Available online at www.sciencedirect.com
ScienceDirect
Bioresource Technology 99 (2008) 975–979
BIORESOURCE TECHNOLOGY

Assessment of siltation and nutrient enrichment of Gilgel Gibe dam, Southwest Ethiopia

Rani Devi [a,*], Esubalew Tesfahune [b], Worku Legesse [b], Bishaw Deboch [b], Abebe Beyene [b]

[a] Department of Energy and Environmental Science, Ch. Devi Lal University, Sirsa, Haryana, India
[b] Jimma University, Department of Environmental Science and Technology, School of Environmental Health, POB 378, Ethiopia

Received 28 December 2006; received in revised form 5 March 2007; accepted 7 March 2007
Available online 25 April 2007

Abstract

Gilgel Gibe hydroelectric power dam was located in the submerging part of the Addis Ababa, Jimma highway in Ethiopia which is about 55 km far from Jimma was constructed in 2004. A cross-sectional study was conducted during 2005 to assess the siltation and nutrient enrichment level of the dam. It was found from the study that siltation and nutrient enrichment were the major problems in this reservoir. The sheet erosion of catchment area was found to be 4.47×10^7 ton/year and hence 2210 ton/km^2. The contribution of the sediment load deposition of the Gilgel Gibe River to the dam was 277,437 ton/year and the total sediment load was 4.50×10^7 ton/year and this amount could cover 3.75×10^7 m^3/year of the dam. From the analysis of water samples of Gilgel Gibe dam, the concentrations of ammonia, chlorophyll *a*, total dissolved solids (TDS), dissolved oxygen (DO), biological oxygen demand (BOD), pH and temperature were found within the permissible limits as prescribed by WHO standards, but other parameters like phosphate, nitrate, sulphate, total solids (TS), total suspended solids (TSS) and visibility were much higher than the permissible limits. Due to the high concentration of suspended and sediment load, the secchi disc visibility of Gilgel Gibe dam was 0.72 m which indicated that it was well within the range of eutrophic lakes.

Keywords: Assessment; Catchment; Eutrophication; Gilgil Gibe dam; Nutrient enrichment; Siltation

1. Introduction

Siltation is a major problem in reservoirs and dams as it reduces water storage capacity, thus indirectly reducing electricity production besides shortening the lifetime and increasing the maintenance cost. Approximately 880 million tons of agricultural soil is deposited in the American reservoirs and other aquatic systems each year (Biswas, 1996). As a result of human activities, erosion and run-off from croplands contribute about 25 billion metric tons of soil, sediment, and suspended solids to the world surface waters each year. As a result of human activities, erosion and run-off contribute about 25 billion metric tons of soil, sediment, and suspended solids to world surface waters each year. Owing to poor agricultural practices, overgrazing and deforestation, the worst erosion problem in the world per hectare of farmland is in Ethiopia (Saigo, 1995 and Lynch and Phillips, 2000).

Based on the data of the Organization for Economic Cooperation and Development (OECD) monitoring survey as well as nationwide and continent wide studies (Nathanso, 2000) of lakes in 18 countries, 65% of total lakes are eutrophic and 18% are oligotrophic. Similarly, in the United States, 70% are eutrophic and only 7% are oligotrophic (Biswas, 1996).

In Africa the water level of the lake Naivasha declined between 1980 and 1987 and exposed about 35% of the littoral soil, resulting in clearance of lakeside vegetation (Cyprus papyrus and other emergent plants) (Biswas, 1996 and Gizaw et al., 2004).

* Corresponding author. Present address: H. No. 1357, Sector 15, Faridabad 121007, Haryana, India. Tel.: +91 1294006166,67.
E-mail address: rani_sahu@yahoo.com (R. Devi).

0960-8524/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biortech.2007.03.013

In Ethiopia, the annual incremental yield from forests does not exceed 14.5 million m^3 per year (Abiyou, 2004). This situation along with rugged topography of the country exacerbates severe topsoil erosion and run-off agrochemicals, which end up in siltation of various water bodies thereby upsetting their aquatic biota (Abiyou, 2004).

Like any other African nation Ethiopia is also having nutrient enrichment of dams, ponds and lakes, which is a big challenge. Abasamuel Lake in Addis Ababa, for instance, is now completely eutrophied and lost recreational value due to the impacts of town wastes, poor agricultural activities around the reservoir and poor watershed level management (Gizaw et al., 2004). Similarly, some preliminary studies indicate that the levels of some reservoirs (e.g., Koka reservoir), rivers and lakes (e.g., Alemaya, Awassa, Abaya, and Langano rivers) have decreased. The process is so challenging that the initial water carrying capacity of Aba-Samyuel dam (70 m^3) has reduced to about 50% due to progressive silt accumulation (4.45 tones of silt/km^2), while the Koka dam has accumulated about 3.5 million m^3 of silt (or 2300 t/km^2) in just 23 years (Gizaw et al., 2004).

As part of the overall effort to improve the life of its people, the Federal Government of Ethiopia has launched a number of development projects throughout the nation. One notable example worth mentioning is the Gilgel Gibe hydroelectric dam construction (Yonas, 1996). The dam has a capacity of 917 million cubic meter water. The area of the dam is 5 km by 18 km and the depth is 4.0 m at the intake. This modern rock fill hydroelectric dam was constructed using more than three billion cubic meters of stone and is the first of its kind in the nation. It would produce 184 MW electricity. It could increase the nation's electric power by about 40%. 380 towns and 164 woredas would be beneficiaries from this dam and a transmission line of 750 km is under construction for the export of electricity to its neighbouring counties such as Djibouti, Kenya and Sudan (EEPLA, 1996).

The dam was constructed downstream of Jimma where untreated wastewater generated by more than 151,697 inhabitants is being directly discharged into the main tributary of Gilgel Gibe River. As the river flows through various centers of commercial activities, administrative units, rural dwellers and all of these interact with the river in an unceasing manner in the form of cattle grazing, cloth washing, bathing, drinking, and farming. These affect the ecology of the river system as well as the newly constructed dam by its siltation or eutrophication (Jamie and Richard, 1996; and Nezif, 1999).

A rainstorm generally causes increases in discharge and is associated with turbulence in a dam and this turbulence takes its bed sediments in the form of suspended material. The physical and chemical characteristics of the river significantly vary depending on the season of the year (Tebbut, 1983 and Deborah, 1996). Therefore, the findings of this study may not represent the actual condition of the dam throughout the year. The best representative results can be obtained from studies carried out through the whole year.

Although the problems discussed above were likely to be a major setback for the economic life of Gilgel Gibe dam, so far no research work existed on the rate of siltation and nutrient input to address this issue for early recognition and to put remedial solutions in its place. Therefore, the aim of this study was to know its current status and forward remedial solutions for the present and emerging problems.

2. Methodology

The Gilgel Gibe Hydroelectric project is located about 55 km from Jimma (Ethiopia) on the Addis Ababa-Jimma highway as shown in Fig. 1. The Gilgel Gibe dam was built with an estimated total cost of 2.2 billion Birr with the finantial support of the World Bank (Yonas, 1996). A cross-sectional study was conducted during 2005 to assess siltation and nutrient enrichment of Gilgel Gibe dam.

2.1. Data collection

Secondary data were collected from the office of the Gilgel Gibe Hydroelectric Power Project Office. The Catchment disturbances and anthropogenic impacts were also analysed using pre-designed observational checklist.

2.2. Water sampling technique

Composite and integrated sampling techniques were employed to take water samples for physico-chemical analysis following the standard procedures. Samples were stored at 2–3 °C, transported soon within 6 h and analyzed immediately to avoid any change in their physico-chemical characteristics.

2.3. Variables and their measurements

2.3.1. Discharge

The discharge of the river into the dam was calculated using a hydrological formula (Jamie and Richard, 1996) and the instruments and materials used were flow meter, tap measure and chaining pins.

2.3.2. Measurements of the sediment load of river

Sediment concentration was measured in terms of TDS and TSS and turbidity using the standard procedures (Jamie and Richard, 1996). Measurement of the quantity of sand + silt + clay (i.e., $\leqslant$62 μm) in a sample requires that a known volume [V_{sample} (ml)] of well-mixed sample was first passed through a 62 μm mesh sieve. The sample was wet sieved, i.e., distilled water was used to rinse the sample through the sieve. All of the water that passes through the sieve (original sample plus the water in which the sample was rinsed) was collected and filtered through a membrane filter of 0.45 μm pore size and having known

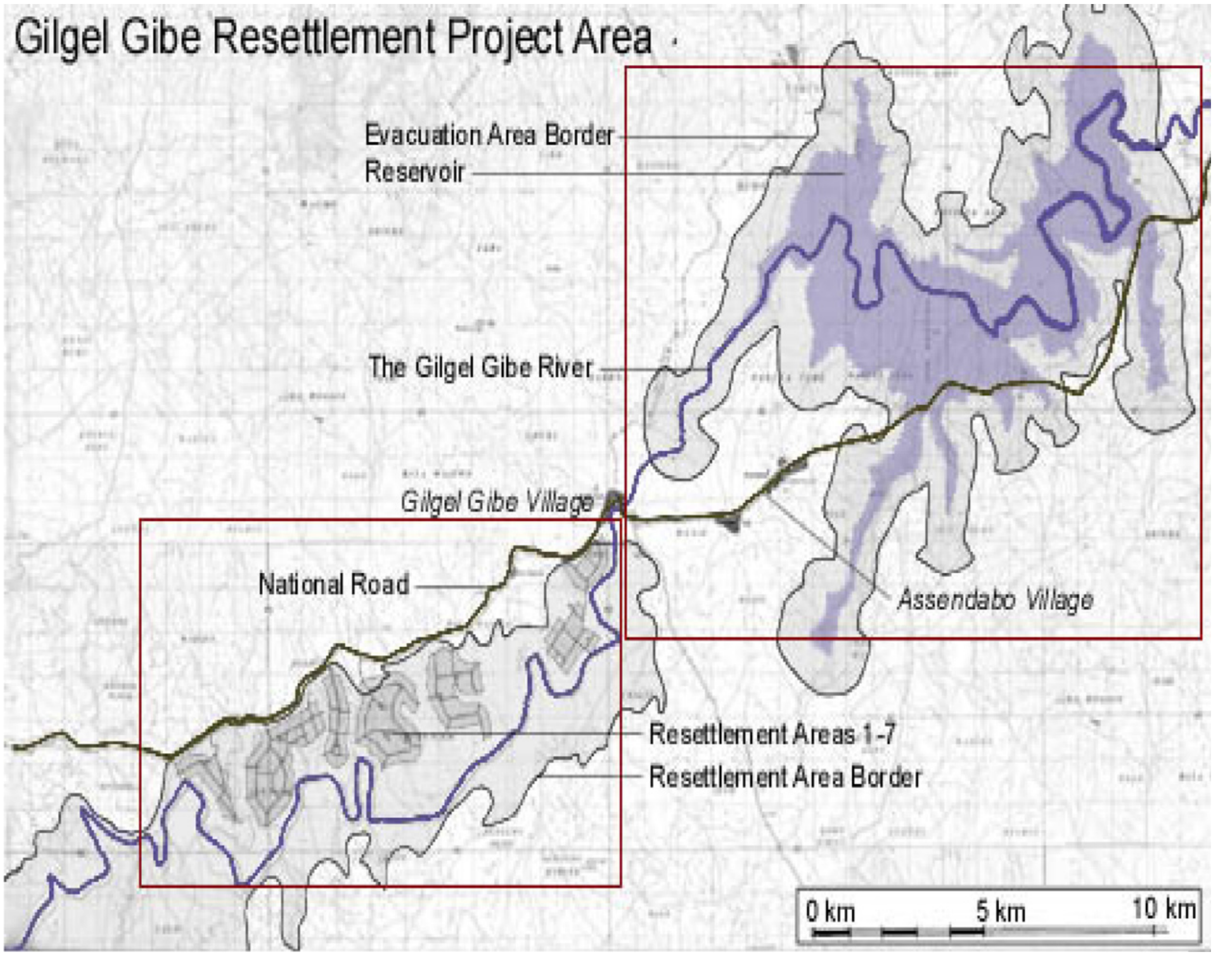

Fig. 1. Map of Gilgel Gibe dam (Source Ethiopian Electric Light and Power, Authority (EELPA)).

weight. A known volume of raw water was filtered through a pre-weighed 0.45 μm pore diameter filter paper. The total sediment concentration (TS) is calculated as

$$\text{TS concentration (mg/l)} = \{W_{\text{sand+silt+clay}}/V_{\text{sample}}\} \times 10^6 \quad (1)$$

where $W_{\text{sand+silt+clay}}$ is the weight of sand + silt + clay, V_{sample} is the volume of the sample and the suspended sediment concentration (SS) is calculated as

$$\begin{aligned}\text{SS concentration (mg/l)} &= [\text{Dryweight (in grams) of the filter paper}\\ &\quad + \text{retained sediment}\\ &\quad - \text{the original weight of the filter paper}]\\ &\quad /\text{volume (ml) of the sample} \quad (2)\end{aligned}$$

2.3.3. Estimation of suspended sediment concentration in rivers

In rivers there was a moderately good relationship between suspended sediment concentration and discharge, i.e., the higher the discharge, the higher the suspended sediment concentration. It was possible, therefore, to develop a rating curve, which was a regression of suspended sediment concentration Y as a function of discharge X. This relationship was, however, subject to a high degree of variability and error. The suspended sediment load (SSL) in tons per day was calculated as (Jamie and Richard, 1996)

$$\text{SSL} = Q_{\text{observed}} \times C_{\text{estimated}} \times 0.0864 \quad (3)$$

where Q is the discharge of the river, C is the concentration of the suspended sediments and 0.0864 is a constant.

This procedure was carried out daily and the daily loads were summed for the months and calculated for the year. The bed load was also estimated as 25% of suspended load (Garg, 1996).

2.3.4. Estimation of catchment sediment load

The sediment yield of a reservoir basically depends on sheet erosion, which can be estimated with the help of empirical Musgrave equation (Garg, 1996).

2.3.5. Measurements of other variables

Temperature, pH, chlorophyll *a* and visibility were measured at the site using a thermometer, portable pH meter, and secchi disc, respectively. Average depth of the dam was also measured using a string and heavy rod attached to it from different sites and calculated. The analysis for ammonia, nitrate, phosphate, BOD, DO and sulphate was done according to the standard methods, such as direct Nesslenzation method for ammonia, phenoldisulfonic acid method for nitrate, stannous chloride method for phosphate, titrometric method for BOD, azide modification of the Winkler method for DO and gravimetric method for sulphate analysis prescribed by the American Public Health Association (APHA, 1995).

3. Results and discussion

During the field visits, it was observed that the people living around the catchment areas used fertilizers to increase land productivity, practised poor agricultural activities besides deforestation and over grazing by animals. There was also no buffer zone and protection measure against sheet erosion.

The sheet erosion of catchment area was calculated and found to be 4.47×10^7 ton/year and hence was 2210 ton/square km as from the secondary data (Yonas, 1996). The contribution of the sediment load of the Gilgel Gibe River to the dam was 277,437 ton/year and the total sediment load was 4.50×10^7 ton/year, and this amount could occupy 3.75×10^7 m^3/year.

The water analysis of Gilgel Gibe dam has indicated that the concentrations of ammonia, chlorophyll *a*, total dissolved solids (TDS), dissolved oxygen (DO), biological oxygen demand (BOD), pH and temperature were 0.142 mg/l, 3.4 μg/l, 140 mg/l, 5.5 mg/l, 3.2 mg/l, 7.7 and 24.9 °C, respectively, and by comparing with WHO norms, these parameters were within the permissible limits as shown in Table 1. But the other important parameters such as phosphate, nitrate, sulphate, total solids (TS), total suspended solids (TSS), turbidity and visibility were much higher than the permissible limits and their values are 952 mg/l 0.165 mg/l, 675 mg/l, 600 mg/l, 460 mg/l, 296 NTU and 0.72 m, respectively, as shown in Table 1.

Nitrogen was also associated with algal growth and eutrophication of this dam. This might be associated with the use of fertilizers around the dam and the decomposition of organic debris added from sheet erosion and the river load. The concentration of phosphate in the Gilgel Gibe dam was found to be 952 mg/l, which was about 99 times the critical concentration and enough to cause high algal growth. This excess concentration in the dam might be due to the use of fertilizers, use of detergents for bathing and washing clothes by rural and Assendabo town residents and land erosion. The newly submerged plants and grasses might also have an impact on the nutrient enrichment of the dam.

The concentration of chlorophyll *a* in the Gilgel Gibe dam was found to be 3.4 μg/l, which was within the limit of mean mesotrophic lakes. The chlorophyll *a*, which provides an indirect measure of algal biomass was highly correlated with the concentration of nutrients such as phosphate, nitrate and ammonia and had the correlation coefficient (γ) of 0.7803, 0.982 and 0.974, respectively. This low algal biomass in the dam unlike other parameters might be due to the recent construction of the dam, and algae and other aquatic plants needed time to grow.

Secchi disc visibility standards for mean value of oligotrophic lake are in the range of 6–3 m and for mesotophic lakes are 3–1.5 m, and for eutrophic lake are 1.5–0.70 m (Deborah, 1996). Due to the high suspended and sediment load, the secchi disc visibility of Gilgel Gibe dam was 0.72 m which indicated that it was within the range of eutrophic lakes.

4. Conclusions and recommendations

Based on the results of physico-chemical parameters and data obtained using the observational checklists, siltation

Table 1
Physicochemical parameters of Gilgel Gibe dam, Ethiopia measured during 2005 and permissible standards limits of WHO for comparison

Parameters	Gilgel Gibe river inlet (A)	Gilgel Gibe dam (B)	Outflow of the dam (C)	WHO permissible limits
Phosphate (mg/l)	634	952	512	10
Nitrate (mg/l)	0.140	0.165	0.120	0.05
Ammonia (mg/l)	0.131	0.142	0.121	0.5
Sulphate (mg/l)	665.1	675	620.25	150
Chlorophyll *a* (μg/l)	1.8	3.4	1.6	20
TS (mg/l)	440	600	993	500
TSS (mg/l)	320	460	280	100
TDS (mg/l)	120	140	119	450
DO (mg/l)	6.0	5.5	6.2	4–6
BOD (mg/l)	3.0	3.2	2.8	20–30
Turbidity (NTU)	260	296	231	5–10
pH	7.2	7.7	7.4	6–8.5
Temperature (°C)	24.6	24.9	24.1	16–32
Depth (meter)	1.29	10.188	0.92	
Volume (m^3)	–	917×106	–	
Secchi disc visibility (m)	0.74	0.72	0.83	0.001
Discharge (m^3/s)	22		13	

and nutrient enrichment were the major problems of Gilgel Gibe hydroelectric power dam. It is estimated that the Gilgel Gibe dam will reduce its volume by half within 12 years and would be completely filled with sediments and eutrified within 24 years unless timely remedial measures are taken although it was expected to serve at least for 70 years. Based on the findings of this study, the following recommendations are forwarded: efficient use of fertilizers, specifically organic fertilizers, for different agricultural activities, reparation of green belt; removal of post flood water; erosion control; and introduction of soil conservation activities besides creation of ecological awareness among the residents dwelling near and around the dam.

References

Abiyou, M., 2004. Integrated water resources management. Basic concepts and approach for sustainable water resource development. Ethiopia first water forum, Addis Ababa.

APHA, (American Public Health Association), 1995. Standard Methods for Examination of Water and Wastewater, nineteenth ed. Washington, DC., New York.

Biswas, A.K., 1996. Water resources, Environmental planning, management, and development.

Deborah, C., 1996. Water Quality Assessments, A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring, second ed. E and FN SPON, WHO and UNCFP.

EEPLA, M.o.M.a.E., 1996. The Federal Democratic Republic of Ethiopia, Gilgel Gibe Hydroelectric Project Resettlement Plan, Addis Ababa, Ethiopia.

Garg, S.K., 1996. Irrigation Engineering and Hydraulic Structures, fourteenth ed. Khanna Publications, Delhi.

Gizaw, E., Legesse, W., Haddis, A., Deboch, D., Birke, W., 2004. Assessment of factors contributing to eutrophication of Abasamuel water reservoir in Addis Ababa Ethiopia. Journal of Health Science 14 (2), 112–113.

Jamie, B., Richard, B., 1996. Water quality monitoring, a practical guide to the design and implementation of fresh water quality studies and monitoring programmers. UNEP, WHO and E and FN SPON.

Lynch, R.A., Phillips, M.L., 2000. Adverse impact on ponds of organic debris deposited by tornadoes. Journal of Environmental, Health 63, 14–16.

Nathanso, J.A., 2000. Basic Environmental Technology, third ed. Prentice-Hall Inc., USA.

Nezif, A.C., 1999. Pre-mobilization survey of agro-ecological situation in the resettlement area Jimma. Adis Ababa, Ethiopia.

Saigo, C., 1995. Environmental Science, third ed. WM.C. Brown Publisher, USA.

Tebbut, T.H.Y., 1983. Principles of Water Quality Control, third ed. New York Pergamon Press, USA.

Yonas, A., 1996. Gilgel Gibe resettlement project: Implementation plan.