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Hydrological and Water Quality Characteristics of Rivers Feeding into Small Earth Dams for Rural Water Supply: A Case Study of Traditional Authority Kalolo in Lilongwe District

S. Najira[1], M. Monjerezi[1]*, C. Ngongondo[1] and H. Mloza Banda[2]

[1] University of Malawi, Faculty of Science, Chancellor College, P.O. Box 280, Zomba, Malawi

[2] Department of Crop Science, Bunda College, University of Malawi, P.O Box 219, Lilongwe, Malawi

* *mmonjerezi@cc.ac.mw*

Abstract

The obligation to ensure adequate and clean water supply to everyone, has necessitated the development of small earth dams for rural water supply in developing countries. In Malawi, there are approximately 750 small and medium dams most of which are used multiple purposes. However, in most cases, the sustainability of these dams is challenged by gross catchment mismanagement and improper designs and set up. In this study, FDC analysis, in conjunction with water quality assessment, was used to evaluate the reliability of rivers flows that supply small earth dams designed for rural water supply in Malawi, using Kalolo area in Lilongwe district as a case study. FDC analysis showed that over 80% of the time, all rivers in the study area would not meet the target community's water demand, without the dams in place. Water quality assessments show biological contamination as the major water quality problem. Significant seasonal variation in water quality is evident, with the dry season having generally better biological water quality. Further, the study categorized the catchments areas as moderately to largely modified using rapid ecological assessment method. Therefore, the low biological water quality may be attributed to uncontrolled anthropogenic activities in the catchment, arising from lack of proper catchment management. It is then recommended that construction of such small earth dams should be preceded by thorough scientific design through appropriate engineering and environmental studies, encompassing hydrological, geological, ecological and socio-economic factors, if the small earth dams are to result into long term outputs.

Key words: *River flow, small earth dams, flow duration curve, water quality, rural water supply.*

Introduction

The need to conserve water resources through technologies that can easily be managed by the rural community has compelled some developing countries to promote the use of small earth dams as sources of water supply for the development of irrigated agriculture, fish farming domestic uses brick making and livestock watering (Chavula, 2000). Most of the small dams face critical challenges due to the absence of proper water quantity and quality management mechanisms. In Malawi, degradation of catchment areas due to anthropogenic activities such as crop cultivation, livestock rearing, deforestation within the catchment or upstream of the feeder rivers or dambos have greatly contributed to the non-functionality of most of these dams, due to heavy siltation, damage to embankments and spillways and low quality water. Community management of these resources has been lacking mainly due to the perception of the resources as being Government property. This is mostly because the beneficiary or surrounding communities were not adequately consulted or involved during construction of the dams (WCD, 2004). Siltation and sedimentation have resulted in declining water flows, making most rivers ephemeral or intermittent resulting into water reservoirs storing water that is not suitable for aquatic life, let alone for human consumption (Government of Malawi, 2005). Despite their importance in rural water supply, studies on the hydrological characteristics of rivers supplying the small earth dams for water supply are scanty and limited. This is because of their perceived less significance, in terms of their impact on water supply and human health than large dams. Globally, there has been massive investment in large dams which called for the establishment of the International Commission on Large Dams (ICOLD) in 1985 and the World Commission on Dams established in 1998, in response to the growing opposition to the management of large dams (World Commission on Dams (WCD), 2000).

The reliability of small earth dams in achieving their intended purpose requires the proper assessment of catchment hydrology during the planning stage. Among the simplest approaches of understanding catchment characteristics is the flow duration curve (FDC) analysis. An FDC gives a relationship between any given discharge value and the percentage of time that the discharge is equaled or exceeded or in other words—the relationship between magnitude and frequency of stream flow discharges (Smakhtin, 2001). FDCs are used in determining water supply potential, design of water resource projects (Mays, 2005; Vogel and Fennessey, 1995), abstraction licensing (Smakhtin, 2001), river and wetland inundation mapping; river, reservoir and lake sedimentation studies; in stream flow assessments; hydropower feasibility analysis; water quality management; waste load allocation; flood frequency analysis; flood damage assessment (Vogel and Fennessey, 1995; Alaouze, 1991; Warnick, 1984; Male, 1984; Searcy, 1959). An FDC is constructed by reassembling the flow time series values in decreasing order of magnitude, assigning flow values to class intervals and counting the number of occurrences (time steps) within each class interval (Smakhtin, 2001). The flow time series can be at daily, monthly or yearly. FDC analysis is based on several critical indices such as the Q100, which is the river's firm yield; the Q95, the index of natural low flows or the environmental flow defines the upper threshold of abstraction (Dysan et al, 2003); the Q50, an index of groundwater contribution to stream flow indicates hydrogeologic conditions. The reviews of Vogel and Fennessey (1995) and Smakhtin (2001) acknowledge the scarcity of relevant literature on the applications of FDC analysis, despite their wide use in hydrological practices. Smakhtin (2001) further observed that FDC applications have not been fully explored yet, in spite of increased interest of FDC in hydrology, water resources and river ecology.

In this study, FDC analysis was applied to assess the hydrological characteristics of small rivers hosting small earth dams designed to supply water to rural communities. Further, the suitability of water in the dams for everyday domestic uses was evaluated using simple physical, chemical and biological parameters (faecal coliforms, pH, colour, turbidity, nitrates, phosphates, sodium, potassium, iron, sulphates, and total dissolved solids). Lastly, the ecological management classes of the river catchments hosting small earth dams, was assessed. The paper, therefore gives a scientific account of some of the critical challenges leading to the failure of small earth dams in meeting rural water supply demands.

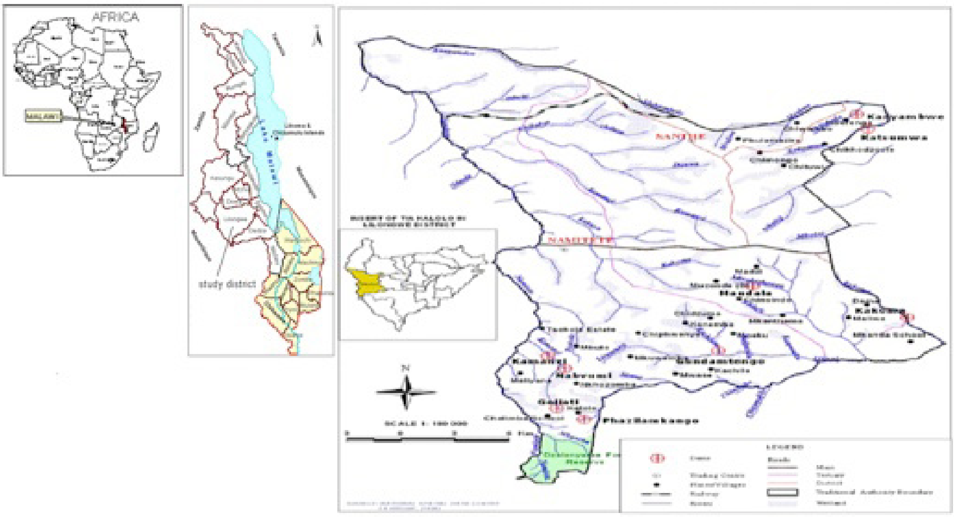
2. Materials and Methods

2.1 Study area

This study is set in the Traditional Authority (TA) Kalolo in Lilongwe district, Malawi (Figure 1). According to the 1998 population census, TA Kalolo had a total population of 104, 939 and the projected population for 2006 was 134, 088 (Lilongwe district socio-economic profile, 2006). Table 1 is a brief description of the dams which were studied. Lilongwe has a warm tropical climate characterised by one rainy period of approximately 5 months, lasting from end November to end April, and dry weather in most areas during the remainder of the year. The district has Mean Annual Temperatures of about 20° to 22.5° Celsius. The passage of the inter-tropical convergence zone, experienced between December and June, is the major rain-bearing system in the district (Malawi Government, 2006). Mean Annual rainfall is from 800 mm to 1, 200 mm. Rainfall distribution is also highly influenced by orographic effects, with windward slopes receiving more than the leeward sides of hills or mountains, and areas with higher elevation receive more rainfall than lower lying areas (Pike and Rimmington, 1965).

Dam	**Location**	**Dam Capacity (m^3)**	**Operational Status**	**Feeder stream**	**Catchment area (km^2)**
Mandala	S 14° 03.213' and E 033° 27.768'	5250	Operational	Mtsukanthanga stream into Likuni River	10.629
Gundamtengo	S14° 06.491' and E033° 26.715'	5250	Operational	Chipoka / Mphafayanjiru stream into Likuni River	10.144
Phazilamkango	S14° 09.955' and E033° 22.580'	5250	Operational	Phazilamkango stream into Likuni River	4.852
Nabvumi	S14° 07.375' and E033° 21.982'	5250	Operational	Kamanzi stream into Namitete River	8.099
Kamanzi	S14° 06.763' and E033° 21.468'	4200	Operational	Kamanzi stream into Namitete River	9.844
Goliati	S14°06.763' and E033° 21.468'	7500	Not Operational	Kamanzi stream into Namitete River	1.039
Kakoma	S14° 04.814' and E033° 32.546'	19,125	Operational but privately owned. Not accessed by communities.	Likuni River	NA
Kanyambwe	S13° 54.585' and E033° 30.9608'	8000	Completely covered with weeds.	Nsaru River	NA
Katsumwa	S13° 55.319' and E033° 31.291'	-	Not constructed but potential dam site.	Nsaru River	NA

NA = information unavailable



2.2 Water quantity assessment

FDC analysis (Vogel and Fennessey, 1995), was used to quantify the total amount of water available for the small earth dams in the study area. The amount of catchment evapotranspiration was estimated using Thornthwaite's model (Ward and Robinson, 1990; Chow, 1965) and environmental flows using Tenant's method (Dysan et al, 2003). Thornthwaite's model has been widely applied in data scarce sites, mostly used in situations where temperature data is the only climate record available in the area (Ward and Robinson, 1990; Chow, 1965).

Daily river flow records of various gauging stations along the streams were obtained from the Ministry of Water Development, Surface Water Section. The FDCs were derived from the Weibul plotting position formula (Gringorten, 1963):

$$P = \frac{i}{n+1} \tag{1}$$

where P is the probability (%) of river flows exceeding a certain magnitude, i is the rank of a particular flow and n is the total length of the record.

Temperature data was obtained from the Department of Meteorological Services in Blantyre through Chitedze Research Station for a 35-year period (1971 to 2006) and was used to estimate the potential evapotranspiration (PET) using Thornthwaite's model (Ward and Robinson, 1990; Chow, 1965), first, as monthly heat index:

$$I = \left(\frac{T}{5}\right)^{1.514} \tag{2}$$

where I is the heat index and T is mean temperature of the month in OC

Then monthly heat indices were added to obtain an annual heat index, which was then used in the calculation of the constant "a" below and further, the PET:

$$E_p = 1.6b\left(\frac{10t}{I}\right)^a \tag{3}$$

$$a = 6.75 \times 10^{-7} I^3 \quad 7.71 \times 10^{-5} I^2 + 1.792 \times 10^{-2} I + 4.9239 \text{ x } 10^{-1} \tag{4}$$

Where Ep is monthly potential evaporation in cm; t is the mean monthly temperature in oC and b is a factor to correct for unequal day lengths

The study used the Tenant-Montana method to estimate environmental water demand. This is a hydrological look up method which uses existing river flow data from gauging stations (Dysan et al, 2003). Hydrological indices such as percentages of the mean flow or certain percentiles from a flow duration curve are set. This method has been adopted for environmental flow setting to determine simple operating rules for dams or off-take structures where few or no local ecological data are available. This study set the environmental flows at the recommended Q90 in the FDC, which is the discharge which is equaled or exceeded 90% of the time, i.e. the most regular occurrences. The Q90 is recommended by the Malawian water department for water abstraction permits (Mhango and Joy, 1998).

Total current water demand for the area was determined using population and livestock figures. Future water demand was estimated by projecting the current water demands exponentially, assuming an exponential pattern of population growth (Goodman, 1984).

$$W_t = E_o^{rt} \tag{5}$$

Where W_t = water consumption at future time t = 0

W_0 = annual water demand at base time t=0

r = Annual growth rate of the consumption

t = Time in years

The 1998 Censual population growth rate for Lilongwe District was 2.9% (Republic of Malawi, 2006), hence r was set to 2.9%.

In order to determine the reliability of the river flows hosting the earth dams for water supply, the total water use, PET and environmental water demand were added and then plotted on the FDCs to find out the probabilities of supply. Considering that the dams in the study area are perched on dambos, with poorly drained soils (Lorkeers & Venema, 1991), seepage dynamics were not considered. According to the Richter method of assessing environmental flows, flows which are not equaled to or exceeded 50% of the times are not reliable, so assessment of reliability of the rivers flows in this study was set at Q50.

2.3 Assessment of ecological management classes

The habitat integrity of the dams' ecosystem was established using a Rapid Assessment / Determination Method, using parameters such as bank erosion, indigenous vegetation removal, water abstraction, water quality, exotic vegetation encroachment, channel modification, flow modification and inundation (Dysan, 2003; Kleynhans, 1996; Tharme & King, 1998). This assessment is done to set an ecosystem into a class category as a function of the flow. In an ideal situation, with adequate resources, the Building Block Methodology (BBM) is used and in this methodology, assessments are based on videographic, low altitude aerial surveys of the river or stream ecosystem which provide information about the characteristics and present condition of the ecosystem.

2.4. Water quality assessment

For collection, preservation and analysis of water samples, the standard methods (Rainwater and Thatcher 1960; Brown et al, 1970; Hem, 1985; APHA, 1989) were followed.

2.4.1 Collection of water samples

Water samples were collected in triplicates from two sampling points, at the inlet and outlet of the dams during rainy season (February 2007) and dry season (July 2007) in order to capture seasonal variations in water quality.

Six water samples were collected in new one-litre polyethylene bottles that had been labelled accordingly and rinsed three to four times with the water sample before filling it to capacity. Three samples were collected for iron, sodium and potassium analyses and three samples for turbidity, TDS, phosphates, sulphates, nitrates and feacal coliform analyses. Samples for iron, sodium and potassium analyses were acidified at the sampling sites by adding 1mL of conc. HNO_3 (AR). Acidification prevents precipitation of unstable metal elements, such as iron, and also prevents adsorption of some metal elements onto the surface of the container. The samples for turbidity, TDS, phosphates, sulphates, nitrates and feacal coliform analyses were kept at a temperature below 4°C in cooler boxes in the field and in a refrigerator in the laboratory prior to analysis. pH and colour were measured at the collection point, whilst the rest of the parameters were analysed at the Central Water Laboratory, Ministry of Irrigation and Water Development.

2.4.2 Analysis of water samples.

A total of 11 water quality parameters were analysed: pH, colour, TDS, nitrates, sulphates, phosphates, iron, potassium, sodium and faecal coliforms. pH was determined using a pH meter, Metrohm Model 744 with an accuracy of ±0.01, in the range 0 to 14 (APHA, 1989), after calibration with buffers of pH 4.0

followed by pH 7.0. Turbidity was determined using a nepheloturbidity meter. Colour was determined using UV/Visible Spectrophotometer (HACH, Model DR/3000) at the wavelength of 455 nm (AOAC, 1990). TDS was determined by evaporation (APHA, 1989). Nitrates, phosphates, sulphates and iron were determined by spectrophotometry (JENWAY 6405 UV/Visible spectrophotometer) (APHA 1989; AOAC, 1990). Na+ and K^+ were determined using flame photometry (APHA, 1989). Faecal coliform counts in the water samples were determined using the Membrane Filtration Method as illustrated in APHA (1989).

2.4.3 Data analysis

FDC analysis was carried out using the historical flow records, in Microsoft Excel, to display the relationship between the ranges of discharges. Descriptive statistics (mean, standard deviation, autocorrelation) of the flows was also done using AQUAPAK for hydrological analysis. For the water samples, descriptive statistics (mean and standard deviation) were used to summarize water quality parameters. In order to examine seasonal differences in the water quality, paired t-test was run in Statistical Package for Social Scientists (SPSS for windows 11.0). The results were compared with national recommended standards dealing with water quality (MBS, 2005a; MBS, 2005b).

3.0 Results and Discussions

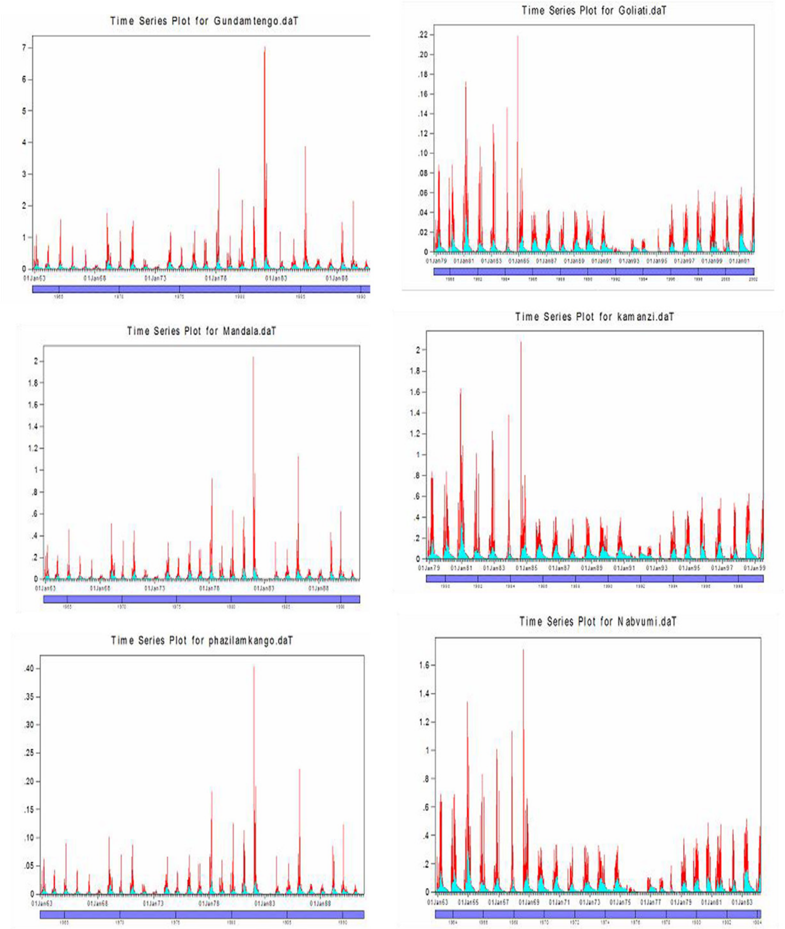
3.1 Availability of water

Descriptive statistics for the flow data was carried out and results are shown in Table 2. Gundamtengo and Kamanzi dams had the highest flows with mean flows of 0.07 m^3/s and standard deviation of 0.19 and 0.12 respectively. Phazilamkango had a mean flow of 0.004 (SD = 0.01), implying a higher potential for drying out.

Table 2: Descriptive statistics for feeder stream flows

Stream	Mean	Standard Deviation	Auto- correlation
Mandala	0.02	0.05	0.7222
Kamanzi	0.07	0.12	0.8045
Gundamtengo	0.07	0.19	0.7212
Nabvumi	0.05	0.10	0.7782
Phazilamkango	0.004	0.01	0.7222
Goliati	0.01	0.01	0.7850

The stream flows for all the dams are highly auto-correlated, between 0.7 and 0.8. This means that daily flows are dependent on each other. Stream flows with high auto-correlation usually have a larger base flow component (Vogel & Fennessey, 1995). The autocorrelation figures for the dams suggest the presence of a large base flow component and this is an indication that the rivers sources are on perched aquifers with minimal groundwater recharge from adjacent aquifers. This is indeed typical of dambos, as observed during the field visits. Soil types in this area are Tenthema (Republic of Malawi, 2006), and this soil type tends to be poorly drained such that in instances of prolonged droughts or minimal precipitation, the dams are prone to completely dry up (Lorkeers & Venema, 1991). Aquapack plots shown in Figure 2 confirm that the flows are mainly derived from groundwater.



3.2 Reliability of the river flows supplying the dams

The FDCs for each dam's feeder-stream are shown in Figure 3. The FDCs indicate that water requirements of the communities would only be met less than 20% of the time for all the rivers without the dams in place, since according to Smathkin (2001), all flows below the median flow (Q_{50}) are not reliable.

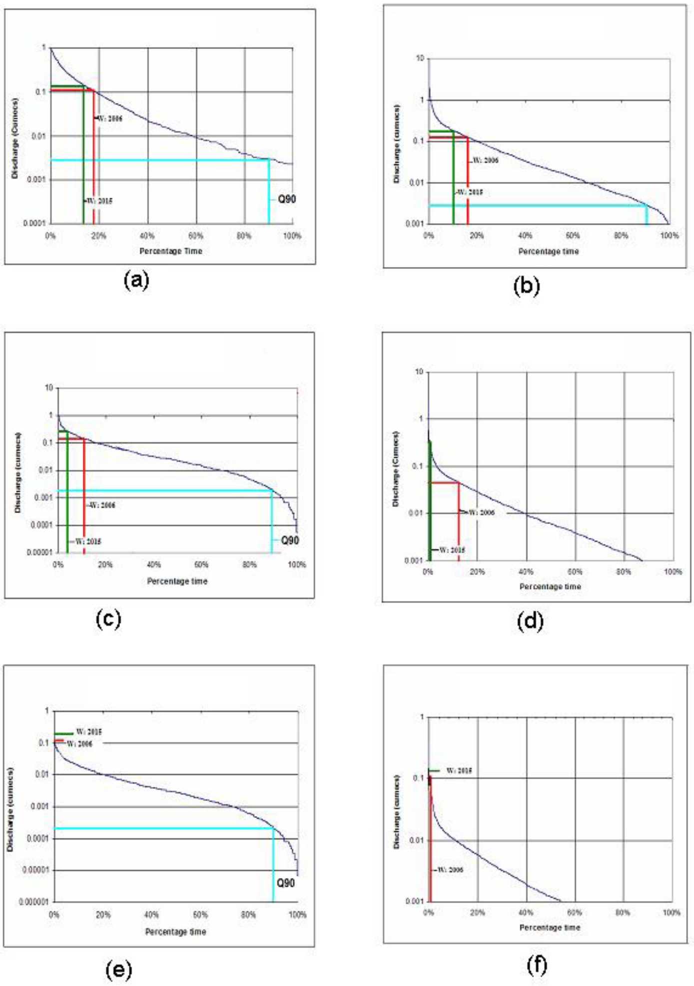


Table 3 shows the percentage of time that stream flows are sufficient to meet water requirements from the communities at the time the study was undertaken (W: 2006) and projected water requirements (W: 2015) without the dams in place. Environmental requirements were set at Q_{90}. Current water demand in Kamanzi stream would be met 18% of the time and future requirements would be met 14% of the time. Gundamtengo stream would be able to meet current water use 16% of the time and future requirements would be met 10% of the time. Mandala stream would be able to meet current uses 12% of the time and future requirements only 1% of the time. Current water use in Nabvumi stream would be met 10% of the time and 4% of the time for future water requirements. Phazilamkango stream is able to meet the current requirements only 1% of the time and future requirements would not be met at all. Goliati stream is neither able to meet current water requirements nor the future requirements (0%).

Table 3: Percentage of time, flow is sufficient to meet water requirements in TA Kalolo

Stream	Current water use (%) (W:2006)	Future water use (%) (W:2015)
Kamanzi	18	14
Gundamtengo	16	10
Nabvumi	10	4
Mandala	2	1
Phazilamkango	0	0
Goliati	0	0

Reliability of water withdrawals was also done based on water allocation derived from the indirect method of assessing rural water demand, which is the amount of water available for withdrawal from the stream in an ideal situation where environmental flows are maintained. FDCs were plotted only for Kamanzi, as the stream with the highest flows and Phazilamkango stream, which has the lowest stream flows (Figure 4). It is apparent that even in the ideal situation, the amount of water available for use from the stream is still less than Q50, with Kamanzi stream having water flows available for use only 25% of the time and Phazilamkango flows having flows available for use only 5% of the time. This implies that the rivers would not be able to meet the water demand for the communities at least 75% of the time, which according to Smathkin (2001) is an indication of unreliability.

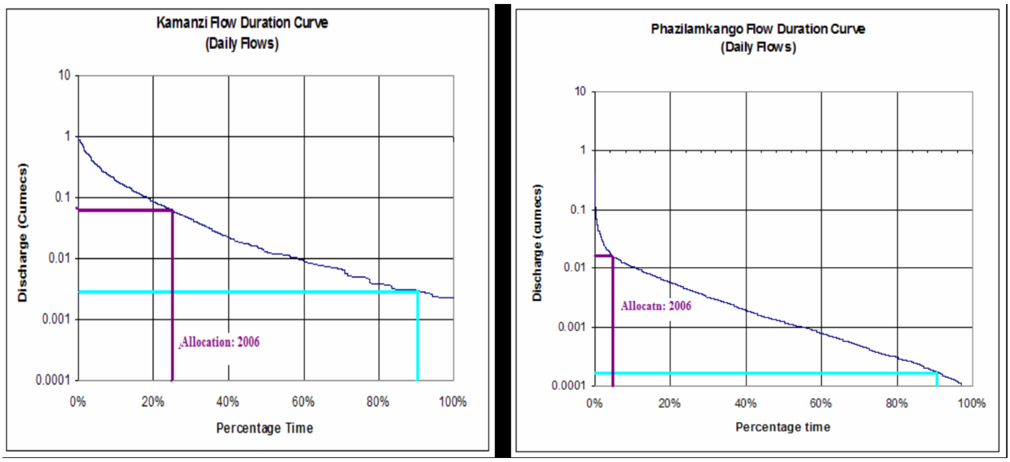


Figure 4: *Flow duration curves for Kamanzi and Phazilamkango rivers showing water allocation plots*

3.3 Ecological Management Classes.

The study established the habitat integrity of the catchment of the stream with the use of digital pictures and from individual interviews. Based on the responses and assessment of the pictures taken, the catchments have been duly classified into ecological management classes (Table 4). Gundamtengo, Goliati and Kamanzi have catchments have been classified into class C which is moderately modified and Mandala, Nabvumi and Phazilamkango dams have been classified into class D which is largely modified.

Table 4: Ecological management classes or habitat integrity of ecosystem of the dams

Dam	Class	Description
Mandala	D	Largely modified. A large loss of natural habitats, biotas and basic ecosystem functions has occurred.
Gundamtengo	C	Moderately modified. A loss of and change from natural habitats and biotas has occurred but the ecosystem functions are still predominantly unchanged.
Phazilamkango	D	Largely modified. A large loss of natural habitats, biotas and basic ecosystem functions has occurred.
Nabvumi	D	Largely modified. A large loss of natural habitats, biotas and basic ecosystem functions has occurred.
Kamanzi	C	Moderately modified. A loss of and change from natural habitats and biotas has occurred but the ecosystem functions are still predominantly unchanged.
Goliati	C	Moderately modified. A loss of and change from natural habitats and biotas has occurred but the ecosystem functions are still predominantly unchanged.

3.4 Water quality assessment

This study used pH, colour, turbidity and levels of iron, nitrates, sulphates, phosphates, potassium, faecal coliforms and total dissolved solids (TDS) as indicators of the suitability of the dams for rural water supply. The results of the water quality assessment are summarised in Table 5, Table 6 and Table 7. The corresponding Malawi Standards (MS 214 and MS 733) parameters are also included. The MS 214 specifies the physical, biological, organoleptic and chemical requirements for water quality from public water supply for human consumption. Since the water from public water supply is treated, this standard is more stringent and would not apply to untreated water from rural earth dams. The MS 733 outlines requirements for untreated or raw groundwater in boreholes and shallow wells suitable for human consumption and all usual domestic purposes. Therefore the MS 733 has been used for further and even reference. p values, at 95% level of confidence, for comparison of each measured parameter at the two sampling points in the dams are summarised in Table 8 and Table 9.

3.4.1 pH, TDS, Turbidity and Colour

The pH (6.6–7.99) of the water samples in the rainy season and for the dry season (6.50-7.82) is within the limits (6.5–8.5) as prescribed by MS 214 (Table 5). There are no significant variations in pH between the seasons and between the inlet and outlet of the dams ($p > 0.05$). The pH of water is important because it affects chemical speciation as chemical dissolution and precipitation depends on pH. Low pH increases metal dissolution and hence bioavailability (and toxicity) whilst high pH values favour precipitation, making them unavailable for uptake by biota and humans. The pH of 'clean' rain or of any other pure water sample in equilibrium with atmospheric carbon dioxide is approximately 5.7 (Van Loon and Duffy, 2005). The pH values from the dams indicate a well buffered system, with bicarbonates (HCO_3^-), $H_3SiO_4^-$ and HPO_4^{2-} being the most probable proton acceptors in the water system.

Turbidity is a measure of relative clarity of water and indicates the presence of dispersed suspended solids like silt, clay, plankton or other microscopic organisms and organic matter. The major impact of high turbidity is its effect on aesthetics. However, the suspended particles may also carry viruses, bacteria and many other toxic chemicals such as heavy metals and pesticides. Turbidity levels for the dams ranged from 12.3 ± 1.53 to 39 ± 1.15 NTU for the rainy season and from 7.13 ± to 47.7 ± 0.6 NTU for the dry season (Table 5). In the rainy season, turbidity levels were generally within the guidelines given by MS 733 (25 NTU) with an exception of water at the outlet point of Phazilamkango dam (39.3 ± 1.15). Most dams show differences in levels of turbidity between seasons ($p < 0.05$) and between inlet and outlet of the dams, but these vary amongst the dams (Tables 8 and 9)

Table 5: Mean levels of TDS, Colour, Tubidity and pH

Dam	Parameters (x ± SD)															
	pH				TDS (mg/ℓ)				Colour (TCU)				Turbidity (NTU)			
	Rainy season		Dry Season		Rainy season		Dry Season		Rainy season		Dry Season		Rainy season		Dry Season	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Mandala	7.29±0.09	7.27±0.06	7.79±0.01	7.37±0.17	53±1.8	47±1	169±2.5	217±3.8	120±2.9	145±5.8	40±2.9	30±0	20±2	21±2.65	47.7±0.6	26±0.0
Gundamtengo	7.28± 0.03	7.19±0.02	6.68±0.03	7.06±0.21	16±1	15±0.8	156±1.5	72±1.2	145±5.8	145±5	10±2.8	5±2.9	20.3±0.58	12.3±1.53	7.13±0.21	7.7±0.58
Nabvumi	7.36±0.09	7.99±0.04	7.42±0.04	7.82±0.31	18±0.8	25±0.4	224±3.5	141±1.0	80±5.8	50±2.9	20±2.9	20±5	20±2	23.3±2.31	16.2±0.2	18.3±0.58
Phazilamkango	6.62±0.02	6.6±0.2	6.5±0.03	6.55±0.13	18±0.7	37±0.3	44±1.5	40±1.1	70±0	140±5.8	40±2.9	30±2.9	20±0	39.3±1.15	39.3±1.14	32.7±2.09
Kakoma	7.13±0.06	7.38±0.05	7.16±0.02	7.15±0.38	30±1	52±0.6	57±2.0	75±0.5	140±5.8	140±2.9	35±2.8	20±2.8	20±1	18.3±0.58	32.9±0.91	20.7±1.15
Kamanzi	ND	ND	7.02±0.08	7.21±0.03	ND	ND	16±1.5	52±0.6	ND	ND	30±5	35±2.8	ND	ND	21.3±0.58	21±1
MS 214	5.0 – 9.5				450 - 1000				5-10				0.1 – 1.0			
MS 733	6.0 – 9.5				2000				50				25			

SD = standard deviation; ND = Not determined; NA = not available; x = mean, n =3

Colour also affects aesthetics of water, but unlike turbidity, colour indicates the presence of dissolved and suspended organic materials, inorganic materials, sediments from soil erosion and overland flow. In the rainy season the water from the dams was generally muddy and unattractive as can be evidenced by the high mean levels of colour (Table 5). The results summarised in Table 5 show the apparent colour of water, as opposed to the true colour (since the samples were not filtered before analysis). Apparent colour is the colour of the whole water sample, and consists of colour due to both dissolved and suspended components. Colour levels ranged from 50 ± 2.9 TCU to 145 ± 5.8 TCU for the rainy season, exceeding the recommended 15 TCU from MS 214 and 50 TCU from MS 733. These levels could be indicative of the presence of sediments and dissolved natural organic matter (DNOM) which was carried as run off with overland flow. The results indicate a significant difference between the rainy and dry seasons in levels of colour ($p < 0.05$).

A total dissolved solid (TDS) is a measure of total dissolved solute in water (WHO, 1996). Results for the rainy season ranged from 15 ± 0.8 to 53 ±1.8 mg/ℓ and dry season levels for TDS ranged from 16 ± 1.5 to 224 ± 3.5 mg/ℓ. These levels imply that the water can be categorised as fresh (Fetter, 1990), and the values are low when compared with the guidelines from the Malawi Standards (Table 5). There is however significant difference in TDS values ($p < 0.05$) between the seasons, with higher values in the dry season than the rainy season, which may be attributable to concentration by evaporation during the dry season and dilution in the rainy season.

3.4.2 Levels of nitrates, sulphates, phosphates and feacal coliforms

Excessive nitrates (NO_3^-) in drinking water can cause a number of health disorders, such as methemoglobinemia, gastric cancer, goitre, birth malformations and hypertension (Majumdar and Gupta, 2000; Van Loon and Duffy, 2005). In the rainy season, levels of nitrates ranged from 0.002 ± 0.001 mg/ℓ to 0.165 ± 0.002 mg/ℓ and were within recommended local water quality standards (Table 6). Compared with the levels of nitrates in the dry season (<0.001 mg/ℓ), the wet season levels were higher and may be attributable to run off from agricultural fields washing away inorganic fertilizers into the dams. Low usage of inorganic fertilizers, as revealed during Focus Group Discussions (results not shown), coupled with uptake of nitrates by aquatic plants can be responsible for the generally low levels of nitrates especially in the dry season.

Presence of sulphates in very high concentrations in drinking water is associated with respiratory problems (Subba Rao, 1993). In conjunction with sodium and magnesium, sulphates may also exerts a cathartic effect on digestive tracts. Wet season levels of sulphates were much lower than the guidelines from the standards (Table 6). The wet season levels ranged from 0.013 ± 0.01 mg/ℓ to 20.6 ± 0.59 mg/ℓ and the dry season sulphate levels were within the range of 7.21 ± 0.22 mg/ℓ to 23.3 ± 0.35 mg/ℓ. According to GEMS/WATER, a global network of water monitoring stations, typical sulphate levels in fresh water are in the vicinity of 20 mg/ℓ and range from 0 to 630 mg/ℓ in rivers. The generally low levels could be due to geology of the area which affects sulphate levels in surface water and low loading from run off.

Phosphates enter water bodies from human and animal wastes, phosphate-rich rocks, and wastes from laundries, cleaning and industrial processes, and farm fertilizers. In Malawi, there are no standards available for recommended levels of phosphates in water but WHO set recommended levels of phosphates in water at 0.05 mg/ℓ. Rainy season levels of phosphates ranged from 0.036 ± 0.003 mg/ℓ to 0.053 ± 0.002 mg/ℓ and dry season levels were between 0.005 ± 0.002 mg/ℓ and 0.068 ± 0.002 mg/ℓ. The source of phosphates could be from animal wastes considering the livestock watering practices observed and sanitary facilities available in the area.

Table 6: Mean levels of Nitrates, Phosphates, Sulphates and feacal coliforms

Dam	Parameters (x ± SD)															
	Nitrates (mg/ℓ)				**Phosphates (mg/ℓ)**				**Sulphates (mg/ℓ)**				**Feacal Coliforms (counts/100 mℓ)**			
	Rainy season		**Dry Season**		**Rainy season**		**Dry Season**		**Rainy season**		**Dry Season**		**Rainy season**		**Dry Season**	
	Inlet	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**
Mandala	0.027 ±0.004	0.016 ±0.002	0.001 ±0	0.001 ±0	0.036 ±0.003	0.053 ±0.002	0.04 ±0.02	0.02 ±0.003	20.6 ±0.59	16.2 ±0.4	23.3 ±0.35	22.2 ±0.25	20.6 ±0.59	1304 ±6.9	0	504 ±6
Gundamtengo	0.021 ±0.002	0.009 ±0.002	0.001 ±0	0.001 ±0	0.048 ±0.003	0.05 ±0.002	0.02 ±0.005	0.01 ±0.002	2.4 ±0.23	3.3 ±0.11	7.3 ±0.19	7.21 ±0.22	2.4 ±0.23	1155 ±5	48 ±7.6	252 ±4.9
Nabvumi	0.165 ±0.002	0.002 ±0.001	0.001 ±0	0.001 ±0	0.047 ±0.002	0.05 ±0.002	0.023 ±0.003	0.02 ±0.002	0.02 ±0.01	0.013 ±0.003	8.9 ±0.2	8.5 ±0.17	0.02 ±0.01	701 ±6.6	2996 ±5.77	903 ±5.8
Phazilamkango	0.006 ±0.003	0.202 ±0.003	0.001 ±0	0.001 ±0	0.049 ±0.002	0.072 ±0.003	0.045 ±0.004	0.043 ±0.003	2.6 ±0.1	6.2 ±0.18	14.1 ±0.3	14.4 ±0.23	2.6 ±0.1	1800 ±9.5	2251 ±6.1	1505 ±6.03
Kakoma	0.127 ±0.002	0.093 ±0.003	0.001 ±0	0.001 ±0	0.039 ±0.002	0.045 ±0.002	0.009 ±0.002	0.005 ±0.002	15.4 ±0.4	17.5 ±0.16	10.1 ±0.25	10.8 ±0.38	15.4 ±0.4	2248 ±7.6	1504 ±5	406 ±5.3
Kamanzi	ND	ND	0.001 ±0	0.001 ±0	ND	ND	0.062 ±0.003	0.068 ±0.002	ND	ND	11.7 ±0.28	14.7 ±0.14	ND	ND	552 ±6.4	1002 ±3.8
MS 214	6 - 10				NA				200 - 400				0			
MS 733	45				NA				800				50			

SD = standard deviation; ND = Not determined; NA = not available; x = mean (n =3)

Faecal coliform was used as an indicator of faecal pollution in water. In the rainy season, levels of faecal coliforms in the dams ranged from 600 to 2,300 counts per 100 mℓ of water sample. Dry season levels of faecal coliforms ranged from 0 to 3000 counts (Table 6). Faecal coliform levels for both seasons are way beyond the guidelines of the Malawi water quality standards. There are significant differences ($p < 0.05$, Table 9) in levels of faecal coliform between the rainy and dry seasons with the dry season being higher due to dilution during the rainy season. There are also significant differences in levels of faecal coliform between the sampling points ($p < 0.05$; Table 8), with the dam inlets exhibiting higher levels of faecal coliform. These very high levels can be attributed to run off in the rainy season, disposing both cattle and human excreta into the dams, followed by concentration by evaporation the dry season. The socio-economic survey (results not shown) that was carried out in the study area revealed that cattle stop for a drink of water at the dams on their way to communal pastures. In addition there are limited sanitary facilities in the area, with people use bushes for toilets (focus group discussions, results not shown). The high levels of feacal coliform render the water unsuitable for drinking without prior treatment.

3.4.3 Levels iron, potassium and sodium

Although iron has got little concern as a health hazard, it is still considered as a nuisance (stains clothes and plumbing) when available in excessive quantities. The form of iron depends on the redox potential of the water. The iron usually exists in water as dissolved Fe^{2+} species but gets oxidised to isoluble forms of Fe^{3+}. Levels of iron in the dams ranged from 0.02 ± 0.01 mg/ℓ to 0.98 ± 0.01mg/ℓ in the rainy season and from 0.06 ± 0.03 mg/ℓ to 0.48 ± 0.016 mg/ℓ in the dry season. Both seasons had iron levels within the guidelines of the Malawi Standards (Table 7). Variations in the levels of iron in natural waters are mainly due to the geology of area, as a result of the dissolution of iron rich cements in sandstone. During sampling, red colour was observed at the outlets. This red colour is presumably due to precipitated hydrous iron (III) oxide (Fe(OH)3), formed after the oxidation of soluble iron in the iron (II) form:

$$4Fe^{2+}\,(aq) + 3O_2 + 6H_2O \rightarrow 4Fe\,(OH)_3\,(s) \qquad (6)$$

The red colour affects water aesthetics and hence acceptability.

Table 7: Mean levels of iron, potassium and sodium for the dry and rainy season

Dam	Parameters (x ± SD)											
	Iron (mg/ℓ)				Potassium (mg/ℓ)				Sodium (mg/ℓ)			
	Rainy season		Dry Season		Rainy season		Dry Season		Rainy season		Dry Season	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Mandala	0.05±0.02	0.98±0.01	0.07±0.003	0.06±0.003	0.31±0.02	0.21±0.01	0.2±0.02	0.2±0.01	10.1±0.4	9.03±0.08	9.2±0.32	8.4±0.12
Gundamtengo	0.02±0.01	0.12±0.02	0.11±0.02	0.095±0.01	0.49±0.02	0.3±0.02	0.21±0.01	0.2±0.03	9.01±0.1	9.02±0.03	7.2±0.09	7.1±0.14
Nabvumi	0.03±0.01	0.02±0.02	0.09±0.004	0.12±0.005	0.61±0.01	0.6±0.02	0.59±0.03	0.59±0.05	5.03±0.15	5.0±0.08	3.04±0.1	3.05±0.17
Phazilamkango	0.11±0.01	0.12±0.01	0.31±0.004	0.34±0.008	0.41±0.03	0.8±0.01	1.9±0.17	1.96±0.12	5±0.04	6.12±0.15	6.57±0.08	6.5±0.16
Kakoma	0.42±0.01	0.3±0.03	0.22±0.005	0.15±0.004	0.4±0.01	0.3±0.03	0.41±0.03	0.39±0.03	7.98±0.05	7.97±0.04	9.6±0.35	9.3±0.05
Kamanzi	ND	ND	0.48±0.016	0.29±0.02	ND	ND	0.9±0.03	1.02±0.06	ND	ND	7.3±0.14	7.9±0.07
MS 214	0.01 – 0.2				25-50				100 - 200			
MS 733	3.00				NA				500			

SD = standard deviation; ND = Not determined; NA = not available; x = mean (n =3)

Levels of potassium in the dams ranged from 0.21 ± 0.01 mg/ℓ to 0.8 ± 0.01 mg/ℓ in the rainy season and dry season ranges were from 0.2 ± 0.01 mg/ℓ to 1.96 ± 0.12 mg/ℓ. All the values are below those given in MS 214 (Table 7). The low levels of potassium in the dams are possibly due to low use of NPK fertilizers in the area. In drinking water, the concentration of Na^+ should not exceed 200 mg/ℓ (Table 7). A sodium-restricted diet is recommended to patients suffering from hypertension or congenial heart diseases and also from kidney problems. For such people, extra intake of Na^+ through drinking water may prove critical (Holden, 1971). Further, electrical conductivity (EC) and Na^+ play a vital role in suitability of water for irrigation. Higher EC in water creates a saline soil, whilst higher salt content causes an increase in soil solution osmotic pressure (Thorne and Peterson, 1954). The salts, besides affecting the growth of plants directly, also affect the soil structure, permeability and aeration, which indirectly affect plant growth (Subba Rao 2006). The total concentrations of soluble salts in irrigation water can be classified into low (C1), medium (C2), high (C3) and very high (C4) salinity zones. The zones (C1–C4) have the value of EC less than 250, 250–750, 750 − 2,250 µS cm–1 and more than 2,250 µS cm–1, respectively (US Salinity Laboratory Staff, 1954). One can calculate EC values from TDS values by dividing with a factor (0.55-0.75), depending on the relative concentrations of ions. Most of the dams (see Table 5 for TDS values) in the study area fall in the low and medium salinity hazard range. However, for a more elaborate analysis of irrigation suitability, values of Ca^{2+} and Mg^{2+} are required in addition to K^+ and Na^+ data. The values of sodium in the earth dam water were also within the guidelines.

Table 8: A summary of p values for comparison of parameters between inlet and outlet points in the same season

Parameter	***p* values for comparison between the inlet and outlet of dams**									
	Rainy Season					**Dry Season**				
	Mandala	**Gundamtengo**	**Nabvumi**	**Phazilankango**	**Kakoma**	**Mandala**	**Gundamtengo**	**Nabvumi**	**Phazilankango**	**Kakoma**
pH	0.763	0.0214	0.0022	0.88	0.0049	0.052	0.08	0.15	0.88	0.98
Turbidity	0.631	0.0061	0,13	0.0012	0.082	0.0002	0.25	0.015	0.0154	0.0002
TDS	0.011	0.19	0.0007	0.00004	0.000025	0.0001	0.0000004	0.0002	0.0324	0.0026
Colour	0.011	0.73	0.0072	0.0025	0.27	0.038	0.52	0.6495	0.0474	0.0015
Phosphates	0.0047	0.32	0.06	0.0013	0.019	0.31	0.04	0.3868	0.4240	0.033
Sulphates	0.0008	0.011	0.45	0.0001	0.0064	0.018	0.64	0.0417	0.2234	0.096
Nitrates	0.034	0.0015	0.00000004	0.0000001	0.0002	ND	ND	ND	ND	ND
Sodium	0.031	1.00	0.55	0.0036	0.81	0.0361	0.2642	0.96	0.39	0.25
Potassium	0.0062	0.0003	0.50	0.0005	0.020	0.8305	0.5942	0.92	0.77	0.52
Iron	0.0094	0.36	0.0013	0.034	0.0001	0.0094	0.3606	0.0013	0.03	0.0001
Feacal Coliform	0.00000004	0.000001	0.00004	0.0001	0.00000002	0.006 0048	0.000012	0.0000000002	0.00000001	0.000000001

Table 9: A summary of p values for comparison of dry and rainy season parameters

Parameter	*p* values for comparison between the dry season and rainy season values									
	Rainy Season					Dry Season				
	Mandala	Gundamtengo	Nabvumi	Phazilankango	Kakoma	Mandala	Gundamtengo	Nabvumi	Phazilankango	Kakoma
pH	0.0075	0.00003	0.208	0.0059	0.42	0.42	0.423	0.423	0.423	0.42
Turbidity	0.0010	0.0012	0.089	0.0012	0.0015	0.08	0.020	0.038	0.070	0.12
TDS	0.00031	0.00001	0.00008	0.00044	0.00062	0.0002	0.00038	0.00005	0.023	0.00037
Colour	0.0016	0.00046	0.0027	0.0028	0.0025	0.0009	0.00015	0.019	0.00076	0.00073
Phosphates	0.98	0.0032	0.00079	0.149	0.00012	0.0080	0.0026	0.00050	0.013	0.00007
Sulphates	0.0059	0.0023	0.00018	0.00026	0.00082	0.0026	0.00038	0.00014	0.00064	0.0021
Nitrates	0.0092	0.0035	0.00003	0.082	0.00008	0.0061	0.013	0.423	0.00005	0.00035
Sodium	0.00073	0.0041	0.0050	0.0020	0.011	0.028	0.0011	0.00129	0.206	0.0011
Potassium	0.045	0.0045	0.525	0.0055	0.80	0.423	0.0012	0.580	0.0044	0.0041
Iron	0.176	0.023	0.0039	0.00055	0.00002	0.00008	0.330	0.0154	0.0014	0.014
Feacal Coliform	0.00001	0.00004	0.00001	0.00040	0.00003	0.000002	0.00015	0.00005	0.00002	0.00029

4.0 Conclusion

FDC analysis, in conjunction with water quality assessment, was applied in order to evaluate the reliability of river supplying small earth dams designed to supply water to rural communities. The FDC analysis showed the inadequacy of river flows in the study area in meeting the water demand of the target rural community, if the dams were not in place. Over 80% of the time, all the river flows were unable to meet the required amounts of water for domestic purposes. Water quality assessments show biological contamination as the major water quality problem. Water quality shows significant seasonal dependency, with the dry season having generally better biological water quality. During the study period, four of the 9 dams in the area were not operational due to suspected design and site location problems and the study categorized the catchment areas as moderately to largely modified through rapid assessment method. Therefore, uncontrolled anthropogenic activities in the catchment, arising from lack of proper catchment management may be attributable for the low biological quality. The study showed that if development decisions of small dams were to result into long term outputs, their development needed to use results from appropriate engineering and environmental studies so as to take into consideration hydrological, geological, ecological and socio-economic factors.

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