Problems of sedimentation in small dams in Zambia

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Abstract An inventory of small dams in Zambia and the results of a preliminary analysis of sediment loads for rivers and reservoirs are reported. A regression approach was used to determine relationships between drainage area and sediment load for 21 rivers based on available sediment concentration and discharge data. The resulting regression equation was applied to the drainage areas of 66 small dams located in Southern Province and rates of sediment input to the reservoirs were computed. By assuming 95% trap efficiency for sediment by the dams, the expected useful life of the reservoirs was also calculated. Calculated annual rates of sedimentation in small dams were found to range from 2 to 183 m^3 $year^{-1}$ with a mean of 24.6 m^3 $year^{-1}$. The estimates of reservoir useful life ranged from 200 tp 5100 years with a mean of 7314 years. Anthropogenic factors contributing to sediment generation and sedimentation in reservoirs, community participation in dam construction and rehabilitation efforts together with conservation measures embarked on in the country are discussed. Qualitatively, it is concluded that sedimentation in the dams of Southern Province is serious. This calls for detailed quantitative research to assess the problem and to find ways of minimizing adverse impacts of soil erosion on environment and society.

INTRODUCTION

The increased frequency of drought since 1980 has encouraged the construction of small dams in Zambia and 250 to 300 small rural dams were planned to be constructed during the period 1988-1994 (Morris, 1991). Field observations undertaken by the Department of Agriculture indicate that many small dams have lost considerable storage capacity due to sedimentation. However, no measurements of rates of sedimentation in dams currently exist. The only known study of siltation in Zambian rivers is probably that conducted by Cleak (1935). Undoubtedly, a number of dams constructed in the country have been filled with sediment to varying degrees (Fig. 1(a)). In Zambia, assessments of sedimentation in dams appear to be undertaken only at the planning stage. For instance, Roberts *et al.* (1961) estimated that siltation rates in reservoirs on the Nangoma River were 0.3% of the total volume of discharge. JICA (1995) found sediment inputs into planned dams in the upper Kafue River basin to be 0.3% of total discharge per year, giving a reservoir useful life of 300 years which suggested that sedimentation was not a problem. In other countries, more thorough investigations of this problem have been undertaken (cf. Lahlou, 1996; Lajczak, 1996; Christiansson, 1981).

In Zambia, erosion of agricultural lands has been of concern since the 1930s and this has resulted in the introduction of conservation measures. This study which forms part of an on-going research project on Zambian rivers based in the

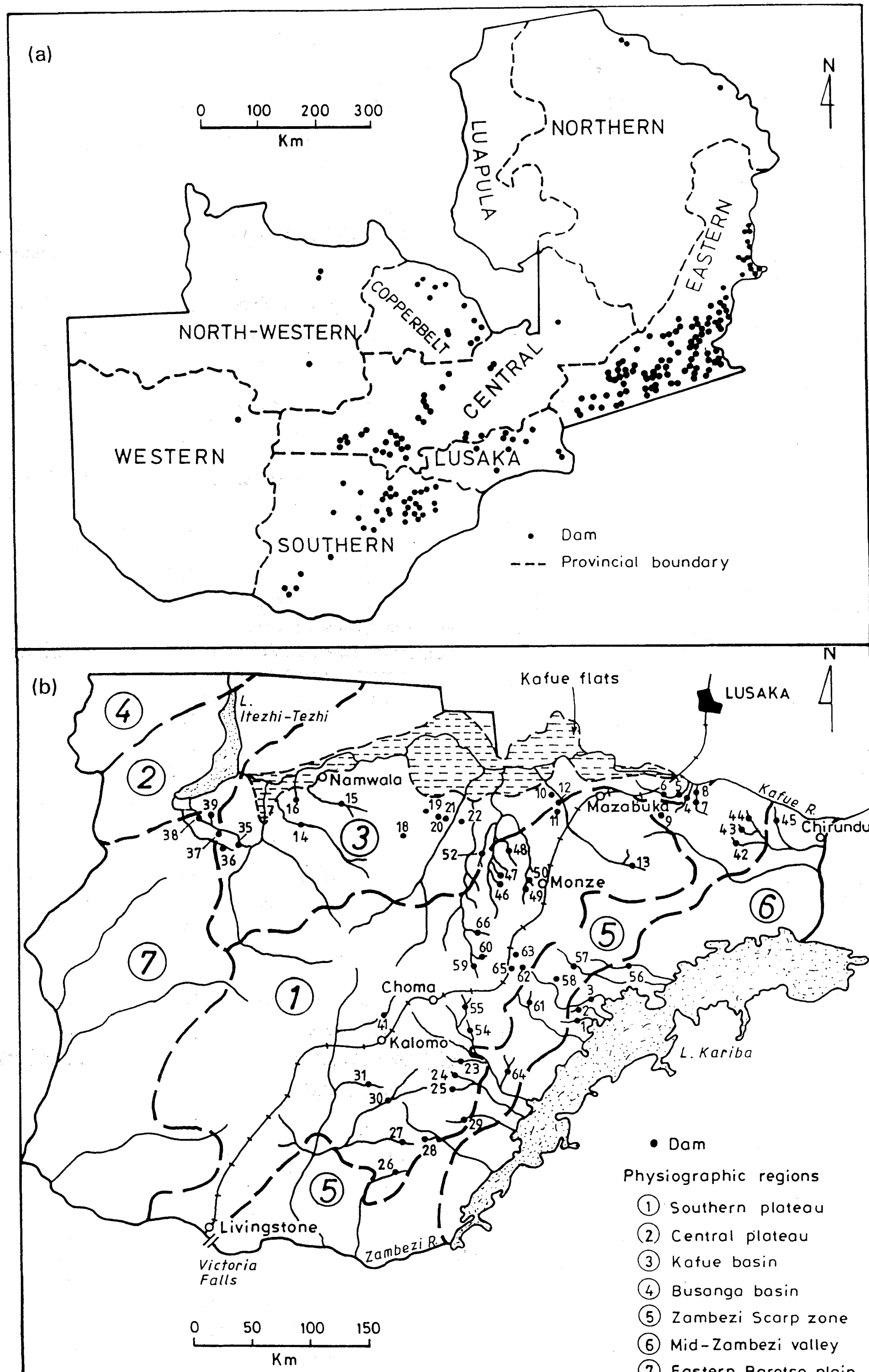

Fig. 1 The spatial distribution of (a) old small dams by provinces, and (b) new dams constructed between 1988 and 1994 in Southern Province, Zambia.

Department of Geography at the University of Zambia, has conducted an inventory of dams and reports preliminary analyses of the sediment loads of the rivers. The objectives were: (a) to determine the spatial distribution of small dams and (b) to estimate rates of sediment input to the dams and the expected useful life of the reservoirs.

STUDY AREA

Zambia with an area of 752 620 km^2 is located in the southern African tropics and experiences a seasonal climate with distinct dry (May-October) and wet (November-April) periods. Mean annual rainfall increases northwards, ranging from 717 mm in the southwest to over 1400 mm in the north. Elevations range from about 300 m in the mid-Zambezi Valley to 1800 m in the Mafinga Mountains in the northeast.

Detailed analysis of erosion and sedimentation in small dams, was conducted for Southern Province which has an area of 85 280 km^2. This region is characterized by an elevated plateau downwarped into a shallow faulted trough around the Kafue Flats and down-faulted to the south into the rift trough of the mid-Zambezi Valley (Williams, 1978) (Fig. 1(b)). Geologically, it is underlain by metamorphic pre-Cambrian basement rocks intruded by granites, Karroo (Permian-Triassic) sedimentary and basalt rocks, Pleistocene deposits, ferricrete and alluvium (Money, 1978). Sandveldt soils cover most of the plateau, while hydromorphic soils are found in dambos, swamps and flood plains (Brammer, 1976). Rock outcrops and regolith, valley and podzolitic soils are found in the Zambezi escarpment zone where the relief is high. The plateaux and escarpments are covered by open miombo woodland, while in the low-lying Zambezi Valley mopane woodland vegetation is found and acacia species dominate in the west and southwest areas covered by Kalahari Sands.

DATA

Information on the number, size and location of dams was obtained from the Department of Agriculture. Further information on the status of some of the dams was obtained from limited field observations and interviews with people who had lived in the areas where dams are found. Unpublished sediment concentration data were obtained from the Department of Water Affairs, while discharge data were obtained from Water Affairs (1982) and JICA (1995). By about 1991 there were at least 537 small dams in the country (Fig. 1(a)). With the exception of the dams constructed for drought relief during the period 1988-1994 in Southern Province, detailed information on other dams was difficult to obtain from district and provincial offices.

METHODS AND RESULTS

Mean annual sediment loads expressed in tonnes were determined as the product of mean sediment concentration and mean discharge for 21 stream gauging stations. Equation (1) shown below and based on log-log regression analysis indicated that

Table 1 Estimated suspended sediment deposition and useful life of new small reservoirs in Southern Province, Zambia.

No.	Name of dam	Drainage area (km^2)	Capacity (10^3 m^3)	Sedimentation (m^3 year^{-1})	Useful life (10^3 years)
	Masopu	3.30	94	6.45	14.6
54	Syakenku	5.60	72	10.94	6.6
55	Ziyani	2.50	27	4.89	5.5
56	Hamaundu	1.29	99	2.52	39.3
61	Mudenda	1.65	64	3.22	19.9
57	Kakumba	2.15	81	4.20	19.3
58	Siacholobwe	3.95	65	7.72	8.4
	Mutandalike	81.50	86	159.3	0.5
62	Ndondi	12.40	120	24.2	5.0
59	Chigaba	34.00	132	66.5	2.0
	Kasyongo	4.63	112	9.05	12.4
63	Cheelo	2.30	70	4.49	15.6
60	Nachibanga	13.50	186	26.38	7.1
65	Hamitebe	3.22	14	6.29	2.2
64	Simuleya	1.18	58	2.31	25.2
66	Simundima	4.00	142	7.82	18.2
	Sibusenga	9.10	80	17.8	4.5
	Maunga	2.91	40	5.7	7.0
	Nakempa	80.01	31	156.4	0.2
1	Siabunga	6.30	218	12.3	17.7
2	Lukuzu	13.00	40	25.4	1.6
3	Chizilo	15.00	49	29.3	1.7
42	Bakasa	14.00	49	27.4	1.8
43	Njami	6.00	298	11.7	25.4
44	Chirundu	3.00	40	5.9	6.8
45	Nyanzara	6.00	99	11.7	8.4
35	Chikanta	10.10	40	19.7	2.0
36	Simakanta	12.00	326	23.5	13.9
37	Shabulule	12.50	18	24.4	0.7
38	Malama	6.25	78	12.2	6.4
39	Hamanga	15.55	78	30.4	2.6
30	Kabanga	6.25	28	12.2	2.3
31	Sikotwe	11.25	55	22.0	2.5
26	Siamutu	7.50	72	14.7	4.9
27	Siamafumba	14.74	48	28.8	1.7
28	Nkungwe	14.73	45	28.8	1.6
29	Kabembe	37.50	27	73.3	0.4
25	Kanchele	6.88	75	13.4	5.6
24	Mundi	8.76	60	17.1	3.5
23	Nakabanga	6.25	105	12.2	8.6
41	Kalomo Sch.	9.95	121	19.5	6.2
4	Shikwela	10.63	34	20.8	1.6
5	Kasengo	21.25	73	41.5	1.8
6	Naluama N3	14.22	29	27.8	1.0
7	Nansenga	5.60	5	11.0	0.5
8	Dombwi	5.03	18	9.82	1.8
9	Naluama NA4	12.50	5	24.4	0.2
11	Simwaba	4.15	5	8.11	0.6
12	Munenga	6.98	9	13.64	0.7
	Magoye S	1.03	30	2.00	15.0
13	Ngwezi	1.03	22	2.00	11.0
46	Moowa	10.93	15	21.4	0.7
47	Kamwi	6.43	15	12.6	1.2
48	Choobana	1.65	21	3.2	6.5
49	Siamafwa	17.80	46	34.8	1.3
50	Ngoma	3.75	50	7.33	6.8
52	Kase 'A'	2.03	8	3.97	2.0
14	Izovwe	21.25	57	41.5	1.4
15	Kahuma	12.50	50	24.4	2.0
16	Makuzu	9.38	207	18.3	11.3
18	Namayovu	2.69	268	5.25	51.0
19	Muchila	17.50	48	34.2	1.4
20	Chidakwa	93.75	327	183.2	1.8
21	Sibabwa	10.00	14	19.5	0.7
22	Mpinda	12.50	288	24.4	11.8
	Syanyoola	12.50	218	24.4	8.9

Numbered dams are shown in Fig. 1(b).

drainage area explained 75% of the variation in mean annual sediment loads at the 99% level of significance.

$$Y = 2.0572A^{1.077} \qquad n = 21, \qquad r^2 = 0.751, \qquad P = 0.0001 \qquad (1)$$

This equation was applied to the drainage areas of 66 small dams mostly constructed between 1988 and 1994 and the sediment yields and deposition rates were estimated (Hudson, 1971) (Table 1). By assuming a 95% trap efficiency (JICA, 1995) of sediment by the dams and a bulk density of 1000 kg m^{-3} for the sediment deposited in the reservoirs, a simple index of the expected useful life of the reservoirs was also computed as reservoir capacity divided by annual sedimentation rates. The estimates of the suspended sediment loads of streams draining into the dams were found to range from 2.11 to 192.86 t $year^{-1}$ while the useful life of the reservoirs ranged from 200 to 5100 years with a mean of 7314 years. Lack of information on completion dates of construction and the unknown status of sedimentation in the dams listed in Table 2 precluded computation of loss of reservoir capacity.

DISCUSSION

The regression method tends to underestimate the sediment yields of very small drainage basins and such underestimates result in longer expected lives for the reservoirs. Consequently the estimates of useful life for the small dams in Southern Province differ from the results of studies in comparable drainage basins in Africa. For example, Christiansson (1981) indicates that reservoirs with drainage basins sizes ranging from 2.2 to 612 km^2 in semiarid parts of Tanzania have a useful life of 30 to 130 years. In Southern Province, the low rates of sedimentation in dams may be accounted for by the low relief and low population density of 11.1 persons per km^2 (Hampwaye *et al.*, 1995).

Soil erosion has long been recognized as a problem in Zambia due to the long history of sedentary agriculture and the large herds of cattle kept by local people. In Southern Province, 79.9% of the population live in rural areas and both cattle and the human population have similar distribution patterns, largely because all humans aspire to own cattle. Of the 5.2 million head of cattle owned in the country 1.8 million or 35%, are found in Southern Province (Central Statistical Office, 1994a).

Table 2 Dams and indices of pressure on land in Southern Province.

District	No. of dams[a]	Cattle population[a]	Human population[b]	Cultivated area in 1990 (ha)[b]
Monze	117	250 187	157 451	17 190
Kalomo	113	192 078	154 875	43 049
Choma	112	189 836	164 387	34 235
Namwala	42	171 017	83 416	16 404
Mazabuka	10	154 491	157 531	44 594
Gwembe	10	101 729	144 384	26 371
Livingstone	1	55 471	84 116	1 168
Total	293	1 114 809		183 011

[a] Morris (1991a, p.3 and 5);
[b] Central Statistical Office (1994a,b).

Morris (1991) reports that the highest cattle populations are found in Monze and Kalomo districts, which also experienced the greatest human distress and greatest environmental destruction during the recent droughts. Considering that in 1990 a total of 1830 km^2 of land was under cultivation in Southern Province and therefore at high risk of sheet and rill erosion, it is probably not by chance that the worst eroded areas were found in the Monze and Kalomo districts (Morris, 1991).

The above discussion suggests that although there are no data on soil erosion, sedimentation in dams of Southern Province could be a serious problem. The problem of lack of data on dams and rivers in Zambia appears to emanate from the success of soil conservation measures undertaken prior to 1974 and the impression created among leaders that erosion and sedimentation did not merit detailed investigation.

Soil conservation measures

Soil conservation measures were introduced in Zambia in the 1930s due to erosion partly caused by the allocation of good arable land for European settlement and the indigenous people being confined to Reserves which were generally too poor for profitable economic activities. In the Mazabuka and Monze districts, more arable land was allocated, such that by the 1920s there was already a serious shortage of land for the indigenous people, which resulted in overutilization of light soils causing erosion (Trapnell & Clothier, 1937). This is because by 1933 commercial maize production using ox-drawn implements and transport was already well established in Southern Province (Johnson, 1956). Johnson also commented that, the erosion that follows from "signs of soil deterioration and sheet erosion ... is not yet so serious that it can be checked."

Thus, by 1940 soil conservation works mainly involving construction of contour ridges on steeper slopes and grass-strips on gentler slopes were introduced in European and African areas. From 1939 to 1944 more than 1600 km of contour ridges were constructed and 180 km of grass-strips were established in Southern Province alone (Robinson, 1978). Robinson also reports that the *ad hoc* application of conservation measures to localized areas where excessive soil erosion affected farmlands in the early years, was replaced by Catchment Regional Planning after 1953. Between 1958 and 1965, 74 regional plans were drawn-up for the protection and development of 1.85 million ha of land at a cost of over £800 000. Some of the conservation measures constructed were located in areas where there are small dams (Table 3). By 1973, at least 459 124 ha of land in Southern Province, 684 169 ha in Central-Lusaka, 110 800 ha in the Copperbelt and 118 392 ha in the Eastern Provinces, were protected against erosion (Fig. 1(a)). Since that time, few conservation works have been constructed largely due to limited financial and political support. During the colonial period and soon after political independence in 1964, there was official concern over soil erosion which ensured support for conservation works. This is not so now despite concerns for soil erosion being expressed such as "soil erosion is proceeding unchecked in many localities and gives cause for concern" (Landuse Services Division, 1974).

Table 3 Catchment area planning in Southern Province, 1960-1970[a].

Plan	District	Area (ha)	Implementation
Upper Ngwezi	Mazabuka	19 712	1960-1963
Chikankata	Mazabuka	33 506	1960-1963
Mwenda	Mazabuka	19 352	1960
Lower Ngwezi	Mazabuka	17 920	1962-1964
Mwanza-Chona	Monze	33 770	1963-1966
Magoye HQ	Mazabuka	29 182	1963-1966
Ufwenuka-Chona	Monze	23 090	1964-1966
Siantontola	Monze	23 884	1967-1969
Kazungula-Mutama	Monze	46 400	1969-1970
Namuseba	Monze	22 400	1969-1970
Malundu	Monze	14 800	1968-1969
Nteme	Monze	21 266	1969-1970
Keemba	Monze	20 484	1968-
Banakaila	Namwala	17 320	1969-1970
Mwanachingwala	Mazabuka	20 000	1969-1970
Lower Magoye	Mazabuka	15 360	1968-1970
Nansenga	Mazabuka	17 408	1973-
Macha-Mapanza	Choma	33 280	1966-1969
Shaloba	Namwala	4 920	1964-1965
Mbabala	Choma	25 068	1967-1969
Dimbwe	Kalomo		1967-1969
Mafuta	Kalomo		1967-
Sipatunyana	Kalomo		1970-
Njabalombe	Kalomo		1970-
Total		459 124	

[a] Robinson (1978; Table 4; p.36).

The success of early conservation works probably accounts for the impression created that soil erosion was not a problem in Zambia. Hence the limited support given for soil conservation and the lack of sediment monitoring on rivers and dams (Sichingabula, 1996). Southern Province has good soils, but under continuous cultivation the structure of the topsoil breaks down making the soils susceptible to water erosion (Brammer, 1976). Hence the call for a resumption of regional planning of conservation works (Beaumont, 1979), indicating that soil conservation was effective in reducing erosion from agricultural lands.

Construction and rehabilitation of small dams

"If neglect of land has caused erosion, the same neglect will probably cause damage once conservation works (and dams) have been constructed" (Landuse Services Division, 1970). Lack of maintenance of conservation works today has partly contributed to silting-up of many small dams in Southern Province. Field observations by the Department of Agriculture indicate that many small dams have lost considerable storage capacity due to sedimentation (Capt. Moono, Department of Agriculture; personal communication). Limited field observations by the author in Monze and Mazabuka districts indicated that at least five pre-1970 dams have lost up to three quarters of their storage capacity due to siltation. Interviews with people from other districts revealed that four dams in Gwembe, two in Choma, and three dams in each of Namwala and Mazabuka districts are seriously affected by siltation.

In Southern Province, local people have welcomed the construction of new dams and the rehabilitation of old ones because this reduces their search for water and the need to drive herds of cattle long distances to watering points. Through the "Food for Work" programme, local people have been involved in the construction and rehabilitation of dams and erosion conservation works. However, in some cases it is cheaper to construct new dams than to rehabilitate old ones (Linsley *et al.*, 1975). Some villages in the Mazabuka district have, through their own efforts and donor assistance, constructed dams for livestock and agricultural purposes. Throughout the country 25 more dams have been planned for construction by the Department of Water Affairs (JICA, 1995). Local people are being educated in the value of conservation and the benefits of measures such as tree planting, less cutting of trees and controlling livestock numbers to carrying capacity levels, in lessening the deterioration of the environment.

CONCLUSION

The estimated average useful life of reservoirs in Southern Province of Zambia is 7314 years, based on available information on the suspended sediment loads transported by streams. In areas more seriously affected by soil erosion, reservoir life could be much shorter and in areas where soils are least disturbed it could be longer. Qualitatively, soil erosion and sedimentation in small dams have been shown to be serious in Southern Province, due to increased human and cattle population and the existence of large cultivated areas. Soil conservation works, which have proved successful in reducing soil erosion, and efforts to rehabilitate many dams are beginning to receive more support than before. It is concluded that detailed quantitative research is required to determine actual sedimentation rates and the influence of environmental factors on sediment yields so as to devise ways of minimizing the adverse impacts of erosion on environment and society. The results of this study should be treated as preliminary. More detailed measurement programmes and reservoir surveys are required to provide a definitive assessment of reservoir sedimentation problems in Zambia.

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