Remaining Storage of the Zaria Impounded Reservoir and Rate of Erosion in Its Drainage Basin

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Abstract

Zaria Impounded Reservoir is the only source of piped water supply to Zaria and its environs since its impoundment in 1974 to date. However, its useful life is being threatened by continuous siltation with sediments originating from its drainage basin – the Galma Drainage Basin as a result of improper land use practices. Owing to the great importance of the reservoir in the supply of potable water to Zaria and environs, an attempt was made to study the reservoir's bathymetry using boat, metric tape with a heavy object attached to it and satellite navigator. Result of this measurements shows that the present year, 2010, average weighted depth has been reduced to 2.82 metres from 15.00 metres at the day of impoundment in 1974. Also, the remaining storage was reduced to 21,129,242 m^3, about 46 percent of the original volume, 45,800,000 m^3 at the day of impoundment. Furthermore, the rate of siltation between years 1974 to 2010 was calculated to be 685,299 m^3/year. It corresponds to about 1.5 percent per year of the original storage. Further, the measurement has shown that only the active storage is left in year 2010. The dead storage had been completely silted up about 23 years after the impoundment and active storage has been reduced by 8,670,758 m^3 in year 2010 from the original 29,800,000 m^3. By year 2041 the reservoir will be completely silted up if preventive measures are not taken. Additionally, rate of erosion depth in the drainage basin has been calculated as 0.3 mm/a.

Keywords: Impounded reservoir, Dam, Bathymetry, Siltation, Rate of erosion

Introduction

Reservoirs are vital to the world's economy for their role in electricity generation, flood control, residential water supply, recreation, and irrigated agriculture. An estimated 30 - 40 percent of irrigated land worldwide now relies on dams and also, dams generate 19 percent of world electricity according to World Commission on Dams (2000). The useful life of these impounded reservoirs is continuously threatened by erosion within its drainage basin. According to Graf (1984); Fan and Morris, (1992): In Althaus and De Cesare, (2006), sediment deposition in reservoirs causes loss of water storage. Planning and design of a reservoir requires the accurate prediction of sediment transport, erosion and deposition in the reservoir. However, there are no accurate data on the rates of reservoir sedimentation worldwide, but it is commonly accepted that about 1 - 2 percent of the worldwide dam capacity is lost annually, (Jacobsen, (1999): In Althaus and De Cesare, (2006).

In Nigeria, over 323 dams and reservoirs have been constructed and many more are under construction in different parts of the country, (Etiosa, 2006). The Zaria impounded reservoir is one of them and it is the main source of piped-water supply to Zaria and its environs. The reservoir was constructed in 1974 as recorded in the Nigeria Register of Dams prepared by the Federal Ministry of Water Resources and Rural Development, (FMWRRD, 1995); and also in Compendium of Nigerian Dams prepared by the Department of Dams and Reservoir Operations, Federal Ministry of Agriculture and Water Resources, (FMAWR, 2007). At the same time the new Zaria Waterworks was constructed with an initial designed capacity of 25,000 m^3/day. It was later upgraded to 50,000 m^3/day in order to complement an already existing Old Waterworks constructed in 1939 with a designed capacity of 4,500 m^3/day, whose draw-off system had been giving problem (WAPDECO 1990).

At impoundment in 1974, the dead storage of the Zaria Impounded Reservoir was 16,000,000 m^3, while the active storage was 29,800,000 m^3, (FMWRRD, 1995). Since its impoundment in 1974, part of the original storage has been lost to siltation. Nobody knew what this part was. Therefore, this paper sought to determine the remaining storage, rate of siltation, and the most probable date of disappearance of the Zaria Impounded Reservoir from the map, if measures aimed at reducing erosion are not taken.

Generally, two methods are employed in the determination of remaining storage – direct and indirect methods. The direct method, employed in this study involves obtaining field measurements directly using metric tape, a heavy weight and a slow moving boat, have previously been applied elsewhere: Iguisi (1997); Ahmadu Bello University Committee on Protection of Kubani Dam Drainage Basin (2008); and Baba *et al*. (2009). Dada (2009) carried out measurements of the remaining depth at the Zaria Impounded reservoir, however the measurement did not cover the entire dam.

The Study Area

Zaria dam is located on the Crystalline Hydrogeological Province of northern Nigeria, within the Guinea Savannah belt. The study area, Zaria Impounded Reservoir, is located at $11^0 08'$N, and $7^0 45'$E on 102 Zaria SW, Federal Surveys 1:50,000 Series Topographical Sheet, upon the Galma River, near Shika village, within the upper Galma River Drainage Basin as shown in Figure 1. This basin is one of the sub-basins of the River Kaduna Basin, itself being a sub-basin of the river Niger

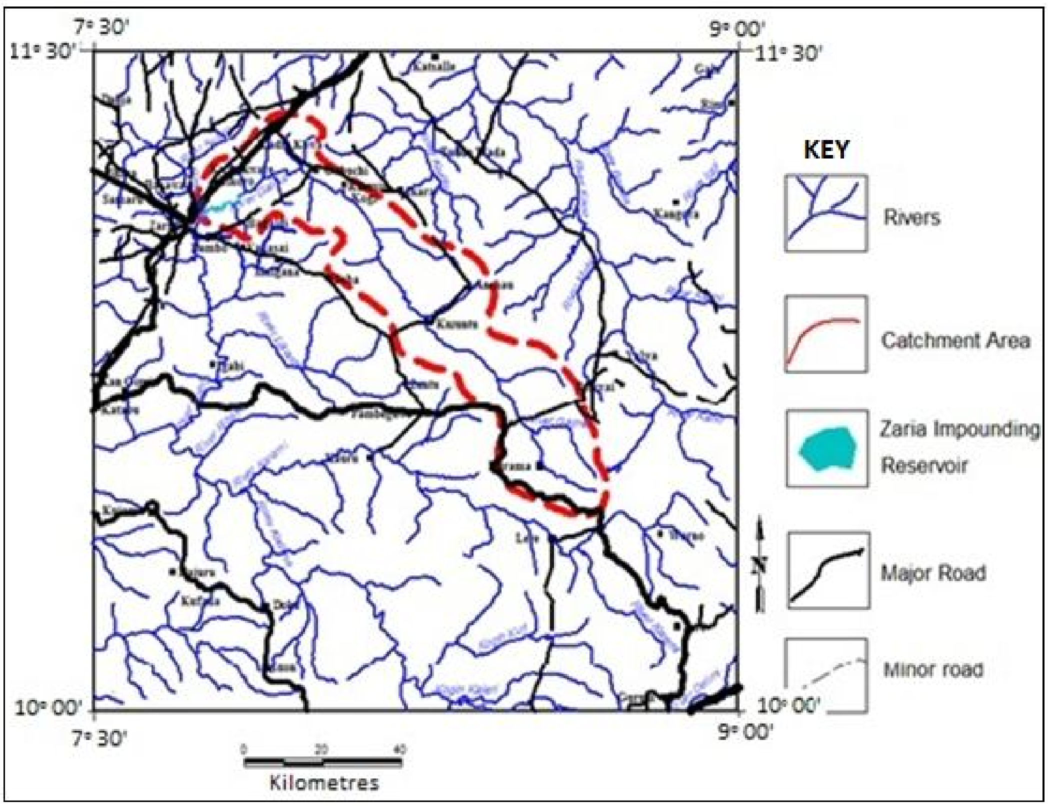

Figure 1: Location of the study area within the Upper Galma River Drainage Basin.

Methodology

Data on delineation of edge of the open water table with satellite navigator (GPS) at the time of spillway flowing, measurement of remaining depth of the impounded reservoir from a boat with measuring tape, satellite navigator and a heavy object were obtained through field measurements by the authors. Measurements were carried out at the time when the reservoir has a maximum storage capacity (between 20th October to 6th November, 2010), towards the end of rainy season.

Edge of the open water-table was located in the field with a satellite navigator (GPS). For the depth measurement, irregular network of points was used. This was done from a fishing boat using a measuring tape with a heavy weight tied to its end. This is the remaining depth, measured in metres at that particular station point. The same procedure was repeated for all sampling points randomly selected but closely spaced, within the extent of the reservoir surface in order to determine the depth of the lake at each respective point. Depth measurements already taken from each station points are then located on an already prepared map to scale 1:25,000. Isobaths were interpolated between the depth points.

The area bounded by the water body was then measured by the least square method. Paper contracts during the dry season and expands during the wet season, and so in order to avoid error in area, correction for the graph paper must be carried out. Thus, the area calculated, which is enclosed between successive isobaths is then multiplied by the average depth obtained.

Results and Discussions

Data from the measurements carried out to determine depth of the impounded reservoir is shown in the Table 1 below carried out between 20th October, 2010 to 4th November, 2010.

Table 1: Depth measurement in Zaria Impounded Reservoir from a boat and located with a satellite navigator.

Points	Latitude (N)	Longitude (E)	Elevation of water, masl	Depth below level of spillway (m)
1	11°08'07.0"	07°45'37.1"	620	1.69
2	11°08'06.5"	07°45'37.3"	619	3.04
3	11°08'05.4"	07°45'37.5"	620	3.34
4	11°08'04.8"	07°45'37.9"	620	5.24
5	11°08'02.9"	07°45'38.5"	620	5.99
6	11°08'00.8"	07°45'39.5"	619	4.31
7	11°07'58.5"	07°45'39.9"	620	2.54
8	11°07'57.0"	07°45'40.0"	620	1.89
9	11°07'55.5"	07°45'40.3"	620	1.94
10	11°07'53.8"	07°45'39.3"	620	1.59
11	11°07'55.8"	07°45'42.6"	622	1.89
12	11°07'56.7"	07°45'43.4"	622	1.74
13	11°07'57.2"	07°45'44.3"	621	1.99
14	11°07'59.1"	07°45'44.8"	621	1.44
15	11°08'00.3"	07°45'44.4"	621	3.51
16	11°08'01.6"	07°45'44.5"	620	4.69
17	11°08'02.5"	07°45'45.3"	619	7.09
18	11°08'04.0"	07°45'45.9"	617	4.99
19	11°08'05.2"	07°45'47.1"	615	5.09
20	11°08'06.7"	07°45'48.4"	615	4.69
21	11°08'10.2"	07°45'49.6"	616	2.09
22	11°08'10.2"	07°45'49.9"	618	2.04
23	11°08'08.7"	07°45'51.0"	620	2.59
24	11°08'06.8"	07°45'52.1"	620	4.54
25	11°08'05.3"	07°45'52.9"	620	7.94
26	11°08'03.9"	07°45'53.4"	621	6.24
27	11°08'02.3"	07°45'53.7"	621	3.99
28	11°08'01.5"	07°45'54.2"	621	2.46
29	11°08'02.2"	07°45'55.9"	621	3.79
30	11°08'01.0"	07°45'54.0"	621	1.89
31	11°08'01.2"	07°46'02.7"	622	1.96
32	11°08'03.5"	07°45'57.3"	621	5.22
33	11°08'05.4"	07°45'58.3"	618	5.49

34	11°08'07.4"	07°45'58.8"	619	8.59
35	11°08'08.4"	07°45'59.2"	620	2.99
36	11°08'10.9"	07°45'59.9"	621	2.34
37	11°08'10.2"	07°46'01.7"	621	2.89
38	11°08'12.9"	07°45'56.5"	622	1.75
39	11°08'13.9"	07°46'02.2"	620	2.33
40	11°08'09.3"	07°46'02.9"	621	2.34
41	11°08'08.5"	07°46'04.7"	622	7.89
42	11°08'07.5"	07°46'06.5"	625	6.79
43	11°08'05.9"	07°46'08.2"	625	5.84
44	11°08'04.6"	07°46'09.6"	624	8.34
45	11°08'02.5"	07°46'11.3"	624	6.94
46	11°08'01.4"	07°46'12.5"	624	2.54
47	11°08'02.2"	07°46'13.9"	624	3.99
48	11°08'01.0"	07°46'21.0"	625	1.97
49	11°08'04.9"	07°46'16.3"	625	5.29
50	11°08'06.4"	07°46'18.6"	626	6.49
51	11°08'07.7"	07°46'19.8"	624	5.49
52	11°08'09.1"	07°46'20.9"	622	4.19
53	11°08'08.3"	07°46'12.4"	623	6.03
54	11°08'13.5"	07°46'09.7"	624	2.51
55	11°08'16.8"	07°46'05.5"	624	2.77
56	11°08'21.6"	07°46'04.7"	625	1.26
57	11°08'19.8"	07°46'11.7"	625	1.41
58	11°08'11.6"	07°46'17.8"	624	1.94
59	11°08'13.6"	07°46'17.8"	623	3.89
60	11°08'14.7"	07°46'25.5"	622	4.24
61	11°08'11.2"	07°46'22.7"	622	4.74
62	11°08'07.2"	07° 46' 28.5"	622	4.21
63	11°08'01.2"	07°46'27.5"	624	3.12
64	11°07'58.1"	07°46'27.2"	624	1.61
65	11°07'57.5"	07°46'31.8"	624	1.83
66	11°08'08.0"	07°46'34.2"	625	1.60
67	11°08'13.1"	07°46'33.0"	622	4.02
68	11°08'18.0"	07°46'1.2"	622	3.96
69	11°08'16.8"	07°46'27.6"	620	4.19
70	11°08'19.1"	07°46'28.9"	625	4.69
71	11°08'20.2"	07°46'22.2"	624	2.11
72	11°08'23.9"	07°46'24.0"	625	1.72
73	11°08'20.9"	07°46'30.1"	625	5.14
74	11°08'22.8"	07°46'31.2"	625	3.09
75	11°08'23.8"	07°46'31.9"	625	2.54
76	11°08'23.8"	07°46'33.3"	625	3.89
77	11°08'23.8"	07°46'34.5"	624	4.04
78	11°08'23.9"	07°46'36.9"	624	3.34
79	11°08'27.7"	07°46'33.0"	624	3.82
80	11°08'32.0"	07°46'34.0"	624	1.98
81	11°08'30.0"	07°46'39.3"	624	2.61
82	11°08'33.9"	07°46'8.7"	624	3.24
83	11°08'24.0"	07°46'44.7"	623	6.89
84	11°08'24.0"	07°46'46.7"	623	3.99
85	11°08'22.8"	07°46'49.6"	623	2.24
86	11°08'27.4"	07°46'52.7"	620	2.39
87	11°08'33.9"	07°46'48.7"	621	2.41
88	11°08'35.6"	07°46'43.5"	620	1.35
89	11°08'30.0"	07°46'59.1"	620	1.62
90	11°08'33.2"	07°46'57.0"	621	2.33

91	11°08'37.5"	07°46'54.8"	618	2.31
92	11°08'43.0"	07°46'55.6"	621	2.19
93	11°08'45.1"	07°46'54.4"	620	2.00
94	11°08'45.6"	07°46'56.8"	621	0.76
95	11°08'42.4"	07°46'58.6"	621	4.04
96	11°08'40.3"	07°46'59.9"	621	2.27
97	11°08'42.6"	07°47'00.6"	621	2.12
98	11°08'45.1"	07°47'00.2"	620	3.32
99	11°08'47.6"	07°47'00.0"	620	2.39
100	11°08'49.1"	07°47'00.1"	621	1.74
101	11°08'50.8"	07°47'00.9"	619	2.24
102	11°08'4.7"	07°46'58.5"	621	1.86
103	11°08'52.5"	07°47'00.4"	620	2.27
104	11°08'55.0"	07°47'03.0"	620	2.34
105	11°08'56.5"	07°47'04.7"	621	2.44
106	11°09'0.4"	07°47'07.5"	623	2.40
107	11°09'03.8"	07°47'06.3"	623	1.84
108	11°08'03.7"	07°47'10.2"	620	2.21
109	11°09'08.2"	07°47'12.7"	620	2.24
110	11°09'04.0"	07°47'12.8"	621	2.34
111	11°09'04.6"	07°47'15.3"	621	1.94
112	11°09'02.0"	07°47'14.1"	621	2.24
113	11°09'02.2"	07°47'12.1"	621	2.74
114	11°08'59.8"	07°47'09.6"	621	3.04
115	11°08'57.0"	07°47'13.6"	621	2.94
116	11°08'55.6"	07°47'15.4"	621	2.44
117	11°08'52.3"	07°47'10.9"	622	3.24
118	11°08'46.0"	07°47'14.8"	621	3.94
119	11°08'43.7"	07°47'17.2"	620	2.04
120	11°08'46.4"	07°47'08.2"	621	4.24
121	11°08'45.0"	07°47'13.6"	621	3.40
122	11°08'43.8"	07°47'12.3"	623	2.24
123	11°08'47.3"	07°47'10.9"	621	2.04
124	11°08'41.2"	07°47'15.8"	621	2.04
125	11°08'39.4"	07°47'11.7"	622	5.54
126	11°08'37.8"	07°47'09.9"	621	2.24
127	11°08'35.8"	07°47'16.7"	621	1.84
128	11°08'35.0"	07°47'15.1"	621	7.14
129	11°08'33.6"	07°47'13.0"	620	2.09
130	11°08'33.5"	07°47'18.8"	621	1.79
131	11°08'29.4"	07°47'17.7"	617	2.44
132	11°08'26.8"	07°47'18.8"	617	1.64
133	11°08'26.5"	07°47'20.9"	619	1.84
134	11°08'24.9"	07°47'22.6"	619	1.94
135	11°08'22.0"	11°08'22.0"	619	4.84
136	11°08'19.5"	07°47'19.0"	618	1.12
137	11°08'19.7"	07°47'25.5"	618	1.34
138	11°08'22.3"	07°47'27.2"	618	1.74
139	11°08'23.3"	07°47'27.7"	618	2.04
140	11°08'24.4"	07°47'27.1"	618	3.94
141	11°08'23.8"	07°47'24.4"	619	5.34
142	11°08'25.4"	07°47'24.2"	619	1.94
143	11°08'25.8"	07°47'25.9"	618	4.84
144	11°08'27.6"	07°47'21.7"	620	2.44
145	11°08'24.3"	07°47'29.9"	618	3.24
146	11°08'30.7"	07°47'17.8"	620	7.54
147	11°08'29.5"	07°47'26.9"	617	3.44

148	11°08'29.3"	07°47'29.6"	618	4.14
149	11°08'31.0"	07°47'27.9"	619	3.34
150	11°08'33.0"	07°47'26.0"	619	1.31
151	11°08'40.1"	07°47'31.3"	618	3.44
152	11°08'43.2"	07°47'36.1"	619	2.54
153	11°08'48.5"	07°47'36.0"	620	3.84
154	11°08'53.5"	07°47'31.7"	620	0.41
155	11°08'50.6"	07°47'42.0"	620	0.92
156	11°08'42.12	07°47'49.7"	617	1.72
157	11°08'40.8"	07°47'48.1"	617	5.34
158	11°08'38.6"	07°47'46.3"	617	2.94
159	11°08'37.0"	07°47'44.5"	617	3.14
160	11°08'35.6"	07°47'43.1"	618	2.17
161	11°08'28.1"	07°47'37.3"	619	1.24
162	11°08'31.0"	07°47'47.6"	619	1.45
163	11°08'28.9"	07°47'52.0"	619	1.13
164	11°08'30.6"	07°47'55.6"	619	2.01
165	11°08'26.5"	07°48'00.6"	620	0.61
166	11°08'24.7"	07°47'55.6"	618	3.64
167	11°08'21.4"	07°47'55.7"	619	8.14
168	11°08'18.0"	07°47'52.5"	619	1.54
169	11°08'18.5"	07°47'59.5"	618	4.04
170	11°08'12.2"	07°48'02.9"	618	1.18
171	11°08'16.7"	07°48'05.5"	619	3.01
172	11°08'23.0"	07°48'11.9"	620	2.24
173	11°08'20.9"	07°48'19.0"	620	5.24
174	11°08'17.1"	07°48'16.3"	619	1.20
175	11°08'19.4"	07°48'25.1"	620	0.94
176	11°08'29.5"	07°48'22.4"	619	1.13
177	11°08'26.1"	07°48'16.6"	619	6.01
178	11°08'26.3"	07°48'11.9"	619	4.61
179	11°08'32.2"	07°48'11.7"	619	2.00
180	11°08'35.8"	07°48'15.4"	619	1.84
`181	11°08'38.5"	07°48'17.8"	619	6.24
182	11°08'44.7"	07°48'22.2"	619	1.92
183	11°08'48.5"	07° 48'23.5"	620	2.99
184	11°08'57.0"	07°48'19.2"	620	0.94
185	11°08'50.3"	07°48'28.3"	620	2.46
186	11°08'46.3"	07°48'33.1"	618	3.24
187	11°08'40.1"	07°48'34.3"	619	1.02
188	11°08'46.7"	07°48'37.6"	619	3.34
189	11°08'45.8"	07°48'45.1"	620	2.78
190	11°08'38.2"	07°48'51.1"	619	0.97
191	11°08'41.9"	07°48'50.8"	620	2.14
192	11°08'45.8"	07°48'54.9"	619	1.16
193	11°08'49.9"	07°48'42.7"	620	2.01
194	11°08'46.8"	07°48'57.7"	620	0.73
195	11°08'52.9"	07°48'43.7"	620	3.99
196	11°08'56.4"	07°48'52.7"	620	2.34
197	11°08'58.9"	07°48'48.5"	620	4.74
198	11°08'36.9"	07°48'57.0"	618	4.63
199	11°08'58.3"	07°48'29.5"	618	3.74
200	11°08'56.8"	07°48'45.7"	620	2.41
201	11°09'08.0"	07°48'34.8"	620	3.97
202	11°09'02.2"	07°48'46.7"	617	4.44
203	11°09'04.8"	07°48'52.2"	619	2.09
204	11°09'07.5"	07°48'53.5"	620	3.69

205	11°09'11.5"	7°49'58.2"	620	0.77
206	11°09'11.3"	07°48'51.1"	620	2.37
207	11°09'13.5"	07°48'51.4"	617	1.94
208	11°09'14.0"	07°48'39.0"	617	1.40
209	11°09'13.0"	07°48'29.8"	619	0.81
210	11°09'19.7"	07°48'38.5"	618	0.96
211	11°09'21.0"	07°48'49.1"	617	2.84
212	11°09'17.8"	07°48'50.6"	617	2.64
213	11°09'13.0"	07°49'05.5"	618	2.04
214	11°09'16.0"	07°49'07.0"	620	0.93
215	11°09'17.1"	07°48'58.6"	618	1.33
216	11°09'19.7"	07°49'02.9"	618	3.81
217	11°09'23.4"	07°48'58.1"	618	4.19
218	11°09'26.6"	07°48'53.3"	616	4.04
219	11°09'24.4"	07°48'47.3"	618	4.24
220	11°09'18.3"	07°48'44.4"	619	1.95
221	11°09'27.3"	07°48'45.8"	617	2.09
222	11°09'28.1"	07°48'50.9"	617	3.84
223	11°09'31.7"	07°48'52.5"	620	0.95
224	11°09'34.8"	07°48'58.7"	618	3.64
225	11°09'34.8"	07°49'02.6"	618	2.69
226	11°09'34.1"	07°49'05.7"	618	1.34
227	11°09'26.1"	07°49'10.0"	617	3.04
228	11°09'22.0"	07°49'15.5"	617	3.04
229	11°09'20.2"	07°49'17.4"	617	1.74
230	11°09'23.3"	7°49'17.5"	618	4.11
231	11°09'24.1"	07°49'13.0"	618	3.39
232	11°09'24.1"	07°49'26.4"	618	3.11
233	11°09'27.4"	07°49'16.1"	618	2.11
234	11°09'30.1"	07°49'15.6"	618	2.74
235	11°09'32.8"	07°49'13.8"	619	4.34
236	11°09'35.3"	07°49'17.3"	619	2.04
237	11°09'34.0"	07°49'09.7"	618	2.54
238	11°09'42.0"	07°49'07.5"	618	4.04
239	11°09'44.8"	07°49'18.0"	620	0.84
240	11°09'41.2"	07°49'20.0"	618	6.03
241	11°09'32.2"	07°49'25.6"	618	1.54
242	11°09'33.0"	07°49'28.2"	618	1.59
243	11°09'28.6"	07°49'31.6"	620	2.00
244	11°09'25.3"	07°49'31.5"	617	0.54
245	11°09'28.5"	07°49'37.1"	617	0.54
246	11°09'30.5"	07°49'34.6"	620	1.74
247	11°09'34.7"	07°49'29.2"	618	3.68
248	11°09'48.0"	07°49'28.1"	620	0.67
249	11°09'43.5"	07°49'30.0"	620	4.17
250	11°09'36.2"	07°49'35.9"	620	6.24
251	11°09'37.2"	07°49'42.8"	620	1.44
252	11°09'36.4"	07°49'38.9"	620	2.04
253	11°09'32.7"	07°49'45.8"	618	2.94
254	11°09'48.0"	07°49'27.0"	618	4.04
255	11°09'22.6"	07°49'47.6"	617	5.24
256	11°09'20.0"	07°49'53.2"	617	2.68
257	11°09'15.8"	07°49'46.7"	619	0.88
258	11°10'14.1"	07°50'57.3"	619	0.91
259	11°09'18.9"	07°49'59.8"	617	1.44
260	11°09'19.0"	07°50'05.5"	617	5.44
261	11°09'23.2"	07°50'01.2"	617	1.84

262	11°09'25.6"	07°49'58.3"	617	2.52
263	11°09'28.5"	07°49'55.5"	617	2.81
264	11°09'29.2"	07°49'51.1"	617	1.41
265	11°09'29.6"	07°49'59.0"	619	0.49
266	11°09'29.6"	07°50'02.0"	619	0.61
267	11°09'24.7"	07°50'05.2"	617	1.54
268	11°09'22.0"	07°50'09.8"	617	1.59
269	11°09'20.1"	07°50'10.1"	617	2.34
270	11°09'20.1"	07°50'17.9"	617	1.30
271	11°09'20.5"	07°50'25.2"	617	1.25
272	11°09'19.3"	07°50'31.0"	617	1.17
273	11°09'24.8"	07°50'17.5"	616	6.34
374	11°09'26.1"	07°50'14.4"	617	2.54
275	11°09'28.7"	07°50'16.2"	619	0.96
276	11°09'26.0"	07°50'31.0"	619	1.11
277	11°09'23.1"	07°50'32.7"	617	4.84
278	11°09'19.0"	07°50'37.0"	619	1.45
279	11°09'20.4"	07°50'39.0"	617	5.74
280	11°09'21.6"	07°50'42.8"	618	0.72
281	11°09'16.7"	07°50'44.8"	617	2.32
282	11°09'18.1"	07°50'49.9"	619	1.21
283	11°09'13.9"	07°50'51.4"	619	1.45
284	11°09'16.7"	07°50'57.0"	620	0.51
285	11°09'20.5"	07°50'53.2"	617	2.21
286	11°09'21.5"	07°50'54.7"	617	4.87
287	11°09'26.1"	07°50'55.6"	617	2.14
288	11°09'29.0"	07°50'49.0"	619	0.92
289	11°09'31.6"	07°50'55.4"	619	0.57
290	11°09'36.4"	07°50'50.7"	617	5.54
291	11°09'42.0"	07°50'49.2"	620	0.70
292	11°09'44.4"	07°50'49.5"	617	1.91
293	11°09'47.6"	07°50'49.7"	617	5.34
294	11°09'56.8"	07°50'49.3"	617	1.59
295	11°10'02.1"	07°50'50.0"	620	0.69
296	11°10' 07.2"	07°50'55.5"	619	1.21
297	11°10'09.7"	07°50'51.7"	618	2.54
298	11°10'13.8"	07°50'57.0"	620	0.92
299	11°10'16.2"	07°50'54.0"	620	0.70
300	11°10'16.1"	07°51'06.3"	618	2.54
301	11°10'20.0"	07°51'11.7"	617	5.44
302	11°10'22.8"	07°51'10.2"	619	1.64
303	11°10'22.9"	07°51'17.5"	618	2.84
304	11°10'24.3"	07°51'18.7"	617	5.41
305	11°10'25.9"	07°51'17.0"	619	0.96
306	11°10'20.8"	07°51'15.0"	619	0.97

The present surface area, average depth and remaining storage volume for the Zaria Impounded Reservoir as at year 2010, in which measurements were carried out and presented below are derived from the map in Figure 2. The result is thus summarized in Table 2 below. Note that the year 2010 average weighted depth of the reservoir from measurement carried out is 2.82 metres below the level of the spillway.

The remaining storage for the Zaria Impounded Reservoir using field technique at the time the spillway is flowing, was thus determined as 21,129,242 m^3 or (21,129,242 m^3 ÷ 45,800,000 m^3) × 100 percent = 46 percent of the original total storage from its date of impoundment in 1974, and this is the same as present total storage.

Table 2: Results of measurements of the remaining storage (done on paper in figure 2, by least square method).

Depth interval below spillway (m).	Area of depth interval (m^2).	Average depth of water (m).	Volume of water (m^3).
0 – 2	2,404,892	1.0	2,404,892
2 – 4	3,751,401	3.0	11,254,203
4 – 6	935,449	5.0	4,677,245
6 – 8	389,931	7.0	2,729,517
> 8	7,683	> 8.25	63,385
Total	**7,489,356**	**2.82**	**21,129,242**

With the present remaining storage of 21, 129,242 m^3, and when compared to the original total storage of 45,800,000 m^3, it can thus be concluded that the reservoir capacity has been lost over the years due to its gradual siltation. Since according to Jain and Singh, (2002); Brooks *et al.*, (2003); and Ahmadu Bello University Committee on Protection of Kubani Dam Drainage Basin, (2008); sediments settle in the reservoir and reduces its storage capacity. Therefore, this implies that a total of 45,800,000 m^3 - 21,129,242 m^3 = 24,670,758 m^3 of the original storage capacity have been silted right from the date of impoundment of the dam since 1974. The volume lost to siltation amounts to (24,670,758 m^3 ÷ 45,800,000 m^3) × 100 percent = 54 percent of the original storage volume. It therefore means that 24,670,758 m^3 of sediment materials have continuously been eroded, transported and deposited into the impounded reservoir from within its drainage basin during its 36 years of existence.

So, the rate of siltation, which is the same as rate of bed load deposition for the Zaria Impounded Reservoir is 24,670,758 m^3 ÷ 36 years = 685,299 m^3/year. This is the volume of materials which settles and is deposited at the reservoir's bottom. It corresponds to a percentage annual loss of original total storage due to the bed load siltation of (685,299 m^3/year ÷ 45,800,000 m^3) × 100 percent = 1.5 percent per year. Therefore the implication of the above is, that if measures aimed at reducing erosion within the Galma Drainage Basin is not taken, the Zaria Impounded Reservoir will be completely silted up in 45,800,000 m^3 ÷ 685,299 m^3/year = 67 years from the date of impoundment (year 1974 + 67 years = year 2041) or alternatively, 21,129,242 m^3 ÷ 685,299 m^3/year = 31 years from year 2010. Hence, the predicted date of the final disappearance of the Zaria Impounded reservoir from the map due to its complete siltation is year 2041, which is 31 years from now.

It has already been shown that there is no more dead storage remaining (dead storage is equal to zero) by year 2010 and also that the active storage has been silted by 8,670,758 m^3. Therefore with the rate of siltation estimated as 685,299 m^3/year for the Zaria Impounded Reservoir, it then implies that siltation of the active storage had already started about 8,670,758 m^3 ÷ 685,299 m^3/year = 13 years ago. This further means that siltation of the active storage started by year 2010 - 13 years = year 1997, about 23 years after impoundment of the reservoir.

The rate of erosion in the drainage basin, upstream from embankment of the Zaria Impounded Reservoir was calculated on the assumption that the sum of bottom load, suspended load and dissolved load is equal to the weight of material removed by erosion from the drainage basin. First, area of the drainage basin was measured on the topographical map of scale 1:1,000,000 as 3,242 km^2. Then, total run-off – surface runoff and the base flow – in the drainage basin was calculated from the average depth of rainfall at the Institute of Agricultural Research (I. A. R.) meteorological station, Samaru, and total run-off coefficient corresponding to this depth of rainfall from Schoeneich and Lawal, (2010).

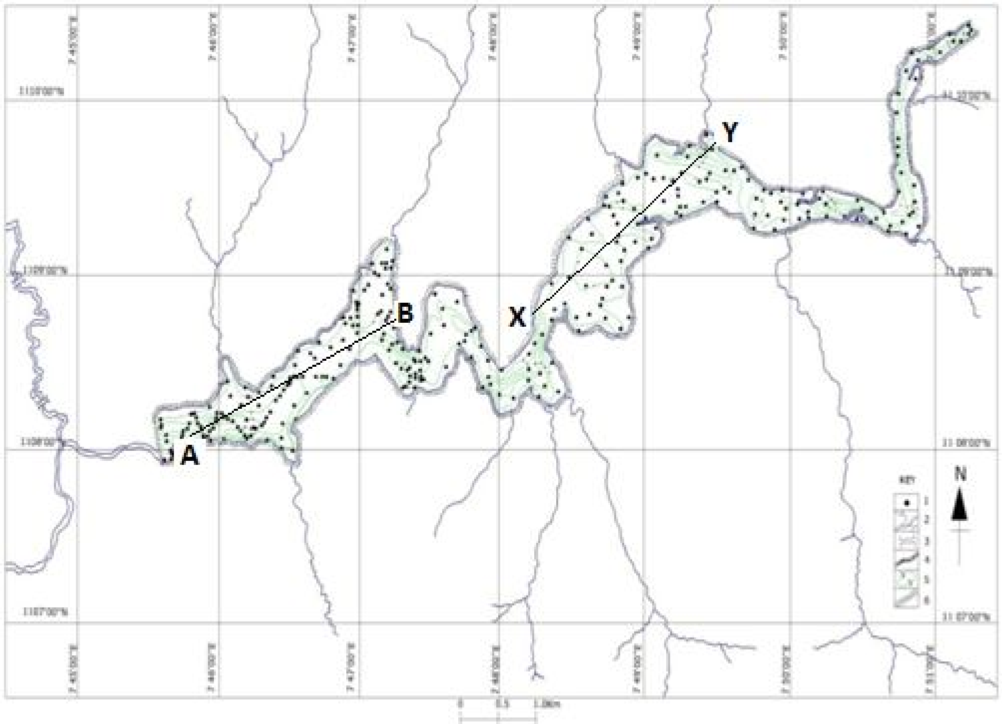

Figure 3: Bathymetric map showing remaining depth of the Zaria Impounded Reservoir. Explanations: 1- Points of depth measurement. 2- Rivers. 3- Bridge and/culvert. 4- Boundary of the impounded reservoir. 5- Isobaths. 6- Dam crest.

Thus, volume of total run-off, or, the same, volume of water entering the drainage basin is 3,242,000,000 m^2 x 1.053 m/year x 0.24 = 819,629,470 m^3/year. Having bed load calculated earlier as 685,299 m^3/year, the third step taken was to calculate suspended load. With average concentration in the rainy season of total suspended solids (TSS) in water as TSS = 500 mg/l, the weight of suspended load entering the reservoir in wet season, or the same as weight of suspended load removed from the drainage basin is 819,629,470,000 litres x 500 mg/litres = 409,814 tonnes of suspended clayey material, most of it flowing through the spillway. Since density of wet, plastic clay is 2.0 tonnes per cubic metres, then volume of clay removed by erosion from the drainage basin during one year, to form suspended load, is 409,814 tonnes/year ÷ 2 tonnes/m^3 = 204,907 m^3/year, The last, fourth step it was to calculate volume of the dissolved load. Total dissolved solids in water on the Crystalline Hydrogeological Province are on average TDS = 80 mg/l while density of salt is 2.22 g/cm^3. Then the volume of dissolved load entering every year Zaria Impounded Reservoir is 819,629,470 m^3 x 80 kg/m^3 ÷ 2.220 kg/m^3 = 29,536 m^3/year.

A profile of the section across the lower part of the reservoir closer to the dam crest indicates the deepest points; see Figure 4(i). Thus, despite the siltation, portion of the reservoir closer to the dam crest still store water much to a depth of 0 – 8 metres. However, the middle part of the reservoir shows that it has suffered significant siltation centrally with depth between 0 – 4 metres (Figure 4(ii) below).

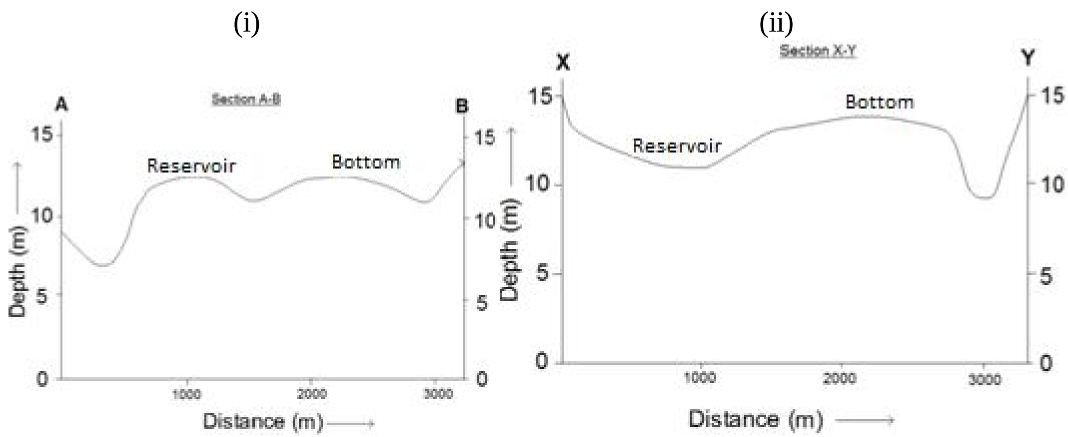

Figure 4: Cross-section along profiles A-B and profiles X-Y across the Zaria Impounded Reservoir.

Thus, the total volume of earth material removed by erosion in the drainage basin upstream of embankment of Zaria Impounded Reservoir, entering the reservoir as bed load, suspended load and dissolved load, is 685,299 m^3/year + 204,907 m^3/year + 29,536 m^3/year = 919,742 m^3/year. The depth of erosion is equal to the volume of the eroded material divided by area of the drainage basin: 919,742 m^3/year ÷ 3,242,000,000 m^2 = 0.000283696 m/year or 0.28 mm/year.

Conclusions

Knowledge of the remaining depth has proven to be a viable tool in determination the remaining storage, and subsequently the rate of siltation within the Zaria impounding reservoir. This was achieved through the bathymetric technique. It was found that the year 2010 storage capacity of the Zaria Impounding Reservoir is 21,129,242 m^3, or about 46 percent of the original storage. It was also found that the average rate of siltation between years 1974 and 2010 was 685,299 m^3/year or 1.5 percent per year of the original storage. Additionally, rate of erosion depth in the drainage basin has been calculated as 0.28 mm/year. By year 2041 the reservoir will be completely silted up if preventive measures are not taken.

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