MODELLING OF SEDIMENT TRANSPORT CAPACITIES OF OGBESE AND OWENA RIVERS IN SOUTH WESTERN NIGERIA

BY

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A THESIS IN THE DEPARTMENT OF CIVIL ENGINEERING IN THE SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY (Ph.D) IN CIVIL ENGINEERING OF THE FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE ONDO STATE, NIGERIA.

OCTOBER, 2002

CERTIFICATION

I certify that Engr. Okoli, Chuks Shadrack of the Department of Civil Engineering, Federal University of Technology Akure, did the work described in this thesis under our supervision.

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DEDICATION

This thesis is dedicated to my Lord **Jesus Christ** who gave me the opportunity, strength, and life to be able to go through the stresses and temptations involved in this difficult study. (Amen).

Dedicated also to all students of Hydraulics and Fluid Mechanics who may be interested in doing further studies in this complex subject of River Sediment Transport processes and Fluvial Hydraulics.

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ABSTRACT

The movement of sediment such as sand, silt or gravel by flowing water is of interest to a wide range of engineering disciplines. This study is aimed at developing models, which can be used to predict the magnitude and levels of sediment concentration in Ogbese and Owena Rivers in Ondo State. S W. Nigeria for engineering design purposes. Data were collected from field investigations conducted at the respective sampling stations on the two rivers. The live bed concept used was derived from Liu – Hwang (1954) resistance equations and that of Einstein – Brown (1981) sediment transport concept. The problem was reduced to that of a power law relationship. These data were fitted into the power relationship to obtain the predicted model of the form; $F^1Q = k_2\Phi^{k}{}_1$, where the parameters F^1Q is the dimensionless sediment discharge. Φ is the dimensionless bed shear stress, k_1 and k_2 are sediment transport coefficients. Calibrating the models yielded the values of k_1 and k_2 for Ogbese river as 0.592 and 0.865 and for Owena river as 0.335 and 1.197 respectively. When tested, the predicted models for Ogbese and Owena rivers performed well in comparison with the established models such as Ackers and White (1973), Engelund and Hansen (1967), Yang (1973) and Karim (1998). It is concluded that the models developed would be useful for engineering design purposes for Ogbese and Owena rivers. These models which relate the sediment discharge, q_s, to the flow parameters, velocity, v, shear stress, τ_o and the characteristic size of the sediments, d_{50} are:

(i) For Ogbese River:

$$\frac{q_s}{\sqrt{(\gamma_s - 1)gd_{50}}} = 0.865 \frac{V}{\sqrt{(\gamma_s - 1)gd_{50}}} \left[\frac{\tau_o}{(\gamma_s - 1)d_{50}} \right]^{0.592}$$

(ii) For Owena River:

$$\frac{q_s}{\sqrt{(\gamma_s - 1)gd_{50}}} = 1.197 \frac{V}{\sqrt{(\gamma_s - 1)gd_{50}}} \left[\frac{\tau_o}{(\gamma_s - 1)d_{50}} \right]^{0.335}$$

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NOTATIONS

B	channel bed width (m)
C_*	coefficient in Liu – Hwang resistance equation
C_s	sediment concentration in p.p.m.
D	channel depth (m)
d_s	bed material size (mm)
d_{50}	median grain size (mm)
F	term represents the settling velocity (m/s)
G	term relating wetted perimeter (P) and slope (S) to flow the (Q)
k_1	sediment transport coefficient
k_2	sediment transport coefficient
M	term relating hydraulic radius (R) to flow velocity
P	wetted perimeter (m)
Q	rate of flow (m^3/s)
q	discharge per unit length along wetted perimeter (m^3/s)
q_s	sediment discharge per unit length and time (m^3/s
R	hydraulic radius (m)
S	channel longitudinal slope
V	average flow velocity (m/s)
γ_f	Fluid specific weight
γ_s	sediment specific weight
ν	fluid kinematic viscosity
τ_o	bed shear stress (N/m^2)
F^1Q^*	Einstein bed load function or dimensionless bed load discharge
Φ	Entrainment function or dimensionless shear stress

CHAPTER ONE

INTRODUCTION

It is a well-known fact that large quantity of sediments in streams and reservoirs constitute serious engineering problems both for agriculture, water resources and hydropower developments. Some of these problems include siltation of reservoirs, land erosion and degradation, sediment loads, floods, river meandering and local scour.

Reports of Berlekom (1971), Rooseboom *et. al.* (1981), Fleming (1969) and Gondwe, (2000) show that rivers in Africa transport large quantities of sediments, but very little scientific and engineering study have been conducted on these rivers by researchers. This is contrary to the volume of work already done on rivers and streams in Europe and North America where annual research reports and information banks established are usually published.

1.1 Justification for the Study

The paucity of research in Africa has resulted in availability of very limited useful information for planning and designs for its tropical rivers. In addition, because sediment transport is associated with a wide range of water-related engineering problems the phenomenon has generated great interest.

1.2 Existing Sediment Transport Models

Many model equations for solutions of problem created by sediment loads and transport have been derived by researchers. Some of these models are based on universal quantitative law whereas the majority are empirical for approximate estimations. Very few of the sediments transport problems involved can be considered to be approximately solved and consequently there are few universal quantitative laws. Indeed, there is a great diversity of opinion generated by the apparently contradictory findings of different investigators. It is also evident from the numerous sediment transport models that have been evolved, that it is ultimately necessary to resort to the use of empirical relationships that may be applicable only to a given location or set of experimental results. Many of the more commonly used of these models have been tested recently over an extensive range of flume and field data (White and Wabbe 1976). It would appear that in the absence of more detailed studies of the various governing phenomena, the most satisfactory method of making predictions of sediment movement has been to obtain relationships empirically from field data. It is generally accepted that in a unidirectional flow the sediment can be considered to be transported in two regions: a bed load region where sediment is transported in a layer adjacent to the stationary part of the bed supported by inter-particle collisions, and a suspended load region in which gravitational forces are overcome by fluid turbulence. Owing to observational difficulties the transition between the suspended load region and the bed load region has for a long time remained undefined.

1.3 Some Important Topics in Sediment Model Studies

Two of the relevant theories that have gained most general acceptance are given in the form of the turbulent velocity distribution and the suspended concentration distribution. However, in order to apply the respective theories in a predictive sense, it is necessary to predetermine the magnitude of fluid velocity and sediment concentration at a given reference level above an assumed datum. These distributions cannot be considered to be wholly applicable in the region very close to the bed because of the neglect of the governing forces in that area. It is the understanding and formulation of bed load transport and hence of total sediment transport that is at present particularly unsatisfactory.

Figure 1a shows the schematic representation of the modes of transport of sediment load. Figure 1b shows the generalized distribution of various sizes of sediments.

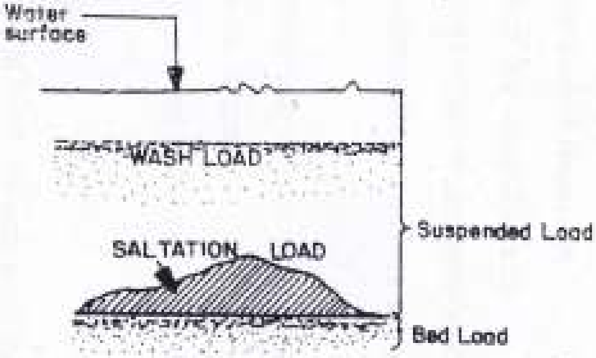

Fig.11: SCHEMATIC REPRESENTATION OF THE MODES OF TRANSPORT OF SEDMENT LOAD.

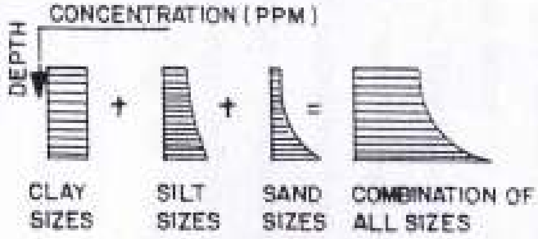

Fig. 17. GENERALISED DISTRIBUTION OF VARIOUS SIZES OF SEDIMENTS.

1.4 Proposed Sediment load Transport Studies.

The difficulties in formulating sediment transport models that can predict the fluid velocities and sediment concentration may be overcome by adopting the following hypotheses. Firstly, it is suggested that there is continuity of both fluid and sediment velocity and also of sediment concentration at a transitional level between bed load and suspended load. Secondly, the exact definition of this level should not be of crucial importance as the order of magnitude of sediment flux above and below the transitional level will be similar under the previous assumption that the regime of flow between the bed loads and the suspended load transport is ill defined, because of the transition regime of flow involving intermediate size particles in suspension. In the case of suspended load transport mode, the application of the existing theories requires the knowledge of reference sediment concentrations at some elevation. Based on these concept a predictive empirical mathematical model for sediment transport in uniform flow will be proposed. Although not attempting a complete description of the physical processes involved, the model will rely on the simplest possible theories of bed load and suspended load behaviour capable of predictive use.

In this study, the reliability of the proposed models was tested by comparing them with established river models such as the Ackers and White (1973), Engelund and Hansen (1967), Yang (1973) and Karim (1998)

1.5 Specific Objectives of Research

The objectives of the research are to:

(a) Evaluate the level of sediment transport capacity of the rivers.

(b) Develop a mathematical model of the sediment transport processes of Ogbese and Owena Rivers.

(c) Determine appropriate design guidelines for hydraulics structures based on data generated from the two rivers.

(d) Evolve sediment control measures along the rivers based on the data generated from the study.

1.6 Scope of Work

The scope of work covers both the suspended and bed load sediment transport investigations for Ogbese and Owena Rivers respectively. Two rivers were selected for meaningful comparison.

CHAPTER TWO

THE TWO RIVERS UNDER STUDY

Ogbese and Owena are two major rivers in the old Ondo State, which up till 1976 was a part of the Western State of Nigeria. The old Ondo State was also split into two States of Ondo and Ekiti on 1st Oct., 1996 and has an area of 20, 595km^2 (Barnabas, 1982). According to the census report (NPC, 1991), the two States have a population of 4,529,690.

2.1 Study Locations

2.1.1 River Ogbese

Ogbese river flows within the area bounded by Longitude 5^0 25′ East and Latitude 7^0 16′ North and Longitude 5^0 45′ East and Latitude 8^0 15′ North, on the topographical map sheet No. 264 S. W of Nigeria . The river is selected for the study because no previous sediment transport study has been conducted on it. It has the largest catchment area of 1312.5kms (BORBDA, 1991) compared with other rivers in the old Ondo State (now Ondo and Ekiti States), with a total length of about 180 km and the average width of about 30m where it crosses major highways. It springs from the north of Ekiti State, passes through Ondo State and empties into Ose River in the western part of Edo State, near a village called Ogbese.

The Ogbese River also passes through Edo State where it discharges into little Ose River, which also discharges into Benin River that finally discharges into the Atlantic Ocean. Ogbese River has two major tributaries, namely Owuruwu with a catchment area of 150km^2 and Ala with a catchment area of about 120km^2. These bring the total drainage area for Ogbese River to 1582.5km^2. The basin is fairly flat making it suitable for agricultural practice. It is perennial only at its lower portion. Active fishing takes place on the entire length of the river. Presently the Benin – Owena River Development

Authority (BORBDA), whose responsibility is to manage and develop the river among others, is proposing a dam at the upper portion of the river. Figure 2.1 shows the major rivers in the study area, including Ogbese and Owena. Figure 2.2 shows the sampling points for the stream sediments, over-bank sediments and soil sample.

The area around Ogbese town forms a part of the basement complex of South Western Nigeria that is underlain by hard crystalline igneous and metamorphic rocks. According to Olarewaju (1988), these rocks are composed of migmatite gneiss complex inter-located bands of quartzite's which are intruded by rocks of the older granite smite. There consist of a wide variety of porphritic granites ranging from medium to coarse-grained types. Closely associated with these granites are dark coloured rocks known as the charnorkites which underline most of the central part of Ogbese village and extending northwards parallel to Akure – Owo expressway.

2.1.2 Owena River

Another river of major interest is Owena River, which is perhaps the most well known of all rivers in Ondo State. Owena river flows within an area, bounded by longitude 5^0 01′ East and Latitude 7^0 12′ North of the equator, and Longitude 5° 45′ E and Latitude 8° 15′N, on the topographical map No, 264 S. W. of Nigeria. The main objective of including Owena River in this study is to widen the scope of the research by including a river, which is dammed along its length. Background information will be provided by this study for the future evaluation the effect of sediment transport mechanism on a river with such reservoir built on its length within the same hydro-geological basement complex.

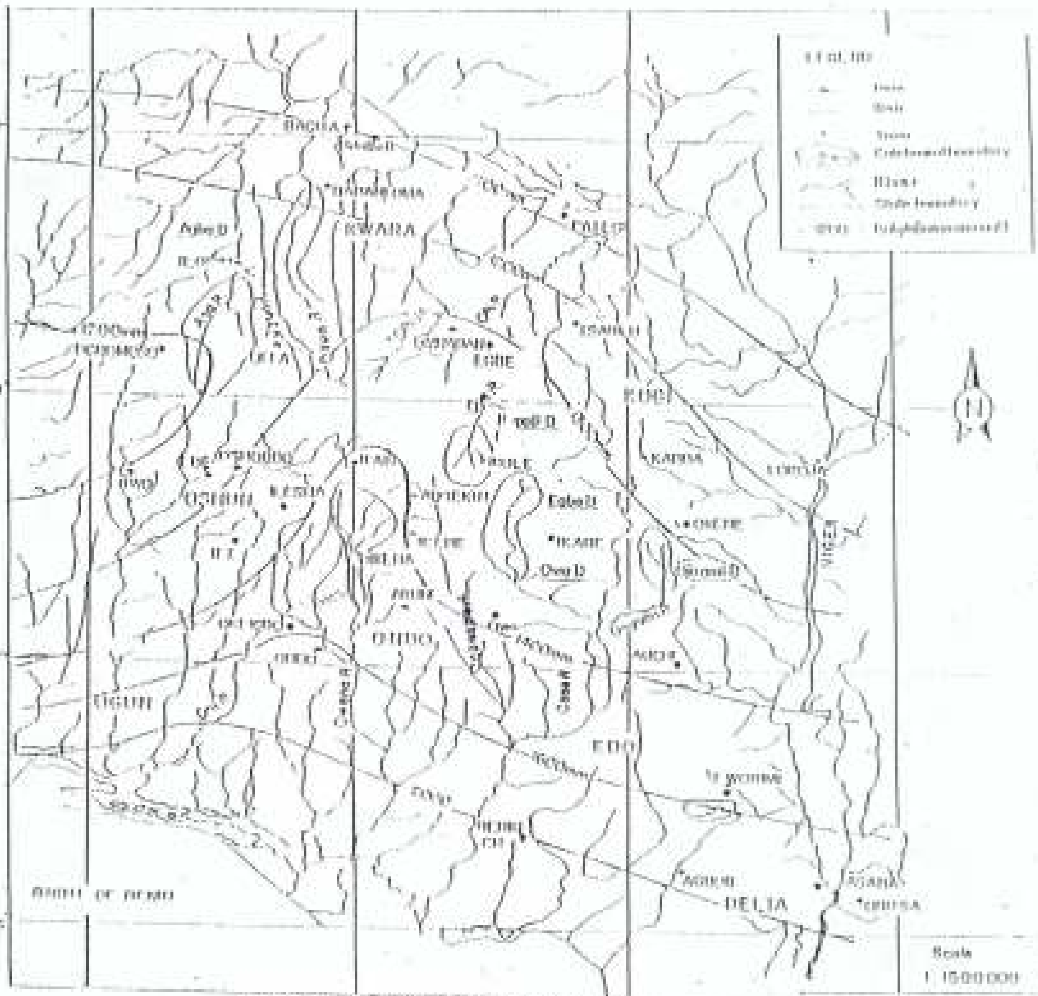

FIG 2.1 RIVERS IN THE STUDY AREA

(SOURCE: OBRDA 1993 Handbook)

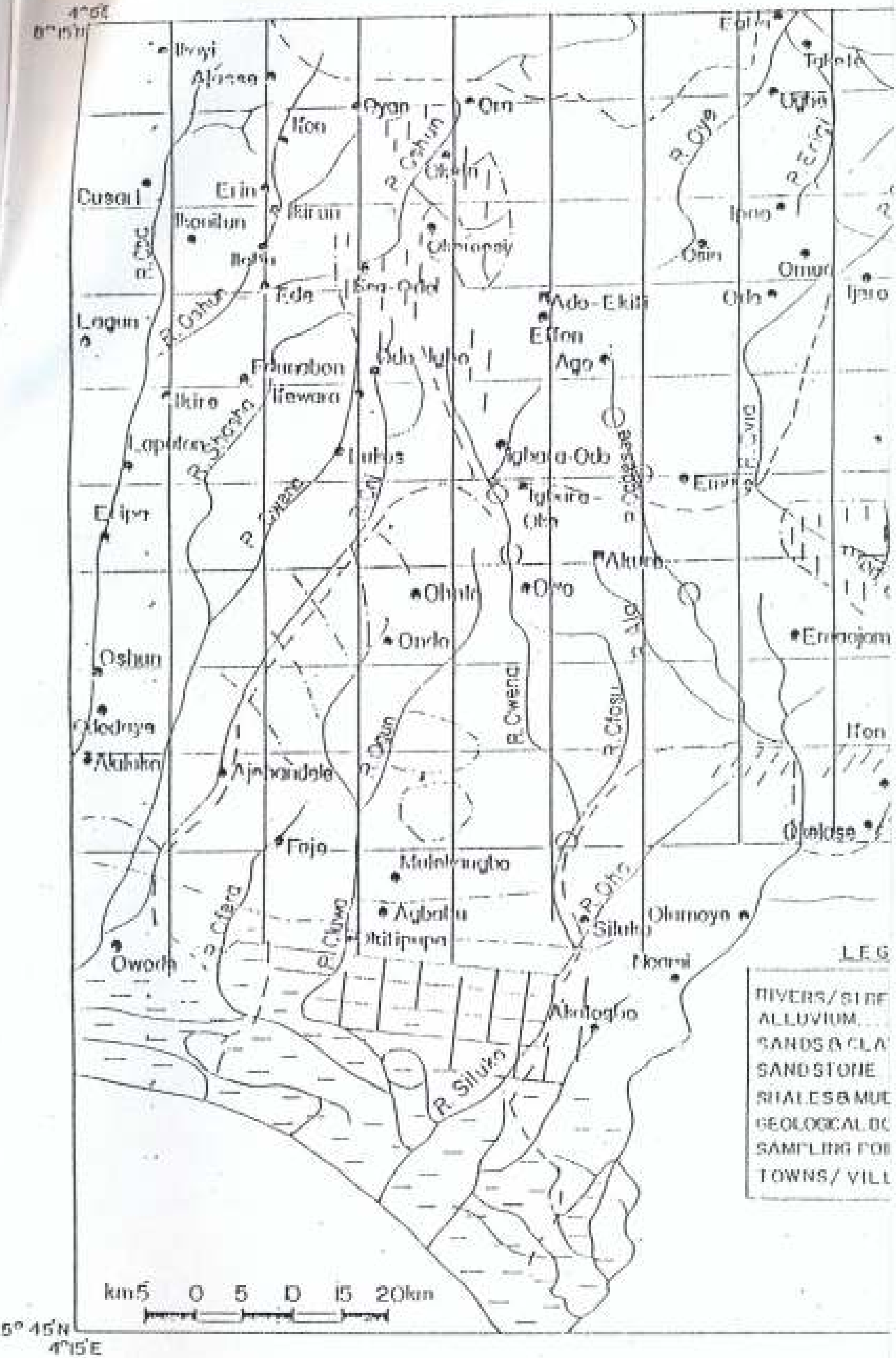

Fig.2.2: Map showing the sampling points for stream sediment ,overbank s sample. (SOURCE: OBRDA

A cofferdam was constructed on Owena River, close to Akure – Ondo road at Owena village in Ondo West Local Government Area. A new dam located at 18km west of Akure – Ilesa road and about 18km north of Akure – Ondo road is under construction. The cofferdam was constructed in 1981 to augument the water supply for Akure and Ondo towns, until the Owena river dam is built upstream under programme of the Federal Government. The drainage area of the Owena River is 790km2 (BORBDA, 1991). It is important to mention that during the period of this study, the main Owena river dam construction is in progress. The new Owena dam is a multipurpose dam proposed to impound raw water of the Owena River for water supply to selected rural and urban communities in Ondo State, and irrigation schemes in the lower reaches. Owena River has a total length of 44km and average width of 27m. It is a perennial river with a maximum average depth of 2m, at the lower reach where boating is possible during rainy season from the Siluko River confluence up to Owena village on the Akure – Ondo road section. The river discharges into Siluko River, which flows into the Atlantic Ocean.

Owena river area lies on the basement of Southwest of Nigeria. According to Elueze (1988), the area is dominated by a rocky plateau starting from Okemesi and Ikogosi down to the lowlands of Ilesha and Ipetumodu. The Ipetumodu and Owena lowlands consist of granite, gneisses and schists, comprising derivatives such as grandiosities, variably igmatised biotite, quartz, and hornblende granites and graneriferous biotite gneiss. The weathering products derived from the degradation of the constituent minerals of basement rocks, provide sediments for the streams and rivers in the area.

2.2. Rainfall and Vegetation

Three-rainfall belt are reflected in the vegetation zone of Ondo State. In the coastal rainfall belt we find he brackish and fresh water mangrove forests. The forests have a heavy rainfall of over 2,000mm per annum. The interior rainfall belt is vegetated by evergreen forest giant trees including mahogany, walnut, Iroko and Obeche. Oil palms are found nearly everywhere in the rain forest zone. Edible fruit such as bananas, plantains, citrus, oranges are also found in this zone. Much of the forest has be cleared and has been turned virtually into derived savannah type of vegetation because of heavy logging activity. The mean annual rainfall exceeds 1200mm and it also reaches up to 1500mm in some areas, as could be seen from the isohyets in Figure 2.1. The northern rainfall belt is covered by the derived and Guinea savannah woodland. Mahogany, oak, fan palms are found. It has moderate rainfall ranging from 1000-1500mm each year. (Barnabas, 1982). The climate is typical of tropical zones and is marked by two distinct seasons: the rainy season lasting from April to October, and the dry season lasting from November to March. There are a number of storage (non-recording) rain gauges within the catchments area. Mostly, returns of rainfall data from selected rainfall stations are sent to the Federal Ministry of Aviation, Akure. Therefore, daily rainfall data from two stations with the catchments covering the period 1977 – 1995 were collected from the Federal Ministry of Aviation. (Table 2.1 and Table 2.2.) Table 2.3 shows the weighted average of Ondo and Akure rainfalls covering the period 1977 - 1995. The method used to obtain the data in Table 2.3 is the theisen polygon method or weighted average method. This method implies that the precipitation value at rain-gauge station were presumed to indicate the representative of rainfall on a surrounding area. An arbitrarily constructed polygon was assumed to give the area for which the rainguage station gives the representative value. For example, if P_1 and P_2 ....P_n represents the rainfall records at the Ondo and Akure stations enclosed by polygons, the areas of which are respectively A_1, A_2......A_n, then the mean precipitation P for the entire area A of the basin is given by the formula below as

$$P = \frac{A_1P_1 + A_2P_2}{A_1 + A_2} \cdots\cdots\cdots \frac{A_nP_n}{A_n}$$

$$= \frac{A_1P_1}{\sum A} + \frac{A_2P_2}{\sum A} \cdots\cdots\cdots \frac{A_nP_n}{\sum A}$$

Here $\frac{A_2}{\sum A}, \frac{A_2}{\sum A}$ .... e.t.c. are termed as weightage factors for the corresponding rain-gauge and in this method these weightages are constant for different storms. This method is better than other methods due to the fact that each rain-gauge is better than other methods due to the fact that each rain-gauge station is given weightage according to its position with respect to the boundary of the basin under study.

Table 2.4 shows the monthly runoff of 1977 – 1995. The long term annual mean rainfall at the two stations varied between 1472.1mm and 1633.5mm. Higher rainfall amounts are experienced in the Ondo catchments; the amount is 2298mm in 1992. Simple arithmetic average of the annual mean rainfall value is approximately 1552.8mm. The coefficient of variation (CV) of the data series is a moderate 20% indicating a reasonably consistent value of annual rainfall of the catchments. Their highest monthly rainfall amount recorded was approximately 278.6mm in October 1982. from the available statistics, the distribution of the mean annual rainfall showed from the available statistics that the months June – October experienced heavier rainfall with about 82% of annual amount . The month of October has the highest monthly rainfall amount approximately 277.8mm, which is 17% of the long-term annual mean rainfall amount. Figure 2.3 shows the rainfall distribution of the basin and probable maximum rainfall (PMP) at 260mm per month in October. Figure 2.4 shows the rainfall distribution curve for Owena basin. Figure 2.5 shows the rainfall depth - frequency relationship for the basement complex. Figure 2.6 shows the annual catchments rainfall for the basement complex.

The importance of rainfall in the study of sediment transport of a basin cannot be overemphasized. According to many researchers among them Kinori and Menorach (1984), the storm water carries suspended load across a stream above the bed layer. This storm water carries sediment particles that stay suspended for an appreciable length of time and usually consists of sand and finer fractions.

Table2.1 Akure Station: Mean Monthly Rainfall (mm) 1980 – 1995

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total
1980	0.0	41.8	64.6	129.8	88.3	298.0	104.0	227.6	242.5	179.9	13.6	0.0	1415.0
1981	0.0	22.4	34.1	253.3	223.3	258.6	148.2	152.7	210.6	5.9	10.1	0.0	1119.0
1982	8.2	68.1	73.0	211.3	211.8	170.7	180.9	25.2	131.0	269.6	11.0	0.0	1361.0
1983	0.0	26.2	7.9	161.9	254.5	194.8	89.4	59.9	343.6	142.9	6.0	52.9	1350.0
1984	0.0	TR	174.9	188.6	203.0	218.3	154.3	206.6	202.1	166.1	21.9	0.0	1533.0
1985	2.4	0.0	155.7	146.5	220.9	186.7	231.3	326.6	252.6	99.5	24.3	TR	1647.0
1986	12.7	150.3	130.8	41.8	157.5	142.2	100.6	77.5	217.9	8 2.0	46.6	0.0	1160.0
1987	7.7	42.7	107.1	94.3	93.1	116.7	158.1	384.4	276.4	113.7	0.0	0.8	1395.0
1988	18.4	74.7	74.1	182.9	156.9	203.5	193.1	82.6	278.1	229.9	44.7	17.6	1557.0
1989	0.0	0.0	123.3	59.1	183.7	226.8	199.6	357.8	175.5	111.5	19.1	0.0	1456.0
1990	4.4	15.5	0.0	199.1	113.6	90.7	320.2	245.8	220.9	213.3	72.4	62.5	1558.0
1991	1.2	98.6	136.0	223.2	201.2	160.9	463.0	203.6	200.9	152.6	TR	10.4	1333.0
1992	0.0	0.0	40.8	107.8	151.1	237.0	265.3	101.7	348.1	194.6	25.6	0.0	1472.0
1993	0.0	57.0	18.8	84.6	95.1	1.4.1	131.8	274.1	303.7	95.6	72.3	21.4	1259.0
1994	11.2	39.4	44.4	97.8	109.9	225.8	147.6	218.2	181.3	157.3	28.0	0.0	1321.0
1995	0.0	28.4	128.0	196.3	181.4	214.2	268.6	379.6	290.6	87.3	14.2	0.0	1797.0
Mean	**4.1**	**41.6**	**82.1**	**148.6**	**169.1**	**190.6**	**197.3**	**207.7**	**242.2**	**143.9**	**25.6**	**10.4**	**1472.1**

Source: Federal Ministry of Aviation, Akure

Table2.2 Ondo Station: Mean Monthly Rainfall (mm) 1977 – 1995

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total
1977	18.8	33.1	56.0	138.1	164.9	257.1	210.2	106.2	104.9	188.4	3.4	39.8	1339.0
1978	TR	62.7	126.1	288.2	203.5	233.0	425.7	72.1	296.3	168.4	8.4	1.8	1886.0
1979	9.0	96.1	12.5	155.4	140.0	169.0	297.4	290.7	364.2	173.4	100.7	4.7	1774.0
1980	TR	50.5	127.0	188.9	124.8	303.7	186.0	404.9	348.6	308.8	52.0	21.9	2112.0
1981	0.0	5.0	98.5	140.2	165.9	253.3	209.9	150.3	183.0	132.6	49.7	0.0	1388.0
1982	9.6	101.4	60.5	208.5	165.4	176.2	156.1	44.7	185.6	186.4	14.5	0.0	1310.0
1983	0.0	17.2	34.7	127.2	158.5	282.6	129.4	45.3	312.1	80.2	46.9	22.0	1257.0
1984	0.0		171.2	121.2	199.5	130.8	214.3	232.7	263.9	124.6	17.4	1.1	1478.0
1985	TR												
1986	40.4	125.4	190.7	41.6	211.1	271.1	170.6	102.2	256.9	132.3	23.4	0.0	1566.0
1987	0.0	22.1	145.4	91.2	86.6	140.8	244.4	355.1	230.0	263.2	0.8	6.6	1597.0
1988	3.7	92.3	93.9	193.9	240.	223.4	141.7	104.4	301.7	244.8	27.7	29.7	1695.0
1989	0.0	TR	115.0	200.7	4223.4	230.0	300.3	210.5	158.9	124.2	23.6	TR	1608.0
1990	0.0	1.2	0.0	140.0	230.0	197.2	210.4	115.5	277.3	150.0	76.0	5.5	1306.0
1991	12.1	55.3	171.3	295.3	197.2	281.3	552.2	223.6	309.6	204.9	TR	12.6	2298.0
1992	TR	4.9	74.9	96.7	281.3	221.9	185.0	52.0	488.2	131.4	67.1	TR	1520.0
1993	31.3	38.8	121.0	100.1	223.9	1954.3	91.7	219.4	351.2	88.3	91.1	5.6	1455.0
1994	0.0	50.9	74.5	180.2	192.7	263.3	305.1	271.4	219.1	165.7	39.2	0.0	1799.0
		49.8	101.0	130.7	130.7	407.5	251.3	319.4	348.8	245.4	36.6	0.0	2015.0
Mean	**6.6**	**45.5**	**91.6**	**156.8**	**172.0**	**236.6**	**237.9**	**184.3**	**277.8**	**172.2**	**37.7**	**8.4**	**1633.5**

Source: Federal Ministry of Aviation, Akure

Table 2.4 Owena River Basin Monthly Run off (mm) – (1977-1995)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total
1977	3.4	6.0	10.2	24.9	29.7	46.3	37.8	19.1	18.9	33.9	0.6	7.2	238.0
1978	0.0	11.3	22.7	51.9	36.6	41.9	76.6	13.0	53.3	30.8	1.5	0.3	339.4
1979	1.6	17.3	2.3	28.8	25.2	30.4	53.5	52.3	65.6	31.3	18.1	0.8	327.2
1980	0.0	9.2	19.2	27.7	21.3	60.2	29.0	63.3	59.1	48.3	11.8	2.2	351.3
1981	0.0	2.8	13.3	39.4	38.9	51.2	35.8	30.3	39.4	18.9	6.0	0.0	276.0
1982	1.8	17.0	13.4	42.0	37.7	34.8	33.7	7.0	31.7	45.6	2.6	0.0	267.3
1983	0.0	4.3	4.32	28.9	41.3	47.7	21.9	10.5	65.6	22.3	5.3	7.5	259.6
1984	0.0	0.1	34.6	31.0	40.3	34.9	36.6	43.9	46.6	29.21	3.9	0.1	301.2
1985	0.1	0.0	31.1	29.3	44.2	37.3	46.3	65.3	50.5	19.9	4.9	0.0	328.9
1986	5.3	27.6	32.2	8.3	36.9	41.4	27.1	18.0	47.5	21.4	7.0	0.0	272.7
1987	0.8	6.5	25.3	18.6	18.0	25.8	40.3	74.0	50.7	37.7	0.1	0.7	298.5
1988	2.2	16.7	16.8	37.7	39.7	42.7	33.5	18.4	58.0	47.5	7.2	4.7	325.1
1989	0.0	0.0	23.8	26.0	42.9	45.7	50.0	56.8	33.4	23.6	4.3	0.0	306.5
1990	1.7	1.7	0.0	33.9	23.5	28.8	53.1	36.1	49.8	36.3	14.8	7.8	287.5
1991	0.1	15.4	30.7	51.9	40.5	44.4	10.1	42.7	51.0	35.8	2.6	2.6	419.2
1992	0.0	0.1	11.6	20.5	34.7	46.1	45.0	15.4	83.6	32.6	9.3	0.0	298.9
1993	0.0	9.6	14.0	18.5	24.8	29.9	23.6	49.4	65.6	18.4	16.3	2.7	272.8
1994	4.4	9.8	12.0	28.4	36.3	48.9	45.3	49.0	40.0	32.3	6.7	0.0	313.0
1995	0.0	7.8	22.9	32.7	31.4	62.2	52.0	69.9	63.9	33.3	5.1	0.0	381.2
Mean	**8.8**	**8.6**	**17.9**	**30.5**	**33.9**	**42.1**	**44.3**	**38.7**	**51.3**	**31.5**	**6.7**	**1.9**	**305.6**

Source: Federal Ministry of Aviation, Akure

Table 2:4 Jwena River Basin Monthly Run off (mm) – (1977-1995)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total
1977	3.4	6.0	10.2	24.9	29.7	46.3	37.8	19.1	18.9	33.9	0.6	7.2	238.0
1978	0.0	11.3	22.7	51.9	36.6	41.9	76.6	13.0	53.3	30.8	1.5	0.3	339.4
1979	1.6	17.3	2.3	28.8	25.2	30.4	53.5	52.3	65.6	31.3	18.1	0.8	327.2
1980	0.0	9.2	19.2	27.7	24.3	60.2	29.0	63.3	59.1	48.3	11.8	2.2	351.3
1981	0.0	2.8	13.3	39.4	38.9	51.2	35.8	30.3	39.4	18.9	6.0	0.0	276.0
1982	1.8	17.0	13.4	42.0	37.7	34.8	33.7	7.0	31.7	45.6	2.6	0.0	267.3
1983	0.0	4.3	4.32	28.9	41.3	47.7	21.9	10.5	65.6	22.3	5.3	7.5	259.6
1984	0.0	0.1	34.6	31.0	40.3	34.9	36.6	43.9	46.6	29.21	3.9	0.1	301.2
1985	0.1	0.0	31.1	29.3	44.2	37.3	46.3	65.3	50.5	19.9	4.9	0.0	328.9
1986	5.3	27.6	32.2	8.3	36.9	41.4	27.1	18.0	47.5	21.4	7.0	0.0	272.7
1987	0.8	6.5	25.3	18.6	18.0	25.8	40.3	71.0	50.7	37.7	0.1	0.7	298.5
1988	2.2	16.7	16.8	37.7	39.7	42.7	33.5	18.4	58.0	47.5	7.2	4.7	325.1
1989	0.0	0.0	23.8	26.0	42.9	45.7	50.0	56.8	33.4	23.6	4.3	0.0	306.5
1990	1.7	1.7	0.0	33.9	23.5	28.8	53.1	36.1	49.8	36.3	14.8	7.8	287.5
1991	0.1	15.4	30.7	51.9	40.5	44.4	10.1	42.7	51.0	35.8	2.6	2.6	419.2
1992	0.0	0.1	11.6	20.5	34.7	46.1	45.0	15.4	83.6	32.6	9.3	0.0	298.9
1993	0.0	9.6	14.0	18.5	24.8	29.9	23.6	49.4	65.6	18.1	16.3	2.7	272.8
1994	4.4	9.8	12.0	28.4	36.3	48.9	45.3	49.0	40.0	32.3	6.7	0.0	313.0
1995	0.0	7.8	22.9	32.7	31.4	62.2	52.0	69.9	63.9	33.3	5.1	0.0	381.2
Mean	8.8	8.6	17.9	30.5	33.9	42.1	44.3	38.7	51.3	31.5	6.7	1.9	305.6

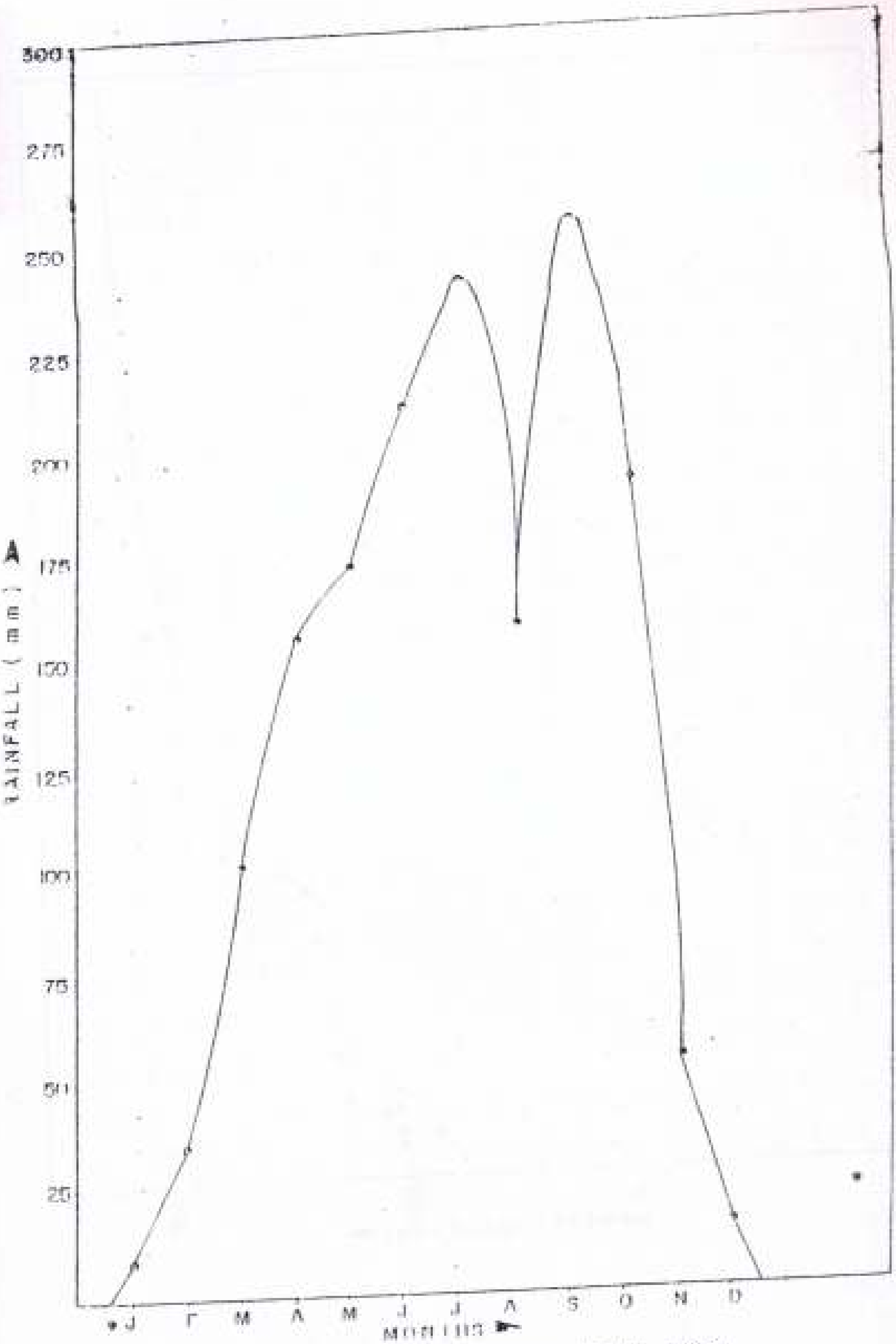

Fig. 3 Rainfall distribution curve for Owena Basin (1943–1999)

Source (ORBDA 1973 data book)

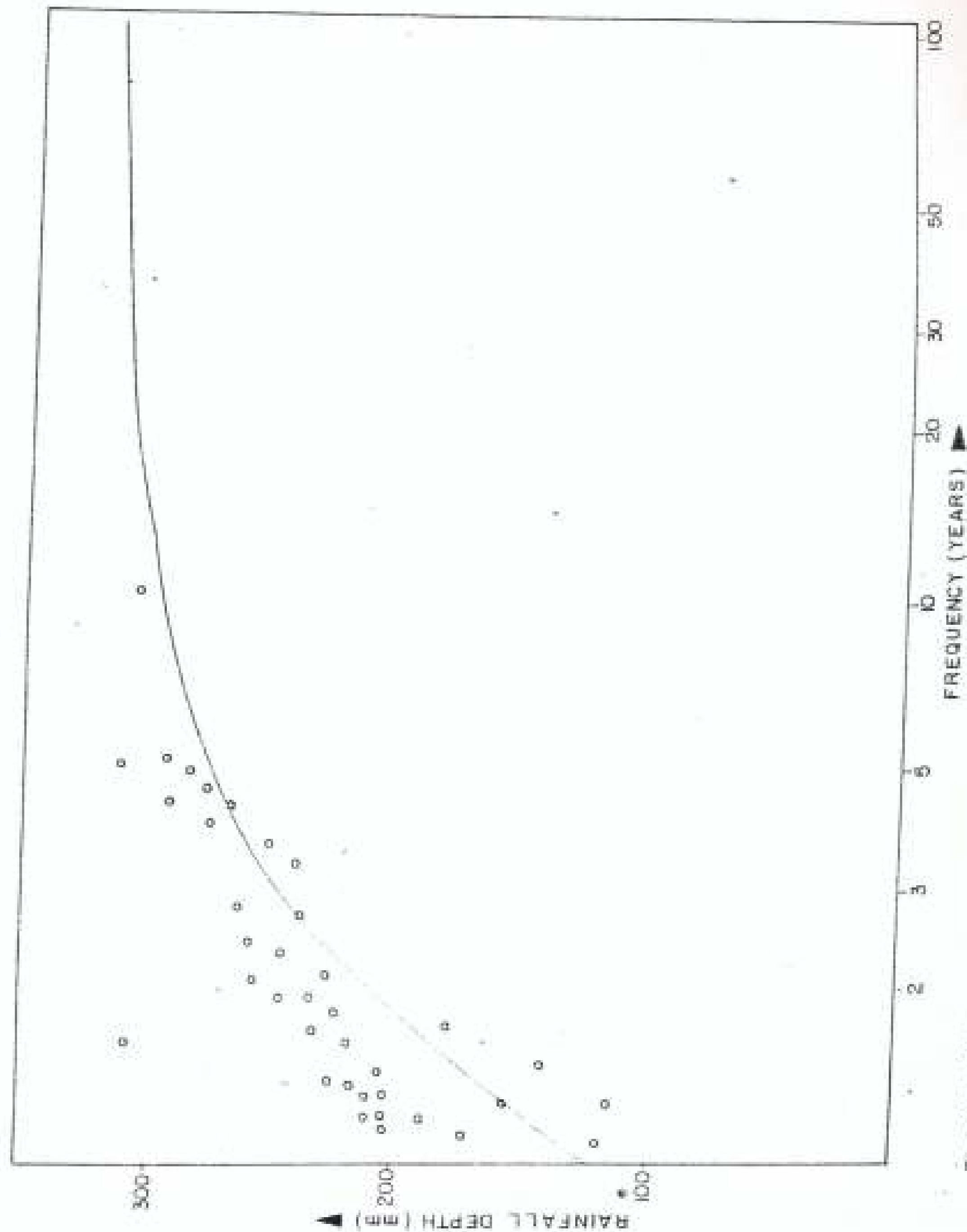

Fig2.4 Rainfall depth: Frequency curve for Owena basin

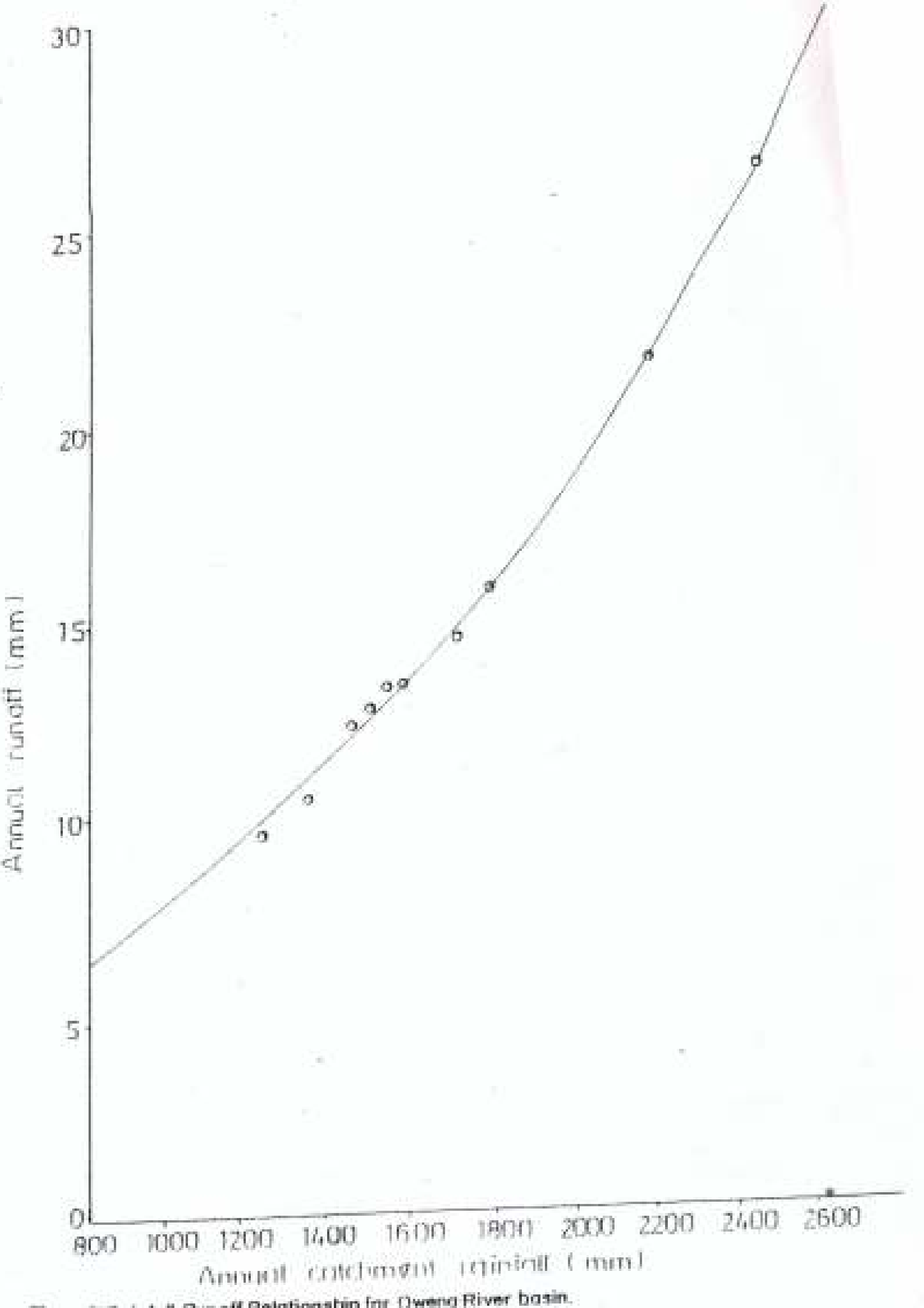

Fig. 2.5: Rainfall-Runoff Relationship for Owena River basin.
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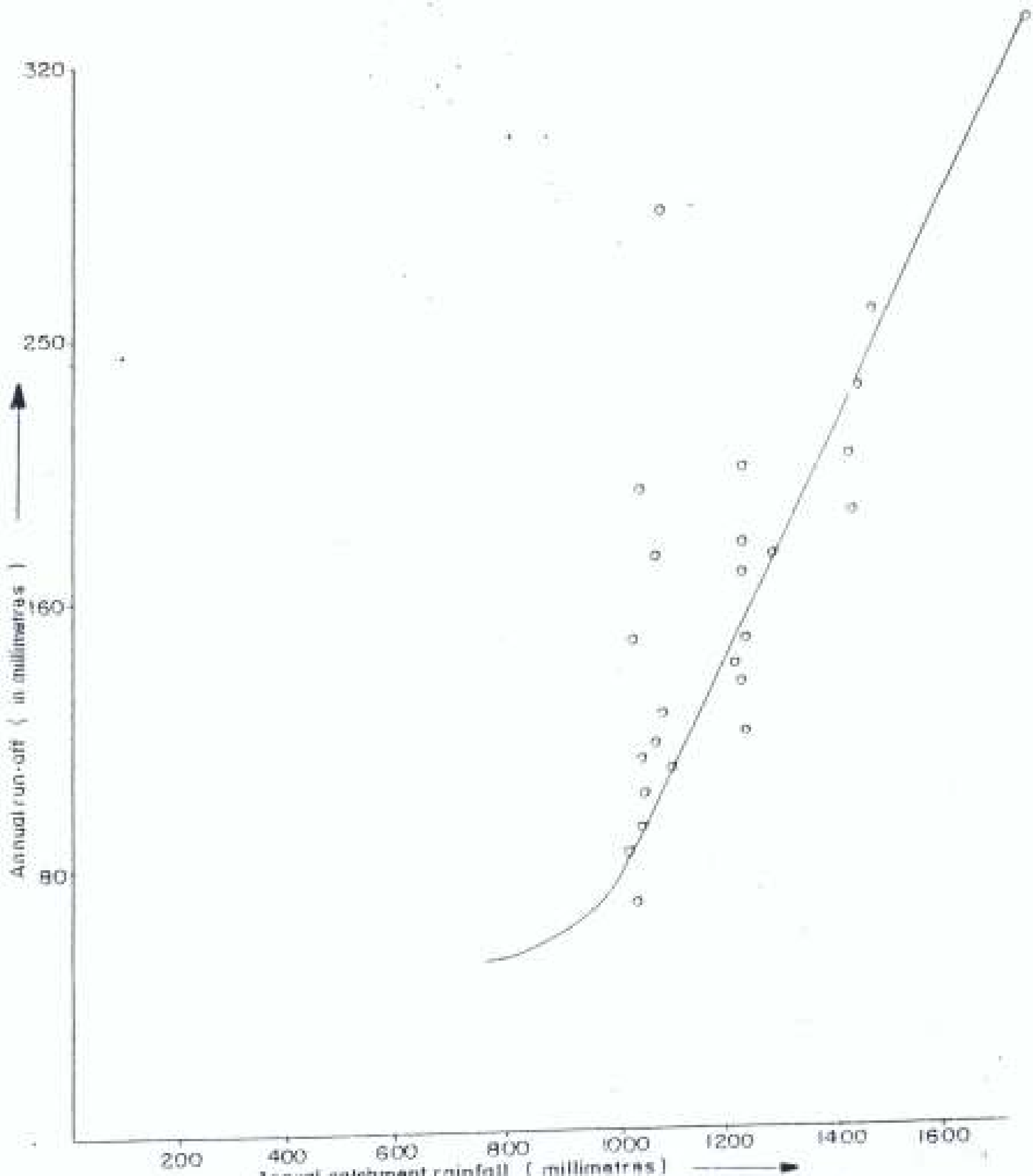

Fig.2.6 Annual rainfall-run off relationship within the basement complex region of Ogbesse river

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The temperature varies from a daily mean minimum of about 21^{0}C to a daily mean maximum of 29^{0}C. There are very slight variations in the daily minimum temperature throughout the year. On the other land, the mean maximum temperature is highest during the months of February and April (35^{0}C) and lowest in the months of July and August (28^{0}C). Relative humidity in the middle of the day average is about 80 percent during the wet season and about 50 percent during the dry season. In the early mornings, humidity is usually constant nearly 95% throughout the year.

2.3 Sediment Transport Problems

The sediment transport problems are mainly;

(a) Land erosion and conservation;

(b) Floods, meandering and flood control

(c) Sediment load computations;

(d) Silting of reservoirs;

(e) Degradation, Aggradations and local scour.

2.3.1 Land Erosion and Soil Conservation

When rainfall occurs in excess of the infiltration capacity of the soil, the flow of water over the soil surfaces exerts a drag of attractive force on the soil. The drag carries the soil particles dislodged due to impact of raindrops on the soil surface. This process of transportation of soil is retarded by the presence of grasses, weeds, tress and other vegetable on the ground. However, agricultural practices and deforestation expose soil mass to abrasive action of water and air-accelerated soil erosion takes place.

Soil conservation measures help to reduce the action of accelerated soil erosion. Study on land erosion and soil conservation requires a thorough knowledge of the mechanics of sediment transport.

2.3.2 Flood Meandering and Flood Control

Rivers, canal and stream drain the surplus water of precipitation of the sea. When there is excessive precipitation, water level in the river rises above the banks of water and spills to the low-lying areas. Such situations are known as flooding of riverbanks and streams. Rivers flowing through loose alluvial are characterized by the property that most of them follow zigzag paths. This phenomenon is known as meandering. These streams follow a more or less sinusoidal path in which water flows very slowly. Sometimes rivers change their courses considerably. The meandering, however, can be controlled through the construction of levees.

2.3.3 Sediment Load Computations.

Sediment transport process has been divided into wash load, suspended load and bed load as shown in Figure 1a.

(i) Wash Load

Much of the research into sediment transport has concentrated on suspended and bed loads. Wash load is that the matérial which river transports to its outlet, staying in suspension, without making contact with the riverbed. The particle size of wash load is very fine, consisting mostly of fine silts and clay sizes.

Wash load is measured in an indirect way compared with the suspended and bed loads, which are all observed directly as the quantity of particles passing per unit of time at the point of measurement, such observation is not possible with regard to wash load, as this very fine material does not settle quickly enough to be caught but remains in suspension. A sample of water - silt mixture must be taken and further analysed in the laboratory where the concentration of silt water is determined.

The amount of suspended sand in a wash load is negligible. By assuming that the silt particles travel at exactly the same speed as the water particles, the total transport of wash-load can then be computed.

(ii) **Saltation load:** It is the form of transported load in which sediment grains intermittently leave contact with the bed to form suspended load in turn, regains contact at some point downstream.

(iii) **Suspended load:** The suspended load is the combination of wash load and saltation. The amount of solid materials moving in suspension is quantified as a proportion of weight per unit volume of water containing the sediment and some sampling analysis was conducted to find out the weight sediment per unit volume of water. This weight per unit volume is termed the suspended solids concentration, expressed as milligrams per litre or parts per million (ppm). The concentration of sediments within a stream usually increases with depth, higher concentrations being observed nearest the streambed. The variation in concentration with depth depends on the particle size of sediment. The component sizes making up a generalized sediment concentration profile are shown in Figure 1.2

2.3.4 Silting of Reservoirs:

Storage of water for irrigation, water supply and power generation necessitates the construction of dam across rivers. As a consequence of reduced velocity upstream of the dam, all the bed load and part of the suspended load is deposited in a pool of water in the reservoir. This reduces the capacity of the reservoir to store water. Some of the problems in silting of reservoirs that need consideration and research are trap efficiency of the reservoir and its relation to the characteristic of the basin and the dam, pattern of deposition of sediment in the reservoir and passage of dense currents through sluices.

All reservoirs formed by dams on natural watercourses are subject to some degree of sediment inflow and deposition. The problem confronting the project planner is to estimate the rate of deposition and the period of time before the sediment will interfere with the efficient functioning of the reservoir. At the design stage, provision should be made for sufficient sediment storage in the reservoir so as not to impair the reservoir functions during the useful life of the project. The replacement cost of storage lost to sediment accumulation in American reservoirs amount to millions of dollars annually (Carreker and Hendrickson 1952).

2.3.5 Degradation, Aggradation and Local Scour

A certain length of an alluvial stream is said to be in regime or in equilibrium, if the amount of sediment coming into this reach is equal to the sediment going out from the same. This is also equal to the sediment transport capacity of the stream for given characteristics of sediment, flow and fluid. Hence the streambed elevation will not change over a long period of time. However, if incoming and outgoing sediment loads are different, the bed level must either rise or fall. A rise in bed level is known as aggradations, while a fall in bed level is known as degradation. If there is some obstruction, the increased shear stress causes the removal of the bed material around the vicinity of the obstruction, a phenomenon known as scour. Estimation and analysis of the variation of bed level in this way are necessary for proper hydraulic design of these structures.

2.4 Summary

Sediment load of a stream is a unique function of flow, fluid and bed material characteristics. Because the stream is the transporting agent it is reasonable that any attempt to predict the sediment yield of a watershed should utilize the sediment transporting characteristics of the stream as a key factor in the prediction. The watershed characteristic determines the runoff, and the bed material composition. The stream characteristic determines the sediment transport capacity. Together, the watershed and the stream characteristics are used to evaluate the sediment yield.

CHAPTER THREE

LITERATURE SURVEY

3.1 Introduction

It has been found convenient to split this review into two parts, namely the suspended load transport and bed load transport studies. A large number of past researchers have made significant contributions on the prediction on sediment transport in alluvial rivers. The contributions of Rouse (1937), O'Brien (1933), Einstein (1956), Hunt (1954), Ackers and White (1973), Graf (1971), Engelund and Hansen (1967), Laursen (1952), Vanoni (1952), Garde and Ranju (1985), McTigue (1981), Novntoft (1970), Wills (1979), Itakura and Kishi (1980), and Shvidchenko and Kapaliani (1999) are noted.

Rooseboom and Miham (1981) presented techniques for determining sediment loads in South African rivers. Yang and Wu (1996)studied transport in Laba River in Russia, they concluded from their findings that the rate of sediment yield is a direct function of its watershed and stream characteristics. Garde and Ranju (1985) found from the study of sediment transport in the Ganges River, India, that peak sediment discharges correspond with peak floods. Gondwe (2000) studied the relationship of sediment transport with discharge of the Ruvu river in Tanzania and came up with the conclusions that the duration of data collection influences the parameters of rating equations and that the rating equation varies with stage. All these contributions were geared towards the proper understanding of suspended sediment transport theory.

3. 2. Basic Theory of Sediment Transport

3.2.1 Suspended Sediment and Turbulent Flows

Schmidt (1925), while studying the suspension of dust particles in the atmosphere gave the general diffusion equation as:

$$\omega_o C + \epsilon_s \frac{\partial C}{\partial y} = 0 \qquad \text{.........................} \qquad (1)$$

where ω_o = fall velocity of sediment

ϵ_s = sediment diffusion coefficient

c = sediment concentration, and

C_a = sediment concentration at 'a'.

According to Garde and Ranju (1985), Figure 3 is applicable in sediment transport where the net upward sediment transport is proportional to the concentration gradient $\partial c/\partial y$ and hence it can be represented by $\epsilon_s\, \partial c/\partial y$ in which ϵ_s is the sediment diffusion coefficient. The net download sediment transport at any horizontal will be ω_o C, where ω_o is the fall velocity of the sediment and C is the sediment concentration. Equation (1) for equilibrium of sediment obtained from the general diffusion equation is one dimensional and can be extended to three dimensional. Dobbins (1994), Iwaki (1947) and McNowin (1944) gave the form of a general diffusion equation of foreign particles in fluid.

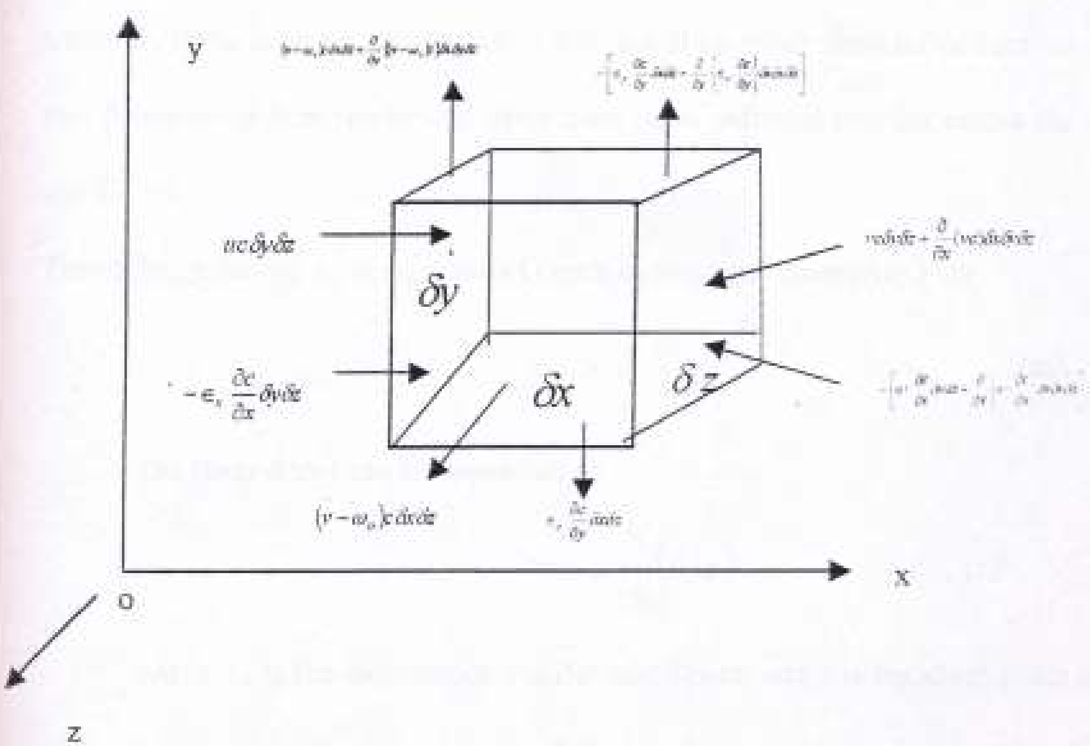


Figure 3.1: Inflow and outflow of sediment flux through various faces of a parallelepiped.

Consider an elementary cube of sides ∂x, ∂y, ∂z and volume $\partial v = \partial x\ \partial y\ \partial z$ to the change per unit time due to diffusion, by equating all the horizontal forces with the vertical forces acting on the element together as shown in Figure 3.1 above, one obtains equation (2)

$$\left(\frac{\partial c}{\partial t}\right)\partial x\partial y\partial z = \left[-\frac{\partial}{\partial x}(uc)+\frac{\partial}{\partial x}\left(\in_x \frac{\partial c}{\partial y}\right)-\frac{\partial}{\partial y}\left((v-\omega_o)+\frac{\partial}{\partial y}\left(\in_y \frac{\partial c}{\partial y}\right)-\frac{\partial}{\partial z}(\omega C)+\frac{\partial}{\partial z}\left(\in_z \frac{\partial c}{\partial z}\right)\right)\right]\partial x\partial y\partial z \quad \text{.........(2)}$$

Dividing equation (2) by $\partial x\ \partial y\ \partial z$, one gets

$$\frac{\partial c}{\partial t}+\frac{\partial}{\partial x}(uC)+\frac{\partial}{\partial y}(vC)+\frac{\partial}{\partial z}(\omega C)=\frac{\partial}{\partial x}\left(\in_x \frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(\in_y \frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(\in_z \frac{\partial C}{\partial z}\right)+\omega_o \frac{\partial C}{\partial y} \quad \text{.............(3)}$$

The foregoing equation was also given by Hayami (1938).

Integrating Equation (3) with respect to y, we get in one dimension

$$\in_y \frac{\partial C}{\partial y}+\omega_o C = C_1(x,z,t) \quad \text{.............................(4)}$$

where C_1 is the constant of integration which will be either constant or zero for steady uniform two dimensional flow. However, since there is no sediment transfer across the free surface so that $C_1 = 0$.

Therefore, replacing $\in_y$ in equation (4) with $\in_s$ one gets equation (1) viz

$$\omega_o C + \in_s \frac{\partial c}{\partial y} = 0 \quad \text{.........................(4a)}$$

The shear stress can be expressed as

$$\tau = \in_m \frac{\partial}{\partial y}(\rho_f \mu) \quad \text{.......................(5)}$$

where $\in_m$ is the momentum transfer coefficient, and τ is the shear stress at the distance y from the boundary, ρ_f is the density of fluid and μ is the dynamic viscosity of the fluid This equation proposed by Boussinesq Karman (1934) gave the analogy between transfer of mass, heat and momentum. Therefore an equation similar to equation (5) can be written for the transfer of suspended sediment viz

$$G = -\in_s \frac{\partial}{\partial y}(C) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Here G is the rate of sediment transport per unit area in the upward direction.

Karman also pointed out that transfer coefficients for momentum, mass and heat may not be the same.

3.2.1.1 Integration of Sediment Distribution Equation

Equation (1) is the differential equation for distribution of suspended material in the vertical. Direction in order to get the relative distribution, separating the variables of equation (1) gives:

$$\frac{\partial c}{c} = -\frac{\omega_o}{\in_s}\partial y \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7a)$$

This can be integrated between the limits a and y to give

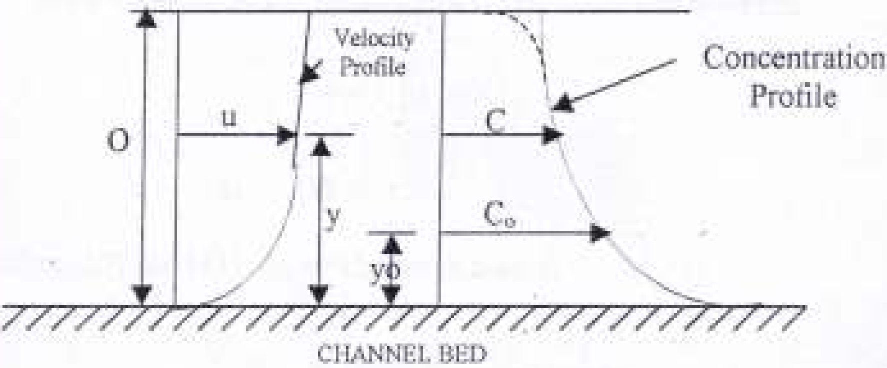


Figure 3.2: Definition sketch for velocity and concentration profiles in a channel vertical section

$$\ln \frac{C}{C_a} = -\int \frac{\omega_o}{\in_s}\partial y \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7b)$$

in which C and C_a represent the concentrations of suspended load at distances y and a respectively from the bottom (Figure 3.2). The expression on the right-hand side of equation (7b) can be integrated if the variations of ω_o and $\in_s$ with y are known.

As an approximation, it can be assumed that both ω_o and $\in_s$ remain constant with respect to y.

$$\ln\frac{C}{C_a} = -\frac{\omega_o}{\in_s}(y-a) \qquad \text{.........................(8)}$$

or

$$\frac{C}{C_a} = \exp\{-\omega_o(y-a)/\in_s \qquad \text{.............................(9)}$$

Although, the variation of $\in_m$ with y (in clear water) is known, $\in_s$ varies with y. As an approximation, $\in_s$ and $\in_m$ are assumed to have the same value. The coefficient $\in_m$ can then be evaluated as follows.

From equation (5) for constant ρ_f:

$$\in_m = \frac{\tau}{\rho_f}\left(\frac{du}{dy}\right) \qquad \text{.............................(10)}$$

Since the shear stress varies linearly with distance from bed

$$\tau = \tau_o\left(1-\frac{y}{D}\right) \qquad \text{..........................(11)}$$

where $\tau_o = y_f DS$

combining (10) and (11), $\in_m$ can be expressed as

$$\in_m = \frac{\tau_o}{\rho_f}\left(\frac{D-y}{D}\right)\frac{1}{du\ dy} \qquad \text{.............................(12)}$$

Furthermore, the velocity gradient du/dy can be obtained from Karman's velocity defect law for open channels, as

$$\frac{U-U_{max}}{U_*} = \frac{1}{K_o}\ln\frac{y}{D} \qquad \text{..............................(13)}$$

$$\frac{du}{dy} = \frac{U_*}{K_o}\frac{1}{y} \qquad \text{...............................(14)}$$

where U_{max} is the maximum local velocity and K_o is Karman's constant for clear-water flow and is equal to 0.4.

Combining equations (12) and (14) gives:

$$\in_m = \frac{\tau_o}{\rho}\left(\frac{D-y}{D}\right)\frac{K_o y}{U_*}$$

$$= U_*^2\left[\frac{D-y}{D}\right]\frac{K_o y}{U_*}$$

$$\in_m = U_* K_o y\left(\frac{D-y}{D}\right) \qquad \text{.................................(15)}$$

Assuming $\in_s = \in_m$ and substituting equation (15) and Equation (1) gives:

$$\frac{dc}{c} = -\frac{\omega_o}{U_* K_o y}\frac{Ddy}{(D-y)}$$

and hence

$$\ln\frac{c}{c_a} = -\frac{\omega_o}{U_* K_o}\int_a^y \frac{Ddy}{y(D-y)} \qquad \text{.............................(16)}$$

Integrating gives

$$\frac{C}{C_a} = \left(\frac{D-y}{y}\cdot\frac{a}{D-a}\right)^{z_o} \qquad \text{.........................(17)}$$

in which $$z_o = \frac{\omega_o}{U_* K_o} \qquad \text{.................................(17a)}$$

Equation (17) is the Rouse (1937) sediment concentration function. The quantity ($z_o = \omega_o / U_* K_o$) is the exponent of sediment distribution equation, presented in equation (17a). Equation (17) was first published by Rouse (1937) but independently derived by Ippen (1939).

In equation (17), the parameters are:

D = Stream depth at vertical

ω_o = Fall velocity of sediment particles

K = A constant given by von Karman (0.4 in clear water)

C = Concentration at discharge of y from the bed

C_a = Concentration at some reference level a

τ_0 = Bed shear stress

ρ = Density of water

S = Slope of river bed

U_* = Bed of shear velocity $\sqrt{\tau_o / \rho}$

3.2.2 Bed Loads

Sediment load is generally divided into suspended and bedload. While suspended load distribution can be determined fairly accurately on the basis of equation (17), prediction of the bedload transport is still problematic and the formulas proposed so far do not provide a good fit to all the data.

The earliest know bedload equation was derived by Duboys (1878) on the basis of a simplified hypothesis in which layers of bed material were supposed to move due to the bed shear as part of which acted on each such layer. Among these can be cited Meyer – Peter and Muller (1948) and O'Brien (1933). All their derivations can be said to be empirical.

Einstein (1950) departed radically from the Duboy's type of analysis. He equated the probability of the movement of particles, and the ratio of the fluid forces to the resistance of the article, and obtained what is called a general bed load function. Bagnold (1954) equated the rate of useful work done on the bed load transport to the available fluid energy at the bed.

All the preceeding formulas give results which may be several time in error compared to the actual bed load movement. Einstein's method is considered to be most satisfactory so far but its universal applicability has been doubted by several investigators. Egiazorff (1985) compared actual measured values for bed load transportation with values calculated by Einstein's method and found large variations between the two. However, Bagnold's method has not also been widely accepted. A new formula based on energy balance theory as proposed by Garde and Ranju (1985) has been found to give better results. The concept is based on the fact that as no sediment transport occurs if the shear force on the bed is below a certain value. The work done by any shear force in excess of this critical value should be responsible for the movement of the sediment particles and sustenance of turbulence in flow, the total bed shear, τ'_o. For determining the shear due to grain τ''_o Einstein's. method using Prandtl's logarithmic formula for mean flow velocity can be used. The shear due to bed form τ''_o which is exclusively responsible for overcoming the grain shear τ'_o only should be considered.

The fluid energy per unit area per second which overcomes the grain resistance, the sediment particles and sustains turbulence, is given by Egaizorff (1985) as τ_o V in which V was taken as the mean velocity of flow in the channel. The work done in transporting the bed load was also considered as a function of the size and the velocity of the moving particles as well as the fluid velocity, which varies along the depth of flow. Bagnold (1954) considered the effective velocity of flow to occur at the top of the bed particles for purposes of bed movement. However, the concept of Einstein seems move reasonable, according to which the velocity, V_1, pertinent to the determination of the fluid forces acting on a particle placed on the bed can be taken to be that a height 0.35 X from the theoretical bed. The symbol X represents the characteristic grain size of the mixture and is given by

$$X = 1.39\delta \text{ if } \frac{\Delta}{\delta} < 1.80$$
$$= 0.77\Delta \text{ if } \frac{\Delta}{\delta} > 1.80 \qquad \text{.......................(18)}$$

in which Δ is the diameter of apparent roughness and δ is the thickness of the laminar sub layer. The theoretical bed is defined as the position of datum for which the measured velocity conforms to the Prandtil's flow equation. The energy available for moving the sediment particles and overcoming grain friction is therefore given by $\tau_o V_1$. Because the grain resistance is overcome by the critical attractive force, τ_c leaving the balance force (τ_o - t_c) per unit area to move the bed material, the energy unit area, E_f, available after doing work in overcoming the rain resistance is given by:

$$E_f = (\tau''_o - \tau'_c)V_1 \qquad \text{.............................(19)}$$

Beside the fluid energy, the gravitational force component, F_g in the direction of motion of the particles supplies additional energy to them. If he particles are considered spherical this energy rate is given by

$$F_g V_s = [\gamma_s - \gamma_f] \frac{\pi d^3 n}{6} Sin\alpha \, V_s \qquad \text{.......................................(20)}$$

in which γ_s and γ_f are the unit weight of sand and water respectively, d is the mean sand diameter, n is the number of moving particle and V_s is the velocity. If the bed slope of the channel is small sin α can be replaced by the bed slope S, and the expression becomes

$$F_g V_s = [\gamma_s - \gamma_f] \frac{\pi d^3 n}{6} \, nSV_s \qquad \text{.......................(21)}$$

fluid force, F_D, acting on the moving particles per unit area is given by

$$F_g V_s = [\gamma_s - \gamma_f] \frac{\pi d^3 n}{6} Sin\alpha \, V_s \, \rho_f \qquad \text{.......................(22)}$$

In which C_D is the coefficient of drag and f is the density of the fluid.

Therefore the rate of work done on the particles per unity area is given by

$$F_D V_S = \frac{\pi d^3 n}{8} \, n(V_1 - V_s)^2 \, \rho_f V_s \qquad \text{.......................(23)}$$

The energy available for sediment transport should be equal to the rate of work done on the articles and so, from equations 19, 21 and 23,

$$(\tau^1 - \tau_c) V^- + [\gamma_s - \gamma_f] \frac{\pi d^3}{6} \, {}_n SV_s$$

$$= \frac{\pi d^2}{8} \quad nC_D (V_1 - V_s)^2 \rho_f V_s \qquad \text{.......................(24)}$$

The average bed transport by weight per second per unit width q_b depends upon the number and size of the particles being moved, their specific weight and their average velocity. For spherical particles this is given by

$$q_b = \frac{\pi d^3}{6} n\gamma S V_s \qquad \text{.......................(25)}$$

substituting the values of n from equation (24) into (25), the expression for bed load transport rate may be written as

$$q_b = \frac{(\tau^{1_o} - \tau_c)V_1}{\left[\frac{3C_D(V_1 - V_s^2)\rho f}{4d\gamma_s}\right] - \left[\frac{(\gamma_s - \gamma_f)s}{\gamma_s}\right]} \qquad \text{.......................(26)}$$

According to Garde and Ranju (1985) particles travelling as bed would move with an average velocity which would require maximum expenditure of energy. Thus the derivates of rate of work done with respect to grain velocity should be zero. Assuming the drag coefficient to be constant, equation (26) becomes

$$\frac{\partial}{\partial v_s}\left(\frac{\pi d^2}{8} nC_D\{V_1 - V_s\}^2\right)\rho_f\ V_s = 0 \qquad \text{.......................(27)}$$

gives Vs = V or $V_1/3$. When Vs = V the workdone will be zero and as such V1/3 will result in the maximum work. On substituting value of Vs equation (27) reduces to

$$q_B = \frac{(\tau^{1_o} - \tau_c)V_1}{\left[\frac{C_D\rho_f V_1^2}{3d\gamma_s}\right] - \left[\frac{(\gamma_s - \gamma_f)s}{\gamma_s}\right]} \qquad \text{.......................(28)}$$

The term $(\gamma s - \gamma_f)s/\gamma_s$ s is generally negligibly small in comparison to the term $C_D\rho_f V_1^2 / (3d\gamma_s)$. Equation (29) can therefore be used in the following simple form for most of the practical computations of bed load transportation in alluvial channels or rivers.

$$q_b = \frac{3(\tau_o - \tau_c)\, d\gamma_s}{C_D\ \rho_f\ V_1} \qquad \text{.......................(29)}$$

3.2.3 Recent Advances in Sediment Transport Studies

Guo and Wood (1995) presented a simple analytic expression for calculating the suspended transport rates by assuming a parabolic distribution of eddy viscosity, which results in a Von Karma - Prandtl - type velocity distribution profile, and Rouse's sediment concentration profile., the resulting equation for sediment transport rate requires a set of hydraulic conditions and a reference sediment concentration. This expression is easy to use in practical applications, and predicted transport rates compare favourably to rates calculated from field measurements. Cellino and Graf (1999) studied the effect of β - values used in Rouse number, defined as $Z^1 = \frac{V}{\beta K U^*}$ on the sediment laden flow in laboratory flume under capacity and non capacity conditions. Cellino and Graf (1997) study focussed on the experimental determination of the β - value which incorporates the ratio of the sediment flux C^1V^1 and the momentum flux U^1V^1, as well as the velocity small particles, d_{50} = 0.135mm, the β - value at capacity condition are smaller than unity; at non capacity condition, the β – values are usually larger than the ones at capacity condition, but are still smaller than unity.

Monilas and Wu (1999) did a comparative study of different bed load material formula. The result he obtained showed the overall accuracy of the fomulas in descending order as those of Yang (1968), Engelund and Hansen (1967), Ackers and White (1973). Laursen, (1958), Colby and Hembree (1955), Einstein (1950) and Toffaleti (1969) formula when applied to laboratory flumes. The accuracy in descending order when applied to natural rivers are the formulas by Yang, (1973) Toffaleti, Einstein, Ackers and White, Colby and Hembree, Laursen, Engelund and Hansen. However, these rating vary depending on the values of sediment concentrations, Froude number and slope for the data used in the comparison. The study also indicates that Yang's formula by size fraction can accurately predict the size distribution of bed material in transportation, while Einstein's hiding and lifting correction factors corrected the effect of bed material size gradation on transport of sediment mixtures such as D_{35} or D_{50}

Molinas and Wu (1999) studied the effect of size gradation on transport of sediment mixtures. Total bed material load computations for non-uniform sediment mixtures were evaluated for commonly used Engelund and Hausen, Ackers and White, and Yang formulae. The result of sediment transport computation indicate considerable scatter in bed-material load Transport relations for non-uniform sediment mixtures. The study demonstrated that a single fixed gradation, such D_{35} or D_{50} cannot reflect the presence of various size fractions on the transport of no-uniform sediment mixtures.

In this study, size gradation compensation factor Kg was used to normalize the effect size distribution on the transport of sediment mixtures. The size gradation compensation factor, Kg, which is a function of the geometric standard deviation, □g, of the bed material and the flow conditions, in conjunction with D_{50} of the bed material yields an equivalent representative diameter De. By including De in the Engelund and Hansen, Ackers and White, and Yang formulas, the agreement between computed and measured bed-material concentrations was improved significantly. These results for 118 sets of laboratory and field data were further verified by the use of Colorado State University (CSU) experimental data that included three different Kg, values for the same sediment size.

Most of the existing sediment discharge relations either give total sediment discharge only or are unreliable for predicting sediment discharge for each size fraction. The interaction between different size fractions in a non-uniform sediment bed is taken into account through the formulation of a weighting function for each fraction; consisting of two components: (a) Areal fraction for each grain size on bed and (b) a "Sheltering" factor reflecting reduction in the transport of finer grains due to sheltering by larger ones. The relation was applied to several data sets including both river and laboratory flows. Agreement between computed and observed values was good for both total sediment discharge and its size distribution. However, prediction was less accurate for flows with significant amounts of nonmoving coarser particles armoring the bed surface, indicating the need for further research for such flows. A simplified relation based on median sediment size (D_{50}) only proposed by Karim (1993) is found to give good result for predicting total sediment discharge per unit width q, for an alluvial stream. It was also found to perform better than several existing sediment transport functions. This relation is given as

$$\frac{q}{\sqrt{(\gamma-1)gd^{3}_{50}}} = 0.000139\,\frac{[V]^{2.97}}{\sqrt{[g(s-1)D^{3}_{50}]^{2.97}}}\,\frac{[U_{*}]^{1.47}}{[\omega]} \qquad \text{......................(31)}$$

where V is the flow velocity, m^3/s, ω is the particle fall velocity, mm/s, U_* is the particle shear velocity, m^3/s, D_{50} is the mean sand sample (mm), S is the specific gravity of sediment. Areal fraction of bed materials P_m, and a sheltering factor η, were incorporated by Karim (1998) to obtain his final equation given by

$$\frac{q}{\sqrt{(\gamma - 1) g d_{50}^{3}}} = 0.000139 \left[\frac{V}{\sqrt{(\gamma - 1) g d_{50}^{3}}} \right]^{2.97} \left[\frac{U_*}{\omega} \right]^{1.47} Pai\,\eta \quad \text{.................(31)}$$

In conclusion, Karim (1998) observed that his equations (30) and (31) are basically the same as no significant difference exists between the results obtain with any of them, since the value Pai η is almost unity. He therefore, recommended the use of any of the equations above for use in the computation of total sediment discharge for alluvial streams. It is for these reasons that Karim (1998) equations (31) above is used in the verification of the models obtained in this study.

CHAPTER FOUR

RESEARCH METHODOLOGY

The research procedure consisted of two main approaches: Field Data Collection and Model Development. Field investigations were conducted on the two rivers, Ogbese and Owena to obtain the relevant data water discharges and sediment loads.

4.1 Field Investigation Approach

Field measurements of sediments transport consisted of the following procedures (a) selection of the sampling stations (b) survey of the cross – section profile of the river (c) suspended load sampling and (d) Bed load sampling.

The choice of a site for a field station were made such that the results obtained were representative of conditions in the stream as well as providing the necessary information. The following sampling stations were identified for this research work on Ogbese and Owena rivers respectively. These are shown in the boxes below

Ogbese River

Stations	Locations	Reach
A	Ado, Ijan Ekiti Road Bridge at Adeloju	Upper
B	Ikere – Ise Ekiti Road Bridge at Ogbese	Middle
C	Akure – Owo Road Bridge at Ogbese	Lower

Owena River

Stations	Locations	Reach
D	Ikogosi / Okemesi	Upper
E	Akure – Ondo Bridge at Owena	Middle
F	Siluko along Benin – Ore old Road.	Lower

However, two stations were selected, one on each river. These were Ogbese Bridge crossing for Ogbese River on the Akure – Owo highway and Owena Bridge crossing for Owena River on the Akure – Ondo highway. These samplings had to be done at stations where there are man – made structures, such as bridges, within the river for the purpose of convenience. Figures 4.1 and 4.2 show the locations of the sampling stations Figures 4.3 and 4.4 show the cross section of the rivers under study respectively at the sampling locations.

Already existing at each of the stations was a water level recorder for measurement of river level, which was converted to discharge through calibration with current meter. Stream velocities were obtained at these stations by relating the cross- sectional profiles obtained by survey on the river to the corresponding discharges. Depths were determined by sounding using each sounder and poles to dip into the stream vertical down to the riverbed. Sediment discharge data were obtained using Delft or slough bottle DH – 59 samplers for suspended load (Fig. 4.5) and Bed load Transport meter "Arthem" (B.T.M.A.) instrument for bed load, (Fig 4.6).

BTMA is a modern equipment designed and developed by the Netherlands Rijkswaterestat (see Figure 4.5a). The instrument consists of a frame with a steering fin, which keeps the apparatus in the right direction relative to the current. In that frame, a catch – basket is fixed with an entrance opening of 8½ x 5cm. The B.T.M.A. was lowered into the river bottom and it remained there for few minutes (mostly 2 minutes). The amount of sediment caught was measured after emptying into a glass cylinder container. This procedure was repeated five times in order to arrive at an average figure for the streambed load discharged.

The volumes of both the suspended load samples and bed load samples were recorded in the standard recommended form. Ten beds – load observations were taken each time by lowering BTMA instrument into river bottom and leaving it there for two minutes.

Using the appropriate conversion table the amount of bed load transported in m^3/day/km was computed from the amount of sediment caught by the B.T.M.A instrument.

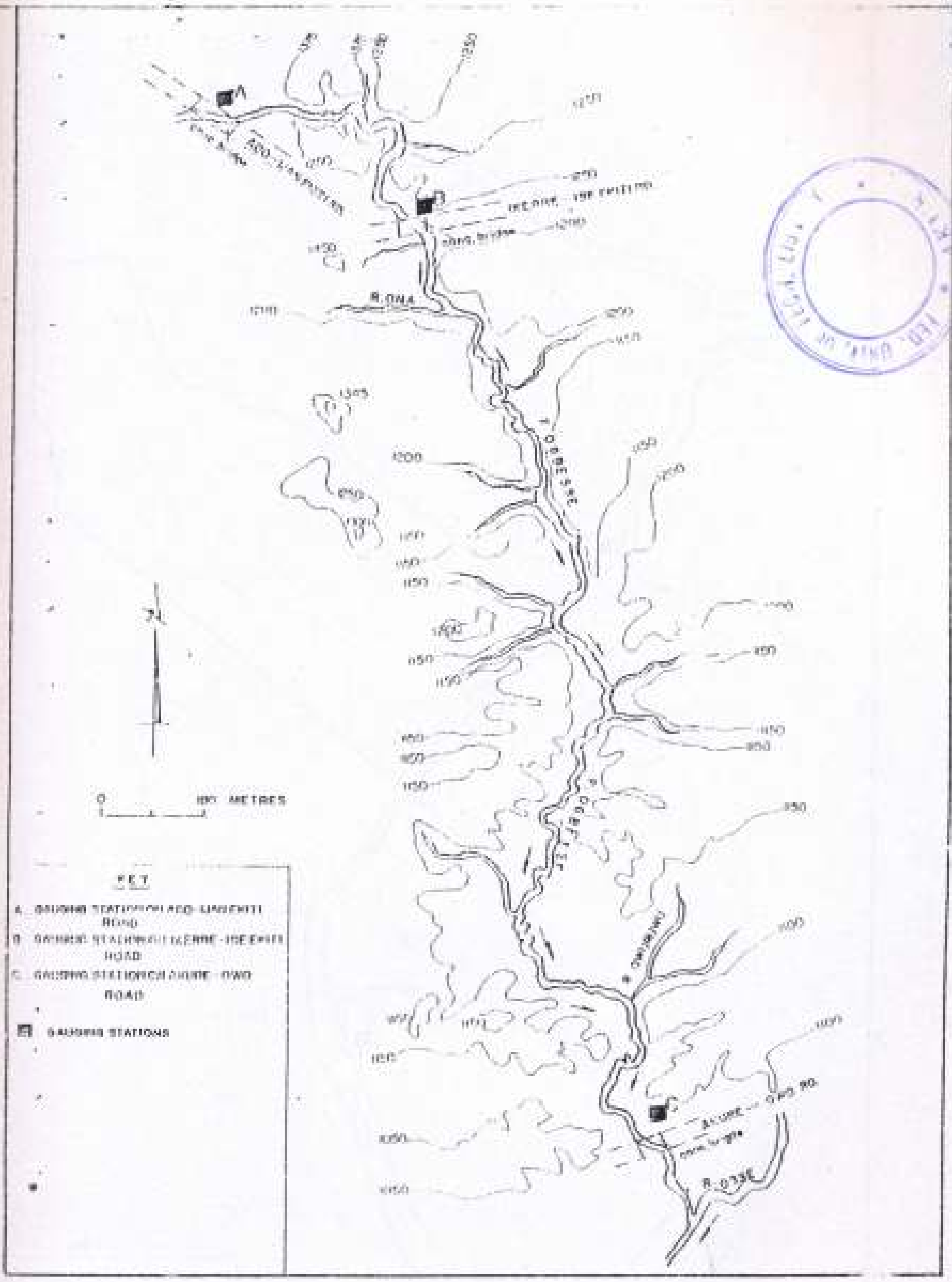


Fig. 4.1 Locations of Gauging stations along the upper, middle and lower Ogbese River

(SOURCE: OBRDA 1993 Handbook)

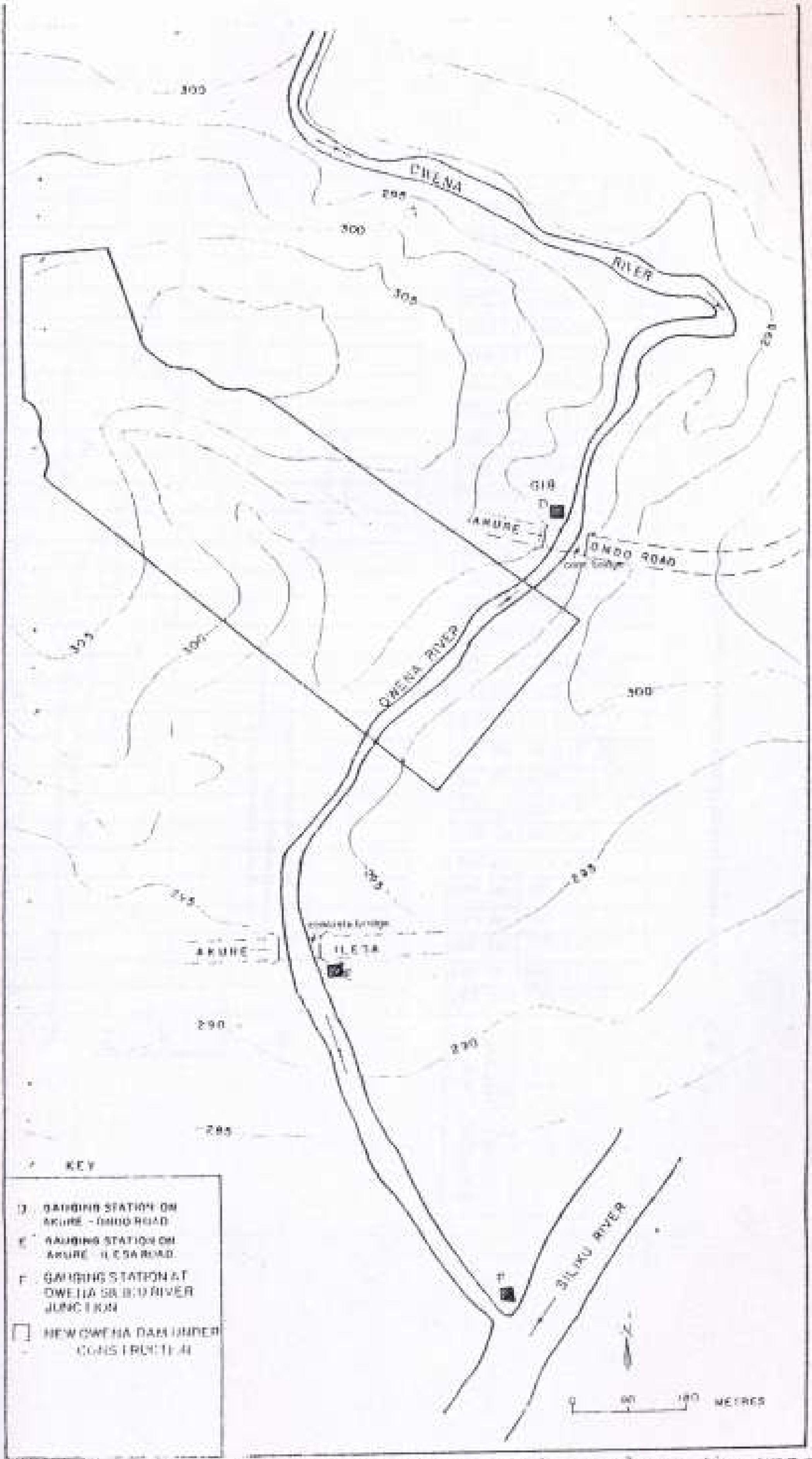
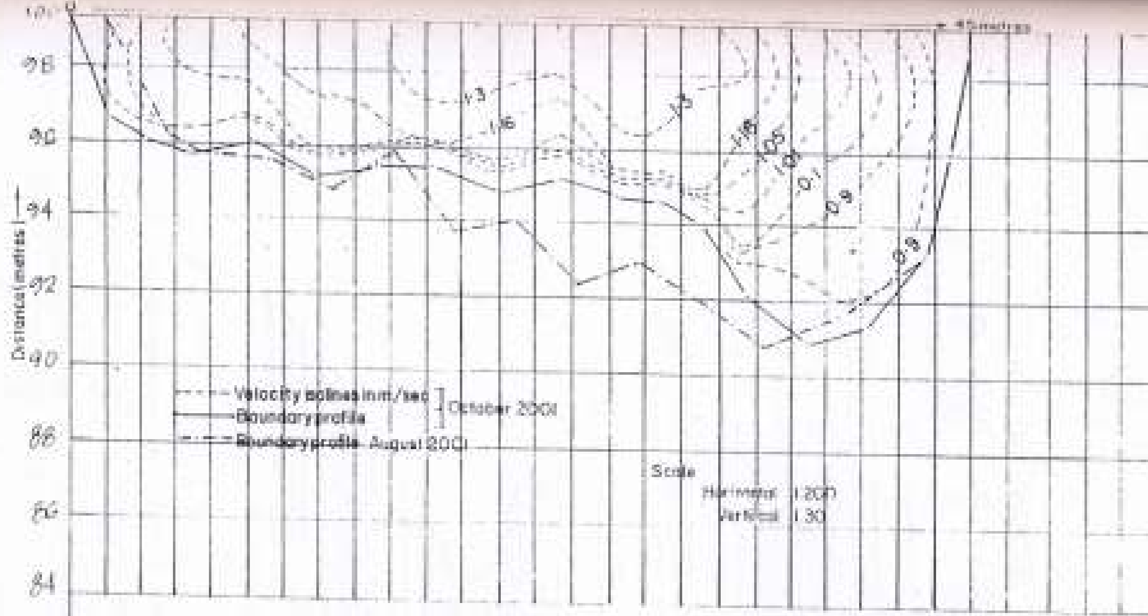


Fig. 4.2 Locations of Gauging stations along the upper, middle and lower Owena River.

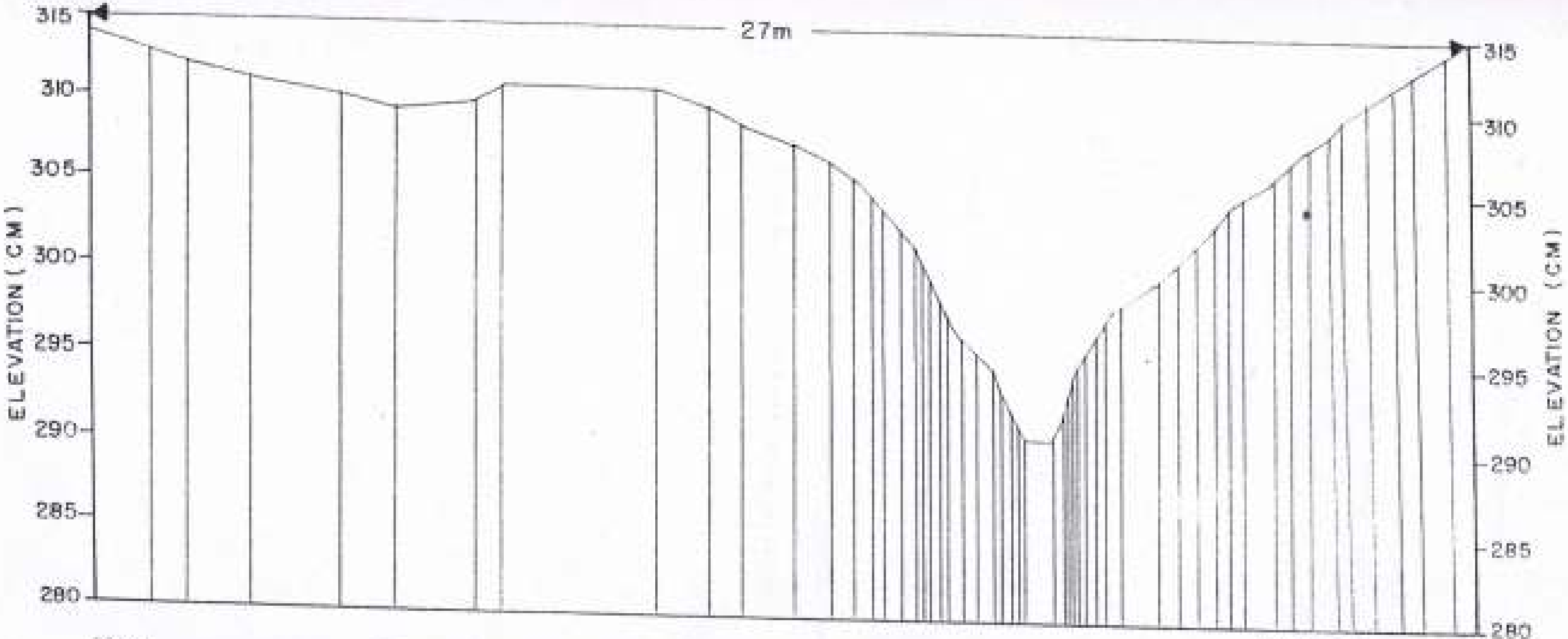
(SOURCE: OBRDA 1993 Handbook)



EXISTING GROUND LEVEL UPPER AXIS	CHAINAGE
100.483	0+140
100.542	0+150
99.884	0+160
99.521	0+170
99.163	0+180
98.924	0+190
98.377	0+200
97.562	0+210
96.218	0+220
94.717	0+230
94.819	0+240
93.841	0+250
91.782	0+260
90.047	0+270
90.348	0+280
92.140	0+290
92.616	0+300
93.001	0+310
94.000	0+320
94.200	0+330
95.100	0+340
96.000	0+350
96.558	0+360
97.000	0+370
97.387	0+380
97.708	0+390
98.264	0+400
98.413	0+410
99.862	0+420

Fig 4.3 Cross section of River Ogbese at Akure – Owo road bridge

PSE Consultants (1999)



SCALE
HORIZONTAL 1:250
VERTICAL 1:50

SOURCE: FSE CONSULTANTS ENUGU

Fig. 4-4: CROSS SECTION OF OWENA RIVER AT AKURE - ONDO ROAD BRIDGE

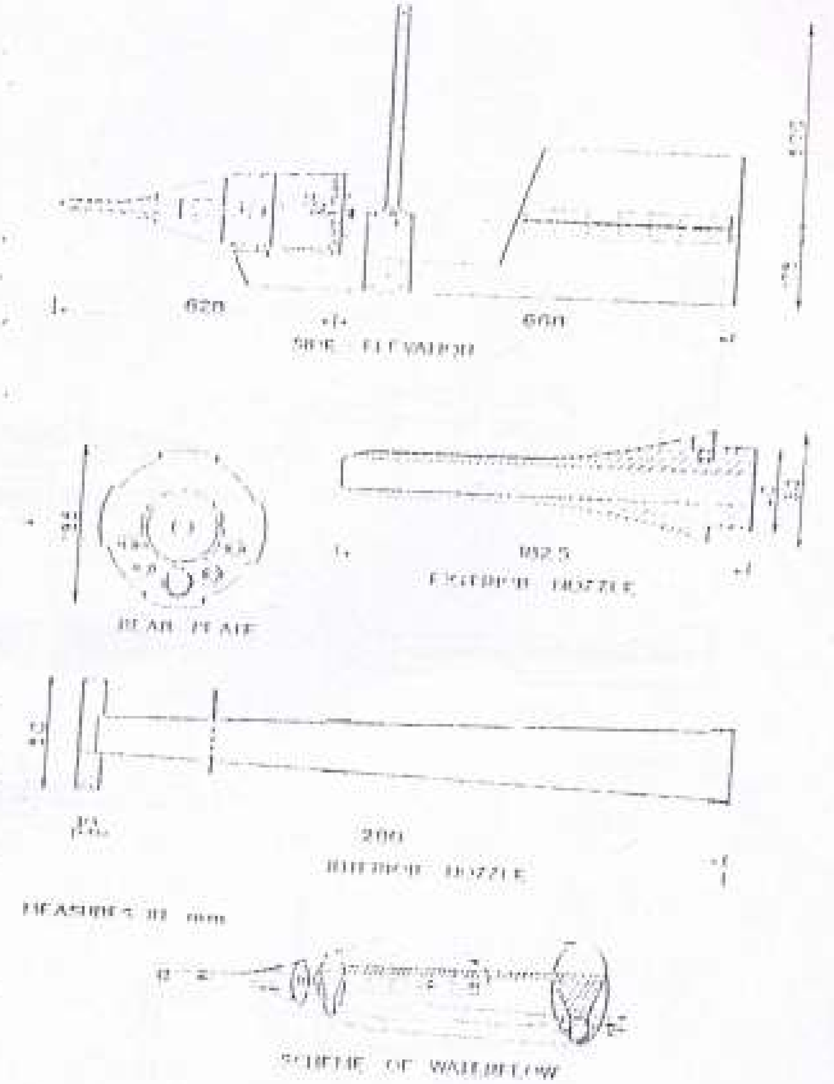


Fig. 4.5 Delft bottle on wire DF_1

(Source: Berlekom 1971)

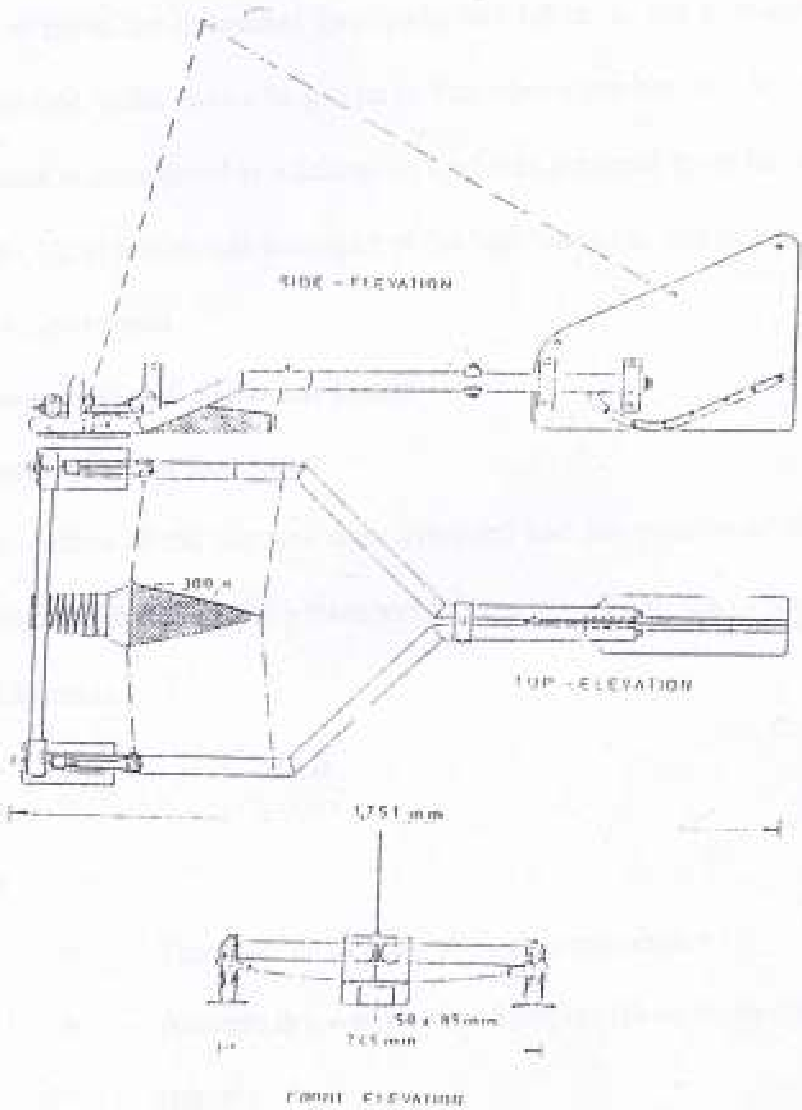


Fig. 22 Bed-load transport meter "Arnhem" (B.T.M.A.)

The mean of these ten computed bed loads was taken as the average quantity of sediment transport per unit width over a height up to 5cm above the bottom. An addition of 15% to this amount, which is considered as a salutation load was assumed to be transported over the height from 5cm to 10cm which still belonged to the bed loads but which was not directly measured by B.T.M.A. instrument.

4.2. Computation of Sediment Loads

4.2.1 Computation of Bed Load

The catches of the samples were averaged and the volume of the average catch or the complete catch converted to daily transport m^3/day/km / by means of the (ISO 1977a, 1977b) conversion formula.

$$S = \frac{2.G.B}{0.085T} \quad \text{.............................(32)}$$

where

S = Transport in kg / day through cross section

G = Average dry weight of all samples taken in the cross section (kg/m^2)

B = Width of the river (m)

T = Sampling time (of one measurement) 2 mins.

4.2.2 Computation of Suspended Sediment Load

According to many researchers among them Kinori et al (1984), suspended load is carried by water across a stream section above the bed layer. It consists of particles that stay suspended from an appreciable length of time and usually consists of sand and finer fractions.

From the collected sediment transport sample, the concentration Cs (mg/l) was determined in the laboratory, from which the daily sediment yield (Qs) ton / m^2 / day) was obtained, using the equation;

$$Qs = Q \times C_s \times K \qquad \text{..(33)}$$

where ,

Qs = Sediment discharge

Q = Water discharge

C_s = Concentration of suspended sediment

K = 86.4

The value of K has already incorporated the specific gravity of 2.65 typically used for soil volume conversion during the computation. The suspended sediment concentration can be obtained in the Laboratory by using the formula below:-

$$\frac{\text{Dry weight of Sediment}}{\text{Weight of Water + Sediment mixture}} \text{ X1000} \quad \text{in parts per million}$$

Sediment concentration in parts per million C_s was converted to milligram per litre by a factor C_s According to the Iso 4363, 1977a, methods measurement of suspended sediments recommendations, Geneva, 1977a uses the following relation

C_s (milligram per litre) = $C \times C_s$ (Part per million)

C was given as 0.0864 by report No 14 US Federal International - Agency on sedimentation projects (1963)

4.3. Analysis of Data

The data were either subjected to one - way analysis of variance (ANOVA), or F - statistics test, in accordance with the procedure of Steel and Torrie (1960) with the coefficient of variation of 1 to 5% and to correlation and multiple regression analysis (Snedecor and Cochran, 1973). Means were separated by multiple range test of Duncan (1955).

The results obtained were tested with some established river models of Ackers and White (1973), Englund and Hansen (1967), Yang (1973), Karim and Kennedy (1991) and Karim (1998). These models were chosen because they are deterministic in nature, and can be applied to rivers in both temperate and tropical regions of the world.

Four different statistical methods of comparisons were used to compare the results obtained with these established relations with the new river models developed by the investigator. These are

(1) A discrepancy ratio

$$R = \frac{X_{ci}}{X_{mi}} \quad \text{.......................................(34)}$$

in which X_{ci} and X_{mi} = computed and measured bed material concentration in Kilogram / cubic meter, respectively.

(2) The standard deviation between computed and measured bed material concentrations

$$\delta = \sqrt{\sum_{n=1}^{n}\left[\frac{(X_c - X_m)^2}{n-1}\right]} \quad \text{.................................. (35)}$$

in which n = data set number, n = 1,2.............n

= total number of data sets.

(3) The mean normalized error (MNE)

$$MNE = \frac{100}{n}\sum_{n=1}^{1}\left[\frac{(X_c - X_{mi})}{X_{mi}}\right] \quad \text{................................(36)}$$

and

(4) Mean Prediction Factor (MPF)

$$MPF = \frac{1}{n}\left[\frac{X_m - X_{ci}}{X_c - X_{mi}}\right] = \frac{X_{mi}}{X_{ci}} \quad \text{............................ (37)}$$

4.4 Development of Sediment Transport Models For Ogbese and Owena Rivers

The development of sediment transport equation for the two rivers (Ogbese and Owena) have been achieved by the coupling of Liu – Wang (1959) resistance equation with Einstein – Brown (1981) sediment transport concept. Two expressions were deduced to get the total sediment discharge per unit width across the river channels.

4.4.1 Introduction

The equations were developed based on two principles:

(i) The tractive force theory and (ii) the regime theory

The two methods are complementary, with the tractive force method representing the limiting case. However, for any model to be successful it must be based on the principle as presented by the Task Force Committee on Sedimentation of the American Society of Civil Engineers (1963). According to the ASCE Task Force on Sedimentation (1963), it is recommended that calculations with equation be based on observed stream characteristics such as slope, depth, velocity, bed material size and grading and temperature whenever possible. Also if reliable sediment discharge quantities are essential they should be based on suspended load samples and estimates of unmeasured discharge by the modified Einstein method.

Therefore, before deciding an approach to the formulation of the sediment discharge equations for the two rivers, it was necessary to adhere to above-mentioned principles while also identifying the dependent and independent variables of the problems. The independent variables were (a) the rate of flow (Q) of the rivers (b) the gravitational field causing flow (g) (c) the physical properties of the alluvial material such as particle size (d_{50}) and particle fall velocity (w_o). The slope (S) is a dependent variable since the channels is subjected to adjustment. The other independent variables were channel width and channel depth.

In the process of developing a relation for total sediment discharge per unit width q_s, the above-mentioned variables were most significant (Saleh and Abdou – Seida, 1987)

In order to get the required value of sediment discharge per unit width (q_s) with relation to depth, width and slope of the rivers, two basic equations were considered; these were the resistance equation and the sediment transport expression. This means that the two of the dependent variables could be obtained while the investigator could choose the third.

4.4.2 Assumptions

The following assumptions were made before the development of the equation for the rivers:

(a) The bed form was assumed to be fully developed.

(b) The channel depth are assumed constant

(c) The channel width was assumed constant.

(d) The water temperature was assumed constant 28^0C equal to the average annual temperature.

(e) The river channel was assumed to be straight.

(f) The riverbank was assumed to be hydraulically "Smooth".

(g) The river discharge was assumed to be steady.

(h) The riverbed load movement was considered tractive.

(i) The river was flowing at less than the critical velocity

(j) The particle sediment size was considered small compared to depth.

(k) The width and slope have adjusted to the regime final values.

4.4.3 The Theoretical Approach

The equations are available by means of which the proper dimension of a stable channel can be obtained together with the channel longitudinal slope (S). The first equation is the Liu and Wang (1959) equation given as:

$$V = C_a R^x S^y \quad \text{.............................(38)}$$

where V is the average velocity in metre per second, R is the hydraulic radius in metres, S is the non-dimensional slope, C_a x, y are coefficients which depend on the median diameter of bed material and formation.

This equation is adopted because it takes into account the variation of the channel roughness due to the bed forms and size of sediment particles. It is also a sort of dynamic equation where the coefficient and powers are not constant, but changes according to resistance conditions.

For a channel of very large width, to the first approximation, it is possible to write area $A \equiv R$ per unit width , so that

$Q = VA = V.R$

$$= C_a R^{1+x} S^y \quad \text{......................................(39)}$$

where Q is the water discharge per unit length along the wetted perimeter, C_a, x, y are functions of grain diameter and bed forms, and these values are determined from Einstein (1950) Bed Load Chart. (see Appendix)

The second selected equation for sediment transport calculation is the Einstein (1950) equation modified by Brown, which may be written in the form.

$$\Phi = \frac{q_s}{\sqrt{g(\gamma_s - 1)d^3{}_{50}}} \quad \text{.............................(40)}$$

where Φ is a dimensionless measure of the bed load transport and is called the intensity of bed load transport, q_s is the sediment discharge in volume per unit length and time, d_s is the bed material size, γ_s and γ are the weight of bed particles and water respectively, F^1 is the settling velocity representation term in the form

$$F^1 = \sqrt{\frac{2}{3} + \frac{36v^2}{gd_s^3(\gamma_s/\gamma - 1)}} - \sqrt{\frac{36v^2}{gd_s^3(\gamma_s/\gamma - 1)}} \quad \text{.............................. (41)}$$

Einstein showed that ϕ was related to the entrainment function ψ defined as:

$$\psi \quad = \quad \frac{(\gamma_s - \gamma)\, d_s}{\tau_o} \quad \text{..................................(42)}$$

where ι_o is the bed shear stress and is given as

$$\iota_o \quad = \quad \gamma RS \quad \text{..(43)}$$

The general form of $\phi - \psi$ relationship, suggested by Einstein is

$$\phi \quad = \quad k_1\, \psi^{-k2} \quad \text{.. (44)}$$

Where k_1 and k_2 are constants, determined to be 40 and 3, respectively, by Einstein.

Equation (40) may be used to represent the total load in the case where the suspended load is small and the main load is due to sediment motion on bed load, Abdou – Seida et al. (1987).

The rate of sediment motion per unit length of the wetted perimeter can be determined by substituting equation (40), (41), and (42) into (44) and rearranging this gives:

$$\frac{q_s}{\sqrt{g(\gamma_s/\gamma - 1)d_s^3}\,F} = K_1\left[\frac{RS}{(\gamma_s/\gamma - 1)d_s}\right]^{k_2} \quad \text{................................(45)}$$

$$q_s = F\left(g\left(\frac{\gamma_s}{\gamma} - 1\right)d_s^3\right)^{\frac{1}{2}} = k_1\left[\frac{RS}{(\gamma_s - 1)d_s}\right]^{k_2} \quad \text{........................(46)}$$

$$\frac{q_s}{\sqrt{g(\gamma_s/\gamma - 1)d_s^3}} = \frac{V}{\sqrt{(\gamma_s - 1)gd_s}}\ k_1\left(\left(\frac{\tau_o}{(\gamma_s/\gamma - 1)}\right)d_s\right)^{k_2} \quad \text{........... (47)}$$

where $\iota_o = \gamma RS$ and

d_s = d_{50} (i.e. mean particle diameter).

Therefore, equation (47) becomes

$$\frac{q_s}{\sqrt{(\gamma_s - 1) g d_{50}^{3}}} = \frac{V}{\sqrt{(\gamma_s - 1) g d_{50}}} \; k_1 \left(\left(\frac{\tau_o}{(\gamma - 1) d_{50}} \right) \right)^{k_2} \qquad \text{.....................(48)}$$

Through the process of transposition, equation (48) can be written as:

$$\frac{g(\gamma - 1) d_{50}}{V_2} = \left(\frac{q_s}{\sqrt{(\gamma_s - 1) g d^{3}_{50}}} \right) k_2 \left(\frac{\tau_o}{(\gamma_s - 1) d_{50}} \right)^{k_1} \qquad \text{.........(49)}$$

If the arms are replaced by a single factor such that

$$F^1 = \frac{g(\gamma - 1)\, d_{50}}{V^2} \qquad \text{...(49a)}$$

$$Q = \left(\frac{q_s}{\sqrt{(\gamma_s - 1) g d^{3}_{50}}} \right) \qquad \text{.......................................(49b)}$$

$$\Phi = \theta^3 = \left(\frac{\tau_o}{(\gamma_s - 1) d_{50}} \right) \qquad \text{.......................................(49c)}$$

where F^1 is a term representing particle settling velocity, then F^1Q is the term representing intensity of sediment discharge or Einstein Bed load function and Q is a term representing dimensionless sediment discharge. Φ is a term representing dimensionless bed shear stress or Entrainment function. According to many researchers among them, Kinori and Menorach (1984), Eustace Gondwe (2000) the relationship between the dimensionless bed load discharge F^1Q and the dimensionless stress- Φ is often expressed mathematically by the equation of the form

$$F^1Q = k_2 \, \Phi^{k1} \qquad \text{.......................................(50)}$$

4.5 Summary

This research was conducted based on the approved international recommendations on sedimentation such as, U.S. Federal Agency on sedimentation Project Report No 14, (1963); International Organization for Standardization Ref; Nos 4363, 3716 Geneva 1977a,b IAHS Publication No 133, 1971.

Results obtained were calibrated and compared with those of established river models mentioned above to confirm their validity under various conditions of flow. Verification of the models, were carried out with new sets of data collected from field measurements.

CHAPTER FIVE

DATA COLLECTION AND ANALYSIS

Following extensive field investigation the following data were collected for the study. The nature of these data collected for the purpose of analysis of the two river models are presented in Tables A1, B1 , C1 and D1 in the appendices. The data collected for the study of Ogbese and Owena Rivers were divided into two categories. There were: (i) Stream flow data and (ii) Sediment discharge data.

The sampling stations and the apparatus used to measure the four parameters: water discharge; sediment discharge; flow velocity and temperature have been presented in Chapter Four. The type and frequency of the sampling programme including other field investigations that were carried out on each sampling station, for example, water depth, velocity, discharge and temperature measurements depended on the availability of instruments and the nature of the observed parameters.

5.1. Stream Flow Data Analysis:

5.1.1 Gauging Stations and Availability of Records

Extensive data were required to adequately develop, calibrate and verify a model under unsteady flow conditions. An extensive database for use in developing the river flow models spans the period (1982 – 99). The Benin Owena River Basin Authority provided the data from 1982 – 1994, (ORBDA) while the researcher provided the data from 1995 to 1999. River cross-section and vertical control were surveyed 0.6km to 0.8km along the reach. The channel widths generally ranged from 33m to 45m and were roughly rectangular in cross section.

About six stream gauging stations were examined and studied with the basin. Following a cross examination the records from only two stations, C, Akure – Ogbese bridge crossings for Ogbese river and, D, Akure – Ondo bridge crossings for Owena river were adjudged adequate in terms of quality for eventual hydraulic investigation. Only these selected stations, therefore, are dealt with below. Information on the selected stations and the period of their records are given in (Tables A_1 and B_1 respectively). At each station water levels were generally observed twice daily (morning and evening) although for various reasons this routine were not always followed. In addition flows were occasionally measured by means of current meters and gauge readings recorded simultaneously.

5.1.2 Computations Procedure

The data obtained from each of the above – mentioned selected stations were processed as follows:

(a) All flow metering data were scrutinized for any computational errors and rectified where necessary.

(b) The measured discharges were plotted versus the simultaneous observed stages and a curve was graphically fitted through the plotted points

(c) The fitted curves were extrapolated up to the highest ever-recorded stage, on the basis of hydraulic considerations. This complete rating (or stage – discharge) curves were established for the stations.

(d) Up to four stage – discharge equations of the type $Q = C\ (H - H_0)^n$ were derived to represent mathematically the complete rating curve by distinct ranges. In these equations, Q denotes discharge in cu. m/sec, it also demotes gauge readings (or stage) in m, H_0 is the height correction factor and C and n are constants.

(e) The derived rating equation were applied to the arithmetic averages of each observed water levels to produce mean daily flows and subsequently, monthly and annual flows.

5.1.3 Water Level Records

The bulk of the water level records available from the selected stations was continuous and apparently reliable. However, in several cases, records were either dubious, due mainly to occurrences of gauge over topping or discontinuous where only partial records were available in a particular month, they were either (i) ignored or (ii) if the interruptions did not last more than a few days, supplements with the estimated values, based on records from stations elsewhere in the basin. Where a gauge was obviously over topped, records were used for evaluations in their original form and thus, the resulting computed flows are lower then the actual ones

5.1.4 Discharge Measurements

Tables A1 and B1 in the appendices, list the results of the discharge measurements studied in the Ogbese and Owena rivers. Table 5.1 and 5.2 contain also the stage-discharge measurements obtained for Ogbese and Owena rivers from 1989 to 1999 (mean monthly values) respectively.

Table 5.1. – **Stage -Discharge data for Ogbese river (Mean monthly values) 1989 – 1995.**

Month	Stage (m)	Discharge m^3/s
Jan	1.456	11.03
Feb	1.560	11.82
March	1.425	8.69
April	1.670	11.3
May	2.045	23.13
June	2.100	26.08
July	2.83	62.72
Aug.	3.585	142.23
Sept.	4.07	170.05
Oct.	3.515	130.91
Nov.	2.145	25.06
Dec.	1.90	20.10

Table 5.2: **–Stage- Discharge data for Owena river (Mean monthly values) 1989 – 1999.**

Month	Stage (m)	Discharge m^3/s
Jan	0.19	1.3
Feb	0.114	0.8
March	0.129	0.9
April	0.290	2.0
May	0.214	1.5
June	1.514	10.6
July	1.49	10.4
Aug.	1.870	13.0
Sept.	1.860	13.2
Oct.	3.420	24.63
Nov.	0.69	4.83
Dec.	0.54	3.772

5.1.5 Discharge Measurements and Rating Curves

The results of the discharge measurements and their plotting versus the simultaneous gauge readings are given separately for each of the selected stations. The corresponding graphically fitted curves are shown in Figures 5.1, 5.2, 5.3, 5.4, 5.5 and 5.6. In addition to the cross – sections of the rivers and their longitudinal water surface profiles at sampling stations C and D. data on the river cross sections were also obtained to include the relative low stages from records of current meter measurements and kept in the study file.

The extrapolation of each one of the fitted stage – discharge curves for the two stations was accomplished by applying the slope – area method based on the Manning's Formula

$$Q = \frac{1}{n} AR^{2/3} S^{1/2}$$

where Q is the discharge in cu.m/sec, n is the Manning's roughness coefficient, A is the cross sectional area of flow in (m^2) R is the hydraulic radius (m) and S is the slope of the hydraulic gradient. For the range covered by the measured stage – discharge records, the values of the three parameters in the formula are directly available. Q from the discharge measurements, and A and R from the river cross-section. Using this data, the values of

$$K = \frac{Q}{AR^{2/3}} = S^{1/2}/n$$

were derived for some of the highest measured discharges and examined for variations with stage. Values of K were assumed for selected higher stages, up to the highest stage ever observed and applied to compute the corresponding extrapolated discharges. It was also possible to obtain the cross section by extrapolation from discharge measurement. Finally rating equations were derived for complete (extrapolated) rating curve with the aid of regression analysis by the use of a computer.

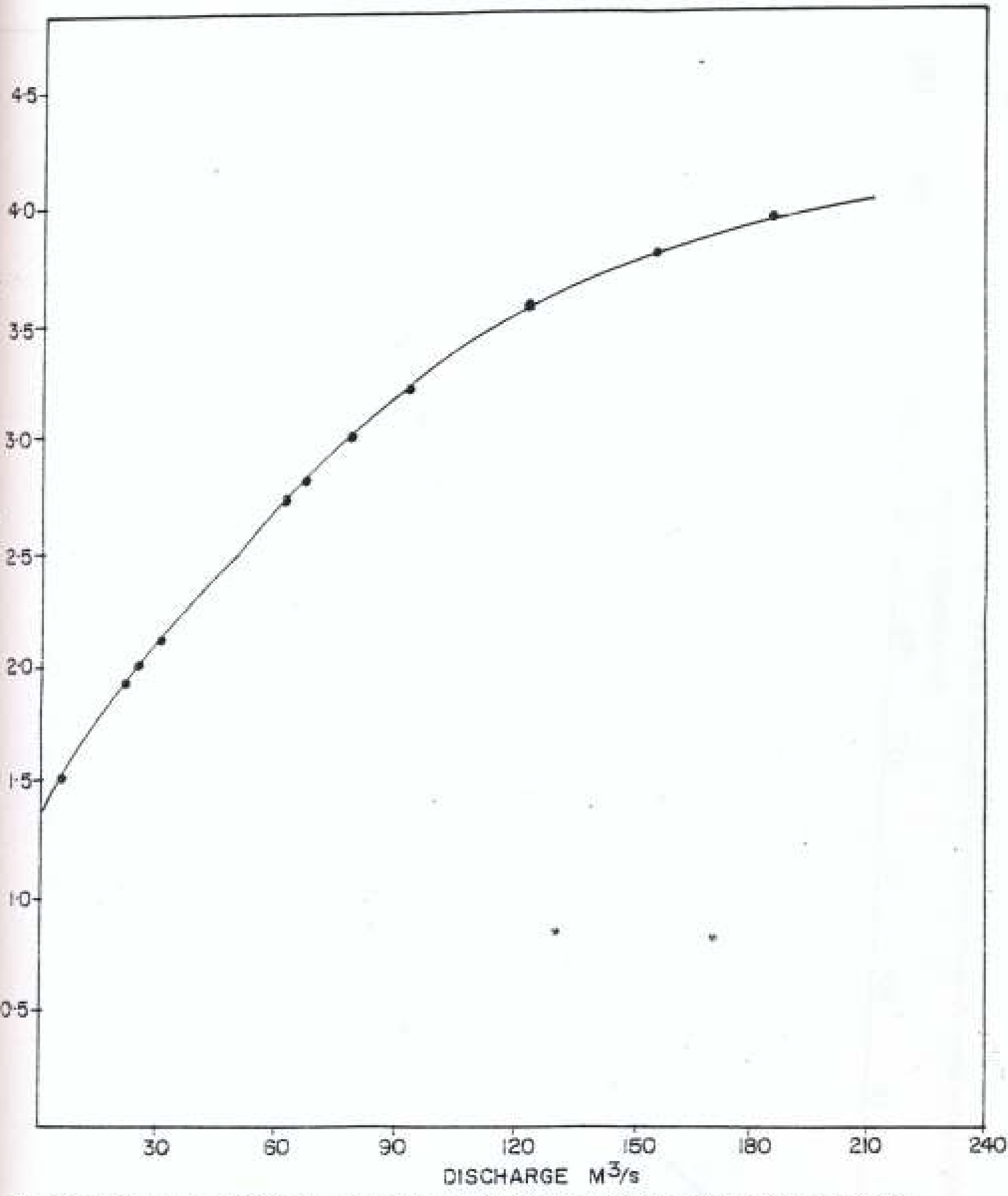


Fig. 5·1: Stage discharge relationship curve for Ogbese river at Akure - Ogbese bridge at 20km from Akure.

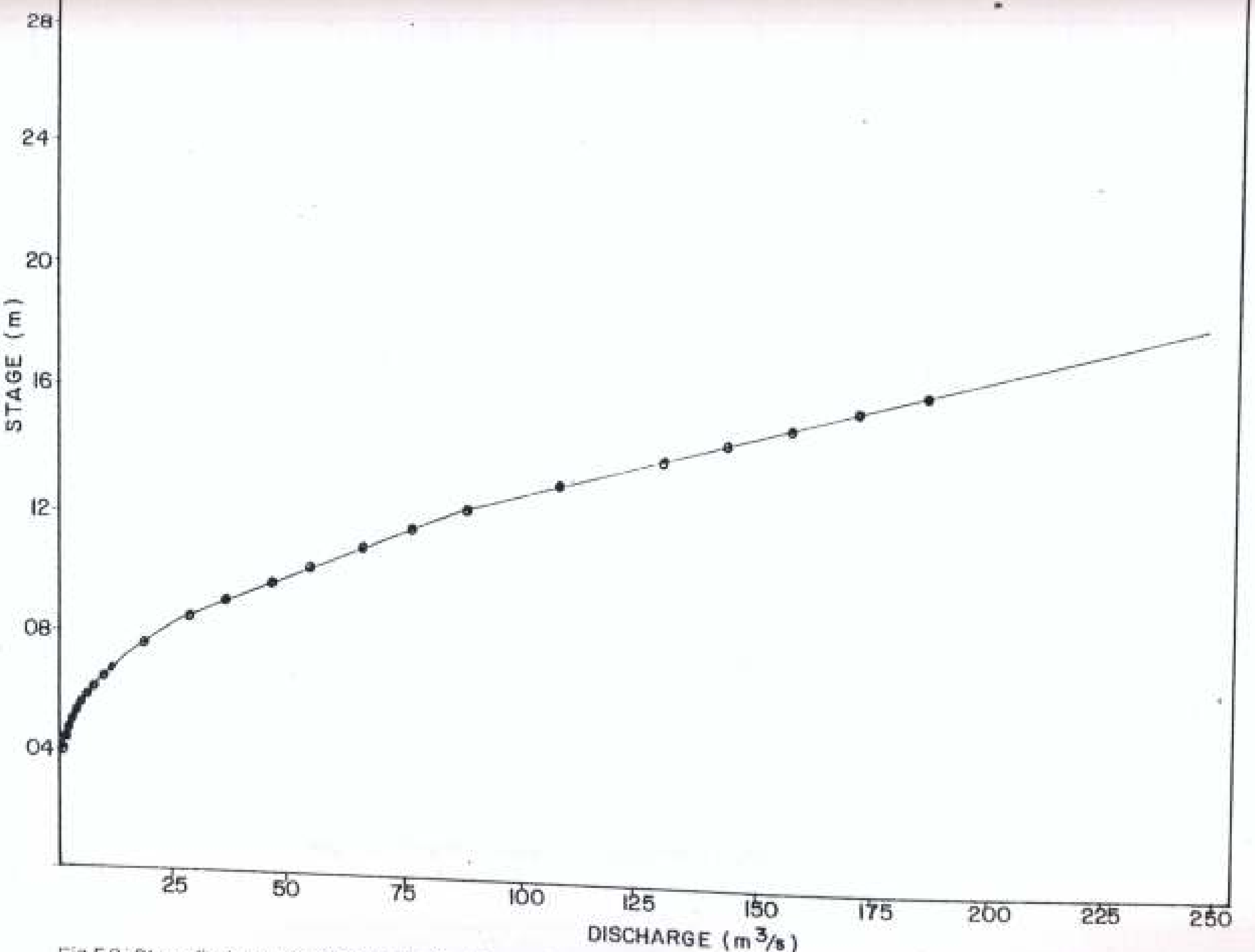


Fig 5.2: Stage discharge relationship curve for Owena river at Akure - Ondo bridge at kilometer 18 from Akure.

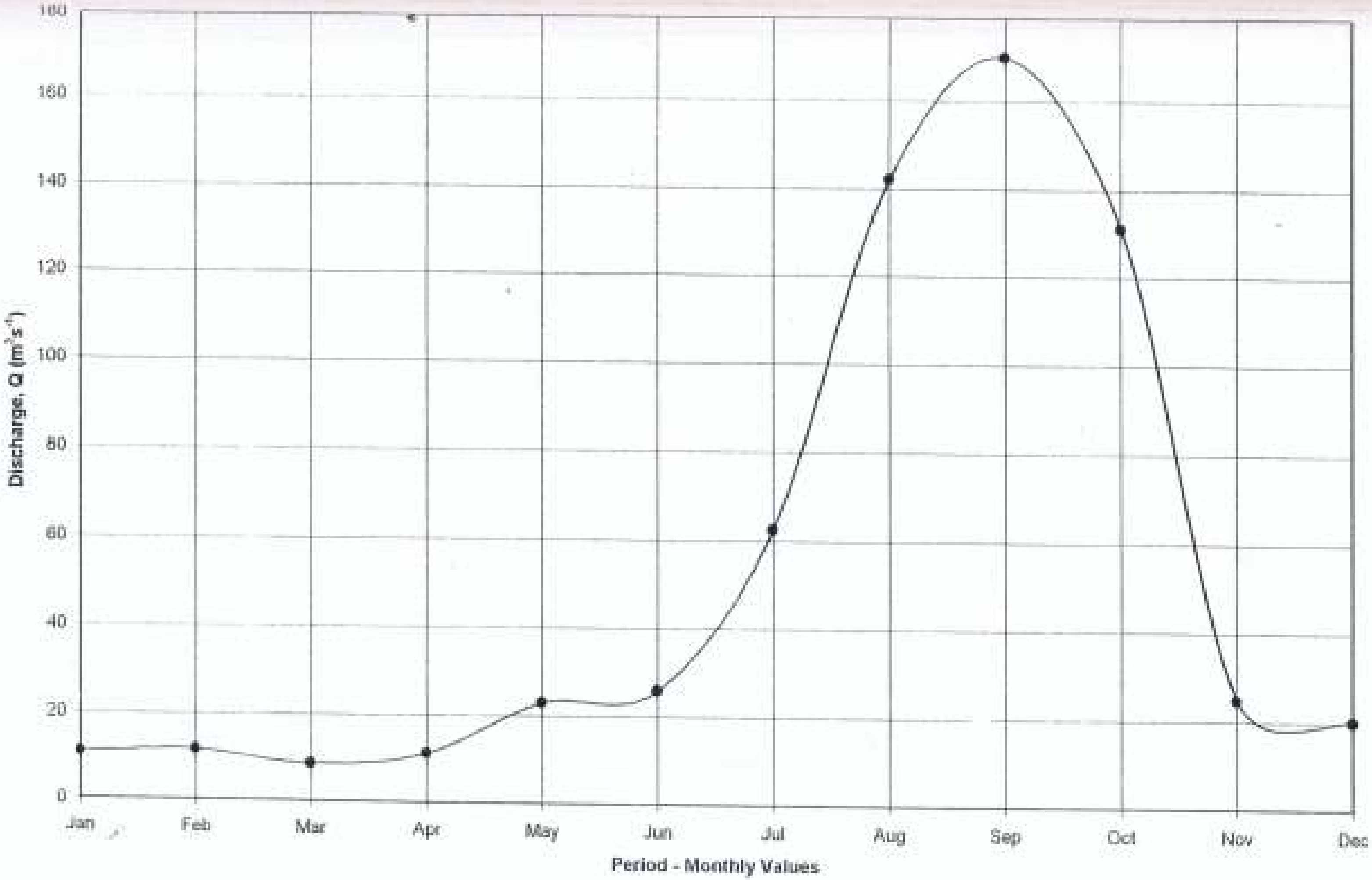


Fig. 5.2 Flow Discharge Hydrograph for Ogbese river (1989 - 1999)

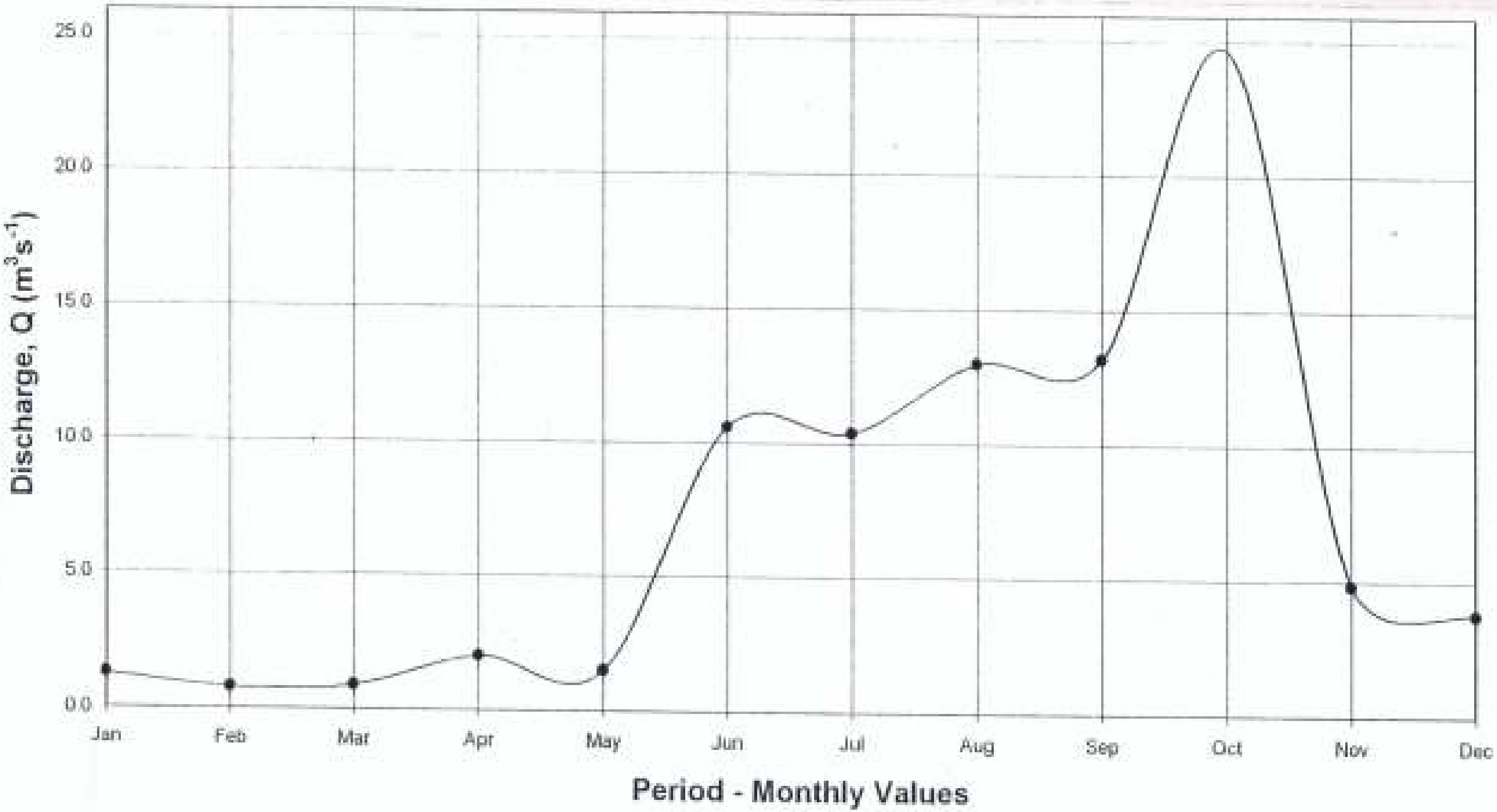


Fig.5.3 Flow Discharge Hydrograph for Owena river (1989 - 1999)

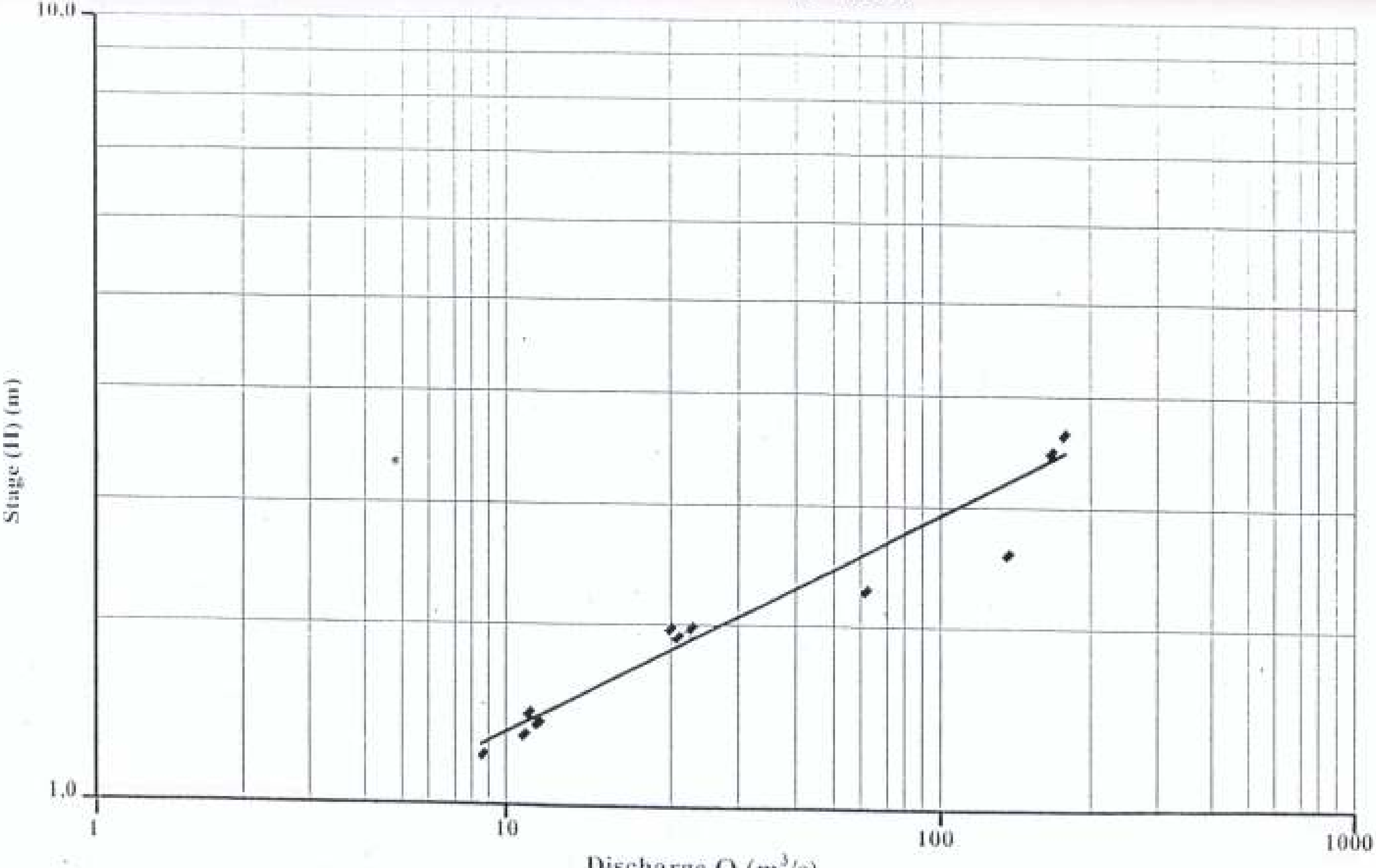


Fig 5.5 Rating Curve for Ogbese river (1989 – 1999). at Ogbese – Owo Bridge (18 km from Owo)

$R^2 = 0.9059$

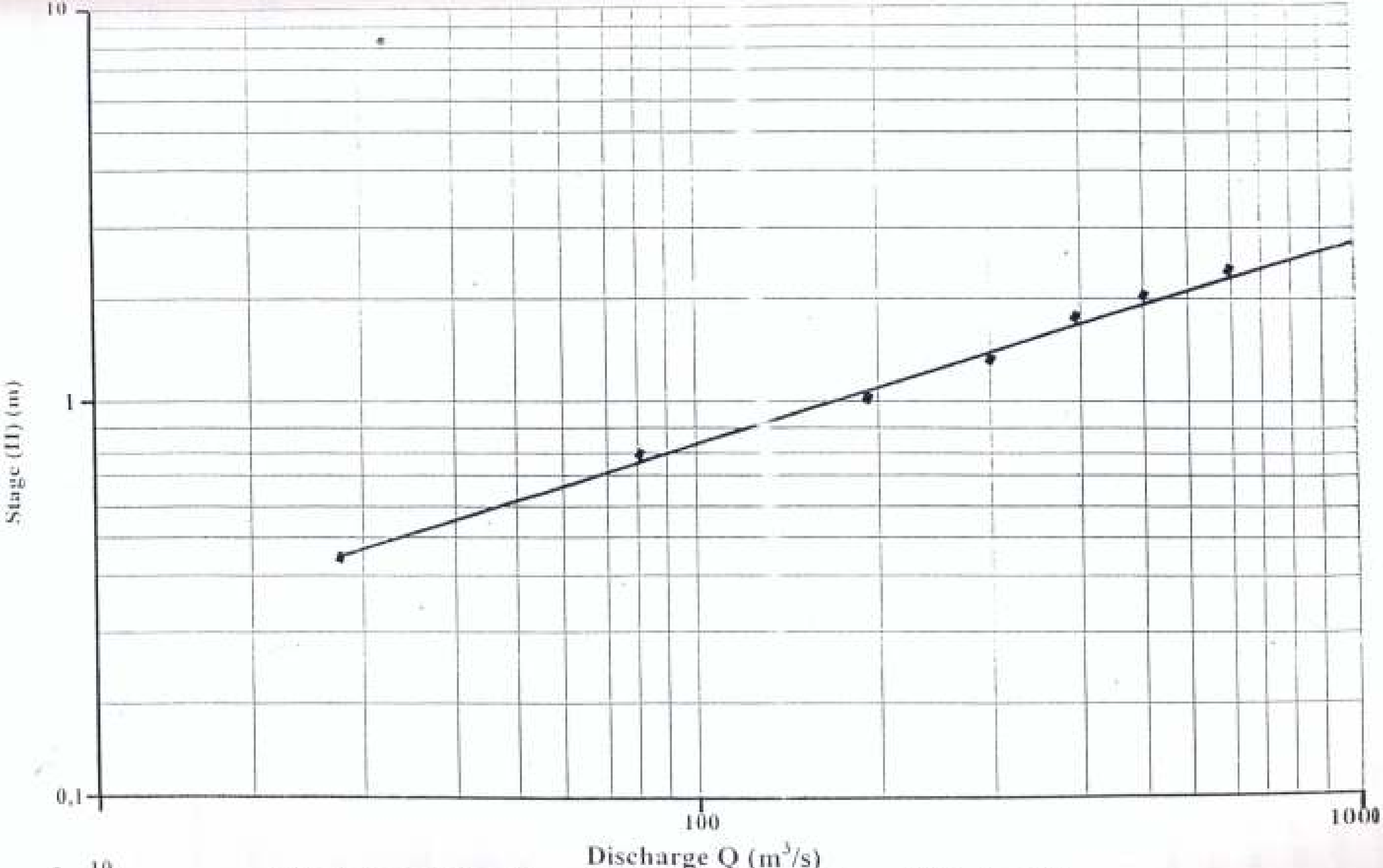


Fig 5.6 :Rating Curve for Owena river (1989 – 1999). At G18.
G 18 is the ganging Station 18km from Akure.

5.1.6 Sediment Discharge Data Analysis

Tables D1 and E1 in the appendices present the recordings of sediment discharge for Ogbese and Owena rivers (1995 – 1999) respectively. The results were obtained through field sampling at the above mentioned sampling stations using sloughs bottle and B.T.M.A sampler, details of which have already been stated in the previous chapter. From this study, about 60 to 80% of the variation of sediment yield can be attributed to difference in discharge. This result is important for future water quality management aspect of the rivers and in the design of water treatment plant for public supply purposes. It was also observed that the highest sediment concentration corresponds with peak flood, which occurs mostly in September. The result is in agreement with the findings of IAHS (1989).

The suspended sediment rating equation for Ogbese River is presented in Figure 5.7 as

$$Q_s = 0.0248\ Q^{0.9584} \text{ with } R^2 = 0.9878 \quad \ldots\ldots\ldots(51)$$

The bed load sediment rating curve equation for Ogbese River is presented on Figure 5.8 as

$$Q_b = 0.1842\ Q^{0.5378} \text{ with } R^2 = 0.9257 \quad \ldots\ldots\ldots(52)$$

Similarly, the suspended load rating curve equation for Owena river is presented on Figure 5.9 as

$$Q_s = 0.0221\ Q^{1.011} \text{ with } R^2 = 0.9539 \quad \ldots\ldots\ldots(53)$$

The bed load-rating curve for Owena river is presented on Figure 5.10 as

$$Q_s = 0.0557\ Q^{0.9062} \text{ with } R^2 = 0.8682 \quad \ldots\ldots\ldots(54)$$

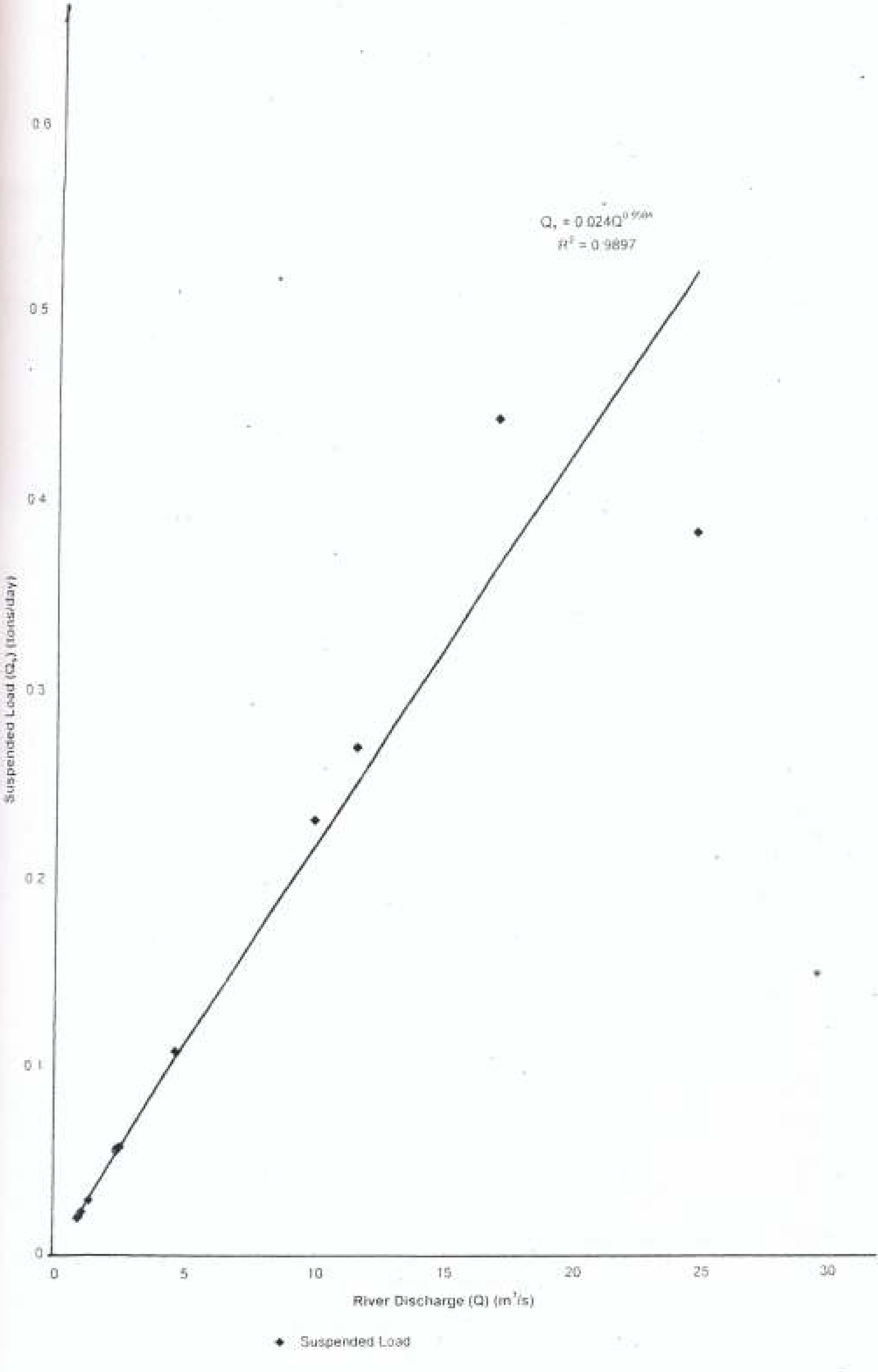
The total load for Ogbese river is presented on Figure 5.10a as

$$Q_s = 0.2063\ Q^{06191} \text{ with } R^2 = 0.9539 \quad \ldots\ldots\ldots(54a)$$

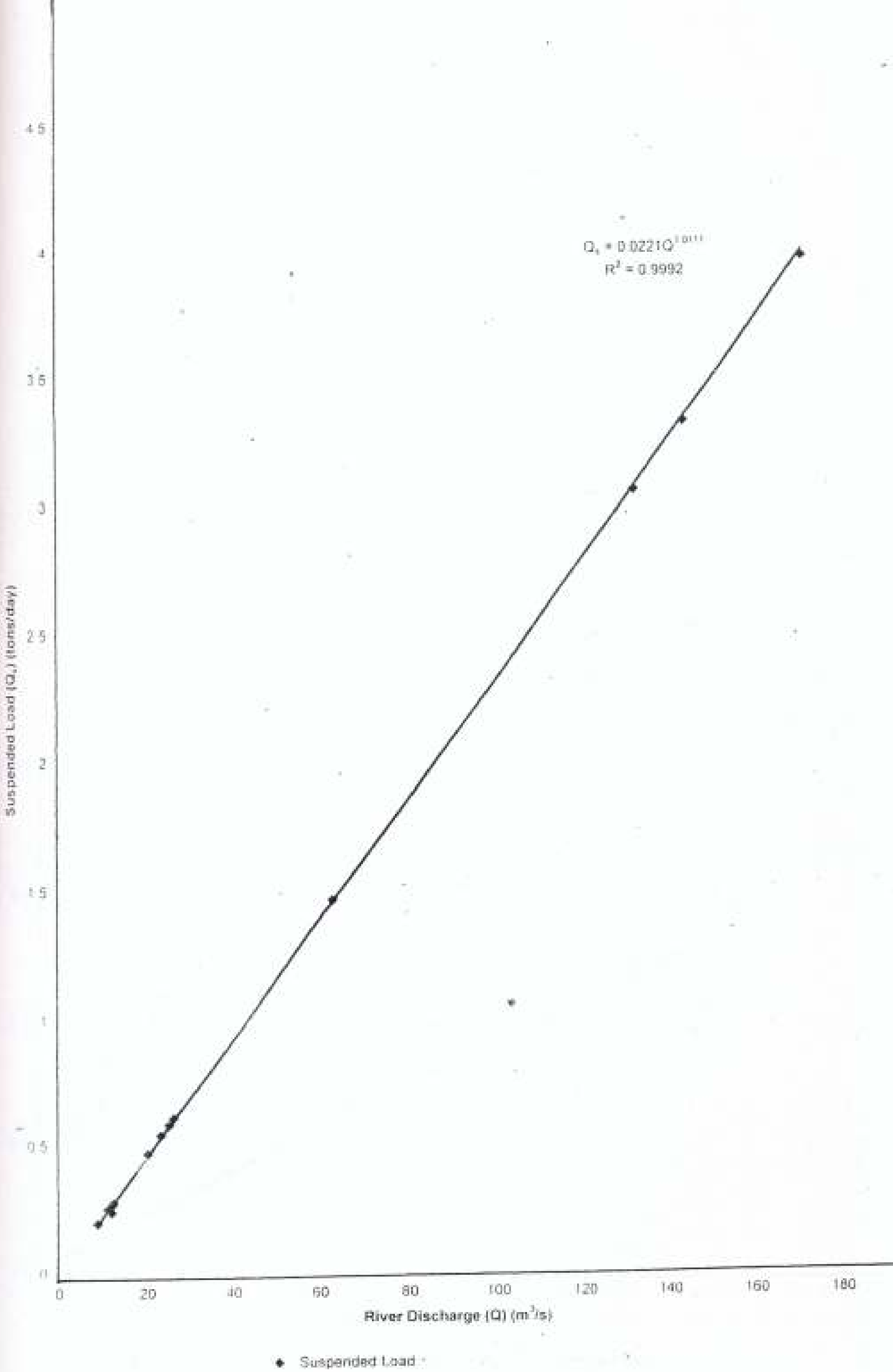
From the analysis of the above data, it is concluded that sediment discharge in Ogbese and Owena rivers demonstrated a positive correlation between rate of sediment yield and water discharge. It is a power law relationship.

5.1.7 Hydraulic Data Analysis

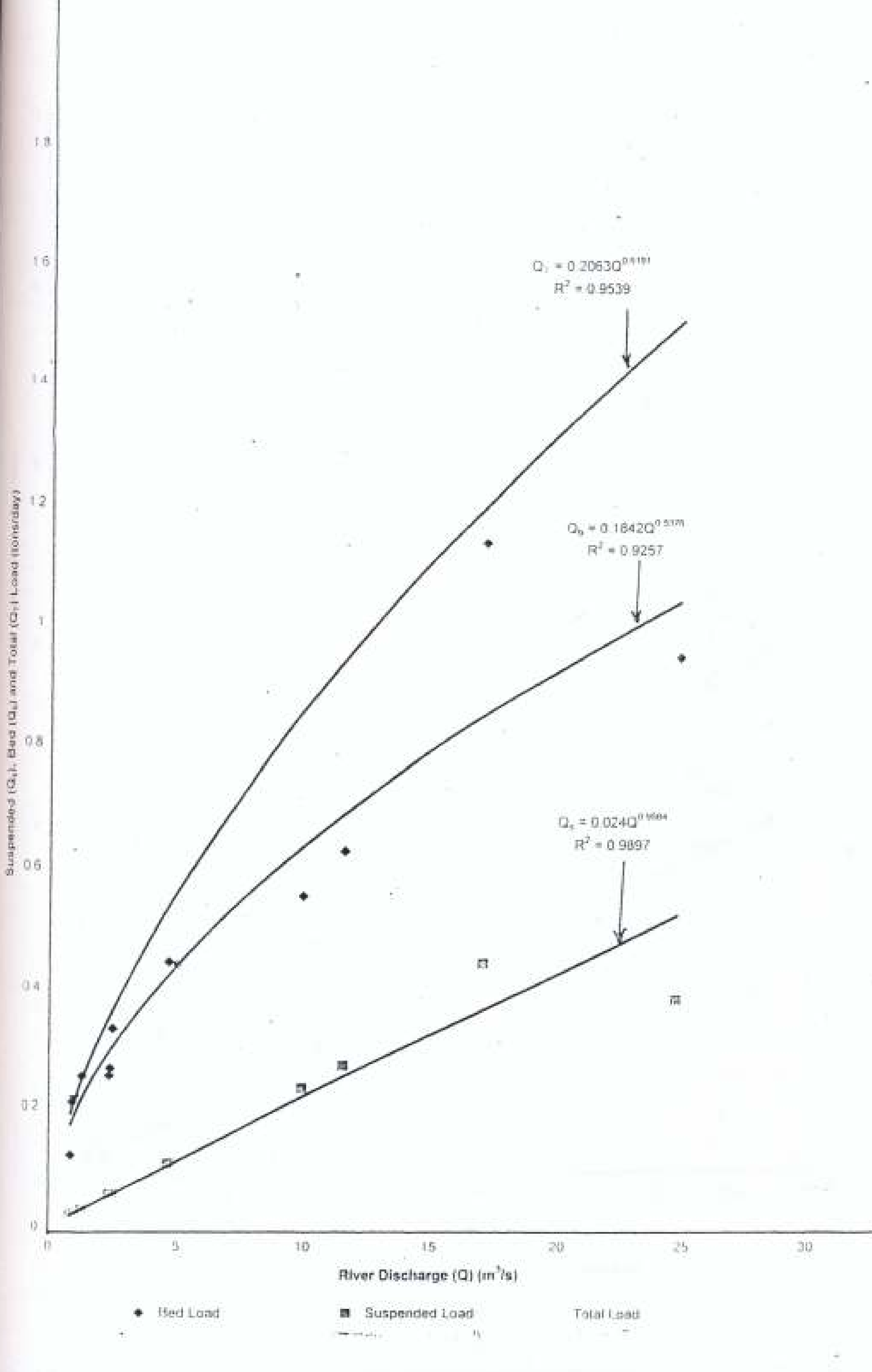
The object of hydraulic data measurements and computations presented in Tables 5.3 and 5.4 for the two rivers was to show the variation in the river profile and flow regimes. The data were useful in obtaining the flow rating curves and also the sediment rating curves, both essential tools in the model formulation.



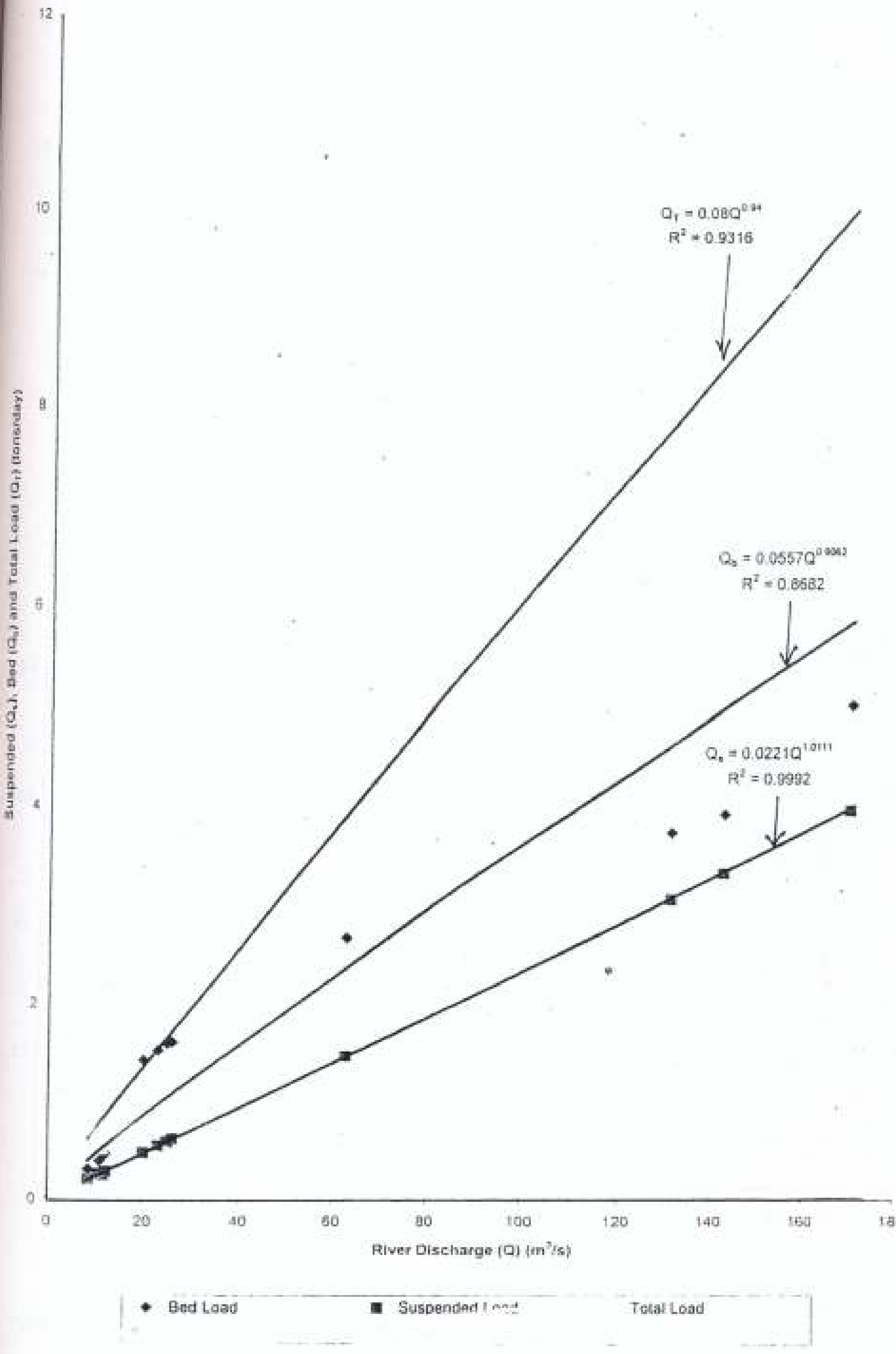
Suspended Load for Ogbese River at Ogbese Station (1980–1990)



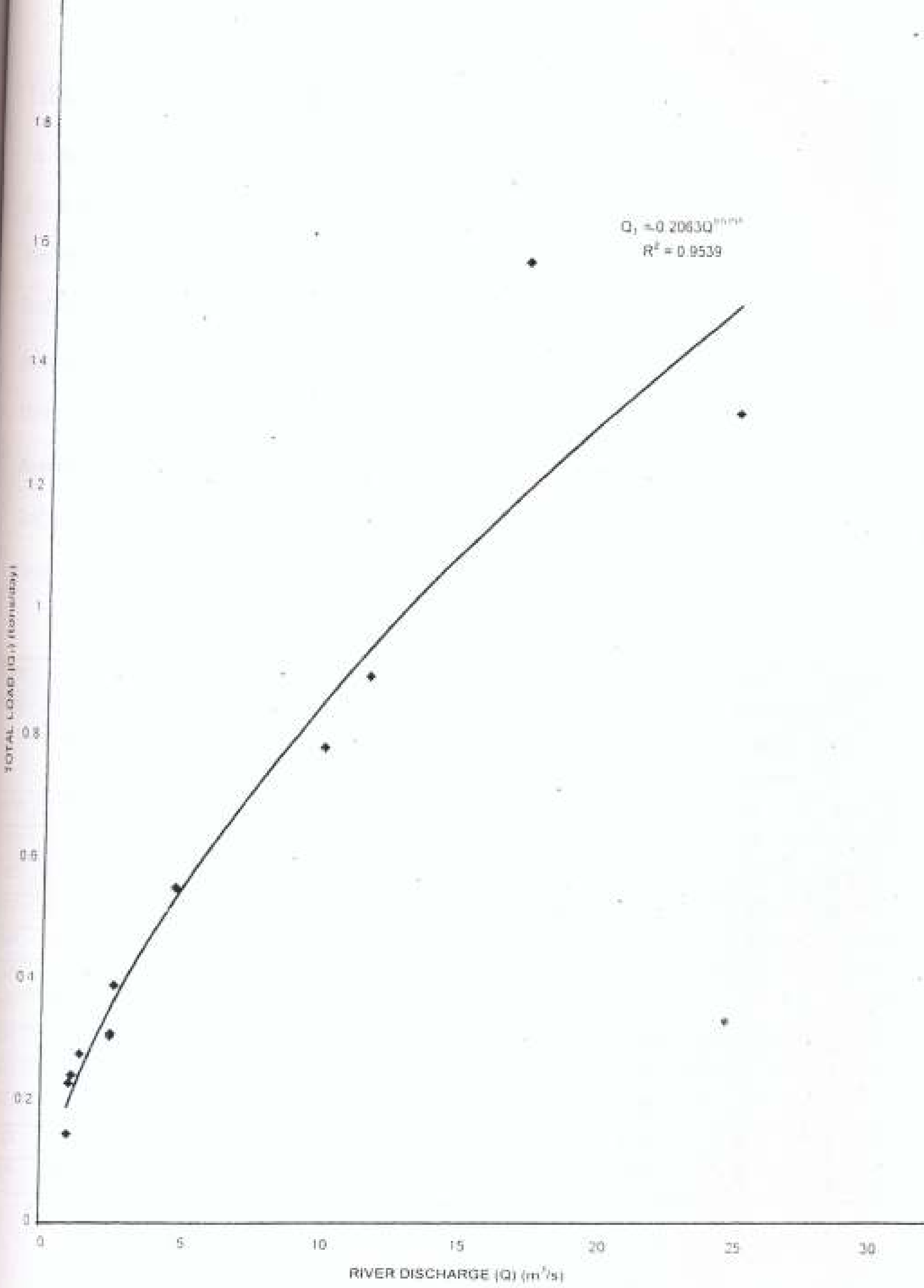
Suspended Load for Owena River at Owena Station G18 (1989 - 1999)



$Q_T = 0.2063Q$
$R^2 = 0.9539$
$Q_B = 0.1842Q$
$R^2 = 0.9257$
$Q_s = 0.024Q$
$R^2 = 0.9897$
Suspended (Qs), Bed (QB) and Total (QT) Load (tons/day)
River Discharge (Q) (m³/s)
Bed Load
Suspended Load
Total Load



5.10 Comparison of Suspended, Bed and Total Load for Owena River at Owena Station G18 (1989 - 1999)



Total Load for Ogbese River at Ogbese Station (1989 - 1999)

Table 5.3 **HYDRAULIC DATA FOR OGBESE RIVER**

PEAK DISCHARGE 230m / sec:

Flood Date: 10/10/97

Maximum flow width:- 23.0m

Bed slope:- 0.0063

Average flow velocity:- 1.361 m/s

Hydraulic Radius:- 1.25m

Average flow depth:- 1.29m

Bed Slope = 0.0063

(Source of data: ORBDA 1994 Data year book).

Stage (m) •	Mean Discharge Q (m/s) *	Flow Area A(m^2) √	Bottom Width B (m) √	Top Width BT (m) *	Mean Depth D (m) *	Wetted Perimeter P (m) √	Hydraulic Radius R (m) √	Mean Sectional Velocity V (m/s)*	Temp (°C) *
1456	11.03	10.71	8.2992	8.2992	1.2905	10.88	0.9840	1.05	28.5
1560	11.82	11.48	8.892	8.892	1.382	10.89	1.054	1.05	28.5
1425	8.69	8.69	8.1225	8.1225	1.263	10.65	0.816	1.05	28.5
1670	12.30	11.71	9.5190	9.5190	1.480	10.38	1.128	1.25	28.5
2045	23.13	22.03	11.6565	11.65	1.813	16.283	1.384	1.55	28.5
2100	26.08	22.28	11.9700	11.97	1.861	21.95	1.0267	2.00	28.5
2830	62.72	40.46	16.131	16.131	2.508	37.28	1.53	2.25	28.5
3585	142.23	64.91	20.4345	20.43	3.177	26.83	2.417	3.50	28.5
4070	170.05	83.67	23.1990	23.19	3.607	30.46	2.75	3.50	28.5
3515	130.91	62.39	20.0355	20.55	3.115	26.32	2.37	3.50	28.5
2145	25.06	28.23	12.2265	12.22	1.901	16.03	1.45	2.50	28.5
1900	20.10	19.14	10.83	10.83	1.684	14.72	1.28	2.50	28.5

• Measured data

√ Computed data

Table 5.4 **HYDRAULIC DATA FOR OWENA RIVER**

Peak flow discharge = $25m^3/s$

Flow width = 5.57m

Average Flow Area = $4.4m^2$

Hydraulic Radius = 0.60m

Average flow velocity = 1.125m/sec

Average flow depth = 0.830m

Bed Slope = 0.00937

(Source: ORBDA 1994 data year book)

Stage H(m) (1989-1999) *	Mean Discharge Q (m/s) (1989 – 1999)	Flow Area A(m^2) √	Bottom Width B (m)	Top Width BT (m) *	Mean Depth D (m) *	Wetted Perimeter P (m) √	Hydraulic Radius R (m) √	Mean Sectional Velocity V (m/s) *	Temp (°C) *
0.19	1.30	1.238	1.12	1.12	0.190	8.84	0.14	0.81	29
0.114	0.80	0.80	0.76	0.76	0.114	13.33	0.058	0.85	29
0.129	0.90	0.90	0.76	0.76	0.129	9.00	0.096	0.85	29
0.290	2.00	2.90	1.71	1.71	0.290	9.00	0.22	0.85	29
0.214	1.50	1.42	1.26	1.26	0.214	8.88	0.16	0.85	29
1514	10.6	9.21	8.93	8.93	1.33	8.99	1.02	0.85	29
1.49	10.4	9.04	8.79	8.79	1.31	8.95	1.01	1.15	29
1.871	13.00	11.30	10.96	10.96	1.63	8.99	1.26	1.15	29
1.860	13.00	11.30	10.96	10.96	1.63	8.99	1.26	1.15	29
3.420	24.63	20.52	20.16	20.16	2.00	20.06	1.99	1.20	29
0.690	4.83	4.83	4.07	4.07	0.68	9.47	0.51	1.06	29
0.540	3.77	3.77	3.18	3.18	0.50	9.92	0.38	1.06	29

- Measured data

√ Computed data

5.1.8 **Hydraulic Measurements and Computation: Location:-**

Ogbese River at Ogbese Village

The gauging station is erected on the downstream of the Akure – Owo Highway Bridge that crosses Ogbese near Ogbese village. The station is on Latitude 7^0 16'N and Longitude 5^0 23'E of topographical map sheet No 264 N.E published by Federal Surveys, Nigeria 1964. Estimated drainage area is 2039.65 km^2. The average annual water temperature 1998 was 28.5^0C taken at Ogbese bridge in Akure – Owo road.

Channel Description: From field data report, channel alluvium of the river was composed of bimodal mixtures of gravel and sand (10 – 20%) and (80 – 90%) with modal diameter of about 30mm and 0.2mm – 0.4mm respectively. The channel is lined with grasses and tress above banks and below water line and throughout its length.

Channel Roughness Coefficient (n) is estimated by ORBDA, (1991) as equal to 0.45

Installation: 4m gauge and punch tape level recorders were installed at the station.

Datum: Two benchmarks were installed Bench Mark I (BM1) is on the left shoulder of the bridge with an assumed elevation of (arbitrary) 100m.

Benchmark 2 (MB2) is also on the same shoulder of the bridge with BM1. The zero of the staff gauge is 91.28. The discharge measurements are given in Table A1 (Appendix A).

5.1.9 **Hydraulic Measurements and Computation: Location:-**

Owena River at Owena Village

The gauging station is located downstream of the bridge that crosses Owena River near Owena Village on Akure Ilesha Road. It is on Lat 7^0 12' and Long 5^0 01' E of the topographical Map sheet No 264S W. The drainage area is 783.00km^2 according to ORBDA Hydro Year book Vol. II 1992.

Channel Description: From the field data, channel alluvium was composed of a bimodal mixture of gravel / pebble (20 – 25%) and sand (75 – 80%), with modal diameters of about 40mm and 0.4mm – 0.5mm respectively. Channel was lined with grasses and tress above banks and below water line throughout its length.

Estimated Roughness Coefficient: (n) = 0.47 (ORBDA Year book 1991)

Average Water Temperature: 29°C at km 18 Akure - Akure road gauging station.

Installation: 3m staff gauge and punch tape level recorder.

Datum: There are two benchmarks. Benchmark 1 (BM 1) is on top of the bridge just in front of the station with an assumed elevation of (arbitrary) 100m. Bench Mark 2 (BM2) is also on the bridge elevation is 89.65m

The zero of the staff gauge is 89.65m

The discharge measurements are given in Table B1 Appendix B.

5.1.10: **Sand Sample Results-**

The characteristic sizes of the sand particles are presented in Tables 5.5, 5.6 and 5.7 from the sieve analyse of the rivers bed materials of the two rivers respectively. The details of the sieve analyses, and the graphs are given in Appendix F. The result shows that sorting action is taking place between the various reaches, Ogbese river sediments consists mostly of coarse sand, medium graded sand, and fine graded sand from the upper to the lower reaches while Owena river sediments consists mostly of fine sand, coarse sand and boulders from the lower to the upper reaches. The channel bed for Owena consists primarily of coarse sand (approximately 0.8 mm to 0.92 mm) on bedrock.

Table 5.5: **Ogbese River: River Sand Data Measured on two different dates**

Date	D_{50} (mm)	D_{35} (mm)	D_{85} (mm)
12-2-98	0.190	0.150	0.460
12-2-98	0.190	0.160	0.500
12-2-98	0.700	0.150	1.500
12-2-98	0.550	0.500	1.00
12-2-98	0.400	0.080	0.75
12-2-98	0.190	0	0.30
10-10-98	525	0.390	1.40
10-10-98	1.000	0.570	2.38
10-10-98	1.240	0.800	3.15
10-10-98	0.525	0.420	2.030
10-10-98	0.680	0.495	2.450
10-10-98	1.360	0.585	2.730

Table 5.6: Owena River: River Sand data Measured on different dates

Date	D_{50} (mm)	D_{35} (mm)	D_{85} (mm)
2-1-98	0.47	0.30	1.50
7-2-98	0.60	0.30	3.70
1-3-98	0.46	0.32	1.50
9-4-98	0.48	0.36	1.40
25-5-98	0.38	0.24	1.30
20-6-98	0.46	0.34	1.50
30-7-98	0.60	0.30	3.60
15-8-98	0.47	0.34	1.50
6-9-98	0.62	0.46	3.00
4-10-98	1.00	0.60	3.90
14-11-98	0.48	0.38	1.20
12-12-98	0.42	0.32	1.40

CHAPTER SIX

PRESENTATION AND DISCUSSION OF RESULTS

This chapter presents the results of the mathematical modelling of the sediment transport capacities of Ogbese and Owena rivers respectively. Tables 6.1 and 6.2 contain the summary of the average values of the field measurements (1995 – 1999) for Ogbese and Owena rivers respectively.

Table 6.1 Summary of the average Field readings (1995 – 1999) for Ogbese River

Measured D_{50} (mm)	Particle fall Velocity (w) (mm/s) Ref: Graf (1971)	Depth d (m)	Slope, s, (km/m)	Shear stress $\tau = \rho gds$ N/m²	Velocity, u (m/s)	Total sediment discharge (qt) Ton / day
0.20	9.5	1.456	0.0063	0.097728	1.03	0.630
0.21	9.5	1.560	0.0063	0.09828	1.02	0.500
0.20	9.5	1.425	0.0063	0.09775	1.00	0.500
0.25	12	1.670	0.0063	0.1052	1.05	0.730
0.30	15	2.045	0.0063	0.1288	1.05	2.020
0.40	18	2.100	0.0063	0.1323	1.16	2.200
0.40	18	2.83	0.0063	0.17829	1.19	4.130
0.50	24	3.585	0.0063	0.225855	1.31	4.230
0.60	25	4.07	0.0063	0.256410	1.31	8.950
0.40	20	3.575	0.0063	0.221445	1.30	6.780
0.30	15	2.145	0.0063	0.135135	1.05	2.170
0.25	12	1.900	0.0063	0.01197	1.05	1.870

N.B All the results are measured field data except the bed shear stress (τ), which is computed from the formula $\tau = \rho gRS$. Where ρ is the density of water and g is the acceleration due to gravity, R is the hydraulic radius, which is taken as the depth d and S represents the slope of the riverbed

Table 6.2 **Summary of the average Field readings (1995 – 1999) : Owena river**

Measured D_{50} (mm)	Particle fall Velocity (w) (mm/s) Ref: Graf (1971)	Depth d (m)	Slope, s, (km/m)	Shear stress $\tau = \rho gds$ (Nm) N/m^2	Velocity, u (m/s)	Total sediment discharge (qt) Ton / day
0.30	15.0	0.24	0.00937	0.14852	0.65	0.2270
0.40	20.0	0.22	0.00937	0.14220	0.65	0.2250
0.40	20.0	0.14	0.00937	0.11344	0.65	0.1470
0.50	25.5	0.27	0.00937	0.157538	0.85	0.2680
0.60	27.5	0.38	0.00937	0.1868930	0.85	0.3850
0.70	30.0	0.55	0.00937	0.224842	0.85	0.5450
0.80	32.5	0.89	0.00937	0.28602	0.85	0.880
0.80	32.5	0.78	0.00937	0.26776	0.85	0.770
0.90	32.5	1.57	0.00937	0.37988	1.00	1.570
0.90	32.5	1.32	0.00937	0.3483	1.00	1.320
0.30	32.5	0.31	0.00937	0.16880	0.65	0.3500
0.30	32.5	0.30	0.00937	0.16605	0.65	0.300

N.B: All the results are measured field data except the bed shear stress (τ), which is computed from the formula $\tau = \rho gRS$. Where ρ is the density of water and g is the acceleration due to gravity, R is the hydraulic radius, which is taken as the depth d and S represents the slope of the riverbed.

6.1 Calibration of the Model

According to various authors including Saburo (1976), the index "k_1" varies between 2 and 3, and the constant, "k_2" is usually quite small. Logarithmic transformations of equations (55) yielded the equation.

$$\log F^1Q = \log k_2 + k_1 \log \Phi \quad \text{.......................................(55)}$$

Thus, a plot of F^1Q against Φ on double logarithmic paper, yields a straight line whose slope is equal to the index k_1 and the intercept when Φ is unity is equal to the constant k_2. Using equation of a straight line to compare equation (51) yields

$$Y = C + MX \quad \text{.......................................(55a)}$$

$$\left.\begin{array}{lll} \text{Log } y = & Y \text{ (ordinate)} & \\ \text{Log } a = & C \text{ (intercept)} & = k_2 \\ \text{Log } x = & X \text{ (absissa)} & \\ B = & m \text{ (slope)} & = k_1 \end{array}\right\} \quad \text{.........................(55b)}$$

Analysis of the data using the regression method of Snedecor and Cochram (1973), field data were fitted in to the relation equation (56)

$$F^1Q = k_2 \Phi^{k1} \quad \text{.......................................(56)}$$

to give the values of k_1, k_2 for Ogbese river as 0.592, 0.865 and Owena river as 0.335, 1.197 respectively. The index "k_1" and the constant "k_2" are known as the sediment transport coefficients. Substituting these values back into equation (56) yields the predicted equations for the two rivers as:

(i) For Ogbese river.

$$F^1\dot{Q} = 0.865\, \Phi^{0.592} \quad \text{.............................(57)}$$

(ii) For Owena river

$$F^1Q = 1.197\, \Phi^{0.335} \quad \text{.............................(58)}$$

Substituting for the parameters F^1, Q and Φ the predicted models for Ogbese River becomes

$$\frac{q}{\sqrt{(\gamma_s - 1)gd_{50}^3}} = 0.865\frac{V}{\sqrt{g(\gamma_s - 1)d_{50}}}\left[\frac{\tau_o}{\sqrt{(\gamma_s - 1)gd_{50}}}\right]^{0.592} \quad \text{.............. (59)}$$

while that of Owena river is

$$\frac{q}{\sqrt{(\gamma_s - 1)gd_{50}^3}} = 1.197\frac{V}{\sqrt{g(\gamma_s - 1)d_{50}}}\left[\frac{\tau_o}{\sqrt{(\gamma_s - 1)gd_{50}}}\right]^{0.335} \quad \text{.............. (60)}$$

Figure 6.1 Shows a plot of intensity of sediment discharge F^1Q versus Φ the dimensionless shear stress from field data obtained from Ogbese River. From the linear regression analysis of the data the predicted model for total sediment transport of Ogbese River is obtained as

$$F^1Q = 0.865\,\Phi^{0.592} \quad \text{.................................. (61)}$$

Equation (61) is revised by the substitution and the mathematical transformation of the dimensionless terms F^1Q and Φ earlier mentioned in equation (61) to yield the desired equation (62) given below as

$$\frac{qs}{\sqrt{(\gamma - 1)gd^3_{50}}} = 0.865\frac{V}{\sqrt{(\gamma - 1)gd}}\left(\frac{\tau}{(\gamma - 1)d_{50}}\right)^{0.592} \quad \text{.............. (62)}$$

which is the developed model for Ogbese river.

Figure 6.2 shows a plot of intensity of sediment discharge F^1Q versus Φ the dimensionless shear stress from field data obtained from Owena River. From the linear regression analysis of the data the predicted model for total sediment transport of Ogbese River is obtained

$$F^1Q = 1.197\,\Phi^{0.335} \quad \text{.............. (63)}$$

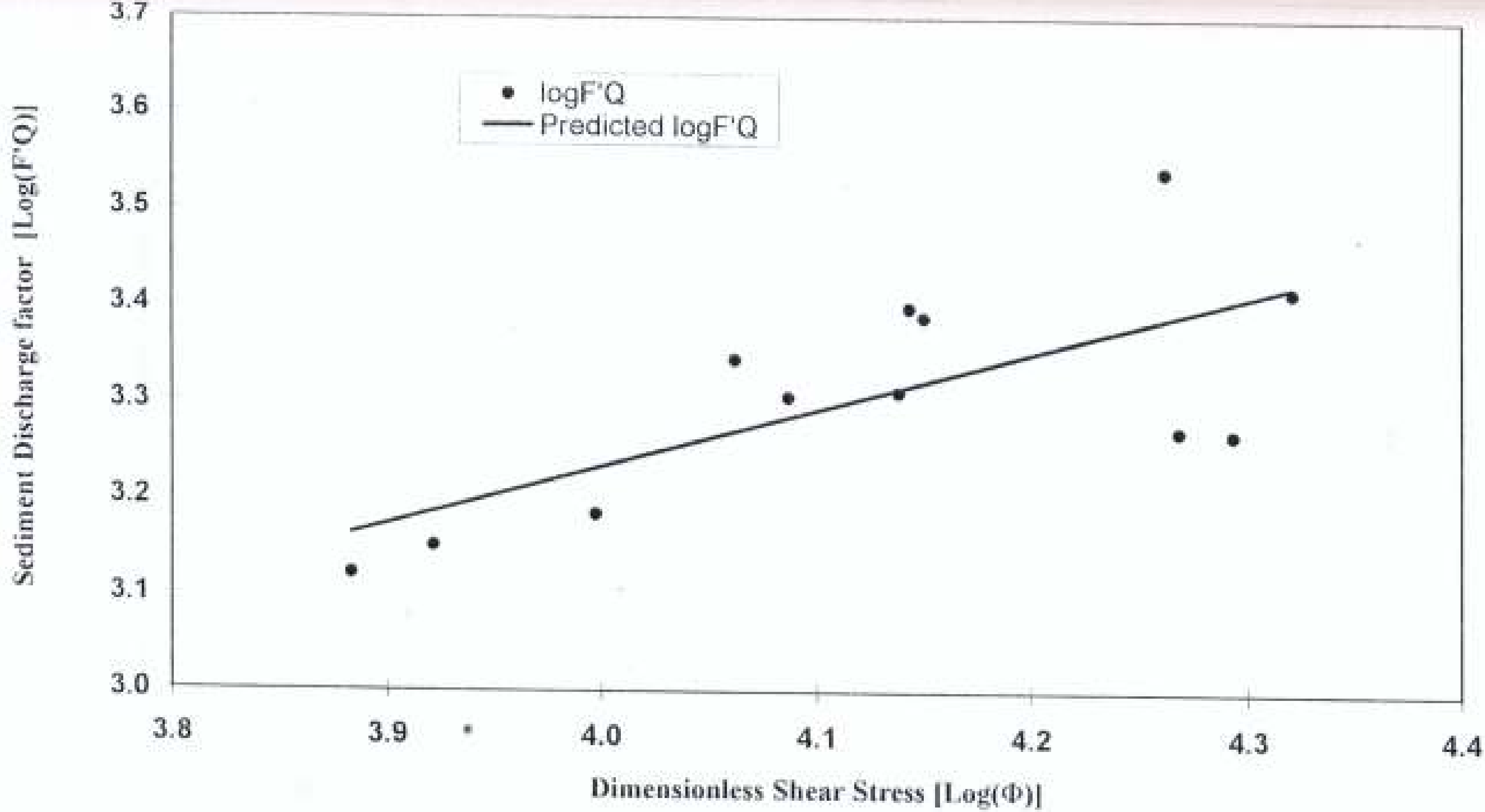


Fig. 6.1 Relationship between Intensity of Sediment Discharge and Dimensionless Shear Stress for Ogbese River ($F'Q = 0.865\Phi^{0.592}$)

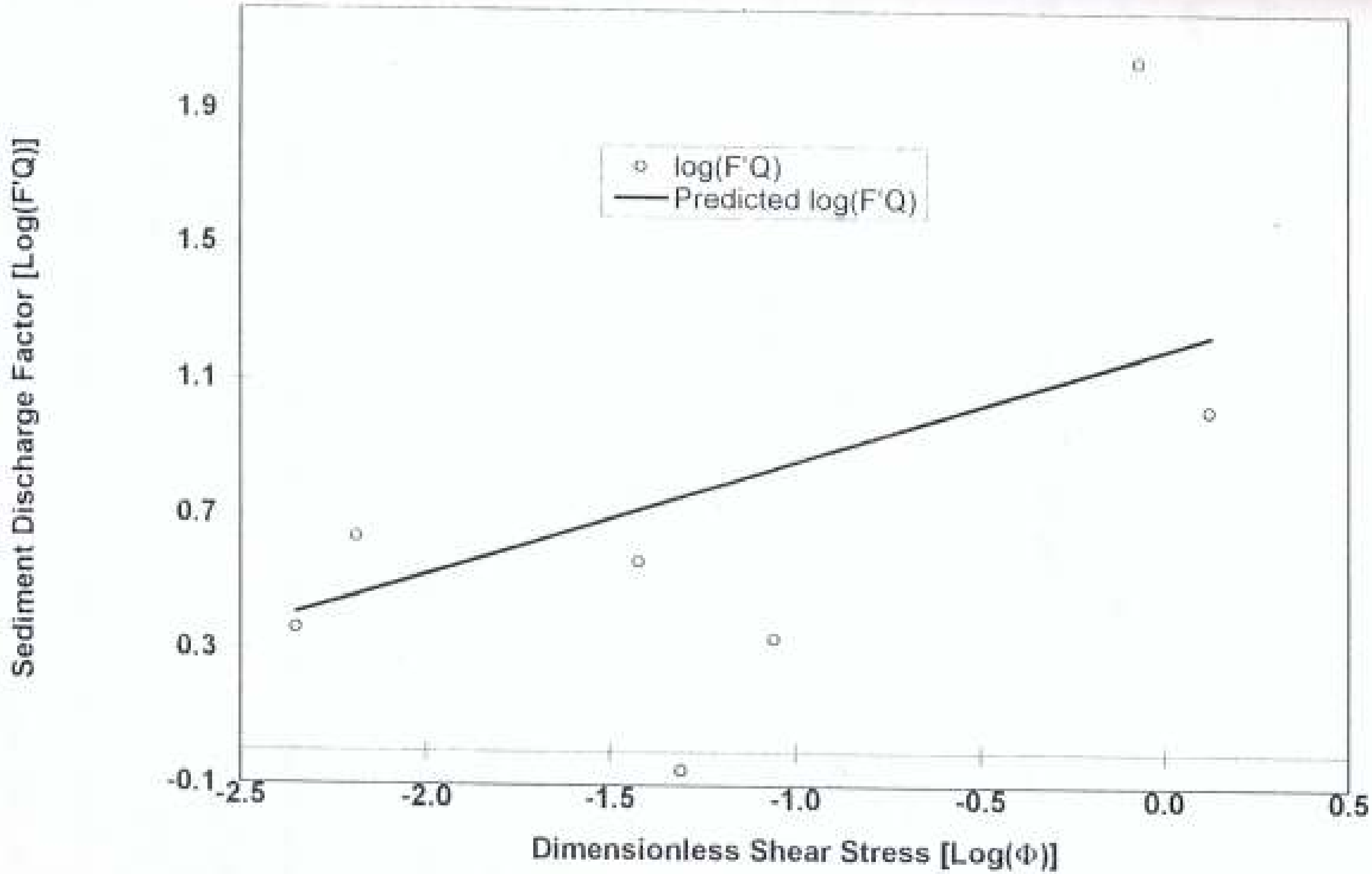


Fig. 6. 2 Relationship between Log (F'Q) and Log (F) for Owena River $(F'Q = 1.197\,F^{0.335})$

Equation (63) is revised by the substitution and the mathematical transformation of the dimensionless terms F^1Q and Φ to yield the desired equation (64) given below as

$$\frac{qs}{\sqrt{(\gamma-1)gd^3_{50}}} = 1.197\frac{V}{\sqrt{(\gamma-1)gd}}\left(\frac{\tau}{(\gamma-1)d_{50}}\right)^{0.335} \quad \text{.........} \quad (64)$$

which in the developed model for Owena River.

Figure 6.3 iIllustrates the relationship between the combined data for Ogbese and Owena rivers; sediment discharges (F^1Q) versus bed shear stress (Φ) for the two rivers. Linear regression analysis of this elongated data base gave the sediment yield equation.

$$F^1Q \quad = \quad 1.327\,\Phi^{0.474} \quad \text{........................} \quad (65)$$

The result shows that a regression line can be fitted between the two sets of data with an R^2 = 0.95. This confirms that a relationship exist between the two rivers because even though they are located differently they are from the same hydro-geological basin. This confirms the validity of the models developed for the two rivers.

Another method of evaluating the accuracy of the developed model was to compare the computed sediment discharge data against measured sediment discharge data. **Figure 6.4** presents the results of the computed against the measured sediment discharged data for Ogbese River using the developed model. The result showed that for a good agreement exist between the measured and the computed data with R^2 = 0.98.

Figure 6.5 presents the results of the computed against the measured sediment discharge data for Owena River using the developed equation. The result obtained showed that a good agreement exist between the measured and the computed with R^2 = 0.88

Figure 6.6 shows the comparison between the measured and computed sediment discharge data for Ogbese River obtained by using Karim (1998) model. The result showed a good correlation between the measured and computed data R^2 = 0.99.

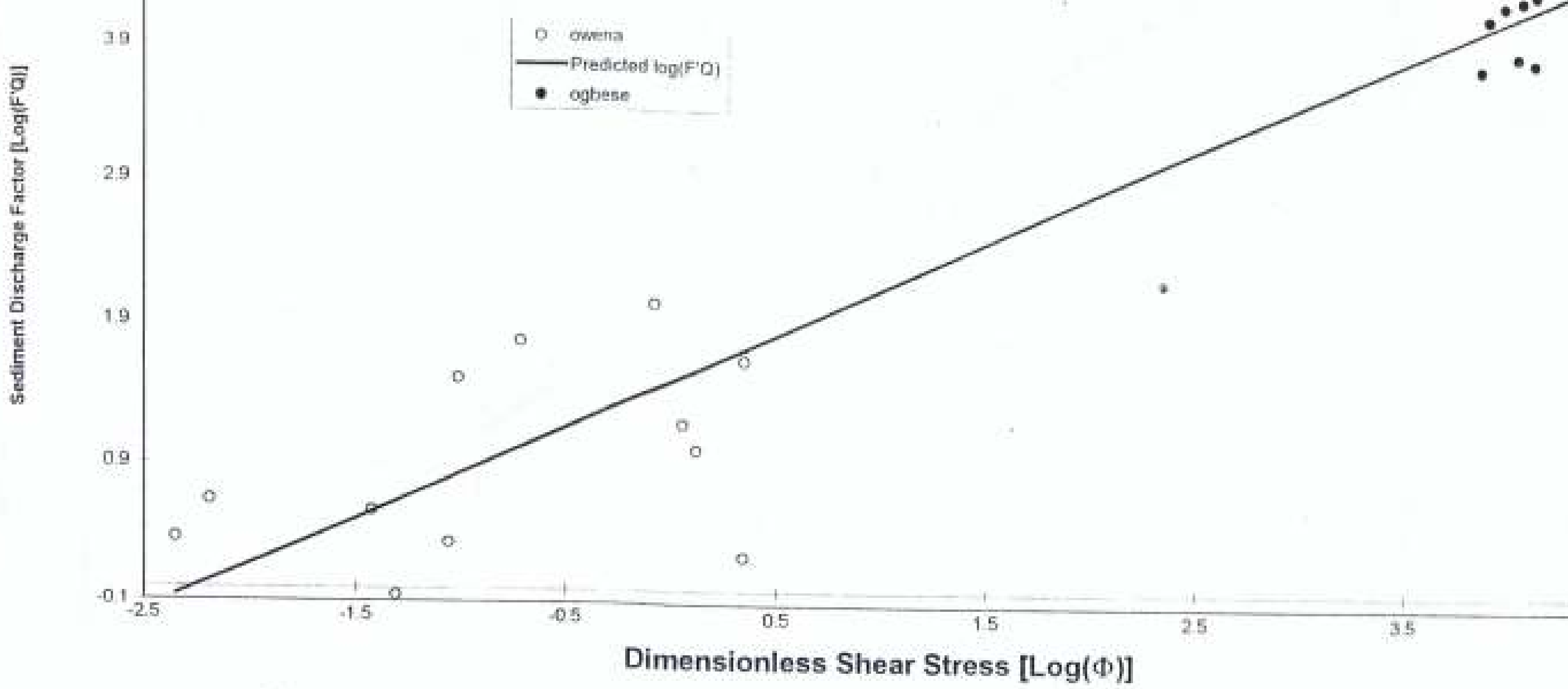


Fig. 6.3 Relationship between Log (F'Q) and Log (Φ) for both Owena and Ogbese Rivers

$$F'Q = 1.499\Phi^{0.661}$$

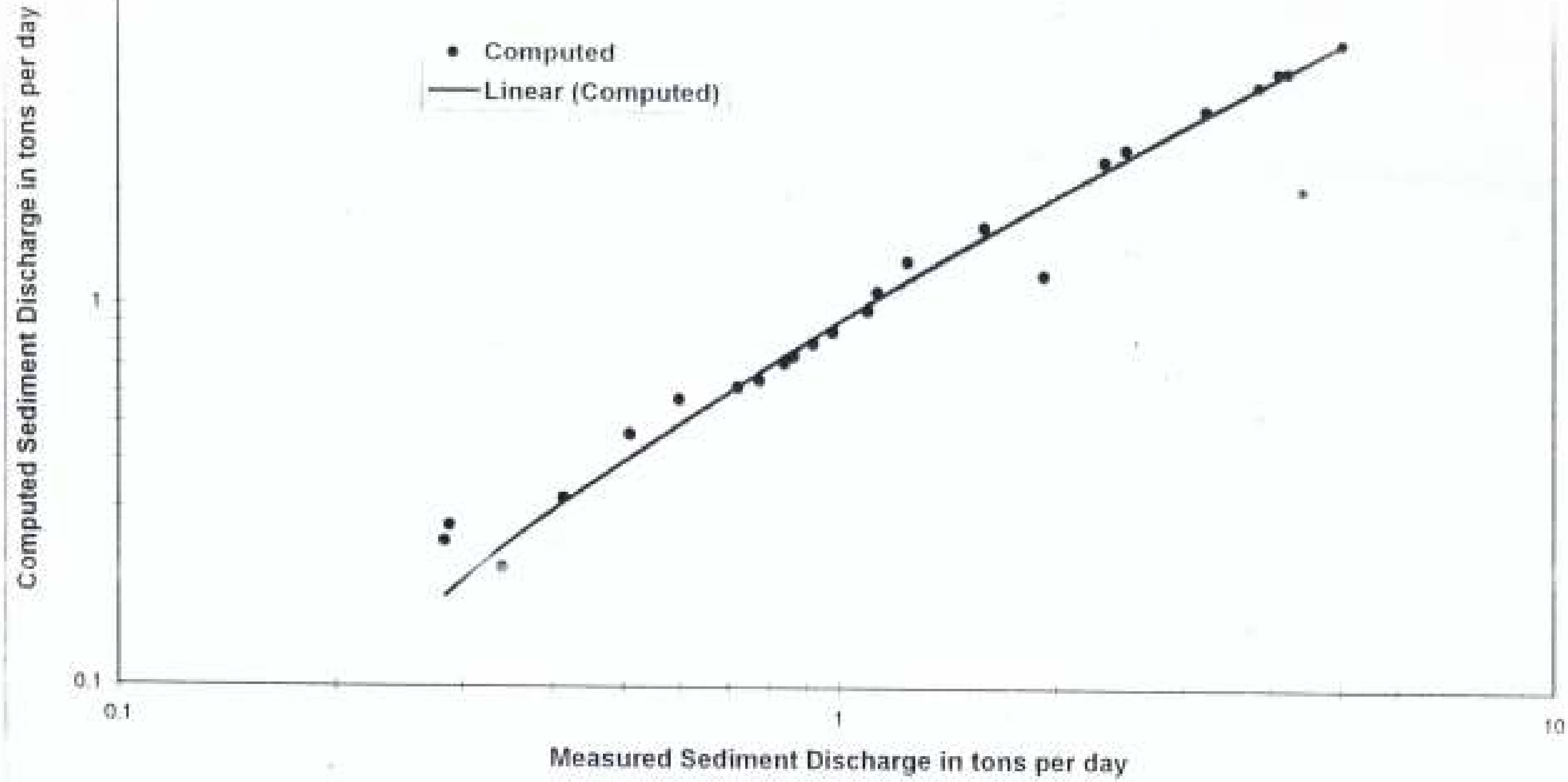


Fig. 6.4 Computed against Measured Sediment Discharge for Ogbese River using karim (1998) and the proposed prediction equation

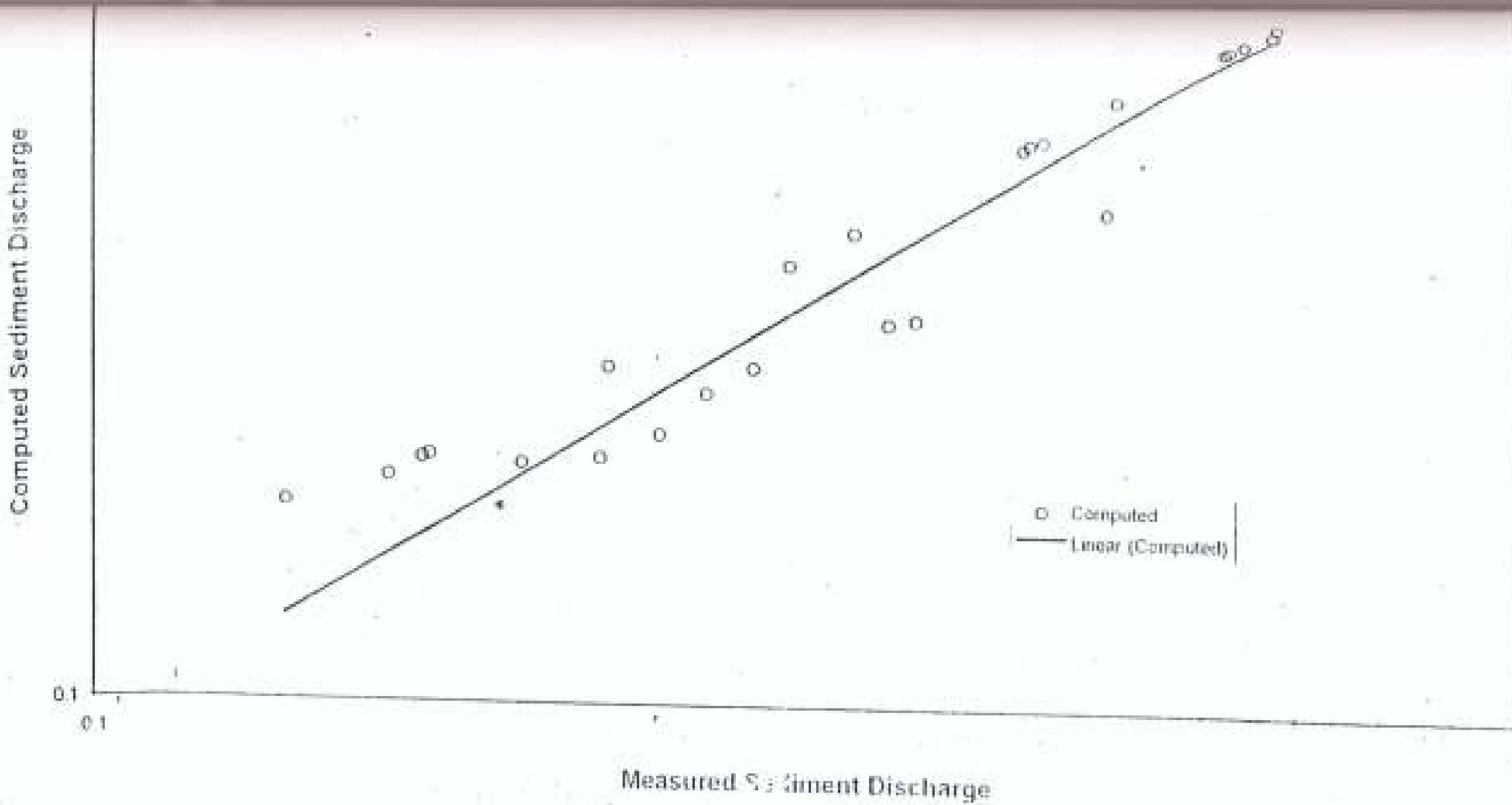


Fig. 65 Computed against Measured Sediment Discharge for Owena River using the proposed prediction equation

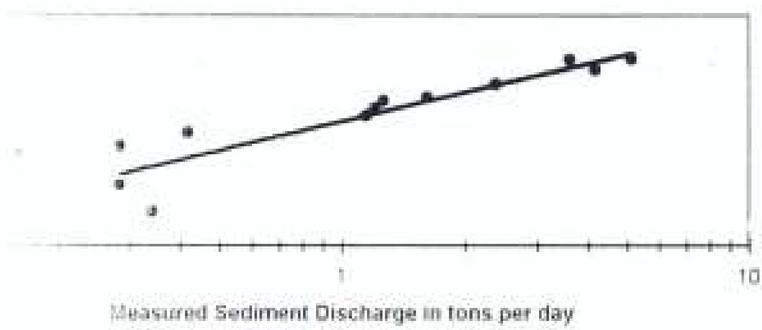


Fig. 5.6 Computed against Measured Sediment Discharge for Ogbese River using Karim's Equation

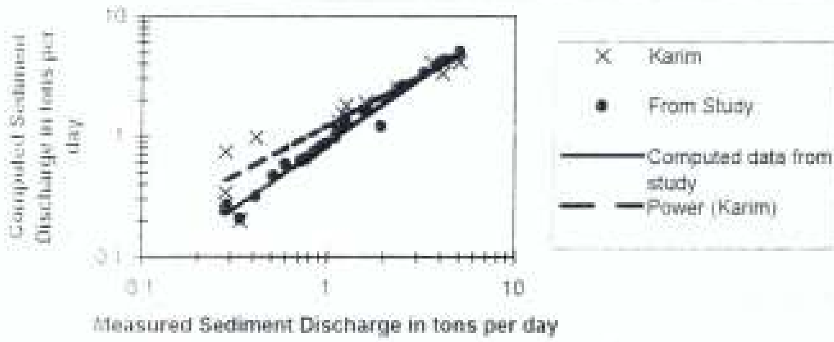
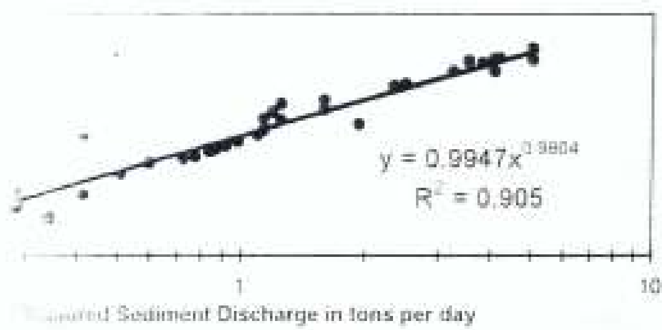


Fig. 5.7 Comparison of computed against Measured Sediment Discharge for Ogbese River using the proposed prediction equation and Karim's (1998) Equation



Computed against Measured Sediment Discharge for River using the data from study and Karim's equation discharges for Ogbese River obtained by using Karim (1998) model and the predicted equation. The result showed that a good agreement exist between the two models $R^2 = 0.95$.

Figure 6.8 illustrates the comparison between the computed and measured discharge for Ogbese River using the combined data from study and Karim equation. The result shows a good correlation exist between the various models with a coefficient of determination, $R^2 = 0.905$.

Figure 6.9 presents a comparison between the computed and measured sediment discharge for Owena river and Karim (1998) equation. The result shows a good agreement exist between the two models with coefficient of determination. $R^2 = 0.96$.

Figure 6.10 iIllustrates a comparison between the measured and computed sediment discharge for Owena River obtained by using Karim (1998) and the predicted equation. The result showed that a good agreement exist between the two models; $R^2 = 0.92$.

Figure 6.11 shows a comparison between the computed and the measured discharge for Owena River using the combined data from study Karim (1998) equation. The result showed a relationship between the models with the test model.

Many comparisons above have been obtained between measured and calculated sediment discharge to assess the accuracy of theoretical prediction for the developed models. The results have been very satisfactory. However, for practical applications, Duru (1984) gave the graphing method of 1:1 marching of results as a means of testing the accuracy of models for practical engineering applications. Against this background, Figures 6.12, 6.13, 6.14, 6.15 showed the results obtained when the various models were subjected to this test.

Figure 6.12 shows that the data points were evenly distributed along the line of perfect agreement. According to Duru (1984) the developed Ogbese model at this stage is predicting accurately.

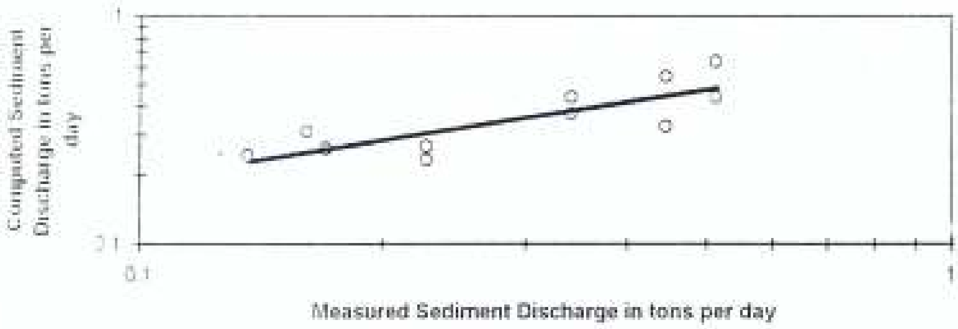


Fig. 6.9 Computed against Measured Sediment Discharge for Owena River using Karim's Equation

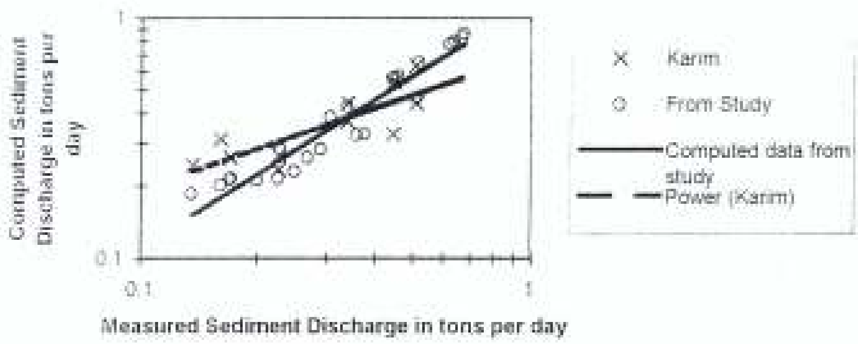


Fig. 6.10 Comparison of computed against Measured Sediment Discharge for Owena River using the proposed prediction equation and Karim's (1998) Equation

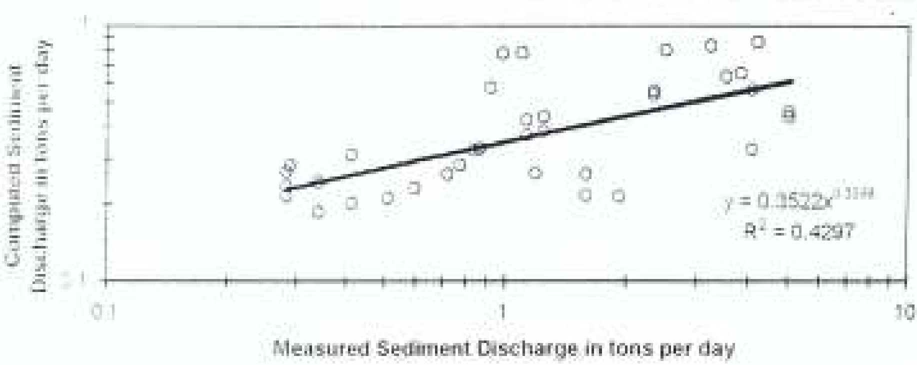


Fig. 6.11 Computed against Measured Sediment Discharge for Owena River using the data from study and Karim's equation

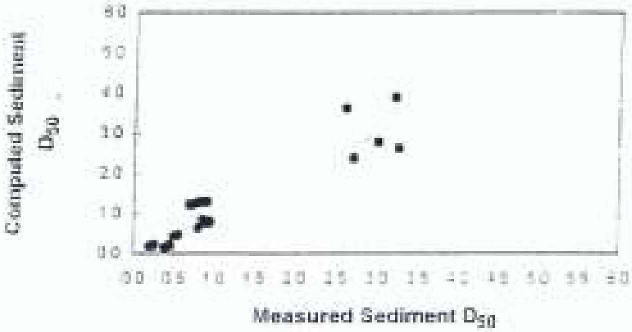


Fig. 6.12 Comparison between Measured and Computed sediment discharge D_{50} for Ogbese River

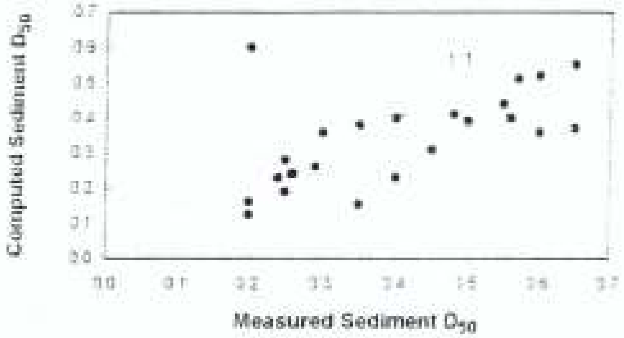


Fig. 6.13 Comparison between Measured and Computed sediment discharge D_{50} for Owena River

Figure 6.13 shows that the data points lie below the line of perfect agreement. According to Duru (1984) the Owena model is under predicting.

Figure 6.14 shows that the data points lie below the line of perfect agreement. Karim (1998) models is under predicting for Ogbese River

Figure 6.15 shows that the data points lie below the line of perfect agreement. Therefore, Karim (1998), models are also under predicting for Owena River.

According to Duru (1984) a model is said to be over predicting if the data points lie above the line of perfect agreement. Also a model is said to be under predicting if the data points lie below the line of perfect agreement. When the data points are distributed evenly on the line of perfect agreement, the models is said to be predicting perfectly. By over prediction, it means the models are over designing and by under prediction it means the model is under designing the structures to which they are applied. The inherent advantages and disadvantages associated with over design and under design of structures are well documented in literature

From the above observations it could be stated that the predicted models for both Ogbese and Owena rivers performed well when tested for engineering applications and compared favourably with the established river models Karim (1998) Gondwe (2000).

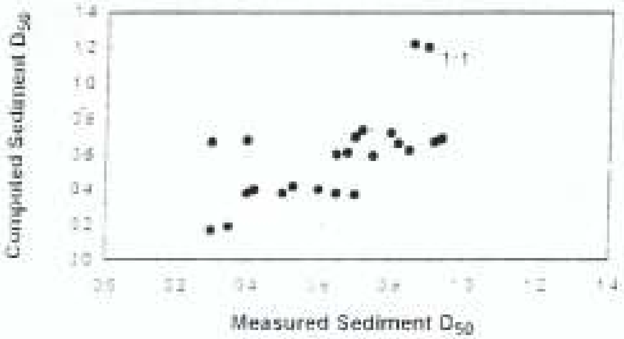


Fig. 6.14 Comparison between Measured and Computed sediment discharge D_{50} using Karim Equation for Ogbese River

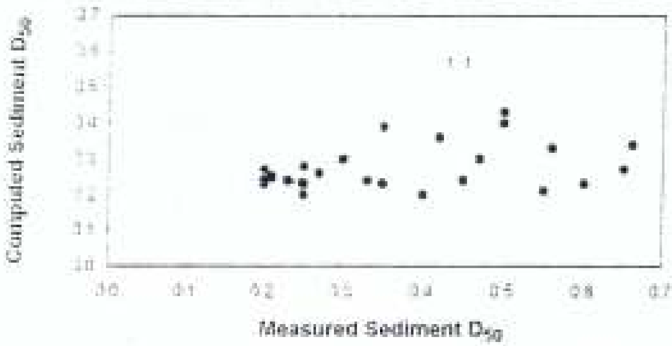


Fig. 6.15 Comparison between Measured and Computedsediment discharge D_{50} using Karim Equation for Owena River

6.2. Typical Calculations for Ogbese River

The proposed prediction equation is given below as:

$$\frac{qs}{\sqrt{g(\gamma-1)D^3_{50}}} = 0.865\frac{V}{\sqrt{g(\gamma-1)D_{50}}}\left(\frac{\tau}{(\gamma-1)D_{50}}\right)^{0.592} \quad \text{.....................(66)}$$

$$\frac{qs}{\sqrt{g(\gamma-1)D^3_{50}}} = (0.865)^2\frac{V^2}{\sqrt{g(\gamma-1)D_{50}}}\left(\frac{\tau}{(\gamma-1)D_{50}}\right)^{1.184}$$

$$\frac{q^2}{g(\gamma-1)D^3_{50}} = \frac{(0.865)^2V^2\tau^{1.184}}{g(\gamma-1)^{2.184}D_{50}^{\ 2.184}}$$

$$q^2 . g. (\gamma-1)^{2.184} D^{2.184} = (0.865)^2 . V^2\tau^{1.184} g.(\gamma-1) D^3$$

$$\frac{D_{50}^{\ 2.184}}{D^3_{50}} = \frac{(0.865)^2 . V^2 . \tau^{1.184}}{(\gamma-1)^{1.184} q^2}$$

$$\frac{1}{D_{50}^{\ 0.816}} = \frac{0.74825 V^2 . \tau^{1.184}}{(\gamma-1)^{1.184} q^2}$$

$$\frac{1}{D_{50}^{\ 0.816}} = \frac{(3.373)^2V^2\tau^{1.184}}{q^2}$$

$$D_{50}^{\ 0.816} = \frac{q^2}{(3.373)^2V^2\tau^{1.184}}$$

$$q^2 = (3.373)^2 V^2\tau^{1.84}D_{50}^{\ 0.816}$$

$$q = \sqrt{3.373 . V^2 . \tau^{1.184}D_{50}^{\ 0.816}} \text{ kg/day}$$

Available data (from Table 6.1 line 1)

(1) q = 0.342 kg/day, d = 1.456m, slope = 0.0063, D_{50} = 0.20mm, Velocity V = 1.05m/s, τ = 0.089985N/m^2

$$q = \sqrt{3.373 \times (1.05)^2(0.089985)^{1.184} \times (0.20)^{0.816}}$$

$$q = \sqrt{3.373 \times 1.1025 \times 0.0577 \times 0.2689}$$

q predicted = 0.441kg/day.

(2) D_{50} = 0.50mm, q_s = 0.342 kg/day, d = 1.456m, Slope = 0.0063, V = 1.05m/s

$$\therefore \quad \tau = gRS = 0.089985 N/m^2$$

$$q = \sqrt{3.373 \times (1.05)^2 (0.089985)^{1.184} \times (0.50)^{0.816}}$$

$$q = (3.373 \times 1.1025 \times 0.0577 \times 0.5680)^{1/2}$$

$$q = 0.349 kg/day$$

(3) D_{50} = 0.09mm, q_s = 1.193 kg/day, d = 1.9m. V = 2.50m/s.

$$\tau = 0.117415 N/m^2$$

$$q = \sqrt{3.373 \times (2.5)^2 (0.11741)^{1.184} \times (0.9)^{0.816}}$$

$$q = (3.373 \times 6.25 \times 0.07915 \times 0.9176)^{1/2}$$

$$q = 1.237 kg/day$$

Table 6.3: Summary of Results for Ogbese River Sediment discharge q_{ci}

Measured discharge q_m (kg/day) X_m	Computed based on equation (18) (mm)X_{ci}
0.342	0.441
0.284	0.349
1.193	1.237
0.415	0.532
1.136	1.178
1.250	1.296
2.346	2.433
4.107	4.258
5.055	5.241
3.051	3.993
1.596	1.655
1.193	1.237
ΣX_{mi} = 22.768	ΣX_{ci} = 23.85

$$\frac{\sum X_m}{\sum X_c} = \frac{22.768}{23.85} = 0.9546$$

∴ Level of accuracy = 95.46%

In conclusion, the data has a high level of accuracy 95.46% and is therefore very reliable. The degree of correlation is also very significant.

6.3. Typical Calculations for Owena River

This proposed prediction equation is given below as:

$$\frac{qs}{\sqrt{g(\gamma-1)D^3_{50}}} = 1.197\frac{V}{\sqrt{g(\gamma-1)D_{50}}}\left(\frac{\tau}{(\gamma-1)D_{50}}\right)^{0.335} \quad \text{.......................(67)}$$

Therefore, squaring both sides, we have;

$$\frac{q^2}{g(\gamma-1)D_{50}{}^3} = (1.197)^2\frac{V^2\tau^{0.67}}{g(\gamma-1)^{1.67}D_{50}{}^{1.67}}$$

$$\frac{q^2}{g(\gamma-1)D_{50}{}^3} = \frac{(1.197)^2V^2\tau^{0.67}}{g(\gamma-1)^{1.67}D_{50}{}^{1.67}}$$

$$q^2 . g. (\gamma-1)^{1.67} D^{1.67} = (1.197)^2 . V^2\tau^{1.184} .g.(\gamma-1) D^3$$

$$\frac{D_{50}{}^{2.184}}{D_{50}{}^3} = \frac{(1.197)^2 . V^2 .\tau^{0.67}}{(\gamma-1)^{0.67}q^2}$$

$$\frac{1}{D_{50}{}^{1.33}} = \frac{1.4328V^2.\tau^{0.67}}{1.3986q^2}$$

$$\frac{1}{D_{50}{}^{1.33}} = \frac{1.024404V^2.\tau^{0.67}}{q^2}$$

The general equation to obtain the total sediment discharge for Owena River becomes

$$q^2 = 1.024404V^2\tau^{0.67} \text{ kg/day.} \quad \text{.................................(68)}$$

$$q = \sqrt{1.024404V^2\tau^{0.67} \text{ kg/day.}}$$

Available data: (from Table 6.2 were used in the computation.

(1) $D_{50} = 0.20$mm, $q = 0.1363$ kg/day, $d = 0.24$m, $V = 0.65$m/s, $\tau = 0.22052$N/m^2

$$q = \sqrt{1.024404V^2\tau^{0.67}}$$

$$q = 0.1833 \text{ kg/day.}$$

(3) $D_{50} = 0.25$mm, $q = 0.2272$ kg/day, $d = 0.22$m, $V = 0.65$m/s, $\tau = 0.02022 N/m^2$

$$q^2 = \sqrt{1.024404 V^2 \tau^{0.67}}$$

$$= \sqrt{1.024404\,(0.85)^2 \times (0.02022)^{0.67}}$$

$$q = 0.2328 \text{ kg/day.}$$

$$D_{50} = \left(\frac{q^2}{8.851 V^2 . \tau^{0.67}}\right)^{0.752} \qquad \text{.........................(69)}$$

$$\therefore D^{1.33} = \frac{q_{ci}^{\ 2}}{8.851 V^2 . \tau^{0.67}} \text{ mm}$$

$$q_{ci}^{\ 2} = 8.851 V^2 . \tau^{0.67} D^{1.33}$$

$$q_{ci} = (8.851 V^2 . \tau^{0.67} D^{1.33})^{1/2} \text{ kg/day}$$

The general equation to obtain the computed sediment discharge q_{ci} for Owena River becomes

$$q_{ci} = (8.851 V^2 . \tau^{0.67} D^{1.33})^{1/2} \text{ kg/day} \qquad \text{.........................(70)}$$

Available data (from Table6. 2, line 1)

$q = 0.1363$Kg/day, $d = 0.24$m, $D = 0.20$mm, $V = 0.65$m/s, $\tau = 0.022052 N/m^2$

$$\therefore q_{ci}^{\ *} = \sqrt{8.851 (0.65)^2 (0.02205)^{0.67} (0.20)^{1.33}}$$

$$q_{ci} = 0.1846 \text{ kg/day}$$

$$q_{ci} = 0.185 \text{ kg/day.}$$

The value of the computed sediment discharge (q_{ci}) for Owena River, can be obtained from the transformation of equation (70), and shown in Table 6.4

Table 6.4: Summary of results for Owena river Sediment Discharge

Measured D_{50} (mm) X_{mi}	Computed discharge based on equation (20) (mm) X_{ci}
0.1363	0.185
0.2272	0.2328
0.2280	0.2350
0.1613	0.2169
0.3408	0.4583
0.3076	0.4136
0.4454	0.5989
0.4494	0.6002
0.5112	0.6874
0.1764	0.2330
0.1704	0.2291
$\Sigma X_{mi} = 3.1432$	$\Sigma X_{ci} = 4.0811$

$$\sum \frac{X_{mi}}{X_{ci}} = \frac{3.1432}{4.0811} = 0.77$$

Level of accuracy = 77%.

6.4. Typical Calculations for Ogbese and Owena Rivers using Karim's (1998) Model

The general equation as given by Fazle Karim (1998) is presented below

$$\frac{q}{\sqrt{(\gamma-1)D^3{}_{50}}} = 0.00139\left(\frac{V}{\sqrt{g(\gamma-1)gd^3{}_{50}}}\right)^{2.97}\left(\frac{U_*}{W}\right)^{1.47}$$

Therefore, breaking down, it becomes

$$\frac{q^2}{(\gamma-1)gd^3{}_{50}} = (0.00139)^2\left(\frac{V^2}{(\gamma-1)gd^3{}_{50}}\right)^{2.97}\left(\frac{U_*}{W}\right)^{1.47}$$

$$\frac{q^2}{(\gamma-1)gd^3{}_{50}} = (0.00139)^2\,\frac{V^{5.94}}{(\gamma-1)^{2.97}g^{2.97}d^{8.91}}\,\frac{U_*{}^{2.94}}{W^{2.94}}$$

$$\frac{q^2}{(\gamma-1)gd^3{}_{50}} = 0.000001932\,\frac{V^{5.94}U_*{}^{2.94}}{(\gamma-1)^{2.97}g^{2.97}d^{8.91}W^{2.94}}$$

Therefore, breaking down, it becomes:

$$\frac{q^2}{\sqrt{g(\gamma-1)gd^3{}_{50}}} = (0.00139)^2\left(\frac{V^2}{\sqrt{g(\gamma-1)gd^3{}_{50}}}\right)^{2.97}\left(\frac{U_*}{W}\right)^{1.47}$$

$$\frac{q^2}{\sqrt{g(\gamma-1)gd^3{}_{50}}} = (0.00139)^2\,\frac{V^{5.94}}{(\gamma-1)^{2.97}g^{2.97}d^{8.91}}\,\frac{U_*{}^{2.94}}{W^{2.94}}$$

$$\frac{q^2}{(\gamma-1)gd^3{}_{50}} = 0.000001932\,\frac{V^{5.94}U_*{}^{2.94}}{(\gamma-1)^{2.97}g^{2.97}d^{8.91}W^{2.94}}$$

and transformation gives:

$$q^2 = \left(\frac{0.000001932 V^{5.94} U_*^{2.94}}{258.096 q^2 W^{2.94} d^{8.91}} \right)^{1/2}$$

Table 6 line 1 for Ogbese data imputed into Karim's equation gives:

(1) D_{50} = 0.30mm, q = 0.342 kg/day, d = 1.456m, V = 1.05m/s, U_* = 0.3000N/m², W = 9.5mm/s.

$$q_c = \left(\frac{0.000001932\,(1.05)^{5.94}(0.300)^{2.94}}{(0.0095)^{2.94}\,(0.30)^{5.91}} \right)^{1/2}$$

$$q_c = 0.2003 \text{ kg/day}$$

(2) D_{50} = 0.40mm, q = 0.3284 kg/day, d = 1.456m, V = 1.05m/s, U_* = 0.3000N/m², W = 9.5mm/s.

$$q_c = \left(\frac{0.00001932\,(1.05)^{5.94}(0.3)^{2.94}}{(0.0095)^{2.94}\,(0.40)^{5.91}} \right)^{1/2}$$

$$q_c = 0.340 \text{ kg/day.}$$

From Table 2 line 1 for Owena data imputed into Karim's equation gives:

(1) D_{50} = 0.20mm, q = 0.1363Kg/day, d = 0.24m, V = 0.65m/s, U_* = 0.1485N/m², W = 0.0075mm/s.

$$q_c = \sqrt{\frac{0.00001932\,(0.65)^{5.94}\,(0.1485)^{2.94}}{(0.0075)^{2.94}\,(0.20)^{5.91}}}$$

$$q_c = 0.234 \text{ kg/day.}$$

(2) D_{50} = 0.25mm, q = 0.2272Kg/day, d = 0.22m, V = 0.85m/s, U_* = 0.1422N/m², W = 0.0075mm/s.

$$q_c = \sqrt{\frac{0.00001932\,(0.85)^{5.94}\,(0.1422)^{2.94}}{(0.0075)^{2.94}\,(0.25)^{5.91}}}$$

$q_c \quad = \quad 0.233$ kg/day.

(3) D_{50} = 0.30mm, q = 0.2272Kg/day, d = 0.14m, V = 0.85m/s, $U_* = 0.1134 N/m^2$, W = 0.0075mm/s.

$$q_c = \sqrt{\frac{0.00001932\,(0.85)^{5.94}\,(0.111344)^{2.94}}{(0.0075)^{2.94}\,(0.30)^{5.91}}}$$

$q_c \quad = \quad 0.310$ kg/day.

(4) D_{50} = 0.35mm, q = 0.1363Kg/day, d = 0.24m, V = 0.65m/s, $U_* = 0.1485 N/m^2$, W = 0.0075mm/s.

$$q_c = \sqrt{\frac{0.00001932\,(0.85)^{5.94}\,(0.11575)^{2.94}}{(0.0075)^{2.94}\,(0.35)^{5.91}}}$$

$q_c \quad = \quad 0.3696$ kg/day.

Table 6.5 Summary of results for Ogbese River using Karim's equation (31)

S/N	Measured discharge (kg/day) X_m	Computed discharge (kg/day) X_{ci}
1	0.342	0.2003
2	0.284	0.34
3	0.284	0.733
4	0.415	0.960
5	1.136	1.33
6	1.250	1.787
7	2.346	2.508
8	4.107	3.3142
9	5.055	4.1150
10	3.851	4.051
11	1.596	1.930
12	1.193	1.530
	$\Sigma x_m = 21$	$X_{ci} = 22.81772$

$q_m = 21.859$

$q_c = 22.81772$

$$\text{Level} = \frac{X_m}{X_c} \times \frac{100}{1}$$

$$= \frac{21.859}{22.81772} \times \frac{100}{1}$$

$$= 0.9579 \times 100$$

Level of accuracy of result. = 95.8%

Table 6.6 Summary of results for Owena River using Karim 's equation (31)

S/N	Measured discharge (Kg/day)	Computed discharge (Kg/day)
1	0.1363	0.234
2	0.2272	0.266
3	0.2272	0.2330
4	0.1613	0.310
5	0.3408	0.3696
6	0.3076	0.439
7	0.4454	0.537
8	0.4454	0.326
9	0.5122	0.439
10	0.5112	0.630
11	0.1704	0.261
12	0.1704	0.261

$q_m = 3.6554$

$q_c = 4.3056$

$$\text{Level} = \frac{X_m}{X_c} \times \frac{100}{1}$$

$$= \frac{3.6554}{4.3056} \times \frac{100}{1}$$

$$= 0.848987 \times 100$$

Level of accuracy of result = 84.898%

6.5 Analysis and Interpretation of Results

In furtherance of the verification process, a statistical comparison is made betwee computed bed-material concentrations and the measured values using the proposed predictio equations (59) and (60) for Ogbese and Owena rivers respectively. The results obtained ar summarized in Tables 6.7 and 6.8. Four different statistical methods of comparisons we used to compare the results obtained with these established relations with the new river mode developed by the investigator.

The procedure is as follows:

(1) A discrepancy ratio.

$$R = \frac{X_{ci}}{X_{mi}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(71)$$

In which Xci and Xmi = computed and measured bed material concentrations, kilogram/cubic meter, respectively.

(2) The standard deviation between computed and measured bed material concentrations

$$\delta = \sqrt{\sum_{N=1}^{N} \frac{(X_c - X_m)^2}{N-1}} \quad \ldots\ldots\ldots\ldots (72)$$

In which N = data set number, N = 1,2 ....N

and N = total number of data sets.

(3) The mean normalized error (MNE)

$$MNE = \frac{100}{N} \sum_{N=1}^{N} \left(\frac{X_c - X_m}{X_{mi}} \right) \quad \ldots\ldots\ldots\ldots(73)$$

(4) Mean Prediction Factor (MPF)

$$MPF = \frac{1}{N} \sum \text{large of } \frac{X_{mi} - X_{ci}}{X_{ci} - X_{mi}} = \frac{X_{mi}}{X_{ci}} \quad \ldots\ldots\ldots\ldots (74)$$

6.5.1 Statistical Computations for Ogbese River

(1) Prediction accuracy is measured by Mean Normailised Error (MNE)

$$MNE = \frac{100}{N}\sum_{N=1}^{N}\frac{X_{mi} - X_{ci}}{X_{mi}} \quad \text{.................... (75)}$$

$$\therefore MNE = \frac{100}{12}\sum \frac{23.85 - 22.768}{23.85} \quad \text{....................(76)}$$

$$= 0.378$$

$\therefore$ MNE value for Ogbese river = 37.80

(2) Mean Prediction Factor (MPF)

$$MPF = \frac{1}{N}\sum \text{large of } \frac{X_{mi} - X_{ci}}{X_{ci} - X_{mi}} = \frac{X_{mi}}{X_{ci}} \quad \text{....... (77)}$$

$$MPF = \frac{1}{N}\sum \text{large of } \frac{X_{mi} - X_{ci}}{X_{ci} - X_{mi}} = \frac{X_{mi}}{X_{ci}} \quad \text{............ (78)}$$

The Ogbese River has an MPF value of 1.03

(3) Discrepancy ratio, % (Re) for Ogbese River is given as

$$\frac{X_{ci}}{X_{mi}} \times 100 \quad \frac{22.768}{23.85} \times 100 = 95.4\% \quad \text{...... (79)}$$

The discrepancy ratio Re for Ogbese river is 95.46%

(4) The Standard deviation (Q) for Ogbese river data is obtained by the formula

$$\delta = \sqrt{\frac{\sum X_{ci} - X_{mi}}{N-1}} = \sqrt{\frac{22.768 - 23.85}{12}} = 0.3262 \quad \text{...... (80)}$$

$$\left.\begin{aligned} \delta &= 0.33 \\ \delta &= 3.3 \end{aligned}\right\} \text{..........(81)}$$

6.5.2 Statistical Computations for Owena River

(1) Prediction accuracy is measured by Mean Normailised Error (MNE) Karim (1998)

$$MNE = \frac{100}{N}\sum_{N=1}^{N}\frac{X_{mi} - X_{ci}}{X_{mi}} \qquad \text{.....................} \qquad (82)$$

$$MNE = \frac{100}{24}\sum \text{large of } \frac{40892 - 3.154}{4.0882} \qquad \text{.............} \qquad (83)$$

$$= \quad 0.228699$$

∴ MNE value for Ogbese river = 22.869

(2) Mean Prediction Factor (MPF) Karim (1998)

$$MPF = \frac{1}{N}\sum \text{large of}\left(\frac{X_{mi} - X_{ci}}{X_{ci} - X_{mi}}\right) = \frac{X_{mi}}{X_{ci}} \qquad \text{......} \qquad (84)$$

$$\therefore MPF = \frac{1}{N}\sum_{N}^{1} \text{large of } \frac{4.0892}{3.152} \qquad \text{.............} \qquad (85)$$

The Ogbese River has an MPF value of 1.297

(3) Discrepancy ratio, % (Re) for Ogbese River is given as

$$\frac{X_{ci}}{X_{mi}} \times 100 = \frac{3.152}{4.0892} \times 100 \quad = 77.1\% \qquad \text{...........} \qquad (86)$$

The discrepancy ratio Re for Ogbese River is 77.1%

(4) The Standard deviation (δ) for Ogbese river data is obtained by the formula

$$\delta = \sqrt{\frac{\left(\sum X_{ci} - X_{mi}\right)^2}{N-1}} = \sqrt{\frac{(22.768 - 23.85)^2}{12}} \qquad \text{.....................} \qquad (87)$$

$$\delta = 2.82$$

Table 6.7 Comparison of Equation (57) and (58) with other Models

Author of formula (1)	Data in the Range of Discrepancy Ratio R/% 0.25 – 0.88 (2)	2.0 – 9.0 (3)	Standard Deviation Kg/m^3 (4)	Mean Normalized Error. MNE % (5)	Mean Prediction Factor, MPF (6)
*Engelund and Hansan (1967)	74	80	8.4	49.3	2.1
*Ackers and White (1973)	58	54	7.2	62.8	5.2
*Yang (1973)	72	83	9.2	62.0	4.2
*Karim (1998)	72	86	6.8	45.1	2.1
*New relation Eqn. (58) for Ogbese river	95.4	95.4	3.3	37.8	1.05
*New relation Eqn. (60) for Owena river	77.1	77.1	2.82	22.87	1.297

*The results were obtained from the Karim (1998).

Table 6.8: Summary of comparison of sediment discharge prediction using Karim's (1998) equation (31)

Data	Number of flows	Mean Prediction Factor (MPF	Mean Normalized Error (MNE) %
*Einstein-Chien flume data	26	1.51	59.4
*Middle Loup River	59	2.18	37.1
*Missouri River	60	1.60	27.1
*Niobrara River	30	1.39	28.1
Ogbese River	12	1.05	37.8
Owena River	12	1.297	22.87

*The results were obtained from the Karim (1998).

6.6. Discussion of Results

Table 6.7 above shows the results obtained from the comparison between the computed and the observed bed-materials concentrations, with the other established models and the developed models (58) and (60) for Ogbese and Owena rivers respectively. Four statistical parameters were used in the comparison processes.

These are (i) Discrepancy ratio (R) (ii) Standard deviation (δ) (iii) Mean normalized error (MNE) (iv) Mean Prediction Factor (MPF). It is shown from the Table 6.7 that Ogbese, and Owena Rivers have the lowest value of MNE (37.8, 22.87) only comparable to Karim (1998) and Englund and Hansen (1967) with values of 45.1 and 49.3 respectively. It also observed that the developed models (58) for Ogbese river and (60) for Owena river have the lowest value of standard deviation and Mean Prediction Factor (MPF) of (3.3, 2.82) and (1.05 and 1.3) respectively. From the presented results, in Table 6.7 it is seen that the predicted models produced good correlation coefficients (R^2 = 0.99; 0.95) with the established models and in some cases performed better than existing sediment transport models. This confirms the validity of the developed models.

Table 6.8 also listed the mean prediction factor and the mean normalized error for each data set. Their 4 data sets are (31) Einstein-Chien Flume data (Einstein and Chien, 1953) (2) Missouri River (1979) (3) Niobrara River (Colby and Hembree 1955) (4) Middle Loup River (Humble and Matejka, 1959). The Einstein-Chien Flume data is probably the most reliable because the measurements were done under controlled laboratory conditions. Measurement of flow and sediment data under field conditions are much more difficult and therefore less reliable due to many practical factors. It is observed from Table 6.8 above that apart from flume data that has an MPF of 1.51 and MNE of 59.4, the MPF of all the rivers range between 1.05 to 2.18 and the MNE range from 22.87 to 59.4. From the above analysis, it could be concluded that the relations (58) and (60) yielded good agreement with established equations for the purpose of predicting the total sediment discharge and even performed better than several existing sediment transport equations.

6.7 Short Duration Measurements

Further verification process was carried out on these developed models for each river using new sets of data shown on Tables 6.9 and 6.10 respectively. Sediment load measurements were performed on three vertical at 0.1-, 0.5-, and 0.9-, width of the ganging section between July and October 2001. The sediment yields at the three verticals were computed from the respective data of sediment concentration the average value of the discharge of the whole cross – section were used. The purpose of testing the developed model with new sets of data was to confirm their validity. This is because the new sets of data were collected from short duration measurements, while the models were developed from data collected for long duration measurements.

Results obtained from short duration study which are presented on Figure 6.16and 6.17 respectively indicate that sediment discharge measurements for Ogbese and Owena rivers demonstrated a positive correlation between the yield of sediment discharge (F^1Q) and the dimensionless bed shear stress (Φ) of the form

$F^1Q = K_1 \Phi^{k_2}$. This is a power law relationship and is in agreement with the previously developed models (58) and (60) for two rivers and also with the established sediment transport models such as Kinori et al (1984), Acker and White, (1973) Karim (1998), and Gondwe, (2000).

The models obtained from the regression analysis of these new sets of data are presented as equation (86) and (87) below:

$$F^1Q = 2.4216\ \Phi^{0.9306} \quad (81)$$ for Ogbese river and

$$F^1Q = 0.0522\ \Phi^{0.6735} \quad (82)$$ for Owena river.

6.8. Summary

The solutions obtained from the developed models for the two rivers with new sets of data were found to compare favourably with results of field measurements. Therefore the developed models (58) and (60) obtained from long duration measurements is adopted for the estimation of sediment yield of the Ogbese and Owena rivers.

Table 6.9 Sediment concentration of Ogbese River at Akure – Owo Road Bridge Station

Date	Q (Cumes)	C (mg / l)	Mean C (mg / l)	(Ton / day)
2001				
01 – 07	138.4	81.56		
08 – 07	138.6	81.60		
10 – 07	139.3	82.08	(82.4)	(7.10)
12 – 07	140.1	82.50		
15 – 07	140.1	82.50		
18 – 08	139.2	82.02		
20 – 08	139.2	82.02		
22 – 08	139.5	82.20	(85.47)	(7.23)
24 – 08	140.2	82.50		
28 – 08	142	83.68		
30 – 08	150.2	89.30		
23 – 09	161.5	95.72		
24 – 09	165.8	98.27		
25 – 09	166.3	98.56	(103.59)	(8.90)
26 – 09	170.2	103.58		
27 – 09	168.1	99.88		
28 – 09	168.5	100.12		
30 – 09	168.0	99.70		
01 – 10	160.4	95.30		
2 – 10	150.3	79.00		
3 – 10	130.5	77.54		
4 – 10	130.2	77.20		
5 – 10	129.4	76.88	(77.87)	(6.78)
6 – 10	129.0	76.88		

Table 6.10 Sediment concentration of Owena River at Akure – Ondo Road Bridge Station

Date	Q (Cumes)	C (mg /l)	Mean C (mg / l)	(Ton / day)
2001				
03 – 07	11.36	8.20		
09 – 07	11.40	8.22		
14 – 07	11.41	8.27		
16 – 07	11.42	8.28	(8.27)	(0.58)
19 – 07	11.43	8.29		
28 – 07	11.55	8.33		
20 – 08	11.55	8.33		
25 – 08	11.55	8.33	(8.33)	(0.72)
28 – 08	11.55	8.33		
31 – 08	12.00	8.34		
21 – 09	17.01	10.30		
22 – 09	17.00	10.00		
25 – 09	17.00	10.00		
27 – 09	17.00	10.00	(10.00)	(0.86)
28 – 09	17.00	10.00		
29 – 09	17.00	10.00		
30 – 09	17.00	10.00		
02 – 10	24.56	10.00		
03 – 10	24.56	10.00		
04 – 10	24.56	10.00		
05 – 10	24.56	10.00		
07 – 10	24.56	10.30	(10.30)	(0.88)
09 – 10	24.56	10.32		
10 – 10	24.56	10.32		
15 – 10	24.56	10.32		
16 – 10	24.56	10.32		

Summary of statistics

n = 26, conversion formular Qw = 0.0864CQw

(Ref Iso 1977a, b)

Qs = tons / day) (10^3 kg) per day, where C (mg/l), Q_w (m^3/s)

Mean concentration C = 9.54 mg/l.

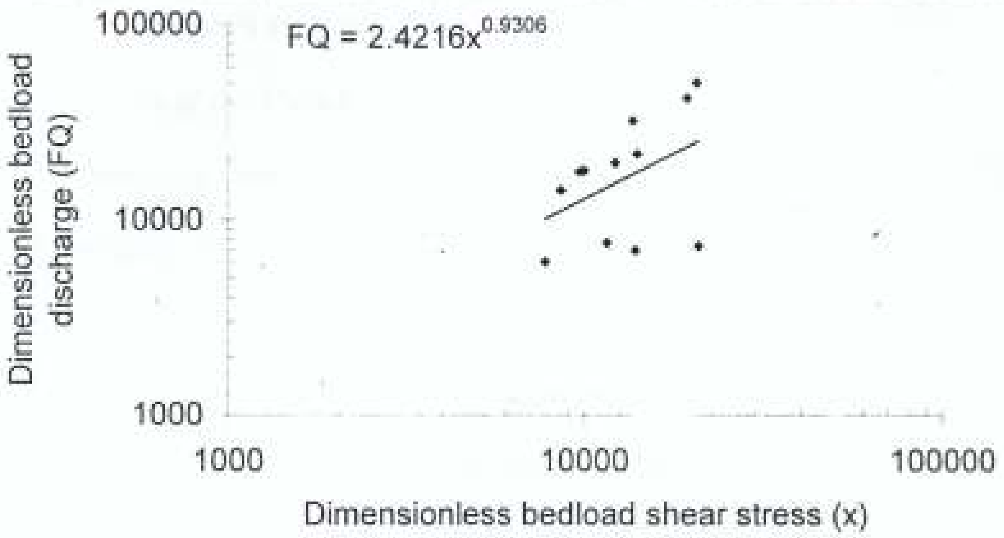


Fig 6:16 Results of short term study for Ogbese River (Jan. - Dec 2001).

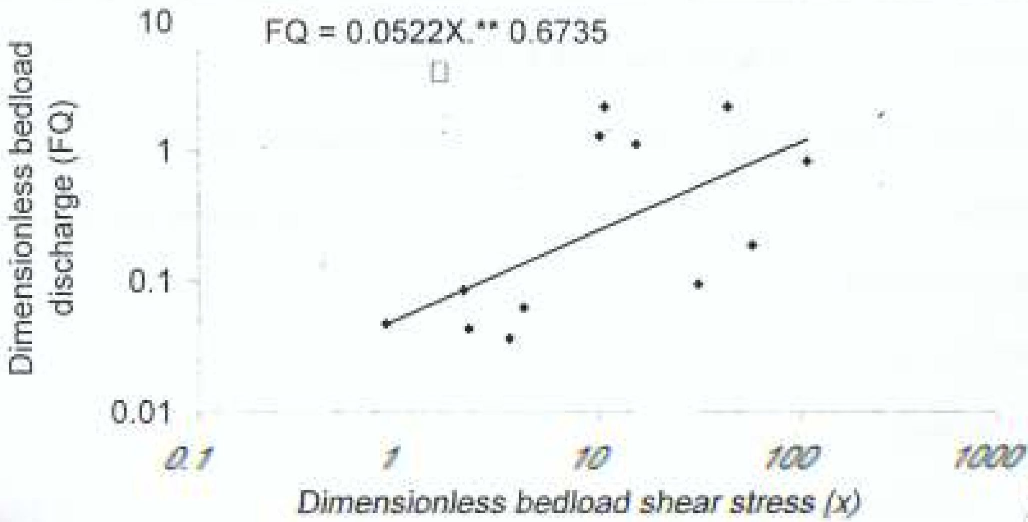


Fig 6:17 Results of short term study for Owena River
(Jan. - Dec. 2001)

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATIONS

7.1 Limitations of the Models

In mathematical models such as the ones developed in this study, there are likely to be three major sources of errors. These are the simplifying assumptions, the set of parameter values and the sampling techniques used.

Errors can arise as a result of simplifying assumptions used in the conceptualization of the river channel flow system. This type of errors result mostly from some assumed conditions e.g. the simplified dimension of the problems and boundary conditions introduced. Though many factors affecting open channel flow and sediment transport were taken into consideration in the formulation of the model nevertheless, the model is one – dimensional. This assumes essentially that both the flow and movement of sediment are totally in the same plane of the section. This assumption will cause deviation between the computed and the measured results because observed channel geometry is usually three – dimensional, some movements will occur in the direction normal to the cross section. In this study of sediment transport, the coefficients of dispersion k_1, k_2 can be adjusted appropriately in the cause of calibration, to minimize the amount of deviation. However, these shortfalls need to be borne in mind when interpreting the results.

The second sources of numerical errors arise from the sampling techniques. Field data collections are subject to human errors. For example repositioning the sampling boat precisely and quickly during sediment load measurements can be difficult. In this study, this has been minimized by taking average values.

7.2 Summary

The results of the sediment transport studies on the two rivers (Ogbese and Owena) provide quantifiable information which are to be useful for engineering, scientific, agricultural and environmental purposes.

(a) Data were collected from field investigations conducted at the two gauging stations on the two rivers respectively.

(b) The live bed concept was derived from Liu – Hwang (1954) resistance equations in combination with the Einstein – Brown (1981) sediment transport concept, the problem was reduced to that of a power law relationship.

(c) The measured data were fitted into the power relationship to obtain the predicted model of the form $FQ = k_2 \Phi^{k}{}_{1}$, for the two rivers.

(d) Calibrating the models yielded the values of the sediment transport coefficients k_1, k_2 for Ogbese river (0.592, 0.865) and Owena river (0.335, 1.197) respectively.

(e) When tested the predicted models for Ogbese and Owena rivers performed well in comparison with established river models such as Ackers and White (1973), Engelund and Hansen (1967), Yang (1973) and Karim (1998)

(f) Further verification of the models was carried out with new sets of data. The results obtained confirmed the reliability of the models for use in scientific and engineering applications.

7.3. Conclusions

(1) From the field investigations, it is concluded that the Ogbese and Owena rivers derive their sediment loads from the erosion activities around their basins and also from the erosion of their banks and beds.

(2) Based on the quantitative interpretation of the field data, it is concluded that the rate of water discharge (q) and the rate of sediment discharge (q_s) for Ogbese and Owena rivers demonstrate a good relationship between the two parameters. They are related by a power law equation of the form $\mathbf{q_s} = \mathbf{cq^n}$ where **c** is a constant and **n** is the slope of the curve. The parameters **n** and **c** are known as the sediment transport coefficients.

(3) Mathematical models that are efficient in both predictive and quantitative requirement have been developed to evaluate the sediment transport capacities of Ogbese and Owena rivers.

The models have been used to compute the sediment transport capacities of the two rivers satisfactorily.

(4) The developed model for Ogbese river is

$$\frac{qs}{\sqrt{(\gamma-1)gd^3_{50}}} = 0.865 \frac{V}{\sqrt{(\gamma-1)gd}}\left(\frac{\iota_o}{(\gamma-1)d_{50}}\right)^{0.592} \quad \ldots\ldots\ldots\ldots\ldots \quad (88)$$

while that for Owena river is

$$\frac{q_s}{\sqrt{(\gamma-1)gd^3_{50}}} = 1.197 \frac{V}{\sqrt{(\gamma-1)gd}}\left(\frac{\iota_o}{(\gamma-1)d_{50}}\right)^{0.335} \quad \ldots\ldots\ldots\ldots \quad (89)$$

(5) These models were tested to certify their validity with established relations mentioned above. The range of application of equation (57) is based on limits of test conditions 0.30mm < d_{50} < 90 mm and the equation (59) is based on limits of test conditions 0.20mm < d_{50} < 90mm.

(6) It is concluded that these models will be useful for engineering design purposes for Ogbese and Owena rivers respectively

7.4 Suggestion for Further Work

This study is based on governing equations for single phase flow (one – dimensional) and are only for low sediment concentration situations. Further studies can be conducted for two-phase flows (two – dimensional), which may involve the study of the influence of water – sediment and sediment – particle interactions.

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LIST OF APPENDICES

Table A:1 FIELD DATA READING FOR OGBESE RIVER (
Discharge Measurements).

Sampling Date	Gauge height (m)	Discharge (m^3 / sec)
24/4/82	1.04	3.73
28/5/82	1.14	4.36
15/6/82	1.12	4.38
29/7/82	0.89	1.87
26/8/82	1.18	4.40
22/9/82	0.96	2.72
23/12/82	0.68	0.75
25/1/83	0.44	0.89
24/6/83	2.75	24.99
27/7/83	3.34	145.00
*Riot	-	-
*Riot	-	-
1/9/93	1.65	10.56
26/10/83	0.905	10.84
22/11/83	071	10.05
13/12/83	0.44	11.03
25/1/84	1.15	9.23
30/3/84	1.30	12.02
10/4/84	1.50	12.59
27/5/84	1.90	24.01
9/6/84	2.20	62.74
15/7/84	3.28	143.10
19/8/84	3.71	171.31
13/9/84	3.00	367.00
25/10/84	1.92	24.50
2/11/84	1.90	23.00
7/12/84	1.29	11.08

SOURCES OF DATA: ORBDA Data year book provided all the data from (1982 – 1994) while field recordings by the researcher provided all the data from (1995 – 1999)

Table A.1 FIELD DATA READING FOR OGBESE RIVER (
(Discharge Measurements).

Sampling Date	Gauge height (m)	Discharge (m^3 / sec)
3/1/85	1.40	12.10
25/2/85	1.26	11.09
22/3/85	1.33	12.8
12/4/85	1.59	13.00
26/5/85	1.93	24.09
23/6/85	2.24	62.82
21/7/85	3.31	143.76
10/8/85	3.75	171.84
14/9/85	3.00	140.00
16/10/85	1.78	29.50
29/11/85	1.22	18.03
1/12/85	1.20	10.69
21/7/85	2.24	62.82
10/8/85	3.31	143.76
14/9/85	3.75	171.84
16/10/85	3.00	140.00
29/11/85	1.78	29.50
1/12/85	1.22	18.03
12/1/86	1.22	11.00
19/2/86	1.13	9.00
20/2/86	1.27	11.66
17/4/86	1.43	12.05
27/5/86	1.83	23.21
12/1/86	1.20	10.69
19/2/86	1.22	11.00
20/3/86	1.13	9.00
17/4/86	1.27	11.66

SOURCES OF DATA: ORBDA Data year book provided all the data from('982 – 1994) while field recordings by the researcher provided all the data from (1995 – 1999)

Table A 1 **FIELD DATA READING FOR OGBESE RIVER (Discharge Measurements).**

Sampling Date	Gauge height (m)	Discharge (m^3 / sec)
27/5/86	1.43	12.05
20/7/86	1.83	23.21
24/8/86	3.12	136.02
26/9/86	3.50	161.32
21/10/86	2.49	130.91
12/11/86	1.90	25.00
1/12/86	1.65	21.00
28/1/87	1.23	11.03
25/12/87	1.20	10.25
4/3/87	1.10	8.60
16/4/87	1.32	12.08
13/6/87	1.80	25.51
17/7/87	2.16	62.74
20/8/87	3.17	142.23
25/9/87	3.66	170.05
23/10/87	2.50	131.00
22/11/87	1.98	25.06
31/1/88	1.26	11.50
21/2/88	1.30	12.02
24/3/88	1.20	9.60
28/4/88	1.65	27.02
18/5/88	1.93	29.00
11/4/88	2.21	63.40
2/8/88	2.60	137.80
12/9/88	3.26	151.07
17/10/88	198	25.40
11/11/88	1.87	20.65

SOURCES OF DATA: ORBDA Data year book provided all the data from (1982 – 1994) while field recordings by the researcher provided all the data from (1995 – 1999)

Table A 1 FIELD DATA READING FOR OGBESE RIVER (... Discharge Measurements).

Sampling Date	Gauge height (m)	Discharge (m^3 / sec)
1/4/91	1.31	12.78
16/5/91	1.58	12.99
12/6/91	1.89	24.00
15/7/91	2.21	61.98
11/8/91	3.30	143.50
17/9/91	3.70	170.23
20/10/91	3.05	141.00
26/11/91	1.76	29.30
5/12/91	1.21	18.20
6/1/92	1.29	11.10
7/2/92	1.40	12.00
26/11/92	0.96	2.72
12/3/92	1.26	11.10
16/4/92	1.32	12.80
20/5/92	1.52	13.00
16/6/92	1.70	24.10
14/7/92	1.22	62.90
12/8/92	3.33	144.11
15/9/92	3.71	172.00
11/10/92	3.06	141.00
23/11/92	1.77	29.65
31/12/92	1.22	18.03
6/1/93	1.38	12.01
16/2/93	1.30	10.88
7/3/93	1.32	12.50
23/4/93	1.40	11.61
20/5/93	1.56	12.78

SOURCES OF DATA: ORBDA Data year book provided all the data from (1982 – 1994) while field recordings by the researcher provided all the data from (1995 – 1999)

Table A 1 FIELD DATA READING FOR OGBESE RIVER Discharge Measurements).

Sampling Date	Gauge height (m)	Discharge (m^3 / sec)
1/4/91	1.31	12.78
16/5/91	1.58	12.99
12/6/91	1.89	24.00
15/7/91	2.21	61.98
11/8/91	3.30	143.50
17/9/91	3.70	170.23
20/10/91	3.05	141.00
26/11/91	1.76	29.30
5/12/91	1.21	18.20
6/1/92	1.29	11.10
7/2/92	1.40	12.00
26/11/92	0.96	2.72
12/3/92	1.26	11.10
16/4/92	1.32	12.80
20/5/92	1.52	13.00
16/6/92	1.70	24.10
14/7/92	1.22	62.90
12/8/92	3.33	144.11
15/9/92	3.71	172.00
11/10/92	3.06	141.00
23/11/92	1.77	29.65
31/12/92	1.22	18.03
6/1/93	1.38	12.01
16/2/93	1.30	10.66
7/3/93	1.32	12.50
23/4/93	1.40	11.61
20/5/93	1.56	12.78

SOURCES OF DATA: ORBDA Data year book provided all the data from (1982 – 1994) while field recordings by the researcher provided all the data from (1995 – 1999)

Table A .1 FIELD DATA READING FOR OGBESE RIVER (Discharge Measurements).

Sampling Date	Gauge height (m)	Discharge (m^3 / sec)
11/6/93	1.88	24.10
25/7/93	2.61	56.50
19/8/93	3.33	143.62
20/9/93	3.58	152.20
22/10/93	3.10	140.85
2/11/93	1.69	18.68
6/12/93	1.23	18.00
12/1/93	1.29	10.56
12/2/94	1.30	10.90
4/3/94	1.85	9.80
17/4/94	2.16	11.20
13/5/94	1.56	12.78
6/6/94	3.64	18.6
14/7/94	2.22	61.50
14/8/94	1.98	130.50
17/9/94	3.70	159.30
5/10/94	3.23	120.00
31/11/94	1.78	29.31
2/12/94	1.18	18.00
31/1/95	1.26	10.21
2/2/95	1.30	10.50
13/3/95	1.24	9.45
2/4/95	1.32	11.00
17/5/95	1.52	17.12
14/6/95	1.68	18.52
3/7/95	2.60	56.00
30/8/95	2.96	130.00

SOURCES OF DATA: ORBDA Data year book provided all the data from (1982 – 1994) while field recordings by the researcher provided all the data from (1995 – 1999)

Table A-1 **FIELD DATA READING FOR OGBESE RIVER (Discharge Measurements).**

Sampling Date	Gauge height (m)	Discharge (m^3 / sec)
13/12/88	1.50	17.10
2/1/89	1.50	17.10
5/2/89	1.30	10.02
14/3/89	1.18	8.69
17/4/89	1.48	11.00
29/5/89	1.75	17.60
16/6/89	1.89	18.00
28/7/89	2.16	56.16
31/8/89	3.17	127.80
30/9/89	3.67	153.05
2/10/89	2.47	117.90
11/11/89	1.98	22.50
3/12/89	1.90	18.00
2/1/90	1.42	11.03
23/2/90	1.16	6.08
3/3/90	1.00	3.84
23/5/90	1.66	23.38
20/6/90	3.00	145.00
22/7/90	2.95	133.00
24/8/90	3.00	145.00
12/9/90	3.69	171.06
17/10/90	2.95	133.00
13/11/90	1.98	25.40
14/12/90	1.19	17.00
30/1/91	1.28	11.00
3/2/91	1.38	12.05
1/3/91	1.25	10.59

SOURCES OF DATA: ORBDA Data year book provided all the data from (1982 – 1994) while field recordings by the researcher provided all the data from (1995 – 1999)

Table A .1 FIELD DATA READING FOR OGBESE RIVER (Discharge Measurements).

Sampling Date	Gauge height (m)	Discharge (m^3 / sec)
28/9/95	3.88	158.07
19/10/95	3.31	120.00
12/11/95	1.35	22.82
10/12/95	1.20	18.10
20/1/96	1.38	17.72
2/2/96	1.31	10.21
11/3/96	1.32	10.28
19/4/96	1.30	9.86
15/5/96	1.56	12.30
17/6/96	1.88	23.13
31/7/96	2.60	25.05
23/8/96	3.00	60.50
20/9/96	3.30	140.31
27/10/96	3.71	170.20
28/11/96	3.35	130.41
7/12/96	7.78	22.50
21/1/97	1.39	18.25
30/2/97	1.29	10.56
13/3/97	1.32	11.03
11/4/97	1.39	11.82
23/5/97	1.05	13.61
17/6/97	1.90	28.30
25/7/97	2.70	58.00
2/8/97	3.00	102.60
27/9/97	3.50	135.40
10/10/97	3.61	142.23
6/11/97	1.72	19.62

SOURCES OF DATA: ORBDA Data year book provided all the data from (1982 – 1994) while field recordings by the researcher provided all the data from (1995 – 1999)

Table A 1 FIELD DATA READING FOR OGBESE RIVER (... /Discharge Measurements).

Sampling Date	Gauge height (m)	Discharge (m^3 / sec)
2/12/97	1.25	19.00
3/1/98	1.38	36.60
2/2/98	1.31	20.10
13/3/98	1.33	11.08
5/4/98	1.30	9.81
6/5/98	1.41	11.62
7/6/98	1.88	24.00
8/7/98	2.62	57.10
20/8/98	3.33	144.62
14/9/98	3.52	150.07
10/10/98	3.10	140.00
1/11/98	1.69	18.00
2/12/98	1.26	17.05
10/1/99	1.29	10.10
25/2/99	1.33	11.61
28/3/99	1.16	8.60
20/4/99	1.54	18.60
15/5/99	1.86	29.10
16/6/99	2.01	58.63
10/7/99	2.88	84.87
9/8/99	3.384	137.81
13/9/99	3.585	144.140
11/10/99	3.750	156.62
4/11/99	2.50	36.60
16/12/99	1.91	20.00

SOURCES OF DATA: ORBDA Data year book provided all the data from (1982 – 1994) while field recordings by the researcher provided all the data from (1995 – 1999)

Table . B1 LD DATA – DISCHARGE MEASUR VENA

RIVER

mpling Date	Gauge height (m)	Discharge (m
27/5/82	0.80	3.49
28/7/82	0.72	2.85
25/8/82	0.63	1.85
23/9/82	0.86	4.56
15/6/82	0.71	2.79
9/11/82	0.98	5.85
23/12/82	0.5[illegible]	1.12
25/1/83	0.39	0.20
22/2/83	0.37	0.19
27/3/83	0.40	0.25
27/4/83	0.42	0.38
22/5/83	1.07	3.36
23/7/83	0.65	2.05
-	-	-
-	-	-
26/10/82	1.06	7.11
23/11/83	0.52	7.10
14/12/83	0.64	1.18
25/5/85	1.04	1.99
[illegible]9/6/85	0.975	4.54
1[illegible] 7/85	0.819	3.70
11/[illegible] 85	1.118	2.41
9/9/8	1.123	6.18
14/10/85	1.274	6.62
14/10/85	0.702	7.60
2/1/86	0.507	1.46
12/2/86	0.481	0.26

SOURCES OF DATA: ORBD[illegible] Data year book provided the data from (1982 – 1994) while Field recordings by the researcher provided the data (1995 – 1999).

Table 2:B1 FIELD DATA READINGS FOR OWENA RIVER (Discharge Measurements).

SOURCES OF DATA:- ORBDA Data year book provided all the data from (1982-1994) while Field recordings by the researcher provided all the data from (1995 – 1999).

Sampling Date	Gauge height (m)	Discharge (m^3/sec)
22/3/86	0.520	0.26
1/4/86	0.546	0.33
11/5/86	1.391	0.50
6/6/86	1.34	11.53
25/7/85	01.01	10.67
5/8/86	2.02	8.46
15/9/86	2.68	14.50
12/10/86	0.92	19.25
2/11/86	0.83	3.53
5/12/86		2.59
20/1/91	0.52	0.98
15/2/91	0.53	1.51
10/3/91	0.57	1.28
5/4/91	0.66	1.71
7/5/91	1.02	7.26
22/6/91	0.96	6.10
27/7/91	1.76	4.40
18/8/91	1.95	41.20
9/9/91	1.80	29.80
25/10/91	1.30	13.70
20/11/91	0.90	4.30
2/12/91	0.80	3.40
31/1/92	0.70	2.14
6/2/92	0.61	1.50
8/3/92	0.64	1.37
[illegible]	0.71	2.24
[illegible]	0.79	3.72

FIELD DATA READINGS FOR OWENA RIVER [illegible] Discharge Measurements).

SOURCES OF DATA - ORBDA Data year book provided all the data from (1982-1994) while Field recordings by the researcher provided all the data from (1995 – 1999).

Sampling Date	Gauge height (m)	Discharge (m^3/sec)
30/8/95	1.15	6.50
17/9/95	0.98	5.28
15/10/95	1.79	33.25
12/11/95	1.63	20.85
3/12/95	1.31	15.20
5/1/96	0.56	1.20
8/2/96	0.52	1.00
12/3/96	0.51	0.95
20/4/96	0.49	0.89
22/5/96	0.55	1.19
30/6/96	0.686	1.1
29/7/96	0.88	5.21
27/8/96	1.005	6.25
2/9/96	0.95	5.22
1/10/96	1.55	33.18
11/11/96	1.54	20.41
2/12/96	0.96	5.22
5/1/97	0.19	1.30
13/2/97	0.11	0.80
17/3/97	0.13	0.90
21/4/97	0.29	2.0
20/5/97	0.21	1.50
13/6/97	1.52	10.60
25/7/97	1.49	10.40
14/8/97	0.87	6.10
31/9/97	1.86	1.3
23/10/97	3.42	24.64

Table E7 . FIELD DATA READINGS FOR OWENA RIVER , (Discharge Measurements).

SOURCES OF DATA:- ORBDA Data year book provided all the data from (1982-1994) while Field recordings by the researcher provided all the data from (1995 – 1999).

Sampling Date	Gauge height (m)	Discharge (m^3/sec)
17/6/92	1.09	7.21
19/7/92	1.20	10.51
18/8/92	1.25	22.6
4/9/92	1.70	44.1
22/10/92	1.59	15.4
16/11/92	1.10	7.64
20/12/92	0.84	3.60
1993 JAN-DEC.	NA	NA
1/1/94	0.56	1.20
21/2/94	0.52	1.00
31/3/94	0.52	0.93
26/4/94	0.49	0.86
15/5/94	0.56	1.19
18/6/94	06.85	1.96
17/7/94	0.86	5.28
9/8/94	1.01	6.25
10/9/94	0.95	5.22
16/10/94	1.55	33.18
13/11/94	1.55	20.41
NA	NA	NA
4/1/95	0.57	1.24
6/2/95	0.53	1.15
17/3/95	0.54	1.20
13/4/95	0.50	1.00
12/5/95	0.605	1.21
22/6/95	0.95	2.00
30/7/95	0.89	5.55

Table [illegible] FIELD DATA READINGS FOR OWENA RIVER ([illegible] Discharge Measurements).

SOURCES OF DATA:- ORBDA Data year book provided all the data from (1982-1994) while Field recordings by the researcher provided all the data from (1995 – 1999).

Sampling Date	Gauge height (m)	Discharge (m^3/sec)
31/11/97	0.69	4.83
2/12/97	0.54	3.78
31/1/98	0.150	1.01
27/2/98	0.128	0.91
27/3/98	0.12	0.86
24/4/98	0.19	1.29
29/5/98	0.35	2.48
26/6/98	0.66	4.63
3/7/98	1.66	11.55
14/8/98	1.43	9.92
25/9/98	2.43	17.01
23/10/98	2.27	19.32
27/10/98	0.34	2.38
4/12/98	0.34	2.35
31/1/99	0.56	1.24
14/2/99	0.55	1.18
13/3/99	0.53	1.20
11/4/99	0.48	0.96
16/5/99	0.60	1.20
16/6/99	0.69	1.98
20/7/99	0.90	5.56
22/8/99	1.15	6.50
21/9/99	0.99	5.28
17/10/99	1.69	33.12
21/11/99	1.61	20.17
15/12/99	1.31	15.20

Source: Field Record takings by the investigator provided all the data presented in table 1 above from 1995 – 1999 while Benin – Owena River Basin Data Book (ORBDA) provided all the data from 1982 – 1994 Owena River.

Table C 1 FIELD DATA (BTMA) READINGS FOR OGBESE RIVER AT OGBESE-OWO ROAD SAMPLING STATION

Year 1989 Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (Tons/day) Q_b	Velocity (m/s) V	Water Temp T°C
3/1/89	0.243	0.378	1.03	28.5
5/2/89	0.236	0.261	1.02	28.5
8/3/89	0,197	0.312	1.01	28.5
12/4/89	0.279	0.447	1.05	28.5
10/5/89	0.531	1.519	1.05	28.1
15/6/89	0.610	1.589	1.16	28.1
17/7/89	1.457	2.659	1.13	28.1
20/8/89	3.32	3.923	1.31	28.1
23/9/89	3.96	4.989	1.31	28.3
25/10/89	3.05	3.73	1.30	28.1
15/11/89	0.566	1.591	1.05	28.5
16/12/89	0.473	1.412	1.05	28.5

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Year 1990 Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (Tons/day) Q_b	Velocity (m/s) V	Water Temp T°C
2/1/90	0.25	0.38	1.03	28.5
5/3/90	0.24	0.26	1.02	28.5
4/3/90	0.20	0.30	1.01	28.5
15/4/90	0.28	0.45	1.05	28.5
5/5/90	0.53	1.52	1.05	28.1
16/6/90	0.60	1.60	1.16	28.1
17/7/90	1.46	2.67	1.13	28.1
14/8/90	3.31	3.92	1.31	28.1
23/9/90	3.96	4.99	1.31	28.3
13/10/90	3.05	3.73	1.30	28
22/11/90	0.58	1.59	1.05	28.5
2/12/90	0.46	1.41	1.05	28.5

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Table C 1

Year 1991 Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (Tons/day) Q_b	Velocity (m/s) V	Water Temp T°C
10/1/91	0.242	0.379	1.03	28.5
16/2/91	0.235	0.263	1.02	28.5
3/3/91	0.198	0.315	1.01	28.5
14/4/91	0.278	0.450	1.05	28.5
15/5/91	0.529	1.519	1.05	28.1
6/6/91	0.605	1.589	1.16	28.1
12/7/91	1.459	2.659	1.13	28.1
19/8/91	3.319	3.913	1.31	28.1
22/9/91	3.886	4.996	1.31	28.3
23/10/91	3.100	3.741	1.30	28.1
11/1191	0.571	1.592	1.05	28.5
24/12/91	0.473	1.413	1.05	28.5

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Year 1992 Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (Tons/day) Q_b	Velocity (m/s) V	Water Temp T°C
3/1/92	0.243	0.379	1.03	28.5
4/2/92	0.236	0.262	1.02	28.5
6/3/92	0.197	0.315	1.01	28.5
13/4/92	0.278	0.450	1.05	28.5
11/5/92	0.530	1.519	1.05	28.1
14/6/92	0.610	1.587	1.16	28.1
7/7/92	1.459	2.658	1.13	28.1
18/8/92	3.320	3.912	1.31	28.1
23/9/92	3.896	4.987	1.31	28.3
26/10/92	3.006	3.740	1.30	28.1
17/11/92	0.572	1.591	1.05	28.5
1/12/92	0.471	1.410	1.05	28.5

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Table C.1

Year 1993 Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (Tons/day) Q_b	Velocity (m/s) V	Water Temp T°C
6/1/93	0.251	0.383	1.03	28.5
16/2/93	0.241	0.269	1.02	28.5
1/3/93	0.201	0.301	1.01	28.5
4/4/93	0.282	0.454	1.05	28.5
27/5/93	0.532	1.523	1.05	28.1
16/6/93	0.60	1.600	1.16	28.1
10/7/93	1.462	2.671	1.13	28.1
15/8/93	3.311	3.921	1.31	28.1
26/9/93	3.961	4.993	1.31	28.3
21/10/93	3.052	3.731	1.30	28.1
20/11/93	0.581	1.593	1.05	28.5
12/12/93	0.461	1.413	1.05	28.5

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Year 1994 Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (Tons/day) Q_b	Velocity (m/s) V	Water Temp T°C
13/1/94	0.249	0.378	1.03	28.5
15/2/94	0.236	0.264	1.02	28.5
21/3/94	0.197	0.315	1.01	28.5
5/4/94	0.278	0.450	1.05	28.5
6/5/94	0.530	1.519	1.05	28.1
23/6/94	0.610	1.600	1.16	28.1
17/7/94	1.459	2.671	1.13	28.1
19/8/94	3.320	3.921	1.31	28.1
5/9/94	3.887	4.996	1.31	28.3
4/10/94	3.100	3.742	1.30	28.1
13/11/94	0.572	1.592	1.05	28.5
1/12/94	0.473	1.412	1.05	28.5

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Table C 1

Year 1995 Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (Tons/day) Q_b	Velocity (m/s) V	Water Temp $T^{o}C$
4/1/95	0.020	0.210	0.81	29.1
6/2/95	0.020	0.200	1.05	29.2
9/3/95	0.020	0.120	1.05	29.3
11/4/95	0.030	0.240	1.05	29.2
15/5/95	0.050	0.330	1.06	29.3
25/6/95	0.100	0.440	1.15	29
23/7/95	0.260	0.620	1.15	29
28/8/95	0.230	0.540	1.15	29.5
6/9/95	0.440	1.130	1.15	29.6
3/10/95	0.380	0.940	1.20	29.4
13/11/95	0.0570	0.260	1.20	29.08
16/12/95	0.050	0.250	1.20	29.08

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Year 1996 (Tons/day) Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (m/s) Q_b	Velocity V	Water Temp $T^{o}C$
14/1/96	0.026	0.220	0.81	29.1
23/2/96	0.021	0.210	1.05	29.2
17/3/96	0.020	0.120	1.05	29.3
23/4/96	0.032	0.242	1.05	29.2
13/5/96	0.050	0.330	1.06	29.3
12/6/96	0.102	0.402	1.15	29
19/7/96	0.260	0.620	1.15	29
7/8/96	0.231	0.541	1.15	29.5
10/9/96	0.443	1.133	1.15	29.6
5/10/96	0.381	0.941	1.20	29.4
2/11/96	0.0572	0.262	1.20	29.08
2/12/96	0.053	0.253	1.20	29.08

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Table C 1

Year 1997 Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (Tons/day) Q_b	Velocity (m/s) V	Water Temp T°C
19/1/97	0.0235	0.21753	0.8	29.1
28/2/97	0.0212	0.20608	1.05	29.2
26/3/97	0.02300	0.12078	1.05	29.3
29/4/97	0.0300	0.24887	1.05	29.2
2/5/97	0.0578	0.33074	1.06	29.3
6/6/97	0.1078	0.44229	1.15	29
13/7/97	0.26911	0.62514	1.15	29
14/8/97	0.2311	0.54958	1.15	29.5
20/9/97	0.4400	1.13068	1.20	29.6
26/10/97	0.3800	0.94093	1.15	29.4
30/11/97	0.1719	0.46322	1.05	29.08
12/12/97	0.0554	0.25047	0.81	29.08

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Year 1998 Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (Tons/day) Q_b	Velocity (m/s) V	Water Temp T°C
4/1/98	0.023	0.217	0.81	29.1
10/2/98	0.021	0.206	1.05	29.2
15/3/98	0.020	0.120	1.05	29.3
22/4/98	0.030	0.248	1.05	29.2
28/5/98	0.057	0.330	1.06	29.3
23/6/98	0.107	0.442	1.15	29
15/7/98	0.269	0.625	1.15	29
18/8/98	0.231	0.549	1.15	29.5
21/9/98	0.440	1.130	1.15	29.6
3/10/98	0.380	0.940	1.20	29.4
4/11/98	0.171	0.463	1.20	29.08
16/12/98	0.055	0.250	1.20	29.08

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Table 2.4

Year 1999 Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (Tons/day) Q_b	Velocity (m/s) V	Water Temp T°C
13/1/99	0.024	0.218	0.81	29.1
21/2/99	0.021	0.206	1.05	29.2
14/3/99	0.020	0.121	1.05	29.3
18/4/99	0.030	0.249	1.05	29.2
14/5/99	0.058	0.331	1.06	29.3
24/6/99	0.108	0.442	1.15	25
10/7/99	0.269	0.625	1.15	29
16/8/99	0.231	0.550	1.15	29.5
18/9/99	0.440	1.131	1.15	29.6
20/10/99	0.380	0.941	1.20	29.4
22/11/99	0.172	0.463	1.20	29.08
6/12/99	0.056	0.251	1.20	29.08

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999).

[illegible] FIELD DATA (BTMA) READINGS FOR OWENA RIVER (1989-1999) AT OWENA – ONDO ROAD KM 18 SAMPLING STATION

Year 1989 Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (Tons/day) Q_b	Velocity (m/s) V	Water Temp T°C
2/1/89	0.021	0.216	0.81	29.1
10/2/89	0.025	0.205	1.05	29.2
15/3/89	0.023	0.124	1.05	29.3
1/4/89	0.023	0.245	1.05	29.2
22/5/89	0.050	0.335	1.06	29.3
25/6/89	0.105	0.440	1.15	29
31/7/89	0.260	0.620	1.15	29
2/8/89	0.230	0.540	1.15	29.5
15/9/89	0.440	1.130	1.15	29.6
10/10/89	0.380	0.940	1.20	29.4
16/11/89	0.070	0.260	1.20	29.08
31/12/89	0.050	0.250	1.20	29.08

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Year 1990 Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (Tons/day) Q_b	Velocity (m/s) V	Water Temp T°C
1/1/90	0.024	0.210	0.81	29.1
9/2/90	0.026	0.200	1.05	29.2
15/3/90	0.023	0.124	1.05	29.3
17/4/90	0.021	0.242	1.05	29.2
25/5/90	0.051	0.331*	1.06	29.3
18/6/90	0.100	0.440	1.15	29
24/7/90	0.260	0.620	1.15	29
23/8/90	0.230	0.540	1.15	29.5
17/9/90	0.470	1.131	1.15	29.6
22/10/90	0.380	0.941	1.20	29.4
29/11/90	0.0570	0.261	1.20	29.08
30/12/90	0.051	0.252	1.20	29.08

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Table D 1

Year 1991 Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (Tons/day) Q_b	Velocity (m/s) V	Water Temp T°C
5/1/91	0.020	0.210	0.81	29.1
23/2/91	0.020	0.200	1.05	29.2
2/3/91	0.020	0.120	1.05	29.3
13/4/91	0.030	0.240	1.05	29.2
15/5/91	0.050	0.330	1.06	29.3
18/6/91	0.100	0.440	1.15	29
27/7/91	0.260	0.620	1.15	29
30/8/91	0.230	0.540	1.15	29.5
31/9/91	0.440	1.130	1.15	29.6
1/10/91	0.380	0.940	1.20	29.4
11/11/91	0.0570	0.260	1.20	29.08
12/12/91	0.050	0.250	1.20	29.08

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Year 1992 Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (Tons/day) Q_b	Velocity (m/s) V	Water Temp T°C
6/1/92	0.021	0.210	0.81	29.1
9/2/92	0.022	0.201	1.05	29.2
10/3/92	0.021	0.123	1.05	29.3
14/4/92	0.031	0.241	1.05	29.2
16/5/92	0.052	0.332	1.06	29.3
20/6/92	0.101	0.442	1.15	29
30/7/92	0.260	0.621	1.15	29
31/8/92	0.230	0.541	1.15	29.5
1/9/92	0.440	1.132	1.15	29.6
3/10/92	0.380	0.944	1.20	29.4
14/11/92	0.0570	0.263	1.20	29.08
19/12/92	0.053	0.251	1.20	29.08

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Table D 1

Year 1993 Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (Tons/day) Q_b	Velocity (m/s) V	Water Temp T°C
10/1/93	0.020	0.230	0.81	29.1
22/2/93	0.020	0.205	1.05	29.2
2/3/93	0.020	0.125	1.05	29.3
28/4/93	0.030	0.240	1.05	29.2
16/5/93	0.050	0.330	1.06	29.3
11/6/93	0.100	0.440	1.15	29
12/7/93	0.261	0.620	1.15	29
23/8/93	0.232	0.541	1.15	29.5
15/9/93	0.440	1.132	1.15	29.6
14/10/93	0.380	0.970	1.20	29.4
1/11/93	0.0570	0.260	1.20	29.08
13/12/93	0.050	0.251	1.20	29.08

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Year 1994 Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (Tons/day) Q_b	Velocity (m/s) V	Water Temp T°C
16/1/94	0.020	0.232	0.81	29.1
21/2/94	0.021	0.203	1.05	29.2
2/3/94	0.022	0.120	1.05	29.3
5/4/94	0.031	0.240	1.05	29.2
17/5/94	0.050	0.330	1.06	29.3
6/6/94	0.100	0.440	1.15	29
8/7/94	0.261	0.620	1.15	29
13/8/94	0.234	0.543	1.15	29.5
18/9/94	0.439	1.134	1.15	29.6
20/1094	0.380	0.970	1.20	29.4
22/11/94	0.0582	0.262	1.20	29.08
3/12/94	0.050	0.250	1.20	29.08

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Table D 1

Year 1995	Suspended Load (Tons/day)	Bed load (Tons/day)	Velocity (m/Monthly	. Water Temp $Q_{ss}S$
Q_b	V	T°C		
17/1/95	0.252	0.379	1.03	28.5
23/2/95	0.240	0.265	1.02	28.5
27/3/95	0.200	0.316	1.01	28.5
14/4/95	0.282	0.449	1.05	28.5
4/5/95	0.532	1.519	1.05	28.1
10/6/95	0.600	1.587	1.16	28.1
25/7/95	1.461	2.659	1.13	28.1
9/8/95	3.300	3.913	1.31	28.1
26/9/95	3.961	4.996	1.31	28.3
10/10/95	3.052	3.741	1.30	28.1
1/11/95	0.582	1.592	1.05	28.5
12/12/95	0.459	1.413	1.05	28.5

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Year 1996	Suspended Load (Tons/day)	Bed load (Tons/day)	Velocity (m/s)	Water Temp
Sampling Date	Q_s	Q_b	V	T°C
16/1/96	0.251	0.380	1.03	28.5
22/2/96	0.241	0.270	1.02	28.5
24/3/96	0.197	0.320	1.01	28.5
7/4/96	0.282	0.450	1.05	28.5
9/5/96	0.530	1.519	1.05	28.1
22/6/96	0.600	1.60	1.16	28.1
24/7/96	1.460	2.661	1.13	28.1
8/8/96	3.310	3.913	1.31	28.1
29/9/96	3.980	4.997	1.31	28.3
2/10/96	3.056	3.740	1.30	28.1
14/11/96	0.581	1.596	1.05	28.5
9/12/96	0.460	1.410	1.05	28.5

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Table .D 1

Year 1997 Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (Tons/day) Q_b	Velocity (m/s) V	Water Temp T°C
1/1/97	0.257	0.386	1.03	28.5
15.2/97	0.245	0.268	1.02	28.5
29/3/97	0.202	0.305	1.01	28.5
17/4/97	0.280	0.459	1.05	28.5
5/5/97	0.539	1.520	1.05	28.1
14/6/97	0.608	1.607	1.16	28.1
12/7/97	1.462	2.670	1.13	28.1
18/8/97	3.314	3.924	1.31	28.1
22/9/97	3.962	4.993	1.31	28.3
10/10/97	3.050	3.934	1.30	28.1
7/11/97	0.584	1.592	1.05	28.5
3/12/97	0.468	1.417	1.05	28.5

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Year 1998 Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (Tons/day) Q_b	Velocity (m/s) V	Water Temp T°C
6/1/98	0.252	0.384	1.03	28.5
11/2/98	0.242	0.266	1.02	28.5
13/3/98	0.201	0.304	1.01	28.5
27/4/98	0.280	0.457	1.05	28.5
23/5/98	0.538	1.518	1.05	28.1
20/6/98	0.610	1.600	1.16	28.1
29/7/98	1.463	2.665	1.13	28.1
16/8/98	3.313	3.923	1.31	28.1
21/9/98	3.960	4.991	1.31	28.3
2/10/98	3.000	3.930	1.30	28.1
14/11/98	0.580	1.586	1.05	28.5
4/12/98	0.460	1.412	1.05	28.5

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

Table D 1

Year 1999 Sampling Date	Suspended Load (Tons/day) Q_s	Bed load (Tons/day) Q_b	Velocity (m/s) V	Water Temp T°C
2/1/99	0.257	0.389	1.03	28.5
4/2/99	0.244	0.270	1.02	28.5
21/3/99	0.203	0.310	1.01	28.5
14/4/99	0.282	0.460	1.05	28.5
7/5/99	0.540	1.530	1.05	28.1
24/6/99	0.608	1.630	1.16	28.1
25/7/99	1.465	2.680	1.13	28.1
6/8/99	3.314	3.960	1.31	28.1
9/9/99	3.960	5.000	1.31	28.3
20/10/99	3.100	3.940	1.30	28.1
22/11/99	0.600	1.600	1.05	28.5
15/12/99	0.467	1.467	1.05	28.5

Sources of Data: ORBDA Data Year Book provided all the data from (1989-1994) while Field recordings by the researcher provided all the data from (1995-1999)

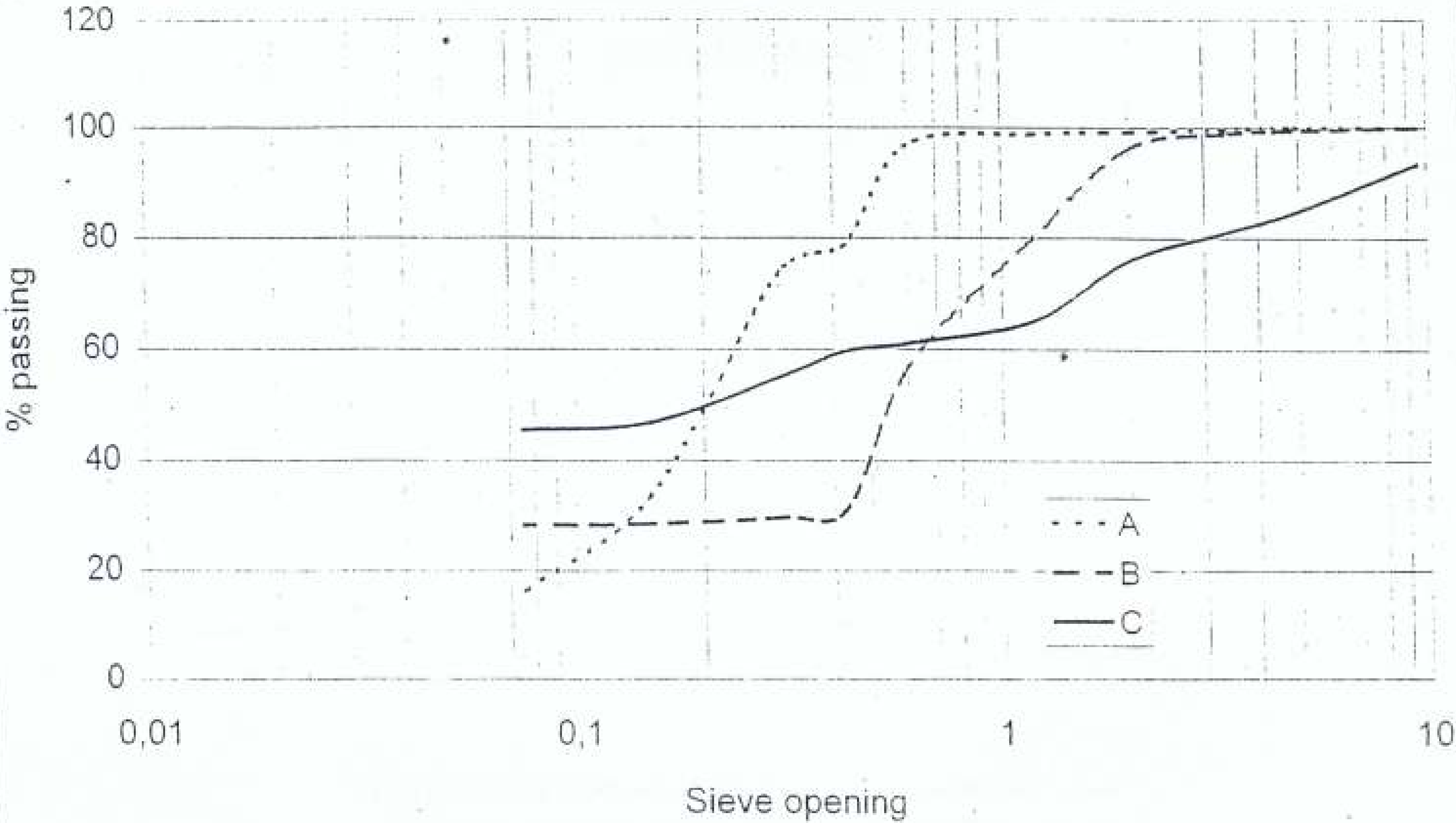


Fig. ' Particle size distribution adeloju on the 10-10-98

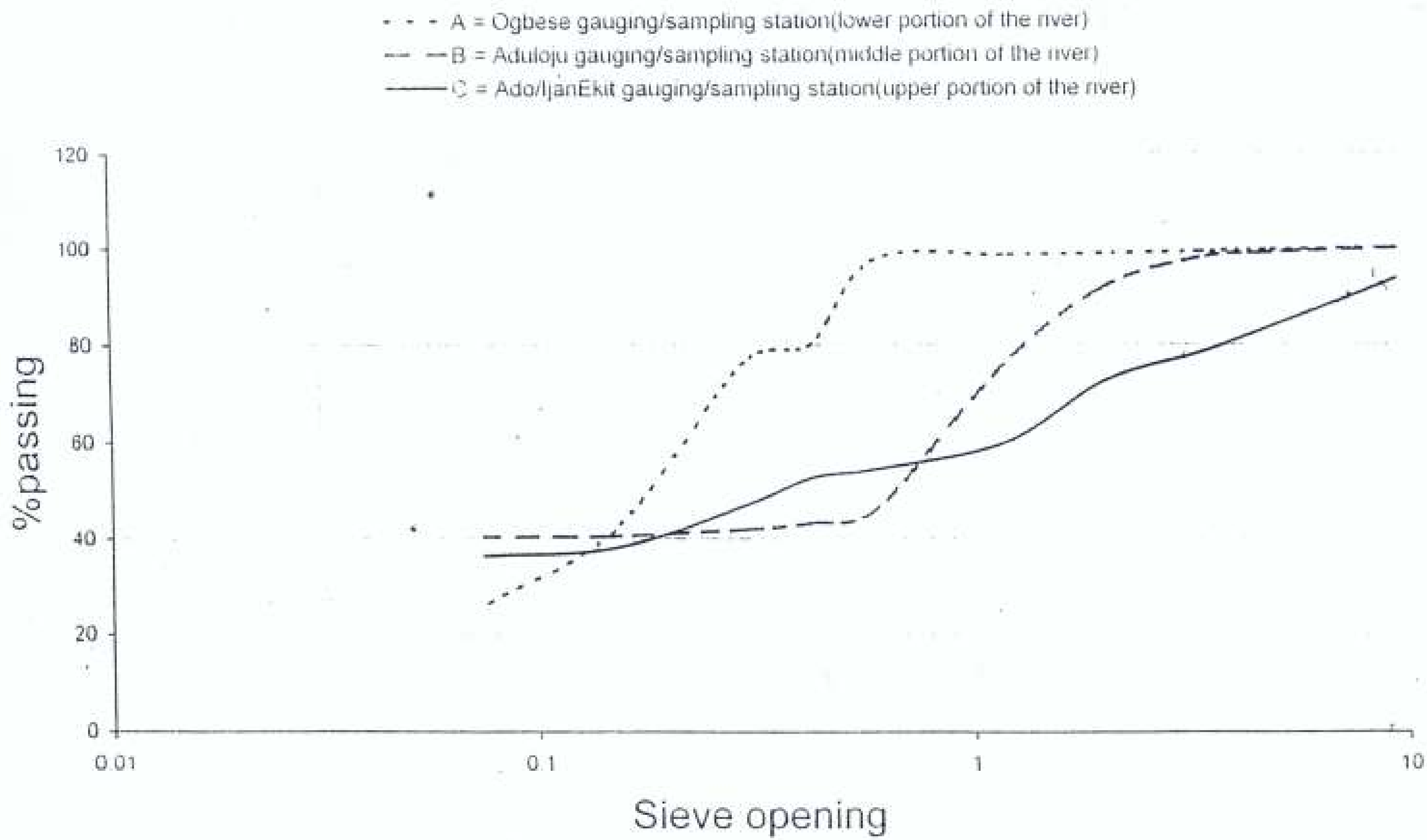


Figure [illegible] Particle size distribution for Ogbese River on the 12-2-98

TABLE 6.1 OGBESE RIVER DATA SAND SAMPLE RESULTS

Initial Wt = 500gm

Water temp = 29°C

Date 12 – 2 – 98

SAMPLE A DISH NO	WEIGHT	% Retnd	% Pass	SIEVE SIZE	WEIGHT	% Retnd	% Pass	SAMPLE B DISH NO
River Ogbese at Ogbese (Akure) 12 – 2 – 98 BTMA	0	0	100	9.50	0	0	100	River Ogbese at Adeloju (Ikere Ekiti 12 2 98 BTMA
	2	0.4	99.60	4.75	5	1.0	99	
	2	0.4	99.20	3.35	5	1.0	98	
	2	0.4	98.80	2.00	31	6.2	91.8	
	1	0.2	98.60	1.18	99	19.8	76.0	
	5	1.0	97.60	0.60	128	25.6	46.1	
	88	17.6	80.00	0.425	13.0	2.6	43.8	
	18	3.6	76.40	0.300	9.0	1.8	42.0	
	173	34.6	41.80	0.150	7.0	1.4	40.6	
	79	15.6	26.0	0.075	1.0	0.2	40.4	

SAMPLE A DISH NO	WEIGHT	% Retnd	% Pass	SIEVE SIZE	WEIGHT	% Retnd	% Pass	SAMPLE B DISH NO
River Ogbese at Ado – Ijan Ekiti 12 – 2 - 98	36	6.2	93.8	9.50				
	52	10.4	83.4	4.75				
	53	23	73.4	3.35				
	54	32	6.4	72.4				
	63	12.6	59.8	1.18				
	27	5.4	54.4	0.60				
	9	1.8	52.6	0.425				
	28	5.6	47.0	0.300				
	45	9.0	38.0	0.150				
	80	1.6	36.4	0.075				

Sieve - Analysis

Contact: Ogbese River

Laboratory: Ogbese River

execut. by/date:	02 · 1 · 98 Okoli C.[illegible]
calcul. by/date:	14 · 05 · 99

Fig A3

Lab. No.	Chainage borrow-pit	[illegible]	position	depth (m)	material: sub-grade	fill	sub-base
	type of material	[illegible]	I				
	weight of soil taken for sieve analysis =	g					
	weight of soil taken for wet washing passing 4.76 mm Sieve	g					

determination of moisture content	bowl No.		g
	wet soil + bowl		g
	dry soil + bowl		g
	bowl alone		g
	water alone		g
	dry soil alone		g
determination of dry-soil weight	bowl No.		g
	wet soil + bowl		g
	bowl alone		g
	Wet soil + bowl		g
	dry soil alone		g
	Note: dry soil = $\frac{\text{Wet soil}}{1 + 0.01 MC \%}$		g
washing through mesh 200	washed soil + bowl		g
	bowl alone		g
	washed soil alone		g
	outwashed soil < 0.075 mm ø		g

$$MC = \frac{\text{water}}{\text{dry soil}} \times 100$$

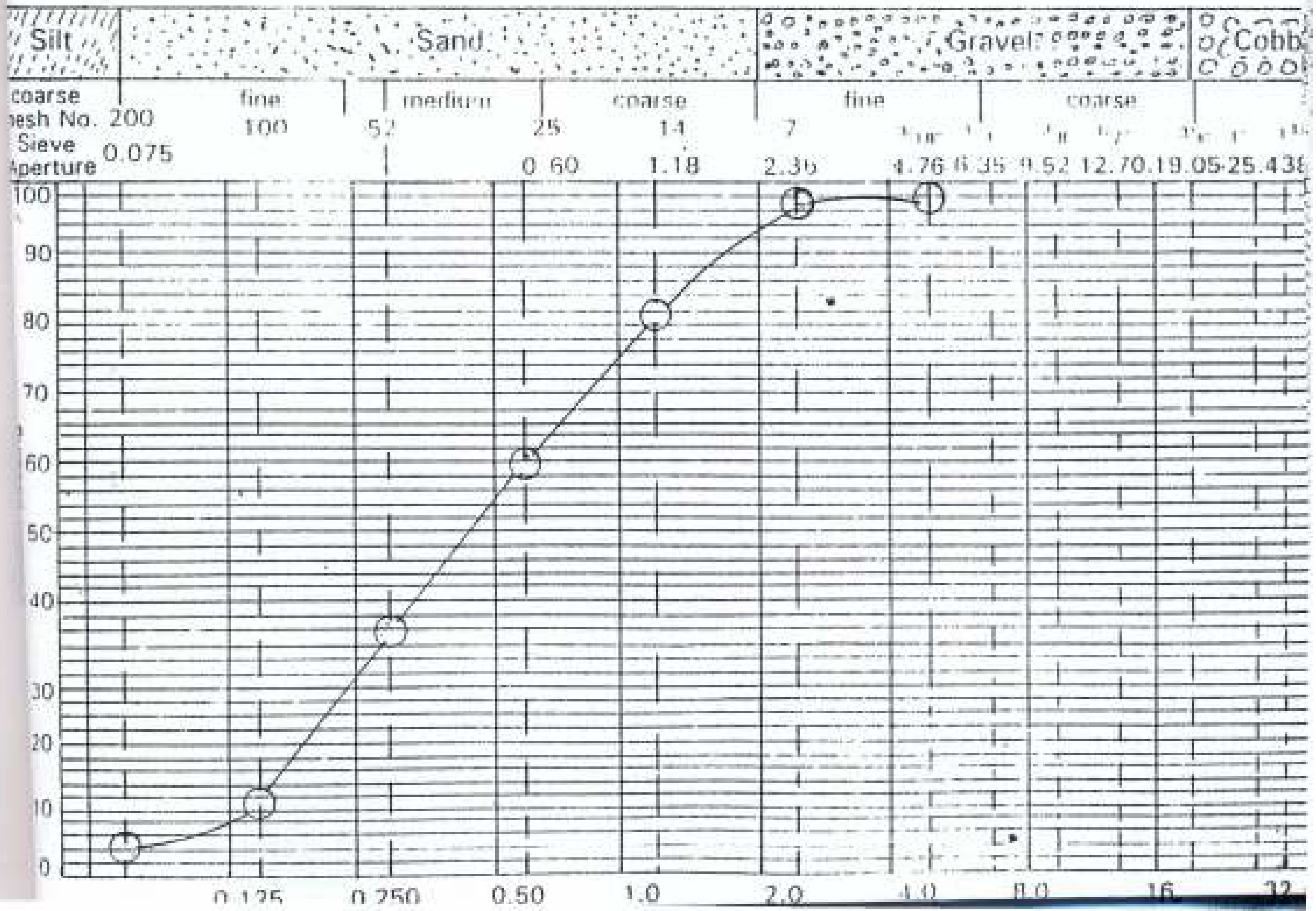
= ______ %

g – B

g – C

g = B–C

B.S. Sieve mm	mesh No.	retained g	retained %	pass %
38.1	1 ½			
25.4	1			
19.05	¾			
12.70	½			
9.52		10.50	1.14	98.[illegible]
4.76		12.9	1.29	97.[illegible]
2.36	7	[illegible]	6.22	91.[illegible]
1.18	14	71.[illegible]	7.16	84.[illegible]
600 mic	25	162.[illegible]	16.26	67.[illegible]
300mic	52	315.5	31.55	36.[illegible]
150mic	100	236.0	23.60	12.[illegible]
75 mic	200	60.[illegible]	6.06	6.[illegible]
			[illegible].72	



Sieve - Analysis

Contact: [illegible]

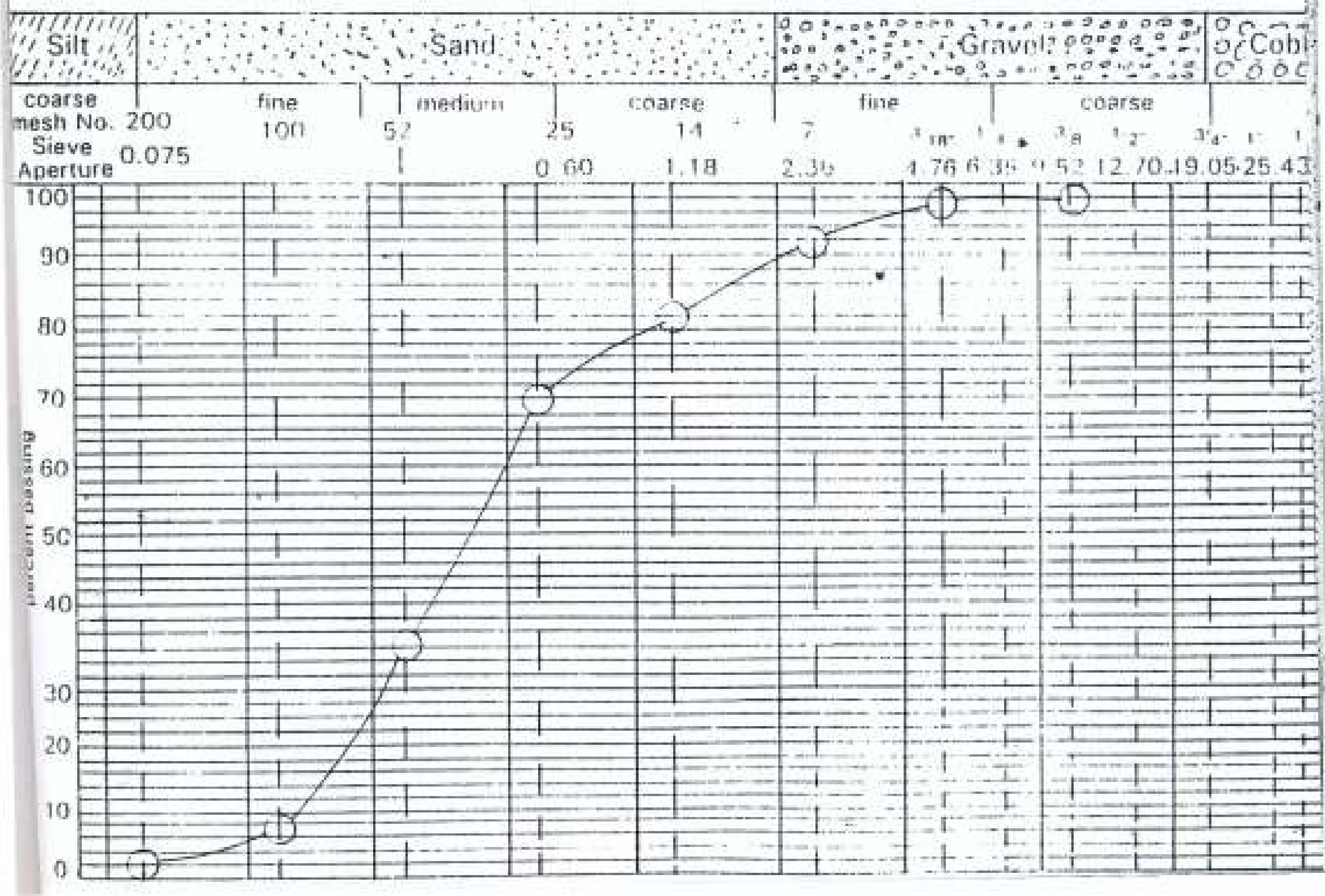
Laboratory: [illegible]

execut. by/date: 07. 7. 98 Okdi C.S.
calcul. by/date: 14. 05. 99

Lab. No.	Chainage borrow-pit	[illegible]	position	depth (m)	material		
Fig A4	type of material	[illegible]	2		sub-grade	fill	sub-base
	weight of soil taken for sieve analysis =	g					
	weight of soil taken for wet washing passing 4.76 mm Sieve =	g					

determination of moisture content	bowl No.	g	
	wet soil + bowl	g	
	dry soil + bowl	g	
	bowl alone	g	MC = water / dry soil x 100
	water alone	g	
	dry soil alone	g	= ____ %
determination of dry-soil weight	bowl No.	g	
	wet soil + bowl	g	
	bowl alone	g	
	Wet soil + bowl	g	
	dry soil alone	g	g - B
	Note: dry soil = Wet soil / 1 + 0.01MC %	g	
washing through mesh 200	washed oil + bowl	g	
	bowl alone	g	
	washed soil alone	g	g - C
	outwashed soil <0.075 mm o	g	g = B-C

B.S. Sieve mm	mesh No.	retained g	retained %	passing
38.1	1 1/2"			
25.4	1			
19.05	3/4"			
12.70	1/2"			
9.52		2.21	0.21	98.
4.76		35.7	3.57	96.
2.36	7	52.4	52.4	90.
1.18	14	80.4	8.04	82.
600 mic	25	212.2	21.22	61.
300mic	52	332.0	33.20	28.
150mic	100	210.4	21.04	7.
75 mic	200	44.3	44.3	5.
			5.00	



Sieve - Analysis

Contact: [illegible]

Laboratory: [illegible]

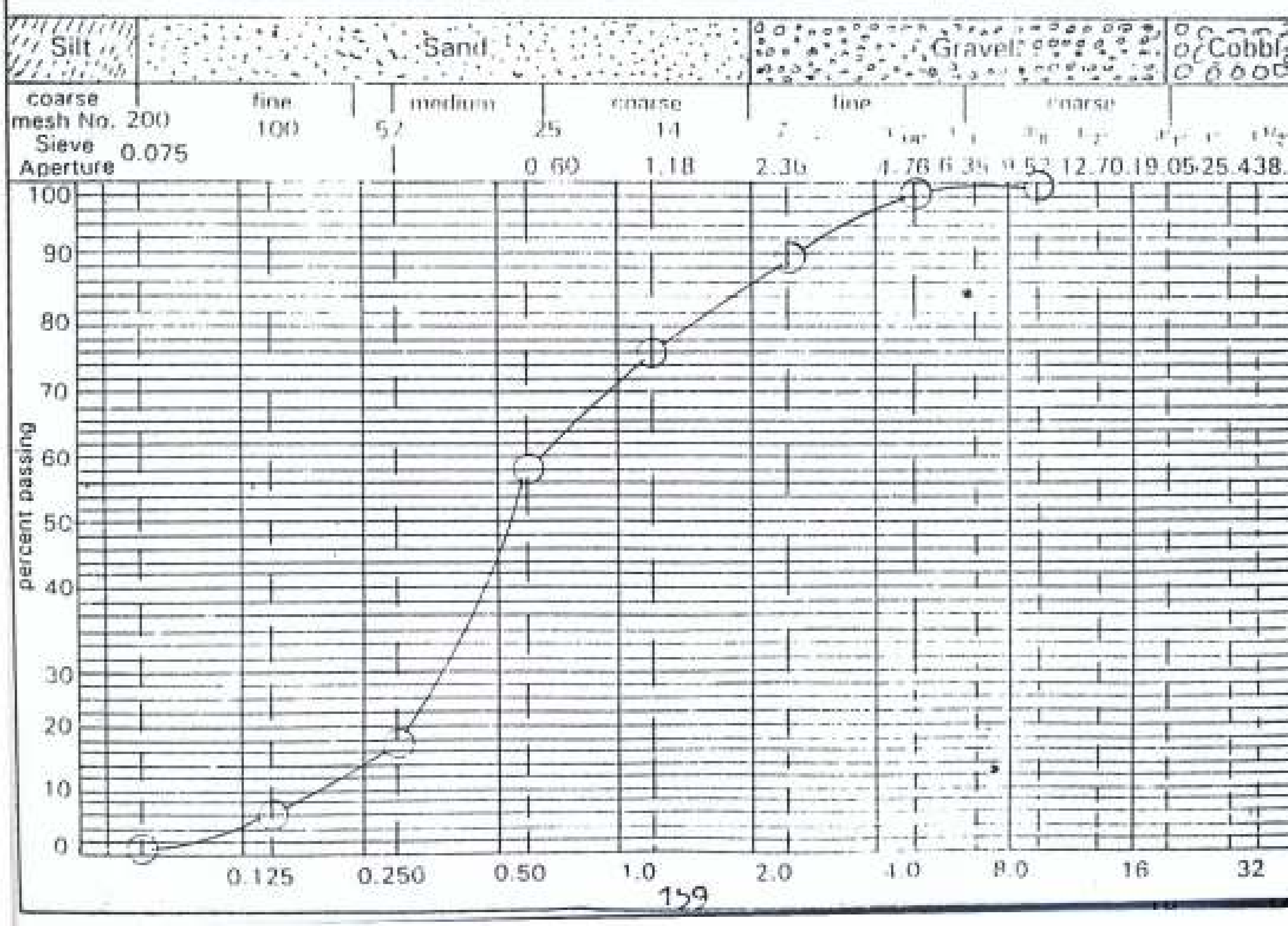
execut. by/date: 1 · 03 · 98 Okali C.S

calcul. by/date: 14 · 5 · 95

Lab. No.	Chainage borrow-pit		position	depth (m)	material: sub-grade	fill	sub-base	base
Fig A5	type of material	[illegible]	3					
	weight of soil taken for sieve analysis =	g						
	weight of soil taken for wet washing passing 4.76 mm Sieve =	g						

determination of moisture content	bowl No.		g	MC = water / dry soil × 100 = ____ %
	wet soil + bowl		g	
	dry soil + bowl		g	
	bowl alone		g	
	water alone		g	
	dry soil alone		g	
determination of dry soil weight	bowl No.		g	
	wet soil + bowl		g	
	bowl alone		g	
	Wet soil + bowl		g	
	dry soil alone		g	g - B
	Note: dry soil = Wet soil / (1 + 0.01 MC %)		g	
washing through mesh 200	washed soil + bowl		g	
	bowl alone		g	
	washed soil alone		g	g - C
	outwashed soil < 0.075 mm o		g	g = B−C

B.S. Sieve mm	mesh No.	retained g	retained %	passed %
38.1	1 1/2			
25.4	1			
19.05	3/4			
12.70	1/2			
9.52		1.60	0.100	98.16
4.76		22.0	2.79	97.70
2.36	7	55.0	5.30	91.75
1.18	14	94.6	9.46	82.52
600 mic	25	247.1	24.71	57.01
300mic	52	331.2	33.12	24.49
150mic	100	177.2	17.72	6.67
75 mic	200	38.7	3.87	2.70
			2.70	



Sieve - Analysis

Contact: OGBESE RIVER

Laboratory: OGBESE RIVER

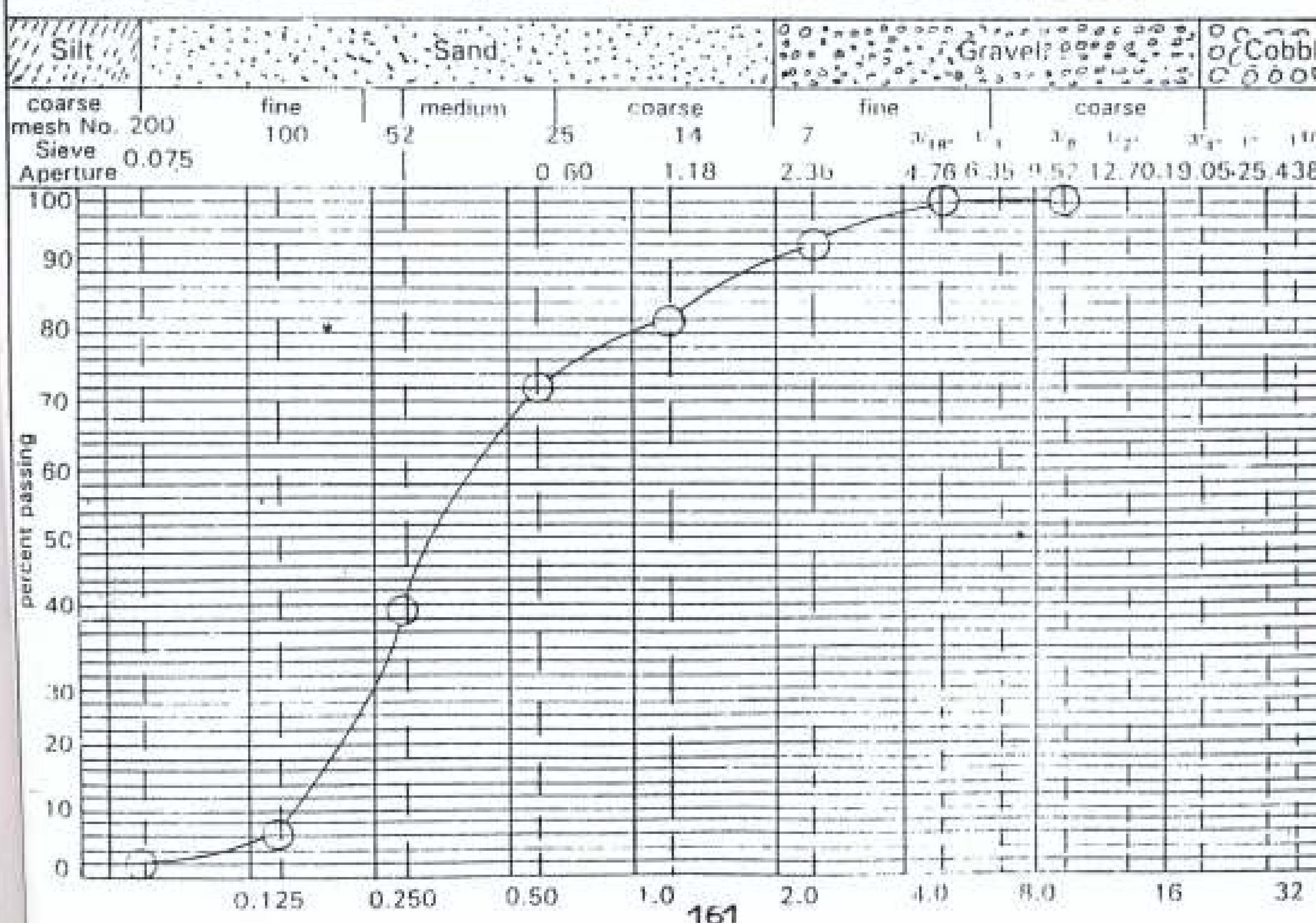
execut. by/date: 25 . 5 . 98 Olcoh' C.S
calcul. by/date: 14 . 05 . 99

Lab. No.			position	depth (m)	material		
	Chainage borrow-pit	BED MATERIAL	5		sub-grade	fill	sub-base
	type of material	BED MATERIAL					
Fig A7	weight of soil taken for sieve analysis = g						
	weight of soil taken for wet washing passing 4.76 mm Sieve = g						

determination of moisture content	bowl No.		g
	wet soil + bowl		g
	dry soil + bowl		g
	bowl alone		g
	water alone		g
	dry soil alone		g
determination of dry-soil weight	bowl No.		g
	wet soil + bowl		g
	bowl alone		g
	Wet soil + bowl		g
	dry soil alone		g ▶ g = B
	Note: dry soil = Wet soil / (1 + 0.01MC %)		g
washing through mesh 200	washed soil + bowl		g
	bowl alone		g
	washed soil alone		g ▶ g = C
	outwashed soil <0.075 mm g		g = B−C ⟶

MC = water / dry soil × 100 = ____ %

B.S. Sieve mm	mesh No.	retained g	retained %	passed %
38.1	1½"			
25.4	1"			
19.05	¾"			
12.70	½"			
9.52				
4.76		22.2	0.55	99.45
2.36	7	35.4	7.8	82.0
1.18	14	41.1	12.4	69.6
600 mic	25	81.1	20.28	61.09
300mic	52	137.2	34.45	27.44
150mic	100	91.8	22.95	4.49
75 mic	200	8.2	2.05	2.45
			2.49	



Sieve - Analysis

Contact: CGBESE RIVER

Laboratory: CGBESE RIVER

execut. by/date:	
calcul. by/date:	

Lab. No.	Chainage borrow-pit	BED MATERIAL	position	depth (m)	material: sub-grade	fill	sub-base	base
	type of material	BED MATERIAL	6					
	weight of soil taken for sieve analysis =	g						
	weight of soil taken for wet washing passing 4.76 mm Sieve =	g						

of moisture content	bowl No.		g
	wet soil + bowl		g
	dry soil + bowl		g
	bowl alone		g
	water alone		g
	dry soil alone		g
of dry-soil weight	bowl No.		g
	wet soil + bowl		g
	bowl alone		g
	Wet soil+ bowl		g
	dry soil alone		g
	Note: dry soil = $\frac{\text{Wet soil}}{1 + 0.01\text{MC }\%}$		g
through mesh 200	washed oil + bowl		g
	bowl alone		g
	washed soil alone		g
	outwashed soil <0.075 mm ø		g

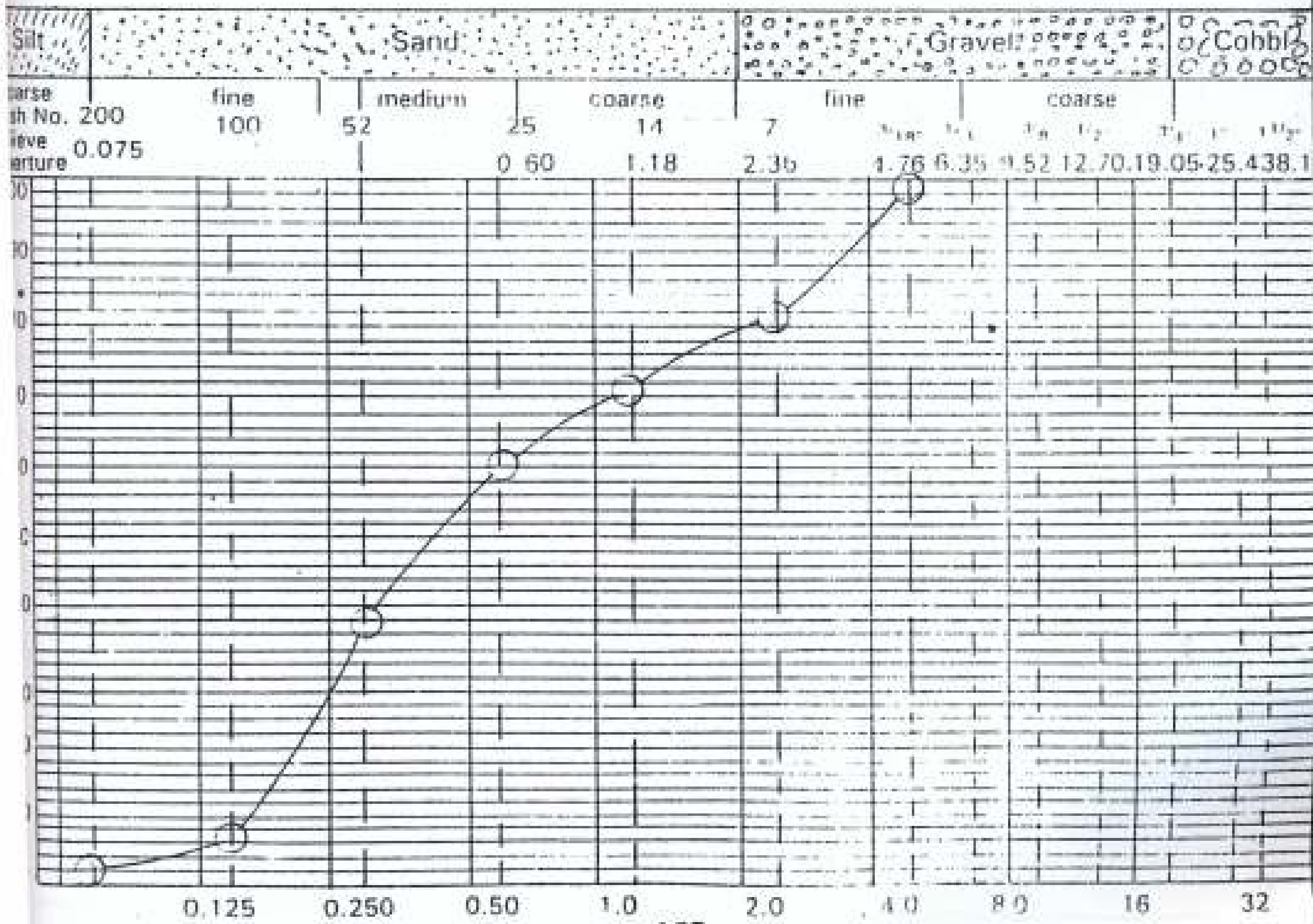
$$MC = \frac{\text{water}}{\text{dry soil}} \times 100 = \_\_\_\_\_\_ \%$$

g – B

g – C

g = B–C →

B.S. Sieve mm	mesh No	retained g	retained %	passed %
38.1	1½"			
25.4	1"			
19.05	¾"			
12.70	½"			
9.52				
4.76		40.2	10.05	89.95
2.36	7	51.1	12.78	77.17
1.18	14	61.1	15.28	61.89
600 mic	25	49.0	12.25	49.64
300mic	52	72.5	18.13	31.51
150mic	100	97.2	24.30	7.21
75 mic	200	13.9	3.40	3.75
			3.75↑	



Sieve - Analysis

g

Contact: OWENA RIVER

Laboratory: OWENA RIVER

execut. by/date: OKOLI C.S/30-7-98
calcul. by/date: 14 - 05 - 99

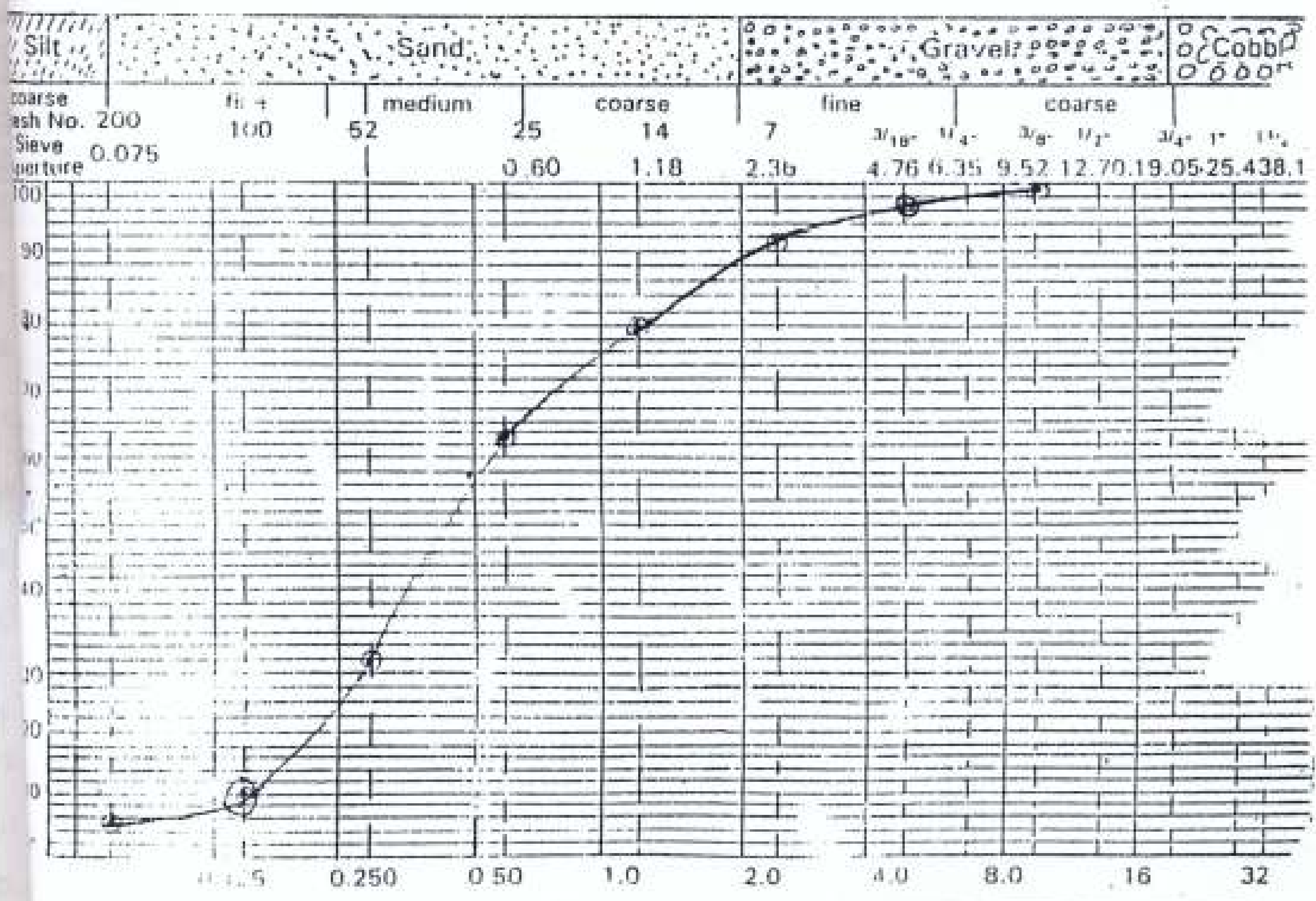
Lab. No.	Chainage burrow-pit	BED MATERIAL	position	depth (m)	material: sub-grade	fill	sub-base	base
	type of material	BED MATERIAL	7	RIVER SAND				

weight of soil taken for sieve analysis = g

weight of soil taken for wet washing passing 4.76 mm Sieve = 500 g

determination of moisture content	bowl No		g	
	wet soil + bowl		g	
	dry soil + bowl		g	
	bowl alone		g	
	water alone		g	MC = water / dry soil x 100
	dry soil alone		g	
determination of dry-soil weight	bowl No		g	
	wet soil + bowl		g	= ______ %
	bowl alone		g	
	Wet soil + bowl		g	
	dry soil alone		g	477.8 g - B
	Note: dry soil = Wet soil / (1 + 0.01 MC %)		g	
washing through mesh 200	washed oil + bowl		g	
	bowl alone		g	
	washed soil alone		g	22.20 g - C
	unwashed soil < 0.075 mm o		g	g = B−C →

B.S. Sieve mm	mesh No.	retained g	retained %	passed %
38.1	1 1/2"			
25.4	1"			
19.05	3/4"			
12.70	1/2"			
9.52		5.78	1.14	98.86
4.76		3.20	1.64	97.22
2.36	7	30.40	6.08	91.14
1.18	14	55.10	11.02	80.12
600 mic	25	95.20	19.04	61.08
300mic	52	158.5	30.70	30.38
150mic	100	112.5	22.50	7.38
75 mic	200	17.2	3.44	4.44
			4.44	



Sieve - Analysis

h

Contact: OWENA RIVER

Laboratory: OWENA RIVER

execut. by/date: OKOLI C.S/15-8-98

calcul. by/date: 4 - 05 - 99

Lab. No.	Chainage bore pit	BED MATERIAL	position	depth (m)	material			
	type of material	BED MATERIAL	8	RIVER SAND	sub-grade	fill	sub-base	

weight of soil taken for sieve analysis = g

weight of soil taken for wet washing passing 4.76 mm Sieve = 500 g

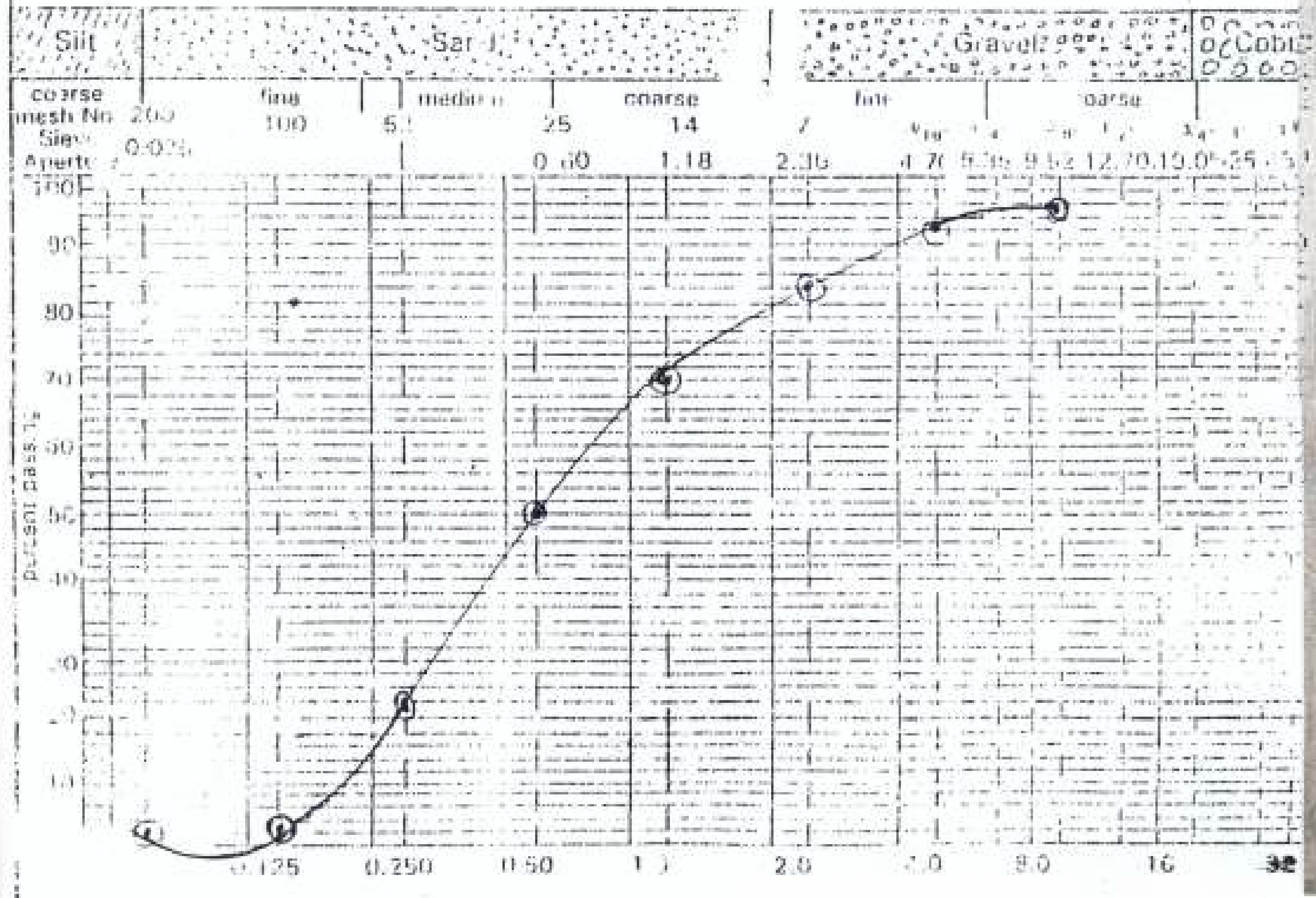
determination of moisture content		
bowl No		g
wet soil + bowl		g
dry soil + bowl		g
bowl alone		g
water alone		g
dry soil alone		g

$$MC = \frac{water}{dry\ soil} \times 100 = \_\_\_\_\%$$

determination of dry soil weight		
bowl No		g
wet soil + bowl		g
bowl alone		g
wet soil + bowl		g
wet soil alone		g ▸ 499.0 g
total dry soil =		g

washing through mesh 200		
washed soil + bowl		g
bowl alone		g
washed soil alone		g ▸ 1.00
soil washed soil < 0.075 mm		g

B.S. Sieve mm	mesh No.	retained g	retained	passing %
38.1	1 1/2"			
25.4	1			
19.05	3/4"			
12.70	1/2"			
9.52		28.2	5.64	94.
4.76		20.3	4.06	90.5
2.36	7	36.4	7.28	83.0
1.18	14	66.8	13.36	69.6
600 mic	25	103.1	20.62	49.0
300 mic	52	143.1	28.62	20.4
150 mic	100	85.4	17.08	3.34
75 mic	200	15.7	3.14	0.20
			0.20	
B+C ⟶				



Contact: OWENA RIVER

Laboratory: OWENA RIVER

execut. by/date:	OKOLI C.S/06-9-98	calcul. by/date:	14 - 05 - 99

Lab. No.		position	depth	material
	BED MATERIAL			
	BED MATERIAL	8	RIVER SAND	

Total soil taken for sieve analysis = g

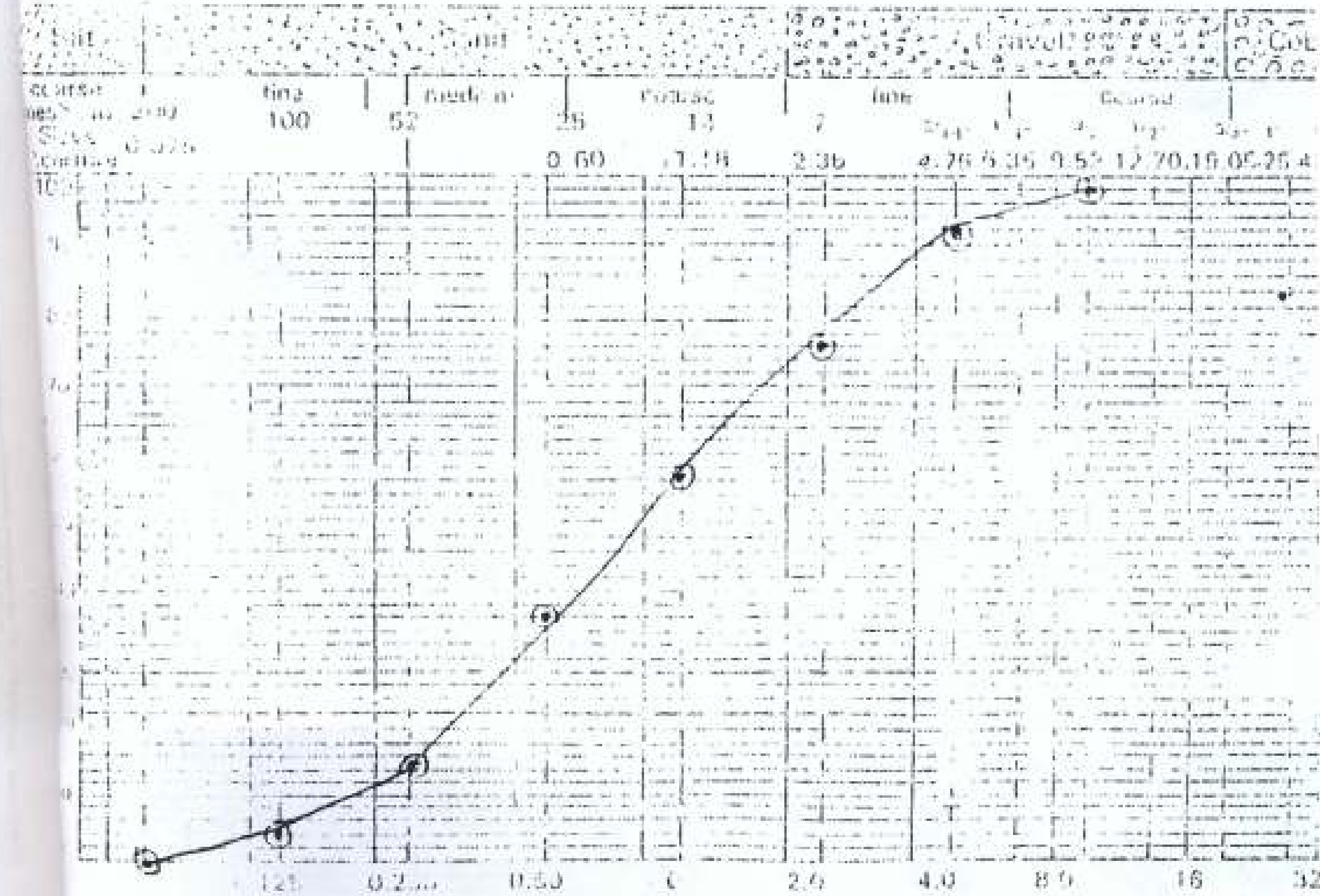
Total soil taken for wet mesh (sieving 4.76 mm Sieve) = 500 g

MC = water / dry soil x 100

499.70 g - B

0.30 g - C

B.S. Sieve mm	mesh No.	retained g	retained %	pa[illegible]
38.1	1½			
25.4	1			
19.05	¾			
12.70	½			
9.52		8.50	1.70	93.
4.76		45.40	9.08	89.
2.36	7	78.10	15.62	73.
1.18	14	86.90	17.38	56.
600 mic	25	104.40	20.88	35.
300 mic	52	103.40	20.68	14.
150 mic	100	59.00	11.80	2.
75 mic	200	14.00	2.80	0.
			0.06	



Sieve - Analysis

Contact: OWENA RIVER

Laboratory: OWENA RIVER

execut. by/date: OKOLI C.S/04.10.98
calcul. by/date: 14 - 05 - 99

Lab. No.			position	depth (m)	material		
	Chainage borrow-pit	BED MATERIAL			sub-grade	[illegible]	sub-base
	type of material	BED MATERIAL	10	RIVER			
	weight of soil taken for sieve analysis =		g	SAND			
	weight of soil taken for wet washing passing 4.76 mm Sieve =		g				

determination of moisture content	bowl No.		g	
	wet soil + bowl		g	
	dry soil + bowl		g	
	bowl alone		g	MC = $\frac{\text{water}}{\text{dry soil}} \times 100$
	water alone		g	
	dry soil alone		g	
determination of dry-soil weight	bowl No.		g	______ %
	wet soil + bowl		g	
	bowl alone		g	
	Wet soil + bowl		g	
	dry soil alone		g	499.7 g – B
	Note: dry soil = $\frac{\text{Wet soil}}{1 + 0.01 \text{ MC \%}}$		g	
washing through mesh 200	washed soil + bowl		g	
	bowl alone		g	
	washed soil alone		g	0.3 g – C
	outwashed soil <0.075 mm		g	g = B–C

B.S. Sieve mm	mesh No.	retained g	retained %	pass. %
38.1	1 1/2"			
25.4	1			
19.05	3/4"			
12.70	1/2"			
9.52				
4.76		2.40	0.48	99.
2.38	7	20.4	4.08	95.7
1.18	14	45.2	9.04	86.1
600 mic	25	119.3	23.86	62.
300mic	52	187.9	37.58	24.
150mic	100	109.1	21.82	3.1
75 mic	200	15.4	3.08	0.06
			0.06