Water is still below the water supply standards specified by WHO, there is the need to keep their concentrations low in order to prevent a decline in the quality of the river water given that it constitutes the source of water to Effon Alaye and Ilesha.

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Table 1: Some Physical and Channel Characteristics of Oni Drainage Basin

Basins Area	5.5 km ²
Total Stream Length	6.3 km
Absolute Relief	258m
Relief Ratio	0.11
Landuse:	% Basin Area covered by:
(i)	Forest (mainly degraded) 61
(ii)	Farming/Agricultural Activities 29
(iii)	Settlements 10
Mean Channel Width	2.6m
Mean Channel Slope	0.08
% x Sand	68.7
% x Silt	4.4
% x Clay	26.9

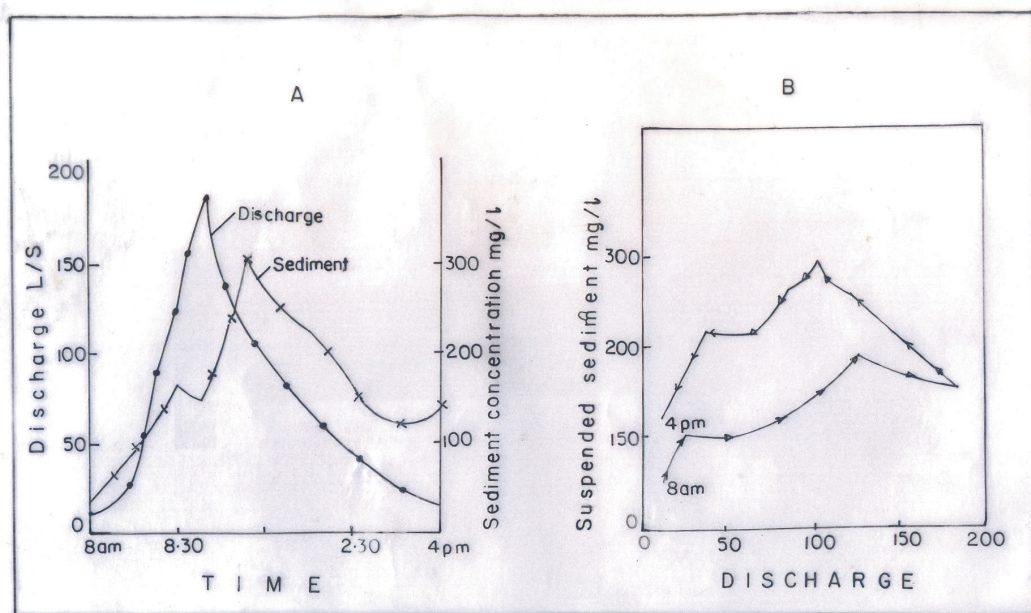
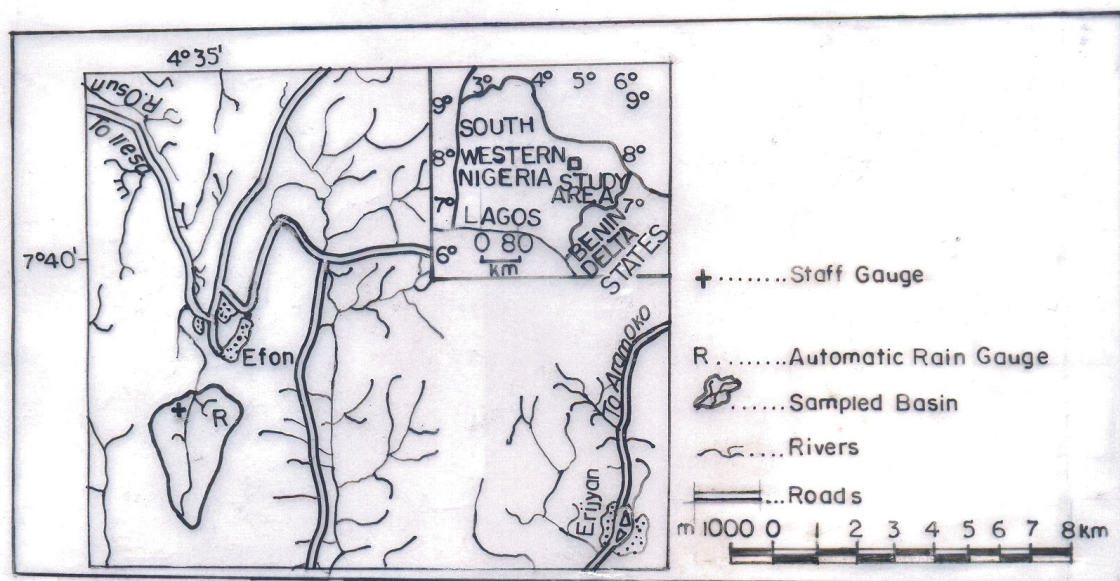
Source: Fieldwork and Map Analysis.

Table 2: Some Chemical Properties of Stream Water

	Max.	Min	X	sd	N
Ca ²⁺ (mg/l)	8.8	5.1	7.6	2.6	180
*Mg ²⁺ (mg/l)	6.6	4.6	5.08	1.2	180
Suspended Sediment (mg/l)	835	2.1	66	148	820
Total Dissolved Solid (mg/l)	581	31	56	44	820
*K ⁺ (mg/l)	3.5	0.6	1.8	0.5	180
*NO ₃ (mg/l)	0.35	.044	0.09	0.003	180
*PO ₄ -P (mg/l)	2.2	0.16	0.31	0.02	180
pH	7.5	6.6	6.8	0.2	150
Cond. (uS /cm)	73.4	66.7	67.2	4.4	150
Alkalinity (mg/l)	29.1	19.3	24	2.6	150
Temp. (°C)	27	25.8	26.1	0.41	150
Annual specific suspended sediment yield :	5.1 t/km ² /yr				
Annual specific solute yield :	14.3 t/km ² /yr				

Table 3: The Mean Ionic Concentrations of the Samples in Equivalent Weight Units (Meg/L)

	X mg/l	meq/l		
Ca ²⁺	7.6	0.455	±	0.156
Mg ²⁺	5.1	0.420	±	0.099
K ⁺	1.8	0.046	±	0.013
NO ₃ ⁻	0.09	0.001	±	0.00005
PO ₄ P	0.31	0.01	±	0.0006



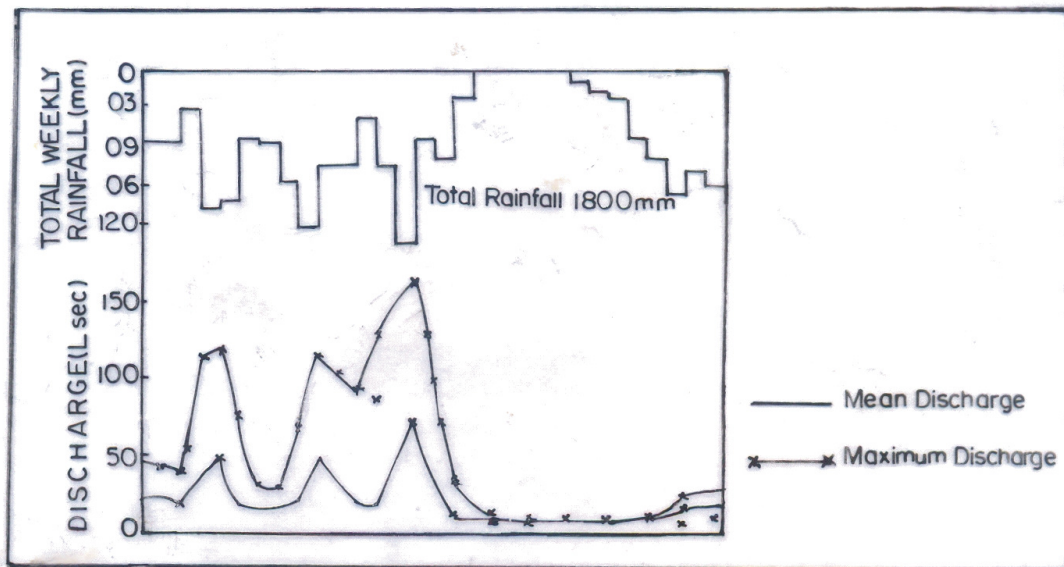


Figure 3. River Oni's response to storm event .

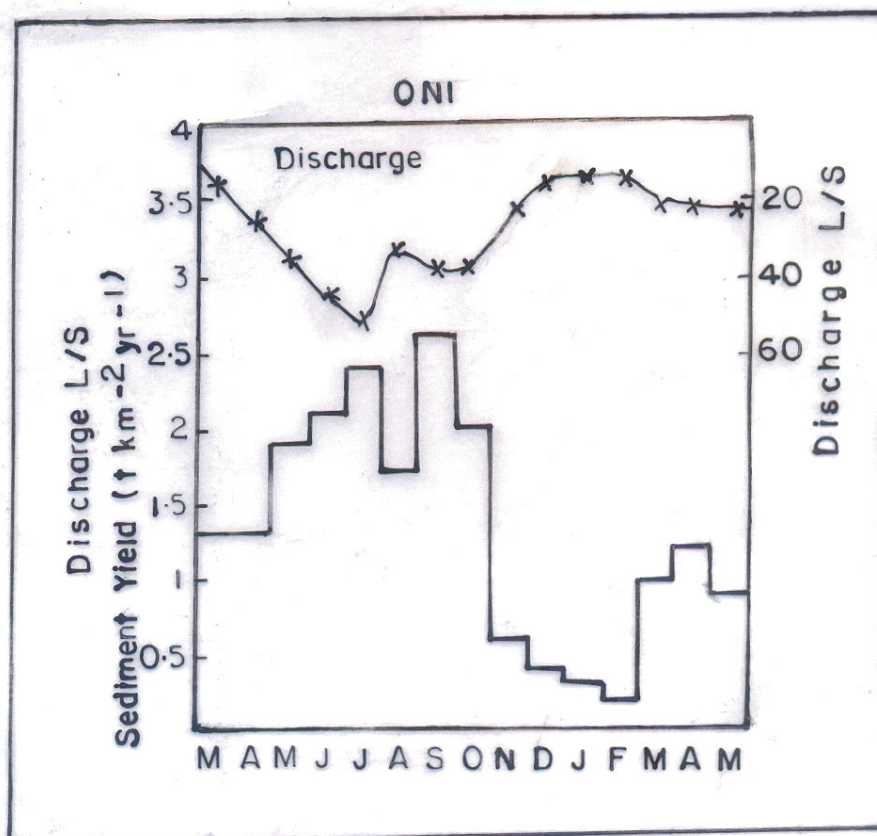


Figure 4. Rainfall and sediment discharge in River Oni 1985/86 .