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Mathematical modeling of sedimentation rate of Ikpoba River reservoir, Benin City

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Abstract

This paper examines the usage of mathematical modeling to establish a relationship between the sedimentation rate (the dependent variable) and velocity of flow, flow rate, trap efficiency and sediment load (independent variables). Reservoir and sedimentation data obtained gave insight into the sedimentation condition of the reservoir. Sediment deposition and distribution pattern of the reservoir were studied. Surveys were carried out using the Global Positioning System (GPS) to determine the sediment distribution pattern in the reservoir. A multiple regression model was developed to establish a relationship between the dependent and independent variables.

Keywords: regression modeling, sedimentation rate, reservoir

1. Introduction

The issue of sediment deposition in reservoirs should attract serious attention in reservoir management studies since it depletes the water storage capacity of reservoirs. As death is an inevitable end for humans, so is siltation an inevitable end for reservoirs. Reservoirs lose their capacity due to sedimentation processes and are therefore seriously threatened in their performances (Chikita, et al., 1991). Sediment content of river inflows into reservoirs depletes the available storage thereby reducing the benefits such as domestic and industrial water supplies, hydro power generation, irrigation, navigation, fish and wild life, sanitation and recreation, flood control, etc. This model establishes a relationship between rate of sediment deposition and many independent variables like character of the rainfall and catchment, trap efficiency of the reservoir, sediment load entering reservoir, shape of the reservoir, density of sediment, etc.

1.1 Study Area

The Ikpoba dam and reservoir site is located, spanning from Okhoro to Teboga, along the Ikpoba river running through Egor and Ikpoba in Okha local government area in Benin City, Edo state. It is found in the Benin-Owena River Basin in Nigeria. Its level of water is the same at all times during the year with just minor variations (Okeligho, 2011).

1.2 Objective of Study

The objective of this work is to derive a mathematical model to study sediment deposition rate in the reservoir of choice.

1.3 Scope of Study

The Ikpoba dam and reservoir site is located, spanning from Okhoro to Teboga, along the Ikpoba river running through Egor and Ikpoba in Okha local government area in Benin City, Edo state. It is found in the Benin-Owena River Basin in Nigeria. Its level of water is the same at all times during the year with just minor variations (Okeligho, 2011). The geological terrain is tertiary while the foundation is pile. The reservoir surface area is 1.07 x 10^6 m^2. The dam is 610m long and with a height, at crest level, of 35m above mean sea level (MSL). It has a spillway length (weir) of 60m and an emergency spillway length of 4m. The dam has a reservoir capacity of 1.5 x 10^6 m^3. The reservoir catchment area is 120 km^2 (www.wds.world bank.org/external/defal.).

It is the main source of water supply for Benin City with water production per pump day of 34080m^3. The water supply design capacity is 90,000m^3/day serving an estimated population of 1.0 million people at design. The dam was impounded first in 1975 and commissioned October, 1987. At present, problems associated with the reservoir are over-silting and growth of weeds over the years (Edo State Urban Water Board, 2007).

2. Modelling Sediment Deposition In Reservoirs

2.1 Multiple Regression Model

In order to study the rate of sedimentation in the reservoir of study, it is necessary to develop a mathematical model that will enable the prediction of the sediment deposition in the reservoir. Due to limited resources, it becomes necessary to be conscious not to be wasteful. The process of mathematical modelling and prediction puts a check on how effective limited field data are put to use in decision-making (Nwagazie, 2006).

A mathematical model is a simplified representation of certain aspects of a real system, created using mathematical concept such as functions, graphs, diagrams and equations to solve problems in the real world (Edwards and Hamson, 1989). Also, Neumaier (2004) defined mathematical modelling as the art of translating physical problems into tractable mathematical formulations whose theoretical and numerical analysis provides an understanding of the real life phenomenon and solution to the problem. Modelling involves identifying and selecting relevant features of real-world situation, representing those features symbolically, analyzing and reasoning about the model and characteristics of the situation, and considering the accuracy and limitations of the model (Aris, 1994). Generally, the success of a model depends on how easily it can be used and how accurate its predictions are (Edwards and Hamson, 1994).

2.2 Areas of Application

According to Agunwamba (2007), modeling has been applied in virtually every sphere of man's existence and it is as wide as nature itself. The list is inexhaustible. Modelling has been used to solve problems of robotics in the area of Artifical Intelligence, detection of planetary systems in Astronomy; population dynamics and spread of infectious diseases (AIDS) in biology; planning of production units in Chemical Engineering; stability of electric circuits, microchip analysis and power supply network optimization in Electrical Engineering; prediction of oil or ore deposits and earthquake in Geosciences; stability of structures and structural optimization in Civil Engineering. It is also applied in Water Resources Engineering to model sedimentation rates in reservoirs, solid waste and wastewater management systems, etc. There is hardly any problem that cannot be modelled mathematically if one is versed in modelling (Neumaier, 2004).

3. Methodology

This consists of using multiple regression model to study the relationship between the dependent variable, the sedimentation rate S_r and the independent variables: V, the velocity of flow Q, the flow rate, the trap efficiency T, and the sediment load, L.

3.1 Data Generation Methodology

The Global Positioning System (GPS) was primarily employed for data collection. The survey was conducted in a rapid and effective manner. The basic equipment used for a GPS hydrographic survey are a boat, two GPS receivers, fathometer, and a lap-top computer with data-logging software. The boat was equipped with the bathymetric equipment, the GPS system mounted on board and a lap-top computer while its reference station is positioned on a known geographical benchmark. The survey software was used to fix grid lines and interfacing of bathymeter and DGPS and taking X, Y, Z values at required interval/grid. The boat was used to navigate the reservoir and this was controlled by the software so that the boat tracks the grid lines accurately. The GPS receiver's output position information was obtained at every two seconds. Survey grade fathometers took soundings at much higher frequencies, as high as 20 times per second. The survey software monitored the GPS serial port for incoming data, and every time a GPS data string was received the programme immediately retrieved a depth reading from the second serial port.

Silt levels were got at different chainages along the reservoir. Also, silt levels were obtained latitudinally at the various chainages. Various areas of the silt deposited were computed for each chainage. Total volume of silt in the reservoir was obtained using Simpson's Rule for volume calculation (Primordial Rule). Hence, total volume of sediment in the reservoir was obtained.

The output from GPS receiver was available at two seconds interval, whereas a fathometer was used to take soundings at much higher frequencies, as high as 20 times per second. The computer programme was used to monitor the GPS serial port for incoming data. Every time a GPS data string was received, the programme immediately retrieved a depth reading from the second serial port. The bathymetric data were first transferred to reduced level format, after removing all collected points without differential correction.

- ***Velocity, V (m/s)***
  Current meter was used to measure the velocity at different sections of the reservoir.
- ***Sediment volume/load, V (m^3)***
  This was calculated by applying the Simpson's Rule for volume as follows:

$$V = \frac{D}{6}\left[A_1 + 4M + A_2\right] \quad (1)$$

where D = distance between the parallel cross sections

A_1= cross sectional area of the first cross section

A_2 = cross sectional area of the next cross section

M = cross sectional area of the area midway between A_1 and A_2

- **Specific weight (tons)**
  According to Lane and Koelzer (1953)

$$W_t = W_i + K \log t \quad (2)$$

where W_t = specific weight at t years

W_i = specific weight after one year of operation of reservoir

K = consolidation constant=7.0

T = number of years of reservoir operation

- ***Trap Efficiency, T (%)***
  This was obtained using the mathematical expression below:

$$T_e = \frac{1}{1 + K\left(C/A\right)} x 100\% \quad (3)$$

where K = a coefficient varying from 0.046 to 1.0 for the data used by Brown (1944)

C/A = ratio of reservoir capacity (in acre-feet) and the catchment area (in square miles).

- ***Flow Rate, Q (m^3/s)***
  This was obtained by multiplying the velocity of flow, V by the cross sectional area, A.

$$V = Q\,A \quad (4)$$

- ***Sedimentation Rate, S_r (tons/Km^2/year)***

$$Se\dim entation\ rate = \frac{Specific\ weight}{Catchment\ area\ x\ number\ of\ years\ of\ reservoir\ operation} \quad (5)$$

The above expressions were used for the calculations as displayed in Table 3.1.

Table 3.1: Sedimentation Data for Ikpoba River Reservoir

Data Set	Chainage (m)	Cross Sectional area (m^2)	Sediment Load/Vol., L (m^3)	Specific Weight (tons)	Velocity, V (M/s)	Flow rate,Q ($M^3/_5$)	Sedimentation Rate, S_r (tons/km^3/yr)	Trap eff., T (%)
1	0+000	387.00	17250.00	17472.35	0.60	232.20	4.04	87.00
2	0+050	522.00	24062.50	24373.67	13.84	7224.48	5.64	90.20

3	0+100	412.50	22287.50	22574.79	17.86	7367.25	5.23	89.50
4	0+150	502.50	24212.50	24524.60	10.14	5095.35	5.68	90.00
5	0+200	483.00	24043.75	24353.67	10.44	4042.52	5.64	90.20
6	0+250	450.75	22518.75	22809.02	16.03	7225.52	5.28	89.60
7	0+300	416.25	21687.50	21969.08	10.83	4507.99	5.09	89.30
8	0+350	486.75	22687.50	22979.94	13.24	6444.57	5.32	89.70
9	0+400	359.25	20481.25	20745.25	8.61	3093.14	4.80	88.70
10	0+450	534.00	24750.00	25069.03	12.90	6888.60	5.80	90.50
11	0+500	474.75	23743.75	24049.81	14.20	6741.45	5.57	90.10
12	0+550	416.25	21275.00	21549.23	10.50	4370.63	4.99	89.10
13	0+600	413.25	21350.00	21625.20	12.73	5260.67	5.01	89.10
14	0+650	492.75	23541.67	23845.12	8.56	4217.94	5.52	90.02
15	0+700	440.75	22507.33	22797.45	9.43	4156.27	5.28	89.61
16	0+750	445.13	22180.00	22465.90	7.46	3320.67	5.20	89.48
17	0+800	440.33	23609.58	23913.91	10.70	4711.53	5.54	90.05
18	0+850	626.70	28516.92	28884.50	14.00	8773.80	6.69	91.62
19	0+900	474.90	25116.25	25440.00	13.68	6496.63	5.89	90.59
20	0+950	487.65	24561.83	24878.43	12.75	6217.54	5.76	90.40
21	1+000	521.92	21461.08	21737.71	10.97	5725.46	5.03	89.16
22	1+050	531.10	21854.42	22136.12	12.60	6691.86	5.12	89.30
23	1+100	498.13	25136.42	25460.43	10.91	5434.60	5.89	90.60
24	1+150	492.75	24766.92	25086.17	10.52	5183.73	5.81	90.47
25	1+200	502.90	24878.75	25199.44	12.10	6085.09	5.83	90.51
26	1+250	481.10	24327.50	24641.08	10.10	4859.11	5.70	90.32
27	1+300	492.00	24544.58	24860.96	12.30	6051.60	5.75	90.31
28	1+350	496.25	24964.58	25286.37	11.97	5940.11	5.85	90.54
29	1+400	518.75	25789.58	26122.01	10.80	5602.50	6.05	90.81
30	1+450	523.50	25923.75	26257.91	13.10	6857.85	6.08	90.86

31	1+500	498.10	25122.08	25445.90	12.13	6036.97	5.89	90.59
32	1+550	498.75	25957.17	26293.78	12.97	6468.79	6.09	90.87
33	1+600	502.00	25183.33	25507.94	12.20	6124.40	5.90	90.61
34	1+650	515.25	25593.75	25923.65	10.10	5204.03	6.00	90.75
35	1+700	508.25	25391.67	25718.97	10.25	5209.56	5.95	90.68

Table 3.2: Transformed Sedimentation Data for Evaluating the Normal Equations

Data Set	Sed. Rate Y= LogSr	Veticity X_1=logV	Flow rate X_2 = logQ	Traff. Eff. X_3 = Log Te	Sed. Load X_4 = log L	X_1^2	X_2^2	X_3^2	X_4^2
1	0.6064	-0.2218	2.3659	1.9395	4.2368	0.0492	5.5974	3.7617	17.9505
2	0.7513	1.1411	3.8588	1.9552	4.3813	1.3021	14.8903	3.8228	19.1958
3	0.7185	1.2519	3.8673	1.9518	4.3481	1.5673	14.9560	3.8095	18.9060
4	0.7543	1.0060	3.7072	1.9542	4.384	1.0120	13.7433	3.8189	19.2195
5	0.7513	1.0187	3.7026	1.9552	4.381	1.0377	13.7092	3.8226	19.1932
6	0.7226	1.2049	3.8589	1.9523	4.3525	1.4518	14.8911	3.8115	18.9443
7	0.7067	1.0346	3.6540	1.9509	4.3362	1.0704	13.3517	3.8060	18.8026
8	0.7259	1.1219	3.8092	1.9528	4.3558	1.2587	14.5100	3.8134	18.9730
9	0.6812	0.9350	3.4904	1.9479	4.3114	0.8742	12.1829	3.7943	18.5882
10	0.7634	1.1106	3.8381	1.9566	4.3936	1.2334	14.7310	3.8283	19.3037
11	0.7459	1.1523	3.8288	1.9547	4.3755	1.3278	14.6597	3.8209	19.1450
12	0.6981	1.0212	3.6405	1.9499	4.3279	1.0428	13.2532	3.8021	18.7307
13	0.6998	1.1048	3.7210	1.9499	4.3294	1.2206	13.8458	3.8021	18.7437
14	0.7419	0.9325	3.6251	1.9543	4.3718	0.8696	13.1414	3.8193	19.1126
15	0.7226	0.9745	3.6187	1.9524	4.3523	0.9497	13.0950	3.8119	18.9425
16	0.7160	0.8727	3.5212	1.9517	4.3460	0.7616	12.3988	3.8091	18.8877
17	0.7435	1.0294	3.6732	1.9545	4.3731	1.0597	13.4924	3.8201	19.1240
18	0.8254	1.1461	3.9432	1.9620	4.4551	1.3135	15.5488	3.8494	19.8479
19	0.7701	1.1361	3.8127	1.9571	4.4000	1.2907	14.5367	3.8302	19.3600
20	0.7604	1.1055	3.7936	1.9662	4.3903	1.2221	14.3914	3.8267	19.2747

21	0.7016	1.0402	3.7578	1.9502	4.3317	1.0820	14.1211	3.8033	18.7636
22	0.7093	1.1004	3.8255	1.9509	4.3395	1.2109	14.6345	3.8060	18.8313
23	0.7701	1.0378	3.7352	1.9571	4.4003	1.077	13.9517	3.8302	16.0240
24	0.7642	1.0220	3.7146	1.9565	4.3939	1.0445	13.7983	3.8279	19.3064
25	0.7642	1.0828	3.7843	1.9567	4.3958	1.1725	14.3209	3.8287	19.3231
26	0.7559	1.0043	3.6866	1.9558	4.3845	1.0086	13.5910	3.8252	19.2238
27	0.7597	1.0899	3.7819	1.9557	4.3900	1.1879	14.3028	3.8248	19.2721
28	0.7672	1.0781	3.7739	1.9568	4.3973	1.1623	14.2416	3.8291	19.3362
29	0.7918	1.0334	3.7484	1.9581	4.4114	1.0679	14.0505	3.8342	19.4604
30	0.7839	1.1173	3.8362	1.9584	4.4137	1.2484	14.7164	3.8353	19.4807
31	0.7701	1.0835	3.7808	1.9571	4.4001	1.1740	14.2944	3.8302	19.3609
32	0.7846	1.1129	3.8108	1.9584	4.4143	1.2385	14.5222	3.8353	19.4860
33	0.7709	1.0864	3.7871	1.9572	4.4011	1.1803	14.3421	3.8306	19.3697
34	0.7782	1.0043	3.7163	1.9578	4.4081	1.0086	13.8109	3.8330	19.4313
35	0.7745	1.0107	3.7168	1.9575	4.4047	1.0215	13.8146	3.8318	19.4014
Σ	**26.0430**	**35.0019**	**129.7865**	**68.4033**	**153.0885**	**38.7998**	**483.4391**	**133.6864**	**608.4757**

Table 3.2 Transformed Sedimentation Data for Evaluating the Normal Equations (continued).

Data Set	X_1X_2	X_1X_3	X_1X_4	X_2X_3	X_2X_4	X_3X_4	X_1y	X_2y	X_3y	X_4y
1	-0.5248	-0.4302	-0.9397	4.5887	10.0238	8.2173	-0.1345	1.4347	1.1761	2.5692
2	4.4033	2.2311	4.9995	7.5447	16.9066	8.5663	0.8573	2.8991	1.4689	3.2917
3	4.8415	2.4435	5.4434	7.5482	16.8154	8.4866	0.8995	2.7787	1.4024	3.1241
4	3.7294	1.9659	4.4103	7.2446	16.2524	8.5672	0.7588	2.7963	1.4741	3.3069
5	3.7718	1.9918	4.4629	7.2393	16.2524	8.5657	0.7653	2.7818	1.4689	3.2914
6	4.6496	2.3523	5.2443	7.5337	16.2211	8.4974	0.8707	2.7884	1.4107	3.1451
7	3.7804	2.0184	4.4862	7.1286	15.8445	8.4595	0.7312	2.5823	1.3787	3.0644

8	4.2736	2.1908	4.8868	7.4386	16.5921	8.5060	0.8144	2.7651	1.4175	3.1619
9	3.2635	1.8213	4.0312	6.7990	15.0485	8.3982	0.6369	2.3777	1.3269	2.9369
10	4.2626	2.1730	4.8795	7.5096	16.8631	8.5965	0.8478	2.9300	1.4937	3.3541
11	4.4119	2.2524	5.0419	7.4842	16.7529	8.5528	0.8595	2.8559	1.4580	3.2637
12	3.7177	1.9912	4.4197	7.0986	15.7557	8.4390	0.7129	2.5414	1.3612	3.0213
13	4.1110	2.1542	4.7831	7.2556	16.1097	8.4419	0.7731	2.6040	1.3645	3.0297
14	3.3804	1.8224	4.0767	7.0845	15.8482	8.5438	0.6918	2.6895	1.4499	3.2434
15	3.5264	1.9026	4.2413	7.0651	15.7497	8.4974	0.7042	2.6149	1.4108	3.1450
16	3.0732	1.7032	3.7928	6.8723	15.3031	8.4821	0.6249	2.5212	1.3974	3.1117
17	3.7812	2.0120	4.5017	7.1793	16.0633	8.5472	0.7654	2.7310	1.4532	3.2514
18	4.5193	2.2486	5.1060	7.7366	17.5674	8.7409	0.9460	3.2547	1.6194	3.6772
19	4.3316	2.2235	4.9988	7.4618	16.0633	8.6112	0.8749	2.9362	1.5072	3.3884
20	4.1938	2.1626	4.8535	7.4210	16.6550	8.5883	0.8406	2.8847	1.4875	3.3384
21	3.9089	2.0286	4.5058	7.3285	16.2777	8.4477	0.7298	2.6365	1.3683	3.0391
22	4.2096	2.1468	4.7752	7.4632	16.6008	8.4659	0.7805	2.7134	1.3838	3.0780
23	3.8764	2.0311	4.5666	7.3102	16.4360	8.6118	0.7992	2.8765	1.5072	3.3887
24	3.7963	1.9995	4.4906	7.2676	16.3216	8.5967	0.7810	2.8387	1.4952	3.3578
25	4.0976	2.1187	4.7598	7.4047	*16.6350*	8.6013	0.8291	2.8976	1.4982	3.3659
26	3.7025	1.9642	4.4034	7.2103	16.1639	8.5752	0.7592	2.7867	1.4784	3.3142
27	4.1219	2.1315	4.7847	7.3963	16.6025	8.5855	0.8280	2.8731	1.4857	3.3351
28	4.0685	2.1096	4.7407	7.3846	16.5945	8.6046	0.8271	2.8953	1.5013	3.3736
29	3.8736	2.0235	4.5587	7.3397	16.5357	8.6380	0.8079	2.9305	1.5308	3.4488
30	4.22862	2.1881	4.9314	7.5128	16.9318	8.6438	0.8759	3.0072	1.5352	3.4599
31	4.0965	2.1205	4.7675	7.3994	16.6359	8.6114	0.8344	2.9116	1.5072	3.3885
32	4.2410	2.1795	4.9127	7.4631	16.8220	8.6450	0.8732	2.9900	1.5366	3.4635
33	4.1143	2.1263	4.7814	7.4121	16.6674	8.6138	0.8375	2.9195	1.5088	3.3928
34	3.7323	1.9662	4.4271	7.2758	16.3818	8.6302	0.7815	2.8920	1.5236	3.4304
35	3.7566	1.9784	4.4518	7.2756	16.3714	8.6222	0.7828	2.8787	1.5161	3.4114
Σ	**135.3796**	**70.3431**	**157.5323**	**253.6779**	**566.6662**	**299.1984**	**26.9678**	**96.8149**	**50.9034**	**113.9636**

3.2 Model Development

It is proposed that sedimentation model be developed using the transformed sedimentation data (Table 3.2). Sedimentation rate (silt yield/year) is found to be related to the velocity of flow, V, the flow rate Q, the trap efficiency T, and sediment load L, in the following manner by applying power function.

$$Sr = CV^{a_1} Q^{a_2} T^{a_3} L^{a_4} \quad (6)$$

where C, a_1, a_2, a_3, a_4 are constants

V,Q,T,L are independent variables

S_r is the dependent variable.

It is required that a sedimentation model be developed by applying the least square regression analysis to the data set. A least square multiple regression model is to be developed.

Linearizing equation (4.1) we obtain:

$$\log S_r = \log C + a_1 \log V + a_2 \log Q + a_3 \log T + a_4 \log L \quad (7)$$

or $$y = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + a_4 x_4 \quad (8)$$

where, $y = \log S_r$, $a_0 = \log C$, $x_1 = \log V$, $x_2 = \log Q$,

$x_3 = \log T$, $x_4 = \log L$

Data sets were collected at different times from the study area and were used to calibrate the model.

3.3 The Normalized Equations

The Normalized equations for above four independent variables x_1, x_2, x_3 and x_4 give five equations thus:

$$\left.\begin{aligned}
\sum y &= a_0 n + a_1 \sum x_1 + a_2 \sum x_2 + a_3 \sum x_3 + a_4 \sum x_4 \\
\sum yx_1 &= a_0 \sum x_1 + a_1 \sum x_1^2 + a_2 \sum x_1 x_2 + a_3 \sum x_1 x_3 + a_4 \sum x_1 x_4 \\
\sum yx_2 &= a_0 \sum x_2 + a_1 \sum x_1 x_2 + a_2 \sum x_2^2 + a_3 \sum x_2 x_3 + a_4 \sum x_2 x_4 \\
\sum yx_3 &= a_0 \sum x_3 + a_1 \sum x_1 x_3 + a_2 \sum x_2 x_3 + a_3 \sum x_3^2 + a_4 \sum x_3 x_4 \\
\sum yx_4 &= a_0 \sum x_4 + a_1 \sum x_1 x_4 + a_2 \sum x_2 x_4 + a_3 \sum x_3 x_4 + a_4 \sum x_4^2
\end{aligned}\right\} \quad (9)$$

By direct substitution of the terms of Table 3.1 into the normal equation in equation (9), the following five normal (simultaneous) equations are obtained:

$$\left.\begin{aligned}
35a_0 + 35.0019a_1 + 129.7865a_2 + 68.4033a_3 + 153.0885a_4 &= 26.0430 \\
35.0019a_0 + 38.7998a_1 + 135.3796a_2 + 70.3431a_3 + 157.5323a_4 &= 26.9678 \\
129.7865a_0 + 135.3796a_1 + 483.4391a_2 + 253.6779a_3 + 566.6662a_4 &= 96.8149 \\
68.4033a_0 + 70.3431a_1 + 253.6779a_2 + 133.6864a_3 + 299.1984a_4 &= 50.9034 \\
153.0885a_0 + 157.5323a_1 + 566.6662a_2 + 299.1984a_3 + 608.4757a_4 &= 113.9636
\end{aligned}\right\} \quad (10)$$

Putting Eqn (10) in matrix form, we have:

$$\begin{bmatrix} 35.0000 & 35.0019 & 129.7865 & 68.4033 & 153.0885 \\ 35.0019 & 38.7998 & 135.3796 & 70.3431 & 157.5323 \\ 129.7865 & 135.3796 & 483.4391 & 253.6779 & 566.6662 \\ 68.4033 & 70.3431 & 253.6779 & 133.6864 & 299.1984 \\ 153.0885 & 157.5323 & 566.6662 & 299.1984 & 608.4757 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix} = \begin{bmatrix} 26.0430 \\ 26.9678 \\ 96.8149 \\ 50.9034 \\ 113.9636 \end{bmatrix} \quad (11)$$

4. Results and Discussion

4.1 Results

The values of the constants a_1, a_2, a_3, and a_4 were determined from the matrix using MATLAB computer software as shown in MATLAB command window thus:

$$a_0 = 0.0201 = C$$
$$a_1 = 0.0020$$
$$a_2 = 0.1053$$
$$a_3 = 0.1748$$
$$a_4 = -0.0023$$

The sedimentation model is

$$S_r = CV^{a_1} Q^{a_2} T^{a_3} L^{a_4}$$

$$S_r = 0.0201\, V^{0.0020} Q^{0.1053} T^{0.1748} L^{-0.0023} \quad (12)$$

Putting the above sedimentation model in a linear form, we have

$$y = 0.0201 + 0.0020x_1 + 0.1053x_2 + 0.1748x_3 - 0.0023x_4 \quad (13)$$

where $y=\log S_r$, $x_1=\log V$, $x_2=\log Q$, $x_3=\log T$, $x_4=\log L$

4.2 Model Interpretation

The model above shows that the independent variable, the sediment load, L does not have significant contribution to the model, hence it is discarded. The power for the variable L is negative implying negligible contribution in the model. As a result it is now eliminated from the model to obtain:

$$S_r = 0.0201\, V^{0.0020} Q^{0.1053} T^{0.1748}$$

By inspection it can be seen that the constant a_3 for the trap efficiency has highest contribution to the model while sediment load has negligible contribution and is now eliminated.

$$a_0 = 0.0201 = C$$
$$a_1 = 0.0020$$
$$a_2 = 0.1053$$
$$a_3 = 0.1748$$

The new sedimentation model is

$$S_r = 0.0201\, V^{0.0020} Q^{0.1053} T^{0.1748} \quad (14)$$

Putting the above sedimentation model in a linear form results in

$$y = 0.0201 + 0.0020\, x_1 + 0.1053\, x_2 + 0.1748\, x_3 \quad (15)$$

The above linear equation implies that sedimentation rate depends on the independent variables, velocity, flow rate and trap efficiency. Increase in any of them will result to increase in sedimentation rate.

4.3 Model Verification

Regression

Descriptive Statistics

	Mean	Std. Deviation	N
SR	.744329	.0397167	35
V	1.028057E0	.2306161	35
FR	3.708189E0	.2524557	35
T	1.954666E0	.0044997	35
SL	4.373957E0	.0393662	35

Correlations

		SR	V	FR	T	SL
Pearson Correlation	SR	1.000	.623	.712	.920	.999
	V	.623	1.000	.986	.613	.627
	FR	.712	.986	1.000	.688	.715
	T	.920	.613	.688	1.000	.922
	SL	.999	.627	.715	.922	1.000
Sig. (1-tailed)	SR	.	.000	.000	.000	.000
	V	.000	.	.000	.000	.000
	FR	.000	.000	.	.000	.000
	T	.000	.000	.000	.	.000
	SL	.000	.000	.000	.000	.
N	SR	35	35	35	35	35
	V	35	35	35	35	35
	FR	35	35	35	35	35
	T	35	35	35	35	35
	SL	35	35	35	35	35

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	SL, V, T, FR[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: SR

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.999[a]	.998	.998	.0018736

a. Predictors: (Constant), SL, V, T, FR

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.054	4	.013	3.812E3	.000[a]
	Residual	.000	30	.000		
	Total	.054	34			

a. Predictors: (Constant), SL, V, T, FR

b. Dependent Variable: SR

Coefficients[a]

	Unstandardized Coefficients		Standardized Coefficients			Correlations		
Model	B	Std. Error	Beta	t	Sig.	Zero-order	Partial	Part
1 (Constant)	-3.627	.284		-12.760	.000			
V	.003	.011	.020	.306	.761	.623	.056	.002
FR	-.004	.011	-.028	-.380	.707	.712	-.069	-.003
T	-.038	.186	-.004	-.204	.840	.920	-.037	-.002
SL	1.019	.025	1.010	40.611	.000	.999	.991	.329

Model verification was carried out by applying the Statistical Package for Social Sciences (SPSS) software (version 17) on the developed multiple regression model. The analysis of variance (ANOVA) table used to check the adequacy of the model indicates that the model is adequate.

4.4 Discussion of Results

The result shows that the dependent variable, sediment rate is dependent on the independent variables. Trap efficiency is mostly related to the sedimentation rate; followed by flow rate and the velocity of flow. Sediment load was found to have least relationship with the dependent variable.

5. Conclusion

There is lack of adequate data on sedimentation in most reservoirs in Nigeria. The rates of sedimentation in these reservoirs are not monitored. This may lead to the reservoirs being filled up with sediments before the estimated reservoir life is reached leading to sudden end of the benefits.

Sediment trapping in reservoirs is a serious issue that threatens their functionality and benefits. In view of tremendous amount of money spent on putting up a dam and reservoir facility, there is urgent need to protect this to prolong its life and benefits.

The Statistical Approach Model (by Least squares method) presented considers many independent variables affecting sedimentation as outlined. By taking into account many independent variables the model will always give a good estimate of the sedimentation rate in the study area.

6. Recommendations

- It is recommended that studies should be carried out on different reservoirs in the country periodically (say every ten years) to monitor their sedimentation rates.
- Measures to control reservoir sedimentation like putting up vegetation at reservoir area, construction of check dams, provision of multiple sluiceways at the foot of the dam, etc should be applied to prolong the life of the reservoir and its benefits.
- It is also recommended that the usage of dead storage zone should be abolished in reservoir design in Nigeria. Multiple sluice gates should be provided at the dead storage region to ensure that most sediments entering the reservoir are flushed out as they approach the dam.
- There is urgent need to commence sedimentation and general reservoir management studies in all reservoirs in the country to save them from rapid siltation and loss of benefits
- The Ikpoba water supply reservoir should be optimized by making it a multi-purpose facility by using it to provide potable water, hydroelectric power and irrigated agriculture to Benin City and environs to improve standard of life of people in the area.
- Sedimentation data should be obtained for different reservoirs in the country and empirical model developed and applied for periodic sedimentation studies.
- There is urgent need to commence desilting of the reservoir to save it from total reservoir siltation and loss of benefits. The Edo State government should embark on this immediately in view of the tremendous cost to save the dam-reservoir facility.

References

Agunwamba, J.C. 2007: Engineering Mathematical Analysis. De-Adroit Innovation, Enugu.

Aris, R. 1994: Mathermatical Modelling Techniques. New York, Dover.

Brown, C.B. 1944: “ Discussion of Sedimentation on Reservoirs” Proceedings of the American Society of civil Engineers, Edited by J.Witzig,vol 69, pp 1493-1500.

Chikita,K.; Yonemitsu, K. and Yashida, M. 1991: Dynamic Sedi-mentation processes in a glacier-fed lake, Peyto lake, Alberta, Canada. Japanese. J. of Limnology, vol.52, No 1, pp.27-43.

Edwards, D. and Hamson, M. 1989: Guide to Mathematical Modelling, CRC Mathematical Guide, CRC Press.

Lane, E.W. and Koelzer, V.A. 1953: Density of Sediments Deposited in Reservoirs, Report No.9, in A study of Methods Used in Measurement and Analysis of Sediment Loads in Streams, Hydraulic Lab, University of Iowa.

Neumaier, A. 2004: Mathematical Model Building. Chapter 3 in: Modelling Language in Mathematical Optimization (J. Kallrath ed.), Applied Optimization, Vol 88, Kluwer Boston.

Nwagazie, I. 2006: Probability and Statistics for Science and Engineering Practice. University of Port Harcourt Press.

Okeligho M.I. 2011: Adjustment and Error Analysis for Control Network for Dam Deformation Monitoring by GPS.