



ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

**RIVER SEDIMENT TRANSPORT MONITORING TO IMPROVE THE
LIFE SPAN OF DAMS**

**A Thesis Submitted to the School of Graduate Studies of Addis Ababa
University in Partial Fulfillment for the Requirement of the Degree of
Master of Science in Civil and Environmental Engineering (Major in
Hydraulic Engineering)**

BY

SIED ZNABU MEHAMED

ADVISOR

DR. ING. MEBRUK MOHAMMED

August, 2014

ADDIS ABAB UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES

RIVER SEDIMENT TRANSPORT MONITORING TO IMPROVE THE LIFE SPAN OF
DAMS

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment for the Requirements of the Degree of Master of Science in Civil and Environmental Engineering (Major in Hydraulic Engineering)

BY

SIED ZNABU MEHAMED

APPROVED BY BOARD OF EXAMINERS:

----- Chairman (department of graduate committee)	----- Signature	----- Date
----- Advisor	----- Signature	----- Date
----- Internal Examiner	----- Signature	----- Date
----- External Examiner	----- Signature	----- Date

CERTIFICATION

The undersigned, certify that I have read the thesis entitled: **“River Sediment Transport Monitoring to Improve the Life Span of a Dams”** and here by recommended for acceptance by the Addis Ababa University in partial fulfillment for the requirement of the degree of Master of Science in Civil and Environmental Engineering majoring Hydraulic Engineering.

Dr. Ing. Mebruk Mohammed
(Advisor)

Date

DECLARATION AND COPYRIGHT

I, the undersigned, declare that this thesis is my own original work and it has not been presented and will not be presented by me to any other University for the similar or any other degree award.

Declared by:

Name _____

Signature: _____

Date _____

This thesis is a copyrighted protected under the Berne Convention, the copyright Act 1999 and other international and national enactments, in that behalf, on intellectual property. It may not be reproduced by any means in full or in part, except for short extract in fair dealing, for research or private study, critical scholarly review or discourse with acknowledgement, without written permission of the school of postgraduate studies, on behalf of both the author and the Addis Ababa University.

ACKNOWLEDGMENT

First and foremost, I would like to thank the Almighty God for giving me life, patience, courage, wisdom and who made it possible, to begin and finish this work successfully.

I am very grateful to my advisor Dr. Ing. Mebruk Mohammed and I extend my heartfelt gratitude to his unreserved support in guiding me through this research from its start to the end with limitless help in giving valuable advice, providing supportive materials and critical constructive comments. Without his supports and valuable advices, the entire work could not have come in to existence

I also forward my sincere thanks to Water, Irrigation and Energy Minister, particularly for the staff members of the Department of Hydrology and Data Base, GIS and library, for their considerable support in providing me with hydrological data and other reference materials. In addition, I would like to thank to Water Works, Design and Supervision Enterprise for sharing their experiences and co-operations in availing the necessary data.

My all-time thanks spread out to my family who were always beside me giving their cordial support, patience and love.

At last but not least, I would like to extend my deepest gratitude to all my friends and course mates for their contributions to my course and the research work; they really made for me a wonderful social atmosphere.

ABSTRACT

With reasonable levels of maintenance, the structural life of dams is virtually unlimited. Most reservoirs are designed and operated on the concept of a finite life which ultimately be terminated by sediment accumulation rather than structural obsolescence. In Ethiopia sedimentation has theoretically been expected to be controlled through watershed management practices, however the story behind dams like Koka, Angereb, Legedadhi, and Gilgel Gibe-I, which are threatened by an accelerated sedimentation, tells a different approach is needed in monitoring the sedimentation of reservoirs. River sediment transport towards a reservoir monitoring can achieve through implementing upstream silt traps, bypassing heavily sediment laden flows, reservoir drawdown and flushing, density current flushing etc.

Ethiopian rivers usually contain a larger sediment concentration at the beginning of the rainy season. Thus among the approaches of monitoring sediment inflow to a reservoir, bypassing days of heavily sediment laden flows was analyzed in this study for its practicability on newly constructed Kesem-Kebena, Tendaho and Rib dams. Such sediment control measure enables to reduce annual inflow of sediments to a reservoir on the expense of losing the water that would join the reservoir.

The merits and demerits of using storage approach tool and benefit cost analysis based on the income of the project, are comparatively tasted on those three Ethiopian dams for both effects of the dam storage and the improved life span of the dam. The result showed that, by passing the days of flow of August, August & September, August & July for Kesem Kebena, Tendaho and Rib dams, respectively will bring about more reasonable benefit than letting the river's flow in these months to the reservoir. By passing a day of river flow in August will improve the life span by 2.1 year for Kesem, 0.7 year for Tendaho and 0.9 year for Rib dam. The extended life span of the dams has net storage benefit of 454 million cubic meters (MCM), 788 MCM and 50 MCM, for the three dams, respectively. The cost benefit analysis of a day of August flow by passing has benefit cost ratio of 4.3, 2.7 and 1.7, respectively. However, the result shall be seen with caution that it does not considered the possible sediment volume reduction by watershed management practices. Thus, the research also put some directions of monitoring techniques; however, to select the most suitable sediment treatment method shall be decided with the consideration of topography and flows of river, effectiveness, economic, environmental and various conditions.

Key words: Kesem- Kebena Dam, Life Span of Dams, Ribb Dam, Sediment by passing, Sediment Transport Monitoring, Sediment Transport, Tendaho Dam, Reservoir Sedimentation, Benefit Cost Analysis

TABLE OF CONTENTS

ACKNOWLEDGMENT.....	I
ABSTRACT.....	II
TABLE OF CONTENTS.....	IV
LIST OF TABLES.....	VII
LIST OF FIGURES.....	VIII
ABBREVIATIONS.....	X
CHAPTER ONE.....	1
INTRODUCTION.....	1
1.1. Background.....	1
1.2. Statement of the problem.....	2
1.3. Research Questions and Hypothesis.....	3
1.4. Objectives.....	3
1.3.1 General Objective.....	3
1.3.2. Specific Objectives.....	3
1.5. Thesis Organization.....	4
CHAPTER TWO.....	5
LITERATURE REVIEW.....	5

2.1. Sediment Transport in Rivers	5
2.2. Reservoir Sedimentation	5
2.2.1 Types of Reservoir Sedimentation	7
2.3. Trap Efficiency	8
2.4. Rating Curve.....	9
2.5. Concepts of Reservoir Life.....	10
2.6. Sedimentation Extent and Subsequent Effect on Reservoir	10
2.7. Assessing Sediment Reduction/Monitoring Techniques.....	13
2.7.1 Retention of Coarse Sediments in Upstream Silt Trap Dams	16
2.7.2 Bypassing of Heavily Sediment-Laden Flows	16
2.7.3 Reservoir Drawdown and Flushing.....	17
2.7.4 Density Current Flushing	17
2.7.5 Venting of Sediments through Under Sluices	18
2.7.6 Reservoir Operation Policy for Sediment Control	19
 CHAPTER THREE	 20
 METHODS AND MATERIALS.....	 20
3.1. DESCRIPTION OF THE STUDY AREA	20
3.1.1 Location.....	20
3.1.2 Climate	23
3.1.3 Hydrology.....	25
3.1.4 Land Use and Land Cover.....	30
3.1.5 Soil.....	32
3.2. METHODS AND MATERIALS	33
3.2.1 Materials Used.....	33
3.2.2 Data Analysis and Screen.....	34
3.2.3 Storage Variation Analysis.....	34

3.2.4 Benefit- Cost Analysis.....	37
CHAPTER FOUR.....	41
RESULT AND DISCUSSION	41
4.1. Storage Variation Analysis.....	41
4.1.1. Kesem Kebena Dam Irrigation Project.....	41
4.1.2. Tendaho Dam Irrigation Project.....	49
4.1.3. Ribb Dam Irrigation Project	56
4.2. Benefit Cost Analysis Based on Annual Income of the Project.....	63
4.2.1. Kesem Kebena Dam Irrigation Project.....	63
4.2.2. Tendaho Dam Irrigation Project.....	65
4.2.3. Ribb Dam Irrigation Project	67
CHAPTER FIVE	70
CONCLUSION AND RECOMMENDATION.....	70
5.1. Conclusion	70
5.2. Recommendation	73
APPENDIXES	78

LIST OF TABLES

Table 4.1: Monthly inflow and storage loss of Kesem Kebena dam	45
Table 4.2: Storage due to sediment reduction of Kesem Kebena dam	47
Table 4.3: Net storage of Kesem Kebena dam.....	49
Table 4.4: Net storage of Kesem Kebena dam for the selected month (August), daily basis.....	52
Table 4.5: Monthly inflow and storage loss of Tendaho dam	53
Table 4.6: Storage due to sediment reduction of Tendaho dam.....	54
Table 4.7: Net storage of Tendaho dam.....	55
Table 4.8: Net storage of Tendaho dam for the selected month (August), daily basis.....	58
Table 4.9: Net storage of Tendaho dam for the selected month (September), daily basis	60
Table 4.10: Monthly inflow and storage loss of Ribb dam.....	61
Table 4.11: Storage due to sediment reduction of Ribb dam.....	62
Table 4.12: Net storage of Ribb dam	63
Table 4.13: Net Storage of Ribb dam for the selected month (August), daily basis.....	66
Table 4.14: Net Storage of Ribb dam for the selected month (July), daily basis	67
Table 4.15: Benefit cost analysis of Kesem Kebena dam.....	68
Table 4.16: Benefit cost analysis of Tendaho dam	70
Table 4.17: Benefit cost analysis of Ribb dam	73

LIST OF FIGURES

Figure 2.1: Longitudinal cross section of reservoir sedimentation	8
Figure 2.: Schematic of over flow, under flow, and inter flow patterns of incoming flow at a reservoir	19
Figure 3.1: Location map of Kesem Kebena dam project area.....	22
Figure 3.2: Location map of Tendaho dam project area	23
Figure 3.3: Location map of Ribb dam project area	24
Figure.3.4: Monthly inflow at Kesem Kebena dam irrigation project based on the 1963-2003 average inflow	27
Figure 3.5: Monthly sediment transport at Kesem Kebena dam project irrigation project based on the 1963-2003 average inflow	28
Figure 3.6: Monthly inflow at Tendaho dam irrigation project based on the 1962-2002 average inflow	29
Figure 3.7: Monthly sediment transport at Tendaho dam project based on the 1962-2002 average inflow	29
Figure 3.8: Monthly inflow at Ribb dam irrigation project based on the 1960-2004 average inflow.	31
Figure 3.9: Monthly sediment transport at Ribb dam project based on the 1960-2004 average inflow	31
Figure 4.1: Net storage of Kesem Kebena dam	49
Figure 4.2: Net storage of Kesem Kebena dam in daily basis	50
Figure 4.3: Net storage of Tendaho dam.....	55
Figure 4.4: Net storage of Tendaho dam in in daily basis	56
Figure 4.5: Net storage for Ribb dam	63
Figura 4.6: Net storage of Ribb dam in in daily basis	64

Figure 4.7: Benefit cost analysis of Kesem Kebena dam, for the selected month of august 69

Figure 4.8: Benefit cost analysis of Tendaho dam, for the selected month of august 71

Figure 4.9: Benefit cost analysis for Tendaho dam, for the selected month of september 71

Figure 4.10: Benefit cost analysis of Ribb dam, for the selected month of august 73

ABBREVIATIONS

AI:	Annual Inflow
AI:	Annual Income of the Project
ASI:	Annual Sediment Inflow
asl:	At Mean Sea Level
B:	Benefit
BCR:	Benefit-Cost Ratio
BCA:	Benefit-Cost Analysis
BCEOM:	French Engineering Consulting
C:	Cost
CBKB:	Cost Benefit Knowledge Bank
DL:	Design Life
ESI:	Expected Sediment Inflow
ET:	Evapotranspiration
HPTA:	Hydrology Project Technical Assistance
ILS:	Improved Life Span
ITCZ:	Inter-Tropical Convergence Zone
MB:	Million Birr
MCM:	Million Cubic Meters
MI:	Monthly Inflow
MoWE:	Ministry of Water and Energy

MSI:	Monthly Sediment Inflow
NBCBN-RE:	Nile Basin Capacity Building Network for the River Engineering
NLS:	New Life Span
NS:	New Storage
NSI:	New Sediment Inflow
PR:	Production Rate
SL:	Storage Lost
NS:	Net Storage
SR:	Storage Due to Sediment Reduction
tc/ y:	Tons of Cane per Year
TCD:	Tons of Cane per Day
USA:	United State of America
URS:	Unit Rate of Stored water
UTM:	Universal Transverse Mercator
WPCOS:	Water and Power Consultancy Service
WR:	Water Release
WWDSE:	Water Works, Design and Supervision Enterprise

CHAPTER ONE

INTRODUCTION

1.1. Background

Reservoirs are created through the construction of dams across rivers for the purpose of flood control, hydropower generation, irrigation, navigation, water supply, fishing and recreation. Due to these human interventions, Environmental impacts and long-term morphological changes on the natural water course are inevitable. Sedimentation is the major problem which endangers and threatens the performance and sustainability of reservoirs. It reduces the effectiveness of flood control volume, it presents hazards to navigation, it changes water stage and underground water conditions, it affects operation of low-level outlets gates and valves and reduces stability, water quality and recreational benefits.

Worldwide Reservoir Sedimentation is a serious problem and considered as salient enemy. The graduate loss of capacity reduces the effectiveness of the life span of dams and diminishes the benefits for irrigation, hydropower generation, flood control, water supply, navigation and recreation. On one hand sediment deposition propagates upstream and up tributaries, it raises local groundwater table, it also reduces channel flood capacity and bridge navigation clearance, and affects water division and withdrawals. On the other hand, the reduction of the sediment load downstream can result in channel and tributary degradation, bank erosion and it brings changes of the aquatic habits to these more suited to a clearer water discharge.

Sedimentation is a complex hydro-morphological process which is difficult to predict. It was underestimated and perceived in the past as a minor problem which could be controlled by sacrificing a certain volume of the reservoir for accumulation of the sediment (dead zone). Nowadays, experience teaches us that it has of paramount importance to take design and implementation of sediment control measures in to consideration in the plan, design, operation, and maintenance of the reservoirs.

The current state of art in combating the problem of reservoir sedimentation ranges from, measures which intend to reduce sediment influx into reservoirs by bypassing, trapping or by watershed

management, to measures which use artificial means (dredging) or utilize natural forces (flushing and sluicing) to clear or release incoming sediment along with the flow.

As can be tried to describe above, reservoir sediment is a severe threat to the optimal use of water resources in many river basins. Realizing the fact that sedimentation has often greatly reduced and endangered the live storages of many existing reservoirs coupled with the limitations of the existing sediment control measures, the subject of reservoir sedimentation has been a focal research area in water resources engineering. Though additional measurements are required in order to improve the life span of a dam's storage of a dam by monitoring sediments that are entered to the reservoir is one of the measurements that this research was interested in conducting a study.

1.2. Statement of the problem

Reservoirs are often threatened by loss of capacity due to sedimentation. Causes of reservoir sedimentation are many. Watershed, sediment and river characteristics are among the main natural contributing factors. Other important ones are reservoir size, shape, and reservoir operation strategy. Manmade activities play also a significant role particularly land use pattern.

The range of the problems caused by reservoir sedimentation is varied and wide. Apart from the already mentioned ones like loss of capacity, increased flood risks, interruption in hydropower generation and downstream river bed degradation; there are some other problems such as degradation of water quality, increased complexity in reservoir operation and maintenance and consequent increase in their associated costs. Generally, sedimentation is the most serious problem which reduces the life span of dams.

To control and/or mitigate reservoir sedimentation, different methods have been adopted. Some of these methods are: i) reduction of sediment inflow by watershed management, ii) upstream trapping, iii) control of sediment deposition in the reservoir, and iv) removal of deposited sediment. But, still the life spans of different Ethiopian dams are not long enough for the fact that they are not serving as expected because of sedimentation. So, additional studies are required on the river sediment flow and make the reservoir functional throughout the life span of its design by putting proper mitigation measures. This study focuses on investigating the sediment concentration distribution and reservoir inflow, by monitoring the extent of sediment entering the reservoir in order to improve the valuable life span of the dams.

1.3. Research Questions and Hypothesis

- What is the effect on the life of the projects design if sediment is monitored before it enters to the reservoir?
- What are the benefits and costs (merits or demerits) when the entering sediment to a reservoir is monitored?
- What sediment monitoring mechanisms can we use in a dam project?
- In the design phase of dam projects, is monitoring the entering sediment to a reservoir necessary to any Ethiopian dams?

1.4. Objectives

The study implied in a better knowledge for consideration of entering sediment monitoring, to improve the existing life spans of dam which are under construction and those to be constructed. This study also looks for existing dams which are already affected by siltation.

1.3.1 General Objective

- To improve the existing life spans of dams by monitoring the river sediment transport rate.

1.3.2. Specific Objectives

- To evaluate comparatively the merits and demerits of monitoring entering sediment on a dam projects based on its effect on the storage of the dam (storage approach).
- To analyze the benefit and cost of the method on a dam project when monitoring the entering sediment based on annual income of the project.
- To propose sediment monitoring mechanism to improve the existing life spans of the Ethiopian dams under investigation.

1.5. Thesis Organization

This thesis is organized in to five chapters:

Chapter one outlines the statement of the problem, objectives of the study, research questions and hypothesis. The chapter also provides some background information on the problems of optimal use of water resources in many river basins caused by sediment accumulation in reservoirs.

Chapter two briefly reviews related literature about sediment transport and erosion in rivers and reservoirs that sedimentation has often greatly reduced and endangered the live storage of many existing reservoirs. It also assesses on appropriate sediment monitoring techniques that may be used in order to remedy the sedimentation problems and improve the life spans of dams.

Chapter three deals with the location and general catchment characteristics of the study areas and it outlines the research methodology employed in this study. The approaches used for this study are included and discussed.

Chapter four concentrates on analysis, result and discussions using appropriate approaches of storage and BCA based on annual income of the project.

Chapter five summarizes the entire study by outlining a brief conclusion, and forwarding some recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1. Sediment Transport in Rivers

The sediment which is transported in rivers originates from soil erosion caused by wind and water with heat and frost being significant assisting forces. Sources of Sediment transported in a river are the catchment (sheet, rill, and gully erosion), the tributaries, bed erosion, bank erosion including landslides and falling rocks. Sediment transport can take place in various forms, according to the hydraulic conditions provided by the flow, and according to the properties of the sediment. Bed load and suspended load are only rough and ready, but inaccurate, classifications of the phenomena taking place in the river. There is no clearly defined separation point between the two kinds of motion in nature. Analytical description of sediment transport is difficult even when restricted to idealized one-dimensional considerations. In the vicinity of an intake structure, however, the flow is far from being one-dimensional. The complex three-dimensional flow pattern makes a strictly theoretical analytical treatment of the behavior of the sediment a nearly irresolvable task. The sediment transported by the river flow is usually not uniformly distributed. Transport rate and grain size distributions vary with the flow depth as well as the channel width. The sediment distribution with depth is dependent on flow characteristics and sediment properties: the coarser the sediment and/or lower the flow intensity, the higher the rate of bed load transported and the lower the amount of sediment in suspension (Scheuerlein H. & Mitalo F., 1993).

2.2. Reservoir Sedimentation

The reservoir sedimentation involves entrainment, transport and deposition. They originate from the catchments area, river system and settle in reservoirs. As a river enters the reservoir, its cross section of inflow is enlarged due to the effect of the backwater curve. Thus it causes a decrease in the water flow velocity; subsequently the sediment carrying capacity of water is reduced too. The major part, or all, of the sediment transported will deposit in the u/s part of the reservoir influenced by the back water curve. Reservoir sedimentation undergoes different processes of transportation and settling of sediment. This causes the reservoir to possess different kinds of deposition at different positions. These differences are controlled by the effects of the sediment particle size, hydraulic condition and sediment transportation methods in the reservoir (NBCBN-RE, 2010).

Natural river reaches are usually in state of morphological equilibrium where the sediment inflow on average balances the sediment outflow. Sediment deposition occurs as the flow enters the impounded reach of a reservoir due to a decrease in flow velocity and drop in transport capacity of the flow. The impounded reach will accumulate sediment and lose storage capacity until a new balance with respect to sediment inflow and outflow is again achieved. Sustainable sediment management should seek to balance sediment inflow and outflow across the impounded reach while maximizing long-term benefits. Traditional approaches to sediment management have not considered the sustainable use of reservoirs which resulted in losing reservoirs storage capacity rapidly, possibly as fast as 1 % per year, (*Mahmood 1987*).

Due to different behavior of sediment particles in transportation and deposition, they have different impacts on the reservoir sedimentation pattern and storage losses. Thus, it is important to treat each type separately, so as to understand how they are deposited and transported in the reservoir. This is hardly needed in analyzing the reservoir sedimentation problem and providing the best measures. The rate of the reservoir sedimentation and form of the deposition is affected by the rate of sediment transport and the method of its deposition in reservoir. Sediment particles are transported by different mechanism depending on the sediment size and the water sediment holding capacity. Due to existence of different kinds of sediment particle in the stream inflow, several transporting and depositing kinds occur in the reservoir. In general, the river sediment is divided in two major parts; bed-load and suspended load. They exist in the stream inflow at different ranges and different quantity with respect to the time and space. The increase or decrease of any type of sediment has direct reflection on the deposition pattern in the reservoir (NBCBN-RE, 2010).

Reservoir sediment deposition is a reflection of watershed erosion and deposition processes which are controlled by terrain form, soil type, surface cover, drainage networks and rainfall-related environmental attributes. In general, countries in Africa are experiencing deforestation, mainly from agricultural expansion and land degradation which are the leading causes of erosion and sedimentation (Julien and Shah, 2005). All reservoirs, formed by dams on natural rivers, are subject to some degree of sedimentation, which is continuously supplied by rainfall, runoff, snowmelt and river channel erosion (Randle *et al.*, 2007). The question is: How long will it take before the erosion adversely affects the dam's water control goal? Accumulation of sediment in the reservoir reduces its storage capacity. When this occurs at an accelerated rate, the reservoir's designed life is shortened.

Combined with this, chemicals and nutrients from cultivated land, industries and other related sources adversely affect water quality in reservoirs. The cost of removing these sediments and treating the pollutants is enormous. Smaller reservoirs (Angereb, Koka, Sennar and Khashm El Girba) are impacted more adversely by reservoir sedimentation than the larger ones (Roseires and Aswan) because the relative loss in capacity is much faster. However, Owen and Bujagali reservoirs receive almost negligible or limited amount of sediment since they are located each after another few kilometers downstream Victoria Lake, where almost all the sediment loads deposits (*Pro.Dr.Abdella, 2008*).

2.2.1 Types of Reservoir Sedimentation

The river flow usually carries a wide range of the sediment particle sizes and they are transported either as a bed load or as a suspended load. In general, the bed load material (coarse sediment particles) move near the bed and start to deposit in the beginning of the reservoir entrance in the form of the delta as shown in figure 2.1. The suspended sediments (fine sediment particle with lower settling velocities) are transported deeper into the reservoir either by non-stratified flow forming a uniform deposition at the middle of reservoir, or by stratified flow depositing at lower part of the reservoir forming a muddy lake. Generally the suspended load is divided in two parts; one comes from the bed of the river, and the other load from the catchments area as wash load (NBCN-RE-2010).

Batuca and Jordaan (2000) have classified the reservoir sedimentation based on the location of deposition into three categories, with inclusion of the sedimentation in backwater reaches as a part of the reservoir sedimentation. The position of each type of reservoir sedimentation can be seen in the longitudinal profile of the reservoir shown in figures 2.1 which are classified as Back water deposition, Delta deposition and Bottom set deposition. The Back water type of deposition occurs in the river reach before entering the reservoir. After changing the water level in the river by the effect of back water curve, the velocity of water will be reduced. Subsequently a small part of the coarse sediment will deposit in this region till it reaches the reservoir delta deposition. It is considered as a transition between the original river bed and delta formation as shown in figure 2.1. And the Delta deposition is formation is caused by rivers that enter a reservoir, lake, or sea. The process involves deposition of sediment of large sand sizes (bed load) due to the reduction of stream sediment holding capacity. Mainly, the change of the water level and the expansion of the inflow cross section in the reservoir are considered to be the most important reasons to diminish the water

velocity and continuity of sediment movement in the stream at the delta reach. Therefore the deposition happens in this place at the beginning. The deltaic deposition takes place along and across the reservoir and its basin (in the main river reach and over the flood plain as well). Bottom set deposition of the reservoir is formed by transporting and depositing the fine sediment, which is carried by the water to the middle and end of the reservoir in suspension stage. This type of deposition is mainly composed of clay and silt fraction, which are transported in the reservoir water body either by the turbulent suspension or by turbidity currents. Its deposition starts beyond the delta upstream the dam wall site (NBCBN-RE, 2010).

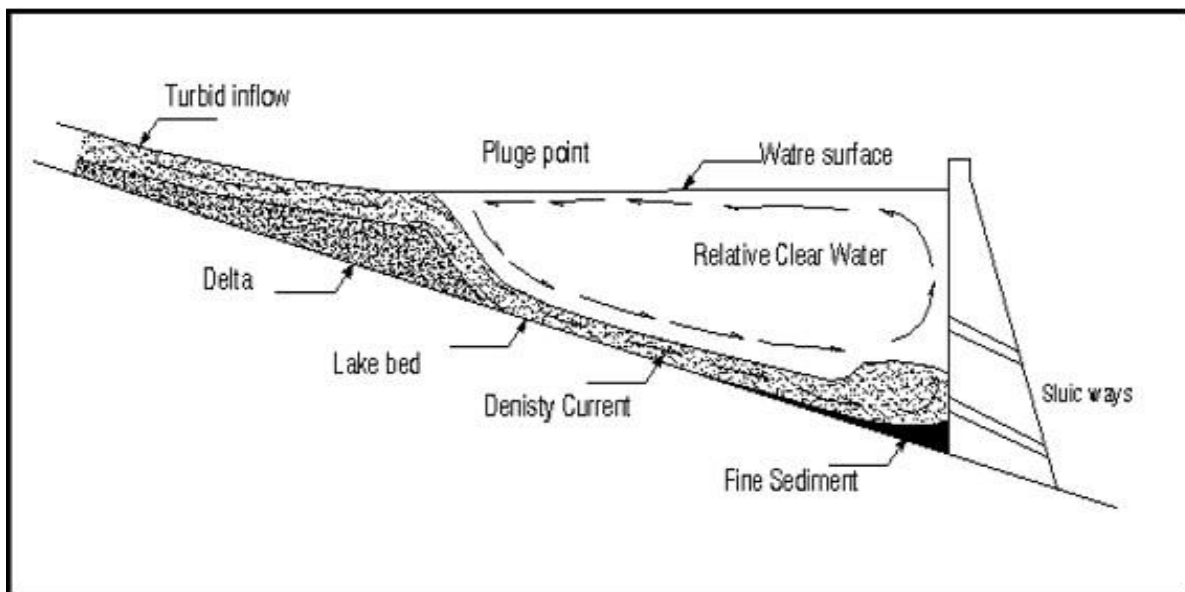


Figure 2.1: longitudinal cross section of reservoir sedimentation

2.3. Trap Efficiency

Reservoir trap efficiency is defined as the ratio of deposited sediment to total sediment inflow for a given period within the reservoir economic life. Trap efficiency is influenced by many factors but primarily is dependent upon the sediment fall velocity, flow rate through the reservoir and reservoir operation. The detention-storage time in respect to character of sediment appears to be the most significant controlling factor in most reservoirs, (Gottschalk, 1964). Trap efficiency estimates are empirically based upon measured sediment deposits in a large number of reservoirs mainly in USA. (Brune, 1953) and (Churchill, 1948) methods are the best known ones. Brune presented a set of envelope curves for use with normal ponded reservoirs using the capacity-inflow relationship, while

Churchill developed a relationship between the percentage of incoming sediment passing through a reservoir and a reservoir sedimentation index, which is defined as the ratio of the period of retention to the mean velocity through the reservoir. For a given reservoir experiencing sediment deposition, its trap efficiency decreases progressively with time due to the continued reduction in its capacity. Thus, trap efficiency is related to the reservoir remaining capacity after a given elapsed time (usually considered from the reservoir commissioning date). The trap efficiency is influenced by reservoir operation procedures.

2.4. Rating Curve

Flow is the variable usually required for hydrological analysis but, continuous measurement of flow past a river section is usually impractical or prohibitively expensive. However, stage can be observed continuously or at regular short time intervals with comparative ease and economy. Fortunately, a relation exists between stage and the corresponding discharge at river section. This relation is termed a stage-discharge relationship or stage-discharge rating curve or simply, rating curve. A rating curve is established by making a number of concurrent observations of stage and discharge over a period of time covering the expected range of stages at the river gauging section. At many locations, the discharge is not a unique function of stage; variables such as surface slope or rate of change of stage with respect to time must also be known to obtain the complete relationship in such circumstances. The rating relationship thus established is used to transform the observed stages in to the corresponding discharges (HPTA, 1999).

Discharge measurement is an issue of major importance for the evaluation of water balance at catchment scale, for the design of water-control and conveyance structures, for rainfall-runoff and flood routing model calibration and validation. Although several direct measurement approaches exist, only indirect approaches tend to be used operationally in medium and large rivers. Usually, discharge estimates are based on a one-to-one stage-discharge relationship, or steady-flow rating curve, which is derived on the basis of a number of simultaneous stage and discharge measurements. A measure of stage is then directly converted into discharge by means of the developed rating curve. Such an approach can be considered adequate for all rivers under steady-flow conditions, and also under unsteady-flow conditions, when flood waves show a marked kinematic behavior, which generally corresponds to rivers with steep bed slopes (F. Dottori and E. Todini, 2009).

The scatter in the data is considerable despite the attempt of imposing some order by plotting data

according to the time of the year. This is to be expected because sediment transport is a seasonal supply limited phenomenon resulting from rainfall-runoff in the catchment area. The suspended sediment is mostly fine material because weathering of the soils of the watershed during long, dry periods produces large transportable load of fine material. For a given water flow, suspended sediment transport rate is higher during the rising (July-August) than the falling flood stage (September-October). This loop in the sediment transport – water discharge relationship (sediment rating curve) is common for many rivers. A segment of the sediment rating curve is usually approximated by a power relation of the form:

$$Q_s = m Q^n \dots\dots\dots 1$$

Where: Q_s = suspended sediment transport (M tons/day)

Q = water discharge (m³/s)

m and n coefficient and exponent respectively.

The exponent n for many rivers varies little about a mean value of 2.0 (Garde, Ranga Raju 1985). Observations indicate that for higher and higher flood discharges, the exponent n will diminish and approach a value of unity ($n = 1$).

2.5. Concepts of Reservoir Life

With reasonable levels of maintenance, the structural life of dams is virtually unlimited, and most reservoirs are designed and operated on the concept of a finite life which will ultimately be terminated by sediment accumulation rather than structural obsolescence. Design life is the planning period used for designing the reservoir project. Planning and economic studies are typically based on a period not exceeding 50 years, whereas engineering studies often incorporate a 100-year sediment storage pool in the design. The target of a very long reservoir life should be a key point of a right design and management of siltation problems (Gregory L.Morros and Jiahan Fan, 1998).

2.6. Sedimentation Extent and Subsequent Effect on Reservoir

Many reservoirs which have been established for hydroelectric power, urban water supply and irrigation accumulate an alarmingly higher level of sediment than expected. Koka, Angereb, Legedadi, Gilgel Gibe-I and other reservoirs are threatened by this accelerated sedimentation. Consequences of reservoir sedimentation include the loss of storage capacity and its subsequent

effects. These effects include water supply shortages for human consumption, irrigation and hydropower; increased hydro-equipment maintenance and repair; a decline in water quality; the cost of removing sediment; blockage of navigational waters and loss of recreation opportunities. Aquatic ecosystems are modified by increased deposition of sediments and adsorbed or dissolved nutrients and chemicals, which commonly causes eutrophication which in turn negatively influences habitats of fish and other organisms. Some of the techniques suggested to reduce reservoir sediment concentration are technically less feasible as it requires design considerations during construction (which is difficult to implement for the existing dams). Removal of sediment is also economically demanding (Kebede, 2012).

The reservoirs of many countries are adversely affected by high rate of sedimentation: For instance, Nepal loses approximately 240 million m³ of sediment per year (Julien and Shah, 2005); and Afghanistan loses 150 million m³ per year (Seddeqy, 2007). It is estimated that 1.5 billion Mg of sediment are deposited each year in the USA reservoirs (Brady and Weil, 2002). Despite their technological sophistication, which did not consider soil erosion and sediment transport processes, four major Australian dams (Moore Creek, Gap, Korrumbyn Creek, Quipolly) built to provide water supply for domestic, agriculture and mining uses, became fully-silted in less than 25 years (Chanson and James, 1998). Diverse environmental problems and their consequences have been reported for Malaysia (Begum and Pereira, 2008). The deforestation and degradation of the Ethiopian Highlands have a negative impact on the downstream catchments (Awulachewet *al.*, 2008; Hathaway, 2008). More than 95% of Egypt's Aswan High Dam's mean annual suspended sediment load (120×10^6 t year⁻¹, Teodoruet *al.*, 2006) comes from Ethiopia, in which 72% comes from the Blue Nile and 25% from the Atbara River. Whereas, the White Nile contributes only 3% of the total sediment load (Teodoruet *al.*, 2006). Due to this high inflow of sediment, the design life age of the aswan high dam reservoir is estimated to be 265 years, which is only 50% of the reservoir's original design life (Shahin, 1993).

Moreover, land degradation due to anthropogenic factors in the Blue Nile's upper catchment dramatically increased sedimentation in Sennar, Khashm el-Girba and Roseires dams (all in Sudan) (Awulachewet *al.*, 2008; Shahin, 1993). Consequently, according to these authors, the Sennar reservoir is no longer used to store significant volumes of water but does generate a limited amount of hydropower, 15 MW). Khashm el-Girba dam lost 55% of its original capacity in 25 years and

Roseires dam lost 38% in 28 years. The problem of sedimentation is also widespread in Ethiopian reservoirs in which many lost storage capacity and water quality within a short period of time.

The Koka reservoir, supplied by the Awash and the Modjo rivers, was formed by the construction of the Koka dam in 1959 (with an original storage capacity 1650 Mm³) for developing hydroelectric power for domestic use (Musa *et al.*, 2005; Shahin, 1993). In 2000, Addis Ababa suffered power outages, even during the rainy season, after turbines at the Koka Dam became clogged with sediment (Hathaway, 2008). The mean annual sedimentation rate of this reservoir has been estimated or cited by several authors: 2302 tons/km²/year (Devi *et al.*, 2007); 13-20 Mm³ years (Musa *et al.*, 2005); 17 Mm³/year Amare (2005). It has been forecasted that using the existing operation, this reservoir will not be able to function effectively after some decades in the future (Shahin, 1993). Impacts of the Koka reservoir sedimentation have been well documented. In Koka dam, 481 Mm³ sediment has accumulated displacing an equivalent volume of water with an estimated economic loss of 60 million birr (displacement of 481 Mm³ of water by sediments translates into an energy loss of 128 M KWh, considering the average energy price of 0.45 Birr/KWh) (Elias, 2003). Koka reservoir serves as the only impounding reservoir for the awash watershed, which is the country's most important river basin in terms of existing developments and associated flood management (Elias, 2003; Achamyeleh, 2004). Flood control capacity is being reduced due to sedimentation, limiting the amount of retained water during the rainy season.

The Gilgel Gibe I hydroelectric dam has a capacity of 917 Mm³ water (Devi *et al.*, 2007). Hathaway (2008) indicated that according to the 1997 Environmental Assessment on this reservoir, a high sedimentation load was anticipated. The expectation has proven to be true because investigation by Devi *et al.* (2007) showed that the reservoir capacity has been reduced by annual sediment loads of 4.50×10^7 t year⁻¹ (from which Gilgel Gibe River contributes 277, 437 t year⁻¹) which could occupy 3.75×10^7 m³ year⁻¹. Based on the results of physico-chemical parameters and data obtained using the observational checklists, these researchers, estimated that the Gilgel Gibe I dam's volume will be reduced by half within 12 years and would be completely filled with sediments within 24 years unless timely remedial measures are taken. The dam was originally expected to serve at least for 70 years. The Aba-Samuel dam in Addis Ababa provided one of the first electric power generating stations in the country. Sedimentation is so prolific that the reservoir's initial water carrying capacity has been reduced by half due to silt accumulation (4.45 tons of silt km⁻²) and eutrophication (Devi *et*

al., 2007). Another, estimate indicates that it is losing storage capacity at a rate of 664, 980 t per year for the 43 years following construction (Amare, 2005).

Angereb Dam, which was constructed in early 1980 on Angereb River, a tributary of the Blue Nile, was primarily built to adequately supply drinking water to Gondar town (Musa *et al.*, 2005). The dam was feasible in terms of cost consideration and a judicious use of abundantly available local materials. Nevertheless, the Angereb Reservoir has not lived up to the design expectations because of siltation, in which about 1.4 Mm³ sediment has been accumulated (Amare, 2005; Hathaway, 2008). Other estimates by Musa *et al.* (2005) shows that the mean annual sedimentation rate in Angereb reservoir is 1200 t/km²/year. They predicted that the reservoir will lose 30% of its volume by the year 2015. Legedadi reservoir supplies 60% of water demand to Addis Ababa city, delivering 165, 000 cubic meters of water per day. A 20 years bathymetric survey (1978-1998) of this reservoir shows an average silt accumulation of 26, 000 m³ year, which results in a water shortage for the rapidly increasing Addis Ababa city residents (over 4 million people) (Gessese, 2008).

Ethiopia is building and planning to build, many hydroelectric power dams hoping electricity will become the biggest export, replacing coffee. The Gilgel Gibe III hydroelectric power project, which will dam the Omo River, creating a reservoir with a live storage of about 11, 750 Mm³ and a total surface area of 200 km² at normal operating level (889 masl) (EEPC, 2009). The reservoir is expected to be 155 km in total length with a catchment area of 34,150 Km². High rates of sedimentation are anticipated in the Gilgel Gibe III reservoir, where one-third of its space is reserved for sediments to accumulate over time (Hathaway, 2008). Heavy sedimentation experienced by Ethiopia's existing dams is a very real risk to the lifespan of new dams. The soon to be constructed on Blue Nile „Renaissance Dam“, which will be the largest hydroelectric dam in the country, is expected to experience a high sedimentation rate. These sediments are currently being captured in the Egypt and Sudan dams but will soon be trapped by the Renaissance Dam.

2.7. Assessing Sediment Reduction/Monitoring Techniques

In order to increase the life of the reservoir and to best achieve the purpose for which it has been constructed, reducing sediment inflow and removing sediment from the reservoir are substantial activities (Amare, 2005). Sediment inflow can be reduced either by implementing land management methods, particularly integrated watershed management, that reduce sediment yield or by implementing reservoir designs that reduce sediment intake. Haregewenyet *al.* (2006) categorized the

causes of threatening sedimentation in Tigray micro-dams in to two main groups: Poor design which is mainly engineering work that did not appropriately consider sediment yield; and absence of initial catchment management prior to dam implementation. Design of the water-holding structure needs to be considered to minimize sediment accumulation. Haregewenyet *al.* (2006) advises that the design of new dams and reservoirs should facilitate sediment management (e.g., providing bottom outlets) to assure long-term reservoir conservation. Various reservoir sediment removal techniques have been adopted taking into consideration, the different climate, hydrological and geographic conditions (Liu *et al.*, 2002). Awulachewet *al.*, 2008 stated that maximization of sediment through flow (i.e., sluicing), diversion of heavy sediment flow (by passing) and dredging, all help control sediment. Dredging, which most experts consider a costly operation, gathers bottom sediments and disposes of them at a different location Amare (2005) suggested that the outlet sluice will play a great role in reducing deposited sediment from the Angereb reservoir. Increasing water discharge in high runoff period is an alternative method suggested to reduce sediment retention.

To realize Ethiopian vision and to sustain water from these reservoirs, based on reviewed sources, the following practices should be strengthened (*Kebede, 2012*):

- Integrated watershed management, including various types of soil and water conservation measures, should be practiced in the upstream areas of the river basins
- Vegetation cover of the reservoirs' buffer zones should be increased
- Since the cost of desilting is enormous, during the design phase of new dams and reservoirs, more emphasis should be given to watershed based soil conservation
- National strategy and policy should be prepared and exercised with technically acceptable and coordinated approaches to erosion and sediment mitigation
- Ongoing efforts should be strengthened and continued through incorporating new research and continuous feedback

In many reservoirs, 50% or more of the original storage capacity is occupied by sediments. Sediment accumulation in reservoirs reduces their storage capacity and yield and limits their useful life if it is not controlled in some manner. There are two basic approaches for reservoir Sedimentation control: 1) controlling soil erosion through watershed management/ Reducing

Sediment Inflow into the Reservoir, and 2) handling sediment where it creates the problem, namely, in the reservoir/ Methods of Maximizing Sediment removal through flow. Watershed Management and Soil Conservation, Retention of Coarse Sediments in Upstream silt trap Dams, Bypassing of Heavily Sediment-Laden Flows, Trapping and Retention of Sediments by a Vegetative Screen are the first sediment control methods and Reservoir drawdown and flushing, Density Current Flushing, Venting of Sediments through under sluices are the second sediment control methods. The costly operation Mechanical removal of silt/sediment from reservoirs is the other method. Nevertheless, it is a standard means of maintaining the operational volume free of sediments if no other alternatives exist. AAWSA will practice mechanical removal of sediments from the reservoirs at least at the mean annual sedimentation rate (with the addition of a safety factor) once the dead storage is filled with sediments. This would be justified in the absence of other alternatives to prolong the reservoir life span. Dredging of Sediments and Excavation are included on this Mechanical removal of silt/sediment from reservoirs (Fasil, 2012).

The Problem of handling sediment that complicates the process of withdrawing water for human needs is addressed. Practical solutions based on analysis of sediment characteristics and flow behavior, are presented. These involve hydraulic structures associated with the intake works that are designed to divert, exclude or remove sediment from the water being abstracted. The extraction of water from rivers is one of the most ancient human activities in the field of hydraulic engineering. Nevertheless, the design of an intake structure in a natural river still belongs to the most delicate tasks even in our days. Problems arise mainly from the fact that in natural rivers besides the water also a considerable amount of sediment is transported. Therefore, the designers of intake structures repeatedly find themselves confronted with the problem of how to take the water out of the river while leaving the sediment behind. In developing countries construction and operation of river intakes deserve particular attention as the natural conditions in the rivers are usually more complex and at the same time less well documented than in industrialized areas. The separation from the water of sediment moving close to the bed is somewhat easier to handle than the exclusion of sediment in suspension. Sediment Rejection, sediment extraction and sediment ejection are the three control methods of bed load sediment and upstream settling basin, longitudinal settling tanks and circular settling tanks are the three control methods of suspended load sediments (Scheuerlein H. & Mitalo F., 1993).

Reservoir sedimentation is a significant problem in reservoir. Sediment accumulation in reservoirs reduces their storage capacity and yield and limits their useful life if it is not controlled in some manner. When a dam is built across a stream, the flow cross section progressively increases and the flow velocity decreases toward the dam. This leads to a decrease in sediment transport capacity, causing deposition of sediments, first in the backwaters created by the reservoir and then in the reservoir. Coarse particles are deposited first, and silt and clay particles are deposited in the deep portions of the reservoir in the vicinity of the dam. Sediment deposition continues to reduce the useful storage capacity of the reservoir, so much so that after a certain number of years, the reservoir may not be able to meet the purposes it was designed for. Due to the above mentioned problems it is must to reduce sediment inflow to the reservoir and also reduce sediment deposition in the reservoirs. Generally river sediment monitoring can be solved using different river monitoring techniques such as:

2.7.1 Retention of Coarse Sediments in Upstream Silt Trap Dams

Silt trap dams are low dams built across the main sediment-contributing tributaries of reservoirs. These dams are designed to control sediment inflow into the reservoir. They create small reservoirs, which tend to silt up faster than the main reservoir. Silt trap dams retain the coarse fraction of the sediment and thus are helpful in reducing sediment deposits in the main reservoir. A small dam can be built a few meters upstream of the lake or reservoir to induce deposition of coarse sediments in the pool. This silt trap dam has dual benefit i.e. silt trap and storage of water.

2.7.2 Bypassing of Heavily Sediment-Laden Flows

A great amount of sediment is carried by a stream or river during flood flows. A large part of such flow can be bypassed through a channel, tunnel, or pipes, can be constructed to bypass sediment-laden flow around the reservoir or part of it significantly reducing silting in the reservoir. It may be built initially and possibly used for flood control during construction. Most may also be built according to precise needs after years or decades of operation. The bypass may consist of a barrage for diversion of floods and a bypass canal joining the main stream or river some distance downstream of the dam; or it may be a bypass tunnel instead of a bypass canal. Pipelines can be anchored in a low submerged weir near the stream/lake junction, can be placed along the lake bed or partially embedded in it, and can discharge downstream of the dam. This technique has been successfully

applied in Italy . It has the ability of removing sediment quickly before joining to the reservoir. The above measures can considerably reduce the input of coarse sediment to the reservoir, and this can reduce extensive delta formation. The site conditions, topography, dam foundation and economic analysis will determine the feasibility and practicality of this measure. This solution may have much future for large schemes. (Roveri, 1981)

2.7.3 Reservoir Drawdown and Flushing

Drawing down the water level in a reservoir for the sake of reducing the amount of sedimentation, or in order to induce erosion of deposited sediment to recover storage capacity, is a method often used in reservoirs. The efficiency of sediment flushing depends on the topographic position of the reservoir, the capacity of the outlet, the outlet elevation, the characteristics of the inflow sediment, the mode of operation, the time duration of flushing, the flushing discharge, etc. Draw-down flushing has got some setbacks. The quantity which could have been evacuated is limited partly because the fine sediment deposits becoming consolidated, partly because deposition of the bed loads occurring in the upper part of the reservoir, and partly due to the high elevation of spillway through which the flushing discharge must pass. Sediment flushing must be done before the formation of considerable valley deposits. The outlet gates will require protection against abrasion by high sediment concentrations and blockage by sediment deposits.

2.7.4 Density Current Flushing

Gould defines a density current as a gravity flow of turbid water through, under or over water of different density (Fuat, 1994). The density difference being a function of the differences in temperature, salt content or silt content of the two fluids. The venting of density currents has long been considered an effective means of reducing the rate of reservoir silting, especially in impounding reservoirs. Following the recognition of the phenomenon of density currents, the method of density current flushing has been adopted in many reservoirs to reduce sedimentation (UNESCO, 1985).

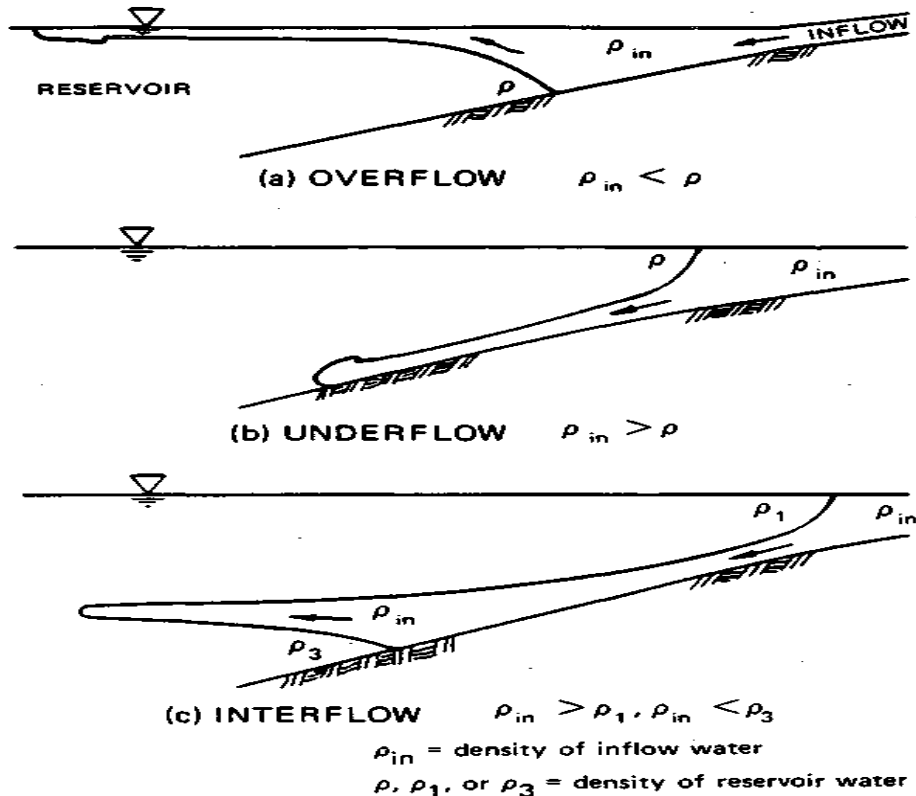


Figure 2.2: Schematic of over flow, underflow, and interflow patterns of incoming flow to a reservoir (after Wunderlich and Elder, 1973)

Density currents are very active during floods when sediment concentration loads are quite high. The topographic features of the reservoir and the hydraulic structures for sluicing are favorable for venting density currents. The original river channel has a steep slope, the inflowing sediments are composed primarily of fine materials, a relatively short distance of backwater exists, and the locations of the bottom outlets just above the river bed are favorable to density current flushing or venting. Generally, more sediment will be vented from short and medium-length reservoirs with large incoming discharges; high density sediment concentrations; low, large-capacity outlets; and high outflow discharges. Provision of multilevel, multiple outlets improve the venting efficiency of the density currents.

2.7.5 Venting of Sediments through Under Sluices

Under sluices can be incorporated in the design of the impounding structure or dam. The total capacity of these sluices should lie in the range of 0.3 to 1.0 times the maximum daily flood inflow.

Many sediment deposition models can be used in identifying the most suitable locations for the sluices. Knowledge of the expected sediment distribution pattern in the reservoir is useful in sizing and locating the gated outlets. Frequent venting of sediments may be resorted to during the high-inflow season when the excess flows may all be routed through the sluices. This operation not only greatly reduces the sediment entrapment by drastically reducing the residence time but also substantially reduces the surcharge in the reservoir that occurs with an overflow type of spillway. This leads to less flooding of lowlands around the reservoir. Release of water and sediment through the bottom outlets reduces degradation of the bed and caving-in of banks downstream of the dam (Singh, 1987). Sediment sluicing is distinct from sediment flushing because the main sediment load entering a reservoir is released downstream before it has time to settle down.

2.7.6 Reservoir Operation Policy for Sediment Control

The goal of reservoir operation and management is not only to adequately meet the design water demands, but also to release as much sediment as possible from the reservoir with the floodwaters so that the reservoir trap efficiency is reduced to as small a value as is economically and practically feasible. About 80 to 90% of the annual sediment load enters the reservoir during the flood season. Lowering pool levels during flood season further increases the efficiency of the operation. If reservoir sedimentation is perceived as a serious problem, the flow releases from the bottom outlets should be considered in dam design together with a reservoir operation that helps in maximizing flow-through of the incoming sediment. The outlets also help in drawing down reservoir levels during emergencies and repairs. These gates are part of the permanent hydraulic structure of the dam. In this case, the removal of sediments is through reservoir operation. This method makes use of the hydraulics of flow and mechanical means to remove sediments that have accumulated in the reservoir. Water is released through these low-level outlets leading to large flow velocities in the approach channel, providing a local concentration of flow that washes out the sediments downstream.

CHAPTER THREE

METHODS AND MATERIALS

3.1. DESCRIPTION OF THE STUDY AREA

3.1.1 Location

I. Kesem Kebena Dam Irrigation Project

Kesem Kebena Dam and Irrigation Project, is located at the southern end of the Afar depression (rift) in Afar regional state, 225km East of Addis Ababa and 40 Km NW of Metehara town (Fig 3.1). It lies in between UTM 37 zone coordinates of 580000, 608000mE and 9810000-1020000mN in western part of Sabure sub-sheet. Geographically the area is located 39° 54' E and 09° 09' N. The Kesem river catchment to dam site covers about 3000 km². It rises on the high Ethiopian plateau and descends the western scarp of the Great Rift Valley to join the Awash. The main dam has been proposed as a rock fill dam, making advantageous use of the Kesem gorge, with a length of 250 meters, in North South direction across the Kesem. The height of the dam in the deepest section from bed level of river Kesem is 85 meters. The reservoir formed upstream is to have a full capacity of 500 million cubic meters, which corresponds to nearly the mean flows of Kesem. The simulation studies indicate that 20000 hectares of sugarcane can be irrigated. This plan would produce 2.34 million tons of cane per year (tc/y) since; the full capacity of the factory is 10000 TCD which may run for a period only 8 months/year. The drainage area available at main dam site is 3113 square kilometers.

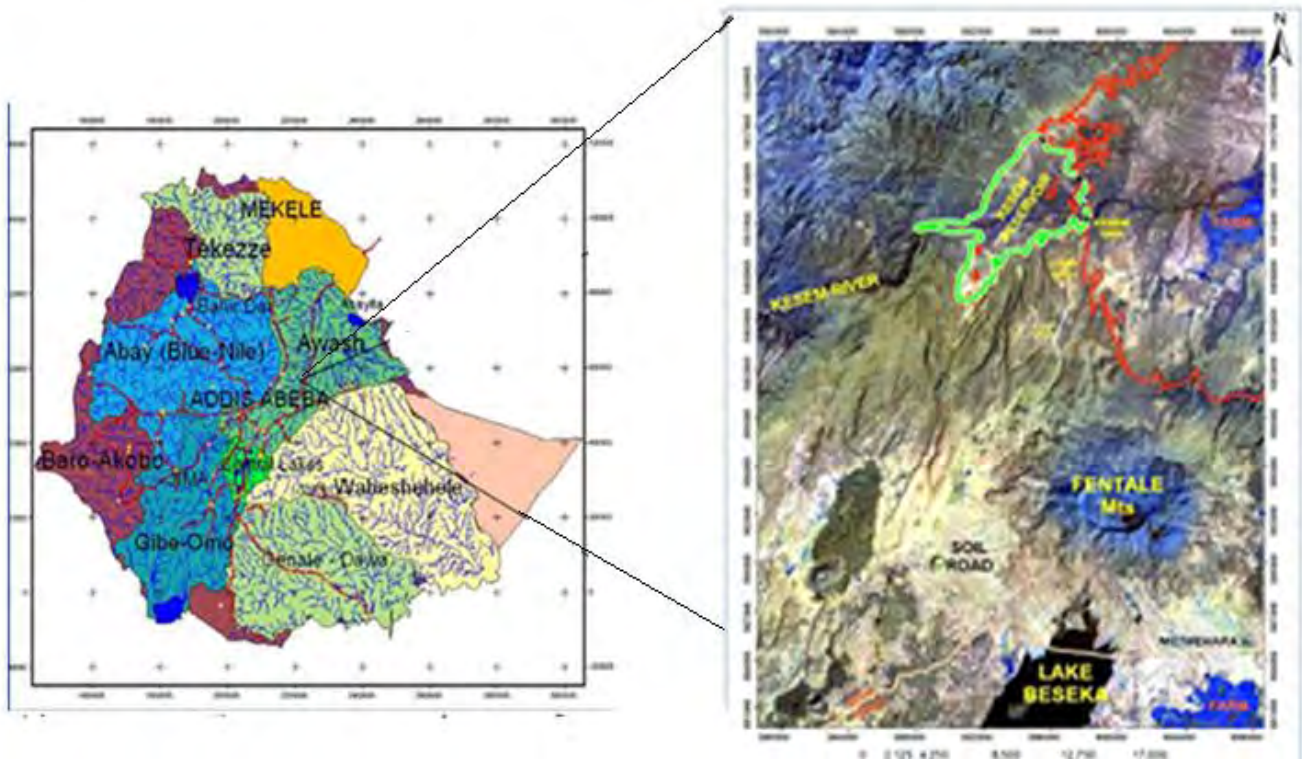


Figure 3.1: Location map of Kesem Kebena Dam project area

II. Tendaho Dam Irrigation Project

Tendaho Dam and Irrigation Development Project is suited at Afar Regional State 577 km from Addis Ababa (fig 2.2). Geological location of Tendaho dam is at $11^{\circ}48'N$ and $40^{\circ}54'E$. The height of Tendaho Dam, as per selected scheme, would be about 44 m above river bed level and 54.5 m above the deepest foundation level. The main dam is Earth with impervious clay core. Tendaho Sugar Project (TSP) is aimed at establishing sugar-manufacturing factory with a capacity of processing about 26,000 tons of cane per day (TCD) from a net area of about 50,000 ha through irrigation. This plan would provide 6.2 million tons of cane per year (tc/y) after completion and reaching its full production capacity. To supply water continuously the reservoir is built with a capacity of holding 1.8 billion cubic liter of water.

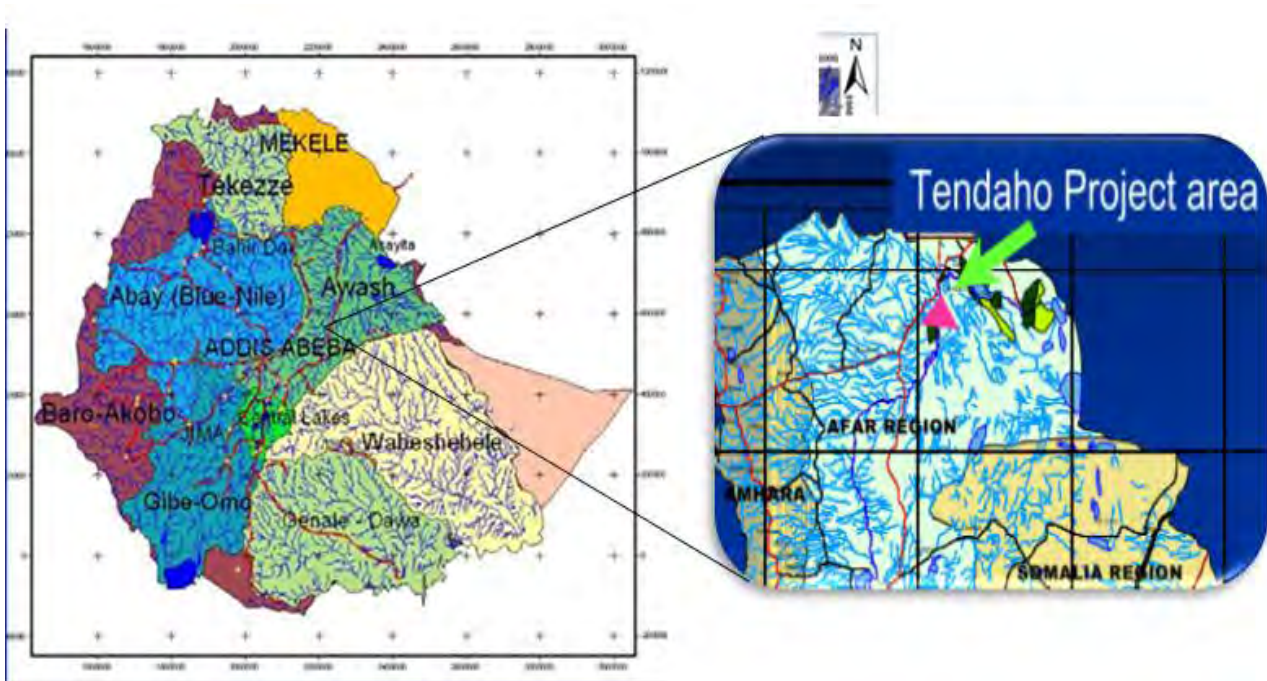


Figure 3.2: Location map of Tendaho Dam project area

III. Ribb Dam Irrigation Project

Rib watershed located at a distance of 625km north of Addis Ababa, 60km from Bahir Dar town. Geographical coordinate of the area is $12^{\circ} 35''$ North and $41^{\circ} 25''$ East and $13^{\circ} 54''$ N and 35° E at an attitude of 1880m to 1970m (fig 3.3). The elevation in the watershed ranges from 1900m asl around dam to almost in the upper ridge 4135m asl. The Ribb River, which is some 130 km long, has a drainage area of about 1,790 km² and an average annual discharge of 11.6m³/s. The catchment area at the dam site is 685 km². The river, which flows generally in a westerly direction and empties into Lake Tana, is one of the main streams flowing into Lake Tana from the east. The Ribb River, with its tributaries, drains the western slope of the high mountainous area east of the town of Debre Tabor, with a peak elevation of approximately 3050 m.

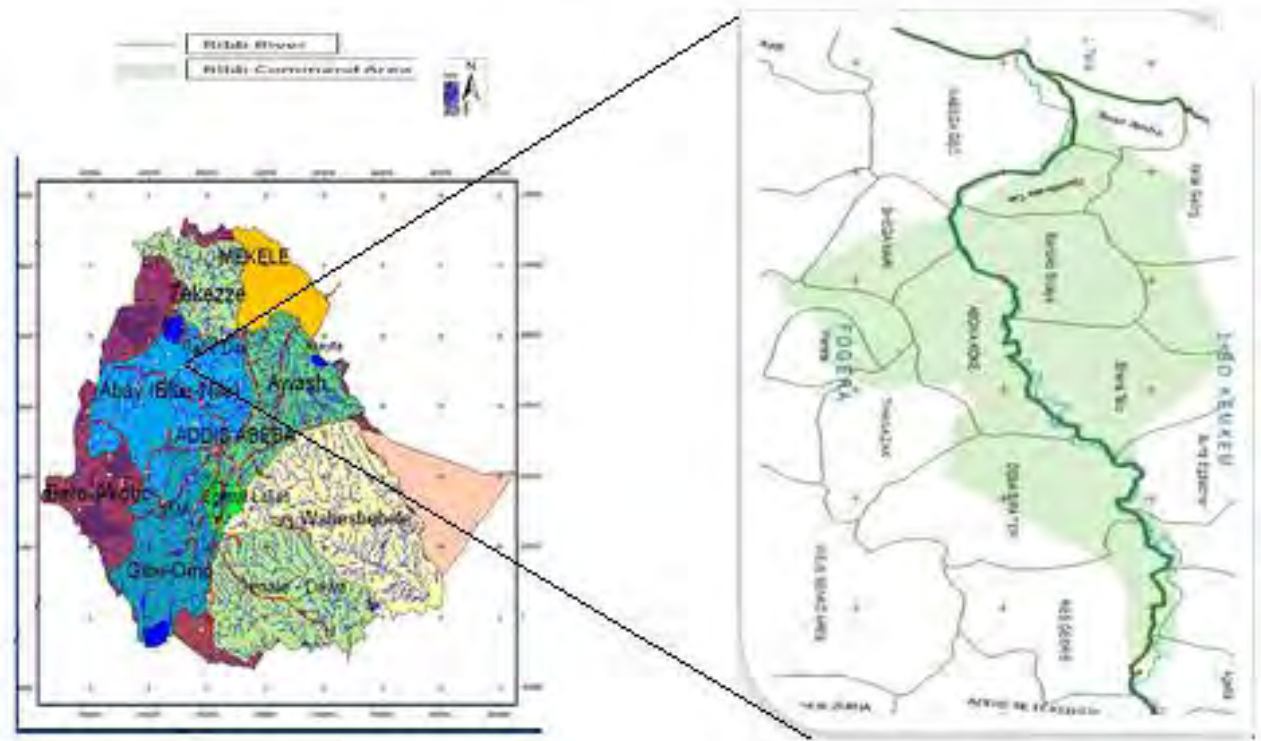


Figure 3.3: Location map of Ribb Dam project area

3.1.2 Climate

I. Kesem Kebena Dam Irrigation Project

The Awash Basin is under the influence of Inter-tropical Convergence Zone (ITCZ), which produces a rainfall distribution characterized by two distinct wet seasons, Spring (February to May) and Summer (July to September), in the northern plains of the Basin (HALCROW, 1989). As per WWDSE (2005) the rainfall within the basin increases three fold with the rise in altitudes from the Awash basin into the highland plateau. Though this increase is asymmetrical, the north of the basin being much wetter and the evapotranspiration (ET) increases as the altitude decreases. The climate of the Kesem dam site is hot and semi-arid to arid (mean maximum of 38 °C and mean minimum of 15 °C) climatic zone with very low rainfall (Mean annual rain fall of 899.3mm). The elevation at the dam site varies from 850m to 1040m above mean sea level. However, in the Upper Kesem watershed, the climate is cool and moist with elevations variation between 1,500 and 2,800m above mean sea level.

II. Tendaho Dam Irrigation Project

The climate of the Awash River Basin varies from humid subtropical over central Ethiopia to arid over the Afar lowlands. The climate of this basin comes under the influence of the inter-tropical convergence zone (ITCZ). The seasonal rainfall distribution within the basin results from the annual migration of the ITCZ. Generally, in the basin, plateaus over 2,500m receive 1,400 - 1,800 mm per year, mid altitude regions (600 - 2500m) receive 1,000 - 1,400mm per year and lowlands get less than 200 mm per year. The rainfall distribution of the basin is bimodal with a short rainy season in March to April and the main rains from July to September. The mean annual rainfall distribution of the Tendaho sub-watershed varies from about 1123 mm at Sirnka, and 1064 mm at Haike, the upper part of the watershed to 196 mm at Dubti station around the outlet of the basin. The rainfall distribution of the middle watershed shows that high rainfall was occurred in the months July to September and also short rainy season March to April. The mean annual temperature of the Tendaho watershed ranges from 18.8 °C at Sirnka to 29 °C at Dubti with the highest mean monthly temperatures at these stations occurring in June and 29.8 °C and 33.6 °C respectively.

III. Ribb Dam Irrigation Project

Basing on the agro climatic classification of Ethiopia (Hurni, 1986), Ribb watershed is characterized with High wurch (on southern edges), wet dega and Wet Woyna Dega (northern area) agro-climatic zones, with altitude ranges from 1900masl around dam (northern edge) to 4135 masl in the upper ridge (southern edge). The watershed area represents humid, with moderately cool to high frost, agro-climate. Generally, the rainfall pattern in the watershed is unimodal. The mean annual precipitation is about 1295mm with the minimum monthly rainfall of 1mm in January and maximum 411mm in July. Dependable rainfall varies from less than 13mm during the dry season to 80 to 275 mm/month during the period of June to July/August, equivalent to 40-80% of the average values. The mean annual temperature is about 20.4 °C while mean minimum temperature is 19 °C in December and monthly maximum temperature is 23 °C in May. Humidity values vary between 70% in December and 88% in August. Average daily sunshine hours are 8.1. Wind speed is reportedly low minimizing potential evapotranspiration values between 95mm in December and 140mm in April. In general, a year in the area is divided into two seasons: a rainy season (Kiremt), which occurs from May to September and a dry season (Bega) from October to April.

Seasonal variations are four namely, winter (rainy season), summer (dry season), autumn (Small rain), and spring (a spell between rainy and dry season) where dry conditions with high rate off evapo-transpiration occur. The Evaporation from the Ribb reservoir is compared to other evaporation estimates near the project area. BCEOM (1999) estimate of PET at Bahirdar was 1,428mm. While mean annual rainfall was 1450/1500mm. The agro ecological zone of the catchment area varies from Woina Dega to Dega. However, at the dam site, the elevation of the river is approximately 1867 masl, which is Woinadega.

3.1.3 Hydrology

I. Kesem Kebena Dam Irrigation Project

The basic input for establishing the reservoir sizing is the historical flow series. For this, for the period, 1963 to 1985, already, the previous study has done considerable analysis on the review of the rating curve at that time and established the flows. Hence, it is prudent to use these as much as possible. Whereas in the present study, the rating curve has been reviewed for the years 1983 to 2003 with more up to date data (appendix V). In the present study, two set of relations have been established, one for the years 1983 to 1988 and another for the years 1989 to 2003. Based on such a situation, the data established by the previous study up to 1982, combined with the corrected data based on the present analysis beyond that year up to year 2003, could form the ideal historical flow series. Thus, for the present study, a good length of data for 41 years (1963 to 2003) is available. The inflow rate averagely varies from 6.839 MCM in January to 235.006 Million Cubic Meter (MCM) in August and its annual inflow rate is 523.459 MCM (fig 3.4).

As Seen in the appendix VI the latest updated sediment rate is $1338 \text{ m}^3/\text{km}^2/\text{year}$. This gives an annual sediment volume of 4.19 Mm^3 for the catchment area of Kesem reservoir. However, these are based on analysis of inadequate observed data and on the basis of update analysis of previous studies, also based on inadequate data. Hence it is necessary to take support of various empirical formulas in vogue also into consideration to have a broader data base for finalizing the sediment rate. Omitting these results, the range of variation of total sedimentation is from $192 \text{ tons}/\text{km}^2$ to $3540 \text{ tons}/\text{km}^2$. In this situation, the best approach is to adopt the mean value which is the robust statistics for estimation purposes. The mean estimate comes to $1496 \text{ tons}/\text{km}^2$ of the catchment area. This is taken up and adjusted scientifically for adoption. In Kesem catchment we propose such watershed management practices Hence the proposed measures are bound to reduce the sediment rate at least by

about 20 to 25 percent. The ultimate future scenario will thus produce a sediment yield of $1496 * 0.75 = 1122 \text{ tons/km}^2$. For capacity inflow ratio of about 0.96 in the case of Kesem reservoir, the trap efficiency is about 98 %. Hence the sediment rate will work out to $1122 * 0.98 = 1099.56 \text{ tons/km}^2$. The sediment density varies between 1.25 to 1.6 tons / m^3 so, assuming a density of 1.45 tons / m^3 , the volumetric rate of sediment is $758.32 \text{ m}^3/\text{km}^2$. For Kesem catchment area of 3113 km^2 , the annual sediment rate is about 2.35 Mm^3 (fig 3.5).

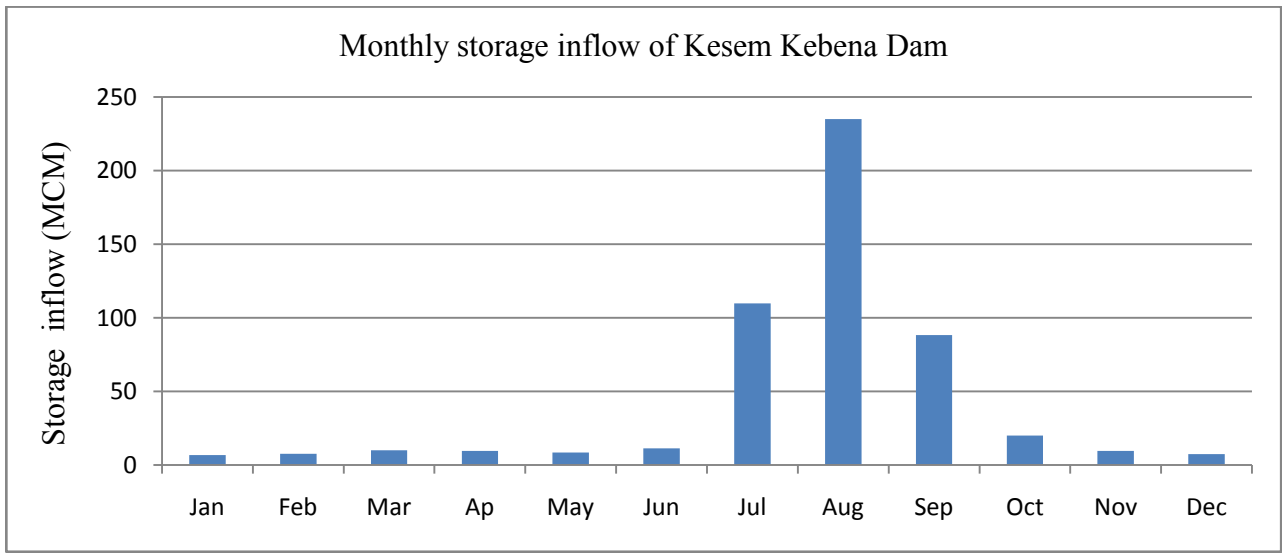


Figure 3.4: Monthly inflow at Kesem kebena dam irrigation project based on the 1963-2003 average flow.

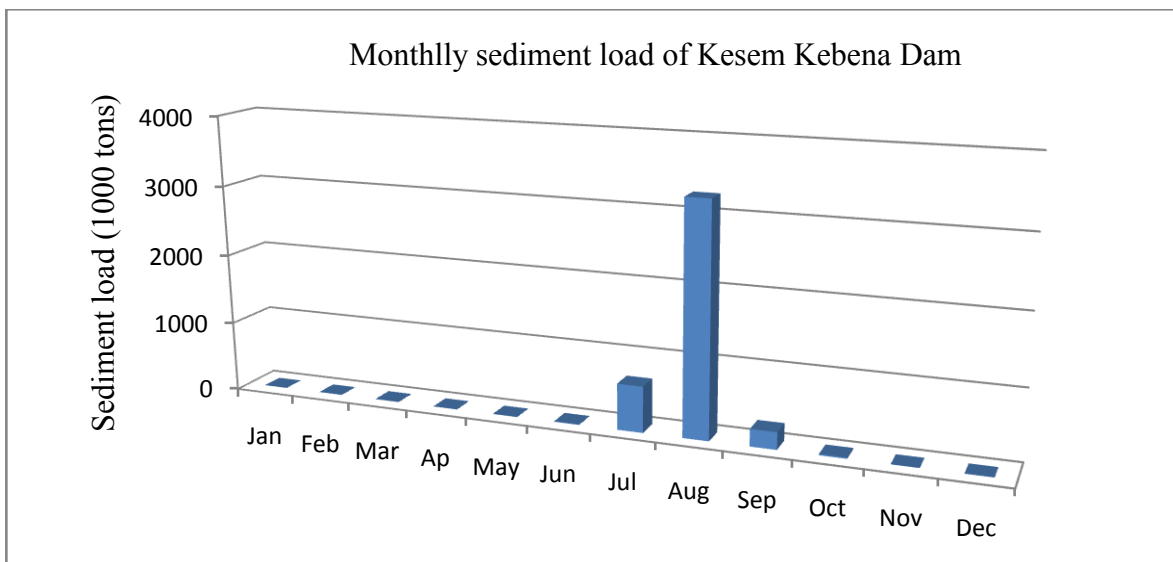


Figure 3.5: Monthly sediment transport at Kesem kebena dam irrigation project based on the 1963-2003 average flow

II. Tendaho Dam Irrigation Project

The monthly discharge - sediment load rating and the monthly historical flow over the period 1962-2002 of Tendaho dam is used for the study. The monthly historical flow data is in Appendix VII. And the resulting monthly sediment load is in Appendix VIII. It is seen that the annual sediment load varies from minimum 2 million ton in year 1984 (drought year) to 90 million ton 1975 (wet year). The mean value of the suspended sediment load is 26 million ton per year (fig 3.7). The bed load is taken as 5% of the suspended load. Similarly the inflow rate varies from 91.7 MCM in January to 483.88 MCM in August and its annual inflow rate is 2334.47 MCM according to 1962-2002 data. But different researchers estimates of the mean annual mean flow of Awash river at Tendaho Dam site varies from low 1690 to a high 2820 Mm³ per year (fig 3.6).

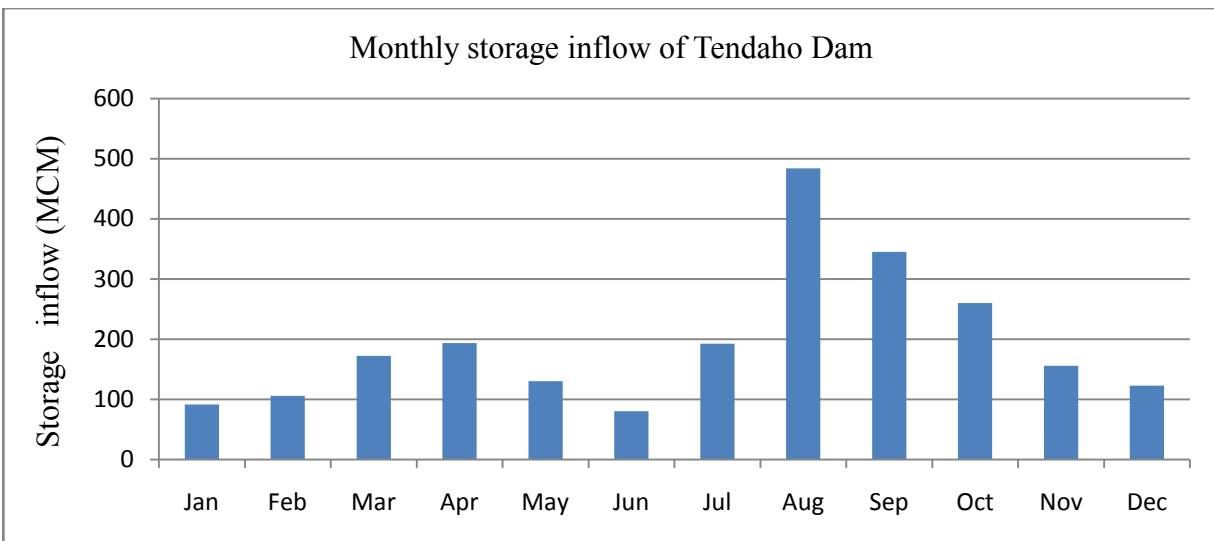


Figure 3.6: Monthly inflow at Tendaho dam irrigation project based on the 1962-2002 average flow.

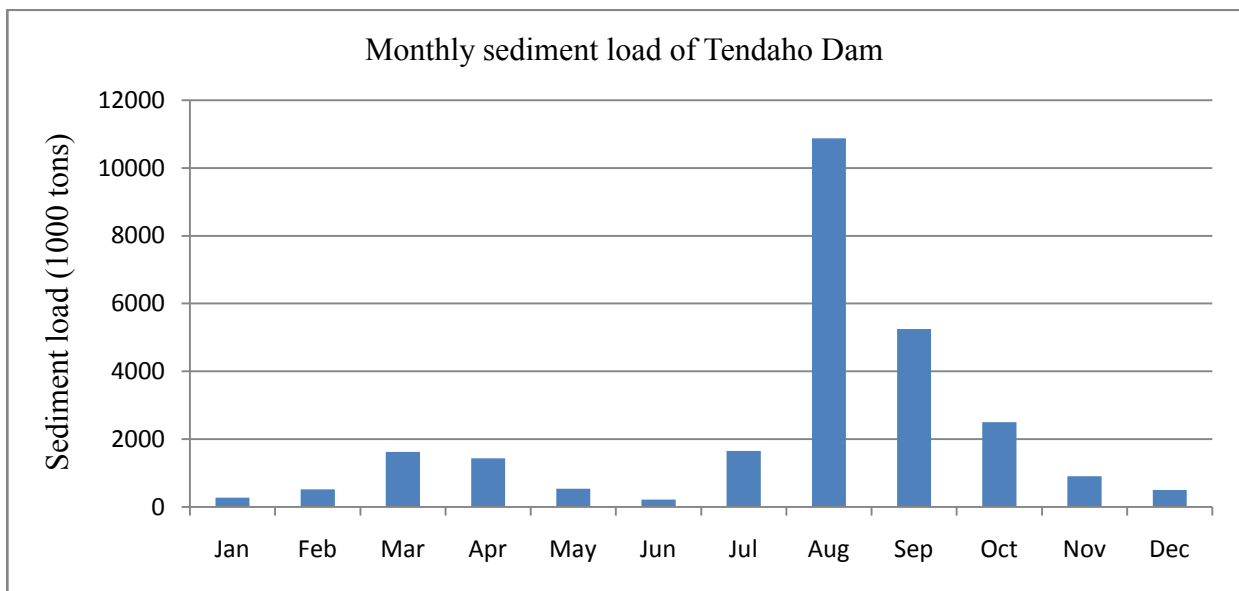


Figure 3.7: Monthly sediment transport at Tendaho dam irrigation project based on the 1962-2002 average flow.

III. Ribb Dam Irrigation Project

The relevant hydrometric station to estimate river flows at the Ribb dam site (715 km²) is the Upper Ribb near Debre Tabor station, with catchment area of 844 km². The Upper Ribb (9.98 L/s/km²) and The Ribb (7.91 L/s/km²) specific Q values are very close to each other, but are low as compared to the Gumara specific Q value (21.65 L/s/km²). Both the Ribb and the Gumara watersheds are characterized by similar rainfall conditions and such a large difference of the Q values could not readily be explained. Until sufficient explanation is found the existing measured values of the Upper Ribb flows are taken for the generation of the Ribb dam site inflows. Missing flow data in the Upper Ribb station were filled by using the following relationship: Upper Ribb Watershed area / Ribb Watershed Area * Ribb Monthly Flows. Monthly flow data of the Ribb River near Addis Zemen and the Upper Ribb River at gauging sites, after the missing data at the upper station was filled, are given in appendix IX. The present mean values of annual flow at the Ribb dam site is 225 Mm³ (fig 3.8).

Ribb and Gumara watersheds have relatively similar characteristics regarding rainfall intensity and soil erodibility. Brownish, sandy, clay loams and sandy loam dominates the watersheds corresponding to Hydrological soil group B. As a result of the above mentioned discussion, an attempt has been made to apply a regional approach in order to construct a composite sediment rating

curve by using the Megech, Ribb, Gumara and Gilgel Abbay Q-Qs data based on 1964-2005 period. Sediment load of rib dam is developed in appendix I. Since there is not metrological station on the Ribb dam a nearby station of upper rib was used similarly for development of the sediment load the upper rib inflow is used. Considering the mountainous nature of Upper Ribb river, it is a standard procedure to add bed load (sand, gravel and bolder) transported by the river. Direct measurements of bed load transport are very difficult and inaccurate. Therefore it was decided that the bed load for the Upper Ribb watershed would be estimated as being 10% of the suspended load. The sediment calculation procedure for Megech dam is the same. The total mean annual sediment load entering the Ribb reservoir is thus estimated as 0.62 million ton, which corresponds to 897 ton /km²/year. Taking as a first estimate the mean density of deposited sediment in the reservoir as 1.2 ton/m³, the total mean annual sediment volume is estimated to be 0.52 MCM and the 50 year sediment accumulation with ~98% trap efficiency would be about 27 MCM (fig 3.9).

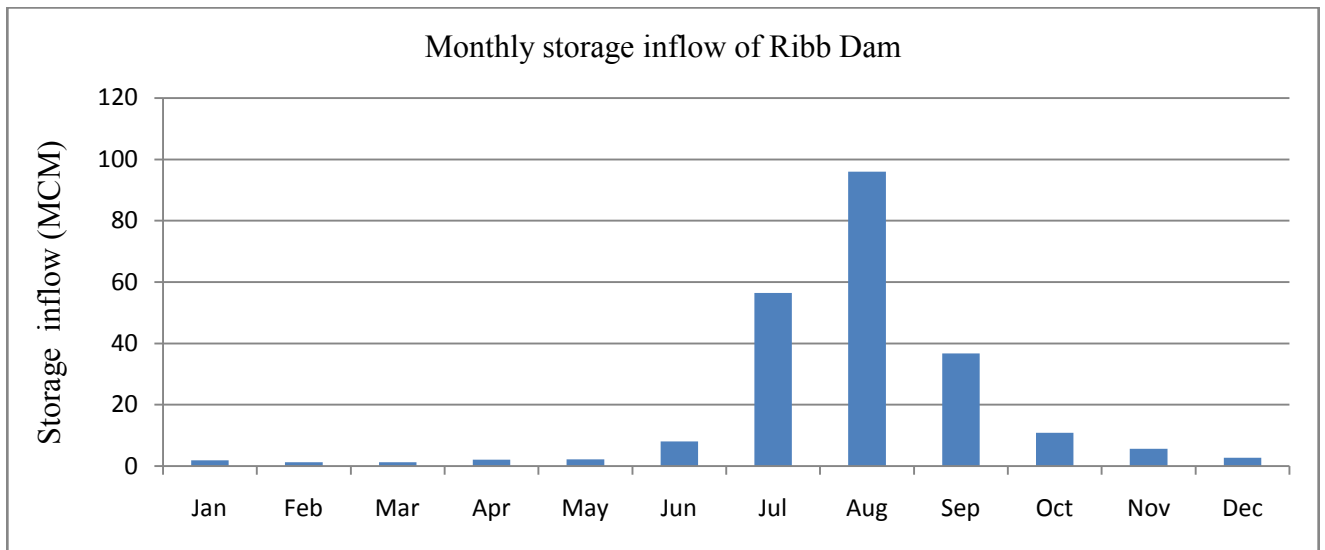


Figure 3.8: Monthly inflow at Ribb dam irrigation project based on the 1960-2004 average flow.

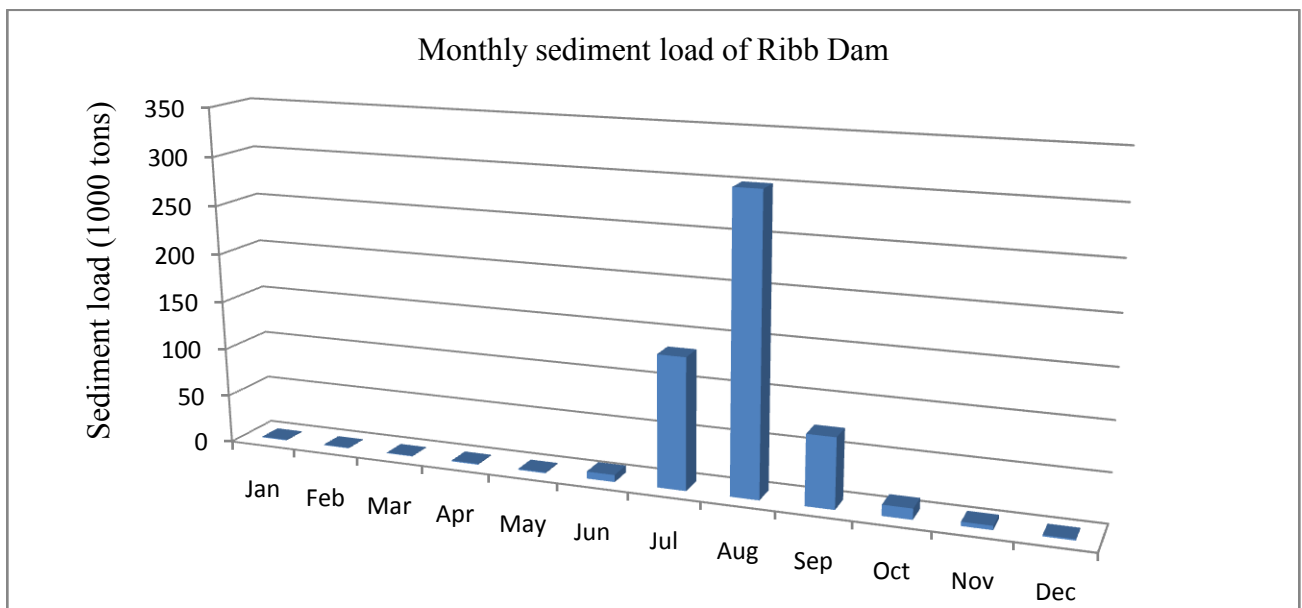


Figure 3.9: Monthly sediment transport at Ribb dam irrigation project based on the 1960-2004 average flow.

3.1.4 Land Use and Land Cover

I. Kesem Kebena Dam Irrigation Project

Land use is the most important determinant factor of erosion, affecting not only the soil protective cover, but also soil erodibility and even slope. About 80 percent of the erosion from highlands occurs from crop lands and most of which is from overgrazed grass lands, watersheds and newly deforested areas. Erosion results primarily from exploitive use of land. Various forms of water erosion can be seen everywhere in the highlands, for instance sheet erosion, rill erosion, gully erosion, bank erosion and tunnel erosion. These processes affect the landscape in different ways and they are often of decisive importance to the productivity of arable land, pasture land, etc. Sheet and rill erosion are by far the most wide-spread kinds of accelerated erosion, and are more significant to agricultural production than all other kinds. The main causes are poor farming practices characterized by a general lack of conservation measures, the cultivation of excessively steep-slopes, deforestation and over-grazing. Four main landscape units occur in the Kesem-Kebena area. Irrigated agricultural development will be confined to the last of these units, the alluvial plains, which are generally flat or almost flat, with slopes of 2% or less down to the main drainage lines. In the west, towards the escarpment, slopes up to 4% occur with undulating or gullied micro relief; in the vicinity of water courses, the levees and/or small dunes often form an irregular micro relief of up to about 1 m

amplitude. The presence of naturally saline parent materials and the occurrence of saline groundwater, often associated with hot springs (of which Filweha is one - with a temperature of about 43°C and electrical conductivity of about 2 500 µS/cm). The Kesem - Kebena area covers 21823 ha alluvium plain in the middle awash valley. (WWDSE and WAPCOS, 2003)

II. Tendaho Dam Irrigation Project

Presently, the natural vegetation of the region is highly disturbed by man and livestock and partly cleared and replaced by permanent cultivated fields. Grass, shrub, wood land, wet land, exposed soil and exposed rocks were identified as dominant land use and cover types. The shrub vegetation coverage of the watershed, usually do not exceed six meters in height with a canopy cover greater than 20%, and heavily invades significant portion of land area of the watershed. Annual grass species constitute 10-20% of the ground cover and the dominant specie is bushy acacia. The major vegetation types of the rangelands are riparian woodland, which is composed of open stands of trees of five to ten meters high and has a canopy cover of more than 20% is found along major rivers and water ways (WWDSE and WPCOS, 2005).

III. Ribb Dam Irrigation Project

The farming system in the watershed is mixed with dominantly oxen plough cereal crop production and livestock rearing, which is centuries old system. Accordingly, the major land use types in the watershed include cultivated, grazing, very spares and patches of shrub/bushes, plantations, settlement and miscellaneous lands. According to Farta and Ebinat Wereda Agriculture and Rural Development Departments report, about 59% and 5.8% of the watershed area is used for annual and perennial crops cultivation respectively. Grazing land occupies 11240.9 ha that is about 16.4% of the total watershed area. In addition, 14655 ha shrub lands, afro alpine and manmade plantations, which account for about 21.4.2% of the watershed area, is used for grazing. Excluding 158 ha of state owned natural forestland, the land under natural and manmade forest is insignificant (MoWE, 2010).

It is well understood that Vegetation in a watershed plays multiple effects that include intercepting raindrops, reducing surface runoff, and there by control erosion, maintain soil fertility and maintain the microclimates. It also helps to enrich ground water sources. Nevertheless, in this watershed, the vegetation cover is very scant. There is no natural dense vegetation cover. Only patches of spare and open trees, bush/shrubs exist in hillsides, along river courses and pocket areas.

Economically and ecologically important indigenous trees are almost disappeared because of the use of tree resources for different socio-economic and socio-cultural needs at the rate of beyond its regenerative capacity. The main needs and uses of tree resources include firewood, construction, charcoal making and rapid population growth and accompanied expansion of cultivation in to marginal lands. Over livestock population and overgrazing systems also contributed for aggravating the loss of vegetation. The sparse patches of bushes exist particularly in the northern reach hills and natural big trees around churches and on the southern mountain (Guna) range while manmade plantations along main roads, towns and rural homesteads. The central part, all across east to west edges, is absolutely denuded of vegetation cover except only very sparse on farm trees here and there observed. There are, however, two state forest areas, one on the southern mountain (Guna) range of which some parts in the watershed and another on the northeast of the watershed. These will be a good seed source to be used during the watershed management plan implementation (MoWE, 2010).

3.1.5 Soil

I. Kesem Kebena Dam Irrigation Project

The soil classification of the area silty soils predominates, comprising 49% of the surveyed area, as compared with 13% of the sandy and coarser soils and 20% of the clays. The miscellaneous land categories, some of which are also silty soils but unusable because of extreme topography, salinity or sodicity. The irrigable soils of the study area are all young alluvial soils, without any marked profile development (WWDSE and WPCOS, 2003).

II. Tendaho Dam Irrigation Project

Soils that have predominantly available in the study area are Andosols, Cambisols, Fluvisols, Leptosols, Luvisols, Nitisols, Solonchaks and regosols. From these soil groups Andosols have a high potential for agricultural activity because of their fertility, ease of cultivation and ease of root penetration. In areas covered by such soils, there is less probability of occurrence of erosion. Erosion is the greatest threat to Leptosols. As a result, severe erosion problems may be observed in Leptosols under high anthropogenic effects. The erosion risk of Nitisols is high on hilly sides, where there are no proper land management practices. Solonchaks are characterized by high salt concentration and predominantly available in arid and semiarid climate zones of the watershed (WWDSE and WPCOS, 2005).

III. Ribb Dam Irrigation Project

Geology, climate and vegetation have been the major soil forming entities active in the watershed area. Luvisols soil formed in the south to north through south-west (large belt crossing from north-east west and west-north) of the watershed from the basaltic rock cap are deep, well structured, inherently well drained and relatively productive agricultural soil. The second large group of soil in the watershed is Leptosols on the eastern reach with some at the middle and very small on the southern part. This soil is on hill slopes partly on continued hard rocks and partly gravels. The soil is limited in depth having calcareous material or cemented layer within 30 to 40cm depth. There are small pockets of vertisols particularly on hills and mountains tops and fluvisols in valleys along rivers and streams particularly around the proposed dam/reservoir site.

The major soils of the watershed are therefore Chromic Luvisols (57.3%), Eutric Leptosols (42%), and Eutric fluvisols (0.6%) in their respective area coverage with small pockets of vertisols on the hill tops and river and streams" valleys and Chromic Luvisols as small pockets in different parts. The soils seem to have derived from basalts and tuffs. They are brownish to reddish in color, clay to clay loam and sandy to sandy loam in texture, well drained but very shallow on steep slopes. The Luvisols, fluvisols and vertisols have good inherent fertility and agricultural productivity, although those Leptosols on the mountain ranges and hillsides are severely eroded and further prone to soil erosion. The soil erosion on the hillside slopes and sedimentation at the valleys have already taken place because of intensive annual crop cultivation without soil erosion protection measures (MoWE, 2010).

3.2. METHODS AND MATERIALS

3.2.1 Materials Used

The necessary data that were collected and used for this study were time series data. Those were Metrological and Hydrological data that were collected from Ethiopian National Metrological Agency (ENMA) and MoWE.

Monthly reservoir storage inflow and sediment load data for KesemKebena irrigation project of 41 years (1963-2003) and for Tendaho irrigation project of 41 years (1962-2002) were mainly obtained from Water Works Design and Supervision Enterprise (WWDSE) to be used for this study. Besides,

the monthly reservoir storage inflow data of 45 years (1960-2004) for Ribb irrigation project were obtained from MoWE to be used for this study, but the sediment load was developed by the researcher using equation of rating curve.

Micro soft Excel was mainly used for the data input and organization, for preparation of charts and detail analysis of the study.

3.2.2 Data Analysis and Screen

Blocking flow decreased storage that would be entering to a reservoir. This directly had an effect on sediment entering too. But such measure increased the life span of the dam as blocking flow means also blocking the amount of sediment entering the reservoir, the dead storage which will eventually serve for more duration. This upstream sediment blocking measure taken before entering the reservoir reduces the amount of water expected to be stored. The volume of water stored in the reservoir throughout its design life with and without blocking the water flow was analyzed from its cost and benefit to the whole project.

Kesem Kebena, Tendaho and Ribb irrigation projects were selected for the study because of lack of data, time and money. Especially, the availability of sediment load data in most of these Ethiopian dams is difficult even for that of Ribb dam, the sediment load was developed by the researcher using rating curve. The study discusses the merits and demerits of the measure taken to increase the design life of the dams. Primarily the study concentrated on storage variation when the proposed measure taken using storage approach. Then the study continued digging the benefits obtained and the costs incurred through benefit cost analysis. When you block the sediment, you will lose benefit because demand suffers as storage reduces, but you also obtain advantage or benefit because of blocking the sediment since the life span increases. Hence, the value of the blocked water blocked and the life time incremental in terms of the value of water was comparatively seen in detail.

3.2.3 Storage Variation Analysis

As can be tried to discuss previously in this part of the research, the measure taken to improve the life span of the dam is blocking the inflow rate of the river in monthly series which would enter the reservoir on upstream of the storage before it had joined the storage area. This measure will have two main impacts on the dam such as reduction of annual inflow of water and sediment. The first affects the dam in reduction of storage annually so that some storage would be lost because of the blockage.

Secondly, the life span of the dam will improve, which will have additional years of storage that is called replaced storage. This storage is storage due to sediment reduction with the reduced annual inflow.

In this analysis, if the whole month flow is diverted before entering the reservoir, the reservoir storage will reduce by an amount of this volume of water. Besides, sediment volume equal to the total sediment carried by the river in this month would avoid from entering to the reservoir which ultimately made the dam's life span longer than expected. The storage variation analysis was based on such water volume lost by blocking and design life extension of the project.

A. Storage Loss due to the Measure

When the monthly inflow entering a reservoir is blocked, the storage of the reservoir will reduce since it will have new storage inflow and this is called storage lost. If we block the i^{th} month inflow (MF_i) throughout the life span of the dam, the storage loss would be:

$$SL = (AI - NS) * DL \dots\dots\dots 2$$

Where: SL is the storage lost from the reservoir due to the bypassing measure (m^3)

AI is the annual inflow of the reservoir (m^3)

$$AI = \sum_{i=1}^{12} MF_i$$

NS is the new storage of the reservoir (m^3)

DL is the design life span of the dam (years)

The new storage of the reservoir (NS) was annual storage of the reservoir after the measure had been taken. In other word, the new inflow of the reservoir when the inflow is blocked in monthly basis and this could obtain using:

$$NS = AI - MF_i \dots\dots\dots 3$$

Where: MF_i is the i^{th} month inflow of the reservoir (m^3)

So that the storage lost could be simply: $SL = MF_i * DL \dots\dots\dots 4$

B. Corrected Monthly Sediment Inflow (MS_c)

For any dam project, sediment data would be taken from its flow recorded nearby station. However, the data base was on sediment rating with, so to say, it might in adequate observed data both in quality and quantity. Hence, it was necessary to take support of various empirical formulas in vogue also into consideration to have a broader data base for finalizing the sediment rate. Commonly, average rate of sedimentation in the past studies was used. In addition, Watershed Management Approaches suggested for the catchment might bring about reduction in the sediment rate. Accounting for such measures, sediment rate could go down since watershed management was very effective in sediment yield reduction. Similarly, reservoir trap efficiency was a percentage of incoming sediment retained in the reservoir and is related to the „capacity-inflow“ ratio; so it would have reduction in percentage of the sediment rate. Thus, for the effects that describe the above criteria, the flow recorded had to be corrected to be adequate using the following equation:

$$MS_{cj} = MS_j * \left(\frac{ASI_c}{ASI}\right) \dots\dots\dots 5$$

Where:

MS_j is the j^{th} month sediment inflow to the reservoir (m^3)

ASI_c is the annual sediment inflow, passing the correction criteria where the correction factor are the watershed management and trap efficiency effect will have to the reservoir on the retention of the sediment rate (m^3)

ASI is the annual sediment inflow of the reservoir without the proposed measure (m^3);

$$ASI = \sum_{j=1}^{12} MS_j$$

C. Improved Life Span of the Dams (ILS)

It is known that a dam will stop its service when the dead storage of the reservoir is totally filled with sediment. But the life span of the dam can be improved by reducing the sediment entering the reservoir in monthly basis and this could be calculated as:

$$ILS = NLS - DL \dots\dots\dots 6$$

Where: NLS is the new life span of the dam (years)

The new life span of the dam (NLS) is the life span in years required to fill completely the dead storage with sediment under the measure taken. This could be obtained by the following equation:

$$NLS = \left(\frac{ASI_c}{NSI}\right) * DL \dots\dots\dots 7$$

Where: NSI is new annual sediment inflow of the reservoir (m^3)

The new annual sediment inflow to the reservoir when the sediment is blocked on the upstream of the reservoir in j^{th} month could be computed as:

$$NSI = ASI_c - MS_{Cj} \dots\dots\dots 8$$

D. Storage due to Sediment Reduction (SR)

When the sediment entering the reservoir is reduced, the life span of the dam will increase. The storage loss discussed in the earlier section might be compensated by improving life span of the dam. The annual replaced storage throughout the new life span of the dam with reduced annual inflow may be replacing the storage lost because of the measure taken; it may also be more than storage lost. If ILS is the improved life span of the dam in years, the storage gained in this extended life span (SR) will be:

$$SR = NS * ILS \dots\dots\dots 9$$

E. Net Storage (NS)

The net storage tells us whether the proposed measure is efficient or not comparing the two cases of annual inflow of water and sediment. Thus, this could be calculated by comparing equation 5 and equation 6 as:

$$NS = SR - SL \dots\dots\dots 10$$

3.2.4 Benefit- Cost Analysis

Cost-benefit analysis is a systematic process for calculating and comparing the benefits and costs of a project. The formal process is often referred to as either CBA (Cost-Benefit Analysis) or BCA (Benefit-Cost Analysis). The cost-benefit analysis is explicitly designed to inform the practical decision-making of enterprise managers and investors focusing on optimizing their social and

environmental impacts. Cost–benefit analysis is typically used by governments to evaluate the desirability of a given intervention. Cost–benefit analysis is often used by governments and other organizations, such as private sector businesses, to evaluate the desirability of a given “measure”. It is an analysis of the expected balance of benefits and costs, including an account of foregone alternatives. BCA helps predict whether the benefits of a “measure” outweigh its costs (Cellini and Kee, 2010). It is a term that refers both to:

- Helping to appraise, or assess, the case for a project or proposal, which itself is a process known as project appraisal; and
- An informal approach for making decisions of any kind.

Under both definitions the process involves, whether explicitly or implicitly, weighing the total expected costs against the total expected benefits of one or more actions in order to choose the best or most profitable option. The guiding principle is to list all parties affected by an intervention and place a monetary value of the effect it has on their welfare as it would be valued by them. The process involves monetary value of initial and ongoing expenses vs. expected return. Constructing plausible measures of the costs and benefits of specific actions is often very difficult. In practice, analysts try to estimate costs and benefits either by using survey methods or by drawing inferences from market behavior. Cost–benefit analysis attempts to put all relevant costs and benefits on a common temporal footing (David, Nugulube and Dube, 2013).

I. Benefit -Cost Analysis Based on Annual Income of the Project

A project has an income throughout its service time especially in the case of sugar-cane production. For the production of sugar-cane, it is compulsory that, the dam requires enough water supplies in order to produce the desired amount of sugar-cane. This research comparatively studied the benefits and costs of the project with and without the sediment reduction measure.

A. Unit Rate of Stored water (URS)

The amount of water stored on a dam can be used for different purposes like irrigation, hydropower, water supply etc... This study concentrated on irrigation project that produce sugarcane. This sugarcane project has its own annual income, but it needs annual release from the storage to satisfy the demand. Thus, each cubic meter of water release has its own annual income and this is defined here as the unit rate of the stored water (URS) in *Birr/m³* and this could be computed using:

$$\text{URS} = \text{AIP} / \text{WR} \dots\dots\dots 11$$

Where: AIP is the annual income of the project (*Birr/year*)

WR is the water required from the dam in cubic meter per year

The annual income obtains from the project could be obtained by:

$$\text{AIP} = \text{PR} * C_s \dots\dots\dots 12$$

Where: PR is the annual production rate of the sugarcane (*Quintal/year*)

C_s is the cost of the sugarcane (*Birr/Quintal*)

B. Cost of the Sediment Reduction Measure (C)

If the flow entering the reservoir was not as expected on behaves of the measure, the storage of the reservoir would reduce as the same time, and the storage release of the dam would not satisfy the water requirement of the sugar-cane. This would lead to reduction of production capacity. The production capacity lost for the project was the opportunity cost which indicated what benefits would loss annually in Birr. This cost incurred on monthly basis because of the sediment reduction measure could be obtained from:

$$C = \text{SL} * \text{URS} \dots\dots\dots 13$$

C. Benefit of the Sediment Reduction Measure (B)

In other way round, if the sediment entering the reservoir is blocked in monthly basis, the service time of the dam will improve. For the improved life span, additional year of storage service will obtain. Due to the additional year of storage, additional income for the project will be obtain but with reduced capacity. This additional year of income for the project is the benefit and it is directly related to the improved life spans of the dam. This indicates the measurements taken on the upstream of the storage will have annual benefit and can be calculated as:

$$B = \text{SR} * \text{URS} \dots\dots\dots 14$$

D. Benefit Cost Ratio

A benefit-cost ratio (BCR) is an indicator used in the formal discipline of analyzing attempts to summarize the overall value of money of a project or proposal. A BCR is the ratio of the benefits of a

project or proposal, expressed in monetary terms, relative to its costs, also expressed in monetary terms. BCR takes into account the amount of monetary gain realized by performing a project versus the amount it costs to execute the project. A complication with BCR concerns the precise definitions of benefits and costs. These can vary depending on the funding agency. The higher the BCR is the better the investment. General rule of thumb is that if the benefit is higher than the cost the project is a good investment. Generally the decision criterion is to accept any project having benefit cost ratio greater than 1. For the benefit to exceed cost, the BCR must be greater than 1 and the greater the value, the more attractive the project is (CBKB, 2009).

CHAPTER FOUR

RESULT AND DISCUSSION

4.1. Storage Variation Analysis

Applying river sediment monitoring measure is important for irrigation project since monitoring the inflow will only reduce the production of the project (sugarcane) that brings about reduction of income for the project in which this can be replaced periodically on the improved life span of the project. But for the other projects like water supply and hydropower, monitoring the inflow will reduce the storage and the demand will suffer from shortage of water supply and power satisfaction. Thus, applying this measure for water supply and hydropower projects is not recommended rather it is better to find other mitigation measures. Hence, the researcher was interested in studying and applying the measure for irrigation projects. Using this concept, the research tested three Ethiopian dams such as Kesem Kebena, Tendaho and Rib Irrigation Projects.

4.1.1. Kesem Kebena Dam Irrigation Project

According to the data of WWDSE (1963-2003), the annual inflow and sediment inflow of Kesem Kebena dam was 233.459 MCM and 4.198 MCM respectively. But the annual sediment is corrected besides the criteria described in previous chapter and suited to 2.35 MCM. Based on the 80 years of design life span, 188 MCM of this dam will occupy by sediment and it will distribute through the dead and live storage of the reservoir. Applying this river sediment monitoring measure on upstream of the reservoir has a deviation in storage loss, replaced storage and the net storage of the dam.

A. Storage Loss due to the Measure

The storage loss due to the measure in case of Kesem Kebena dam was computed using equation 2 in table 4.1 for each month and it was obtained that the inflow is maximum in August (235.006 MCM) and minimum in January (6.839MCM). Blocking the inflow on monthly basis, the reservoir will have new storage annually. If the inflow of January is blocked the new storage will be maximum and minimum if inflow of August is blocked. Monitoring the inflow on monthly basis throughout the use full life span of the dam, the inflow loss will also maximum in august (18800.468 MCM) and

minimum in January (547.122 MCM). Frequently, if we block the river in upstream of the dam on monthly basis, the annual inflow of the reservoir will reduce as shown in table 4.1.

No	Month	Inflow (MCM) (1)	New Annual Storage (MCM) (2) *	Storage Loss due to the Measure (MCM) (3) **
1	January	6.839	516.620	547.122
2	February	7.539	515.920	603.102
3	March	10.019	513.440	801.502
4	April	9.504	513.955	760.293
5	May	8.571	514.888	685.698
6	Jun	11.206	512.253	896.507
7	July	109.789	413.670	8783.141
8	August	235.006	288.453	18800.468
9	September	88.186	435.273	7054.888
10	October	19.920	503.539	1593.600
11	November	9.481	513.978	758.498
12	December	7.399	516.060	591.902
	Annual	523.459		41876.722

Table 4.1: Monthly inflow and storage loss of Kesem Kebena Dam

Note: * = 523.459 – column 1 and

** = 80 * column 2

B. Storage Due to Sediment Reduction

The storage loss in Kesem Kebena dam after the sediment measure is applied to improve the life span of the dam will replace periodically in the improve life span of the dam with reduced new storage rate (table 4.2). As shown in the table, monitoring of the sediment inflow throughout the design life span for different months, the dam will improve its life span by 0.024, 0.047, 0.082, 0.062, 0.051,

0.123, 14.749, 277.575, 4.940, 0.323, 0.056, 0.028 years from January to December respectively. The storage acquire in this improved life span of the dam is also computed in column 8 from January to December and it is maximum in August and minimum in January, that is, monitoring the river only for the month of January can improve the life span of the dam by 0.024 years and can store about 12.180 MCM. But if we blocked the inflow of August, we can improve the life span by 277.575 years and the reservoir storage will be about 80067.352MCM (Table 4.2).

No	Month	Sediment Inflow (TCM) (1)	Sediment Inflow (MCM) (2)	Corrected Sediment Inflow (MCM) (3)*	New annual Sediment Inflow (MCM) (4) **	New Life Span (Years) (5) ***	Improved Life Span (Years) (6) ****	New annual Storage (MCM) (7)	Storage due to Sediment Reduction (MCM) (8)****
1	January	1.237	0.001	0.001	2.349	80.024	0.024	516.620	12.180
2	February	2.447	0.002	0.001	2.349	80.047	0.047	515.920	24.075
3	March	4.289	0.004	0.002	2.348	80.082	0.082	513.440	42.011
4	April	3.237	0.003	0.002	2.348	80.062	0.062	513.955	31.725
5	May	2.658	0.003	0.001	2.349	80.051	0.051	514.888	26.094
6	Jun	6.421	0.006	0.004	2.346	80.123	0.123	512.253	62.774
7	July	653.526	0.654	0.366	1.984	94.749	14.749	413.670	6101.333
8	August	3258.974	3.259	1.824	0.526	357.575	277.575	288.453	80067.352
9	September	244.166	0.244	0.137	2.213	84.940	4.940	435.273	2150.261
10	October	16.895	0.017	0.009	2.341	80.323	0.323	503.539	162.764
11	November	2.947	0.003	0.002	2.348	80.056	0.056	513.978	28.887
12	December	1.447	0.001	0.001	2.349	80.028	0.028	516.060	14.238
	Annual	4198.244	4.198	2.350					

Note:

* = Column 2 *

$$\left(\frac{\text{Actual Sediment Inflow}}{\text{Computed Sediment Inflow}} \right)$$

**= 2.35 – Column 3

***= 188 / Column 4

**** = Column 5 – 80

***** = Column 6 * column 7

Where:

- Actual Sediment Inflow = 2.35

- Computed Sediment Inflow = 4.198

- 1880MCM Storage of sediment through 80 years life span of the dam

Table 4.2: Storage due to Sediment Reduction of Kesem Kebena Dam

C. Net Storage

Net storage which was the boundary to select the best and useful month of river sediment monitoring that was applied and tested in table 4.3 and fig 4.1. As can be noticed from the table and figure, the net storage was negative in all months except in August. Thus, monitoring of sediment for Kesem Kebena dam only in this month is desirable since the storage due to sediment reduction is more than that of storage loss due to the measure. If we apply the measure only for month of August, 61266.883 MCM of advantage in storage can acquire. But river sediment monitoring in other months is not recommended since the amount of water loss because the measure could not be replaced in the respective improved life span of the dam. In other words, the improved life span is not sufficient for the replacement of the amount of water lost that was expected to be stored in the reservoir. The negative net storage showed that monitoring on these months will have more storage loss than storage due to sediment reduction which was not recommended to apply the measure. The more the negative is the more storage loss will be. So, in these months in which their storage difference is more negative like in September and July it was un expected to monitor since they are highly sensitive which can lead us to be uneconomical, that is, the high the benefit loss in storage will be.

No	Month	Storage Loss due to the Measure (MCM)	Storage due to Sediment Reduction (MCM)	Net Storage (MCM)
1	January	547.122	12.180	-534.942
2	February	603.102	24.075	-579.028
3	March	801.502	42.011	-759.492
4	April	760.293	31.725	-728.567
5	May	685.698	26.094	-659.603
6	Jun	896.507	62.774	-833.734
7	July	8783.141	6101.333	-2681.808
8	August	18800.468	80067.352	61266.883
9	September	7054.888	2150.261	-4904.627
10	October	1593.600	162.764	-1430.836
11	November	758.498	28.887	-729.610
12	December	591.902	14.238	-577.664

Table 4.3: Net Storage of Kesem Kebena Dam

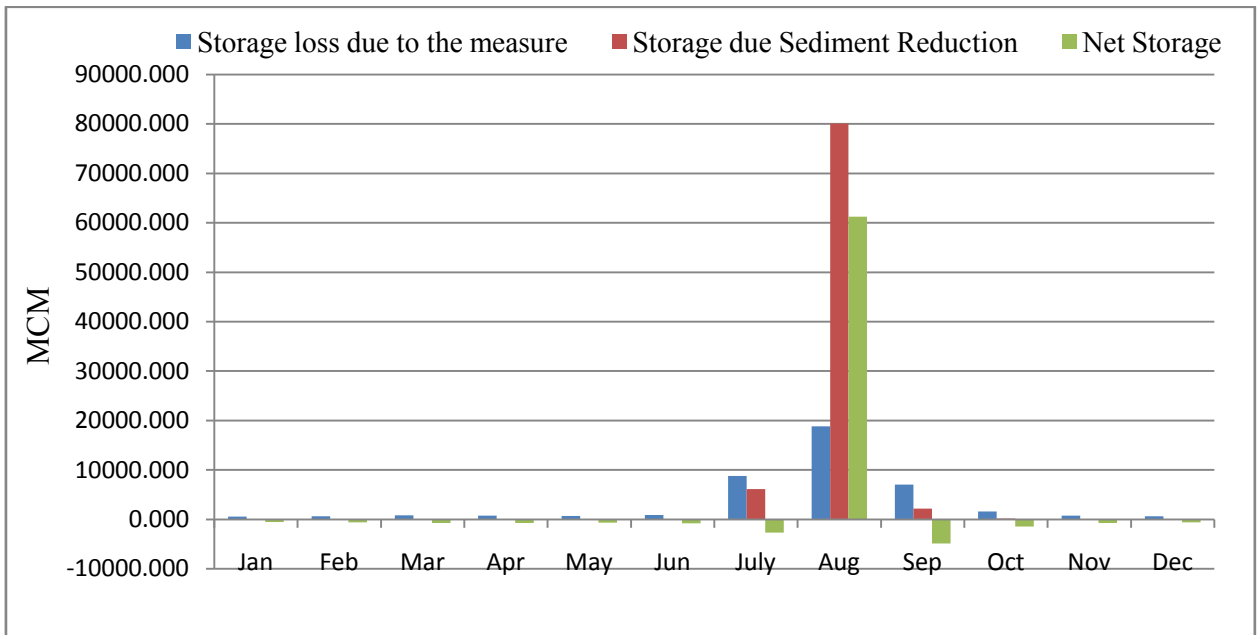


Figure 4.1: Net Storage of Kesem Kebena Dam

D. Net Storage on Daily Basis

The selection of best fit months for river sediment monitoring measure was also tested on daily basis (see appendix II and fig 4.2). Similarly, net storage except month of August was negative. Thus, according to the daily basis test applying the measure on this month was better which is similar to that of monthly basis tested before. Therefore, for Kesem Kebena dam, river sediment monitoring to improve the life span of the dam is desirable, useful and economical on month of August.

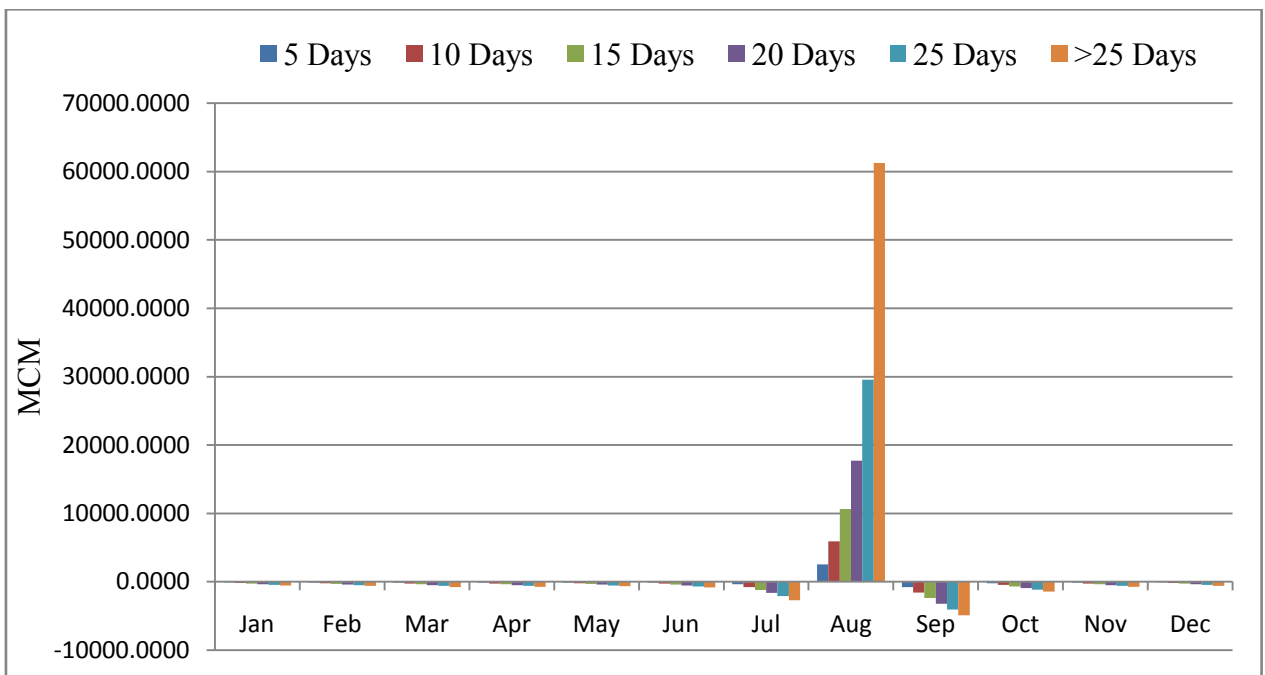


Figure 4.2: Net Storage on Daily basis of Kesem Kebena Dam

E. River Sediment Monitoring for the Selected Month

Based on the previous testes, only the month of August was the better and useful to bypass heavily sediment laden flows. But the dam would not be expected to serve effectively for infinitive years since full month inflow monitoring of August will improve the life span of the dam by 277.5749 in addition to high runoff rate is obtained on this month. Hence, the improved period at the same time the advantage achieves applying river sediment monitoring measure in each one day incremental was evaluated in table 4.4. As to the table, upstream monitoring only one day inflow of August throughout the life span of Kesem Kebena reservoir, the life time will be 82.0547 years in which 2.0547 years incremental. The storage loss and storage replaced will be 606.4667 MCM and 1059.9912 MCM respectively. Therefore, on this month one day sediment bypassing on Kesem Kebena reservoir will acquire 453.5245 MCM benefits in storage. In a similar manner, if we bypass the first ten days of inflow in this month, the life span of the dam will be 106.7250 years in which 26.725 years incremental of the design life span could attain 11963.461 MCM benefit in storage.

Month	Monitoring Interval (days)	New Annual Storage (MCM)	New Annual Sediment Inflow (MCM)	New Life Span (Years)	Improved Life Span (Years)	Storage loss due to the Measure (MCM)	Storage due to Sediment Reduction (MCM)	Net Storage (MCM)
August	0	523.4590	2.3500	80.0000	0.0000	0.0000	0.0000	0.0000
	1	515.8782	2.2912	82.0547	2.0547	606.4667	1059.9912	453.5245
	2	508.2974	2.2323	84.2178	4.2178	1212.9334	2143.8933	930.9599
	3	500.7165	2.1735	86.4980	6.4980	1819.4002	3253.6485	1434.2483
	4	493.1357	2.1146	88.9051	8.9051	2425.8669	4391.4151	1965.5482
	5	485.5549	2.0558	91.4500	11.4500	3032.3336	5559.5985	2527.2649
	6	477.9740	1.9969	94.1449	14.1449	3638.8003	6760.8879	3122.0876
	7	470.3932	1.9381	97.0034	17.0034	4245.2670	7998.2989	3753.0318
	8	462.8124	1.8792	100.0410	20.0410	4851.7338	9275.2246	4423.4909
	9	455.2315	1.8204	103.2750	23.2750	5458.2005	10595.4974	5137.2969
	10	447.6507	1.7615	106.7250	26.7250	6064.6672	11963.4613	5898.7941
	11	440.0699	1.7027	110.4135	30.4135	6671.1339	13384.0611	6712.9272
	12	432.4890	1.6438	114.3661	34.3661	7277.6006	14862.9495	7585.3489
	13	424.9082	1.5850	118.6122	38.6122	7884.0673	16406.6189	8522.5516
	14	417.3273	1.5262	123.1857	43.1857	8490.5341	18022.5628	9532.0287
	15	409.7465	1.4673	128.1260	48.1260	9097.0008	19719.4769	10622.4761
	16	402.1657	1.4085	133.4792	53.4792	9703.4675	21507.5102	11804.0427
	17	394.5848	1.3497	139.2945	59.2945	10309.9342	23396.6953	13086.7611
	18	387.0040	1.2908	145.6499	65.6499	10916.4009	25406.7842	14490.3833
	19	379.4232	1.2319	152.6073	72.6073	11522.8677	27548.9028	16026.0351
	20	371.8423	1.1731	160.2628	80.2628	12129.3344	29845.0909	17715.7565
	21	364.2615	1.1142	168.7268	88.7268	12735.8011	32319.7595	19583.9584
	22	356.6807	1.0554	178.1347	98.1347	13342.2678	35002.7638	21660.4960
	23	349.0998	0.9965	188.6538	108.6538	13948.7345	37931.0113	23982.2767
	24	341.5190	0.9377	200.4931	120.4931	14555.2013	41150.6738	26595.4725
	25	333.9382	0.8788	213.9179	133.9179	15161.6680	44720.2899	29558.6220
	26	326.3573	0.8200	229.2695	149.2695	15768.1347	48715.2021	32947.0674
	27	318.7765	0.7611	246.9949	166.9949	16374.6014	53234.0524	36859.4510
	28	311.1957	0.7023	267.6907	187.6907	16981.0681	58408.5439	41427.4757

	29	303.6148	0.6435	292.1720	212.1720	17587.5349	64418.5584	46831.0236
	30	296.0340	0.5846	321.5817	241.5817	18194.0016	71516.4050	53322.4034
	31	288.4532	0.5258	357.5749	277.5749	18800.4683	80067.3515	61266.8832

Table 4.4: Net Storage of Kesem Kebena Dam for the selected month (August), Daily basis

4.1.2. Tendaho Dam Irrigation Project

Based on the data of WWDSE of (1962-2002), the annual inflow and sediment inflow of Tendaho dam was 2334.470 MCM and 26.289 MCM respectively. But the annual sediment was corrected in addition to the criteria described in the previous chapter and suited to 20.716 MCM. Based on the 50 years of design life span, 1035.8 MCM of this dam will occupy by sediment and it will distributed through the dead and live storage of the reservoir. Applying this river sediment monitoring measure on the upstream of the reservoir has a deviation in storage loss, replaced storage and the net storage of the dam.

A. Storage Loss due to the Measure

Similarly, the storage loss due to the measure in case of Tendaho dam was also computed using equation 2 in table 4.5 for each month and the obtained inflow was maximum in August (483.880 MCM) and minimum in January (91.70 MCM). Blocking the inflow on monthly basis, the reservoir will have new storage annually. If the inflow of January is blocked the new storage will be maximum and minimum if inflow of August is blocked. Monitoring the inflow in monthly basis throughout the use full life span of the dam, the inflow loss will also maximum in august (24194.00 MCM) and minimum in January (4585.00 MCM). If we block frequently the river in upstream of the dam on monthly basis, the annual inflow of the reservoir will reduce as shown in table 4.5.

No	Month	Inflow (MCM)	New annual storage (MCM)	Storage loss due to the measure (MCM)
1	January	91.700	2242.770	4585.000
2	February	105.760	2228.710	5288.000
3	March	172.390	2162.080	8619.500
4	April	193.770	2140.700	9688.500
5	May	130.150	2204.320	6507.500
6	Jun	80.190	2254.280	4009.500
7	July	192.440	2142.030	9622.000
8	August	483.880	1850.590	24194.000

9	September	345.180	1989.290	17259.000
10	October	260.120	2074.350	13006.000
11	November	156.080	2178.390	7804.000
12	December	122.810	2211.660	6140.500
	Annual	2334.470		116723.500

Table 4.5: Monthly inflow and storage loss of Tendaho Dam

B. Storage due to Sediment Reduction

The storage acquired due to sediment reduction in case of Tendaho dam was computed in table 4.6. As to the table, monitoring of the sediment inflow throughout the design life span for different months, the dam will improve its life span by 0.526, 1.005, 3.301, 2.883, 1.046, 0.419, 3.344, 35.290, 12.472, 5.248, 1.786, 0.974 years from January to December respectively. The storage acquired in the improved life span of the dam was evaluated and it was maximum in August and minimum in January, that is, monitoring the river only for the month of January can improve the life span of the dam by 0.526 years and can store about 1178.98 MCM. But if we block the inflow of August and September, we can improve the life span by 35.29 and 12.472 years with reservoir storage of 65307.285 MCM and 24809.47 MCM respectively (See table 4.6).

	Month	sediment inflow (MCM)	Adjusted sediment inflow (MCM)	New annual Sediment Inflow (MCM)	New Life Span (Years)	Improved life span (Years)	New annual Storage (MCM)	Storage due to Sediment Reduction (MCM)
1	January	0.274	0.216	20.500	50.526	0.526	2242.770	1178.980
2	February	0.518	0.408	20.308	51.005	1.005	2228.710	2238.954
3	March	1.628	1.283	19.433	53.301	3.301	2162.080	7136.358
4	April	1.433	1.129	19.587	52.883	2.883	2140.700	6170.797
5	May	0.539	0.425	20.291	51.046	1.046	2204.320	2306.010
6	Jun	0.218	0.172	20.544	50.419	0.419	2254.280	943.611
7	July	1.648	1.299	19.417	53.344	3.344	2142.030	7162.568
8	August	10.878	8.572	12.144	85.290	35.290	1850.590	65307.285
9	September	5.248	4.136	16.580	62.472	12.472	1989.290	24809.470

10	October	2.497	1.968	18.748	55.248	5.248	2074.350	10886.763
11	November	0.907	0.714	20.002	51.786	1.786	2178.390	3890.831
12	December	0.502	0.396	20.320	50.974	0.974	2211.660	2153.191
	Annual	26.289	20.716					

Table 4.6: Storage due to Sediment Reduction of Tendaho Dam

C. Net Storage

The net storage in case of Tendaho dam which was the boundary to select the best and useful month of river sediment monitoring to be applied was tested in table 4.7 and figure 4.3. According to the table and figure, the net storage is negative in all months except August and September. Thus, monitoring sediment for Tendaho dam only on these months was desirable since the storage due to sediment reduction was more than that of storage loss due to the measure. If we applied the measure only for the months of August and September, 41113.285 MCM and 7550.47 MCM of advantage in storage could be achieved respectively. But river sediment monitoring in the other months was not recommended since the amount of water loss due to the measure could not be replaced in the respective improved life span of the dam.

No	Month	Storage loss due to the Measure (MCM)	Storage due to Sediment Reduction (MCM)	Net Storage (MCM)
1	January	4585.000	1178.980	-3406.020
2	February	5288.000	2238.954	-3049.046
3	March	8619.500	7136.358	-1483.142
4	April	9688.500	6170.797	-3517.703
5	May	6507.500	2306.010	-4201.490
6	Jun	4009.500	943.611	-3065.889
7	July	9622.000	7162.568	-2459.432
8	August	24194.000	65307.285	41113.285
9	September	17259.000	24809.470	7550.470
10	October	13006.000	10886.763	-2119.237
11	November	7804.000	3890.831	-3913.169
12	December	6140.500	2153.191	-3987.309

Table 4.7: Net Storage of Tendaho Dam

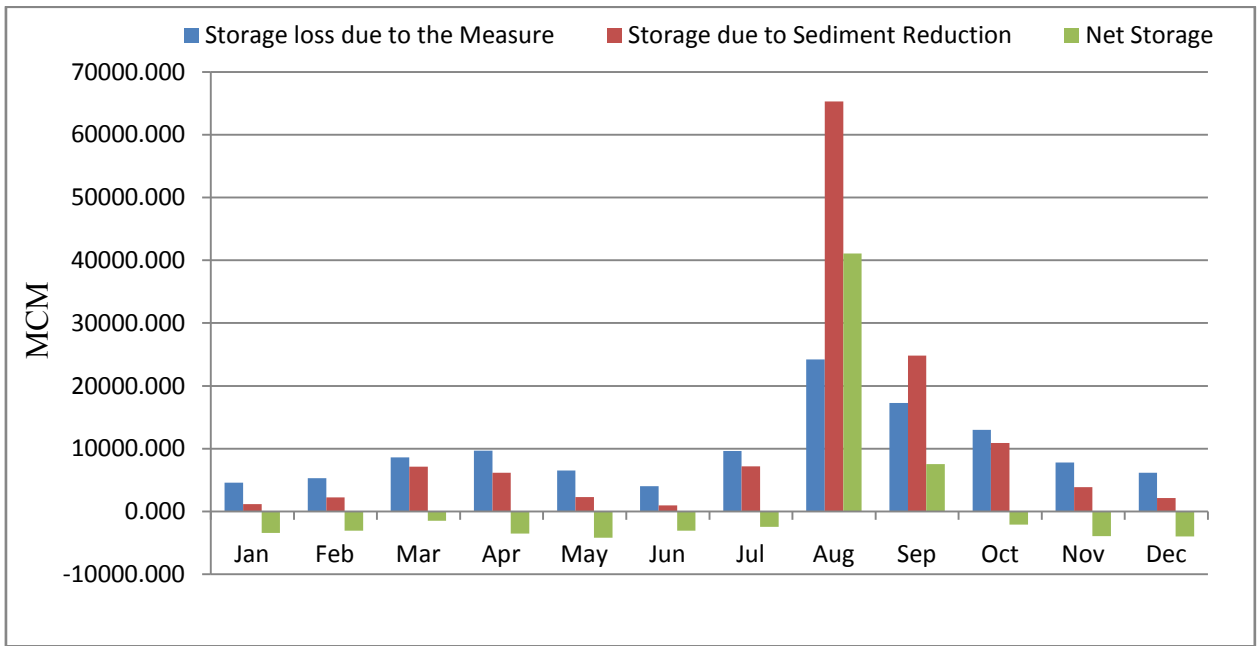


Figure 4.3: Net Storage of Tendaho Dam

D. Net Storage on Daily Basis

The selection of best fit months for the river sediment monitoring measure was also tested on daily basis (see appendix III and fig 4.4). Similarly, the net storage except month of August and September were negative. Thus, according to test on daily basis that was also applied the measure on this month was better which is similar to that of monthly basis that was tested before. So, for Tendaho dam, river sediment monitoring and improves the life span of the dam, is desirable, useful and economical on month of August and September.

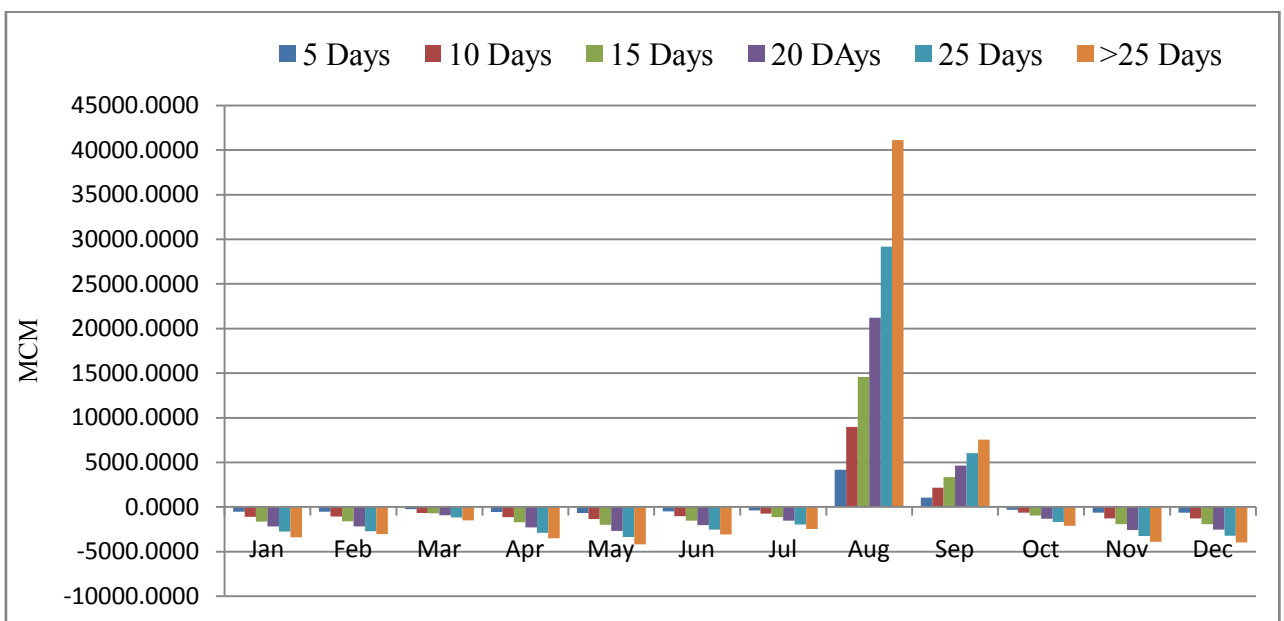


Figure 4.4: Net Storage on daily basis of Tendaho Dam

E. River Sediment Monitoring for the Selected Months

Based on the previous test, only the month of August and September were the best and useful to bypass heavily sediment laden flows. But the dam would not be expected to serve effectively for infinitive years since the full month inflow monitoring of August and September will improve the life span of the dam by 35.2901 and 12.9953 years respectively in addition to the high runoff rate was also obtained in those months. Hence, the improved period at the same time the advantage achieves applying river sediment monitoring measure in each a day incremental was evaluated in table 4.8 and 4.9. As can be noticed from the table, upstream monitoring for only one day inflow of August and September month throughout the life span of Tendaho reservoir, the life time will be 50.6764 and 50.3350 years in which 0.6764 and 0.3350 years incremental. The storage loss and storage due to sediment reduction of the month August will be 780.4516 MCM, 1568.4551 MCM and 575.3 MCM, 778.0871 MCM for the month of September. Therefore, on those months, one day sediment bypassing of Tendaho reservoir will acquire 788 and 202.79 MCM benefits in storage respectively. In a similar manner, if we bypass the first ten days of inflow for those months the life span of the dam will be 57.7016 and 53.1853 years in which 7.7016 and 3.1853 years incremental of the design life span could attain 8972.4306 MCM and 2157.9795 MCM benefit in storage.

Month	Monitoring Interval (days)	New Annual Storage (MCM)	New Annual Sediment Inflow (MCM)	New Life Span (Years)	Improved Life Span (Years)	Storage loss due to the Measure (MCM)	Storage due to Sediment Reduction (MCM)	Net Storage (MCM)
August	0	2334.4700	20.7160	50.0000	0.0000	0.0000	0.0000	0.0000
	1	2318.8610	20.4395	50.6764	0.6764	780.4516	1568.4551	788.0035
	2	2303.2519	20.1630	51.3713	1.3713	1560.9032	3158.5225	1597.6193
	3	2287.6429	19.8865	52.0856	2.0856	2341.3548	4771.1036	2429.7488
	4	2272.0339	19.6100	52.8200	2.8200	3121.8065	6407.1509	3285.3445
	5	2256.4248	19.3335	53.5754	3.5754	3902.2581	8067.6711	4165.4130
	6	2240.8158	19.0570	54.3528	4.3528	4682.7097	9753.7295	5071.0198
	7	2225.2068	18.7805	55.1530	5.1530	5463.1613	11466.4540	6003.2927
	8	2209.5977	18.5040	55.9771	5.9771	6243.6129	13207.0400	6963.4271
	9	2193.9887	18.2275	56.8263	6.8263	7024.0645	14976.7556	7952.6911
	10	2178.3797	17.9510	57.7016	7.7016	7804.5161	16776.9467	8972.4306
	11	2162.7706	17.6745	58.6043	8.6043	8584.9677	18609.0437	10024.0759
	12	2147.1616	17.3980	59.5356	9.5356	9365.4194	20474.5677	11109.1483
	13	2131.5526	17.1215	60.4971	10.4971	10145.8710	22375.1382	12229.2672
	14	2115.9435	16.8450	61.4901	11.4901	10926.3226	24312.4810	13386.1585
	15	2100.3345	16.5685	62.5163	12.5163	11706.7742	26288.4373	14581.6631
	16	2084.7255	16.2920	63.5773	13.5773	12487.2258	28304.9728	15817.7470
	17	2069.1165	16.0155	64.6750	14.6750	13267.6774	30364.1895	17096.5121
	18	2053.5074	15.7390	65.8112	15.8112	14048.1290	32468.3368	18420.2078
	19	2037.8984	15.4625	66.9880	16.9880	14828.5806	34619.8250	19791.2444
	20	2022.2894	15.1860	68.2077	18.2077	15609.0323	36821.2401	21212.2079
	21	2006.6803	14.9095	69.4726	19.4726	16389.4839	39075.3598	22685.8759
	22	1991.0713	14.6330	70.7854	20.7854	17169.9355	41385.1717	24215.2362
	23	1975.4623	14.3565	72.1487	22.1487	17950.3871	43753.8937	25803.5066
	24	1959.8532	14.0800	73.5655	23.5655	18730.8387	46184.9965	27454.1578
	25	1944.2442	13.8035	75.0392	25.0392	19511.2903	48682.2288	29170.9385
	26	1928.6352	13.5270	76.5730	26.5730	20291.7419	51249.6457	30957.9038
	27	1913.0261	13.2505	78.1709	28.1709	21072.1935	53891.6410	32819.4474
	28	1897.4171	12.9740	79.8369	29.8369	21852.6452	56612.9829	34760.3377

	29	1881.8081	12.6975	81.5754	31.5754	22633.0968	59418.8550	36785.7582
	30	1866.1990	12.4210	83.3913	33.3913	23413.5484	62314.9024	38901.3540
	31	1850.5900	12.1445	85.2900	35.2900	24194.0000	65307.2845	41113.2845

Table 4.8: Net Storage of Tendaho Dam for the selected month (August), Daily basis

Month	Monitoring Interval (days)	New Annual Storage (MCM)	New Annual Sediment Inflow (MCM)	New Life Span (Years)	Improved Life Span (Years)	Storage loss due to the Measure (MCM)	Storage due to Sediment Reduction (MCM)	Net Storage (MCM)
September	0	2334.4700	20.7160	50.0000	0.0000	0.0000	0.0000	0.0000
	1	2322.9640	20.5781	50.3350	0.3350	575.3000	778.0871	202.7871
	2	2311.4580	20.4403	50.6744	0.6744	1150.6000	1558.9095	408.3095
	3	2299.9520	20.3024	51.0185	1.0185	1725.9000	2342.5229	616.6229
	4	2288.4460	20.1646	51.3673	1.3673	2301.2000	3128.9846	827.7846
	5	2276.9400	20.0267	51.7209	1.7209	2876.5000	3918.3534	1041.8534
	6	2265.4340	19.8889	52.0794	2.0794	3451.8000	4710.6897	1258.8897
	7	2253.9280	19.7510	52.4429	2.4429	4027.1000	5506.0557	1478.9557
	8	2242.4220	19.6132	52.8115	2.8115	4602.4000	6304.5152	1702.1152
	9	2230.9160	19.4753	53.1853	3.1853	5177.7000	7106.1340	1928.4340
	10	2219.4100	19.3375	53.5645	3.5645	5753.0000	7910.9795	2157.9795
	11	2207.9040	19.1996	53.9490	3.9490	6328.3000	8719.1214	2390.8214
	12	2196.3980	19.0617	54.3392	4.3392	6903.6000	9530.6311	2627.0311
	13	2184.8920	18.9239	54.7351	4.7351	7478.9000	10345.5823	2866.6823
	14	2173.3860	18.7860	55.1367	5.1367	8054.2000	11164.0506	3109.8506
	15	2161.8800	18.6482	55.5443	5.5443	8629.5000	11986.1142	3356.6142
	16	2150.3740	18.5103	55.9580	5.9580	9204.8000	12811.8532	3607.0532
	17	2138.8680	18.3725	56.3778	6.3778	9780.1000	13641.3506	3861.2506
	18	2127.3620	18.2346	56.8041	6.8041	10355.4000	14474.6914	4119.2914
	19	2115.8560	18.0968	57.2368	7.2368	10930.7000	15311.9635	4381.2635
	20	2104.3500	17.9589	57.6761	7.6761	11506.0000	16153.2575	4647.2575
	21	2092.8440	17.8210	58.1223	8.1223	12081.3000	16998.6667	4917.3667
	22	2081.3380	17.6832	58.5754	8.5754	12656.6000	17848.2874	5191.6874

	23	2069.8320	17.5453	59.0356	9.0356	13231.9000	18702.2188	5470.3188
	24	2058.3260	17.4075	59.5031	9.5031	13807.2000	19560.5632	5753.3632
	25	2046.8200	17.2696	59.9781	9.9781	14382.5000	20423.4265	6040.9265
	26	2035.3140	17.1318	60.4608	10.4608	14957.8000	21290.9177	6333.1177
	27	2023.8080	16.9939	60.9512	10.9512	15533.1000	22163.1494	6630.0494
	28	2012.3020	16.8561	61.4497	11.4497	16108.4000	23040.2379	6931.8379
	29	2000.7960	16.7182	61.9564	11.9564	16683.7000	23922.3034	7238.6034
	30	1989.2900	16.5804	62.4715	12.4715	17259.0000	24809.4700	7550.4700

Table 4.9: Net Storage of Tendaho Dam for the selected month (September), Daily basis

4.1.3. Ribb Dam Irrigation Project

According to the data of MoWE (1960-2004), the annual inflow and sediment inflow of Ribb dam was 225.10 MCM and 0.53432 MCM respectively. But the annual sediment was corrected in addition to the criteria described in the previous chapter and suited to 0.54 MCM. Based on the 50 years of design life span, 27 MCM of this dam will occupy by sediment and it will distribute through the dead and live storage of the reservoir. Applying this river sediment monitoring measure on the upstream of the reservoir has a deviation in storage loss, replaced storage and the net storage of the dam.

A. Storage Loss due to the Measure

The storage loss due to the measure in the case of Ribb dam was also computed using equation 2 in table 4.10 for each month and the inflow was maximum on August (96.00 MCM) and minimum on January (1.90 MCM). Blocking the inflow on monthly basis, the reservoir will have new storage annually. If the inflow of January is blocked the new storage will be maximum and minimum if inflow of August is blocked. Monitoring the inflow in monthly basis, throughout use full life span of the dam the inflow loss will also maximum in august (4800.00 MCM) and minimum in January (95.00 MCM). If we blocked frequently the river in the upstream of the dam on monthly basis, the annual inflow of the reservoir will reduce as shown in table 4.10.

No	Month	Inflow (MCM)	New annual storage (MCM)	Storage loss due to the Measure (MCM)
1	January	1.900	223.200	95.000
2	February	1.300	223.800	65.000
3	March	1.300	223.800	65.000

4	April	2.100	223.000	105.000
5	May	2.200	222.900	110.000
6	Jun	8.000	217.100	400.000
7	July	56.400	168.700	2820.000
8	August	96.000	129.100	4800.000
9	September	36.700	188.400	1835.000
10	October	10.900	214.200	545.000
11	November	5.600	219.500	280.000
12	December	2.700	222.400	135.000
	Annual	225.100		11255.000

Table 4.10: Monthly inflow and storage loss of Ribb Dam

B. Storage due to Sediment Reduction

In the case of Ribb dam, the storage acquired due to the sediment reduction was also evaluated in table 4.11. Based on the table, monitoring the sediment inflow throughout the design life span on different months, the dam will improve its life span by 0.074, 0.043, 0.046, 0.091, 0.095, 0.688, 16.793, 64.255, 7.757, 1.069, 0.395, 0.130, 91.435 years from January to December respectively. The storage acquired in the improved life span of the dam is maximum on August and minimum on January, that is, monitoring the river only for the month of January can improve the life span of the dam by 0.074 years and can store about 16.431 MCM. But if we block the inflow of July and August we can improve the life span by 16.793 and 64.255 years with reservoir storage of 2832.974 MCM and 8295.285 MCM respectively (Table 4.11).

	Month	sediment inflow (MCM)	Adjusted sediment inflow (MCM)	New annual Sediment Inflow (MCM)	New Life Span (Years)	Improved life span (Years)	New annual Storage (MCM)	Storage due to Sediment Reduction (MCM)
1	January	0.00079	0.001	0.539	50.074	0.074	223.200	16.431
2	February	0.00046	0.000	0.540	50.043	0.043	223.800	9.731
3	March	0.00049	0.000	0.540	50.046	0.046	223.800	10.185
4	April	0.00097	0.001	0.539	50.091	0.091	223.000	20.249
5	May	0.00101	0.001	0.539	50.095	0.095	222.900	21.120

6	Jun	0.00726	0.007	0.533	50.688	0.688	217.100	149.437
7	July	0.13434	0.136	0.404	66.793	16.793	168.700	2832.974
8	August	0.30049	0.304	0.236	114.255	64.255	129.100	8295.285
9	September	0.07176	0.073	0.467	57.757	7.757	188.400	1461.391
10	October	0.01119	0.011	0.529	51.069	1.069	214.200	229.059
11	November	0.00419	0.004	0.536	50.395	0.395	219.500	86.719
12	December	0.00138	0.001	0.539	50.130	0.130	222.400	28.844
	Annual	0.53432	0.540					

Table 4.11: Storage due to Sediment Reduction of Ribb Dam

C. Net Storage

The net storage in the case of Ribb dam was also evaluated in table 4.7 and figure 4.3. Based on the table and figure, the net storage is negative in all months out of July and August. Therefore, monitoring of sediment for Ribb dam only on those months was desirable since the storage due to sediment reduction was more than that of storage loss due to the measure. If we applied the measure only for the months of July and August 12.974 MCM and 3495.285 MCM of advantage in storage can achieve respectively. But river sediment monitoring in the other months is not recommended since the amount of water loss because of the measure cannot replace in the respective improved life span of the dam.

No	Month	Storage loss due to the Measure (MCM)	Storage due to Sediment Reduction (MCM)	Net Storage (MCM)
1	January	95.000	16.431	-78.569
2	February	65.000	9.731	-55.269
3	March	65.000	10.185	-54.815
4	April	105.000	20.249	-84.751
5	May	110.000	21.120	-88.880
6	Jun	400.000	149.437	-250.563
7	July	2820.000	2832.974	12.974
8	August	4800.000	8295.285	3495.285
9	September	1835.000	1461.391	-373.609
10	October	545.000	229.059	-315.941
11	November	280.000	86.719	-193.281

12	December	135.000	28.844	-106.156
----	----------	---------	--------	----------

Table 4.12: Net Storage of Ribb Dam

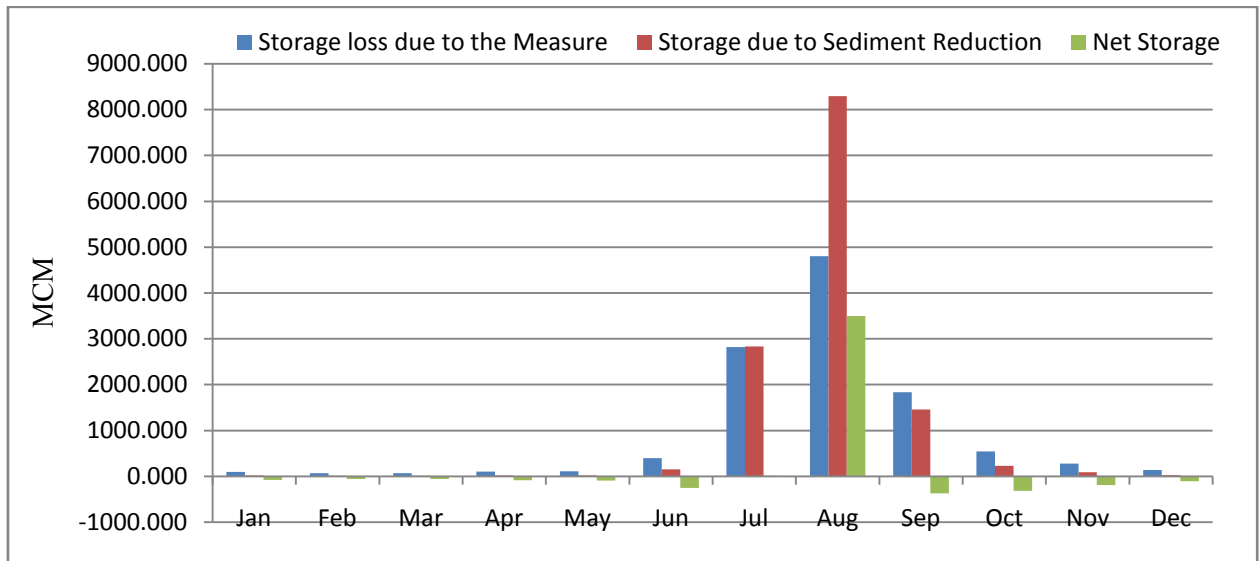


Figure 4.5: Net Storage for Ribb Dam

D. Net Storage on Daily Basis

The selection of best fit months for the river sediment monitoring measure was also tested on daily basis (see appendix IV and fig 4.6). Similarly, net storage except month of July and August were negative. Thus according to the test on that also applied the measure on this month was better which is similar to that of the test on monthly basis that was tested before. Therefore, for Ribb dam, river sediment monitoring to improve the life span of the dam is desirable, useful and economical on month of July and August.

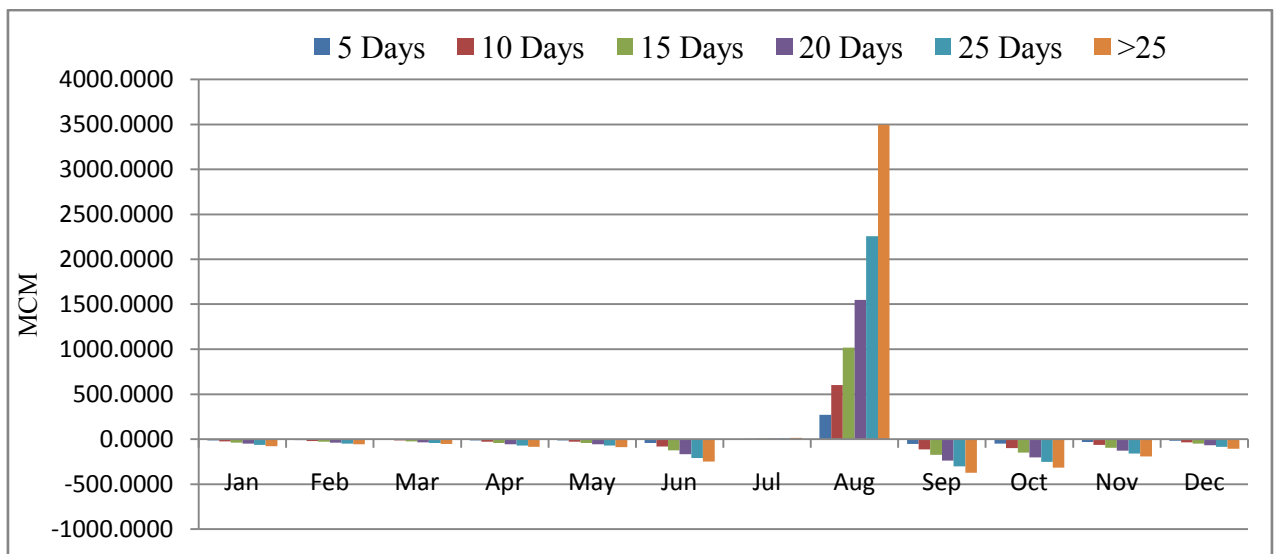


Figure 4.6: Net Storage on day basis of Ribb Dam

E. River Sediment Monitoring for the Selected Months

Based on the previous testes only for months of July and August were the better and useful to bypass heavily sediment laden flows. But the dam would be not expected to serve effectively for infinitive years since the full month inflow monitoring of July and August will improve the life span of the dam by 16.7952 and 64.2501 years respectively in addition to the high runoff rate was also obtained on those months. Hence, the improved period at the same time the advantage achieves applying river sediment monitoring measure in each one day incremental was evaluated in table 4.13 and 4.14. Based on the table, the upstream monitoring for only one day inflow of July and August throughout the life span of Ribb reservoir, the life time will be 50.4088 and 50.9238 years in which 0.4088 and 0.9238 years incremental. The storage loss and storage due to sediment reduction of July month will be 90.9677 MCM, 91.2836 MCM and 154.8387 MCM, 205.0924 MCM for the month of August. Therefore, on those months, one day sediment bypassing of Ribb reservoir will acquire 0.3158 and 50.2537MCM benefits in storage respectively. In a similar manner, if we bypass the first ten days of inflow for those months, the life span of the dam will be 54.413and 61.0809 years in which 4.413 and 11.0809 years incremental of the design life span could attain 8972.4306 MCM and 2157.9795 MCM benefit in storage.

Month	Monitoring Interval (days)	New Annual Storage (MCM)	New Annual Sediment Inflow (MCM)	New Life Span (Years)	Improved Life Span (Years)	Storage loss due to the Measure (MCM)	Storage due to Sediment Reduction (MCM)	Net Storage (MCM)
July	0	225.1	0.54	50	0	0	0	0
	1	223.2806	0.5356	50.4088	0.4088	90.9677	91.2836	0.3158
	2	221.4613	0.5312	50.8244	0.8244	181.9355	182.5724	0.6369
	3	219.6419	0.5269	51.2469	1.2469	272.9032	273.8665	0.9633
	4	217.8226	0.5225	51.6764	1.6764	363.8710	365.1661	1.2952
	5	216.0032	0.5181	52.1133	2.1133	454.8387	456.4714	1.6326
	6	214.1839	0.5137	52.5575	2.5575	545.8065	547.7823	1.9759
	7	212.3645	0.5093	53.0094	3.0094	636.7742	639.0992	2.3250
	8	210.5452	0.5050	53.4692	3.4692	727.7419	730.4221	2.6802
	9	208.7258	0.5006	53.9370	3.9370	818.7097	821.7513	3.0416
	10	206.9065	0.4962	54.4130	4.4130	909.6774	913.0868	3.4094
	11	205.0871	0.4918	54.8976	4.8976	1000.6452	1004.4289	3.7837
	12	203.2677	0.4874	55.3908	5.3908	1091.6129	1095.7777	4.1648
	13	201.4484	0.4831	55.8930	5.8930	1182.5806	1187.1334	4.5528
	14	199.6290	0.4787	56.4044	6.4044	1273.5484	1278.4962	4.9478
	15	197.8097	0.4743	56.9252	6.9252	1364.5161	1369.8663	5.3502
	16	195.9903	0.4699	57.4557	7.4557	1455.4839	1461.2439	5.7601
	17	194.1710	0.4655	57.9962	7.9962	1546.4516	1552.6293	6.1776
	18	192.3516	0.4612	58.5470	8.5470	1637.4194	1644.0225	6.6031
	19	190.5323	0.4568	59.1083	9.1083	1728.3871	1735.4239	7.0368
	20	188.7129	0.4524	59.6805	9.6805	1819.3548	1826.8337	7.4789
	21	186.8935	0.4480	60.2639	10.2639	1910.3226	1918.2522	7.9296
	22	185.0742	0.4437	60.8588	10.8588	2001.2903	2009.6795	8.3892
	23	183.2548	0.4393	61.4655	11.4655	2092.2581	2101.1160	8.8580
	24	181.4355	0.4349	62.0845	12.0845	2183.2258	2192.5620	9.3362
	25	179.6161	0.4305	62.7161	12.7161	2274.1935	2284.0177	9.8241
	26	177.7968	0.4261	63.3607	13.3607	2365.1613	2375.4834	10.3221
	27	175.9774	0.4218	64.0186	14.0186	2456.1290	2466.9594	10.8304
	28	174.1581	0.4174	64.6904	14.6904	2547.0968	2558.4461	11.3494

	29	172.3387	0.4130	65.3764	15.3764	2638.0645	2649.9439	11.8794
	30	170.5194	0.4086	66.0771	16.0771	2729.0323	2741.4530	12.4207
	31	168.7000	0.4042	66.7930	16.7930	2820.0000	2832.9738	12.9738

Table 4.13: Net Storage of Ribb Dam for the selected month (July), Daily basis

Month	Monitoring Interval (days)	New Annual Storage (MCM)	New Annual Sediment Inflow (MCM)	New Life Span (Years)	Improved Life Span (Years)	Storage loss due to the Measure (MCM)	Storage due to Sediment Reduction (MCM)	Net Storage (MCM)
August	0	225.1000	0.5400	50.0000	0.0000	0.0000	0.0000	0.0000
	1	222.0032	0.5302	50.9238	0.9238	154.8387	205.0924	50.2537
	2	218.9065	0.5204	51.8824	1.8824	309.6774	412.0767	102.3993
	3	215.8097	0.5106	52.8778	2.8778	464.5161	621.0620	156.5458
	4	212.7129	0.5008	53.9122	3.9122	619.3548	832.1655	212.8106
	5	209.6161	0.4910	54.9878	4.9878	774.1935	1045.5141	271.3205
	6	206.5194	0.4812	56.1072	6.1072	929.0323	1261.2449	332.2126
	7	203.4226	0.4714	57.2731	7.2731	1083.8710	1479.5064	395.6354
	8	200.3258	0.4616	58.4885	8.4885	1238.7097	1700.4597	461.7500
	9	197.2290	0.4518	59.7566	9.7566	1393.5484	1924.2799	530.7315
	10	194.1323	0.4420	61.0809	11.0809	1548.3871	2151.1576	602.7705
	11	191.0355	0.4322	62.4652	12.4652	1703.2258	2381.3007	678.0749
	12	187.9387	0.4224	63.9138	13.9138	1858.0645	2614.9364	756.8719
	13	184.8419	0.4126	65.4311	15.4311	2012.9032	2852.3134	839.4102
	14	181.7452	0.4029	67.0222	17.0222	2167.7419	3093.7046	925.9627
	15	178.6484	0.3931	68.6926	18.6926	2322.5806	3339.4102	1016.8295
	16	175.5516	0.3833	70.4485	20.4485	2477.4194	3589.7610	1112.3417
	17	172.4548	0.3735	72.2964	22.2964	2632.2581	3845.1226	1212.8645
	18	169.3581	0.3637	74.2439	24.2439	2787.0968	4105.8999	1318.8031
	19	166.2613	0.3539	76.2992	26.2992	2941.9355	4372.5427	1430.6072
	20	163.1645	0.3441	78.4716	28.4716	3096.7742	4645.5519	1548.7777
	21	160.0677	0.3343	80.7713	30.7713	3251.6129	4925.4873	1673.8744
	22	156.9710	0.3245	83.2098	33.2098	3406.4516	5212.9763	1806.5247

	23	153.8742	0.3147	85.8002	35.8002	3561.2903	5508.7243	1947.4339
	24	150.7774	0.3049	88.5570	38.5570	3716.1290	5813.5273	2097.3982
	25	147.6806	0.2951	91.4969	41.4969	3870.9677	6128.2871	2257.3194
	26	144.5839	0.2853	94.6387	44.6387	4025.8065	6454.0296	2428.2231
	27	141.4871	0.2755	98.0039	48.0039	4180.6452	6791.9262	2611.2810
	28	138.3903	0.2657	101.6172	51.6172	4335.4839	7143.3212	2807.8374
	29	135.2935	0.2559	105.5072	55.5072	4490.3226	7509.7650	3019.4424
	30	132.1968	0.2461	109.7069	59.7069	4645.1613	7893.0544	3247.8931
	31	129.1000	0.2363	114.2547	64.2547	4800.0000	8295.2845	3495.2845

Table 4.14: Net Storage of Ribb Dam for the selected month (August), Daily basis

4.2. Benefit Cost Analysis Based on Annual Income of the Project

To compute benefit cost ratio the cost out lay and benefit obtained were analyzed based on unit rate of stored water (URS). This URS may have a variation in future because of time value of money. But, this will have an equal value for both cost out lay and benefit obtained. By this ground the variation may exist were considered constant.

4.2.1. Kesem Kebena Dam Irrigation Project

According to the WWDSE in association with WAPCOS (India) Ltd final design report of Kesem Kebena dam, the irrigation production rate of the project is about 0.646-2.34 million tons annually. The feasibility study of January 2006 states that one quintal of sugarcane can be sold 450 birr; So, from equation 12, the annual income of this project will be 10,530 million birr when the 20,000 ha entire planting area is covered. To satisfy this demand or to have this annual income, the annual water release required from the reservoir has to be 392.4 MCM (appendix XIII). Therefore out of equation 11, the unit rate of the stored water (URS) will be 26.83 birr. This means out of the cubic meter of the stored water 26.83 birr benefit were taken as the same time losing one cubic meter of water outlays or costs 26.83 birr.

The cost (C) indicates the annual loss of the silt reduction measure taken on the upstream of the reservoir if the inflow is monitor on monthly basis. Based on this concept, the cost loss is

evaluated using equation 13 in table 4.15. According to the table, monitoring the inflow for month of January will lost minimum benefit (14,679.282 Million Birr) and maximum benefit (504,416.564 MB) for the month of August. In other words, benefit will obtain from the project as applying the measure is directly related to the improved life span and to the new storage of the reservoir assessed in the previous sections. The benefits obtained from the storage due to sediment reduction for each month is computed using equation 14, and obtained monitoring the inflow of sediment in the month of January will have minimum benefit (326.7810 MB) and maximum benefit (2,148,207.041 MB) for the month of August.

Then after, benefit cost ratio was analyzed on monthly basis in the case of Kesem Kebena dam resulted maximum on the month of August. The BCR obtained for the other months was less than one means blocking the river flow on those months will result in loss of the project benefit for the project. Thus, diverting the flow of August away from the reservoir will make the project design life to extend larger and worthier than any other months.

S.NO	Month	Storage loss due to the Measure (MCM)	cost (MB)	Storage due to Sediment Reduction (MCM)	Benefit (MB)	Benefit / Cost
1	January	547.122	14679.282	12.180	326.781	0.022
2	February	603.102	16181.238	24.075	645.919	0.040
3	March	801.502	21504.310	42.011	1127.148	0.052
4	April	760.293	20398.653	31.725	851.187	0.042
5	May	685.698	18397.266	26.094	700.113	0.038
6	Jun	896.507	24053.291	62.774	1684.218	0.070
7	July	8783.141	235651.685	6101.333	163698.771	0.695
8	August	18800.468	504416.564	80067.352	2148207.041	4.259
9	September	7054.888	189282.640	2150.261	57691.503	0.305
10	October	1593.600	42756.288	162.764	4366.955	0.102
11	November	758.498	20350.490	28.887	775.045	0.038
12	December	591.902	15880.742	14.238	382.008	0.024

Table 4.15: Benefit cost analysis of Kesem Kebena Dam

The benefit cost analysis for August on daily base was also evaluated in appendix X and figure 4.7. Based on the result, the benefit will increase when the monitoring days of the river is increased and it had better benefit than the cost on the selected month of August.

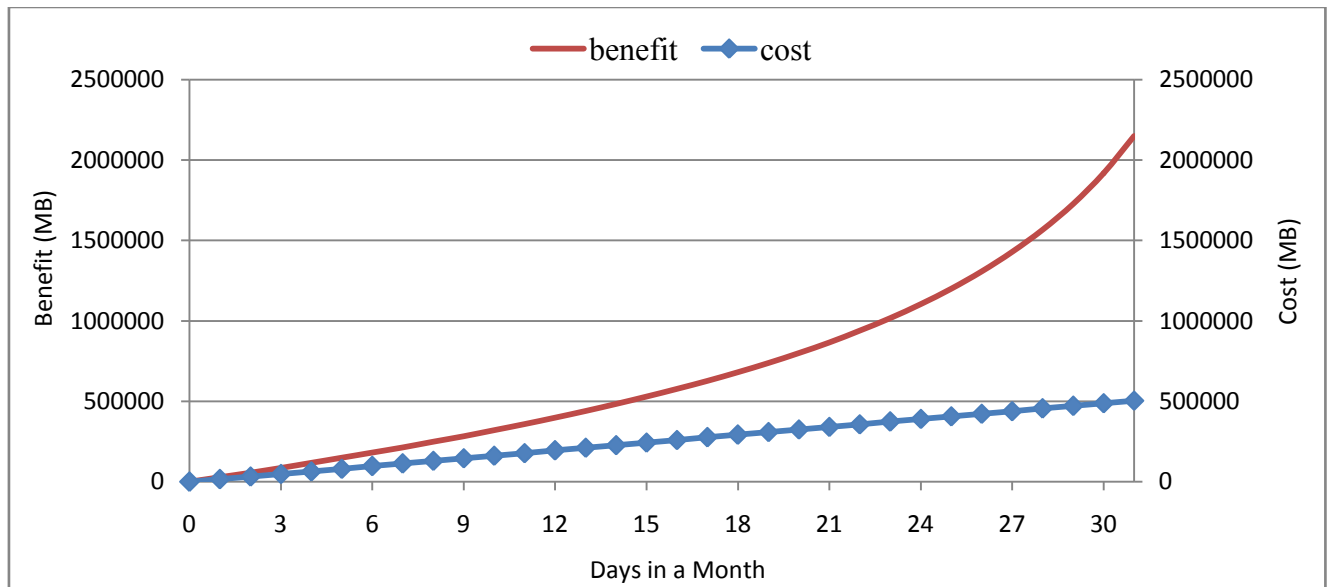


Figure 4.7: Benefit cost analysis of Kesem Kebena Dam, for the selected month of August

4.2.2. Tendaho Dam Irrigation Project

According to the WWDSE in association with WAPCOS (India) Ltd final design report of Tendaho dam the irrigation production rate of the project is about 1.73-6.2 million tons annually out of the proposed command area of 48,000 ha. The feasibility study states that one quintal of sugar-cane could be sold 450 birr; so, from equation 12, the annual income of this project will be 27,900 million birr when the entire planting area is covered. To satisfy the demand or to have this annual income, the annual water releases required from the reservoir have to be 1769 MCM (See appendix IVX). Therefore, from equation 11, the unit URS will be 19.72 birr. This means out of the cubic meter of stored water 19.72 birr benefit were taken as the same time losing one cubic meter of water outlays or costs 19.72 birr.

In the case of Tendaho dam one cubic meter of water worth 19.72 birr and the cost loss applying the measure was computed using equation 13 in table 4.16. Based on the table, monitoring the inflow for the month of January will lost minimum benefit (90,402.445 MB) and maximum benefits (477,033.098 MB) for the month of August. In other words, the benefit obtained from the storage due to the sediment reduction for each month was computed using equation 14 and the

results on month of January will have minimum benefit (23,245.942 MB) and for the month of August will have maximum benefit (1,287,663.729 MB).

Then after, benefit cost ratio was analyzed on monthly basis in the case of Tendaho dam and resulted for two consecutive maximums in months of August and September. The BCR obtained for the other months was less than one means blocking the river flow in those months will result in loss of the project's benefit. Thus, diverting the flow of August and September away from the reservoir will make the project design life to extend larger and worthier than any other months.

No	Month	Storage loss due to the Measure (MCM)	Cost (MB)	Storage due to Sediment Reduction (MCM)	Benefit (MB)	Benefit / Cost
1	January	4585.000	90402.445	1178.980	23245.942	0.257
2	February	5288.000	104263.496	2238.954	44145.463	0.423
3	March	8619.500	169950.682	7136.358	140707.578	0.828
4	April	9688.500	191028.155	6170.797	121669.597	0.637
5	May	6507.500	128308.378	2306.010	45467.601	0.354
6	Jun	4009.500	79055.312	943.611	18605.178	0.235
7	July	9622.000	189716.974	7162.568	141224.353	0.744
8	August	24194.000	477033.098	65307.285	1287663.729	2.699
9	September	17259.000	340295.703	24809.470	489168.319	1.437
10	October	13006.000	256439.302	10886.763	214654.303	0.837
11	November	7804.000	153871.468	3890.831	76715.518	0.499
12	December	6140.500	121072.239	2153.191	42454.466	0.351
	Annual	116723.500	2301437.250	134184.818	2645722.047	9.303

Table 4.16: Benefit cost analysis of Tendaho Dam

The benefit cost analysis for August and September on daily base was also evaluated (See appendix XI and figure 4.8-4.9). Based on the result, the benefit will increase when the monitoring days of the river is increased and it have better benefit rather than the cost for both selected months.

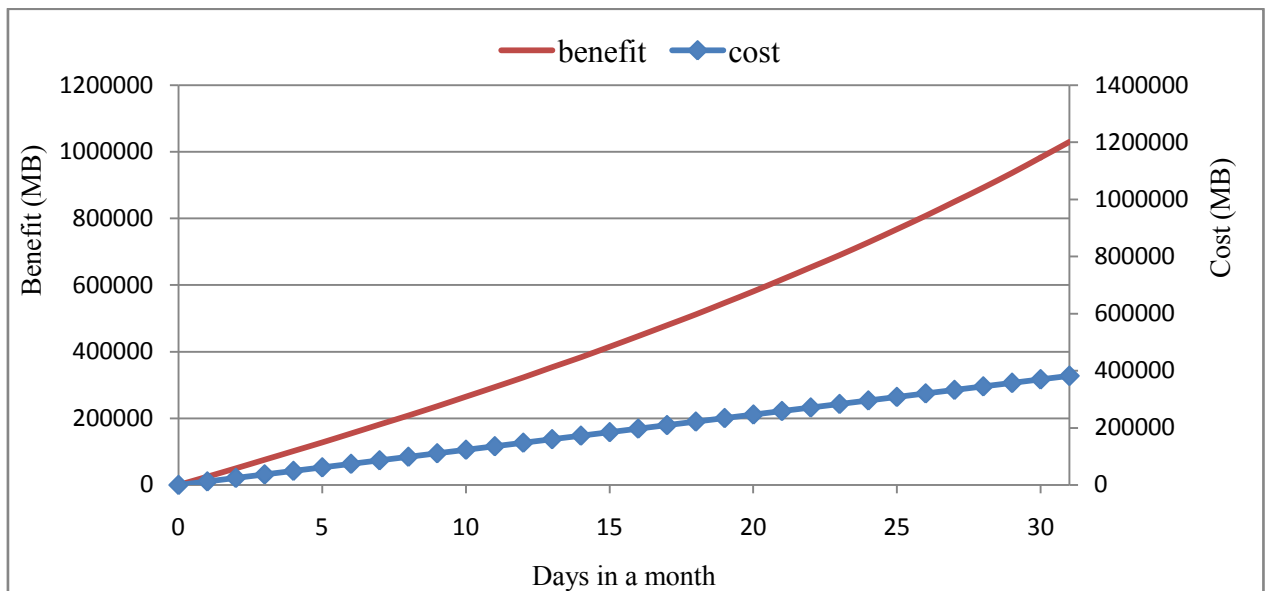


Figure 4.8: Benefit cost analysis of Tendaho Dam, for the selected month of August

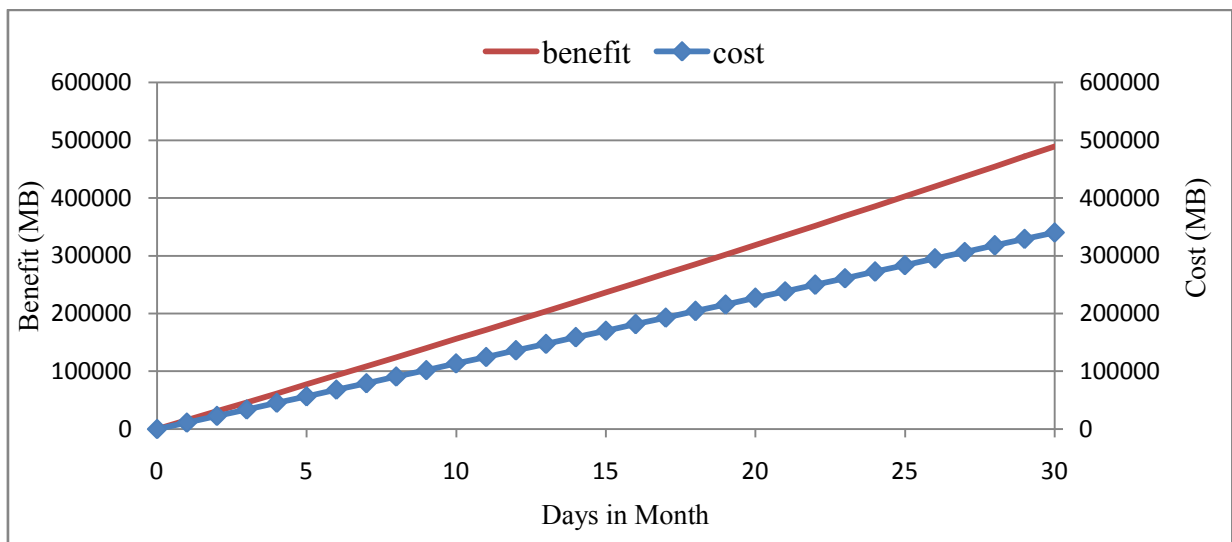


Figure 4.9: Benefit cost analysis for Tendaho Dam, for the selected month of September

4.2.3. Ribb Dam Irrigation Project

According to the MoWR final design report of Ribb dam, the irrigation production rate of the project was about 0.53-1.12 million tons annually from the proposed command area of 20,000 ha. The feasibility study states that one quintal of sugarcane could be sold 450 birr; so, from equation 12, the annual income of this project would be 5,040 million birr when the entire planting area was covered. To satisfy the demand or to have this annual income, the annual water release required from the reservoir has to be 198 MCM (See Appendix XV). Therefore, from equation 11, the unit URS will be 25.455 birr. This means out of cubic meter of stored water, 25.455 birr benefit were taken as the same time losing one cubic meter of water outlays or costs 25.455 birr.

In the case of Ribb dam, one cubic meter of water worth 25.455 birr and the cost loss applying the measure was computed using equation 13 in table 4.17. Based on the table, monitoring the inflow for the month of January will lost minimum benefit (2418.225 MB) and maximum benefits (122184.00 MB) for month of August. In other words, the benefit obtained from the storage due to the sediment reduction for each month was computed using equation 14 and the results on month of January will have minimum benefit (418.253 MB) and for the month of August will have maximum benefit (211,156.467 MB).

Then after, benefit cost ratio was analyzed on monthly bases in the case of Ribb dam and resulted for two consecutive maximums on the n month of July and August. But BCR of July is nearly one it was neither beneficiary nor costly if the flow in this month was diverted away from the reservoir. The BCR obtained for other months is less than one that means blocking the river flow on those months will result in loss of the project's benefit. Thus diverting the flow of August away from the reservoir will make the project design life to extend larger and worth full than any other months.

S. No	month	Storage loss due to the Measure (MCM)	Cost (MB)	Storage due to Sediment Reduction (MCM)	Benefit (MB)	Benefit / Cost
1	January	95.000	2418.225	16.431	418.253	0.173
2	February	65.000	1654.575	9.731	247.698	0.150
3	March	65.000	1654.575	10.185	259.266	0.157
4	April	105.000	2672.775	20.249	515.444	0.193
5	May	110.000	2800.050	21.120	537.618	0.192
6	Jun	400.000	10182.000	149.437	3803.922	0.374
7	July	2820.000	71783.100	2832.974	72113.347	1.005
8	August	4800.000	122184.000	8295.285	211156.467	1.728
9	September	1835.000	46709.925	1461.391	37199.697	0.796
10	October	545.000	13872.975	229.059	5830.706	0.420
11	November	280.000	7127.400	86.719	2207.436	0.310
12	December	135.000	3436.425	28.844	734.216	0.214
	Annual	11255.000	286496.025	13161.425	335024.071	5.711

Table 4.17: Benefit cost analysis of Ribb Dam

The benefit cost analysis for July and August on daily base was also evaluated in appendix XII and figure 4.8. Based on the result, the benefit will increase when the monitoring days of the river is increased and it have better benefit rather than the cost for both selected months.

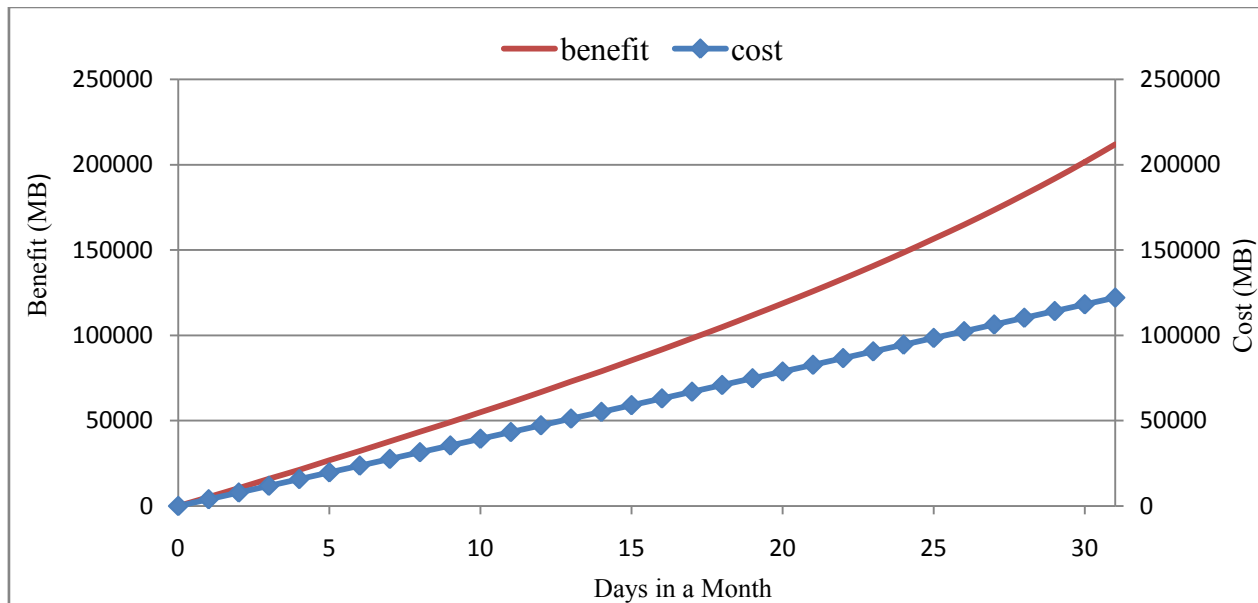


Figure 4.10: Benefit cost analysis of Ribb Dam, for the selected month of August

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The river sediment monitoring measure which was tested for the three dams such as Kesem Kebena, Tendaho and Ribb Irrigation Projects were studied in detail using the storage approach and benefit cost analysis based on the annual income of the project and the result shows the following:

In the case of Kesem Kebena the research found the measure is advantageous if we apply in month of August only using both storage approach and benefit cost ratio analysis. For this project, if the monitoring measure is taken for the full month of August, it found benefit in storage advantage of about 61266.883 MCM. But for all of the other months, it is not requiring to apply the measure because replacing the amount of water loss on its improved life span is not sufficient enough. On daily basis, desirability of the measure was also tested. Similarly, it was found profitable only on the month of August. But full month monitoring, especially on the month of August which had maximum inflow rate is not recommended. So, the research found it better to monitor the river on the daily basis or in some percent according to the water requirement of the project. Thus, if we bypass the inflow only for one day on this month the life span of the dam can improved by 2.054 years and the benefit obtained in storage become about 453.5245 MCM which is above annual release requirement of the project. Using the second approach of BCA, diverting the flow of August away from the reservoir will make the project design life to extend larger and worthier than any other months; since the BCR obtained for the other months is less than one but 4.259 for this month. But blocking the river flow except on this month will result in loss of the project's benefit. Monitoring the river on full month of August will have 1643790.47 MB benefit, bypassing only for one day on this month have 12168.0617 MB benefit with a benefit cost ratio of 4.259 which is much greater than one. These all show us that, for Kesem Kebena dam, the river sediment monitoring can improve the life span of the dam and it is desirable, useful and economical bypassing on the month of August.

Similarly the study tested for Tendaho dam and the measure is found to be advantageous if we applied in month of August and September using both approaches. For this project if the monitoring measure is taken for the full month of August and September, it found benefit in storage advantage of about 41113.285 MCM and 755.470 MCM respectively. But for all of the other months, it is not requiring to apply the measure because replacing the amount of water loss on its improved life span is not sufficient enough. On daily basis, desirability of the measure is

also tested. Similarly, it is found profitable only for the months of August and September. But full month monitoring, especially on the months of August and September which had maximum inflow rate is not recommended. So, the research found it better to monitor the river on daily basis or in some percent according to the water requirement of the project. Thus, if we bypass the inflow only for one day on these months, the life span of the dam can improved by 0.6764 and 0.3350 years and the benefit obtained in storage become about 788.0035 MCM and 202.7871 MCM respectively. Using the second approach of BCA, diverting the flow of August and September away from the reservoir will make the project design life to extend larger and worthier than any other months; since the BCR obtained for the other months is less than one but 2.699 and 1.437 for these months. But blocking the river flow except on these months will result in loss of the project's benefit. Monitoring of the river in the full month of August and September will have 648,397.61 MB and 119,078.462 MB benefit respectively, but bypassing for only one day on these months have 12,427.60 MB and 3,98.15 MB benefit with a benefit cost ratio of 2.699 and 1.437 respectively which are greater than one. These all show us that, in case of Tendaho dam, river sediment monitoring can improve the life span of the dam and it is desirable, useful and economical bypassing on the month of August and September.

The study also tested for Ribb dam and the result showed the measure is found advantageous if we applied on the month of August. For this project if the monitoring measure is taken for the selected full month of August and July, it found benefit in storage advantage of about 3495.285 MCM and 12.974 MCM respectively. But for all of the other months, it is not requiring to apply the measure because replacing the amount of water loss on its improved life span is not sufficient enough. On daily basis, desirability of the measure is also tested. Similarly, it is found profitable only for the months of August and July. But the full month monitoring, especially on the months of August and July, which had maximum inflow rate is not recommended. So, the research found it better to monitor the river on daily basis or in some percent according to the water requirement of the project. Therefore, if we bypass the inflow only for one day on this month, the life span of the dam can improved by 0.9238 year and 0.4088 year and the benefit obtained in storage become about 50.2537 MCM and 0.3158 MCM respectively. Using the second approach of BCA, diverting the flow of August and July away from the reservoir will make the project design life to extend larger and worthier than any other months; since the BCR obtained for the other months is less than one but 1.728 and 1.005 for these months. But BCR of July is also nearly one; it is neither beneficiary nor costly if the flow in this month is diverted away from the reservoir. So, blocking the river flow except month of August will result in loss of the project's benefit. Monitoring the river in full month of August will have 88972.467 MB benefit, only one day bypassing on this month have 1298.6907 MB benefit with a benefit cost ratio of 1.728 which are

greater than one. These all show us that, for case of Ribb dam, river sediment monitoring can improve the life span of the dam and it is desirable, useful and economical bypassing on the month of August.

This paper also puts some directions of monitoring techniques; but to select the most suitable sediment treatment method should be with consideration of topography and flows of river, effectiveness, economic, environmental and various conditions are the major criteria that are used for the overall judgment. This sediment control measure has two major benefits, firstly, it reduces the amount of desilting required, and hence, costs of sediment removal, and secondly, it improves the reliability of water supply to downstream parts of the irrigation system, enabling the irrigated areas to be maintained. This has a positive impact on farm income, farm investment, productive capacity, and the long term success of the irrigation scheme.

Finally, this measure has valuable impact on the life span of the dam and also bypassing the flow reduces the storage volume, it will have impact on the height of the dam such that, on the coming projects we have to consider this bypassing measure on the study and design phase of the project. In addition, since most Ethiopian dams are suffering from sedimentation and even keeping their design life span become difficult; applying this measure can make them sufficient in order to serve and achieve the desired purpose. So, from now onwards, for those dams that their design is incomplete, complete and those that will be designed, they have to consider and modify the design considering this measure, to reduce sedimentation. Similarly, for dams in which their dead storage level is not totally filled with sediment can extend their life span by applying this measure.

5.2. Recommendation

The following recommendations could be drawn from the foregoing discussion and conclusions:

The key for the improved sediment studies depends on accurate and quality of input data. The constraints in conducting this research work were also lacks of well representative meteorological stations in and around the watershed, continuous measured sediment data, especially sediment data on the daily basis. Not only lack the availability of data, but also there was documentation problem. Hence, responsible bodies should give due attention to minimize this problem for well managed water resource application to get better studies of sedimentation.

Further studies are necessary for the sediment monitoring techniques in order to have fast and periodic application of the measure since full and detail knowledge of sedimentation is essential for the life span of the dams. The additional study are also compulsory on the other Ethiopian dams that are not included in this thesis because of lack of time and money faced this researcher in order to generalize country wise concerning the measure used and tested in this study. In this instance, it is recommended to use this paper as database for further research works since the database created has paramount importance to conduct further studies.

Many researches, studies, and theories have been developed to deal with sediment, however; there is no consensus on a well-defined procedure or approach to deal with sediment problems and their impacts. Worldwide relevant institutes, agencies and researchers in this field need to combine their efforts and works in a more organized research programs to deal with sediment. This is expected to help international communities to achieve practical and effective solutions. A joint and coordinate effort entails partnership, pooling resources, focusing science, sharing information and experiences. Besides, it helps to build and strengthen the human capacity needed it also benefit the policy and decision makers as it would result in more informed decisions.

Furthermore, there is a need to review the operation of the existing dams and for new dams under construction and these that will be constructed in Ethiopia as far as review of the reservoir operation is required in order to facilitate the optimum operation system using this measure.

Sediment has socio-economic, environmental and geomorphological impacts therefore; changes in sediment quantity and quality can have significant implications and impacts on a range of social, economic and environmental systems. It is therefore, important to study the socio-economic and environmental impacts that will be involved before monitoring sediment measure is applied.

This research should be seen with caution that the cost of the upstream structures have to construct in order to divert the inflow were not considered. But, in other side beside irrigation the environmental and economical advantages will obtain because of the storage through the life span extended of the dam were not considered. Such that, in order to have a clear and butter application of the measure, the main approach should revise considering these fundamental concepts.

REFERENCES

- Amare A. (2005), Study of sediment yield from the watershed of Angereb reservoir: M.sc. thesis, department of Agriculture Engineering Alemaya University, Ethiopia.
- M. M. A. SHAHIN, (1993), an overview of reservoir sedimentation in some African river basins: International Institute for Infrastructural, Hydraulic and Environmental Engineering, The Netherlands.
- River morphology research cluster, (2005), Assessment of the current state of the Nile basin reservoir sedimentation problems: NBCBN-RE.
- Kamaleldin E. Bashar, ElTahir Osman ElTahir, Sami Abdel Fattah, Alnazir Saad Ali, Muna Musnad, Ishraqa Osman S.(2010), Nile Basin Reservoir Sedimentation Prediction and Mitigation: UNESCO-IHE.
- Prof. Dr. Abdalla Abdelsalam Ahmed (January 2008), Sediment in the Nile River System: UNESCO International Hydrological Program International Sediment Initiative (ISI).
- Fasil G/meskel (2012), prediction of sediment inflow to Gefersa reservoir using SWAT model and assessing sediment reduction methods, Msc thesis Addis Ababa University.
- Zerihun Yimer (2011), estimation of sediment yield of Mille watershed into Tendaho dam, Msc thesis Arbaminch University.
- Gregory L.Morris and Jiahuan Fan (1998), Design and management of Dams, Reservoirs, and Watersheds for sustainable use,Reservoir sedimentation handbook.
- Scheuerlein H. and Mtalo F. (1993). "Sediment Control at River Intakes", in Water, the Lifeblood of Africa, Victoria Falls, Zimbabwe: Proceedings I.A.H.R. African Regional Division Symposium, July, pp. 13.1-13.8.
- Tensay Getnet (2011), Sedimentation Modeling for Ribb Dam, Msc thesis Addis Ababa University.
- Julien, P. and Shah S. (2005), Sedimentation Initiatives in Developing Countries Draft Report presented to UNESCO-ISI, Colorado State University.
- Randle T.J, Yang C.T and Darajo J. (2007), Erosion and reservoir sedimentation. Erosion and sedimentation manual.
- Brune, G.M. (1953), "Trap Efficiency of Reservoirs." Transactions of American geophysical

Union, Vol. 344, No.3.

Churchill, M.A. (1948), Discussion of “Analysis and Use of Reservoir Sedimentation Data,” by L.C. Gottschalk, Proceedings, Federal Interagency Sedimentation Conference, Denver, Colorado.

Gottschalk, L.C. (1964), “Reservoir Sedimentation,” Section 17.1 in Handbook of Hydrology (V.T.Chow, Editor), McGraw Hill, New York.

HPTP (1999), How to establish stage discharge rating curve, Training module # SWDP – 29, New Delhi

Dottori F., Martina V., and Todini E. (2009), a dynamic rating curve approach to indirect discharge measurement, Universita di Bologna, Italy.

Garde R. J and Raju, K.G. (1985), “Mechanics of Sediment Transportation and Alluvial Stream Problems,” Wiley Eastern Limited, 2nd edition.

Sadiq N., A. Shah and R. Amin (2002), Improvement potential of rod kahi farming in upland Balochistan. Asian J. Plant Sci., 1: 67-69.

Awulachew, S.B., M. McCartney, T.S. Steenhuis and A.A. Ahmed (2008), A review of hydrology, sediment and water resource use in the Blue Nile Basin. International Water Management Institute, Colombo, Sri Lanka, pp: 87.

Begum, R.A. and J.J. Pereira (2008), Environmental problems in Malaysia: A view of contractors’ perception. J. Applied Sci., 8: 4230-4233.

Elias, E., 2003. Environmental roles of agriculture in Ethiopia.,
ftp://ftp.fao.org/es/ESA/Roa/pdf/2_Environment/Environment_EthiopiaNA.pdf

Chanson H. and P. James (1998), Rapid reservoir sedimentation of four historic thin arch dams in Australia. J. Perform. Construct. Facilities, 12: 85-92.

EEPC (2009), Environmental and social impact assessment additional study on downstream impact of Gibe III hydroelectric project. Ethiopian Electric Power Corporation, Ethiopia.

Brady, N.C. and R.R. Weil (2002), The Nature and Properties of Soils. 13th Edn., Prentice Hall, New Jersey, ISBN: 0130167630, Pages: 960.

Devi, R., T. Esubalew, L. Worku, D. Bishaw and B. Abebe (2007), Assessment of siltation and nutrient enrichment of Gilgel Gibe dam, Southwest Ethiopia. Bioresour. Technol., 99: 975-979.
Gessese, A. (2008) Prediction of sediment inflow for legedadi reservoir (using SWAT watershed and CCHE1D sediment transport models). Master's Thesis, Faculty of Technology Addis Ababa University, Ethiopia.

Hathaway, T. (2008), What cost Ethiopia's dam boom? A look inside the expansion of Ethiopia's energy sector. *International Rivers, People, Water, Life*.
<http://www.internationalrivers.org/files/EthioReport06Feb08.pdf>.

Liu, J., B. Liu and K. Ashida (2002), Reservoir sedimentation management in Asia.
<ftp://ftp.hamburg.baw.de/pub/Kfki/Bib/2002-ICHE/ARTICLES/PDF/128C4-SD.pdf>.

Musa, A.S., S. El-Zein, S.M. El-sayed, M. Mirghani and S. Golla (2005), Assessment of the current status of the Nile basin reservoir sedimentation problems. Nile Basin capacity Building Network-for River Engineering.

Shahin, M.M.A. (1993), An overview of reservoir sedimentation in some African River basins. International Institute for Infrastructural, Hydraulic and Environmental, Engineering, The Netherlands.

Teodoru, C., A. Wuest and B. Wehrli (2006), Independent review of the environmental impact assessment for the merowe dam project (Nile River, Sudan). Aquatic Research, Switzerland.

CBKB, (2009), Best Practice Regulation Guidance Note: Decision Rules in Regulatory Cost-Benefit Analysis

APPENDIXES

Appendix I

Ribb dam irrigation project Sediment load

Sediment data is required in order to establish the potential loss of capacity in Ribb reservoir due to sedimentation over the design life of the project (often taken as 50 years). Estimate of sediment transport rate are very difficult to estimate reliably for a number of reasons. Observation techniques permit sampling of suspended sediment, although bed load sampling is possible but it is very inaccurate. Sampling is difficult and it is common to have significant variation in results of consecutive measurements of sediment load in the same flood event whether the sample is taken at the rising or falling portion of the flood hydrograph. There is also seasonal effect, with sediment load in the early wet months (June and July) higher than those on later months (August and September) for the same discharge. BCEOM (1999) gave suspended sediment rating equation for upper Ribb River near Debre Tabor gauging site (844 km²):

$$Q_s = 19.50 Q^{1.044}$$

Where: with $R^2 = 0.971$

Q_s = Suspended sediment mass transport rate (ton/day)

Q = discharge (m³/s)

Based on the above rating equation the monthly suspended sediment loads were estimated at the Upper Ribb gauging site for the period of 1960-2002. The monthly mean plot of suspended sediment shows that nearly 65% of the suspended sediment is transported in August. The mean annual suspended sediment transport (1960-2004) was estimated as 68,992 ton which corresponds to mean sediment specific rate $G = 82$ ton/km²/year. This G value seems to be too low for a steep and nearly un-vegetated watershed such as the Upper Ribb watershed. It is not clear why the sediment yield of Gumara (1,390 ton/km²/year) and Gilegel Abbay (1,695 ton/km²/year) are very high.

Due to its low sediment yield value, neither the BCEOM sediment yield estimate nor the result based on the BCEOM rating curve should be adopted for the Ribb dam sedimentation study. Ribb and Gumara watersheds have relatively similar characteristics regarding rainfall intensity and soil erodibility. Brownish sandy clay loams and sandy loam dominate the watersheds corresponding to Hydrological soil group B. As a result of the above mentioned discussion, an attempt has been made to apply a regional approach in order to construct a composite sediment rating curve by using the Megech, Ribb, Gumara and Gilgel Abbay Q - Q_s data based on 1964-2005 period.

The developed rating curve is given in Fig.9.1 with the equation:

$$Q_s = 34.17 Q^{1.5084}$$

Where: Q_s = Suspended sediment mass transport rate (ton/day)

Q = discharge (m^3/s)

The final mean annual suspended sediment transported at Upper Ribb gauging site was then estimated using monthly inflows at Upper Ribb gauging site given in Table 4.6.3 for the period 1960-2004 and the composite sediment rating equation given above. The estimated yield was calculated to be 688,062 tons. This corresponds to specific suspended sediment yield of 815 $ton/km^2/year$. The dam site estimated mean annual sediment transport is 582,896 ton based on the specific suspended sediment yield of 815 $ton/km^2/year$ estimated for the Upper Ribb gauging site.

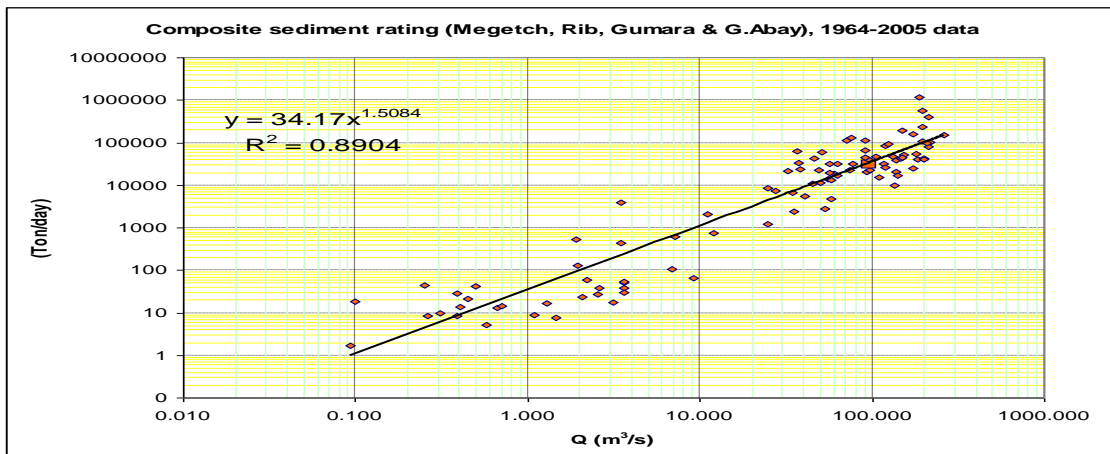


Figure 9.1 Sediment rating curve applied for Ribb dam site

From the above derived rating curve equation average monthly sediment load of Ribb (1960-2004) is developed. Since there is not metrological station on the Ribb dam a nearby station of upper rib was used similarly for development of the sediment load the upper rib inflow.

	Month	January	February	March	April	Jun	May
A	Upper Ribb (UR) inflow (MMC) (A)	2.2	1.5	1.6	2.5	9.5	2.6
B	days in month	31	28	31	30	30	31
C	UR Inflow (m ³ /s)	0.821385902	0.62004	0.597372	0.964506	3.665123	0.970729
D	UR Inflow sediment rating (tons/day)	25.39498978	16.61615	15.70841	32.35718	242.3909	32.67258
E	UR Inflow sediment rating (tons)	787.2446832	465.2523	486.9607	970.7154	7271.726	1012.85
F	UR Adj. Inflow sediment rating (tons)	1011.557332	597.8185	625.7123	1247.305	9343.686	1301.445
G	UR Inflow sediment rating (tons/km ²)	1.198527645	0.708316	0.741365	1.47785	11.07072	1.541997
H	Ribb inflow sediment rating (tons)	856.9472661	506.4457	530.0762	1056.662	7915.564	1102.528
I	RIS Including 10% bed load	942.6419927	557.0903	583.0838	1162.329	8707.12	1212.781
J	Ribb Inflow sediment volume (CM/yr)	785.5349939	464.2419	485.9032	968.6072	7255.933	1010.65
K	Ribb Inflow sediment volume (MCM/yr)	0.000785535	0.000464	0.000486	0.000969	0.007256	0.001011

July	August	September	October	November	December	Annually
66.5	113.4	43.4	12.8	6.6	3.2	265.8
31	31	30	31	30	31	365
24.82826	42.33871	16.74383	4.778973	2.546296	1.194743	100.07
4342.92	9714.4005	2397.218	361.7039	139.9323	44.68954	17366
134630.5	301146.41	71916.53	11212.82	4197.969	1385.376	535484.4
172991.3	386953.22	92407.98	14407.73	5394.113	1780.116	688062
204.966	458.47538	109.4881	17.07077	6.391129	2.109142	815.2393
146550.7	327809.89	78284.01	12205.6	4569.657	1508.037	582896.1
161205.8	360590.88	86112.41	13426.16	5026.623	1658.841	641185.7
134338.1	300492.4	71760.34	11188.47	4188.853	1382.367	534321.4
0.134338	0.3004924	0.07176	0.011188	0.004189	0.001382	0.534321

Note: $D = 3.14 * Row C^{1.5084}$

$E = Row D * Row B$

$F = \left(\frac{Actual\ US\ Sediment}{Computed\ US\ Sediment} \right) * Row E$

$G = Row F / US\ Ribb\ area$

$H = Row G * \left(\frac{Ribb\ Area}{US\ Ribb\ Area} \right)$

$I = Row H + (Row H * 0.1)$

$J = Row I / Density\ of\ rib\ water$

Where:

Actual US Sediment = 688,062 tone

Computed US Sediment = 535,484.4 tone

US Ribb Area = 844 km²

Ribb Area = 715 km²

10 % of bed loads is considered for rib dam.

Appendix II

Kesem Kebena dam daily basis Net Storage

Month	Monitoring Interval (days)	New Annual Storage (MCM)	New Annual Sediment Inflow (MCM)	New Life Span (Years)	Improved Life Span (Years)	Storage loss due to the Measure (MCM)	Storage due to Sediment Reduction (MCM)	Net Storage (MCM)
January	5	522.3560	2.3499	80.0038	0.0038	88.2455	1.9858	-86.2597
	10	521.2529	2.3498	80.0076	0.0076	176.4910	3.9634	-172.5276
	15	520.1498	2.3497	80.0114	0.0114	264.7364	5.9328	-258.8037
	20	519.0468	2.3496	80.0152	0.0152	352.9819	7.8939	-345.0880
	25	517.9437	2.3494	80.0190	0.0190	441.2274	9.8469	-431.3805
	31	516.6200	2.3493	80.0236	0.0236	547.1220	12.1797	-534.9423
February	5	522.1128	2.3498	80.0083	0.0083	107.6969	4.3485	-103.3483
	10	520.7666	2.3495	80.0167	0.0167	215.3937	8.6756	-206.7182
	15	519.4204	2.3493	80.0250	0.0250	323.0906	12.9810	-310.1096
	20	518.0742	2.3490	80.0333	0.0333	430.7875	17.2650	-413.5225
	25	516.7280	2.3488	80.0417	0.0417	538.4843	21.5274	-516.9569
	28	515.9202	2.3486	80.0467	0.0467	603.1024	24.0745	-579.0279
March	5	521.8431	2.3496	80.0132	0.0132	129.2746	6.8809	-122.3937
	10	520.2272	2.3494	80.0206	0.0206	258.5492	10.6986	-247.8506
	15	518.6112	2.3488	80.0396	0.0396	387.8238	20.5217	-367.3021

	20	516.9953	2.3485	80.0528	0.0528	517.0983	27.2815	-489.8169
	25	515.3794	2.3481	80.0660	0.0660	646.3729	34.0008	-612.3721
	31	513.4402	2.3476	80.0818	0.0818	801.5024	42.0107	-759.4917
April	5	521.8751	2.3497	80.0103	0.0103	126.7154	5.3656	-121.3499
	10	520.2911	2.3494	80.0206	0.0206	253.4309	10.6999	-242.7310
	15	518.7072	2.3491	80.0309	0.0309	380.1463	16.0031	-364.1433
	20	517.1233	2.3488	80.0411	0.0411	506.8618	21.2750	-485.5868
	25	515.5393	2.3485	80.0514	0.0514	633.5772	26.5157	-607.0615
	30	513.9554	2.3482	80.0617	0.0617	760.2927	31.7252	-728.5675
May	5	522.0766	2.3498	80.0082	0.0082	110.5964	4.2653	-106.3311
	10	520.6941	2.3495	80.0163	0.0163	221.1928	8.5088	-212.6839
	15	519.3117	2.3493	80.0245	0.0245	331.7891	12.7307	-319.0585
	20	517.9292	2.3490	80.0327	0.0327	442.3855	16.9307	-425.4548
	25	516.5468	2.3488	80.0409	0.0409	552.9819	21.1091	-531.8728
	31	514.8878	2.3485	80.0507	0.0507	685.6976	26.0944	-659.6031
Jun	5	521.5913	2.3494	80.0204	0.0204	149.4179	10.6394	-138.7785
	10	519.7236	2.3488	80.0408	0.0408	298.8358	21.2081	-277.6277
	15	517.8559	2.3482	80.0612	0.0612	448.2537	31.7059	-416.5478
	20	515.9881	2.3476	80.0817	0.0817	597.6715	42.1328	-555.5388
	25	514.1204	2.3470	80.1021	0.1021	747.0894	52.4887	-694.6007
	30	512.2527	2.3464	80.1225	0.1225	896.5073	62.7737	-833.7336
July	5	505.7511	2.2910	82.0603	2.0603	1416.6357	1042.0137	-374.6221
	10	488.0431	2.2320	84.2296	4.2296	2833.2714	2064.2211	-769.0503

	15	470.3352	2.1730	86.5166	6.5166	4249.9072	3065.0090	-1184.8982
	20	452.6272	2.1140	88.9314	8.9314	5666.5429	4042.5838	-1623.9591
	25	434.9193	2.0550	91.4848	11.4848	7083.1786	4994.9460	-2088.2326
	31	413.6698	1.9842	94.7493	14.7493	8783.1415	6101.3332	-2681.8082
August	5	485.5549	2.0558	91.4500	11.4500	3032.3336	5559.5985	2527.2649
	10	447.6507	1.7615	106.7250	26.7250	6064.6672	11963.4613	5898.7941
	15	409.7465	1.4673	128.1260	48.1260	9097.0008	19719.4769	10622.4761
	20	371.8423	1.1731	160.2628	80.2628	12129.3344	29845.0909	17715.7565
	25	333.9382	0.8788	213.9179	133.9179	15161.6680	44720.2899	29558.6220
	31	288.4532	0.5258	357.5749	277.5749	18800.4683	80067.3515	61266.8832
September	5	508.7613	2.3272	80.7830	0.7830	1175.8146	398.3824	-777.4322
	10	494.0637	2.3044	81.5816	1.5816	2351.6293	781.3953	-1570.2339
	15	479.3660	2.2817	82.3960	2.3960	3527.4439	1148.5784	-2378.8655
	20	464.6683	2.2589	83.2269	3.2269	4703.2585	1499.4527	-3203.8058
	25	449.9706	2.2361	84.0748	4.0748	5879.0732	1833.5199	-4045.5533
	30	435.2729	2.2133	84.9400	4.9400	7054.8878	2150.2610	-4904.6268
October	5	520.2461	2.3485	80.0520	0.0520	257.0323	27.0317	-230.0006
	10	517.0332	2.3469	80.1040	0.1040	514.0645	53.7644	-460.3001
	15	513.8203	2.3454	80.1561	0.1561	771.0968	80.1975	-690.8992
	20	510.6074	2.3439	80.2082	0.2082	1028.1290	106.3306	-921.7985
	25	507.3945	2.3424	80.2605	0.2605	1285.1613	132.1629	-1152.9984
	31	503.5390	2.3405	80.3232	0.3232	1593.6000	162.7639	-1430.8361
November	5	521.8788	2.3497	80.0094	0.0094	126.4163	4.8857	-121.5306

	10	520.2986	2.3495	80.0187	0.0187	252.8325	9.7429	-243.0896
	15	518.7184	2.3492	80.0281	0.0281	379.2488	14.5717	-364.6771
	20	517.1382	2.3489	80.0375	0.0375	505.6650	19.3720	-486.2930
	25	515.5580	2.3486	80.0468	0.0468	632.0813	24.1439	-607.9374
	30	513.9778	2.3484	80.0562	0.0562	758.4976	28.8872	-729.6103
December	5	522.2657	2.3499	80.0044	0.0044	95.4681	2.3234	-93.1447
	10	521.0723	2.3497	80.0089	0.0089	190.9363	4.6365	-186.2998
	15	519.8790	2.3496	80.0133	0.0133	286.4044	6.9391	-279.4653
	20	518.6856	2.3495	80.0178	0.0178	381.8725	9.2315	-372.6411
	25	517.4923	2.3493	80.0222	0.0222	477.3407	11.5134	-465.8273
	31	516.0602	2.3492	80.0276	0.0276	591.9024	14.2381	-577.6644

Appendix III

Tendaho dam daily basis Net Storage

Month	Monitoring Interval (days)	New Annual Storage (MCM)	New Annual Sediment Inflow (MCM)	New Life Span (Years)	Improved Life Span (Years)	Storage loss due to the Measure (MCM)	Storage due to Sediment Reduction (MCM)	Net Storage (MCM)
January	5	2319.6797	20.6812	50.0840	0.0840	739.5161	194.9598	-544.5563
	10	2304.8894	20.6465	50.1684	0.1684	1479.0323	388.0859	-1090.9464
	15	2290.0990	20.6117	50.2530	0.2530	2218.5484	579.3688	-1639.1796

	20	2275.3087	20.5769	50.3379	0.3379	2958.0645	768.7994	-2189.2651
	25	2260.5184	20.5422	50.4231	0.4231	3697.5806	956.3681	-2741.2125
	31	2242.7700	20.5005	50.5257	0.5257	4585.0000	1178.9797	-3406.0203
February	5	2315.5843	20.6431	50.1765	0.1765	944.2857	408.6534	-535.6323
	10	2296.6986	20.5703	50.3542	0.3542	1888.5714	813.5123	-1075.0591
	15	2277.8129	20.4974	50.5332	0.5332	2832.8571	1214.5362	-1618.3210
	20	2258.9271	20.4246	50.7135	0.7135	3777.1429	1611.6840	-2165.4588
	25	2240.0414	20.3517	50.8950	0.8950	4721.4286	2004.9143	-2716.5143
	28	2228.7100	20.3080	51.0046	1.0046	5288.0000	2238.9544	-3049.0456
March	5	2306.6652	20.5091	50.5044	0.5044	1390.2419	1163.5753	-226.6667
	10	2278.8603	20.3396	50.9253	0.9253	2780.4839	2108.6411	-671.8428
	15	2251.0555	20.0953	51.5445	1.5445	4170.7258	3476.7225	-694.0033
	20	2223.2506	19.8884	52.0807	2.0807	5560.9677	4626.0030	-934.9647
	25	2195.4458	19.6814	52.6283	2.6283	6951.2097	5770.2171	-1180.9926
	31	2162.0800	19.4331	53.3007	3.3007	8619.5000	7136.3583	-1483.1417
April	5	2302.1750	20.5278	50.4584	0.4584	1614.7500	1055.3420	-559.4080
	10	2269.8800	20.3396	50.9253	0.9253	3229.5000	2100.3315	-1129.1685
	15	2237.5850	20.1514	51.4009	1.4009	4844.2500	3134.6785	-1709.5715
	20	2205.2900	19.9632	51.8855	1.8855	6459.0000	4158.0820	-2300.9180
	25	2172.9950	19.7750	52.3793	2.3793	8073.7500	5170.2296	-2903.5204
	30	2140.7000	19.5868	52.8826	2.8826	9688.5000	6170.7966	-3517.7034
May	5	2313.4781	20.6475	50.1658	0.1658	1049.5968	383.6236	-665.9731
	10	2292.4861	20.5790	50.3327	0.3327	2099.1935	762.8153	-1336.3783

	15	2271.4942	20.5106	50.5008	0.5008	3148.7903	1137.5305	-2011.2598
	20	2250.5023	20.4421	50.6700	0.6700	4198.3871	1507.7244	-2690.6627
	25	2229.5103	20.3736	50.8403	0.8403	5247.9839	1873.3513	-3374.6326
	31	2204.3200	20.2914	51.0461	1.0461	6507.5000	2306.0101	-4201.4899
Jun	5	2321.1050	20.6873	50.0693	0.0693	668.2500	160.8086	-507.4414
	10	2307.7400	20.6587	50.1388	0.1388	1336.5000	320.2091	-1016.2909
	15	2294.3750	20.6300	50.2084	0.2084	2004.7500	478.1954	-1526.5546
	20	2281.0100	20.6013	50.2783	0.2783	2673.0000	634.7619	-2038.2381
	25	2267.6450	20.5727	50.3483	0.3483	3341.2500	789.9024	-2551.3476
	30	2254.2800	20.5440	50.4186	0.4186	4009.5000	943.6110	-3065.8890
July	5	2303.4313	20.5066	50.5107	0.5107	1551.9355	1176.3211	-375.6144
	10	2272.3926	20.2971	51.0319	1.0319	3103.8710	2344.8902	-758.9808
	15	2241.3539	20.0877	51.5640	1.5640	4655.8065	3505.4649	-1150.3415
	20	2210.3152	19.8782	52.1073	2.1073	6207.7419	4657.7925	-1549.9495
	25	2179.2765	19.6688	52.6622	2.6622	7759.6774	5801.6094	-1958.0680
	31	2142.0300	19.4174	53.3438	3.3438	9622.0000	7162.5680	-2459.4320
August	5	2256.4248	19.3335	53.5754	3.5754	3902.2581	8067.6711	4165.4130
	10	2178.3797	17.9510	57.7016	7.7016	7804.5161	16776.9467	8972.4306
	15	2100.3345	16.5685	62.5163	12.5163	11706.7742	26288.4373	14581.6631
	20	2022.2894	15.1860	68.2077	18.2077	15609.0323	36821.2401	21212.2079
	25	1944.2442	13.8035	75.0392	25.0392	19511.2903	48682.2288	29170.9385
	31	1850.5900	12.1445	85.2900	35.2900	24194.0000	65307.2845	41113.2845
September	5	2276.9400	20.0267	51.7209	1.7209	2876.5000	3918.3534	1041.8534

	10	2219.4100	19.3375	53.5645	3.5645	5753.0000	7910.9795	2157.9795
	15	2161.8800	18.6482	55.5443	5.5443	8629.5000	11986.1142	3356.6142
	20	2104.3500	17.9589	57.6761	7.6761	11506.0000	16153.2575	4647.2575
	25	2046.8200	17.2696	59.9781	9.9781	14382.5000	20423.4265	6040.9265
	30	1989.2900	16.5804	62.4715	12.4715	17259.0000	24809.4700	7550.4700
October	5	2292.5152	20.3986	50.7780	0.7780	2097.7419	1783.5864	-314.1556
	10	2250.5603	20.0812	51.5806	1.5806	4195.4839	3557.2416	-638.2422
	15	2208.6055	19.7638	52.4090	2.4090	6293.2258	5320.4873	-972.7385
	20	2166.6506	19.4464	53.2644	3.2644	8390.9677	7072.8137	-1318.1540
	25	2124.6958	19.1290	54.1482	4.1482	10488.7097	8813.6773	-1675.0324
	31	2074.3500	18.7481	55.2483	5.2483	13006.0000	10886.7628	-2119.2372
November	5	2308.4567	20.5969	50.2891	0.2891	1300.6667	667.3254	-633.3412
	10	2282.4433	20.4778	50.5815	0.5815	2601.3333	1327.2848	-1274.0485
	15	2256.4300	20.3588	50.8774	0.8774	3902.0000	1979.7490	-1922.2510
	20	2230.4167	20.2397	51.1767	1.1767	5202.6667	2624.5856	-2578.0811
	25	2204.4033	20.1206	51.4796	1.4796	6503.3333	3261.6592	-3241.6741
	30	2178.3900	20.0015	51.7861	1.7861	7804.0000	3890.8312	-3913.1688
December	5	2314.6619	20.6522	50.1545	0.1545	990.4032	357.6226	-632.7806
	10	2294.8539	20.5884	50.3100	0.3100	1980.8065	711.3225	-1269.4840
	15	2275.0458	20.5246	50.4664	0.4664	2971.2097	1061.0630	-1910.1467
	20	2255.2377	20.4607	50.6238	0.6238	3961.6129	1406.8070	-2554.8059
	25	2235.4297	20.3969	50.7822	0.7822	4952.0161	1748.5171	-3203.4990
	31	2211.6600	20.3203	50.9736	0.9736	6140.5000	2153.1909	-3987.3091

Appendix I V

Ribb dam daily basis Net Storage

Month	Monitoring Interval (days)	New Annual Storage (MCM)	New Annual Sediment Inflow (MCM)	New Life Span (Years)	Improved Life Span (Years)	Storage loss due to the Measure (MCM)	Storage due to Sediment Reduction (MCM)	Net Storage (MCM)
January	5	224.7935	0.5399	50.0119	0.0119	15.3226	2.6658	-12.6568
	10	224.4871	0.5397	50.0237	0.0237	30.6452	5.3256	-25.3196
	15	224.1806	0.5396	50.0356	0.0356	45.9677	7.9794	-37.9884
	20	223.8742	0.5395	50.0475	0.0475	61.2903	10.6272	-50.6632
	25	223.5677	0.5394	50.0594	0.0594	76.6129	13.2689	-63.3440
	31	223.2000	0.5392	50.0736	0.0736	95.0000	16.4311	-78.5689
February	5	224.8679	0.5399	50.0078	0.0078	11.6071	1.7447	-9.8625
	10	224.6357	0.5398	50.0155	0.0155	23.2143	3.4863	-19.7280
	15	224.4036	0.5397	50.0233	0.0233	34.8214	5.2249	-29.5965
	20	224.1714	0.5397	50.0310	0.0310	46.4286	6.9604	-39.4682
	25	223.9393	0.5396	50.0388	0.0388	58.0357	8.6928	-49.3429
	28	223.8000	0.5395	50.0435	0.0435	65.0000	9.7308	-55.2692
March	5	224.8903	0.5399	50.0073	0.0073	10.4839	1.6495	-8.8343
	10	224.6806	0.5397	50.0302	0.0302	20.9677	6.7924	-14.1754
	15	224.4710	0.5398	50.0220	0.0220	31.4516	4.9408	-26.5108

	20	224.2613	0.5397	50.0294	0.0294	41.9355	6.5826	-35.3529
	25	224.0516	0.5396	50.0367	0.0367	52.4194	8.2217	-44.1976
	31	223.8000	0.5395	50.0455	0.0455	65.0000	10.1853	-54.8147
April	5	224.7500	0.5398	50.0151	0.0151	17.5000	3.3962	-14.1038
	10	224.4000	0.5397	50.0302	0.0302	35.0000	6.7839	-28.2161
	15	224.0500	0.5395	50.0454	0.0454	52.5000	10.1630	-42.3370
	20	223.7000	0.5393	50.0605	0.0605	70.0000	13.5337	-56.4663
	25	223.3500	0.5392	50.0756	0.0756	87.5000	16.8957	-70.6043
	30	223.0000	0.5390	50.0908	0.0908	105.0000	20.2492	-84.7508
May	5	224.7452	0.5398	50.0153	0.0153	17.7419	3.4293	-14.3127
	10	224.3903	0.5397	50.0305	0.0305	35.4839	6.8498	-28.6341
	15	224.0355	0.5395	50.0458	0.0458	53.2258	10.2615	-42.9643
	20	223.6806	0.5393	50.0611	0.0611	70.9677	13.6646	-57.3032
	25	223.3258	0.5392	50.0764	0.0764	88.7097	17.0588	-71.6509
	31	222.9000	0.5390	50.0948	0.0948	110.0000	21.1203	-88.8797
Jun	5	223.7667	0.5388	50.1134	0.1134	66.6667	25.3798	-41.2868
	10	222.4333	0.5376	50.2274	0.2274	133.3333	50.5719	-82.7614
	15	221.1000	0.5363	50.3418	0.3418	200.0000	75.5750	-124.4250
	20	219.7667	0.5351	50.4568	0.4568	266.6667	100.3878	-166.2789
	25	218.4333	0.5339	50.5723	0.5723	333.3333	125.0089	-208.3244
	30	217.1000	0.5327	50.6883	0.6883	400.0000	149.4371	-250.5629
July	5	216.0032	0.5181	52.1133	2.1133	454.8387	456.4714	1.6326
	10	206.9065	0.4962	54.4130	4.4130	909.6774	913.0868	3.4094

	15	197.8097	0.4743	56.9252	6.9252	1364.5161	1369.8663	5.3502
	20	188.7129	0.4524	59.6805	9.6805	1819.3548	1826.8337	7.4789
	25	179.6161	0.4305	62.7161	12.7161	2274.1935	2284.0177	9.8241
	31	168.7000	0.4042	66.7930	16.7930	2820.0000	2832.9738	12.9738
August	5	209.6161	0.4910	54.9878	4.9878	774.1935	1045.5141	271.3205
	10	194.1323	0.4420	61.0809	11.0809	1548.3871	2151.1576	602.7705
	15	178.6484	0.3931	68.6926	18.6926	2322.5806	3339.4102	1016.8295
	20	163.1645	0.3441	78.4716	28.4716	3096.7742	4645.5519	1548.7777
	25	147.6806	0.2951	91.4969	41.4969	3870.9677	6128.2871	2257.3194
	31	129.1000	0.2363	114.2547	64.2547	4800.0000	8295.2845	3495.2845
September	5	218.9833	0.5279	51.1448	1.1448	305.8333	250.6936	-55.1397
	10	212.8667	0.5158	52.3433	2.3433	611.6667	498.8031	-112.8636
	15	206.7500	0.5037	53.5992	3.5992	917.5000	744.1424	-173.3576
	20	200.6333	0.4917	54.9170	4.9170	1223.3333	986.5072	-236.8261
	25	194.5167	0.4796	56.3011	6.3011	1529.1667	1225.6727	-303.4940
	30	188.4000	0.4675	57.7569	7.7569	1835.0000	1461.3906	-373.6094
October	5	223.3419	0.5382	50.1694	0.1694	87.9032	37.8430	-50.0602
	10	221.5839	0.5364	50.3400	0.3400	175.8065	75.3456	-100.4608
	15	219.8258	0.5345	50.5118	0.5118	263.7097	112.5043	-151.2054
	20	218.0677	0.5327	50.6847	0.6847	351.6129	149.3155	-202.2974
	25	216.3097	0.5309	50.8588	0.8588	439.5161	185.7757	-253.7405
	31	214.2000	0.5287	51.0694	1.0694	545.0000	229.0594	-315.9406
November	5	224.1667	0.5393	50.0654	0.0654	46.6667	14.6639	-32.0027

	10	223.2333	0.5386	50.1310	0.1310	93.3333	29.2440	-64.0893
	15	222.3000	0.5379	50.1968	0.1968	140.0000	43.7399	-96.2601
	20	221.3667	0.5372	50.2627	0.2627	186.6667	58.1513	-128.5154
	25	220.4333	0.5365	50.3288	0.3288	233.3333	72.4778	-160.8555
	30	219.5000	0.5358	50.3951	0.3951	280.0000	86.7192	-193.2808
December	5	224.6645	0.5398	50.0209	0.0209	21.7742	4.6894	-17.0848
	10	224.2290	0.5395	50.0418	0.0418	43.5484	9.3645	-34.1839
	15	223.7935	0.5393	50.0627	0.0627	65.3226	14.0253	-51.2973
	20	223.3581	0.5391	50.0836	0.0836	87.0968	18.6718	-68.4250
	25	222.9226	0.5389	50.1045	0.1045	108.8710	23.3040	-85.5670
	31	222.4000	0.5386	50.1297	0.1297	135.0000	28.8437	-106.1563

Appendix V

Updated Historical Flow Series of Kesem at Dam Site (MCM), (1963-2003)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1963	3.51	4.25	5.79	13.64	12.68	8.69	153.17	45.25	13.40	18.4	4.8	4.2	287.79
1964	4.10	1.20	2.70	22.40	12.50	17.20	174.60	253.30	97.70	24.20	15.80	14.60	640.30
1965	11.00	7.60	7.60	11.80	5.50	5.10	28.50	135.20	62.70	13.00	8.80	3.10	299.90
1966	1.50	19.50	4.50	6.80	0.10	8.80	74.90	400.90	83.80	4.10	3.30	2.70	610.90
1967	2.20	1.70	2.70	2.50	3.80	1.40	85.50	294.90	118.30	20.60	16.30	9.20	559.10
1968	7.30	12.90	7.00	11.10	7.30	8.00	134.10	333.90	107.90	40.00	10.70	8.40	688.60
1969	1.10	3.10	4.50	1.40	1.40	1.00	72.30	376.10	84.00	27.30	19.30	16.40	607.90
1970	20.20	14.90	29.40	16.00	12.10	9.30	120.60	316.70	173.30	77.70	53.20	44.20	887.60
1971	46.90	38.50	40.30	50.60	57.50	70.50	189.40	222.90	39.70	5.10	2.20	1.40	765.00
1972	1.30	2.00	1.30	4.00	1.30	1.20	64.90	128.20	38.90	4.10	1.90	1.70	250.80
1973	2.30	0.80	0.40	0.20	1.10	1.20	77.90	237.10	141.70	37.20	22.40	20.00	542.30
1974	19.00	14.00	25.90	13.90	12.20	24.50	222.70	170.70	40.50	8.60	4.20	2.50	558.70
1975	1.80	2.20	2.50	4.90	0.90	30.50	211.50	196.30	142.60	37.80	24.00	19.50	674.50
1976	17.00	12.00	15.00	16.80	27.20	15.70	72.70	213.60	54.20	9.70	7.50	4.20	465.60
1977	8.30	18.30	2.70	7.20	6.30	6.00	85.40	173.90	43.80	30.70	10.60	3.40	396.60
1978	2.00	6.70	5.20	0.50	0.50	2.70	68.30	170.70	86.10	19.00	5.00	4.80	371.50
1979	7.60	4.10	9.10	2.10	5.50	2.60	70.70	131.40	38.60	10.30	4.60	4.30	290.90
1980	8.60	8.10	4.90	6.40	1.80	3.30	206.00	196.00	70.60	17.50	6.70	5.40	535.30
1981	5.10	4.30	83.10	35.90	6.40	4.20	120.60	206.60	121.50	12.70	4.20	2.70	607.30
1982	2.80	2.80	2.70	5.40	4.40	1.40	13.30	158.20	44.10	30.30	4.90	8.00	278.30
1983	8.57	8.17	8.66	11.87	7.16	8.54	59.88	199.71	66.15	13.19	3.55	1.92	397.37
1984	1.74	1.69	1.52	0.35	2.67	11.72	170.35	196.77	90.62	2.85	2.56	2.57	485.41
1985	2.40	0.96	1.37	2.75	18.01	0.96	162.23	388.46	16.54	18.4	4.93	2.32	619.33
1986	0.88	2.85	8.43	9.98	9.08	49.11	55.41	141.84	73.80	7.82	3.23	2.91	365.34
1987	2.17	1.54	11.14	9.63	21.29	17.17	17.21	77.92	12.84	5.24	1.82	1.65	179.61
1988	2.99	8.01	1.07	5.59	2.47	4.49	143.76	561.30	656.78	17.28	4.46	2.89	1411.08
1989	3.23	2.92	1.92	8.38	1.95	1.24	15.27	154.86	40.88	7.97	1.52	4.56	244.70
1990	4.42	9.66	7.59	5.14	2.06	2.74	42.86	376.12	30.36	6.80	0.67	0.45	488.86
1991	0.56	1.89	1.47	2.45	0.88	1.06	512.59	152.63	24.27	5.76	1.50	1.87	706.93
1992	1.02	4.38	0.46	2.63	1.01	0.82	8.94	230.36	42.35	29.10	5.82	6.06	332.96

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1993	11.87	33.09	6.13	17.05	24.39	13.87	28.05	229.35	57.39	37.96	18.32	15.26	492.76
1994	14.33	11.02	12.05	12.05	15.11	15.95	114.72	123.56	62.43	19.68	14.98	12.35	428.22
1995	10.96	9.39	19.75	12.88	8.11	4.61	16.02	203.50	60.75	13.19	9.57	8.17	376.91
1996	10.54	5.41	12.71	9.07	15.14	26.95	106.46	418.99	19.86	18.53	10.29	6.97	660.91
1997	7.97	4.38	7.92	11.54	3.74	10.46	77.44	137.97	15.54	15.41	13.00	8.48	313.86
1998	7.79	4.90	5.90	8.47	5.68	10.55	212.42	299.69	69.79	59.77	20.20	10.83	716.00
1999	6.08	6.00	9.02	4.21	2.73	23.94	128.16	550.64	57.36	19.76	4.39	2.01	814.31
2000	7.80	5.06	6.73	9.39	11.76	9.12	42.93	262.95	18.02	48.77	29.69	26.07	478.29
2001	0.09	3.82	17.50	5.95	10.69	14.17	210.66	238.13	31.11	0.76	0.30	0.15	533.32
2002	0.10	3.91	11.73	6.27	6.65	8.32	107.97	151.72	58.81	0.97	0.82	0.73	358.02
2003	1.28	1.09	0.41	0.46	0.36	0.38	20.96	176.92	506.58	19.21	6.71	4.43	738.80
Average	6.84	7.54	10.02	9.50	8.57	11.21	109.79	235.01	88.19	19.92	9.48	7.40	523.46
Std	8.26	8.04	14.38	9.49	10.35	13.78	90.88	115.01	120.52	16.32	10.08	8.42	224.41
CV	1.21	1.07	1.43	1.00	1.21	1.23	0.83	0.49	1.37	0.82	1.06	1.14	0.43
Skew	3.14	2.39	3.73	2.62	2.97	2.66	2.26	1.17	3.82	1.58	2.42	2.59	1.52

Appendix VI: Kesem sediment Monthly Total (Suspended plus Bed Load) Sediment (1000 m3), (1963-2000)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total	Rate: m ³ /km ² /yr
1963	0	0	0	1	0	0	563	6490	193	8	0	0	7255	2314
1964	0	0	0	13	3	7	1871	4651	472	15	5	4	7041	2246
1965	2	1	1	3	0	0	21.9	1000	160	3	1	0	1193	381
1966	0	10	0	1	0	1	235	7148	325	0	0	0	7720	2462
1967	0	0	0	0	0	2	250	6758	755	10	6	1	7783	2483
1968	1	4	1	2	1	1	980	7509	603	51	2	1	9155	2920
1969	0	0	0	0	0	0	216	9090	326	20	9	6	9667	3084
1970	7	5	24	6	3	1	756	5618	953	84	21	7	7485	2387
1971	6	6	9	17	23	39	2285	3403	52	0	0	0	5840	1863
1972	0	0	0	0	0	0	165	876	50	0	0	0	1092	348
1973	0	1	0	0	2	2	259	3386	594	42	13	9	4308	1374
1974	8	5	17	4	3	16	3396	1770	55	1	0	0	5275	1683
1975	0	0	0	0	2	12	2992	2492	730	44	15	9	6295	2008
1976	6	3	5	6	20	5	218	3064	112	2	1	0	3442	1098
1977	1	9	0	1	1	1	325	1852	66	26	2	0	2284	728
1978	0	1	0	0	0	0	187	1770	347	8	0	0	2315	739
1979	1	0	1	0	0	0	204	932	49	2	0	0	1190	380
1980	1	1	0	1	0	3	2017	3055	213	7	1	0	5299	1690
1981	0	0	81	41	1	0	756	2824	806	3	0	0	4513	1439
1982	0	0	0	0	0	0	3.41	1469	67	26	0	1	1567	500
1983	0	1	1	2	0	1	24.4	1108	56	4	0	0	1197	382
1984	0	0	0	0	0	4	811	588	19	0	0	0	1423	454
1985	0	0	0	0	1	2	205	3553	160	3	1	0	3926	1252
1986	0	0	1	2	1	88	108	510	114	1	0	0	825	263
1987	0	0	2	2	11	7	4.34	317	2.3	0	0	0	345	110
1988	0	1	0	0	0	0	478	6915	288	5	0	0	7688	2452
1989	0	0	0	1	0	0	9.5	1072	69	1	0	0	1153	368
1990	0	2	1	0	0	0	74.7	3464	40	1	0	0	3583	1143
1991	0	0	0	0	0	2	870	4198	28	0	0	0	5099	1626
1992	0	0	0	0	0	0	3.74	2137	153	23	0	0	2319	740
1993	3	37	1	7	15	4	65.7	1862	263	44	8	5	2313	738
1994	4	3	3	3	5	6	780	989	282	9	5	3	2090	667
1995	2	2	9	3	1	0	25.1	1974	165	3	2	1	2188	698
1996	2	0	3	1	5	20	408	4550	138	8	2	1	5137	1639
1997	1	0	1	3	0	2	616	1165	11	5	3	1	1808	577
1998	1	0	0	1	0	2	1746	3513	176	92	10	2	5588	1783
1999	0	1	1	0	0	15	571	7259	199	9	0	0	8055	2569
2000	1	0	1	2	3	1	333	3510	187	82	5	4	4128	1317
Average	1	2	4	3	3	6	653	3254	244	18	3	2	4199	1338
Std	2	6	14	7	5	15	843	2351	247	29	5	2	2682	855
CV	2	3	3	2	2	2	1.29	0.72	1	2	2	2	0.64	0.64
Skew	2	5	5	4	3	4	1.91	0.82	1.4	3	2	2	0.36	0.36

Appendix VII

Historical monthly Iflow of Tendaho dam site, (1962 – 2002)

Historical Monthly flow at Tendaho (MMC) the data from (1962 to 1964) is Awash Dubti station data from Sogreah (1965)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1962	105.61	102.59	123.77	103.12	81.14	44.28	77.77	520.35	340.81	244.98	127.71	92.34	1964.48
1963	117.77	49.52	57.15	238.76	320.00	130.86	161.73	397.57	571.17	213.74	125.42	109.80	2493.49
1964	129.46	107.02	93.31	183.49	121.97	86.54	592.99	1158.03	685.20	313.09	145.00	387.00	4003.09
1965	92.65	70.93	109.43	201.85	105.76	54.79	80.51	329.90	245.01	185.62	153.96	115.75	1746.16
1966	103.61	153.18	146.96	166.46	110.95	85.33	100.47	274.61	293.86	238.14	125.97	89.10	1888.64
1967	68.26	97.96	68.29	151.78	215.92	59.40	204.51	642.96	208.88	332.73	340.01	167.59	2558.29
1968	108.17	232.65	174.50	303.22	148.34	118.74	558.03	578.27	383.10	202.47	129.09	110.53	3047.11
1969	266.36	218.67	225.71	211.20	200.57	200.57	135.23	572.91	332.54	242.76	121.71	77.26	2805.49
1970	139.46	84.86	373.89	117.14	100.94	67.19	358.48	1040.13	510.80	299.46	122.39	72.55	3287.29
1971	63.77	42.95	41.48	59.74	80.63	49.24	87.11	455.86	482.98	282.22	157.16	85.15	1888.29
1972	87.00	262.00	122.10	200.23	178.07	124.48	164.33	216.17	194.64	148.12	75.90	52.35	1825.39
1973	47.00	33.44	17.40	13.78	32.99	9.30	184.77	1430.55	242.93	185.06	98.22	56.67	2352.11
1974	39.08	27.14	761.84	94.70	60.90	59.27	492.70	1015.10	570.01	248.27	128.98	76.94	3574.93
1975	89.48	97.29	67.63	253.76	107.30	48.94	289.08	709.40	1254.88	600.48	196.38	115.08	3829.70
1976	143.16	124.53	142.40	175.74	179.58	137.76	114.24	315.35	221.64	184.53	160.92	113.46	3013.31
1977	79.11	72.35	61.69	236.46	187.31	56.63	124.96	531.00	291.63	682.27	362.17	173.28	2858.86
1978	127.16	425.49	284.60	188.72	183.56	67.82	471.26	393.92	201.98	169.22	143.55	126.15	2783.43
1979	281.71	118.64	566.00	198.77	148.97	33.18	163.72	718.34	345.18	363.95	157.96	141.18	3237.60
1980	82.84	86.55	60.38	79.90	41.97	18.49	114.71	659.33	285.38	226.68	88.43	46.74	1791.40
1981	16.91	9.88	517.46	270.54	114.37	54.26	135.53	354.04	332.21	222.68	158.56	112.27	2298.71
1982	88.44	64.98	173.89	205.84	166.90	40.72	51.13	132.86	137.34	545.26	551.47	167.91	2326.74
1983	111.92	140.81	113.40	265.91	189.78	131.98	99.03	194.37	210.37	233.76	155.96	124.92	1972.21
1984	106.65	84.82	67.64	43.64	131.21	40.94	57.58	57.80	116.51	73.52	44.58	107.28	932.17
1985	56.96	47.04	55.44	260.14	188.62	79.15	124.60	255.47	526.46	260.27	133.24	108.06	2095.45
1986	82.86	199.81	218.90	284.41	136.78	120.36	216.79	344.68	283.23	190.51	134.83	86.86	2300.02
1987	53.02	32.82	537.36	431.02	135.86	149.67	77.42	281.62	150.00	114.96	68.69	69.28	2101.72
1988	2.26	63.11	20.55	392.44	130.00	80.00	193.00	97.00	446.67	142.88	138.19	76.34	1782.43
1989	66.42	39.09	58.99	303.06	33.23	44.09	66.46	138.33	138.58	175.36	112.07	84.91	1260.59
1990	51.90	369.53	194.55	480.10	217.71	87.69	86.39	98.99	113.02	187.27	120.84	78.58	2086.55
1991	46.22	47.12	164.07	100.17	81.88	56.13	77.63	363.02	177.55	266.75	148.07	68.68	1597.28
1992	77.18	122.41	102.36	108.12	88.14	41.83	109.37	527.62	345.00	623.77	244.86	100.74	2491.39
1993	135.47	233.34	151.92	270.10	98.51	236.87	243.72	271.00	420.45	328.27	284.12	144.96	2818.73
1994	78.98	42.91	116.48	193.00	130.00	80.00	193.00	483.00	345.00	260.00	156.00	227.56	2305.93
1995	91.00	105.00	172.00	193.00	130.00	80.00	147.00	483.00	345.00	260.00	156.00	122.00	2284.00
1996	91.00	19.10	62.72	31.64	130.00	44.69	19.45	537.37	227.31	113.93	156.00	122.00	1555.22
1997	33.28	32.69	119.80	139.57	56.13	58.17	93.11	191.71	67.66	319.64	281.73	61.43	1454.92
1998	87.78	63.90	177.29	32.47	3.40	28.15	439.46	1155.12	848.77	281.72	52.61	213.08	3383.75
1999	119.76	79.23	134.05	63.19	34.48	25.38	352.72	499.15	482.82	225.47	160.96	179.82	2357.02
2000	101.82	59.59	48.14	25.28	67.47	18.62	192.00	483.00	345.00	260.00	156.00	122.00	1878.91
2001	47.93	32.25	170.50	161.93	233.58	171.63	299.89	576.73	365.99	182.09	21.46	122.00	2385.98
2002	40.32	39.19	192.11	510.33	231.17	164.53	137.98	353.46	64.88	33.06	2.22	325.69	2094.94
mean	91.70	105.76	172.39	193.77	130.15	80.19	192.44	483.88	345.18	260.12	156.08	122.81	2334.48
STD	53.47	91.82	160.91	119.37	66.24	51.99	143.90	311.05	221.99	137.11	96.51	67.83	678.03
CV	0.58	0.87	0.93	0.62	0.51	0.65	0.75	0.64	0.64	0.53	0.62	0.55	0.29

Appendix VIII

Generated monthly Sediment load of Tendaho dam site, (1962 – 2002)

Monthly sediment (1000 tones) estimated based on the sogrea data (1962 to 1964) is Awash Dubti station data from FAO (1965)

a= 0.0101 b= 2.1778

1

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Volume (MMC)
1962	257.98	242.17	364.40	244.91	145.29	38.86	132.46	8315.25	3308.42	1611.96	390.19	192.57	15244	15
1963	327.02	49.57	67.72	1524.21	2884.22	411.44	652.59	4627.34	10185.99	1197.71	375.12	280.77	22584	23
1964	401.88	265.52	196.99	859.00	352.98	167.20	11052.67	47478.13	15141.10	2750.27	514.46	4363.53	83544	84
1965	193.96	108.41	278.71	1057.34	258.75	61.78	142.85	3082.15	1612.45	880.91	586.22	314.96	8578	9
1966	247.44	579.77	529.72	694.85	287.21	162.13	231.40	2067.08	2395.73	1515.61	378.69	178.14	9268	9
1967	99.72	218.99	99.81	568.29	1224.46	73.67	1087.92	13182.09	1139.18	3140.03	3291.58	705.16	24831	25
1968	271.77	1440.55	770.02	2565.04	540.61	332.95	9682.60	10463.80	4268.34	1064.42	399.41	284.85	32084	32
1969	1934.23	1258.68	1348.60	1166.92	1042.79	1042.79	441.95	10253.73	3136.12	1580.37	351.35	130.59	23688	24
1970	472.61	160.20	4048.02	323.26	233.76	96.34	3693.47	37578.10	7986.38	2496.27	355.64	113.87	57558	58
1971	85.98	36.36	33.70	74.59	143.31	48.96	169.59	6233.39	7069.40	2193.87	613.08	161.39	16864	17
1972	169.12	1865.94	353.81	1038.94	804.74	369.00	675.63	1227.55	976.81	538.87	125.64	55.95	8202	8
1973	44.24	21.08	5.08	3.06	20.47	1.30	872.15	75227.37	1582.79	875.13	220.26	66.49	78939	79
1974	29.60	13.38	19074.11	203.43	77.78	73.32	7382.91	35636.60	10141.03	1659.54	398.67	129.41	74820	75
1975	179.80	215.74	97.72	1740.50	267.03	48.31	2311.67	16330.23	56553.21	11358.88	995.93	311.00	90410	90
1976	500.35	369.33	494.58	781.99	819.68	460.15	306.08	2793.78	1296.21	869.69	645.47	301.55	9639	10
1977	137.50	113.19	79.99	1492.42	898.47	66.39	372.11	8690.25	2356.31	15000.69	3776.77	758.35	33742	34
1978	386.52	5364.34	2234.37	913.27	859.76	98.32	6701.13	4535.25	1058.82	720.18	503.32	379.87	23755	24
1979	2185.25	332.34	9986.31	1022.52	545.63	20.72	670.18	16781.74	3401.55	3817.32	619.89	485.40	39869	40
1980	152.01	167.23	76.34	140.50	34.57	5.80	308.83	13923.98	2247.72	1361.26	175.24	43.71	18637	19
1981	4.77	1.48	8214.90	2000.94	306.84	60.49	444.09	3594.57	3129.35	1309.49	625.03	294.70	19987	20
1982	175.28	89.58	764.17	1103.38	698.85	32.37	53.15	425.25	457.10	9206.55	9436.43	708.10	23150	23
1983	292.71	482.63	301.20	1927.12	924.48	419.14	224.23	973.86	1156.95	1455.56	602.93	371.85	9133	9
1984	263.52	160.03	97.75	37.64	413.84	32.75	68.84	69.41	319.48	117.21	39.43	266.92	1887	2
1985	67.24	44.32	63.39	1837.21	912.21	137.65	369.78	1766.14	8529.25	1839.21	427.91	271.17	16265	16
1986	152.09	1034.20	1261.56	2231.12	453.06	342.92	1235.23	3390.83	2211.01	932.24	439.11	168.53	13852	14
1987	57.53	20.24	8918.42	5517.34	446.44	551.22	131.18	2183.71	553.88	310.32	101.07	103.00	18894	19
1988	0.06	84.05	7.30	4498.30	405.57	140.89	958.98	214.32	5963.00	498.20	463.32	127.22	13361	13
1989	93.94	29.62	72.55	2562.13	20.80	38.49	94.07	464.33	466.11	778.35	293.58	160.38	5074	5
1990	54.90	3945.93	975.80	6977.94	1246.65	172.05	166.55	224.02	298.99	898.03	345.91	135.51	15442	15
1991	42.66	44.49	673.29	229.87	148.20	65.13	131.97	3796.20	799.62	1940.34	538.45	101.05	8511	9
1992	130.30	355.75	240.96	271.47	173.99	34.33	278.36	8570.06	3397.69	12340.30	1610.31	232.76	27636	28
1993	443.64	1449.80	569.46	1993.93	221.67	1498.12	1593.99	2008.30	5226.98	3049.11	2226.22	514.15	20795	21
1994	137.02	36.27	319.31	958.98	405.57	140.89	958.98	7070.03	3397.69	1835.06	603.26	1372.75	17236	17
1995	186.52	254.72	746.20	958.98	405.57	140.89	530.04	7070.03	3397.69	1835.06	603.26	353.18	16482	16
1996	186.52	6.23	82.93	18.69	405.57	39.64	6.48	8919.03	1369.56	304.30	603.26	353.18	12295	12
1997	20.86	20.07	339.44	473.39	65.13	70.39	196.07	945.03	97.83	2877.27	2185.55	79.25	7370	7
1998	172.45	86.37	797.11	19.76	0.15	14.48	5755.34	47218.51	24134.42	2185.45	56.55	1189.61	81630	82
1999	339.24	137.93	433.60	84.30	22.53	11.56	3565.49	7595.07	7064.28	1345.42	645.80	822.03	22067	22
2000	238.23	74.17	46.61	11.47	97.21	5.89	948.19	7070.03	3397.69	1835.06	603.26	353.18	14681	15
2001	46.17	19.48	732.14	654.35	1453.11	742.68	2504.15	10403.35	3864.01	844.79	8.02	353.18	21625	22
2002	31.69	29.78	949.35	7970.33	1420.70	677.45	461.76	3581.69	89.28	20.56	0.06	2997.16	18230	18
mean	273.52	517.80	1627.99	1433.02	538.77	218.26	1647.93	10877.60	5248.28	2497.34	906.72	502.11	26289	26
STD	431.30	1061.38	3652.91	1810.66	552.55	309.87	2678.03	15722.39	9413.03	3334.63	1586.04	798.70	23260	23
CV	1.58	2.05	2.24	1.26	1.03	1.42	1.63	1.45	1.79	1.34	1.75	1.59	0.88	0.88

Appendix IX

Monthly Inflow at Ribb dam site having watershed area of 715 Km², (Mm3), (1960-2004).

	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec	Annual
1960	1.587	0.927	0.974	1.241	1.681	0.470	27.307	87.045	38.397	6.967	2.737	1.361	170.70
1961	0.971	2.854	1.717	3.164	0.347	1.400	71.553	160.414	49.860	6.918	4.682	3.706	307.58
1962	1.917	1.360	1.148	0.842	1.424	2.437	64.731	175.927	58.074	20.323	4.394	2.736	335.31
1963	2.024	0.626	0.853	1.505	3.111	1.321	51.403	102.945	24.717	6.928	3.679	2.658	201.77
1964	2.238	1.408	0.671	1.059	1.021	4.537	82.754	151.701	51.686	19.859	8.632	4.872	330.44
1965	2.888	1.801	1.251	3.106	0.318	1.020	13.953	5.452	11.296	15.229	5.064	3.837	65.21
1966	1.859	1.686	2.444	1.785	0.050	3.763	81.342	93.773	32.901	6.547	3.668	2.084	231.90
1967	1.481	1.169	2.490	2.090	3.438	4.675	104.799	130.729	42.128	20.921	8.804	5.342	328.06
1968	2.995	2.165	1.955	2.235	2.014	8.460	87.933	102.790	22.148	11.469	5.358	3.049	252.57
1969	1.374	1.255	3.092	2.177	1.442	0.994	44.993	113.342	21.540	4.200	2.067	1.133	197.61
1970	1.028	0.642	0.637	0.261	0.276	6.898	25.726	93.493	40.022	12.573	2.526	1.589	185.67
1971	1.382	1.274	0.784	0.464	1.798	7.907	25.768	68.938	31.417	7.595	3.657	2.058	153.04
1972	1.670	1.025	0.534	0.958	0.637	4.096	34.392	58.923	18.098	4.941	4.183	3.374	132.83
1973	1.617	0.851	0.808	0.665	1.561	4.785	44.044	131.508	54.005	20.892	2.829	1.562	265.13
1974	0.968	0.647	0.433	0.418	1.356	10.983	80.585	111.029	35.042	4.585	1.413	0.822	248.28
1975	0.948	0.874	0.609	0.940	0.123	43.559	37.093	120.379	79.531	11.039	3.219	2.755	301.07
1976	1.826	2.144	0.767	0.681	1.790	7.112	53.370	96.714	34.434	6.616	8.028	2.944	216.43
1977	2.114	1.149	1.933	2.184	3.803	21.387	84.003	106.971	27.925	17.102	23.242	4.742	296.56
1978	4.665	3.735	4.070	4.948	3.850	6.429	61.689	106.370	28.638	9.606	4.853	3.290	242.14
1979	1.892	0.680	0.423	0.184	2.364	1.857	22.835	72.721	29.823	6.389	2.604	1.657	143.43
1980	1.053	0.787	0.614	2.844	0.406	2.826	52.028	80.209	22.288	7.610	1.881	1.326	173.87
1981	1.818	1.446	1.273	1.393	1.517	5.084	48.479	92.877	31.337	7.926	3.978	3.062	200.19
1982	0.755	0.522	1.558	3.178	2.004	1.002	13.344	57.858	14.989	9.270	2.826	1.537	108.84
1983	0.559	0.304	0.148	0.091	0.335	2.118	13.368	76.236	16.909	9.115	4.109	2.338	125.63
1984	0.268	0.839	0.898	9.946	11.801	14.791	2.220	56.649	5.828	1.601	1.118	1.381	107.34
1985	0.460	0.327	0.302	0.818	2.796	11.682	41.934	46.365	28.651	6.659	2.541	1.023	143.56
1986	0.510	0.966	0.668	0.786	0.596	18.824	66.586	120.550	52.981	16.265	5.659	4.981	289.37
1987	3.999	2.152	2.567	2.711	2.440	9.149	11.538	10.022	9.980	10.471	3.126	2.533	70.69
1988	1.618	1.660	0.932	0.428	2.660	10.462	169.652	168.220	49.923	27.126	10.081	7.743	450.51
1989	6.998	5.523	7.269	6.413	5.379	10.479	21.586	139.662	87.604	23.703	3.834	3.146	321.60
1990	2.534	1.782	1.546	1.770	0.984	2.337	47.473	70.934	45.199	10.362	4.333	4.351	193.60
1991	4.031	1.695	1.546	4.890	0.728	5.331	68.769	137.776	69.969	8.242	2.914	2.000	307.89
1992	0.954	0.326	0.239	7.633	3.487	3.482	67.938	154.901	41.604	13.717	30.306	1.726	326.31
1993	1.481	0.859	1.081	2.710	10.514	4.667	54.527	53.494	48.258	13.835	1.769	1.088	194.28
1994	0.431	0.229	0.183	0.242	0.553	16.175	96.224	119.759	49.425	2.631	0.652	0.380	286.89
1995	0.178	0.097	1.065	2.648	1.423	2.196	57.868	90.043	68.208	4.587	1.488	1.449	231.25
1996	0.777	0.438	1.387	3.496	7.492	31.357	126.962	167.057	46.565	7.482	4.478	3.138	400.63
1997	1.927	1.144	1.621	2.432	4.584	12.729	107.149	108.105	18.152	7.315	21.123	4.652	290.93
1998	3.971	0.225	0.178	0.098	1.291	4.307	115.872	118.873	55.082	8.713	0.885	0.378	309.87
1999	1.482	0.629	0.443	0.315	0.452	3.404	39.069	50.531	14.817	15.032	6.697	3.656	136.53
2000	2.357	1.480	1.140	3.146	1.792	7.373	41.839	77.988	28.425	20.217	12.622	6.609	204.99
2001	5.635	4.262	1.898	1.881	1.885	11.400	79.600	92.003	39.051	16.430	11.808	2.302	268.15
2002	1.930	1.271	1.821	1.448	1.030	12.049	31.574	58.616	23.670	1.807	0.998	0.912	137.13
2003	0.459	0.299	0.496	0.097	0.102	2.253	30.941	44.915	32.480	7.821	3.394	2.100	125.36
2004	1.414	1.195	0.978	2.022	1.163	10.819	29.353	36.795	20.267	9.966	3.877	2.699	120.55
Mean	1.9	1.3	1.3	2.1	2.2	8.0	56.4	96.0	36.7	10.9	5.6	2.7	225.1
Max	7.0	5.5	7.3	9.9	11.8	43.6	169.7	175.9	87.6	27.1	30.3	7.7	450.5
Min	0.2	0.1	0.1	0.1	0.1	0.5	2.2	5.5	5.8	1.6	0.7	0.4	65.2
STDEV	1.4	1.1	1.2	2.0	2.5	8.2	34.5	40.9	18.5	6.1	6.0	1.6	88.7
75%	1.0	0.6	0.6	0.7	0.7	2.5	31.1	69.4	22.6	6.9	2.6	1.5	145.9
85%	0.7	0.4	0.4	0.4	0.4	2.1	25.0	55.9	18.1	6.0	1.9	1.3	131.0

Appendix X: Daily Kesem Kebena Benefit-Cost analysis for month of August

Month	Monitoring Interval (days)	Storage loss due to the Measure (MCM)	Cost (MB)	Storage due to Sediment Reduction (MCM)	Benefit (MB)	Benefit / cost
August	0	0	0	0	0	
	1	606.4667	16271.5021	1059.9912	28439.5638	1.7478
	2	1212.9334	32543.0041	2143.8933	57520.6573	1.7675
	3	1819.4002	48814.5062	3253.6485	87295.3886	1.7883
	4	2425.8669	65086.0083	4391.4151	117821.6661	1.8102
	5	3032.3336	81357.5104	5559.5985	149164.0288	1.8334
	6	3638.8003	97629.0124	6760.8879	181394.6232	1.8580
	7	4245.2670	113900.5145	7998.2989	214594.3582	1.8841
	8	4851.7338	130172.0166	9275.2246	248854.2769	1.9117
	9	5458.2005	146443.5187	10595.4974	284277.1949	1.9412
	10	6064.6672	162715.0207	11963.4613	320979.6666	1.9726
	11	6671.1339	178986.5228	13384.0611	359094.3590	2.0063
	12	7277.6006	195258.0249	14862.9495	398772.9362	2.0423
	13	7884.0673	211529.5270	16406.6189	440189.5855	2.0810
	14	8490.5341	227801.0290	18022.5628	483545.3601	2.1227
	15	9097.0008	244072.5311	19719.4769	529073.5660	2.1677
	16	9703.4675	260344.0332	21507.5102	577046.4999	2.2165
	17	10309.9342	276615.5353	23396.6953	627733.3354	2.2693
	18	10916.4009	292887.0373	25406.7842	681664.0203	2.3274
	19	11522.8677	309158.5394	27548.9028	739137.0613	2.3908
	20	12129.3344	325430.0415	29845.0909	800743.7887	2.4606
	21	12735.8011	341701.5436	32319.7595	867139.1465	2.5377
	22	13342.2678	357973.0456	35002.7638	939124.1536	2.6234
	23	13948.7345	374244.5477	37931.0113	1017689.0323	2.7193
	24	14555.2013	390516.0498	41150.6738	1104072.5778	2.8272
	25	15161.6680	406787.5518	44720.2899	1199845.3791	2.9496

	26	15768.1347	423059.0539	48715.2021	1307028.8731	3.0895
	27	16374.6014	439330.5560	53234.0524	1428269.6258	3.2510
	28	16981.0681	455602.0581	58408.5439	1567101.2318	3.4396
	29	17587.5349	471873.5601	64418.5584	1728349.9228	3.6627
	30	18194.0016	488145.0622	71516.4050	1918785.1464	3.9308
	31	18800.4683	504416.5643	80067.3515	2148207.0413	4.2588

Appendix XI

Daily Tendaho Benefit-Cost analysis for month of August and September

1. August

Month	Monitoring Interval (days)	Storage loss due to the Measure (MCM)	Cost (MB)	Storage due to Sediment Reduction (MCM)	Benefit (MB)	Benefit / Cost
	0	0	0	0	0	
	1	780.4516	15388.1645	1568.4551	30925.2292	2.0097
	2	1560.9032	30776.3289	3158.5225	62276.5878	2.0235
	3	2341.3548	46164.4934	4771.1036	94071.8504	2.0378
	4	3121.8065	61552.6578	6407.1509	126329.7944	2.0524
	5	3902.2581	76940.8223	8067.6711	159070.2710	2.0674
	6	4682.7097	92328.9867	9753.7295	192314.2837	2.0829
	7	5463.1613	107717.1512	11466.4540	226084.0730	2.0989
	8	6243.6129	123105.3156	13207.0400	260403.2085	2.1153
	9	7024.0645	138493.4801	14976.7556	295296.6903	2.1322
	10	7804.5161	153881.6445	16776.9467	330791.0583	2.1496
	11	8584.9677	169269.8090	18609.0437	366914.5138	2.1676
	12	9365.4194	184657.9734	20474.5677	403697.0504	2.1862
	13	10145.8710	200046.1379	22375.1382	441170.5994	2.2053

	14	10926.3226	215434.3023	24312.4810	479369.1887	2.2251
	15	11706.7742	230822.4668	26288.4373	518329.1176	2.2456
	16	12487.2258	246210.6312	28304.9728	558089.1496	2.2667
	17	13267.6774	261598.7957	30364.1895	598690.7253	2.2886
	18	14048.1290	276986.9601	32468.3368	640178.1972	2.3112
	19	14828.5806	292375.1246	34619.8250	682599.0904	2.3347
	20	15609.0323	307763.2890	36821.2401	726004.3912	2.3590
	21	16389.4839	323151.4535	39075.3598	770448.8684	2.3842
	22	17169.9355	338539.6179	41385.1717	815991.4301	2.4103
	23	17950.3871	353927.7824	43753.8937	862695.5228	2.4375
	24	18730.8387	369315.9468	46184.9965	910629.5766	2.4657
	25	19511.2903	384704.1113	48682.2288	959867.5048	2.4951
	26	20291.7419	400092.2757	51249.6457	1010489.2641	2.5256
	27	21072.1935	415480.4402	53891.6410	1062581.4850	2.5575
	28	21852.6452	430868.6046	56612.9829	1116238.1832	2.5907
	29	22633.0968	446256.7691	59418.8550	1171561.5634	2.6253
	30	23413.5484	461644.9335	62314.9024	1228662.9313	2.6615
	31	24194.0000	477033.0980	65307.2845	1287663.7290	2.6993

2. September

Month	Monitoring Interval (days)	Storage loss due to the Measure (MCM)	Cost (MB)	Storage due to Sediment Reduction (MCM)	Benefit (MB)	Benefit / Cost
September	0	0	0	0	0	
	1	575.3000	9073.0563	778.0871	12271.2117	1.3525
	2	1150.6000	18146.1126	1558.9095	24585.5619	1.3549

	3	1725.9000	27219.1689	2342.5229	36943.9293	1.3573
	4	2301.2000	36292.2252	3128.9846	49347.2166	1.3597
	5	2876.5000	45365.2815	3918.3534	61796.3515	1.3622
	6	3451.8000	54438.3378	4710.6897	74292.2873	1.3647
	7	4027.1000	63511.3941	5506.0557	86836.0040	1.3673
	8	4602.4000	72584.4504	6304.5152	99428.5091	1.3698
	9	5177.7000	81657.5067	7106.1340	112070.8386	1.3724
	10	5753.0000	90730.5630	7910.9795	124764.0581	1.3751
	11	6328.3000	99803.6193	8719.1214	137509.2638	1.3778
	12	6903.6000	108876.6756	9530.6311	150307.5836	1.3805
	13	7478.9000	117949.7319	10345.5823	163160.1782	1.3833
	14	8054.2000	127022.7882	11164.0506	176068.2425	1.3861
	15	8629.5000	136095.8445	11986.1142	189033.0066	1.3890
	16	9204.8000	145168.9008	12811.8532	202055.7374	1.3919
	17	9780.1000	154241.9571	13641.3506	215137.7397	1.3948
	18	10355.4000	163315.0134	14474.6914	228280.3578	1.3978
	19	10930.7000	172388.0697	15311.9635	241484.9768	1.4008
	20	11506.0000	181461.1260	16153.2575	254753.0247	1.4039
	21	12081.3000	190534.1823	16998.6667	268085.9733	1.4070
	22	12656.6000	199607.2386	17848.2874	281485.3405	1.4102
	23	13231.9000	208680.2949	18702.2188	294952.6920	1.4134
	24	13807.2000	217753.3512	19560.5632	308489.6427	1.4167
	25	14382.5000	226826.4075	20423.4265	322097.8596	1.4200
	26	14957.8000	235899.4638	21290.9177	335779.0629	1.4234
	27	15533.1000	244972.5201	22163.1494	349535.0289	1.4268

	28	16108.4000	254045.5764	23040.2379	363367.5918	1.4303
	29	16683.7000	263118.6327	23922.3034	377278.6465	1.4339
	30	17259.0000	272191.6890	24809.4700	391270.1508	1.4375

Appendix XII

Daily Ribb Benefit-Cost analysis for month of August and July

1. August

Month	Monitoring Interval (days)	Storage loss due to the Measure (MCM)	Cost (MB)	Storage due to Sediment Reduction (MCM)	Benefit (MB)	Benefit / Cost
September	0	0	0	0	0	
	1	575.3000	9073.0563	778.0871	12271.2117	1.3525
	2	1150.6000	18146.1126	1558.9095	24585.5619	1.3549
	3	1725.9000	27219.1689	2342.5229	36943.9293	1.3573
	4	2301.2000	36292.2252	3128.9846	49347.2166	1.3597
	5	2876.5000	45365.2815	3918.3534	61796.3515	1.3622
	6	3451.8000	54438.3378	4710.6897	74292.2873	1.3647
	7	4027.1000	63511.3941	5506.0557	86836.0040	1.3673
	8	4602.4000	72584.4504	6304.5152	99428.5091	1.3698
	9	5177.7000	81657.5067	7106.1340	112070.8386	1.3724
	10	5753.0000	90730.5630	7910.9795	124764.0581	1.3751
	11	6328.3000	99803.6193	8719.1214	137509.2638	1.3778
	12	6903.6000	108876.6756	9530.6311	150307.5836	1.3805
	13	7478.9000	117949.7319	10345.5823	163160.1782	1.3833
	14	8054.2000	127022.7882	11164.0506	176068.2425	1.3861

	15	8629.5000	136095.8445	11986.1142	189033.0066	1.3890
	16	9204.8000	145168.9008	12811.8532	202055.7374	1.3919
	17	9780.1000	154241.9571	13641.3506	215137.7397	1.3948
	18	10355.4000	163315.0134	14474.6914	228280.3578	1.3978
	19	10930.7000	172388.0697	15311.9635	241484.9768	1.4008
	20	11506.0000	181461.1260	16153.2575	254753.0247	1.4039
	21	12081.3000	190534.1823	16998.6667	268085.9733	1.4070
	22	12656.6000	199607.2386	17848.2874	281485.3405	1.4102
	23	13231.9000	208680.2949	18702.2188	294952.6920	1.4134
	24	13807.2000	217753.3512	19560.5632	308489.6427	1.4167
	25	14382.5000	226826.4075	20423.4265	322097.8596	1.4200
	26	14957.8000	235899.4638	21290.9177	335779.0629	1.4234
	27	15533.1000	244972.5201	22163.1494	349535.0289	1.4268
	28	16108.4000	254045.5764	23040.2379	363367.5918	1.4303
	29	16683.7000	263118.6327	23922.3034	377278.6465	1.4339
	30	17259.0000	272191.6890	24809.4700	391270.1508	1.4375

2. July

Month	Monitoring Interval (days)	Storage loss due to the Measure (MCM)	Cost (MB)	Storage due to Sediment Reduction (MCM)	Benefit (MB)	Benefit / Cost
July	0	0	0	0	0	
	1	90.9677	2324.2258	91.2836	2332.2958	1.0035
	2	181.9355	4648.4516	182.5724	4664.7246	1.0035
	3	272.9032	6972.6774	273.8665	6997.2898	1.0035
	4	363.8710	9296.9032	365.1661	9329.9948	1.0036

	5	454.8387	11621.1290	456.4714	11662.8432	1.0036
	6	545.8065	13945.3548	547.7823	13995.8385	1.0036
	7	636.7742	16269.5806	639.0992	16328.9847	1.0037
	8	727.7419	18593.8065	730.4221	18662.2856	1.0037
	9	818.7097	20918.0323	821.7513	20995.7453	1.0037
	10	909.6774	23242.2581	913.0868	23329.3680	1.0037
	11	1000.6452	25566.4839	1004.4289	25663.1581	1.0038
	12	1091.6129	27890.7097	1095.7777	27997.1200	1.0038
	13	1182.5806	30214.9355	1187.1334	30331.2585	1.0038
	14	1273.5484	32539.1613	1278.4962	32665.5783	1.0039
	15	1364.5161	34863.3871	1369.8663	35000.0846	1.0039
	16	1455.4839	37187.6129	1461.2439	37334.7825	1.0040
	17	1546.4516	39511.8387	1552.6293	39669.6774	1.0040
	18	1637.4194	41836.0645	1644.0225	42004.7749	1.0040
	19	1728.3871	44160.2903	1735.4239	44340.0809	1.0041
	20	1819.3548	46484.5161	1826.8337	46675.6014	1.0041
	21	1910.3226	48808.7419	1918.2522	49011.3428	1.0042
	22	2001.2903	51132.9677	2009.6795	51347.3115	1.0042
	23	2092.2581	53457.1935	2101.1160	53683.5143	1.0042
	24	2183.2258	55781.4194	2192.5620	56019.9584	1.0043
	25	2274.1935	58105.6452	2284.0177	58356.6511	1.0043
	26	2365.1613	60429.8710	2375.4834	60693.6000	1.0044
	27	2456.1290	62754.0968	2466.9594	63030.8132	1.0044
	28	2547.0968	65078.3226	2558.4461	65368.2989	1.0045
	29	2638.0645	67402.5484	2649.9439	67706.0659	1.0045
	30	2729.0323	69726.7742	2741.4530	70044.1231	1.0046
	31	2820.0000	72051.0000	2832.9738	72382.4800	1.0046

Appendix XIII

Irrigation Requirement at Dam Head for simulation inputs, Kesem Kebena Dam

Fortnight	Requirement at fields (mm/ha)	Requirement at dam head with 78.1% overall efficiency (mm/ha)	Requirement at Dam head (m3/ha)	Requirement at Dam head			
				20000ha (Mm3)	22000ha (Mm3)	24000ha (Mm3)	25000ha (Mm3)
Jan 1	38.42	49.26	492.60	9.852	10.837	11.822	12.315
Jan 2	38.41	49.24	492.40	9.848	10.833	11.818	12.310
Feb 1	41.02	52.59	525.59	10.512	11.570	12.622	13.148
Feb 2	47.12	60.41	604.10	12.082	13.290	14.498	15.103
March 1	47.85	61.35	613.50	12.270	13.497	14.724	15.338
March 2	53.29	68.32	683.20	13.664	15.030	16.397	17.080
April 1	63.18	81.00	810.00	16.200	17.820	19.440	20.250
April 2	79.09	101.39	1013.90	20.278	22.306	24.334	25.348
May 1	97.50	125.00	1250.00	25.000	27.500	30.000	31.250
May 2	104.40	133.90	1339.00	26.780	29.458	32.136	33.475
June 1	106.36	136.36	1363.60	27.272	30.000	32.726	34.090
June 2	103.43	132.60	1326.00	26.520	29.172	31.824	33.150
July 1	78.95	101.22	1012.20	20.244	22.268	24.293	25.305
July 2	62.39	79.99	799.90	15.998	17.598	19.198	19.998
Aug 1	58.97	75.60	756.00	15.120	16.632	18.144	18.900
Aug 2	64.30	82.44	824.40	16.488	18.137	19.786	20.610
Sept 1	73.67	94.45	944.50	18.890	20.779	22.668	23.613
Sept 2	81.17	104.06	1040.60	20.812	22.893	24.974	26.015
Oct 1	84.97	105.09	1050.90	21.018	23.120	25.222	26.273
Oct 2	76.62	98.23	982.30	19.646	21.611	23.575	24.558
Nov 1	69.71	89.37	893.70	17.874	19.661	21.449	22.348
Nov 2	62.46	80.08	800.80	16.016	17.618	19.219	20.020
Dec 1	-	-	-	-	-	-	-
Dec 2	-	-	-	-	-	-	-
Total	1533.28	1961.95	19619.19	392.384	431.630	470.869	490.497

Appendix IVX

10-day reservoir evaporation and gross irrigation releases data used in simulation, Tendaho Dam

10-day	Reservoir Evaporation (mm)	Scenario I, 60000 ha, Irrigation demand (MMC/10 day)	Scenario II, 48000 ha, Irrigation demand (MMC/10 day)
Jan 1	60	29.7	23.7
2	60	31.7	25.4
3	60	33.8	27.1
Feb 4	58	31.5	25.2
5	58	32.1	25.7
6	58	33.5	26.8
Mar 7	84	34.9	27.9
8	84	35.6	28.5
9	84	34.8	27.8
Apr 10	78	33.4	26.7
11	78	33.8	27.0
12	78	41.1	32.8
May 13	85	59.0	47.2
14	85	64.4	51.5
15	85	72.9	58.3
Jun 16	88	67.3	53.8
17	88	68.0	54.4
18	88	68.1	54.5
Jul 19	92	63.3	50.6
20	92	59.3	47.4
21	92	64.0	51.2
Aug 22	81	62.2	49.7
23	81	64.4	51.5
24	81	63.3	50.6
Sep 25	80	61.0	48.8
26	80	58.7	47.0
27	80	61.8	49.4
Oct 28	73	53.5	42.8
29	73	50.3	40.3
30	73	47.0	37.6
Nov 31	93	44.2	35.4
32	93	45.4	36.3
33	93	46.4	37.1
Dec 34	94	39.0	31.2
35	94	39.6	31.7
36	94	39.5	31.6
Annual	2899	1769	1415

Appendix XV

Mean Monthly Evaporation, Rainfall and Water Demand, Ribb Dam

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Evaporation, mm	152	147	179	169	176	146	121	126	147	154	145	142
Rainfall, mm	9.8	4.9	37.5	36.6	87.0	167.8	421.7	405.8	182.8	88.5	35.1	10.3
Water demand, mm	290	138	155	197	60	0	0	0	0	53	78	17

Water demand was obtained from *Abbay River Master Plan Project – Phase 2, Water Resources Development – Irrigation and Drainage, Appendix 3.4* (1998). Water supply starts from the 2nd year. Multiplying appendix XV monthly demand values by the command area of 19,925 Ha yields an annual irrigation demand value of 198 MCM.