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EFFECTS OF LAND USE CHANGES ON SEDIMENT YIELD AND ITS POTENTIAL CONTRIBUTION TO GREENHOUSE GASES EMISSIONS FROM RESERVOIRS

***Case study*: Tekeze Hydropower Dam in Ethiopia**

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*Master in **Water Engineering track***

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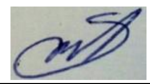
Sadame Mohammed Yimer  28/08/2016

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Abstract

Sedimentation is becoming a big challenge worldwide to water resources development in general and to the reservoirs in particular by reducing the storage capacity and then useful lifetime of the dam. Tekeze dam is the recently constructed hydropower dam in Ethiopia which is threatened by siltation problem. The rugged topographic nature, land use changes and poor watershed management in general, are the main driving factors for high sediment yield to the Tekeze dam reservoir. Despite the perception hydropower dam as a clean energy source, recent researchers have reported that hydropower plants located particularly in tropical region emit a significant amount of greenhouse gases to the atmosphere due to flooding of huge biomass during impoundment and the presence of high tempreture. The continuously flushed nutrients and organic matter with sediment also contributed to reservoirs organic carbon bugdet. The general objective of this research was to assess the effect of land use changes on sediment yield and its potential contribution to the greenhouse gas emission from Tekeze dam reservoir. In particular, it was aimed to estimate the sediment yield with two land use change scenarios, the useful life of the reservoir, estimate the gross GHGs emission level from Tekeze dam, and trends of greenhouse gases emission amount from the reservoir due change in sediment yield which resulted from land use changes.

The research was carried out using secondary data from open sources. Universal soil loss equation (USLE) has been used to estimate soil erosion rate with change in land use scenarios. The two past land use conditions that have been actually on the ground in 2001 and 2010 were used as scenarios. Results indicate that soil erosion rate increases from 104.5 ton/ha/year to 129.2 ton/ha/year with 2001 and 2010 land use scenarios respectively. This change in sediment yield will shorten the expected reservoir lifetime from 29 years to 22 years starting from now.

The Greenhouse gas risk assessment tool (beta version) developed by UNESCO/IHA has been used to estimate the gross emission level of CO_2 and CH_4. The results show that the level of emission for both CO_2 and CH_4 is high in the first 20 to 30 years from impoundment and gradually decline with time. The approaches that used to see the trends of GHGs emission amount due to sediment yield change were by looking at how the organic carbon budget of the reservoir and retention time of the inflow water in the reservoir will be. Thus, empirical equation given by (Gert Verstraeten and Poesen 2002) was adapted to estimate the organic carbon yield in the reservoir sediment. And from the general definition of retention time, the storage capacity divide by outflow rate has been used to estimate the retention time. The analysis showed that the change in land use from 2001 to 2010 scenario is expected to increase the greenhouse gas emission level due to the organic carbon content coming with sediment. On the other hand, the deposited sediment can bury the inundated biomass permanently and may make it inactive from decomposition and involvement in the greenhouse gas production. Regarding the retention time, Greenhouse gases emission is expected to be high in 2001 land use scenario due to more residence time than 2010 land use condition. Particularly CH_4 emission is expected to increase by a greater proportion than CO_2 in 2001 scenario due to the significance of retention time in methane production than CO_2.

Therefore, it is concluded that the change of land use in the catchment has a significant impact in the reservoir useful lifetime due to downstream sedimentation problem. Whereas the effect of sediment yield changes to greenhouse gas emission amount from reservoirs have seen in two contrary directions. Then, it was found that in one side it increases the GHGs emission potential due to more organic carbon addition and on the other side decrease the potential emission due to less retention time in the long term of the dam life. Hence, in order to identify the most significant or overweighed emission tendency due to sediment yield change needs further detail research in this area.

Keywords: Sedimentation, Trap Efficiency, Retention time, Hydropower Dam, GHG Risk Assessment Tool, USLE

Abstrait

Sédimentation devient un grand défi dans le monde entier pour le développement des ressources en eau en général et aux réservoirs, en particulier en réduisant la capacité de stockage et la durée de vie alors utile du barrage. barrage Tekeze est le barrage hydroélectrique construit récemment en Ethiopie qui est menacée par problème de l'envasement. La nature topographique robuste, les changements d'utilisation des terres et la gestion des bassins versants pauvres en général, sont les principaux facteurs de conduite pour un rendement élevé de sédiments dans le réservoir du barrage Tekeze. Malgré le barrage perception de l'hydroélectricité en tant que source d'énergie propre, des chercheurs ont récemment rapporté que les centrales hydroélectriques situées en particulier dans les régions tropicales émettent une quantité importante de gaz à effet dans l'atmosphère en raison des inondations de grande biomasse lors de la mise en eau et la présence de haute tempreture. Les éléments nutritifs en continu rincés et la matière organique des sédiments ont également contribué à des réservoirs organiques bugdet de carbone. L'objectif général de cette recherche était d'évaluer l'effet de l'utilisation des sols sur le rendement des sédiments et sa contribution potentielle à l'émission de gaz à effet de serre Tekeze réservoir de barrage. En particulier, il vise à estimer le rendement des sédiments avec deux scénarios de changement d'utilisation des terres, la durée de vie utile du réservoir, estimer le niveau des GES des émissions brutes de Tekeze barrage, et les tendances de quantité d'émission à effet de gaz de la raison du changement réservoir dans la production de sédiments qui a résulté de l'utilisation des sols.

La recherche a été effectuée en utilisant des données secondaires à partir de sources ouvertes. équation de perte de sol Universal (USLE) a été utilisé pour estimer le taux d'érosion du sol avec le changement dans l'utilisation des terres scénarios. Les deux conditions d'utilisation des terres passées qui ont été réellement sur le terrain en 2001 et 2010 ont été utilisés comme des scénarios. Les résultats indiquent que l'érosion du sol augmente de taux de 104,5 tonnes / ha / an à 129,2 tonnes / ha / an avec 2001 et 2010 l'utilisation des terres scénarios respectivement. Ce changement dans la production de sédiments réduira le réservoir durée de vie prévue de 29 ans à 22 ans à partir de maintenant.

L'outil d'évaluation des risques de gaz à effet de serre (version bêta) développé par l'UNESCO / IHA a été utilisé pour estimer le niveau d'émission brute de CO_2 et de CH_4. Les résultats montrent que le niveau d'émission de CO_2 et de CH_4 est élevé dans les 20 à 30 premières années de la mise en eau et diminuent progressivement avec le temps. Les approches utilisées pour voir les tendances de la quantité d'émissions de GES en raison de sédiments changements de rendement étaient en regardant comment le budget du carbone organique du réservoir et le temps de rétention de l'eau d'entrée dans le réservoir sera. Ainsi, l'équation empirique donnée par (Gert Verstraeten et Poesen 2002) a été adapté pour estimer le rendement en carbone organique dans les sédiments du réservoir. Et à partir de la définition générale du temps de rétention, la fracture de la capacité de stockage par le taux d'écoulement a été utilisé pour estimer le temps de rétention. L'analyse a montré que on prévoit que le changement d'utilisation des terres 2001-2010 scénario pour augmenter le niveau d'émission de gaz à effet de serre en raison de la teneur en carbone organique provenant de sédiments. D'autre part, le sédiment déposé peut enterrer la biomasse inondée en permanence et peut le rendre inactif de la décomposition et de l'implication dans la production de gaz à effet de serre. En ce qui concerne le temps de rétention, les gaz à effet de serre des émissions devrait être élevé en 2001 l'utilisation des terres scénario en raison de plus de temps de séjour qu'en 2010 l'utilisation des terres condition. En particulier, devrait les émissions de CH_4 à augmenter par une plus grande proportion que le CO_2 en 2001 scénario en raison de l'importance du temps de rétention dans la production de méthane que le CO_2.

Par conséquent, il est conclu que le changement d'utilisation des terres dans le bassin versant a un impact significatif dans la durée de vie utile du réservoir en raison de problème de sédimentation en aval. Alors que l'effet du rendement des sédiments changements au niveau d'émission de gaz à effet de serre des réservoirs ont vu dans deux directions contraires. Ensuite, il a été constaté que d'un côté on augmente le potentiel GES d'émission en raison de plus l'addition de carbone organique et de l'autre côté de diminuer l'émission potentielle en raison de moins de temps de rétention à long terme de la durée de vie du barrage. Par conséquent, afin d'identifier la tendance des émissions les plus importantes ou surpondérées en raison de sédiments changement de rendement a besoin de nouvelles recherches de détail dans ce domaine.

Mots-clés: Sédimentation, Piège efficacité, temps de rétention, barrage hydroélectrique, Outil d'évaluation des GES risque, USLE

Table of Contents

List of Figures

List of Tables

Abbreviation

AGNPS	Agricultural Nonpoint Source Pollution Model
ANSWERS	Areal Nonpoint Source Watershed environmental response Simulation
BM^3	Billion Cubes Metric
C/A	Capacity Area ratio
DEM	Digital Elevation Model
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EUROSEM	European Soil erosion Model
FAO	Food and Agriculture Organization
GHGs	Greenhouse Gases
GIS	Geographical Information System
GPS	Geographical Position System
GWP	Global Warming Potential
HEC-HMS	Hydrologic Engineering center's – Hydrologic Modeling system
ha	Hectare
ICOLD	International Commission on Large Dams
KM	Kilometer
KM^2	Square Kilometer
kwh	Kilowatt Hour
m	Meter
m/Km	Meter per Kilometer

M^3	Cubic Meter
Mg $C\text{-}CH_4\ m^{-2}\ d^{-1}$	Milligram of Carbon in Methane Equivalent
mg $C\text{-}CO_2\ m^{-2}\ d^{-1}$	Milligram of Carbon in Carbon Dioxide Equivalent
mg/l	Milligram per Liter
MJ/ha.mm/h	Mega Joule Millimeter per Hectare per Hour
Mm^3	Million Cubic Meter
Mm^3/year	Million Cubic Meter per Year
MODIS	Moderate-resolution Imaging Spectroradiometer
MoWR	Ministry of Water Resources
Mton	Million Tons
Mton/ha/yr	Million Tons per Hectare per Year
Mton/m^3	Million Ton per Cubic Metric
Mton/year	Million Tons per Year
MUSLE	Modified Universal Soil Loss Equation
MW	Mega Watt
OC	Organic Carbon
RESCON	Reservoir Conservation
RT	Retention Time
RUSLE	Revised Universal Soil Loss Equation
SWAT	Soil and Water Assessment Tool
TE	Trap efficiency
t.ha.h/ha/MJ/mm	Ton Hectare Hour per Hectare per Mega Joule per Millimeter

ton/ha/year	Ton per Hectare per Year
ton/ha/year	Tons per Hectare per Year
ton/ m3	Ton/ Cubic Meter
UNESCO	United Nations Educational, Scientific and Cultural Organization
UN	United Nation
USD	United States Dollar
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
WEPP	Water Erosion prediction Project
^{o}C	Degree Celsius
λ	Lambda

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Chapter One. INTRODUCTION

1.1 Background

Water is the most vital resource to support all forms of life on earth and it will remain essential for mankind survival and the future development of the world (Ahmed and Ismail, 2008). The large portion of the fresh water is unusable since it is trapped in various forms such as polar ice, glaciers and in the atmosphere. The rapid increasing of population number together with the socio economic development of the world in the last century increases water demand. Due to this many rivers are tapped to create large reservoirs to meet the needs of water for industrial, urban and agricultural uses and also for Flood control and power generation.

Ethiopia is highly endowed with huge water resources potential that can potentially improve the productivity of agricultural sector and any other water based services. The country has a total of 122 billion cubic meters of surface water and 2.6 billion cubic meters of ground water resources potential. (Awulachew et al., 2007.; Birhan G. 2002; MoWR, 2002). Despite all these potential resources, agricultural production and productivity are lowest in some parts of the country attributed from unsustainable environmental degradation mainly reflected in the form of erosion which leads to losing of soil fertility and other related problems (Awulachew et al., 2007; Haregeweyn N. et al., 2008).

Most of the Ethiopian people rely on rain-fed agriculture which is highly vulnerable to climate variability, seasonal shifts and precipitation patterns. Under the dominant rain-fed agricultural production system, the progressive degradation of the natural resource base, especially in highly vulnerable areas of the highlands coupled with climate variability have aggravated the incidence of poverty and food insecurity (Awulachew et al., 2007).

In fact, African water stress problem (in particular Ethiopia) is not really because of insufficient water availability rather it is a lack of good and sustainable water management action. Due to the continuity of rapid increasing of population number under limited available resource in Ethiopia, people are forced to deforestation or land-use change in order to get more agricultural land to meet their food demand. This causes a lot of sediment deposition and loss of storage structure capacity in the downstream.

Soil resource degradation by accelerated water induced erosion is most series in Ethiopian, particularly in the highland region. The Ethiopian Highlands Study Report by FAO, (1986) estimated that nearly 1.9 billion tons of fertile soil are lost from highlands annually through water erosion alone. This amount is equivalent to an average soil loss of 130 tons per hectare per year from cultivated lands (Mequanint T., 2008). The study further estimated that 50% of the highlands are significantly eroded, 25% seriously eroded, while 4% have reached a point of no economic use. It also estimates that there is an average annual land productivity decline of 2.2% due to soil erosion. An estimated rate of soil erosion on croplands is found to be 42 t/ha on average while this rate has reached up to 300 t/ha on individual fields (Mequanint T., 2008).

Sheet and rill erosion are the most widespread forms of water erosion which cause a severe land degradation and significant loss of agricultural production and productivity. The loss of nutrient-rich topsoil by erosion leads to losing of soil quality and hence reduced crop yield. Since more than 85% of the country’s population depends on agriculture for a living; physical soil and nutrient losses lead to food insecurity (Tamene L., 2005a). The soil erosion and its associated problems together with the climate change effects are therefore recognized as the severe threats to the national economy of Ethiopia.

There is no continent that will be struck as severely by the impacts of climate change as Africa (UNEP, 2007). Adaptation to climate change is a rational must for Africa, which is considered the most vulnerable continent to climate change due to limited adaptive capacity together with widespread poverty and the existing low level of development. Climate change is threatening the effort of Ethiopian people and government for the economic growth of the country. Currently, the Ethiopian government is highly investing for implementing the green development policy to build up the country’s economy through water centered development. Among these, construction of dams across rivers for irrigation, hydropower generation, water supply and any other purposes are the major concern of the government.

Despite all these efforts to tap the water resources potential of the country as the economy allows as possible, sedimentation of the reservoir is still a major barrier for the sustainable utilization of the established reservoirs and also for the proposed dam as long as the problem is there. Sedimentation as an ecological and environmental phenomenon is increasingly affecting the sustainable development of human societies worldwide. One of the main problems pressing and facing water resources management in the Nile Basin is sedimentation (Ahmed and Ismail, 2008).

The flow of water in many African rivers is regulated through storage reservoirs and the service live off some of these reservoirs is exercising a continuous reduction due to the unexpectedly high rate of siltation (Shahin, 1993). However, for the reservoir to be fully effective in working, its storage capacity for which it is designed for should not be depleted due to the accumulated sediments. A study of soil erosion and sedimentation problems in the different agro-ecological zone of the country including the Nile River Basin where the basin of Tekeze hydropower dam is included showed an alarming rate of sedimentation of dams due to the failure of a comprehensive watershed management prior to construction of dams (RODECO, 2002).

The effect of soil erosion is not only reducing the storage capacity of the reservoirs in downstream through siltation rather it is also contributing to the climate change impact on the planet earth. On one hand, it weakens the adaptive capacity of the people to climate change by reducing the volume of structure which is readily available to store water for later use. On the other hand, through its contribution to greenhouse gas emission, this is actually discovered relatively in the recent past time.

In recent years, there has been an increasing concern on greenhouse gas (GHG) emissions from artificial reservoirs, particularly in the tropics, where the flooding of large amounts of carbon from the primary forest, together with high temperatures, lead to high methane (CH_4) and carbon dioxide (CO_2) emissions (Bril et al. 2005). The issue of greenhouse gas emission disfigures the image of the hydropower plant as an environmentally friendly renewable energy source and becomes detrimental towards encouraging hydropower plants particularly in the tropical region. According to Brazilian researcher's estimation on 2007, methane from dams is responsible for around 4% of human-caused climate change and it is 25 times more potent than CO_2 (International Rivers, 2008). And according to UN convention on climate change, Ethiopia has set a target to reduce its emissions of greenhouse gasses by 64 percent by 2030, which is the most ambitious plan to date presented to the united nation, which begins November 2016 (cited from Phys.org website).

Eroded soils, leaves and other plant residues which are enriched in organic matter content together with the nutrients from agricultural land and washed into the reservoir from primary production in upstream watersheds also continuously contributes to the reservoirs organic carbon budget. The high accumulation of nutrients and organic matter in the water body leads to eutrophication problem which again leads to a high accumulation of organic matter from the dead body of aqua plants due to the depletion of available dissolved oxygen.

Since a few decades back, a number of simulation model have been developed to quantify and analyze the processes of soil erosion at the watershed scale. Some of commonly applied erosion models are empirical and others are physically based ones. The universal soil loss equation (USLE) is the most widely used empirical model. Others empirical models include revised universal soil loss equation (RUSLE) and modified universal soil loss equation (MUSLE) etc, which are based on modifications made on USLE (Mequanint T., 2008).

Modeling is highly enhancing the understanding of spatial and temporal aspects of the catchments over a large area and to make an assessment and enabling priority management areas to be identified (Mequanint T., 2008). It also helps to study the scenario like effects of land use change on water flow and sediment yield from the watershed. But the choice of the model depends on data availability and the purpose of the study in hand.

Therefore, watershed-modeling incorporating hydrological processes take a crucial role for proper planning and development of land and water resources in a sustainable way (McCornick P.G, 2003). In this study different empirical models together with GIS application have been used to address the objective of the study, due to lack of data in the required quality and quantity to use the physical based model which are the most applicable in the field of hydrological modeling.

1.2 Problem Statement

Over the next decades, it is predicted that billions of people, particularly those in developing countries, face shortages of water and food and greater risks to health and life as a result of climate change (UNFCCC, 2007). In Ethiopia, particularly the agricultural sector where more than 85 % of the people livelihood depends on is highly influenced by erratic and unpredictable rainfall and is claiming thousands of human and livestock lives through recurrent drought (Meze-Hausken, 2004).

A massive change of land use together with rising fossil fuel burning have emitted and are continuing to emit, increasing quantities of greenhouse gases into the Earth's atmosphere (UNFCCC, 2007). Developing countries are the most vulnerable to climate change impacts because they have fewer resources to adapt: socially, technologically and financially (UNFCCC, 2007).

Adaption to climate change is a must and must for every individual to be able to cope with an uncertain future. The way of adapting the climate change can be by taking the right measures to reduce the negative effects of climate change (or exploit more the positive ones). And by taking radical measures to significantly reduce the anthropogenic sources of greenhouse gas emission depending on its contribution to climate change until the grass root level as much as possible.

One of the adaptive measures to climate change is building dams to create reservoirs to store water for later use during insufficient water available (draught) and also to generate electricity for the case of a hydropower dam. However, sedimentation has become a serious problem worldwide. The gradual loss of capacity reduces the effective life of dams and diminishes benefits for irrigation, hydropower, water supply, navigation, recreation and other purposes for which it intended to be used. However, reservoir sedimentation becomes a severe threat to the optimal use of water resources in many river basins and there is no exception for Nile basin in this regards (Bashar et al., 2010).

On the river Nile, a number of dams have been constructed since the last century and they are seriously affected by sediment deposition at an unexpected rate (Bashar et al., 2010). The Aswan high dam in Egypt, Roseire and Senair dam in Sudan, Tekeze dam and the Grand

Renaissance dam which is under construction currently in Ethiopia are among the water works along the river Nile (Eizel-Din et al. 2010).

The Atbara River is the most northern tributary to join the Nile River and its headwaters originate from the north-western Ethiopian Highlands. Khashm ElGirba reservoir is one of the Sudanese dam constructed across the Atbara River and receives an average sediment concentration of 1500 mg/l which can reach also a maximum of 3000 mg/l annually (Ahmed and Ismail 2008). Small reservoirs are more affected by sedimentation due to the relative loss in capacity is faster than the big one. According to (Ahmed and Ismail, 2008), the Khashm ElGirba reservoir is already lost 50% of its capacity since the initially filled time in 1964.

Tekeze dam, where the case study of this research, is one of the newly constructed hydropower plants constructed along Tekeze River which is the main tributaries of Atbara River. The dam is located in a steep, narrow gorge. The Ethiopian highlands, which are under the Atbara river basin through Tekeze River, are characterized by steep slopes ranging from 5 m/km along the 300 km from the starting point to the catchment outlet (Ahmed and Ismail 2008). Tamene L. et al., (2005b) reported that the major factors that control sediment variability in the catchment of northern Ethiopian highlands are the terrain form, gully erosion, surface lithology, and land cover. The steeper the slope, the high soil erosion risk is expected. Sometimes a very limited change in land use can have a significant effect on regional soil erosion rates (Van Rompaey, Krasa, and Dostal., 2007).

In his study Aforki (2006) reported that 43% of the Tekeze Dam storage capacity, which is about 4 billion m^3, is provided as a room for the sediment inflow throughout the 50 years design lifetime of the dam (cited from Ahmed and Ismail, 2008). From the feasibility study report, the rate of sedimentation expected annually is about 30 million m^3 i.e. less than 1%. Due to limited data availability during the feasibility study, the rate of sedimentation of Tekeze reservoir still remains unpredicted (Ahmed and Ismail, 2008). According to several studies carried out in the Tigray area, there is no doubt that the sediment load in Tekeze river is large compared to other Nile basin systems, since it falls within a dry area with torrential rainfall during short period (July- Sept) and expected to be filled by sediment in less than the suggested period in the feasibility study (Tamene L. et al. 2011; Ahmed and Ismail, 2008).

Soil erosion and sediment delivery processes are not only responsible for high sediment transport rates, but also for associated export of sediment-bound nutrients which finally are deposited in the reservoir and in the river-bed sediments. These could lead to eutrophication of the reservoir water (Macleod and Haygarth., 2003; Sherriff et al. 2015; Steegen et al. 2001; Withers et al., 2014) on top of the loss of productivity of the contributing area (Tesfahunegn, 2011; Niguha Haregeweyn et al. 2008). Moreover, the link between nutrient losses from the erosion source area and nutrient input in the deposited sediment has never been analyzed (Haregeweyn N. et al., 2008). Despite the current global concern to quantify the potential of the reservoir sediment to sequester carbon (Van Oost K. et al., 2004, 2005), this issue has never been studied in the tropical Ethiopian reservoirs (Haregeweyn N. et al. 2008).

Despite the indispensable role of dams in the human development, they gradually recognized the harm of such dams to the environment in the past several decades (Chen et al. 2010). This is because of the flooded biomass following dam impoundment which was initial serving as a carbon sink area. The impoundment enhances the decomposition of organic matter inside the reservoir which finally ends up with the production and release of greenhouse gases to the atmosphere. The significance of GHGs emission from the dam is still in controversial among researcher.

According to (Mendonça et al., 2012), hydropower dams often produce and emit more GHGs in the first twenty years after flooding due to the usually excessive availability of decomposable organic matter from terrestrial vegetation and land erosion. Besides huge biomass potential, the presence of high temperature in the tropical region is the other determining factor for high greenhouse gases emission from tropical reservoirs. Despite the high emission rate at the early age of the dam, the emission is still continued due to the supply of organic matters from the surrounding catchment. This indirectly indicates as the sediment yield from the basin might have an influence on the emission level of the GHGs from the reservoir. The other reason which makes emission from hydropower dam becomes high is that the presence of turbines which potentially used as pathways for the produced GHGs at the reservoir bottom particularly for methane.

Tekeze dam is one of the newly constructed hydropower plants and its location is in the arid climate where the temperature can reach up to 40^o during summer. A very severe land degradation problem in the dam area has been reported by different researchers. Thus, GHGs emission from Tekeze dam might be significant regarding the age of the reservoir, purpose of the dam (hydropower dam), climate condition and soil erosion vulnerability of the basin as well. On the other hand, the Ethiopian government is in implementing the green development policy and has the plan to reduce the greenhouse gas emission significantly in the near future.

For the purpose of applying cause based corrective measures for the problem, assessing the possible response of different factors or scenarios is a very important step for a better decision. Therefore, the potential contribution of land use changes in the watershed to sediment yield which will finally affect the useful lifetime of the dam and its potential contribution to the greenhouse gases emission level from the reservoir should be addressed to take the possible measures.

1.3 Objectives of the Study

The general objective of this research was to assess the effect of land use change on the sediment yield and its potential contribution to the greenhouse gas emission from Tekeze dam.

Specific objectives

The specific objectives of this research are mentioned below.

- To estimate the rate of soil erosion and sediment yield of the basin into the reservoir with two land use change scenarios.
- To estimate the trap efficiency and then the useful lifetime of Tekeze dam with the two land use scenarios.
- To estimate the gross emission of greenhouse gases by diffusive flux from Tekeze dam reservoir.
- To assess the trends of greenhouse gases emission amount from the reservoir due to land use changes effect on sediment yield.

Chapter Two. LITERATURE REVIEW

2.1 Soil Erosion

Soil erosion is the result of detachment, transport process of soil particles mainly by natural forces such as wind and water and deposited in the downstream when the energy of the driving force becomes insignificant to transport the eroded particle (Dahal, 2013). Surface runoff following rainfall event is the main agent for soil erosion problem and downstream sedimentation. The transported soil particles can be deposited in their way inside river bed before it reaches the outlet of the watershed and part of it can be trapped and deposited into the reservoir across the river and part of it again might escape from the reservoir and go further downstream. These mainly depend on the nature of soil particle and flow velocity of water. Soil erosion can happen due to natural causes without human intervention and it is in equilibrium with soil formation process (Mequanint T., 2008). However, the human intervention breaks the equilibrium and creates an accelerated soil erosion rate (Sanders, n.d.; Mequanint T., 2008).

2.1.1 Factors affecting soil erosion

Erosion of soil from the upland catchment area of the basin and its deposition to the downstream of the area is highly influenced by the hydrological and morphological aspects of the watershed. The variation of soil loss from the given catchment and its sediment yield at the outlet of the watershed are attributed to the spatial variability of geomorphologic and topography of the watershed. Different areas have different morphological and hydrological aspect which finally end ups with a different response regarding soil loss and sediment yield from their basin. Accelerated soil erosion causes a damage of top fertile soil, siltation and flooding problem (Taffa, 2002 cited from Mequanint T., 2008).

Hydrological factors

The hydrological parameters are the main driving force behind the detachment/production and transportation of sediment load (Habtamu G., 2011). It includes the intensity and duration of rainfall, rainfall drop size, the amount of runoff and flows velocity. Rainfall is considered as one of the main climatic factors that play fundamental role in soil erosion. The potential of rainfall to cause soil erosion is called erosivity and it depends on the intensity, duration, and frequency of rainfall. According to Morgan (2005), soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff which is actually involved in both detachment and transport phases.

Erodibility

The soil characteristics of the watershed together with organic matter content determine the susceptibility of the soil to the agents of soil erosion. Sandy soils are easily detached due to less surface area and weak cohesion force between the particles. However, they are not easily transported due to larger in size and weight. On the other hand, clay particles are easy to transport. However, they have large surface area and strong cohesive force between the particles which makes them less susceptible to detachment phase of erosion process. As a result of intermediate size and weight, silt particles have proved to be both relatively easy to detach and relatively transportable and frequently highly susceptible to erosion (Mequanint T., 2008).

Land cover and management practice

The land use type of the area has a strong influence on soil erosion through its effects on vegetation cover and management practices. Land cover is highly influential factors on erosion process than any other single factors that can also intervene by a human. The land cover can be a canopy, mulches, plant residues and densely growing plants in direct contact with the soil surface (Mequanint T., 2008).

Not only are hydrological processes such as evapotranspiration, infiltration, surface runoff and groundwater flow altered substantially by land use changes (Fohrer et al. 2001; Sahin and Hall 1996; Tong and Chen, 2002), but also soil erosion and the transport of sediment to water bodies (Bieger, 2013). Vegetation cover helps to reduce the soil erosion by intercepting and dissipating the erosive energy of raindrops, runoff, and the wind. It has also a role in reducing the volume of runoff through increasing the infiltration by following the root system and increases soil organic content which increases the aggregate stability of the soil. The role of plant root system is also by increasing the binding of soil particles thus increasing the mechanical resistance of soil against erosion. According to (Mequanint T., 2008) the highest annual soil losses in Ethiopia occur during the plowing months and in the first month after planting in which the soil is exposed to the raindrop impact. Assessing the impacts of land use change on the quality and quantity of water is fundamental to the sustainable development of water resources and land use alternatives (Bieger K., 2013).

Geomorphologic Parameters

Geomorphology is related to the form of the landscape and other physical features of the watershed. The main geomorphologic parameters include the area of watershed, elongation ratio, circularity ratio, drainage length, shape factor, slope, relief ratio, elevation difference and hypsometric condition of the watershed. The slope gradient, shape, and length are the most important terrain characteristics that affect soil erosion significantly. The experimental investigation indicated that increasing the surface slope by double for the same soil type increase the soil loss by 2.5 times (Mequanint T., 2008). Bobe B., (2004) also discovered that the soil erosion increase exponentially with an increase in slope gradient due to its effect on flow velocity. The longer the length also increases the volume of water generated which finally increases the erosive power of the runoff. The erosion potential is high at the base of the slope where the runoff velocity is greatest and runoff concentrates from upper land (Shrinivas B., 2007).

2.1.2 Soil erosion in Ethiopia

Soil erosion is a concern for farmers, development and government agencies throughout the world since it is affecting soil, land and water resources upon which humans depend on for their sustenance. Today, soil erosion is universally recognized as a serious threat to man’s well – being. The threat is very severe mainly in developing countries, like Ethiopia (Abtew and Melesse 2014).

Ethiopia is considered to have one of the most serious soil erosion problems in the world and a considerable amount of soil is being lost every year by water erosion. The rugged nature of topography together with poor land management practice are the main responsible for the erosion problem. In the highlands of Ethiopia, soil losses are extremely high with an estimated average of 20 tons/ha/year and it can radically exceed this on steep slopes. Berhe

(1996) also reported that soil loss from the six Soil Conservation Research Projects findings ranges from 18 to 214.8 tons/ha/year which reflects the severity of soil erosion in the country (Cited from Abtew and Melesse, 2014). As reported by the Ethiopian Highlands Study Report, (1986), 27% (over 14 million ha) of the highland area of Ethiopia were seriously eroded and some 6 million ha completely withdrawn from agricultural use and 13 million ha was moderately eroded. Of the remaining 28 million ha, about 54% is susceptible to erosion, requiring some form of soil conservation measures (Abtew and Melesse 2014).

2.2 Reservoir Sedimentation Problems

Reservoir sedimentation is one of the off-site effects of soil erosion problem worldwide. Dams are constructed for many reasons such as hydropower generation, for navigation, flood protection, irrigation and domestic water supply. Sustainable use of the available water resources potential with a continued developing of untapped and renewable hydropower potential is critical to eradicate poverty, especially in Africa continent. Despite all these purposes, for how long the constructed dam will provide the intended use is highly threatened by sedimentation problem in many reservoirs worldwide. The annual rate of reservoir sedimentation that occurs worldwide is estimated to 0.3 to 2% of its original capacity (Icold, 2009).

The roles of reservoirs for the economic development of the country are very significant especially for a large number of the African population. However, according to Icold, (2009) report on the historical growth of storage capacity, Africa has a limited gross water storage capacity relative to other continents (figure 2.1). It shows the high needs of development of new water storage capacity to tackle poverty through providing water access to sanitation service, agriculture, domestic use etc. The increasing impact of climate change on temporal and spatial water availability is becoming the main driving force towards the need for more storage capacity.

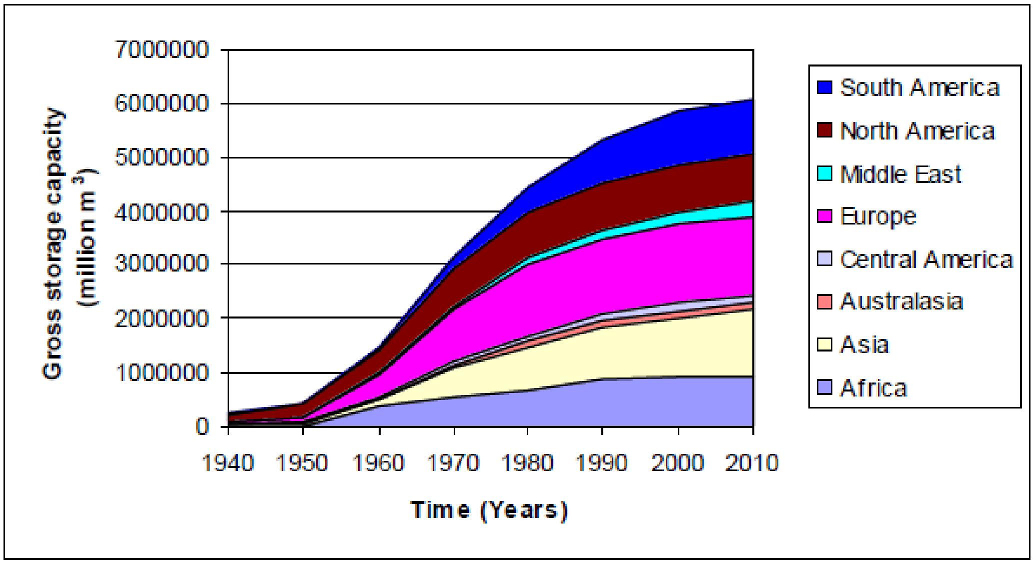


Figure 2.1: Historical growth in global storage capacity (Basson, 2008 cited from Icold, 2009)

Besides the importance of reservoirs, damming the river has significant consequences profoundly in downstream of the dam through reducing the future water supply and by causing sediment starvation in the downstream ecosystem. Coastal areas that rely on the sediment supply from the river system are highly vulnerable to the impact of river damming which may cause the beach to disappear gradually (Vörösmarty et al., 2003). According to Zhou et al., (2013) report, the three George dam and other dams upstream cause a decreasing of 91% of suspended sediment load, 77% total phosphorous and 83% particulate phosphorous annually.

According to Icold, (2009), the total yearly impact of siltation is quantified to 21 Billion USD which accounts 37% of the overall yearly costs while the current effort on sediment mitigation measures is much less than 37% and it shows that problems are therefore postponed to the coming generation. In the same report, the author has projected that the sedimentation problem will continue to be a major challenge for the reservoirs development worldwide (figure 2.2).

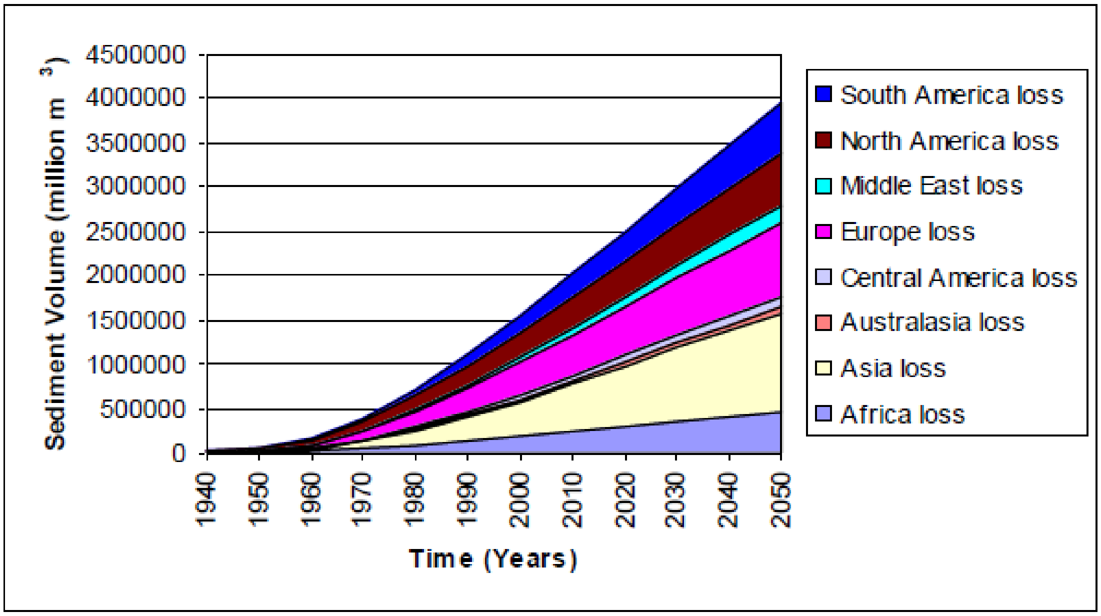


Figure 2.2: Historical growth in global reservoir sedimentation (Basson, 2008 cited from Icold, 2009)

The main problems resulted from reservoir sedimentations are:

- Loss of reservoirs storage capacity for flood protection, to store water for irrigation and other uses.
- Potential damage on the turbines and Reduction in the hydropower production capacity.
- Sediment starvation in the downstream flow regime which can affect aquatic life and river morphology in downstream.
- Economic losses for sediment removal in one hand and on the other hand due to getting less service than the expected benefit during design.
- And Environmental impacts due to carbon contribution to the reservoir which may affect GHGs emission from the reservoir.

Most of the sediment in the Nile flows from the Ethiopian Highlands through the Blue Nile and Atbara River. Nearly all the sediments (~ 95%) in Aswan high dam comes from the Blue Nile and Atbara rivers during the flood season from July to October (Ahmed and Ismail, 2008). Atbara River has a higher sediment concentration compared to Blue Nile which is an indication of the long period of the dry season in Atbara River basin which results in less vegetation cover and heavy rainfall in a short period (Ahmed and Ismail, 2008). A Fast land-use change from natural forest to farmland hurried up the soil erosion process and increases the sedimentation downstream. Tekeze dam is also located inside Atbara River Basin and might have more sediment concentration.

In the Tigray region of Northern Ethiopia alone, where the study area (Tekeze dam) is located, over 55 micro-dams have been constructed between 1995 and 2003 (Haregeweyn N. et al., 2006; Tamene L. et al., 2011). However, the sustainability of the benefits from the water-harvesting schemes is threatened by the rapid loss of the water storage capacity due to siltation. Almost all the reservoirs in the region exhibit a serious siltation problem that overshadows their socio-economic and environmental benefits (Haregeweyn N. et al. 2006; Tamene L. et al. 2005b, 2011).

2.2.1 Reservoir sedimentation management options

Reservoir sedimentation is the big barrier of exhausting the potential use of reservoirs worldwide. Construction of dam across the natural river dramatically alters the balance between sediment inflow and outflow which is approximately balance in the pre-impoundment time (Morris L. and Fan J., 1998). The extent of the problem is increasing proportionally with the current increasing of dam construction in all over the world. It lets the reservoir lose its storage capacity and at the end reduce its design lifetime.

Trapping of sediments in the dam is not unavoidable phenomena for all dams. However, the lacks of sediment management practices in the reservoirs make the problem inevitable and continue to threat many countries in the world (Revel et al. 2013). There are a number of sediment management strategies (as given below in detail) in which part of them used to maintain the reservoirs storage capacity may be after certain volume being lost by sediment and some other are used to keep passing the sediments to downstream continuously.

However, the widely implemented approaches that have been used since many years ago were focusing on design lifetime of the dam without considering the burden after the end of dam useful lifetime. The World Bank has developed an approach or tool called RESCON (REServoir CONservation) approach that supports decision makers on how to manage the reservoir in a sustainable manner (Palmieri et al., 2003). This tool used to simulate the scenario of different management options regarding their sustainability in terms of economically, socially, environmentally even after the end of design lifetime. The choice of appropriate management technique should depend on its role in the sustainable use of the dam in economic, social and environmental aspects.

The possible options to reduce the reservoir sedimentation have mentioned below (Kondolf et al. 2014).

Reduce the sediment load from the watershed that enters into the reservoir: This strategy addresses the issue of maintaining the reservoir capacity, not the downstream sediment starvation problem. This is achieved through watershed management activities like afforestation, construction of soil and water conservation measures. It is the most convenient and recommended way of sediment management approach since it intervened directly to the initial phase of sedimentation which is soil erosion from the catchment. In the old reservoirs with no design consideration for sediment management, which is the characteristics of most of the reservoirs in developing country, it is the most appropriate and can be the only solution to manage the sediment yield from the reservoir. The main disadvantages of this method are it needs a lot effort in time and labor force and/or finance since the implementation is in the whole watershed that drains to the reservoir not just only to a specific place like dam location.

Routing or continuously transporting the sediment through or around the reservoir: It aims to maintain the reservoir storage capacity and delivering the sediment to the downstream river reaches by continuously bypassing the upcoming sediment into the dam.

Sediment Bypassing

Sediment bypassing is a diversion of the inflow sediment-laden water to the downstream river reach before entering the reservoir using weir head work at the upstream (figure 2.3c). The diversion of the inflow water is during the high discharge rate and high sediment load in the coming river. Once the sediment load falls, the water allowed entering to the reservoir. It has an advantage of diverting the sediment without entering the reservoir and interfering the reservoir operation as well (Kondolf et al., 2014).

The other alternative for sediment bypassing technique is the off-channel reservoir (figure 2.3b). It is the diversion of clear water from the weir constructed across the natural river network to the storage facility while the sediment-laden water is left in the river to move downstream (Morris and Fan, 1998). According to Morris and Fan (2010) simulation report carried out in Puerto Rico, off- stream reservoir system has a potential to prevent 90% to 95% of the total sediment load compared to the on-stream reservoir which extends the reservoir lifetime by 10- folds (cited from (Kondolf et al. 2014). The main advantage of sediment bypass method is that they don't disturb the reservoirs regular operation as the drawdown of reservoir level is not necessary.

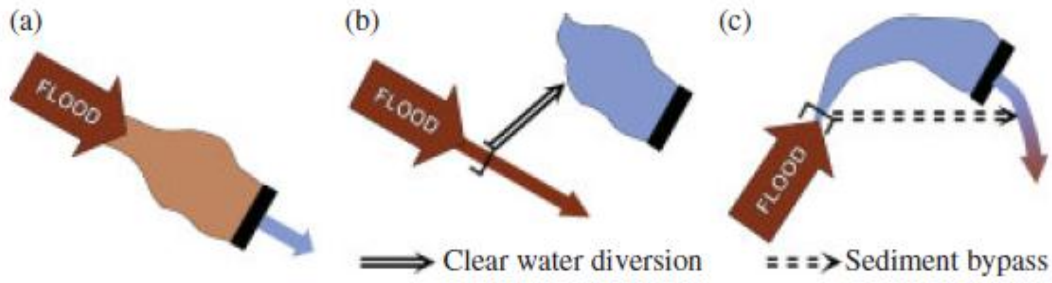


Figure 2.3: (a) Conventional storage which traps the incoming sediment, (b) Off-channel reservoir, and (c) Sediment bypass using a diversion tunnel (Kondolf et al. 2014)

a) Sediment Sluicing

Sediment Sluicing is the second approach for sediment routing techniques with the aim of transporting the sediment through the dam as quickly as possible in order to minimize the sedimentation rate. This is achieved by discharging water with high flow velocity in the period of high inflow rate to the dam (figure 2.4). Due to the low settling velocity of fine sediments than the coarse one, they are most likely effective to be transported through the dam.

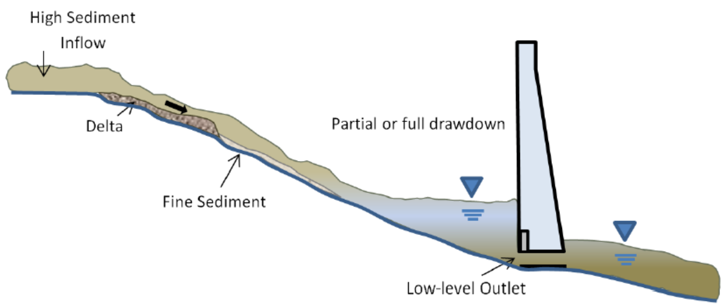


Figure 2.4: Longitudinal section of reservoir with sediment sluicing technique (Healy et al. 1989)

b) Drawdown flushing

This method has a high similarity with sluicing but it is applied during low flow condition of the river in which draw down needs less effort and does not affect the water supply (Annandale, 2013 cited from (Healy et al., 1989). It aims to scour and re-suspending the already settled sediments and transport them to the downstream (figure 2.5). For an effective flushing operation, the ratio of reservoir capacity to the mean annual inflow should not exceed 4% from the fact that large storage reservoirs cannot be flushed easily (Sumi, 2008). Due to the potential damage that may happen in the turbine, flushing of sediment-laden water through powerhouse is not recommended (Kondolf et al. 2014).

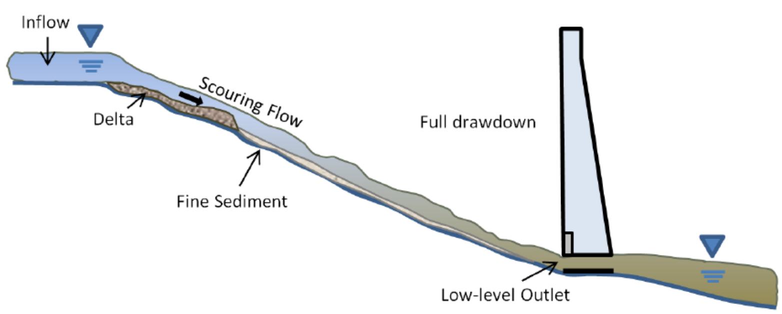


Figure 2.5: Longitudinal section of reservoir with sediment flushing technique (Healy et al. 1989)

c) Density current venting

It is a way of discharging turbid sediment-laden water through the low-level outlet like flushing and sluicing without affecting the surface water (figure 2.6). Turbidity current develops when the water with high sediment load reaches to the reservoir and immediately plunges to the reservoir bottom (Morris and fan, 1998). Continuous management of this sediment current has the potential to control sediment buildup at the base of a dam. In spite of this, it is not a widely used method due to its difficulty in detecting the turbid current.

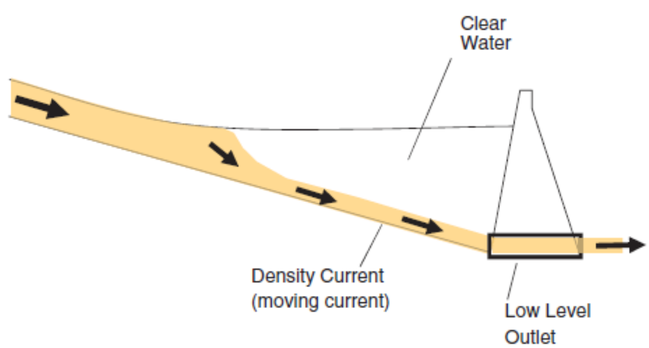


Figure 2.6: Longitudinal section of the reservoir with density current venting technique (Kondolf et al. 2014).

d) ConSed-process (Continuous sediment transfer)

It is a new innovative approach presented by (Jokiel et al., n.d.) for the continuous sediment transport mechanism. This method involves disturbing or re-suspending of the settled sediments in the reservoir bottom by the suction head and then dumping the sediment concentrated water near to the reservoir outlet using a suction pump (figure 2.7). Once the sediment dumped near to the outlet, they will be eroded by the outflow. The device is working automatically and can be moved with tractor cable in order to exactly position the vessels for dredging (Jokiel et al n.d.). According to Jokiel et al (n.d.), the ConSed transfer approach enables to maintain the sediment balance of inflow and outflow water like the pre-impoundment condition of the river system. In the hydropower dam, this method might have a positive impact on the power production capacity due to the increasing of flow water density through continuous sediment addition of sediment-laden water through turbines.

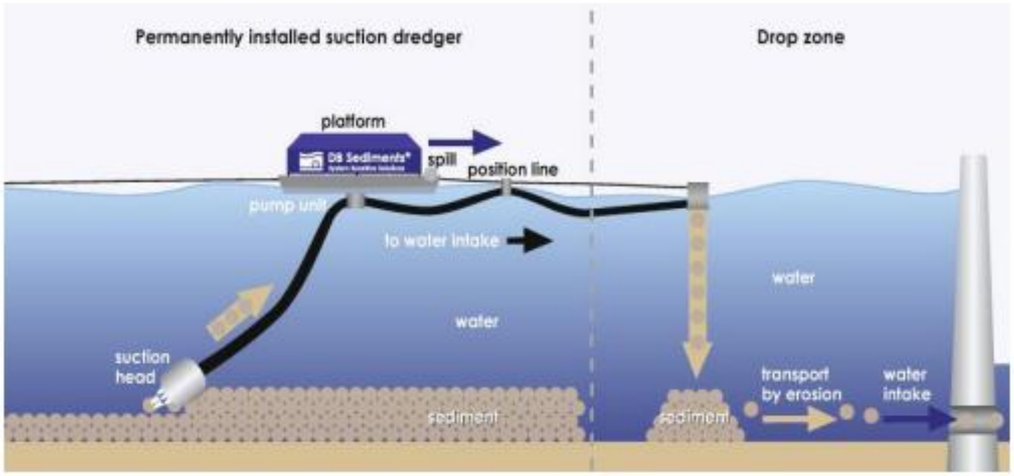


Figure 2.7: Continuous Sediment Transfer (ConSed approach) (Jokiel et al., n.d.)

Recover the reservoir storage volume: It is a technique aims to recover or regain the storage capacity of the reservoir by removing the settled sediments using different techniques such as dry excavation and dredging, hydraulic excavation and redistribute sediment. The size of reservoirs, the water level in the reservoir and sediment characteristic are important to be known to choose a sound sediment removal technique. Hydraulic excavation is used to remove the cohesive sediments by dragging, re-suspending and then discharging down to the reservoir by siphon action. Due to high cost required for a dredging operation, it is mainly used to remove from the specific area near the intake of the dam (Kondolf et al. 2014). Hydraulic dredging is limited to the reservoir with low elevation in order to get a better siphon action facility by atmospheric pressure (Kondolf et al. 2014). In the mechanical excavation method, the reservoir should completely draw down to use scrapers, dump trucks and other heavy equipment to remove the accumulated sediment (Kondolf et al. 2014). It is the best option to recover the flood control reservoir that usually remains dry during the dry season.

2.2.2 Sediment deposition in the reservoir

The most important factors that determine the siltation rate of reservoirs are sediment concentration in the flowing water, retention time, sediment characteristics (type of sediment load), operational method of the reservoirs and ratio of reservoir capacity to inflow volume (Arora and Goel, 1994 cited from Sultana and Naik 2015; Eizel-Din et al., 2010).

The type of sediment load that comes from the upslope catchment has a significant implication on the deposition pattern, on the trap efficiency of the dam and catchment contribution to the organic carbon budget of the reservoir which finally related with the potential GHGs emission from the reservoir. Sediment loads are classified into three based on their way of transport along with the flowing river water. These are Bed load, suspended load and dissolved load.

Bed load is the part of sediment load which transported along the river bed by sliding and bouncing over the river bed. On the other hand suspended loads are a portion of sediment loads that float in the water column and move with the relatively same velocity with flowing water. Dissolved loads are the materials that chemically carried in the water like soluble salts. In the bed load condition, the sediment moves very slowly than the water flow velocity and might deposit behind in the far tail of dam water (backwater) where the coming river water joins the reservoir water and flow velocity reduced drastically. Whereas suspended loads can be distributed to the reservoir area and settle gradually (see figure 2.9). Sand and gravels are examples for bed load sediment and silt and clay for suspended sediment load.

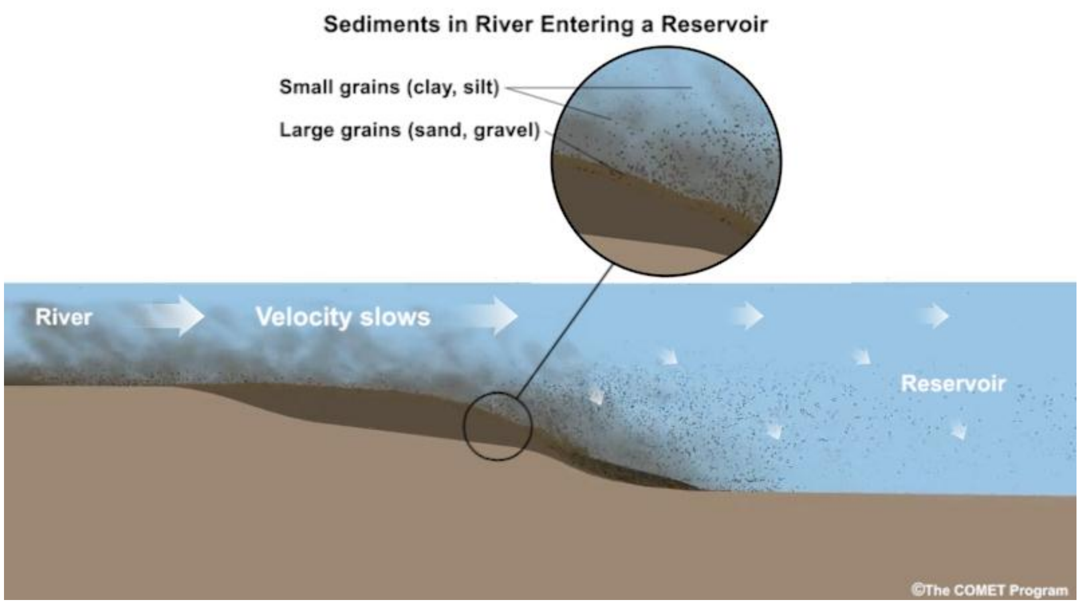


Figure 2.8: Sediment deposition pattern in the reservoir (source, MetEd website)

Accurate estimation of sediment trapping in reservoirs improves the estimates of river sediment export, helps to know the useful life of reservoirs, and provides information about sediment transport and dynamic of the catchment (Lewis et al., 2013). The bathymetric survey is one of the most widely used methods to estimate the amount sediment deposited in the reservoir bottom. This method has been applied in different reservoirs in Ethiopia such as Angerib reservoir, Koka reservoir and many other small reservoirs in a Tigray region where sedimentation is a severe problem relative to another region. The other common and easy alternatives used to estimate sediment load in the reservoir is the trap efficiency method and have discussed in detail below.

2.2.3 Reservoir traps efficiency

Trap efficiency of Reservoir is defined as the ratio of deposited sediment to the total sediment inflow into the reservoir system. In simple word, it is the percentage of stream sediment which is trapped by the reservoir (Eizel-Din et al., 2010). Sediment accumulation in the reservoir starts when the river is dammed by the structure and the river water starts to be stored behind. Through time, the reservoir capacity will be reduced due to the displacement of storage volume by trapped sediments from the sediment-laden inflow water coming from the watershed. The rate of storage loss of the reservoir depends on its trap efficiency to the coming sediments with inflow water. Despite the increasing of sediment load from the catchment mainly due to human intervention, the net effect of the anthropogenic activities (reservoir construction) reduced the sediment load of rivers in global level by an estimated value of 1.4 billion ton per year which is trapped and left behind the reservoirs (Syvitski, et al., 2007).

There are several methods available to calculate trap efficiency of reservoirs in the various literature (Verstraeten G. and Poesen., 2000). The Brown method was the first attempt by Brown in 1944 to estimate the trap efficiency of reservoirs (Sultana and Naik, 2015). This method provides a relation of the trap efficiency to the ratio of the capacity to the watershed area or drainage area (C/A). The other method is the Brune curve which is the most widely used method worldwide and considered to be accurate (Sultana and Naik, 2015). The Brune method provides a graph of trap efficiency versus the ratio of capacity to the river inflow to the reservoirs. It has three curves with one median and two others as an envelope depending on the sediment characteristics.

Gill (1979) has developed an empirical equation based on the three curves given by Brune and has a very close fit with the Brune's curve (Jothiprakash and Garg., 2008). Siyam (2000) empirical equation is the other method which is developed from the Brune equation by incorporating a sedimentation parameter (β) (cited from Revel et al., 2013). Heinemann (1981) also described trap efficiency as the ratio of the net volume of sediment flow to the volume of sediment inflow (Sultana and Naik, 2015). The choice of methods to use in depends on the availability of their input parameter in the study area.

Factors affecting trap efficiency of reservoirs

Trap efficiency is an indication of how much percentages of the incoming sediment load is trapped by the reservoir. The trapping efficiency of the reservoir is affected by a number of factors such as the reservoir operation system, the storage capacity of the reservoir, sediment characteristics or type of sediment load and flow rate of water through the dam which is more or less partly related to the reservoir operation rule. Arora and Goel (1994) mentioned that the siltation rate of the reservoir is highly influenced by sediment concentration in the inflow water, the textural composition of the sediment and the trap efficiency of the reservoir (Sultana and Naik, 2015).

A Sediment characteristic is one of the most important factors that determine the deposition pattern, its consequence to downstream and the water quality in general. Bed load sediments which include gravel and sand settles in the reservoir bottom rapidly than the fine particles and have high certainty to be trapped by the dam. In general, dams have a 100% trap efficiency for the gravel sediment with exceptional for small dams which have a steep channel capable of passing bed loads with turbulent flow. On the other hand, silt and clay particles transported as suspended load and they can travel further downstream of the dam without being deposited in the reservoirs.

The other factor determining the trap efficiency of the reservoir is the retention time which is actually the result of the inflow rate, reservoir operation rule and the reservoir capacity itself. Retention time is the length of time that the inflow water spends in the reservoir before leaving as outflow. Gottschalk (1964), said that the detention time with regards to sediment characteristics appears as the most influential factor in many reservoirs (Eizel-Din et al., 2010). The effect of reservoir size in trap efficiency is due to its role in determining the retention time. Large reservoirs with a prolonged residence time can be able to trap the suspended loads (Morris and Fan, 1998). It can be able to store a large volume of inflow water before getting full and release the water, despite releasing the water also related to the operation policy as well.

All factors are highly interrelated and the change in one factor makes a change in another factor and at the end will affect the trap efficiency. However, the sensitivity of the trap efficiency to each of these factors has not been evaluated to the extent of assigning a quantitative value to each of these factors (Eizel-Din et al., 2010).

2.3 GHGs Emissions from Reservoirs

Power production is a challenging issue facing the world community when it comes to mitigation of greenhouse gas without risking sustainable development goal. Hydropower dam has been seen for a long time as a non-pollutant and sustainable alternative to the use of fossil fuel to generate electricity (Azin A. et al., n.d). Despite this perception of zero pollution energy sources, hydropower reservoirs are emitting substantial amounts of greenhouse gases (Yang Le et al. 2013; Fearnside P. 2016). Since the early 1990's, hydropower reservoirs have been identified as a potentially significant source of carbon dioxide and methane to the atmosphere (Harby et al., 2012). However, this subject is still in controversial discussion between researchers.

In fact, the inland water systems naturally produce and emit carbon to the atmosphere (Cole et al., 2007). However, damming the river causes the surrounding vegetation's to be flooded by water which initially used as a carbon sink from the atmosphere by photosynthesis. Flooding of the landscape for the purposes of creating any kind of reservoirs leads the terrestrial plants to die and no longer absorption of carbon dioxide from the atmosphere by photosynthesis (St. Louis et al. 2000). And decaying of biomass from flooded land may cause severe environmental damage (Azin A. et al., n.d.).

The high amount of greenhouse gas emissions from tropical reservoirs have noticed by different researchers than reservoir located in temperate and boreal region can emit. This is mainly due to the existence of high biomass potential and high temperature in the tropical region. Yang Le et al. (2014) reported that substantial amounts of GHGs released from the tropical reservoirs, especially methane (CH_4) from Brazil's Amazonian areas. The global warming potential (GWP) of the GHG emissions from Brazil's reservoirs are amazing, which are even higher than that from thermal power plants with similar installed capacity (Yang Le et al. 2014). For example, Curuá-Una Reservoir in Brazil emitted 3.6 times more GHGs than those would have been emitted by generating the same amount of electricity from oil (Yang Le et al. 2014).

Carbon dioxide (CO_2) emission from biomass growth in the reservoir and drawdown area does not represent the net contribution of the reservoir to global warming (Fearnside 2016). Because of during the growth of vegetation, the same amount of CO_2 has been absorbed by photosynthesis for biomass production. Unlike CO_2, emission of CH_4 has a net contribution to the global warming effect of reservoir since CH_4 gas cannot be removed from the atmosphere during biomass production of vegetation (Fearnside P., 2016).

The global climate change is closely related to the continuous increasing of greenhouse gases in atmospheric concentration (IPCC, 2007). The three principal greenhouse gases in the atmosphere are Carbon dioxide (CO_2), Methane (CH_4), and Nitrous Oxide (N_2O). The level of emission of these greenhouse gases from the reservoirs varies greatly depending on the actual circumstance in the reservoir. As a general, the CO_2 emission from the reservoir is the largest and followed by CH_4 and N_2O. However, the global warming potential (GWP) of these gases are different. Methane has a GWP 25 times higher than carbon dioxide (CO_2) on a per molecule basis over a 100-year time horizon, and nitrous oxide (N_2O) has a GWP 298 times that of CO_2 (Yang Le et al. 2014).

The emission level of N_2O gas from lakes is significantly lower than croplands do and the contribution of reservoirs on this gas emission might be little (Yang Le et al., 2014). Up to date, there is a lack of research concerning the emission of N_2O gases from the reservoir. Many researchers have exempted this gas from discussion and in this research as well, the emission of N_2O was not discussed. Thus the term greenhouse gas (GHG) used hereafter stands only for CH_4 and CO_2 only.

2.3.1 An overview of greenhouses gases production

Following the impoundment of dam to create reservoirs, a huge amount of biomass in the terrestrial land will be flooded. The inundated organic matter gradually decomposed by different microorganisms. Not only large amounts of soil and terrestrial vegetation are flooded by damming rivers, but also terrestrial organic matter derived from land erosion is continuously flushed and contribute to the carbon budget inside the reservoirs during their lifetime (Fearnside P., 1995; Roland et al., 2010).

Methane (CH_4) is produced due to the decomposition of organic matter in anaerobic condition. The production of methane (CH_4) by methanogenesis process is the last step in organic matter decomposition, which occurs in a strict anaerobic (anoxic zones) (Eizel-Din et al., 2010). The organic matter gradually decomposed and produces CO_2 until the available dissolved oxygen exhausted and then once the anaerobic condition is created methane will take over as the end product of the decomposition process in the reservoir bottom.

However, when the methane transported through the oxic zone (epilimnion layer), part of it can be transformed into CO_2 by methanotrophic bacteria using available dissolved oxygen (Harby et al., 2012). The amount of methane that can be released from the reservoir bottom to the atmosphere through the water surface depends on dissolved oxygen available at the epilimnion zone and water depth in the reservoir.

There are three pathways that the greenhouse gases can be released to the atmosphere. These are diffusive flux, bubbling and degassing at the turbine and spillways of the structure (see figure 2.9). Diffusive flux occurs in the air-water interface when the produced gas coming vertically by diffusion from highly concentrated to less concentrated layer. Bubbling occurs when the water column is supersaturated point by the produced gas due to more production than diffusive flux rate in the bottom and the gas forced to leave as a bubble form. Because of high methane concentration in the sediment at the reservoir bottom, bubbling flux is a significant way in particular for CH_4 emission than CO_2.

Degassing is the other potential pathways for GHGs especially in hydropower dam due to the presence of turbines that aerate the outflow water from the dam. Methane (CH_4) degassing emissions from turbines and spillways are the dominant part of the total CH_4 emissions from a hydroelectric system. For examples, 64.9% and 34.5% of the total CH_4 emissions release from the turbines and spillways of the Tucuruí Dam, respectively, while CH_4 emissions from the reservoir's surface, including bubbles and diffusion, only account for 0.6% of the total CH_4 emissions (Yang Le et al., 2014). CH_4 degassing emissions from the turbines contribute to 42.4–46.6% of the total CH_4 emissions from the Balbina Reservoir (Yang Le et al., 2014). This may be due to the turbine location which is more or less close to the bottom where CH_4 is produced and due to the aerating effect of the turbine itself when the flowing water hits the turbine.

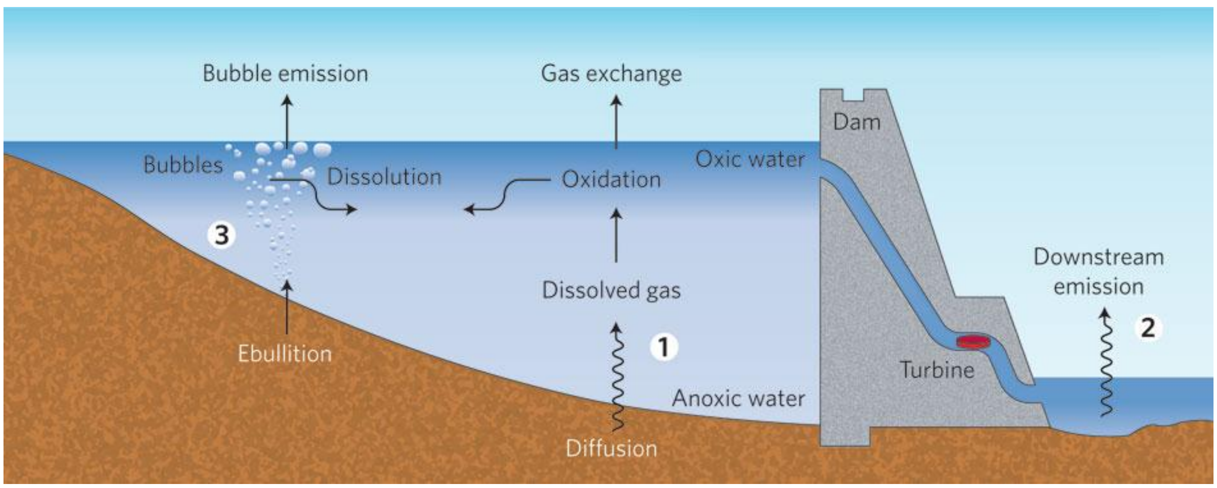


Figure 2.9: Possible pathways for Greenhouse gases emission from Hydropower dam (Nature Geoscience, 2011)

Bastviken et al. (2004) estimated that reservoirs covers an area of 500,000 km2 worldwide and emit 20 million tons of methane (CH_4) annually. However, these numbers only include emissions from the surfaces of the reservoirs through ebullition (bubbling) and diffusion (emanation) – not the emissions that occur as methane-rich water emerges (under pressure) from deep in the water column through the turbines and spillways, which can more than double the total (Abril et al., 2005; Kemenes *et al*., 2007; Yang Le et al. 2013). Due to these reasons, hydroelectric reservoirs often produce and emit more greenhouse gas than any other purpose dams, especially in the first twenty years after flooding (Mendonça et al., 2012).

2.3.2 Factors affecting the greenhouse gas emission

In fact, the greenhouse gas emission from the reservoir is a complex process and currently attracting a lot of researcher's worldwide to understand the process and quantify the net amount of emission due to impoundment of water in the reservoir. The amount of Greenhouse gas emission from the reservoir depends on several factors that interconnected each other in a complex manner. These are:

- Geographical location,
- The age of reservoir,
- Amount of organic matter in the inundated area,
- Algae, bacteria, animals live inside the water by their effect on the dissolved oxygen availability and their contribution to organic matter.
- And characteristics of the reservoir such as water flow, turnover time (retention time), surface area of the reservoir, depth of water, water level fluctuations and the positioning of the turbines and spillways (Fearnside P. 2016; Harby et al. 2012; UNESCO IHA, 2010).

Yang Le et al., (2013) also mentioned that CO_2 emissions from reservoirs are influenced by reservoir ages, wind speeds, pH values, precipitation, chlorophyll-a concentrations, and dissolved organic carbon in the water body, while CH_4 emissions from reservoirs are influenced by water depths, water level fluctuations, DO concentrations, water velocities, and wind speeds (Yang Le et al., 2014).

However, the sensitivity of the emission or how far the greenhouse gas emission affected by each factor is not fully revealed so far. But different researchers are providing their opinions based on their finding. According to Azin A. et al.,(n.d), most of the elements related to the reservoir specifications are found to be the most significant factors determining the emissions. Stewart et al., (2012), from his investigation in Douglas lake, reported that water temperature and water depth were likely to be the most significant factors determining the greenhouse emission. Despite such reports, it is not possible to make a concrete general conclusion about the significant factors since it depends on the actual circumstance of the reservoirs.

Geographic location

According to the natural belts where reservoirs located, the global reservoirs could be divided into tropical reservoirs and temperate reservoirs (Azin A. et al., n.d). Dams in tropical areas emit more methane than do those in temperate or boreal areas (Barros et al., 2011; Matthews et al., 2005; Fearnside P., 2016). The International Rivers Network (IRN) pointed out that emissions from tropical reservoirs are typical between five and 20 times higher per unit of area flooded than those from reservoirs in boreal regions (cited from Azin A. et al., n.d). Azin A. et al (n.d), said that the greenhouse gas emissions are exponentially negatively correlated with the latitudes of the geographic location of hydroelectric reservoirs.

The effect of geographical location with the greenhouse gas emission is related with the potential biomass accumulation and temperature condition of the area. In tropical reservoirs, the average amount of biomass (per hectare) can be five times greater than the biomass in a northern climate (Azin A. et al., n.d). In the tropics, high temperatures and the flooding of large amounts of biomass, including primary forest, result to intense CO_2 and CH_4 production at reservoir bottoms (Fearnside P., 1995; Galy-lacaux et al., 1997; Delmas and Galy-lacaux, 2001).

Organic matter

CO_2 and CH_4 emissions from the reservoir's surface are related to the amount of easily decomposable organic matter that is flooded during impoundment (Azin A. et al., n.d., UNESCO/ IHA, 2010). Emissions of CO_2 and CH_4 from reservoirs are very low if barren soils are flooded in the canyons, such as Ertan Reservoir, Three George River (Azin A. et al., n.d). This indicates how the biomass content of the inundated area is a very important source of greenhouse gas emission. Azin A. et al., (n.d) also reported that cutting trees are a reasonable measure to reduce the GHG emissions from a planned reservoir because there is a significant contribution of pre-existing biomass to produce CH_4 and CO_2.

Temperature

Fluctuation in the water temperature has an impact on the CO_2 solubility, primary production, and the decomposition of organic carbon. Elevation in the water temperature promotes CO_2 emissions by increasing the decomposition rate of organic carbon, which could be seen in the positive correlations between CO_2 emissions and water temperatures in Canadian reservoirs (Azin A. et al., n.d.) According to Stewart et al., (2012), water temperature affects microbial respiration and gas diffusion rates, among many other things. The high temperature in the tropical region enhances the activity of methanogens in the anoxic condition at the bottom of the water and thus more methane will be produced and emitted to the atmosphere in a different way (Rosa L. et al., 1996).

Reservoir Design Condition

The design of reservoirs has a vital role in determining the flux of GHGs from the reservoirs and according to Azin Amini (n.d), it is found to be the most significant factor in greenhouse gas emission from hydropower dam. Reservoir design condition includes the storage size with water surface area, the height of reservoir, the location of turbine and spillway. The depth of water should affect methane emissions in particular. Because methane is produced largely by sediment-dwelling microbes and it is highly concentrated in this hypolimnion layer that exists at the bottom of the reservoir (Stewart et al., 2012).

Turbines are usually located close to the bottom of the dam in order to win the potential energy of water for maximum electric generation. So when the water passes through the turbine, there is an abrupt change in pressure and temperature in which the concentrated methane at the bottom released to the atmosphere by the process called degassing. The high levels of CH_4 concentrations in the hypolimnion are highly correlated with outlet degassing and downstream emissions (Guérin et al 2006 cited from De Faria et al., 2015). When the turbines rotate due to the water pressure from the dam, it enhances the aeration process of the methane concentrated water.

The other important factor is the retention time of reservoir and depends on how big the reservoir storage capacity is. Retention time is defined as the length of stay for the inflow water before leaving the reservoir as outflow. It is one of the determining factors for greenhouse gas emission from reservoirs. The larger the storage size will have more residence time for the inflow water. The existence of high water residence time in reservoirs is one indication of the effect of dams on GHG emission than the river pre-impoundment condition.

Different research works have noticed the relation of stratification process and residence time (De Faria et al., 2015). Reservoirs with retention time more than 100 days can create the lake stratification (StrašKraba 1973; Straškraba et al 1993 cited from De Faria et al., 2015). On the other hand, the main channel of reservoirs with low RT (<10 days), have characteristics that resemble a river zone: a completely mixed water column, with homogenous flow rate and temperature distribution (StrašKraba 1973, Straškraba et al 1993 cited from De Faria et al., 2015). At the Petit Saut reservoir, there is a high positive correlation between retention time, CH_4 concentrations, and emissions (Delmas et al 2001, Abril et al 2005). This is due to the creation of anoxic layer at the bottom of the reservoir layer which is a prerequisite for CH_4 production.

Besides the reservoir storage capacity, the retention time depends on the reservoir operation policy which determines the discharge rate from the reservoir. The operation rule again might depend on the water need from the dam, inflow rate to the reservoir which varies in the season. Therefore, the high retention time in the reservoir combined with high nutrient inputs mainly from an agricultural field favors organic matter decomposition and, thus, the production of two major GHGs – carbon dioxide (CO_2) and methane (CH_4) (Mendonça et al., 2012).

Water Level Fluctuation

The seasonal exposure of the reservoir bottom is a key for the continuity of biomass production in the reservoir. Vegetation in the reservoir bottom grows up and produces biomass by photosynthesis. The seasonally exposed bottom of the reservoir may play a more important role in CH_4 emission (Yang Le et al. 2013). Chen et al., (2010) also reported the spatial variation of methane emission due to the difference in the standing water depth and dissolved organic carbon (DOC) from Three George reservoirs in China. This finding supports the influence of reservoir operation in potential greenhouse gas emission as long as it can determine the water level fluctuation in the reservoir.

Anthropogenic activities

Human activities in different level are threatening the natural ecosystem significantly and its impact is getting worst from time to time. Global climate change is one of the consequences resulting mainly from anthropogenic intervention in the natural system. Natural resources including land and water resources are getting deteriorated due to their improper utilization. Rapid increasing of population number in the globe is the main cause for over-exploitation of resources without safeguarding their quality and sustainability.

Eutrophication is one of the phenomena that happen in poor water resources management. It results from excess nutrients and organic matter accumulation from the upland watershed into the water body. The human activities such as the discharge of wastewater, development of arable land, wetland drainage, deforestation and fertilization have accelerated the eutrophication process (Effects of eutrophication., n.d.). Landslides and higher suspended sediments concentration can lead to degraded aquatic habitats and water quality (Ambers, 2001). This phenomenon has an impact on the GHGs emission due to its effect on the carbon budget inside the water.

Reservoir Age

Reservoir age is one of the factors determining the actual greenhouse gas emission level from the reservoir. Greenhouse gas emission decrease with the increase of reservoir ages because of the gradual decreasing of the stored organic carbon in the reservoirs (Azin A, n.d.). After certain time from the first impoundment of the reservoir, the initially inundated organic matter getting degraded by microorganisms and gradually diminished. Due to the abrupt release of nutrient substances from the flooded lands and decomposition of unstable carbon matters, such as soils, litters, twigs, and leaves, GHG emissions are high in the initial periods after the impoundment (Azin A, n.d.).

However, organic matter from flooded terrestrial land is not the only source of carbon for GHG emission. Rather there is a continuous supply of nutrients and organic matter from the sediment that comes together with the runoff water from the upslope catchment. The carbon amount from this source is more or less continuous, no matter how much the amount will be from year to year. This is because of soil erosion is natural phenomena and always exist even if the extent depends on the land use condition and management practices in the catchment. So concerning this source of organic matter, the GHG emission amount may not change significantly with time (reservoir age) since the supply is still in continuous.

2.3.3 Methods to estimate the greenhouse gases emission

Accurate measurement of greenhouse gases from the water bodies is not as easy as water flow is measured. Though a number of techniques are available to measure the GHG emission flux from the reservoir surface (St. Louis et al. 2000). The most common methods that used widely are the floating chamber and thin boundary layer methods. The floating chamber measurement gives the rate of gas accumulation per unit surface area of the reservoir over time. In the thin boundary layer method, knowledge's on the concentration gradient and gas exchange coefficient of CH_4 and CO_2 gases are necessary (St. Louis et al., 2000; UNESCO/IHA, 2010). The measurement of these methods alone underestimates the possible actual emission from the reservoir particularly from hydropower dams, because of degassing emission through turbines and spillways are not considered. On the other hand, the measured value does not indicate the net emission of GHG due to the creation of the reservoir. It includes emission that the river can do in the pre-impoundment condition regardless of the dam construction.

The complexity of the information needed for reliable estimates of GHGs emissions on a dam-by-dam basis makes a global estimate difficult at present (Fearnside P., 2016). The presence of a sound simulation tool is needed to estimate the level of GHG emission from the reservoir and to assess its impact on environment. Unfortunately, there is no physical model or empirical model available so far to simulate the greenhouse gas emission from the existing or future planned reservoirs by considering all the factors that can affect the emission process.

However, the UNESCO/IHA Greenhouse Gas Emissions from Freshwater Reservoirs Research Project which is going on in collaboration with UNESCO, International hydrological program, and International hydropower association are on doing to develop a model/tool that used to simulate the emissions from reservoirs (UNESCO et al. 2012). Currently, they have already released the GHG Risk Assessment Tool (beta version) for rough estimation of gross GHGs emission from reservoirs surface through diffusive flux only. The input parameters for this tool are reservoir age and mean annual temperature for both CO2 and CH_4 and additionally mean annual precipitation for CO_2 only and mean annual runoff for CH_4 only. This tool is just an indicator for whether further assessment of net emission should be carried out or not.

In addition to this, the UNESCO/IHA research project are on doing to release the new version tool for net emission estimation called G-res tool and is expected to be released in the near future. This new tool will consider the pre-impoundment emission and unrelated anthropogenic sources in order to know how much the net emission of GHGs is due to the creation of the reservoir. But still, the estimation by this G-res tool is the emission through bubbling and diffusion not degassing through turbines and spillway (UNESCO/IHA, 2016).

The variables under consideration in the new G-res tool are

- Monthly mean air temperature (°C),
- Climate,
- Annual precipitation and annual surface runoff,
- Annual mean wind speed,
- Catchment area and Reservoir area,
- Population number,
- Catchment land cover %,
- Reservoir land cover %,
- Impoundment year,
- % Littoral area,
- Reservoir perimeter,
- Catchment mean slope (°),
- Thermocline depth,
- Phosphorus concentration,
- Mean depth and Maximum depth of reservoir water and
- Water residence time is the parameters that need to be used in the new G-res tool (UNESCO/IHA, 2016).

Chapter Three. DESCRIPTION OF THE STUDY AREA

3.1 Tekeze Dam Location and General Design Information

Tekeze dam is a hydropower plant located in the Tigray region of Ethiopia (figure 3.1). The construction of the dam has completed in 2009 after seven and half years period of construction phase by 365 million USD capitals cost (Global Energy Observatory website). It is a double curvature arc dam (logarithmic spiral) constructed across the Tekeze River which flows through one of the deepest canopies in the world (figure 3.2 a&b). Tekeze River has two main tributaries (Angereb and Goang) which rise in the central highlands of Ethiopia and drain to the Atbarah River at the lower course of which is a tributary of the River Nile. The dam is located in the coordinates of 13^o 20’ 40’’ N latitude and 38^o 44’ 43’’ E longitude. The dam watershed covers an area of 30,767 km^2 which falls dominantly in Amhara region and part of it in Tigray regional state. The elevation of the watershed ranges from 4529m in the highlands of Semien Mountain and 979m at the point where the dam is located.

The dam has a total water storage capacity of $9.3BM^3$ of which 5.3 BM^3 is the live storage and the remaining $4BM^3$ is dead storage for sediment deposition throughout the design lifetime. The reservoir covers an area of 147 Km^2 at full reservoir level. During completion of the dam, it was the first African tallest dam with the height of 188 m and has a crest length of 420m. The installed power generating capacity is 300 MW with four Fracis turbine in the underground powerhouse and each turbine has 75MW generating capacity. The design lifetime of the dam is for 50 years (Global Energy Observatory website).

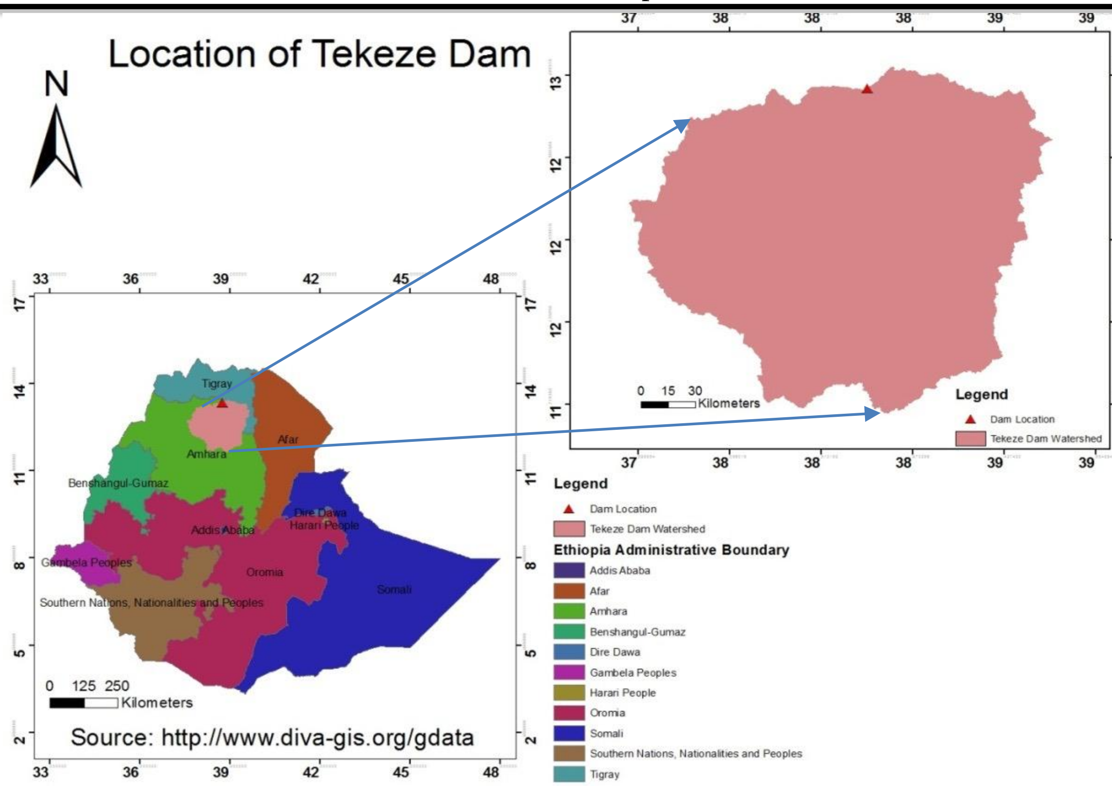


Figure 3.1: Map of location of Tekeze dam and its catchment

(a) (b)

Figure 3.2: (a) Upstream and (b) Downstream view of Tekeze dam (Source, Inauguration report)

3.2 Climate

The northern part of Ethiopia, where the study area is located is highly affected by the recurrent drought. The climate is characterized by large spatial and temporal variations which are highly governed by topographic condition mainly altitude. The rugged topographic nature of the basin results in a diversified climate ranging from humid in the southwestern highlands to semi-arid climate in the lowlands where the dam is constructed. The watershed of the dam has three climatic zones based on geographic location and topography. The area above the elevation of 2,400 m where the temperature ranges from freezing to 16 ^{o}C is the humid zone. The second is the temperate zone which is at an elevation of 1,500 m to 2,400 m with the temperature ranging from 16 to 36 ^{o}C and the hot zone with an elevation of below 1,500 m is under the tropical and arid condition and the temperature ranges from 27 to 40 ^{o}C and sometimes more. Gebrehiwot (2013) reported that the northern part of Ethiopia is warming faster than the national average of 0.25^{o}C per decade. The average annual evaporation rate from the basin is estimated around 718 mm/year.

The rainfall pattern in the Tekeze dam basin is predominantly unimodal with a long rainy season from June to September (figure 3.3). However in the highland parts of the basin, exceptionally there is a rainfall that comes in the month of March to mid of May like shower with less intensity (Gebrehiwot, 2013). The estimated mean annual rainfall that the basin receives is around 860mm. Though, the rainfall amount is spatially varied depending on the climatic zones. In addition, the basin has experienced three different seasons which shows temporal variation of precipitation over the year in the watershed. These are the dry winter season from October to February then followed by the pre-monsoon hot season which lasts from March to May. The rain season in which most of the rain comes is from June to September.

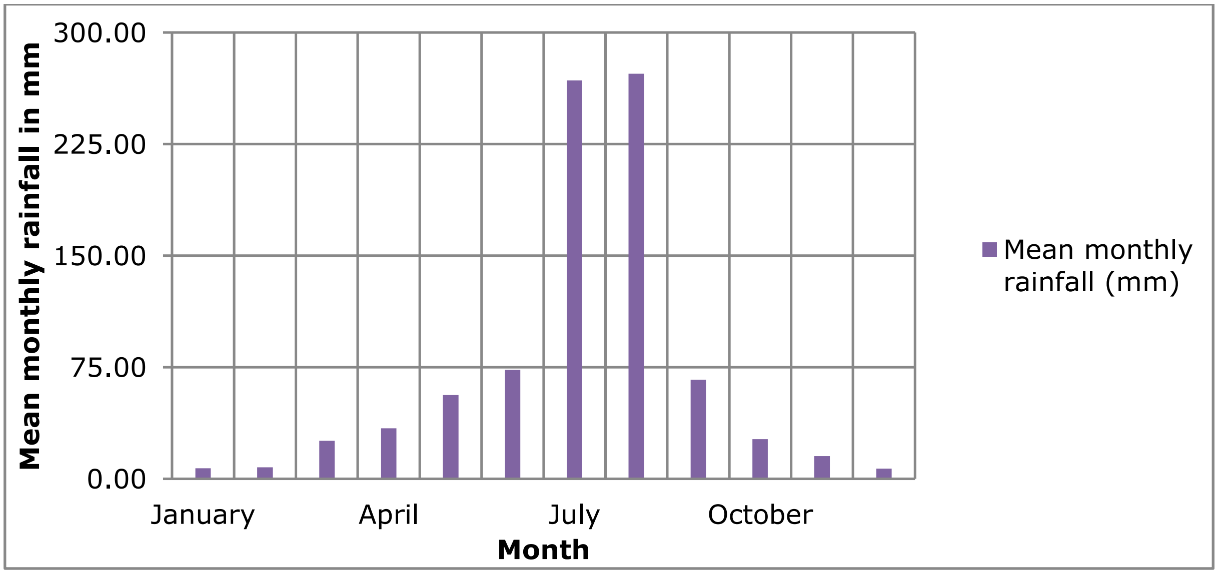


Figure 3.3: Mean monthly rainfall derived from Giovanni Nasa, Africa Flood and Drought Monitor and WorldClim open data source

3.3 Hydrology

The mean annual surface runoff volume that reaches to the dam is estimated to be 3.4 Bm^3 which is equivalent to 112 mm depth of runoff from the whole catchment with an area of 30,767 km^2 (figure 3.4). The runoff amount generated from the catchment varies depends on the rainfall potential in the different climatic zone (figure 5.3).

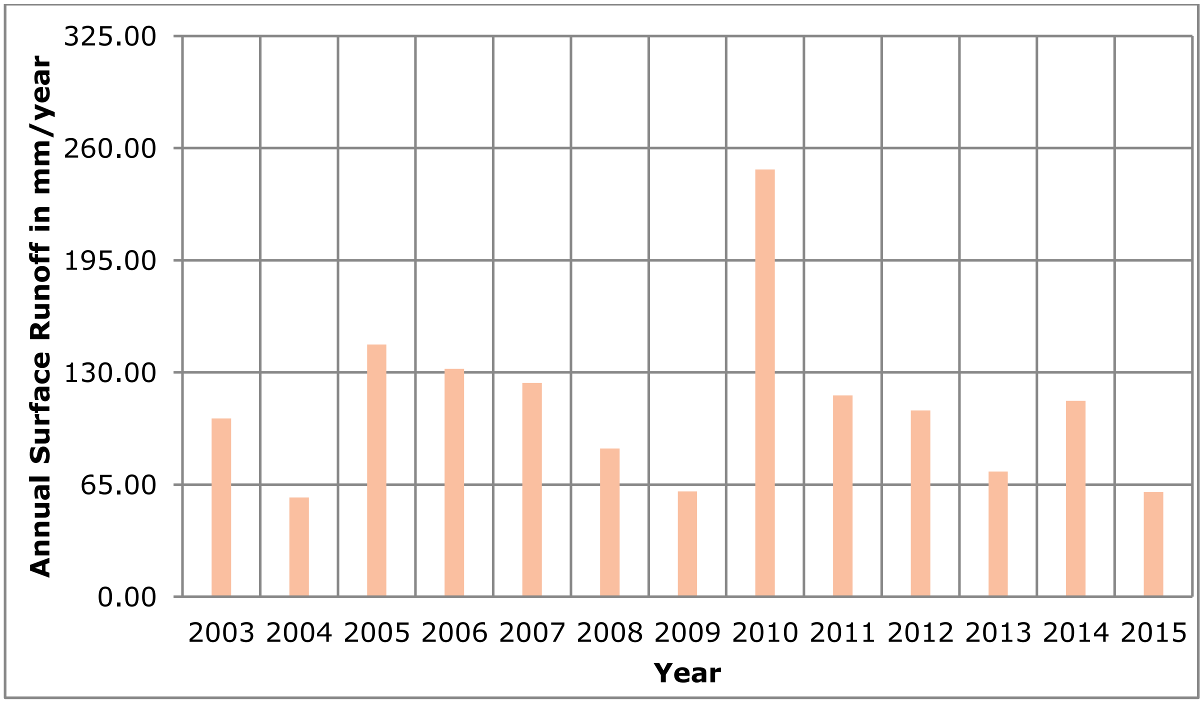


Figure 3.4: Annual surface runoff derived from Giovanni Nasa and Africa Flood and Drought Interface for Tekeze dam catchment

3.4 Land use

From the MODIS land use map information, land use type in the study area is predominantly cropland and followed by Savanna, grassland, woodland and forest land (figure 3.5). Other land uses such as water bodies, bare land, and urban built and wetlands cover a relatively small portion of the watershed. The agriculture sector is mainly dominated by the traditional farming practice which depends on unreliable seasonal rainfall. The spatial and temporal variation of rainfall is a big challenge in rain-fed agriculture.

The study area is highly affected by the negative effect of massive deforestation for different purposes. In the second half of 20th century, the Ethiopian highlands have experienced a significant land use and land cover change (Tesfaye et al., 2014). Vegetation's are found in a largely scattered way near the cultivated land, grazing land and near to the residence area.

In rain-fed agriculture, since cultivation is possible may be one time per year in most cases, shortage of arable land that enables farmers to produce adequate yield is a big challenge. The average size of farm land per household level is very limited and even there are inhabitants without farmland at all. Due to this, cultivation is still practiced on the steep slope by deforestation and without adequate conservation practice which aggravates the risk of fertile top soil loss and again downstream sedimentation as an offsite impact (Meire et al., 2013).

Severe trends of land degradation which results from the expansion of agricultural activities in the steep slope at the expense of forest have been observed in the northwestern highlands, where the Tekeze basin starts (Dubale, 2001). This land use change in the Northwestern Ethiopian highland results to an extensive flooding and damage to agricultural lands and downstream sedimentation problem (Bewketu W., 2003; Tesfaye et al. 2014).

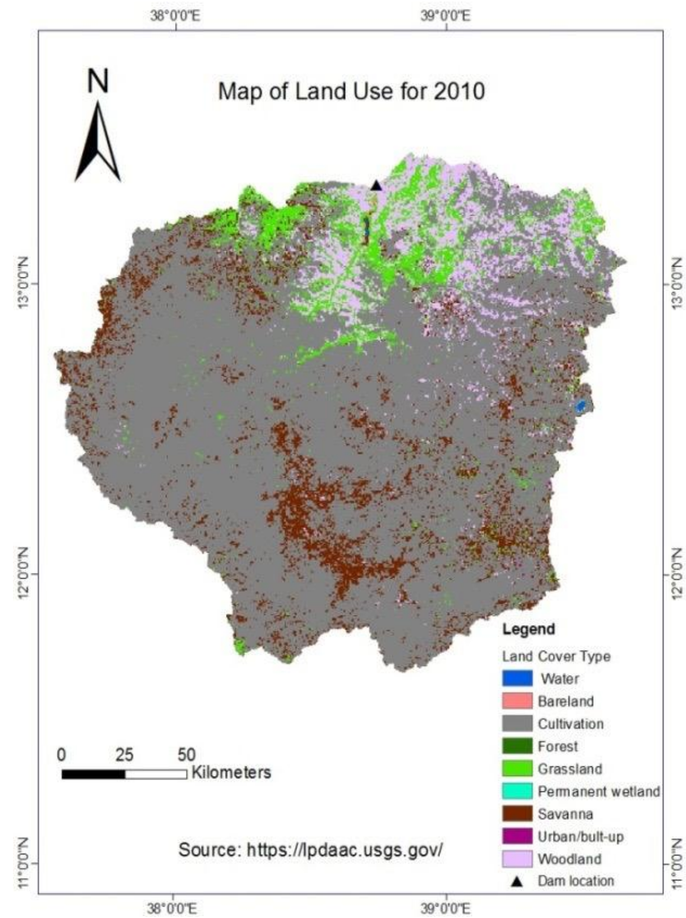


Figure 3.5: Land use map of Tekeze dam Watershed in 2010

3.5 Soil

According to FAO harmonized world soil database, the upper reach of Tekeze dam basin has dominantly a Eutric Cambisol soil type with 71% are coverage and followed by Cambic Arenosols (20%), Eutric Nitosols (5%) and Dystric Cambisols (4%) (FAO, 2012) (figure 3.6). Eutric Cambisol has a loam textural class and it is the most productive soil type in the earth whereas Dystric Cambisols is less fertile and mainly used for grazing and forest land and it covers only around 4% of the study area watershed. Cambic Arenosols which covers the second largest area of the watershed has a textural class of sandy soil. It exists in the lowland part of the watershed with the flood plain. The organic matter content of this soil is very low and has a very scattered vegetation cover.

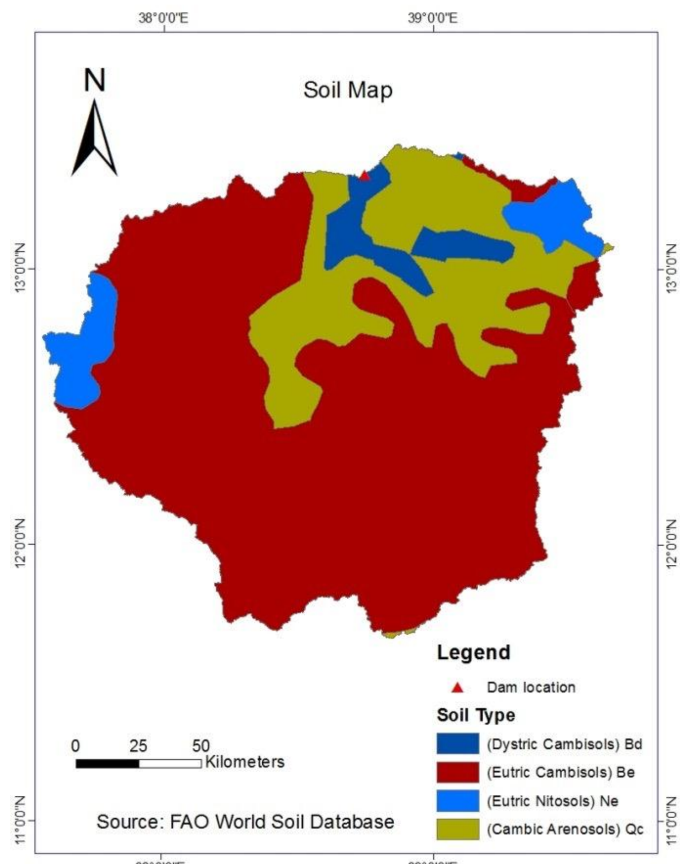


Figure 3.6: Soil map of Tekeze dam watershed from FAO harmonized world soil database

Chapter Four. METHODOLOGY

4.1 Soil Erosion Rate Estimation from Tekeze Dam Watershed

Since a few decades back, a number of simulation model have been developed to quantify and analyze the processes of soil erosion at the watershed scale. Some of commonly applied erosion models are empirical and others are physically based. The universal soil loss equation (USLE) is the most widely used empirical model in worldwide. EUROSEM (European Soil erosion Model), AGNPS (Agricultural Nonpoint Source Pollution Model), WEPP (Water Erosion prediction Project),HEC-RAS, HEC-HMS (Hydrologic Engineering center's – Hydrologic Modeling system), SWAT (Soil and Water Assessment Tool) and ANSWERS (Areal Nonpoint Source Watershed environmental response Simulation) are examples of the physically based models that can able to estimate the sediment yield from the watershed (Mequanint T., 2008). And revised universal soil loss equation (RUSLE) and modified universal soil loss equation (MUSLE) which are based on USLE can be used for estimation. The accuracy of the model depends on a number of input parameters under consideration and the quality of data as well. The more parameter considered the more accurate result is expected. However, the intensive data needs to physically based models for calibration and validation limits their applicability in the data-scarce region.

In this research, the universal soil loss equation (see equation 1) have been chosen to be used to estimate the sediment yield from the Tekeze dam watershed by the two land use scenarios, due to lack of adequate data for calibration and validation that need to be used for physical models. It is the most widely used equation for predicting the average soil loss rate from the watershed. It has been applied in different parts of Ethiopia in a wide range. This equation also involved in a number of physically based models which is developed to compute the soil erosion and sediment yield from the watershed. The USLE considers five different parameters that characterized the interested catchment area in order to compute the average annual soil loss.

This formula is given by:

$$A = R * K * LS * C * P \quad \ldots\ldots (1)$$

Where, A= is the average annual soil loss in tons/ha/year

R= rainfall erosivity factor (MJ/ha.mm/h),

K= erodibility factor (t.ha.h/ha/MJ/mm),

LS= slope length and steepness factor

C= the land use/land cover factor

P= conservation factor

All the factors except the rainfall erosivity and soil erodibility are dimensionless. These factor needs to be prepared from the raw/available data before applying to the formula. The way of preparing each factor for the model is explained in detail below.

4.1.1 Erosivity factor (R)

It is an average index used to measure the kinetic energy of raindrops impact on the sheet and rill erosion. It is determined from rainfall intensity data for the given area. In many cases where the availability of rainfall intensity data is very rare, it is usually difficult to compute the R factor. Because, how much the intensity of rainfall is very important to determine the erosivity value of the given storm. Therefore, due to limited data availability in Tekeze dam watershed, the R factor was computed from the mean annual rainfall data using the empirical equation given in equation (2) which is developed by Hurni (1985a) for Ethiopian climatic condition (Cited from Bewket and Teferi, 2009).

$$R = -8.12 + 0.562\,P \qquad (2)$$

Where, P = mean annual rainfall in mm and

R = rainfall erosivity factor in MJ/ha.mm/h.

4.1.2 Soil erodibility factor (K)

This factor represents susceptibility of soil to erosion by direct rainfall and runoff water. The value of K was computed using the empirical equation given in equation (3) which is developed by Habtamu I., (2011). The equation needs only the texture of soil or average percentage of each soil particles (Sand, Silt, and Clay) in the catchment. The formula is as given below.

$$EC = a\left[\frac{\%Silt}{\%Clay+\%Sand}\right]^{b} \quad \text{.......................... (3)}$$

Where, EC = Soil Erodibility factor (t.ha.h/ha/MJ/mm)

% Sand = percentage of sand in the soil

% Silt = percentage of silt in the soil

% Clay = percentage of clay in the soil

a = 0.32 and b = 0.27 are constant factors

4.1.3 Slope length and Slope steepness factor (SL)

Topography is the most influential parameter that determines the amount of sediment yield from the watershed. These factors were computed separately from the DEM (Digital Elevation Model) data as discussed below.

Slope Length Factor (L): According to Wischmeier and Smith (1978) the slope length or L-factor is defined as the ratio of soil loss from a horizontal slope length to the corresponding soil loss from the slope length of a unit plot with the length of 22.13 m. The empirical equation developed by Mc Cool et al., (1987) to compute the slope length factor (L) as given below in equation (4) has been used (Cited from Vemu and Pinnamaneni 2012). The λ value was assumed to be 100 as it was assumed by Tarek M., (2016) in Nile basin.

$$L = (\lambda/22.1)^{m} \quad \text{.......................... (4)}$$

Where L = slope length factor

λ = field slope length (m)

m = dimensionless exponent which depends on slope steepness. Its value is 0.5 for slopes exceeding 5 percent, 0.4 for 4 percent slopes and 0.3 for slopes less than 3 percent.

Slope Steepness Factor (S): The slope gradient is the main watershed parameter determining the sediment yield and its factor was calculated using formula presented by McCool et al., (1987) as it is given in equation (5) in order to use in the USLE (Cited from Vemu and Pinnamaneni, 2012).

$S = 10.8 \sin\theta + 0.03$ (for slope gradient < 9 %)

$S = 16.8 \sin\theta - 0.05$ (for slope gradient ≥ 9 %) ………….. (5)

Where *S* = slope steepness factor and θ = slope angle in degree.

4.1.4 Management practice factor (P)

This factor is defined as the ratio of soil loss from the area with conservation measures to the area without any management practices or conservation measures to control soil erosion. Due to the rugged topographic nature of the watershed and high need of conservation measures together with the absence of tangible evidence on the extent of conservation practice in the whole study area, the P-factor was decided to be 1 to avoid underestimation of sediment yield.

4.1.5 Land cover factor (C)

It is defined as the ratio of soil eroded from the land with specific vegetation or land cover to the corresponding soil loss value from bare soil (Wischmeier and Smith, 1978). This factor is used to consider the impact of land cover or differences in vegetation cover on the sediment yield. The value of C-factor was computed using the standard table given in different literature for different land use types. After identifying the land use type for the watershed, the corresponding C-factor value for each land use was selected.

4.2 Land Use Scenarios

Scenario is defined as a set of different possible alternatives that may probably happen in the future and used to estimate the possible results of these different circumstances for the purpose of identifying the most appropriate responses to the changing situation (Bieger K., 2013). It is a key for decision makers in giving the direction to the most profitable or sustainable alternatives in their choice. It is also used to know what would be the result of the past condition to the given dependent variable if it was not changed to the current situation and continue to the future as well. This is what actually applied in this research.

The two past land use scenarios have been used to see their effect on sediment yield from the watershed and their related consequence to the reservoirs lifetime, and possible trends of greenhouse gases emission amount from Tekeze dam.

- Land Use Scenario 1 (LUS_2001) is the land use condition which was actually on the ground during the year of 2001 at the Tekeze dam watershed. Since the construction phase started by June 2002, this scenario was chosen to see the actual sediment yield amount just before beginning the construction of dam.

- Land Use Scenario 2 (LUS_2010) is the land use condition which was actually on the ground during the year of 2010 at the Tekeze dam watershed. It was chosen because of the dam was completed and ready to store water by 2009. But the wet season in 2009 including the previous year 2008 were disappointed the area and the dam was not completely full by end of 2009 wet season. Besides, the land use map of 2009 from MODIS land use product with 500 m resolution had some uncertainty compared with 2008 and 2010 land use map which may be related with the dryness of the area. Due to this, 2010 land use condition was considered as the land use during impoundment. In both land use scenarios, there was no manipulation in changing the area of each land uses like what is usually applied in future scenario simulation.

4.3 Sediment Delivery Ratio for Sediment Yield Estimation

The Universal Soil Loss Equation estimates the amount of soil erosion from the given watershed by sheet and rill erosion only. It does not consider the transportation and deposition phase. Due to this, the calculated soil loss from the watershed using USLE does not mean that all the soil will reach to till the outlet of watershed. Thus the sediment delivery ratio of the stream channel has been used in order to determine the amount of sediment that can reach to the final drainage point in the catchment.

Different researchers have developed simple empirical models to estimate the sediment delivery ratio with few catchment characteristics. In this research, the sediment delivery ratio was calculated using the model given by Williams., (1977) in equation (6) which needs only the slope of the mainstream channel. The slope of the river bed was computed by dividing the elevation difference of the mainstream starting point and the river outlet to the length of the mainstream which was computed using ArcGIS 10.2 platform.

$$SDR = 0.627\ SLP^{0.403} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (6)$$

Where SLP = % slope of mainstream channel

After calculating the sediment delivery ratio, the annual sediment yield from the given catchment was executed using the formula given below in equation (7).

SY = (A) * (SDR) …………………………………….. (7)

Where, SY is the average annual sediment yield of a watershed

A= the gross soil erosion estimated by USLE, and

SDR is the sediment delivery ratio

4.4 Trap Efficiency of the Reservoir

The trapping efficiency of the reservoir was estimated using different empirical models which need few input parameters. These methods are easy to implement due to consideration of fewer parameters from a lot of complex factors that actually affects the reservoir trap efficiency (Verstraeten and poesen, 2000). Thus, four different empirical methods have been used to compare the results and get representative value for trap efficiency of Tekeze dam.

The Brune (1953) empirical relation was one of the methods that have been used to estimate trap efficiency of Tekeze dam. Reservoir storage capacity and annual inflow volume to the dam were the input parameters to this empirical formula as it is given in equation (8).

$$TE = (-22 + \frac{119.6*\left(\frac{C}{I}\right)}{[0.012+1.02*(C/I)]}) \ldots\ldots\ldots\ldots \text{(8)}$$

Where TE= Trap Efficiency (%)

C= Reservoir capacity (m3)

I= Annual inflow volume (m3)

The second method was the Brown equation that relates the trap efficiency with the ratio of reservoir storage capacity to watershed area or drainage area (C/A) (see equation 9). The area of the watershed was calculated using the ArcGIS 10.2 platform.

$$TE = 100 * \{1 - \frac{1}{[1+D*(C/A)]}\} \ldots\ldots\ldots\ldots \text{(9)}$$

Where D= constant value ranges from 0.046 to 1 with mean value of 0.1

A= Catchment Area (km^2)

For the constant "D" value Brown suggests taking a value close to 1 for reservoirs which receive smaller flow rate and store flood water behind. So a value of 1 was used for the calculation of the trap efficiency since Tekeze dam has a large storage capacity relative to the annual inflow rate.

The third method that has been used for trap efficiency estimation was an empirical equation given by Gills (1979) for the coarse-grained sediment, for medium grained sediment and for colloidal and dispersed fine-grained sediments separately (Sultana and Naik, 2015). Then the equation given for medium grained sediment was used based on the sediment characteristics of Tekeze River found in literature which shows as it is dominantly suspended load. The input parameters needed to use the Gill's trap efficiency formula (see equation 10) is the reservoir capacity and inflow to the reservoir which is the same as Brune method.

For medium grained sediment

$$TE = \frac{\left(\frac{C}{I}\right)}{0.012+1.02\left(\frac{C}{I}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(10)}$$

The last method used for estimating the trap efficiency was the Siyam (2000) method which is developed in the form of an exponential function (see equation 11) with a defined sediment parameterization (β) for the targeted reservoir (Eizel-Din et al., 2010).

$$T.E\ (\%) = 100 * e^{-\beta I/C} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(11)}$$

The sediment parameter (β) value for Tekeze dam was assumed from the recommended range for reservoirs along Nile River by Eizel-Din et al., (2010), which is in between 0.015 to 0.056. This is because of Tekeze dam is constructed across Tekeze River which drains into Nile River system. Then the value β was picked as 0.056 since it was used by Eizel-Din et al., (2010) for the Roseirs dam which is located down from Tekeze dam along Blue Nile River. The sediment characteristics in Tekeze dam is expected to have more or less same characteristics with sediments in Roseirs dam. Of course, the sediment nature below Tekeze dam can make a difference in sediment characteristics assumption between the two dams. But still, it is the appropriate assumption than taking from other dams placed somewhere else far away even if it is along the Nile.

4.5 Gross Emission of Greenhouse Gases Estimation

The absence of precise empirical model or physical based model to estimate the net greenhouse gas emission from water bodies in general, is still the challenge for the researchers in this field of interest. For the decision makers as well, it is important to assess the environmental risk of the existed reservoirs and/or the future plan dam infrastructures regarding their contribution to greenhouse gas emission. The complexity of the process and involvement of different factors makes it difficult to estimate precisely.

Despite its complexity, the UNESCO/IHA Greenhouse Gas Emissions from Freshwater Reservoirs Research Project teams are on doing by their full effort with different partners to release a tool for net emission of GHGs from reservoirs. For the moment, they have already released the GHG risk assessment tool (Beta version) that used to estimate the gross emission of GHGs by diffusive flux only from the reservoir water surface. Therefore, the Greenhouse gas risk assessment tool (Beta version) has been used to estimate the gross emission of GHGs from Tekeze dam. The estimated value using this tool is the gross emission which includes the natural greenhouse gas emission from the water bodies and natural ecosystem that would occur regardless of the dam construction. The tool is basically used to indicate whether the reservoir net greenhouse gas emission should be assessed or not by comparing the result with datasets used in model calibration. Input variables that need to use the tool to estimate the gross emission of CO2 and CH4 are mentioned below.

For CO_2 emission estimation:

- Reservoir age
- Mean Annual Temperature
- Mean Annual precipitation

For CH_4 emission estimation:

- Reservoir age
- Mean Annual Temperature
- Mean annual runoff (Source from UNESCO/IHA, 2012)

The source of data for each variable and way to handle raw data is explained in detail in the next chapter.

4.6 Effects of Land Use Changes on Greenhouse Gases Emission

The greenhouse gas emission from reservoirs is highly affected by a number of factors which are interconnected in a very complex manner. Land use type in the watershed is one of the factors determining the possible GHGs emission amount from the receiving reservoir downstream. Land use condition has already listed as an input parameter by the UNESCO/IHA research project in their new G-res tool development for net greenhouse gas emission (UNESCO/IHA, 2016).

In this research, the sediment yield variations due to land use change scenarios in the basin have been considered to assess the possible trends of emission amount from Tekeze dam reservoir. Because land use change is one of the factors influencing sediment yield amount from the watershed. The potential or trend of greenhouse gas emission due to changes in sediment yield which resulted from land use changes was evaluated in a qualitative way instead of quantifying by how much the greenhouse gas increases or decreases. The effects of sediment yield in greenhouse gas emission have been seen in two directions based on literature reviews about possible influential factors on GHGs emission level and from parameters mentioned in G-res tool development. Firstly, due to its contribution to the carbon budget of the reservoir. Second, due to its effect in reducing the reservoir capacity which finally affect's the retention time of water in the reservoir. These two values (organic carbon content and retention time of water in the reservoir) were analyzed using the two land use scenarios by the formula given below.

4.6.1 Estimation of organic carbon from the sediment yield

Soil organic matter and nutrients continuously leached by water from the upper catchment and reaches to the reservoir. The carbon contribution of the catchment to the reservoir carbon budget depends on the organic carbon content of the sediment, amount of sediment that reaches and trapped by the reservoir. Soil erosion can be considered as a continuous source of organic carbon to the reservoirs carbon budget as long as erosion is natural phenomena and always happened despite the degree is different in spatially and temporally. The amount of organic carbon transported with sediment was computed using formula adapted from (Gert Verstraeten and Poesen, 2002) as given below in equation (12).

$$OCY = \frac{SM*OC}{A*Y*10^4} * TE \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

$$SM = SV * dBD*10^6$$

Where OCY = the organic carbon yield in the reservoir sediment (Mton/ha/yr)

SM = total measured sediment mass (Mton)

SV = total measured sediment volume in the reservoir (m^3)

dBD = dry bulk density (ton/ m^3)

OC = average organic carbon content of the sediment (in percent)

A = area of the catchment (ha)

Y = reservoir age for a duration of sediment accumulation (year)

TE = trap efficiency of the reservoir (percent)

Constant numbers used in the equation are for unit conversion

4.6.2 Retention time of water in the reservoir

Retention time is the time that the water in the reservoir can stay before renewed and flushed away as an outflow. It is one of the most significant parameters that differentiate the natural river system from the dammed one. The average length of time that the water remains within specified boundaries of an aquatic system is one of the key parameters controlling the systems biogeochemical behavior (Rueda, Moreno-Ostos, and Armengol, 2006). That is why the post-impoundment condition is expected to have more greenhouse gas emission than pre-impoundment, particularly for CH_4 emission.

The most common and widely used expression to estimate the residence time (sometimes called flushing time) in reservoirs is dividing the volume of water (V) stored in the reservoir by the volumetric flow rate (Q) (Rueda, Moreno-Ostos, and Armengol, 2006). From this definition, reservoir storage capacity and water flow rate in the system are the determining factors for a retention time of water in a given reservoir.

Hence the retention time was calculated using the formula given in equation (13).

$$Retention\ Time\ (year) = \frac{Reservoir\ capacity\ (M3)}{Out\ flow\ rate\ (\frac{M3}{year})} \ldots\ldots\ldots\ldots (13)$$

The reservoir capacity for each year was computed by subtracting the annual sediment load volume trapped by the dam (annual storage capacity loss due to sediment) from the net capacity of the reservoir in the previous year. The outflow rate was computed as given below in equation (14).

Outflow rate = Inflow rate – Evaporation loss …………… (14)

The water loss due to seepage and leakage through the dam was neglected since there was no adequate data from the field. The evaporation rate was computed from Africa Flood and Drought Monitor online data source like other meteorological data’s. The two land use scenarios that have already used in other computation have been used to simulate how the retention time will be throughout the reservoir lifetime using graphic representation.

Chapter Five. DATA COLLECTION AND QUALITY CONTROL

5.1 Data Sources and Collection

The source of data that used to carry out this research was secondary data from different open sources. List of data's that have been used during the research work were meteorological data, hydrological data, land use map, soil data and topographic map.

5.1.1 Meteorological data

Rainfall

Precipitation data was collected from three different open data sources in order to take the most reliable and representative rainfall data by comparing with precipitation value in recent literature for the study area. These data sources were Africa Flood and Drought Monitor, Giovanni Nasa (TRMM, 2011), and Worldclim open data sources (Anderson-Teixeira et al., 2014; Hijmans RJ. et al., 2005). The rainfall data considered in this research was from 2000 to 2013 to have a fair comparison from all sources at the same recording time (figure 5.1). The detail information regarding the precipitation data from each source is given below.

Africa Flood and Drought Monitor source:

- Spatial resolution = 0.25^{o}

This data source has the same resolution to others data that have been downloaded from Africa Flood and Drought Monitor Sources.

Giovanni Nasa source:

- Data source name = TRMM (TMPA) Rainfall Estimate L3 3 hour 0.25 degree x 0.25 degree V7. The short name is TRMM_3B42
- Spatial resolution = 0.25^{o}
- Temporal resolution = 3 hours

Worldclim source:

- Resolution = 30 arc-seconds (~ 1km)

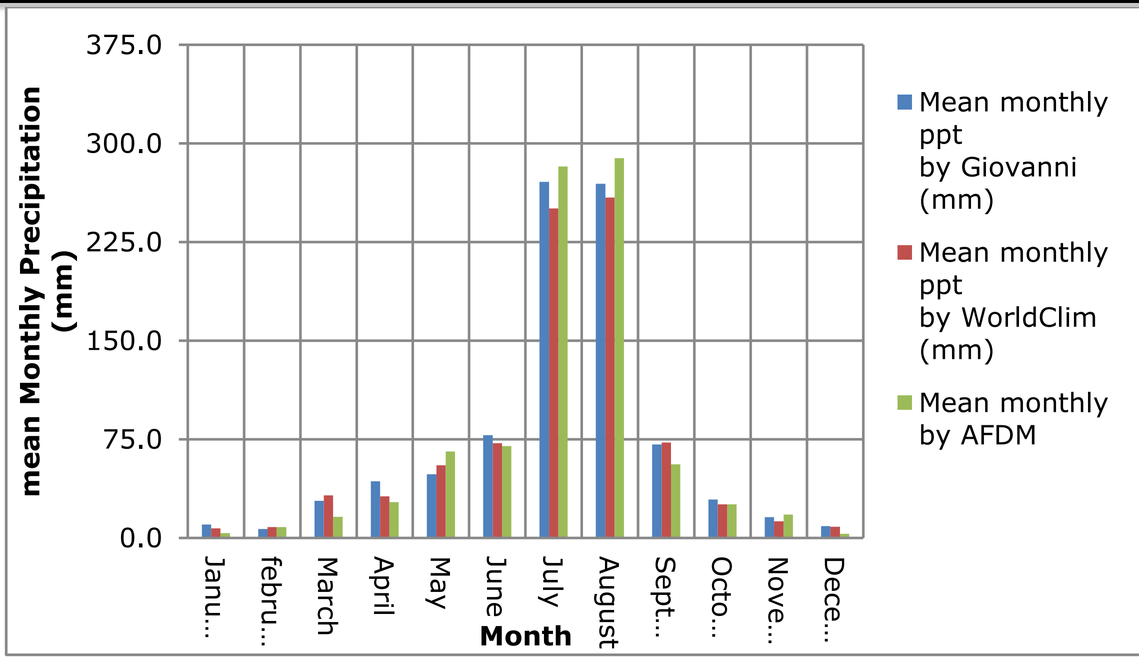


Figure 5.1: Mean Monthly precipitation from Giovanni Nasa, Africa Flood and Drought Monitor Agency and Worldclim data source

Temperature

Temperature data was also available in the online data source from African Flood and Drought Monitor Agency website (for the same period as precipitation data (figure 5.2a). It is a daily maximum and minimum temperature measured at two meters above the surface.

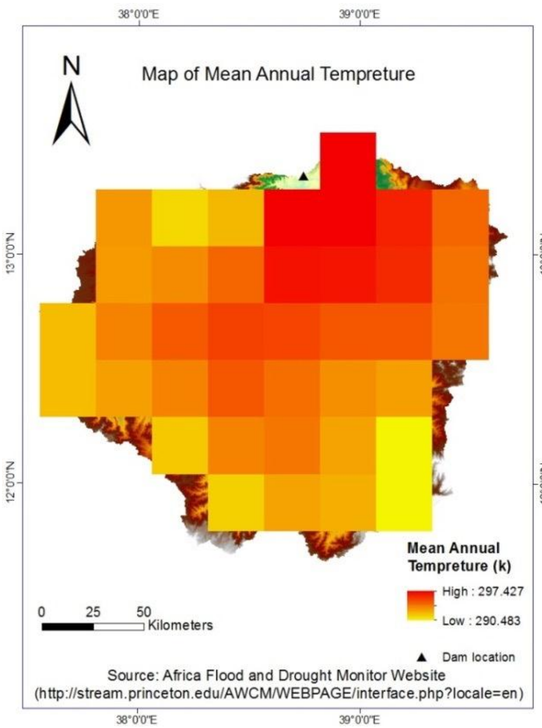
Africa Flood and Drought Monitor source:

- Spatial resolution = 0.25^{o}

Evaporation

Like the temperature data, evaporation data was collected from African Flood and Drought Monitor Agency website for the same period as the above two meteorological data (figure 5.2b). ArcGIS 10.2 version platform was used to handle raw data downloaded from the open source such as in table form. The data required for the model was in mean annual value which represents the study area. Thus, Arc GIS 10.2 software was used to compute the mean value of all the data using zonal statistic in the spatial analysis tool. It is a daily average evaporation rate from the land surface with a spatial resolution of 0.25^{o} like temperature and precipitation.

a)



b)

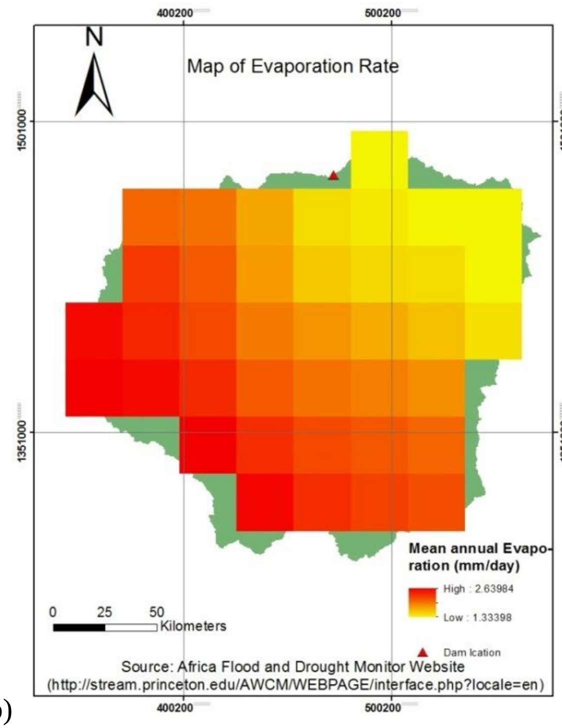


Figure 5.2: (a) mean annual temperature and (b) evaporation rate of Tekeze dam catchment

5.1.2 Hydrological data

Surface Runoff

Surface runoff data which is required basically for the GHG Emission Assessment Tool (Beta Version) was collected from Giovanni Nasa (Amy McNally, NASA/GSFC/HSL, 2015) and Africa Flood and Drought Monitoring online data sources (figure 5.3). The surface runoff data which is considered in this research was from the year 2003 to 2013. This is because of no surface runoff data available before 2003 in Africa Flood and Drought Monitoring Agency. Therefore in order to make a comparison between these two data sources, the surface runoff data used from Giovanni Nasa source was from 2003 to 2013 despite it was possible to get back from 2003 and after 2013. Giovanni Nasa data source name is FLDAS Noah Land Surface Model L4 monthly 0.1 x 0.1 degree, Version 001. It has a spatial resolution of 0.1^o with monthly temporal resolution.

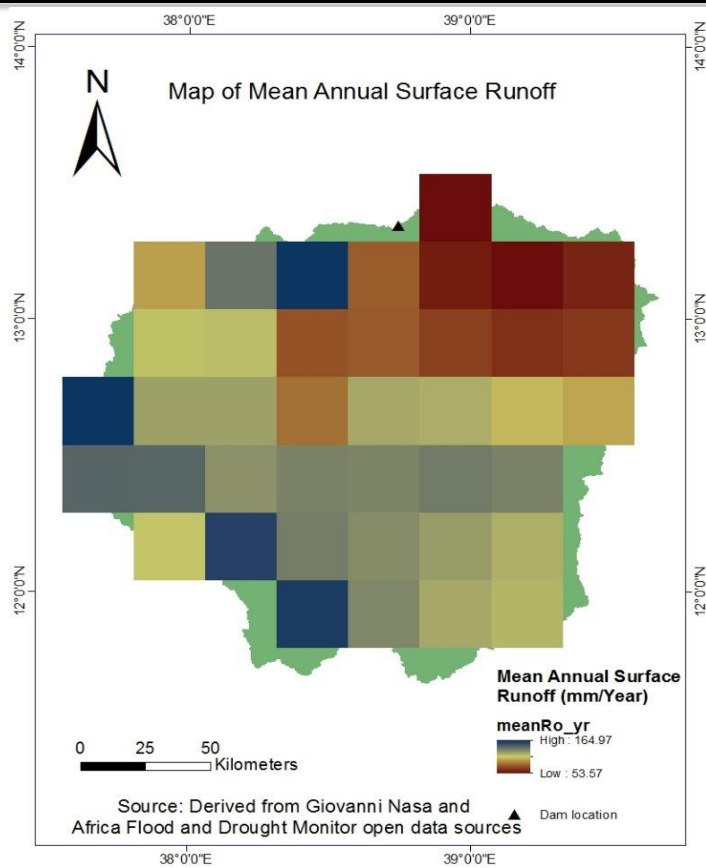


Figure 5.3: Mean annual surface runoff from Tekeze dam watershed

However, the calculated mean annual surface runoff from the above two sources have a significant difference each other which is 74 mm/year and 151 mm/year for Giovanni and Africa Flood and Drought Monitor Interface respectively. Therefore, the average of the two data sources value which is around 112mm/year have been used in the gross GHGs emission using GHG emission Risk Assessment Tool. Because of the average value was found closer with values of annual stream flow that have been used during the design of the dam.

Stream Flow Data

In Ethiopia in general, the availability of River flow data is limited due to the remoteness of the catchments and lack of adequate finance resource to build up and maintain the monitoring infrastructures (Awulachew et al., 2008). The available limited number of gaging station covers an area of more than 1000 km^2 which might not be a good representative for the given area (Awulachew et al., 2008.)

Stream flow data was directly obtained from the African Flood and Drought Monitoring website with stream flow product. However, the value seems to be highly underestimated compared with the values available in literature for the annual stream flow to Tekeze dam. The obtained stream value from African Flood and Drought Monitoring website is 0.74 BM^3 while the value estimated during design is 3.75 BM^3, which is almost only 20% of the design streamflow data. Even when it is compared with the annual surface runoff data (4.7BM^3) obtained from the same source, it is by far smaller. From the description given in the data source, the 4.7BM^3 surface runoff is the value that is expected to reach the stream network after passing subtracting all possible losses in the catchment except in the river network. Therefore, the stream flow value of Africa Flood and drought Monitor is showing that around 84% of the surface water that reaches to the river has lost before reaching the final drainage point which seems unrealistic. Even in most cases, the water loss in the river bed is considered as insignificant compared with the loss in the catchment from the beginning of its generation. because the river bed is like rocks that have already eroded their soil and left bare which may not allow high infiltration rate of water. From this point of view, the stream flow data given by Africa Flood and drought Monitor source looks underestimated and it may lead to the wrong conclusion.

As a result, the stream flow data was estimated from the surface runoff data for the dam watershed by assuming that the loss of water in river network is insignificant relative to the whole catchment area. Based on the assumption, the mean annual surface runoff volume was taken as mean annual streamflow volume to the dam. The mean annual streamflow volume was calculated by multiplying the mean annual surface runoff (which is 112mm/year) with a total area of watershed. The stream flow data that have been used during the design of Tekeze dam was used as a benchmark to check the reliability of the assumed stream flow data. Thus, the design streamflow value was 121 mm/year which is very close to 112 mm/year and it showed that the assumed data was acceptable. Chitati T. et al., (2014) also calculated the annual stream flow by multiplying the annual surface runoff depth by total catchment area.

5.1.3 Soil data

The soil data was obtained from FAO Harmonized World Soil Data Base (FAO, 2012) and ArcGIS 10.2 version have been used to extract the soil map for the study area (figure 3.6). This harmonized world soil database has a resolution of 30 arc-second raster database with more than 16000 different soil mapping units worldwide (FAO, 2012). It has a detail description of the soil properties like texture, organic carbon content, and dry bulk density etc.

5.1.4 Land uses

Land use map of the study area for the year 2001 and 2010 was obtained from MODIS land cover data product with a spatial resolution of 500m (NASA LP DAAC, https://lpdaac.usgs.gov/). This data provides land use map that have already classified to different land use types (see figure 5.4) and doesn’t need to do classification like Landsat image which usually needs either supervised or unsupervised classification. The data has been used directly to get the land cover factor in the estimation of soil erosion rate from the watershed using universal soil loss equation.

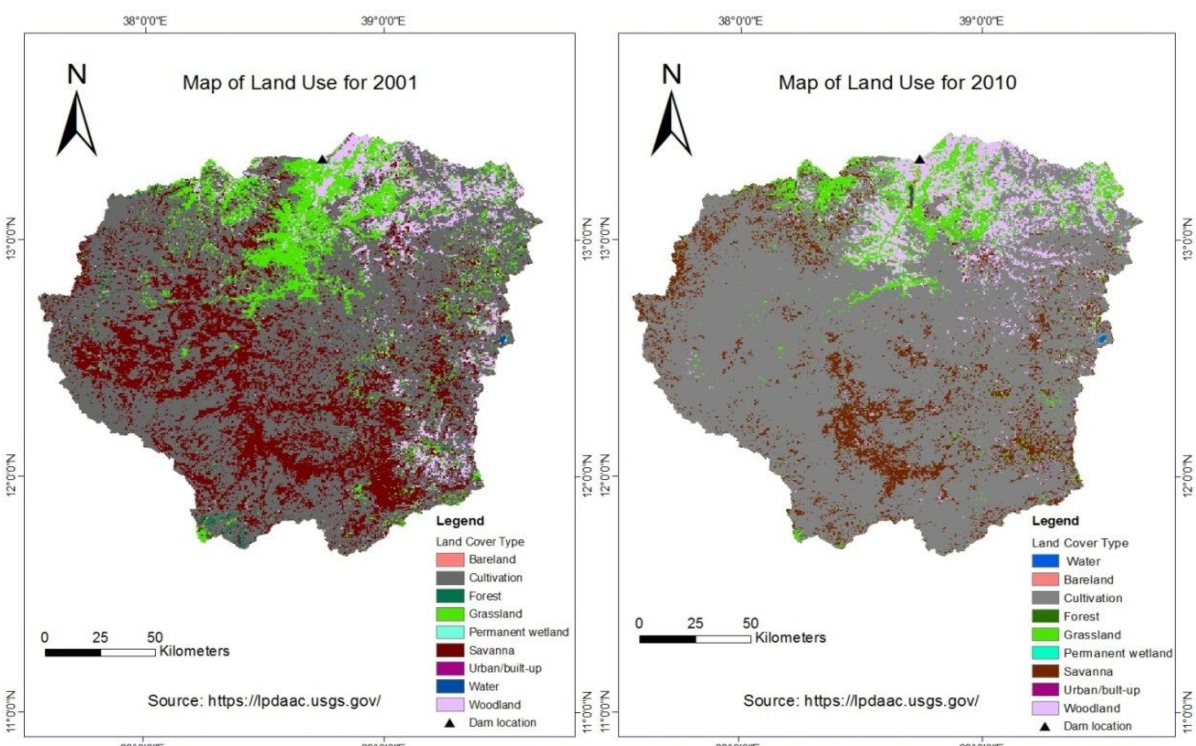


Figure 5.4: Land use map of Tekeze dam Watershed for the year 2001 and 2010 respectively

5.1.5 Catchment parameters

All the catchment parameters that have been used in the empirical model were generated using ArcGIS 10.2 software. These parameters include the area of watershed, perimeter, stream network, the average slope of the watershed and Main River. Delineation of the dam watershed was the first step that needs to be done and for this task, digital elevation model (DEM) was required. This DEM data with the 30m resolution was obtained from USGS database (http://earthexplorer.usgs.gov/) (figure 5.5). The GPS coordinate of the dam location was used as an outlet in order to delineate the watershed that drains into the reservoir.

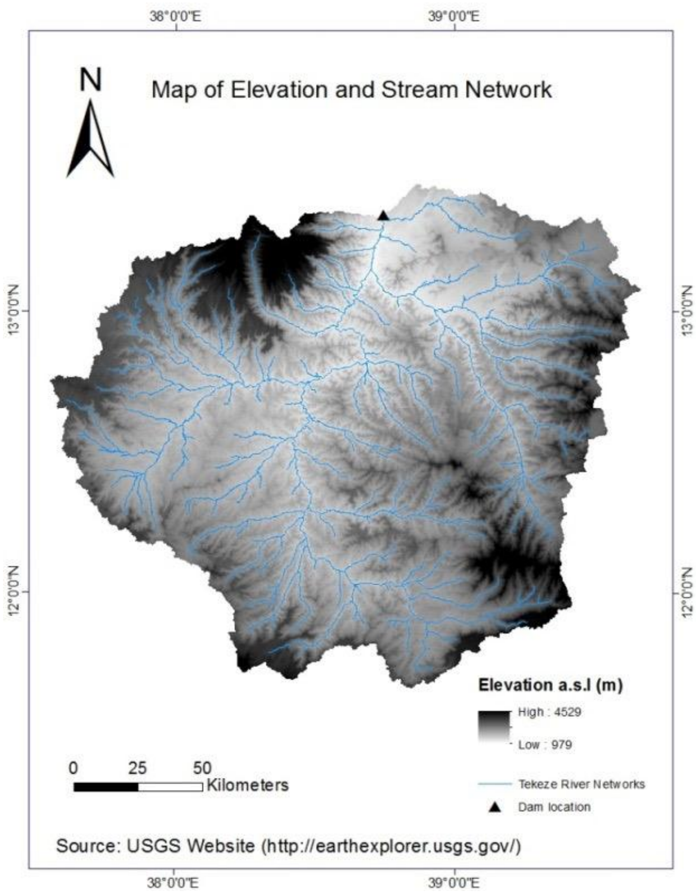


Figure 5.5: Digital Elevation Model (DEM) of Tekeze dam catchment with Stream Networks

5.2 Data Quality Control

Assessing the quality of data is the first step that should be carried out before going to the analysis phase. It is a very important step which determines the accuracy and reliability of the final output of the finding. Time series data, in particular, needs more attention and due to their relative susceptibility to an error than for example soil data which do not have temporal variation like meteorological and hydrological data. The first assessment was done by visualizing if there are some unexpected values such as negative values, missing values and the variation pattern of data from year to year. As long as the data was processed and prepared to be used by the source organization, there was no missed and negative data's from observation assessment. Besides this, in order to see the continuity and linearity trend of the data, accumulation plot method was used for all meteorological and hydrological data as given below in figure 5.6, 5.7 and 5.8 for precipitation, surface runoff and evaporation respectively.

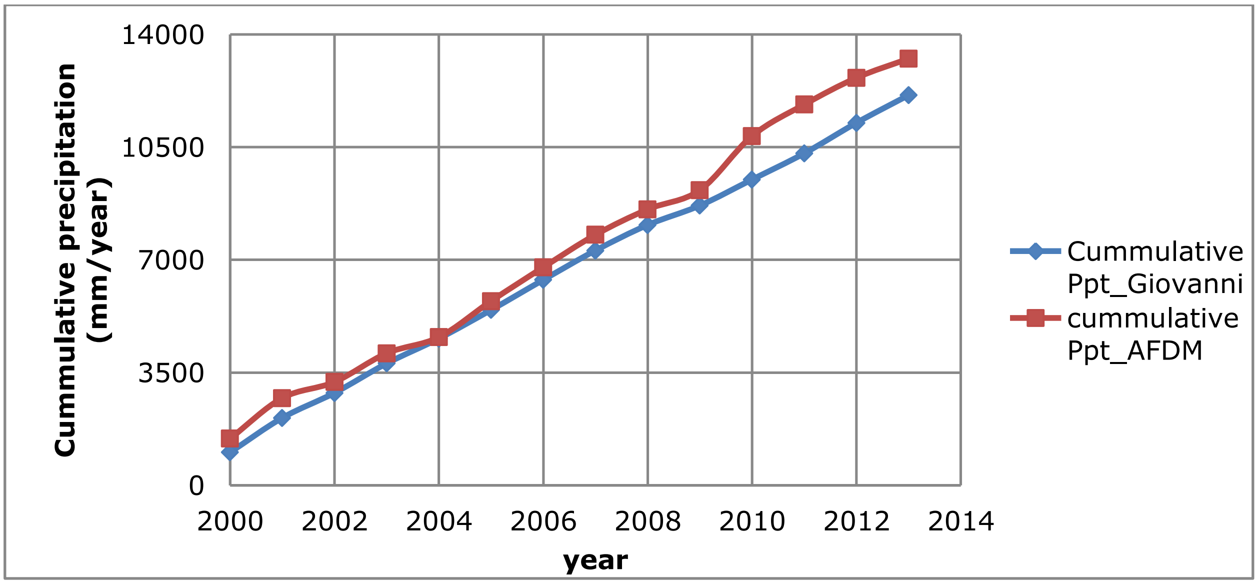


Figure 5.6: Accumulation plot for precipitation data from Giovanni Nasa and Africa Flood and Drought Monitor (AFDM) sources

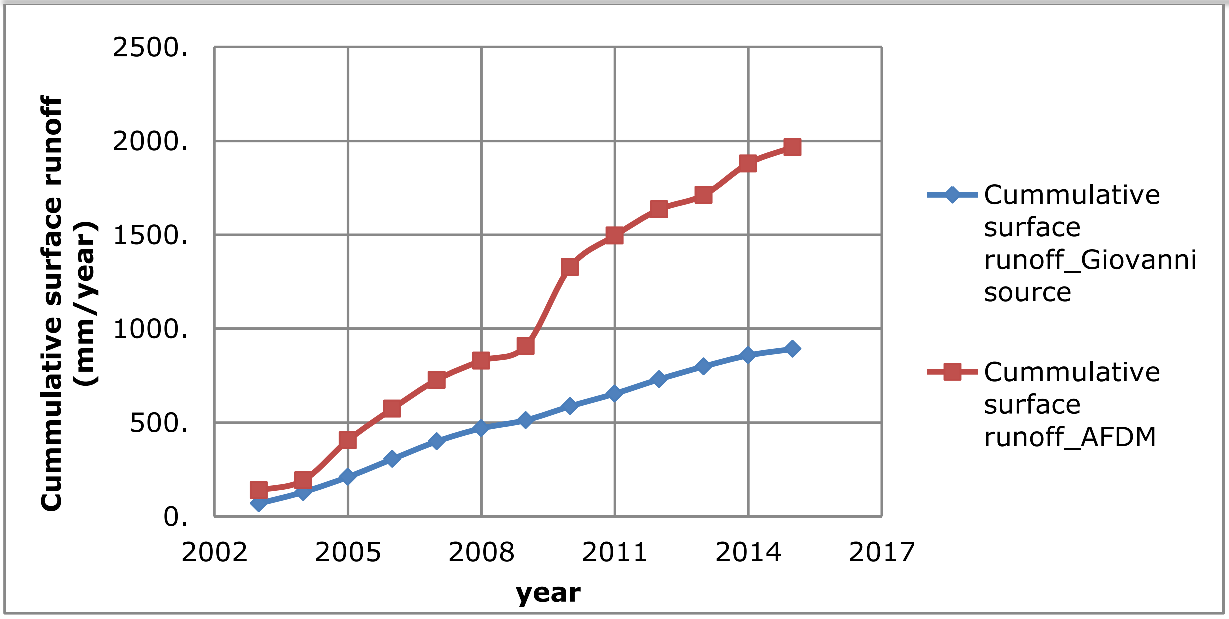


Figure 5.7: Accumulation plot for surface runoff data derived from Giovanni Nasa and Africa Flood and Drought Monitor open sources

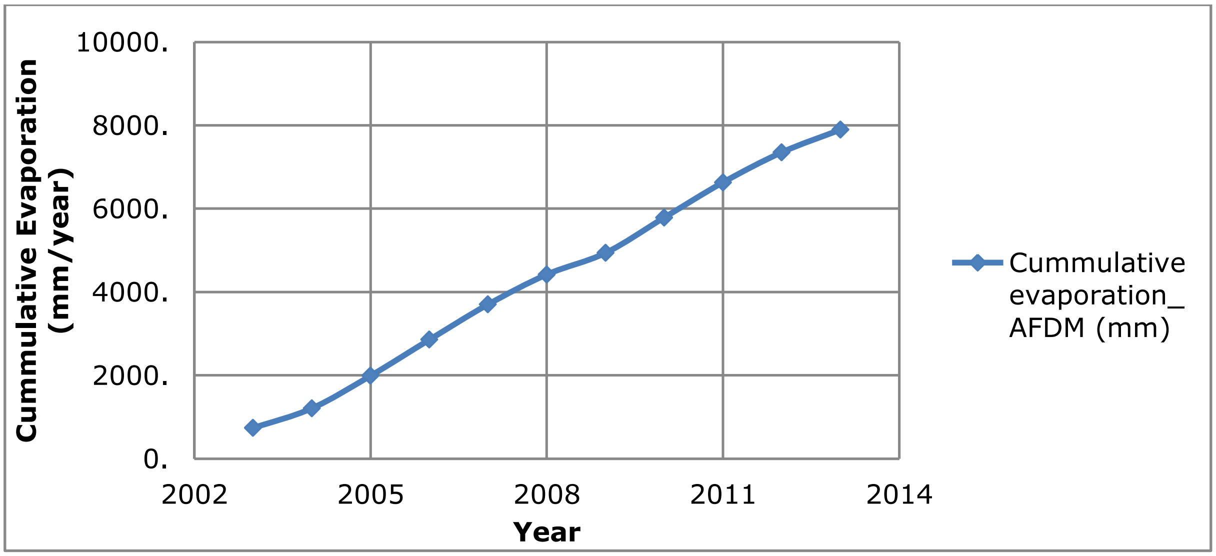


Figure 5.8: Accumulation plot for evaporation data derived from Africa Flood and Drought Monitor open sources

Land use data quality

The general idea in the land use scenario selection was to see how much sediment yield from the catchment changes due to the land uses changes from before starting the dam construction

(2002) and during the first impoundment at 2009. Thus, land uses in 2001 and 2009 have decided to be considered for the scenarios. However, there was some uncertainty as assessed by visualization of the land use data for the year of 2009. Due to this, it was not considered in the scenario to estimate actual sediment yield estimation of Tekeze dam despite the impoundment was on 2009 and instead of it the land cover for the year 2010 was considered by assuming that there was no significant change within a year.

The visual assessment of the land use quality was by summing the area of each land use and compare with the total area of the watershed that have been used to extract in ArcGIS platform. However, for the year 2009, the sum of the area of each land use type was found to be more than the area of the watershed which was actually used to extract from the raw data. The error might be due to double classification of a specific area to more than one land use types during processing of the raw data. This was the reason to avoid the consideration of 2009 land use data in the further analysis.

Chapter Six. RESULTS AND DISCUSSIONS

6.1 Results

6.1.1 Parameter results for the USLE model

Rainfall erosivity (R-Factor)

The average annual rainfall of Tekeze dam watershed is 860 mm. Based on this mean annual rainfall value, the average rainfall erosivity factor was estimated to 475.2 MJ mm ha^{-1} h^{-1} y^{-1}. This value is a representative R factor for the whole catchment since the precipitation value used in computation was the mean value derived for the total watershed.

Soil factor (K-factor)

The calculated k-factor for each soil type and their spatial distribution is given in figure 6.1a. However, due to the difference in the area coverage of each soil type, weighting of each factor by their area was necessary and have been done accordingly. Then the weighted k factor that represents the whole watershed was estimated to be **0.242** t.ha. h (ha MJ $mm)^{-1}$ (table 6.1).

Table 6.1: Weighted K factor value

Soil Type	K_Factor in t.ha.h (ha MJ $mm)^{-1}$	Area (sq. km)	Weighted K_Factor in t. ha.h (ha MJ $mm)^{-1}$
Dystric Cambisols (Bd)	0.255	1203.57	**0.242**
Eutric Cambisols (Be)	0.278	21961.91	
Eutric Nitosols (Ne)	0.179	1511.32	
Cambic Arenosols(Qc)	0.126	6090.49	

(a) (b)

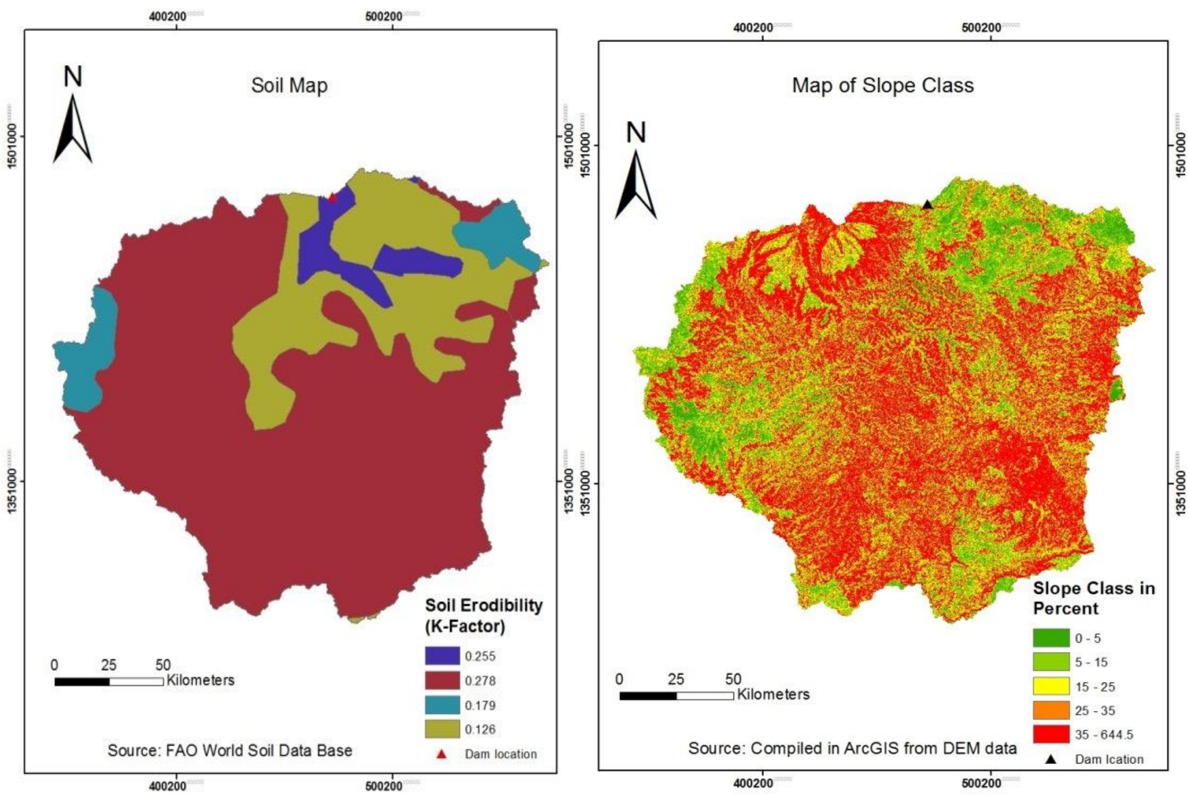


Figure 6.1: (a) Soil erodibility map and (b) Map of Slope Class in Percent

Slope length (L) and Slope steepness (S) factor

As it was computed in ArcGIS platform using zonal statistics tool from DEM (digital elevation model) data of the watershed, the area has a slope ranges from 0 to 644.5% (figure 6.1b) with an average slope of 32 %. Using this value the calculated average slope steepness factor was 4.42. The slope angle needed for slope steepness calculation was computed in a similar way and found to 17.2^{o}. The λ value was assumed to be 100 m as it was assumed by Tarek M., (2016) in Nile Basin and using this value the average slope length factor was 2.12. They are a mean value representing the whole watershed.

Land cover factor (C-factor)

The C-factor for each land use types for the year 2001 and 2010 was assigned using standard tables given in the different literature (See Table 6.2) and weighted by the area that each share in order to get representative value. The value ranges from 0 for water bodies to 1 for bare and urban built area. In this estimation, some specific land use types given by MODIS product were merged as one general land use type as they were assumed to have same C-factor value (table 6.2). The spatial distribution of land uses with the same factor is given in figure 6.2.

Table 6.2: MODIS land use class and the modified land use type for C-factor computation

<table>
<tr><td>MODIS land use type</td><td>Modified land uses class</td><td>C_Factor</td></tr>
<tr><td>water</td><td></td><td>0</td></tr>
<tr><td>evergreen needle leaf forest</td><td rowspan="5">Forest</td><td rowspan="5">0.01</td></tr>
<tr><td>evergreen broadleaf forest</td></tr>
<tr><td>deciduous needle leaf forest</td></tr>
<tr><td>deciduous broadleaf forest</td></tr>
<tr><td>mixed forest</td></tr>
<tr><td>closed shrublands</td><td rowspan="2">Shrublands</td><td rowspan="2">0.06</td></tr>
<tr><td>open shrub lands</td></tr>
<tr><td>woody savannas</td><td rowspan="2">Savannas</td><td rowspan="2">0.01</td></tr>
<tr><td>savannas</td></tr>
<tr><td>grasslands</td><td></td><td>0.01</td></tr>
<tr><td>permanent wetlands</td><td></td><td>0.01</td></tr>
<tr><td>croplands</td><td rowspan="2">Cultivated land</td><td rowspan="2">0.15</td></tr>
<tr><td>cropland/natural vegetation mosaic</td></tr>
<tr><td>urban and built-up</td><td></td><td>1</td></tr>
<tr><td>barren or sparsely vegetated</td><td></td><td>1</td></tr>
</table>

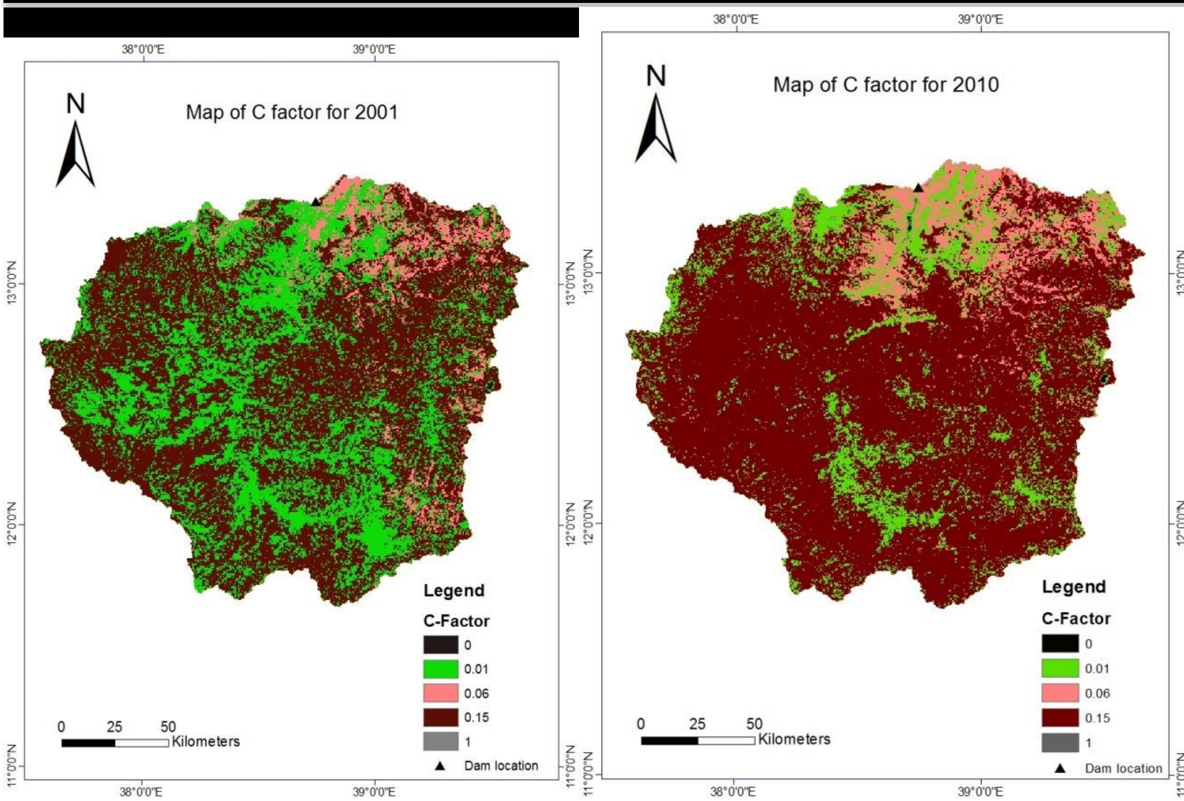


Figure 6.2: Land cover factor (C-Factor) for the year 2001 and 2010 respectively

Management practice (P- factor)

The P-factor value gives the ratio of the soil loss from a certain conservation practice to the area of up and down slope tillage practice (Weishmer and Smith, 1978). It's a dimensionless parameter with values ranges from 0 to 1. Areas of certain conservation practice will have less erosion risk due to its function as a barrier to the runoff with high flow velocity, erosive and transport power. In this paper, the P-factor value was considered to be 1. This was due to, firstly, the absence of clear evidence (qualitatively and quantitatively) about the extent of the conservation practices in the study area. Secondly, the dominant area of the watershed is in a mountainous area and cultivation is the dominant land use type. These shows the high need of conservation measure to tackle erosion risk and thus the existed conservation measure may not be adequate compared to the need.

6.1.2 Soil erosion rate estimation with land use change scenarios

In Tekeze dam watershed, there were a significant land use changes from 2001 to 2010. The cultivation land was the dominant land use type than other land use types in the study area. Within the 10 years interval from 2001 to 2010, there was a high expansion of cultivation land from 59.6% to 74.8%. In the contrary, savanna, grassland, and forest land cover reduced by 13.12%, 3.76%, and 0.74% respectively. Despite small area coverage of shrublands (around 6.86% in 2001), it shows an increment by 2.39% in 2010. Urban built area and permanent wetland in the watershed also decreased by 0.002% and 0.001% respectively from 2001 to 2010 (table 6.3).

Table 6.3: Land use changes in percentage from 2001 to 2010 (Derived from NASA LP DAAC MCD12Q2, 2015)

	Year				
	2001		2010		Increment in %
Land use Type	Area (Km^2)	Percentage (%)	Area (Km^2)	Percentage (%)	from 2001 to 2010
Cultivation	18343.80	59.632	23010.25	74.799	15.168
Shrub lands	2110.56	6.861	2846.26	9.252	2.391
Savanna	6939.74	22.560	2903.12	9.437	-13.122
Forest	232.39	0.755	5.28	0.017	-0.738
Grassland	3119.01	10.139	1962.81	6.381	-3.759
Permanent wetland	3.91	0.013	3.65	0.012	-0.001
Water	8.11	0.026	14.20	0.046	0.020
Bare land	0.86	0.003	14.15	0.046	0.043
Urban/built up	3.51	0.011	2.90	0.009	-0.002
		100.000		100.000	

The land covers condition is the main influential factor that determines the degree of soil erosion together with topographic parameters of the watershed. From the analysis, the mean soil loss rate from Tekeze dam watershed was estimated to 104.5 ton/ha/year by 2001 land use scenario and 129.2 ton/ha/year by 2010 land use scenario (table 6.4). By these rates of soil erosion, nearly 321.5 million tons and 397.5 million tons of soil eroded annually from the total watershed by 2001 and 2010 land use scenario respectively. The increasing of soil loss rate from 2001 to 2010 was 28 ton/ha/year, which is around 23.6% more from 2001 condition. According to Mati et al., (2000), the Ethiopian highland with cropland has an average annual soil loss of 100 ton/ha/year, which is more or less the same with this research result (cited from Tamene L. and Le, 2015).

Table 6.4: Annual soil loss rate estimation using USLE

			Soil loss (A) (ton/ha/year)	
A= RKLSCP	2001	2010	2001	2010
Erosivity factor (R)	475.2	475.2	104.5	129.2
Weighted soil erodibility (K)	0.242	0.242		
Slope length factor (L)	2.12	2.12		
Slope steepness factor (S)	4.42	4.42		
Weighted Cover factor (C)	0.097	0.120		
Management factor (P)	1	1		
	Increament (%)		23.60	

Catchment sediment yields to the reservoir

The entire soil loss amount estimated above using USLE from the dam watershed will not reach to the reservoir area at a time. Part of the eroded sediment from upslope deposited somewhere along its way to downstream before reaching the reservoir area. This does not mean that the deposited sediment will stay forever somewhere in the down catchment from its original place. Rather if it couldn’t reach to the reservoir area for example by the first rain storm, then it may be transported by the next rainfall events. The sediment deposition in the catchment happens when the velocity of the flowing water is no longer enough to carry the sediment to downslope. This flow velocity of runoff depends on the slope of the catchment, river bed slope and volume of flowing water which can determine the flow velocity as well.

For the estimation of sediment yield from the catchment to the reservoir inlet, the average river slope and then sediment delivery ratio were calculated and the values were 0.54% and 49% respectively. The sediment delivery ratio (transporting capacity of the river bed) indicates that almost near to half of the eroded sediment remain in the basin before reaching to the inlet of the reservoir. Based on this value, the sediment yield to the dam from 2001 and 2010 land use scenarios were 157.7 Mton/year and 194.8 Mton/year respectively. Using the estimated dry bulk density of 1.39 ton/m^3, the volume of catchment sediment yield to the reservoir inlet were 113.5 Mm^3/year and 140.1 Mm^3/year for 2001 and 2010 land use scenario respectively (table 6.5). The difference in sediment yield from the catchment by the two land use scenario was due to the difference in soil erosion rate as it was reported above. The area specific sediment yield or net sediment contribution from a unit area of catchment were 51.2 and 63.3 ton/ha/year for 2001 and 2010 scenario respectively. These values are by considering that all the catchment area has same sediment contribution. But in the actual case, the sediment yield is spatially varied from place to place due to the difference in catchment characteristics such as land use condition, topography, soil type and even rainfall pattern. However, since the purpose of this research was to know the sediment yield at the final drainage point of the dam, spatial variation of soil erosion rate was not considered.

Table 6.5: Net sediment yield to the reservoir with 2001 and 2010 land use scenario

	LUS_2001	LUS_2010
River slope (%)	0.54%	0.54%
Sediment delivery ratio (%)	49	49
Soil loss rate (ton/ha/year)	104.5	129.2
Dry bulk density (ton/m^3)	1.39	1.39
Sediment yield to the dam in weight basis (Mton/year)	157.5	194.8
Area specific sediment yield (ton/ha/year)	51.2	63.3
Sediment yield to the dam in volume (Mm^3/year)	113.3	140.1

6.1.3 Rate of reservoir sedimentation

Sedimentation rate of Tekeze dam was computed by determining the trap efficiency of the dam using different empirical models. The trap efficiency value of each method is given in table 6.6 and 6.7 below. As the result indicates, there is no significant difference between the different empirical equations that have been used in the estimation of reservoir rate of sedimentation. Hence, the average value of the above four trap efficiency empirical methods has been used in the further analysis that needs this parameter as an input such as estimation of the reservoir lifespan and organic carbon content estimation. The dam had a trap efficiency of 97.54% during the year of the first impoundment in 2009. From the projected trap efficiency analysis, the initial TE value in 2009 which was 97.54% is reduced to 97.13% in 2038 and to 96.96% in 2045 using the 2001 land use scenario. On the other hand, from 2010 land use scenario, the initial value which was 97.54% in 2009 reduced to 96.97% in 2038. (See Table 6.6 & 6.7 below)

Table 6.6: Trap efficiency of the above four empirical methods with 2001 land use scenario

	Year	2009	2016	2029	2038	2045
Land Use Scenario _2001	Net Capacity (BM^3)	9.30	8.53	7.09	6.10	5.33
	TE_Brune	94.75	94.7	94.59	94.48	94.37
	TE_Brown	99.84	99.83	99.79	99.76	99.73
	TE_Gills	97.61	97.58	97.48	97.39	97.3
	TE_Siyam	97.95	97.77	97.32	96.89	96.45
	Average Trap Efficiency_2001	97.54	97.47	97.3	97.13	96.96

Table 6.7: Trap efficiency of the above four empirical methods with 2010 land use scenario

	Year	2009	2016	2029	2038	2045
Land Use Scenario_ 2010	Net Capacity(BM^3)	9.3	8.34	6.57	5.35	4.4
	TE_Brune	94.75	94.69	94.54	94.37	94.19
	TE_Brown	99.84	99.82	99.78	99.73	99.67
	TE_Gills	97.61	97.57	97.44	97.3	97.15
	TE_Siyam	97.95	97.72	97.11	96.46	95.72
	Average Trap Efficiency_2010	97.54	97.45	97.22	96.97	96.68

As the value shows in both scenarios, there is no significant change in the trap efficiency value after the dam functioning for several years. Due to this the average trap efficiency value over the reservoir expected lifetime by each scenario was computed and found to be 97.17% and 97.28% for 2010 and 2001 land use scenario respectively. Despite the difference is very minor, the reason for more trap efficiency value by 2001 land use scenario was due to less sediment yield from the watershed and as a result relatively more storage capacity available to store the inflow water which gives time for the soil particles to be trapped.

Using the sediment yield of 2001 and 2010 land use condition and their respective average trap efficiency, the rate of sedimentation to the dam were 153.2 Mtones/year and 189.3Mtones/year respectively. Reservoir rate of sedimentation has a direct relation with trap efficiency of the dam. In simple word, the more the trap efficiency, the more sediment will be trapped or deposited in the reservoir. From the result, 97.17% and 97.28% of the coming sediment by 2010 and 2001 scenario respectively will settle down to the reservoir bottom over the reservoir useful lifetime by each scenario while the remaining 2.83% and 2.72% respectively pass and go further downstream of the dam.

In the estimation of sediment volume deposited in the reservoir, the dry bulk density was chosen instead of wet bulk density. This was due to the interest of knowing the net volume displaced by the sediment itself. Even if there is water inside the pores of sediment, it is part of the reservoir water and cannot be considered as the sediment displaced volume. Thus, with the estimated dry bulk density of the soil which is 1.39 ton/m^3, the rate of sedimentation in volume base became 110.2Mm^3/year and 136.2 Mm^3/year for 2001 and 2010 land use condition respectively. This value shows that the 2010 land use condition has increased the annual rate of sedimentation by 23.6% compared to the 2001 land use scenario which will reduce the reservoir capacity and lifetime by the same proportion. Besides the sediment yield from the basin, trap efficiency of the dam is the most important parameter determining the volume of sediment deposited in the reservoir. From the graph drawn with trap efficiency versus net storage capacity, it shows a strong linear correlation with the R^2 value of 0.89 (figure 6.3). This correlation indirectly shows the inverse relation of reservoir storage loss with trap efficiency of the dam since the net storage capacity depends on the annually trapped sediments in the reservoir.

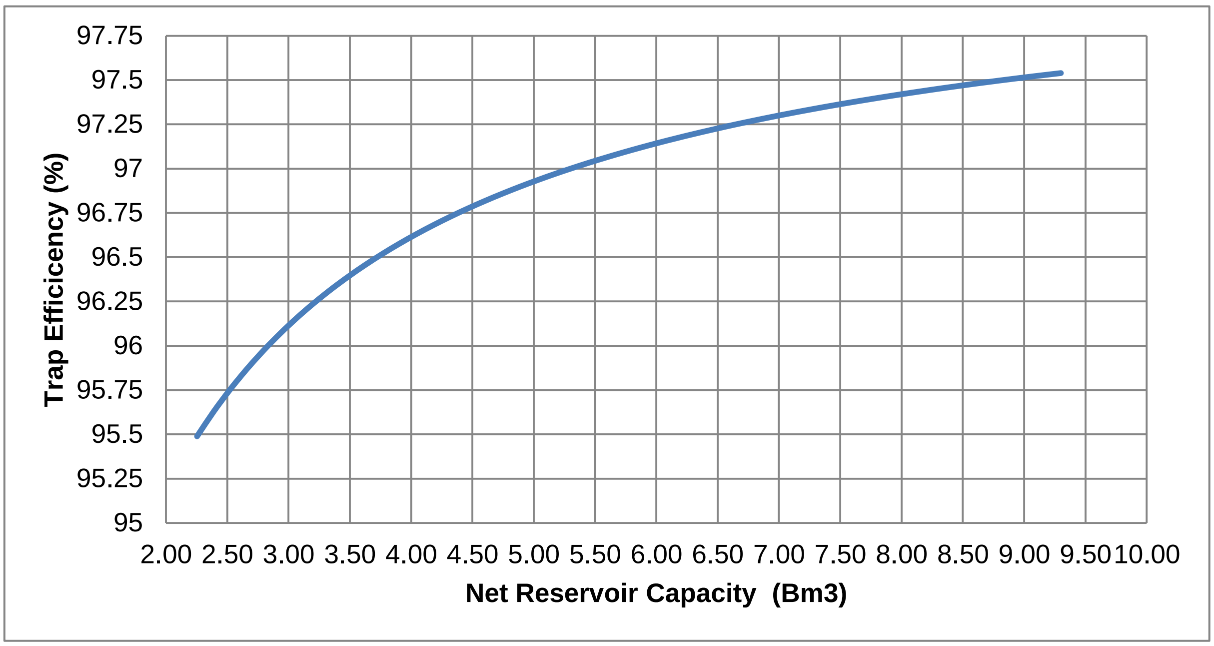


Figure 6.3: Correlation between reservoir net storage capacity and trap efficiency using the 2010 land use scenario

Use full lifetime of Tekeze dam with land use change scenario

The change in sediment yield from the watershed determines how long the dam will stay by providing the full intended services. Land use scenarios considered in this paper for Tekeze dam watershed provided a significant change in the sediment yield which finally affects the useful lifespan of the dam. Continuous analysis of change in storage capacity and trap efficiency of the dam in annual basis has been considered in the estimation of a useful lifetime of the reservoir.

The result indicated that the two land uses have an average annual capacity losses of 1.47% and 1.19% of the original capacity for 2010 and 2001 land use scenarios respectively. The expected annual capacity loss during design was less than 1% (Inauguration report, n.d.), which shows underestimation in sediment yield during the feasibility study. By the estimated rate of loss in this research, 8.33% of the original capacity would have lost so far by 2001 land use condition but due to change in land use to 2010 condition, the estimated storage loss became 10.28% of original capacity (table 6.8). From the projected capacity loss analysis, the dead storage of Tekeze dam which was around 43% of the total original dam capacity was projected to be lost in 2045 by 2001 land use scenario and in 2038 by 2010 land use scenario. Means that, the useful life of Tekeze dam is estimated to be 36 years and 29 years from the year of impoundment which was in 2009 respectively for 2001 and 2010 land sue scenario. However, the design lifetime of the dam was 50 years which is by far greater than nearly double of what is estimated in this paper and by Afiworke, (2006) report as well in Tekeze dam (cited from Ahmed and Ismail, 2008). Despite this report, using the 2010 land use scenario which might be close to the actual land use during impoundment, the reservoir service is expected to end up in the coming 22 years from now (table 6.8).

Table 6.8: Annual capacity loss and projected capacity loss

	Age of the dam at 2016 (years)	Capacity loss from 2009 - 2016 (%)	Annual capacity loss (%)	Projected capacity loss at 2038 (%)	Projected capacity loss at 2045 (%)
Scenario_1_ 2010	7	10.28	1.47	42.6	52.89
Scenario_2_ 2001	7	8.33	1.19	34.50	42.82

6.1.4 Gross emission of greenhouse gases (CH_4 and CO_2)

Using GHGs Risk Assessment Tool, the simulated results of gross emission of CO_2 from Tekeze dam via diffusive flux in the reservoir surface was 722 mg C-CO_2 m^{-2} d^{-1} in current reservoir age (2016) and 312 mg C-CO_2 m^{-2} d^{-1} averaged for 100 years of the dam life. The tool also provided a range of values with 67% confidence interval to avoid uncertainty and these limits were 314 mg C-CO_2 m^{-2} d^{-1} and 1661 mg C-CO_2 m^{-2} d^{-1} for the current reservoir age estimation and 287 mg C-CO_2 m^{-2} d^{-1} and 339 mg C-CO_2 m^{-2} d^{-1} to the estimation averaged over 100 years (see table 6.9 and figure 6.4a below). However, from the projected lifetime analysis, the expected lifetime of the dam until the total storage capacity of the reservoir (dead plus live storage) fully silted is around 68 years by 2010 land use scenario (see Appendix 1). Due to this, the CO_2 diffusive flux over 68 years was computed and the value was 366.26 mg C-CO_2 m^{-2} d^{-1}.

The tool also provided the level of emission of CO_2 and CH_4 by comparing with the distribution of observed dataset from different reservoirs worldwide that have been used during the model calibration. Thus, the level of gross CO_2 emission in the current reservoir age was high and there is a need of taking action in assessing the current net emission of CO_2 from the dam. However, according to the threshold value given for comparison with the datasets, the emission value averaged over 68 years of reservoir age was in medium level and no need of assessing the net GHG emission unless it indicated by other predicted values.

Table 6.9: Simulated result for gross emission of CO_2 by diffusive flux

Results of the simulations - GROSS GHG EMISSIONS*

Period for estimation	Predicted **gross*** annual CO_2 flux (mg C-CO_2 m^{-2} d^{-1})				Action required
	Predicted value	67% confidence interval Lower limit	Upper limit	Compared to calibration dataset	
Selected Reservoir Age	**722**	314	1661	HIGH	Consider assessing Net GHG
Average over 100 years	**312**	287	339	MEDIUM	No need to assess Net GHG, unless indicated by other predicted values

Similarly, the gross annual diffusive flux of CH_4 emission was simulated and found to be 114 and 82 mg C-CH_4 m^{-2} d^{-1} for the current reservoir age and averaged over 100 years respectively. The range of variability with 67 % confidence interval was 32 and 404 mg C-CH_4 m^{-2} d^{-1} for the current reservoir age and 72 and 93 mg C-CH_4 m^{-2} d^{-1} for the value averaged over 100 years (table 6.10 and figure 6.4b). The gross CH_4 diffusive flux was also simulated for over 68 years like CO_2 estimation and the value was 85.6 mg C-CH_4 m^{-2} d^{-1}.

Compared to the distribution of observed dataset used in the model calibration, the simulated annual CH_4 diffusive flux from Tekeze dam was at a high level for the selected reservoir age and averaged over 68 years as well. As a result, the model recommended considering the net assessment of GHG from the reservoir.

Table 6.10: Simulated result for gross emission of CH_4 by diffusive flux

Period for estimation	Predicted **gross*** annual CH_4 diffusive flux (mg C-CH_4 m^{-2} d^{-1})				Action required
	Predicted value	67% confidence interval		Compared to calibration dataset	
		Lower limit	Upper limit		
Selected Reservoir Age	**114**	32	404	HIGH	Net GHG assessment recommended
Average over 100 years	**82**	72	93	HIGH	Net GHG assessment recommended

As the graph given in figure 6.4a and 6.4b indicates the flux of CH_4 and CO_2 is very high at the early age of the dam and rapidly drop and becomes relatively constant after the age of roughly 20 years from impoundment. This result supported the report of Mendonça et al., (2012) that hydropower's emitted more GHGs in the first twenty years after impoundment. Despite the high amount of emission of CH_4 and CO_2 in the first 20 years, their emission to the atmosphere is continuous over the dam lifetime in relatively low level compared to the initial emission (see Appendix 2 for detail values). Despite the end of the dam services at 2038 using 2010 land use scenario, the emission is continuous due to the presence of high retention time of river water in the reservoir even after the loss of dead storage allocated for sediment deposition (see Appendix 1).

(a) (b)

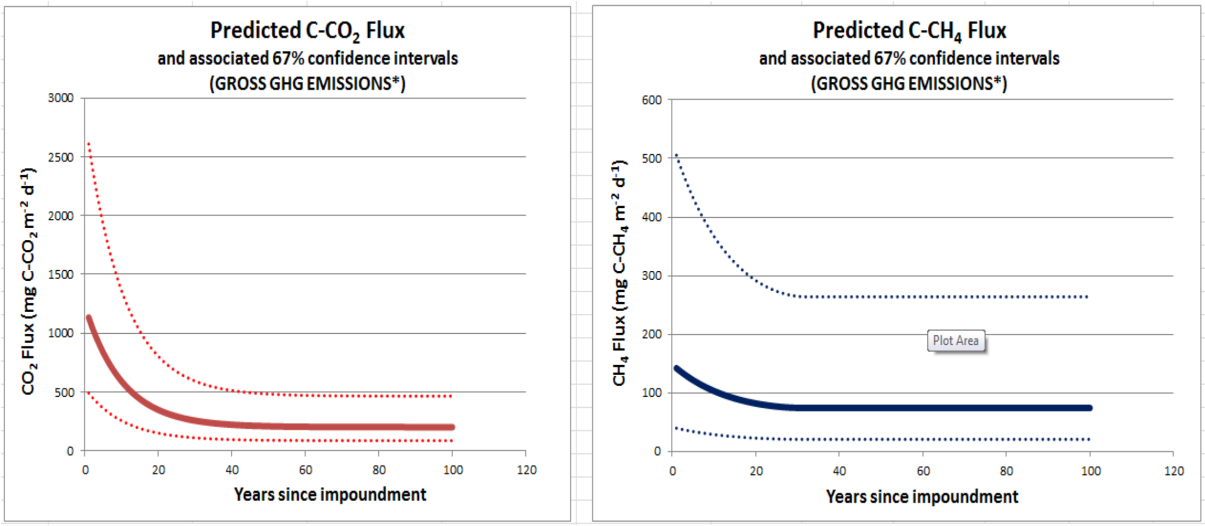


Figure 6.4: Predicted gross emission by diffusive flux over 100 years (a) for CO_2 and (b) for CH_4

6.1.5 Trends of GHGs emission amount due to land use changes effect on sediment yield

The land use condition in the catchment of the dam was identified as one of the factors that determine the level of GHG emission from the reservoirs (UNESCO/IHA, 2016). This is mainly due to its role in determining the sediment and nutrient load and surface runoff from the catchment. The trend of GHGs emission due to change in sediment yield from the catchment have been done by considering the sediment yield effect on the organic carbon budget of the reservoir and retention time of water in the reservoir. The expected emission result from the above two angles is given below in detail.

Organic carbon estimation with land use changes scenario

The organic carbon load from the catchment directly related to the sediment yield amount. The more the sediment yields the higher organic carbon and nutrient load from the watershed. As the result indicated, the annual organic carbon yield was 1.48 Mton and 1.82 Mton for 2001 and 2010 land use scenario respectively. The change in land use from 2001 to 2010 condition has increased the organic carbon yield by 23% which is approximately the same percentage with sediment yield difference between the two scenarios (table 6.11).

Therefore, regarding the organic carbon contribution of the catchment, the emission of greenhouse gases is expected to be high by 2010 land use scenario than the 2001 land use condition. This is because of the more organic matter is available relatively in 2010 land use scenario which might be available in the GHGs production.

Table 6.11: Change in Organic Carbon Yield with the two land use scenarios

Land Use Scenario	Organic Carbon content (%)	Rate of Sedimentation (Mton/year)	Annual total organic carbon yield (Mton/year)	Change in OC yield (Mton/year)	Change in Organic Carbon yield (%)
2001	0.963	153.2	1.48	0.34	23
2010	0.963	189.3	1.82		

Retention time due to change in sediment yield

The retention time of water in the dam depends on the storage capacity of the reservoir, stream flow amount and reservoir operation rule which determines the discharge rate from the dam. Thus, any factors that affect the above-mentioned factors indirectly influence the retention time of water. For example, trapped sediments by the reservoir reduce the storage capacity and due to this the retention time of the inflow water will reduce.

By the empirical formula given in equation (13), the retention time of water in Tekeze dam was estimated using the two land use scenarios effect on sediment yield. As the analysis indicates, land use condition in 2010 has less retention time than the 2001 land use scenario (figure 6.5). In 2010 land use scenario, the reservoir capacity is getting lost rapidly than what could be in 2001 land use condition. Due to this, the reservoir water is forced to get off the reservoir faster by 2010 than 2001 land use scenario.

As a result, the 2001 land use condition has a high potential for greenhouse gases emission than 2010 land use scenario. As the projected retention time is given in (appendix 1), the 2010 land use scenario will have almost close to zero retention time by 2077 while in 2001 land use condition the retention time will be approximately zero by 2094. Thus, from the overall dam lifetime, the 2001 land use condition has more greenhouse gases emission potential than 2010 land use scenario.

From the two greenhouse gases (CO_2 and CH_4), in particularly CH_4 emission from the reservoir depends on the retention time of the inflow water. This is because of the relationship between retention time and creation of stratified layer in the water body which can lead to the presence of anoxic layer in the reservoir bottom. The more the retention time has the more chance for the creation of stratification and then anoxic region. Thus, from the analysis of retention time, the 2001 land use scenario has the potential to emit more CH_4 relative to CO_2 than the 2010 land use condition in the given year. Of course, the CO_2 emission is still in high potential by 2001 land use scenario but looking at the two gases need for being produce, CH_4 has a favorable condition to be produced due to more retention time. The presence of longer retention time is not that much significant for CO_2 emission amount relative to CH_4 since the anoxic region is not required for CO_2 production.

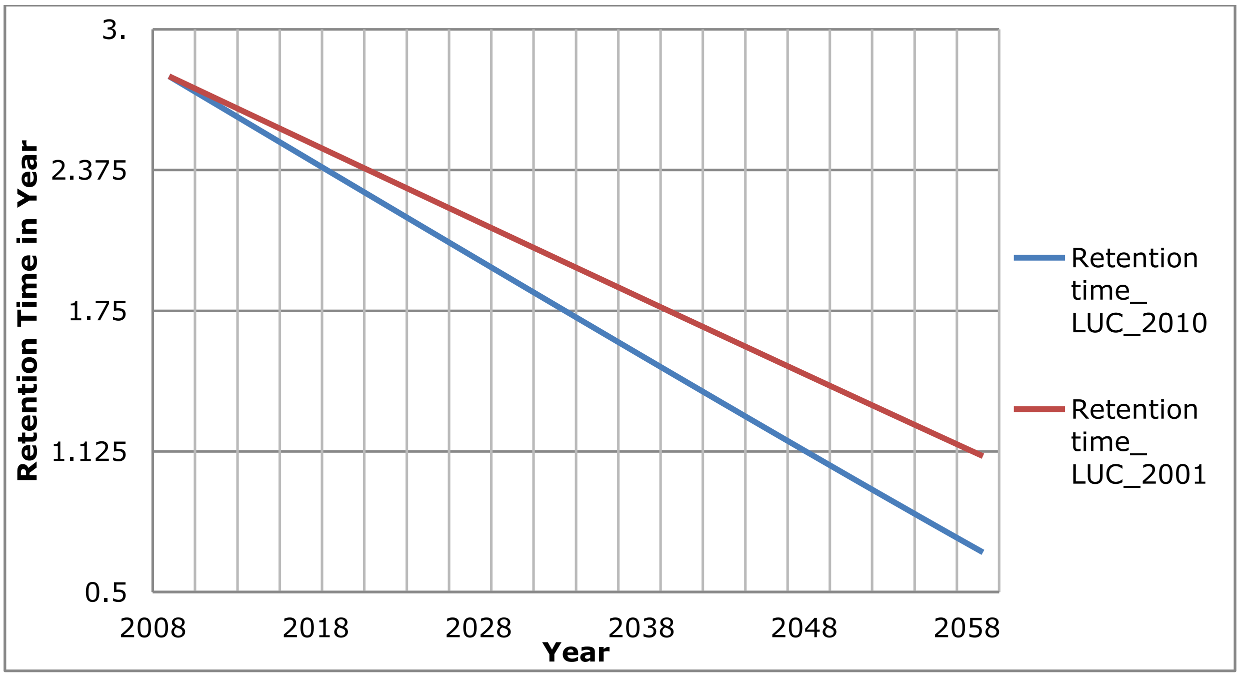


Figure 6.5: Retention time of water with time, due to change in sediment yields by the two land use scenarios.

6.2 Discussions

In this section, the estimated results have discussed by comparing with same research conducted in the study area and in other areas as well which may have a relation with the study. The methods/approach that has been used during the research have also discussed with the possible condition that might change the results from what has been found in this paper. The implications of each result have discussed to know what the estimated value indicates. What is the reason behind the estimated value of each result have discussed in detail as well in order to know the attributed catchment condition to the estimated results. For example, the possible reasons for high sediment yield in the study area and the reason for the simulated result of GHGs emission to be high in the beginning and decline after sometimes have discussed in detail. In addition, the actual conditions of the study site with the assumption considered in the simulation have been compared and discussed the differences which may possible deviate the result. Regarding the effect of sediment yield on GHGs emission, the possible relation of the sediment yield and carbon budget of the reservoir by the two land use scenarios have mentioned and discussed the possible trends of emission by each relation and finally conclusion has been made on the overall results and future prospects.

6.2.1 Soil erosion rate and sediment yield from Tekeze dam basin

The soil erosion rate and sediment yield analysis of Tekeze dam watershed with both 2001 and 2010 land use scenario indicated that the level of soil erosion from the area was very severe. According to FAO soil erosion tolerance limit which is 11 ton/ha/year (FAO, 1986) and soil tolerance limit of Ethiopia which is between 2-18 ton/ha/year (Tamene L. et al., 2005b), the estimated rate of soil erosion by the 2001 and 2010 land use scenario exceeds by far from both limits. This erosion problem endangers the productivity of the area and the useful life of any waterworks at downstream including Tekeze dam.

The northern Ethiopian highlands have already been identified as the most erosion-prone area in the country (Ermias A. et al., n.d.). The rate of soil loss found in this paper is agreed with other research output conducted in the Blue Nile and in the Ethiopian highlands, despite the difference in the model that have been used for prediction and area of emphasis. The estimated annual soil loss rate and sediment yield result from Tekeze dam watershed were

129.2 ton/ha/year and 63 ton/ha/year respectively with 2010 land use condition. These findings are more or less similar with Tamene and Le, (2015) recent report on the Blue Nile basin, which has the same topographic and environmental condition, that the gross soil loss rate and sediment yield were estimated to 140 ton/ha/year and 85 ton/ha/year respectively.

However, the USLE model gives an estimation of only sheet and rill erosion and does not consider gully and river bank erosion in the watershed. In this regard, the estimated soil loss rate value presented in this paper might be underestimated from the actual amount. Because the river water has a high velocity due to a concentrated (high volume) flow and this creates a high erosive power to detach and transport soil materials along the river bank. But the level of risk depends on the type of material in the river bed that whether it is rocky or not which determines the resistance to the running water.

Reasons for high sediment yield

The catchment sediment yield amount is a cumulative result of geomorphological characteristics of the catchment, hydrological condition, soil type, and land use condition. The main causes of large sediment yield in the study area are largely attributed to soil type, topographic condition, and land uses. The first two aspects are natural characteristics of the catchment and cannot be interfered by a human to a large extent. However, the later one is the main catchment characteristics by which mainly anthropogenic effect on catchment erosion risk is reflected. Because of the people can change the land use from one to the other type depending on their interest. The effects of land use have discussed in detail later down.

Regarding the soil condition, the dominant part of the watershed has loam soil type with a high percentage of silt soil particles. This soil type covers around 71% of the catchment area and they are highly susceptible to erosion risk than sand and clay soil type. Because they are small in size than sand particle and they don’t have a strong cohesive force between particles relative to clay soil. As a result, they can easily detach and transported from their original place to downstream by water. That is also one of the main bases why the empirical equation used to compute the soil erodibility factor has a direct relation with silt percentage while inversely related with sand and clay due to their less vulnerability for erosion.

Together with soil type and land use condition, topographic characteristics of the catchment have large attribution to the high results of soil erosion rate and sediment yield to the dam. This is due to its influence mainly to the transportation phase of soil erosion which is the soul of soil erosion processes. The dominant part of the watershed is placed in a highly mountainous area with a slope ranges from 0% to 644% which makes it very vulnerable to erosion risk. Around 65% of the watershed has an altitude of 1800m and above (figure 6.6). In the steep slope area like Tekeze dam basin, the rainwater that reaches to the ground will not have enough time either to infiltrate down to the soil or even to evaporate back to the atmosphere which will reduce the water loss in the catchment. This will increase the amount of runoff generated from the area and finally increase the detaching and transport capacity of the runoff water which will end up with high sediment yield at the down-gauging station. In addition, when the rainfall directly hits the bare soil surface, the dominant part of the splashed particles will move to the downslope direction instead of uniformly distributing to all direction like what is usually happen in a gentle slope. With these main reasons, the topographic condition of Tekeze dam watershed highly attributed to the high rate of soil erosion from the basin.

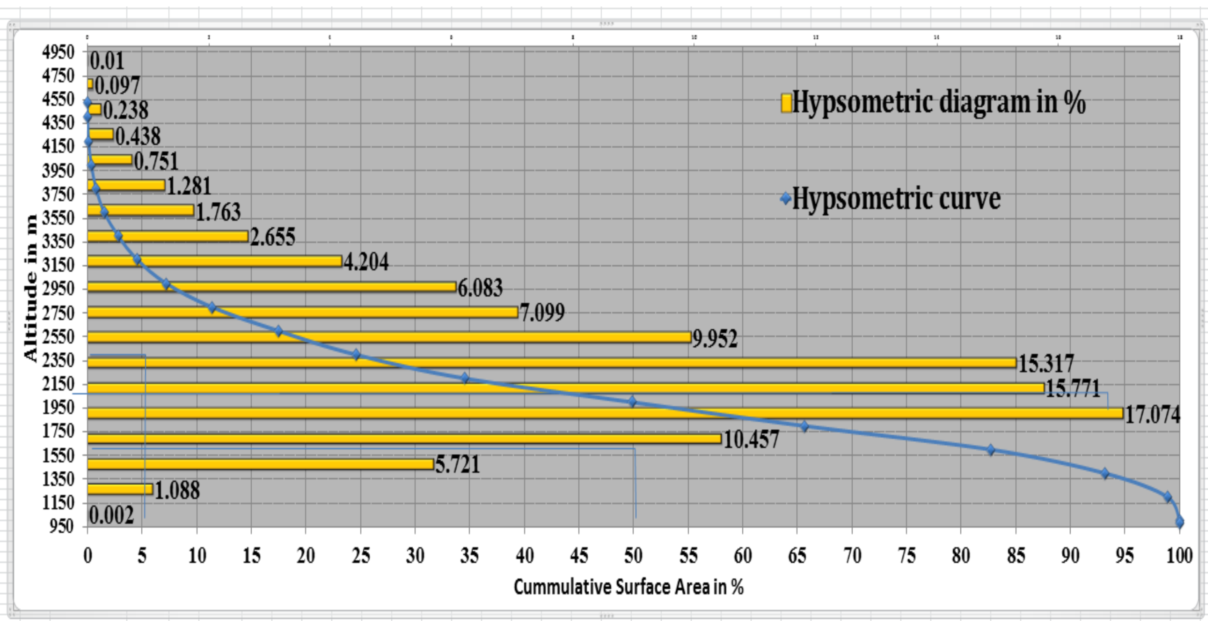


Figure 6.6: Hypsometric curve of Tekeze dam watershed

Tamene and Le, (2015) reported that from the average gross soil loss of white Nile basin which was estimated to 85 tons/ha/year, only 6 tons/ha/year reached to the Nile River due to the flat landscape of the region. In contrary nearly 60% of the gross soil loss from the Blue Nile reached the final drainage point (Tamene and Le, 2015). Tekeze dam watershed is a part of Nile basin which is adjacent to the Blue Nile basin and has same catchment geomorphological characteristics. Ahmed and Ismael, (2008) also mentioned that the contribution of White Nile to the Nile sediment discharge rate is less than 5% and on the other hand the Blue Nile has a contribution near to 90% to the Nile sediment discharge rate. These sediment delivery variations are endorsed to slope condition of the watershed. In this research, the sediment delivery ratio was estimated to 49% and this value is exactly the same with what was estimated by Tekeze hydro study (Tarek M., 2016). This result shows that almost half of the sediment eroded from the catchment can reach to the reservoir area of Tekeze dam which is somehow closer to the Blue Nile sediment delivery reports by (Tamene and Le, 2015).

Effects of land use change on sediment yield

The roles of vegetation to soil surface are like a protective cover against erosion problem by their over ground vegetation and root system as well. It determines the soil resistance to the direct raindrop impact and erosive power of runoff water. The good land cover used as a barrier and gradually break down or dissipate the erosive force (kinetic energy) of the flowing water and then sediment yield.

Bieger K., (2013) reported that a little change in land use can bring a significant change in the sediment yield to downstream. The land use changes with a massive expansion of cultivated land have occurred between 2001 and 2010 in Tekeze dam watershed. As it was given in Table 6.3 above, the cultivation land increases by 15.2% at the expense of other land uses such as savanna which decreased by 13% and grassland by 3.7%. Forest land, permanent wetland, and urban area were decreased by 0.74%, 0.001 and 0.002% respectively. The decreasing of urban area in the basin looks strange but might be due to the low resolution of MODIS land use product which is 500m and it may have a bias in weighting between more than one land use types. For instance, if there were two land uses in one grid or pixel of the image, the satellite will give one of them which are dominant in area coverage. Because the resolution does not allow to detect land uses with the very small area.

In general, by the overall changes in land use from 2001 to 2010, the gross soil erosion rate increased from 104.5 ton /ha/year to 129.2 ton/ha/year respectively. Expansion of cultivated land at the expense of other land uses is the main reason for high soil erosion rate in 2010 land use scenario than 2001 land use condition. Because, in cultivated land, there are continuous tillage operations that need to be carried out during land preparation. This activity will disturb the soil and loosen the aggregate stability of the soil structure and make it susceptible to erosion problem. This significant difference of soil loss rate in the two land use scenarios highly reflected how the land use condition of the catchment determines the risk of soil erosion and sediment yield in the downstream.

6.2.2 Trap efficiency of the reservoir

Many reservoirs in the beginning of their construction have high trap efficiency value due to larger in their storage size (Eizel-Din et al., 2010; Sultan and Naik, 2015). The reservoirs with a high volume of storage capacity can able to store the inflow water for a long time. From the results of trap efficiency analysis using different empirical methods, the predicted initial and projected trap efficiency of Tekeze dam was very high. The estimated average trap efficiency value during impoundment was 97.54%. The trapping efficiency value was also computed by comparing with the two land use scenarios which have different sediment yield and found a slight difference in value (see table 6.6 and 6.7 above). This was due to the difference in the effect of sediment yield to the reservoir net storage capacity. Because of the higher sediment yield leads to the lower net storage capacity available to store water. And the reservoir net storage capacity and trap efficiency value have shown a strong linear correlation with the R^2 value of 0.89. In this case, the 2001 land use scenario has less sediment yield than the 2010 scenario and as a result gives higher TE value when it compares in annual basis despite it is a very small difference. For example, the projected trap efficiency values at 2038 (after 29 years from impoundment) were 97.13% and 96.97 % for 2001 and 2010 land use condition respectively. The projected trap efficiency value by each scenario is given in table 6.12 below.

Table 6.12: Results of Projected trap efficiency analysis

year	2009	2016	2029	2038	2045	2059	2069
Average Trap Efficiency_LUS_2010	97.54	97.45	97.22	96.97	96.68	95.48	92.49
Average Trap Efficiency_LUS_2001	97.54	97.47	97.3	97.13	96.96	96.42	95.67

The projected TE value showed that there is no significant change in trap efficiency value even after the loss of the dead storage of the dam. From the estimation found in the above result, the majority of the sediment will be trapped by the dam for the next 60 years. Even though the reservoir capacity gets lost, the trap efficiency will not be reduced significantly due to less in the annual river flow amount relative to the net storage capacity.

Use full lifetime of the dam

The predicted use full lifetime of the reservoir was 36 years and 29 years respectively for 2001 and 2010 land use scenario. Means that, the land use change from what was in 2001 to land uses in 2010 reduced the use full life span of Tekeze dam by 7 years. However, the designed lifetime of the dam during construction was 50 years which seems unlikely to get the intended service for this duration. Because assuming that the 2010 land use condition was not different from the actual land use during impoundment in 2009 and will continue as it was for the coming years, the predicted lifetime with this land use condition was 29 years which is only 4 years more from the half of the design lifetime. The lifetime of Tekeze dam has been computed by Aforkis, (1996) (cited from Ahmed and Ismael, 2008) and reported that the dam's dead storage will be lost within 25 years which was very close to what is estimated in this research using 2010 land use scenario. Thus the reservoir capacity allocated for sediment deposition (dead storage) will be fully displaced by sediment at 2038, almost 22 years from now. This is by assuming that no change in all parameters that have been used in the analysis of sediment yield and there will not be sediment management activities and design modification may be by increasing the spillway and freeboard height which may alter the storage capacity as well.

Even though the dead storage allocated for sediment deposition is expected to be full for example by 2038 using 2010 land use scenario, the actual use full lifetime of the dam might be less than the anticipated. Because of the deposition pattern is very important to determine where the sediment is actually deposited either inactive storage or dead storage. The above analysis was just volume based by considering only the volume of sediment entering the reservoir area and comparing with the allocated dead storage volume.

However, in the actual case, all the sediment may not settle in the dead storage rather part of it can deposit in active storage. The deposition pattern of the sediment is highly governed by the topographic condition of the reservoir area and the type of sediment load. In the study area, the sediment deposition is expected to be uniform over the reservoir area due to the high suspended sediment loads which are not highly sensitive to gravity effect to slide down to the bottom of the dam.

In hydropower dam, the water height above the turbine is what matters in its power generating capacity. The storage space below the turbine has no relation to power generating capacity unless used to store the sediment. When the particle deposited in the active storage, it will reduce the height and volume of water that exist above the turbine location. This finally affects the power generating capacity of the dam and indirectly the expected use full lifetime.

Therefore, even if the volume of sediment that reaches to the dam is less than the volume of reservoir allocated for sediment deposition, the dam may not generate power as expected due to deposition of sediment in active storage. In other word, volume alone is not enough to determine the hydropower dam lifetime. Where the sediment deposited is a key to be determined for the accurate estimation of useful lifetime of the hydropower. Such analysis needs information about the original topographic condition of the reservoir area and a continuously taken bathymetric survey results. Since Tekeze dam is new, it was not possible to get the bathymetric survey for the reservoir area.

6.2.3 Emission of greenhouse gases (CO_2 and CH_4) from Tekeze dam reservoir

Even though GHGs emitted from the natural river system, the construction of dam and water impoundment in the upside of the dam changes the carbon cycle through altering several carbon transformation processes. This is due to the fact that, first, the created water body has much longer residence time than the river during the pre-impoundment condition and it gives time for biological processes and sediment deposition which is one of the sources of carbon in the reservoir. Second, it changes the physical and chemical environment of the carbon pool which leads to a rapid degradation of the inundated vegetation and/or submerged soil organic matter and this increase the production of greenhouse gases that can be released to the atmosphere in different ways (UNESCO/IHA, 2010).

The resulted current gross emissions of CO_2 and CH_4 by diffusive flux were 722 mg C-CO_2 m^{-2} d^{-1} and 114 mg C-CH_4 m^{-2} d^{-1} respectively. Whereas the potential emissions which are averaged over 100 years were 312 mg C-CO_2 m^{-2} d^{-1} and 82 mg C-CH_4 m^{-2} d^{-1} for CO_2 and CH_4 respectively. These estimated values given by the tool includes the potential emission before impoundment, emission from reservoir due to unrelated anthropogenic sources and emission due to the creation of the reservoir (post-impoundment emission). The estimated value in this paper does not show the actual or net effect of the reservoir on greenhouse gas emission. Compared to the datasets that have been used in the model calibration, the current gross emission levels of CO_2 and CH_4 are high. As a result, the tool recommended consideration of the net emission of GHGs in order to exactly know the net effect of the reservoir on greenhouse gases contribution to the atmosphere.

According to St. Louis et al., (2000) report on the global rough estimation of greenhouse gas emission, a tropical reservoir with an age of between 1-2 years has a flux of 3500 mg m^{-2} d^{-1} of CO_2 (954.5 mg C-CO_2 m^{-2} d^{-1}) and 300 mg m^{-2} d^{-1} (225 mg C-CH_4 m^{-2} d^{-1}) of CH_4. The estimated average fluxes of CO_2 and CH_4 within the first two years from Tekeze reservoir were 1,191.66 mg C-CO_2 m^{-2} d^{-1} and 145 mg C-CH_4 m^{-2} d^{-1} respectively, which is a very close result with the above report in global extent. This may show the good performance of GHGs risk assessment tool for rough estimation of gross emission of greenhouse gases from reservoirs.

Regarding the emission level averaged over 100 years, the CO_2 emission level is medium compared to the dataset used in model calibration. Due to this, there is no need of assessing the net emission of CO_2 over 68 years of the dam life unless it is indicated by other predicted values. Whereas for CH_4 emission amount, it is in high level and assessing the net emission level is highly recommended. This might be due to the high global warming potential of CH_4 than CO_2. According to (UNESCO/IHA, 2010) report, a little change in the emission of CH_4

should be addressed properly due to its high global warming potential than CO_2 gas. This report also magnifies the high potential effect of Tekeze dam reservoirs on methane emission level than CO_2 over the dam's lifetime. However, will the dam really continue the emission until 100 years as the tool considered have discussed in detail later.

The tool recommendation may show that the long-term effect of reservoirs on CO_2 emission may not be as relevant as CH_4 emission. This may be due to the reason that the CO_2 emitted from the reservoir would have occurred somewhere else downstream even if the dam was not there. The effect of the dam on CO_2 emission might be more of changing the spatial and temporal emission of CO_2. Because there is an emission of CO_2 from terrestrial land and damming the river enhances the decomposition of organic matter and produces more CO_2 than before. The net effect of the initial terrestrial land on CO_2 emission level might be positive by its role for carbon sequestration. But, the emission of CO_2 still exists from the land surface even before impoundment. According to UNESCO/IHA (2010), the largest portion of CO_2 emitted from the reservoir is resulting from mineralization of dissolved organic carbon originating from the dam watershed and mineralization of organic carbon would occur in the river system regardless of the dam existence. However, methane doesn't usually emit from the land surface compared to carbon dioxide unless the anoxic region created which is necessary for methane to be produced. Therefore, construction of dam creates a situation of anoxic layer in the reservoir which is a prerequisite for methane production from the available organic matter. So damming the river clearly brings a new source of methane gas production and emission which could not have occurred before impoundment to the extent of post-impoundment condition.

The remarks given by the tool regarding the need of net GHG emission assessment was by comparing with the distributed datasets that have been used in the development of GHG risk assessment tool. However, the overall characteristics such as climate condition, design specification, operation rules, and the purpose of the dams that have been used in model calibration are surely not exactly similar with Tekeze dam and even any other dams. Together with fewer input parameters used in the tool, the estimated value can give a rough image in the trends of emission level and may not be as accurate as what can be measured directly in the site of Tekeze dam itself.

Due to such uncertainty, the tool provided range values with 67% confidence interval to the current emission level and for 100 years of the reservoir lifetime. One of the possible sources of uncertainty in the model estimation averaged over 100 years is that the difference in the lifetime of dam. Because the value given by the model for 100 years estimation seems that the dam will have some storage capacity for 100 years since impoundment. Although the estimated lifetime of Tekeze dam was 29 years using the 2010 land use condition, the emission of GHGs may not stop or become like the pre-impoundment condition immediately after 29 years. On the other hand, Tekeze dam may not continue as GHG emission source for 100 years to come since impoundment like what was simulated in the GHG risk assessment tool.

For instance, using the 2010 land use scenario which was considered as the actual land use during impoundment, the average yearly projected capacity loss was 1.47%. With this rate of sedimentation, the whole reservoir capacity (both dead and active storage) is expected to be lost at 2077 which is 68 years from the time of impoundment. This will actually happen if there will not be any sediment management measures which may recover the storage capacity. Once the dam is fully filled in by sediment, of course, the water will no longer be stored behind and emission of GHGs due to the reservoir may not be expected at a significant level. Because the water will pass like runoff-river with relatively no residence time like what was before damming (see Appendix 1).

Therefore the simulated greenhouse gases averaged over 100 years was underestimated to some extent. Because the emission of GHG reduced with time and if the 100 years emission value considered while the potential emission from the dam will be for 68 years only, then the emission value above 68 years pull down the mean value since they are expected to be lower relative to the earlier emission values (See Appendix 2). As a result, the estimated gross emission of both CO_2 and CH_4 which is averaged over 68 years of dam lifetime was computed manually by extracting from the 100 years simulated value given by the model and found to be 366.26 mg C-CO_2 m^{-2} d^{-1} and 85.6 mg C-CH_4 m^{-2} d^{-1} respectively. The empirical formula that has been given with the tool guideline (UNESCO/IHA, 2012) in order to compute the limit of uncertainty has been used. Therefore, the limits of uncertainty were estimated to be from 159.24 mg C-CO_2 m^{-2} d^{-1} to 842.4 mg C-CO_2 m^{-2} d^{-1} and from 24.1 mg

C-CH_4 m^{-2} d^{-1} to 303.88 mg C-CH_4 m^{-2} d^{-1} for the averaged emission of CO_2 and CH_4 respectively over 68 years of the dam life. Regarding the need of net emission assessment, CH_4 emission still needs to be assessed as it was suggested by the tool. But, for CO_2 emission level, it does not need net emission assessment compare with datasets used in model calibration.

Using the annually averaged emission amount over 68 years lifetime by 2010 land use scenario, the reservoir has a total emission of 617.4 ton of CO_2 per day using 25 times global warming potential for methane than carbon dioxide. Assuming that the reservoir operates for 12 hours at full installed capacity, the emission level is estimated to be 171.5gCO_2/kwh. Compared to the average emission of GHGs from coal and gas combustion which are 900 gCO_2/kwh and 400 gCO_2/kwh respectively (J. Dermaut and B. Geeraert (n.d.) cited from Steen M., n.d), the estimated emission from Tekeze dam is very low together with its gross emission estimation not even net emission from the dam. But since it is only by diffusive flux without consideration of bubbling and degassing in turbines, it cannot be ignored as irrelevant source and needs to be estimated accurately in the future. Because according to (Abril et al., 2005; Kemenes et al., 2007), emission by degassing in turbines and spillway can be more than double of the emission from ebullition and diffusive flux. Besides this, the Kyoto's Protocol Clean Development Mechanism (CDM) proposal said that if the power density of the project exceeds 10 W/m^2, then emission from water reservoir are set to zero (Fearnside P. M., 2013). However, the power density of Tekeze dam using the installed capacity of 300MW and reservoir surface area at the full level of 147 km^2 (Global Energy Observatory website) is around 2 W/m^2 which is by far below the limit. Therefore, it is necessary to conduct field measurement to see the actual contribution of the dam to greenhouse gases concentration in the atmosphere.

6.2.4 Potential GHG emission level from Tekeze dam compared to the GHG risk assessment tool results

In the Greenhouse gas emission from the reservoir, there are three known pathways which are diffusive flux, ebullition and degassing. The importance of each route in the emission may depend on reservoir design condition, the purpose of the dam, dissolved oxygen in the water, and biochemical condition of the reservoir water in general. The simulated value given by the greenhouse gas risk assessment tool was the gross emission by only diffusive flux over the reservoir surface. It does not include a potential release by ebullition and degassing through turbines and spillways. The bubble emission flux is very important in particular for CH_4 than CO_2 due to high CH_4 production rate in sediments at the reservoir bottom leads to bubble formation (Duchemin, 2000 cited from St. Louis et al. 2000). Because the CH_4 accumulation rate will exceed the rate of vertical diffusion towards sediment-water interface and this leads to supersaturation point of CH_4 and bubble formation (St. Louis et al., 2000).

Degassing also contributes to CH_4 emission since they are expected to be closer to the anoxic region where methane production takes place. Since Tekeze dam is a hydropower dam, the degassing emission is expected to be a significant pathway for GHGs emission. In addition, the dam has outlet valves that used to compensate the downstream user side by passing water at the time of maintenance and/or when it is required. These valves are designed to disperse the water as water jet to downstream in order to avoid scoring effect in the toe of the dam. Due to such possible emission ways like turbines and water jet outlet valves together with ebullition flux which was not considered in the tool, the estimated values given by the tool is expected as underestimated the actual emission flux from Tekeze dam.

Due to the dam location in the deep gorge, the open surface area of reservoir water may not be wide compared to some other reservoirs which have the same storage capacity but located in relatively gentle slope. Reservoirs built in low topographic relief and flood large areas to produce few kwh would produce more greenhouse gases per kwh than reservoirs built in canyons where the little area is flooded (St. Louis et al., 2000). Therefore, the less inundation area by Tekeze dam may give an advantage of less GHGs emissions relative to the dam which has same power generating capacity but built in the gentle area.

Besides this, in the deep reservoir water, the possibility of developing anoxic zone is high despite it depends on another factor such as reservoir operation policy and aquatic life. And methane production needs the presence of oxygen-depleted region which is expected to exist in Tekeze dam’s bottom. The potential production of methane with potential degassing at the downstream of turbines and outlet valves; methane emission might be more significant relatively than carbon dioxide emission.

Keller and Stallard (1994) reported that the frequency and extent of water drawdown in the reservoir can affect the rate of bubbling due to the pressure changes resulted from water level fluctuation (cited from St. Louis et al., 2000). However, the canyon nature of the topography of reservoir area may reduce the potential emission of CH_4 by bubbling. Because the bubbles created at the deep reservoir bottom may not go vertical to the reservoir surface by overcoming the high hydrostatic pressure of the reservoir water due to the deep water column.

6.2.5 Trends of GHGs emission amount with sediment yield change in the reservoir

As the simulated results are given in figure 6.4a and 6.4b indicates, the emission of CO_2 and CH_4 is very high roughly in the first 20 years following impoundment. These high emission rates of GHGs are due to the huge potential of biomass available in the inundated area. The flooded ground surface following the dam construction can be considered as new sources of organic carbon which was not involved significantly in greenhouse production from the river system before impoundment. Even though there is a natural emission from the land surface which is not inundated, it may not be high than what can be emitted after impoundment.

However, the continuity of the inundated area as potential carbon sources depends on the drawdown condition of the reservoir which is affected by water level fluctuation. Because when the surface exposed to sunlight, the vegetation grows up by photosynthesis and increases their biomass which will be available as organic matter source for decomposition during inundation in the flood season or less water withdrawal in the dam outlet. The level of water depth in the reservoir can vary with variations in the stream flow amount, reservoir operation policy which determines the discharge rate from the dam. The draw down condition is also responsible for the spatial and temporal variation of GHG emissions from the reservoir due to its influence in the regeneration of biomass at the reservoir bottom. According to Zhou et al., (2013) report, there is a spatial and temporal variation in the GHG emission amount from Three Georges dam in China as a result of drawdown condition.

The potential effects of land use change on the trends of greenhouse gases emission amount was assessed using the 2001 and 2010 land use scenarios as discussed below in detail. However, the assessment was not by involving all the factors related to land use changes that can influence the greenhouse gas emission from reservoirs. For instance, catchment land use has an impact on the water balance of the basin which can alter the stream flow amount. But only the effect of land uses on sediment yield and its related consequences such as organic carbon budget of the reservoir and change in retention time of inflow water in the reservoir have been analyzed.

The assessment of trends of GHGs emission due to the change in sediment yield was in a qualitative way. This was due to the absence of physical or empirical models that are available at present to estimate the GHG emission by considering all the determining factors including sediment yield. Therefore, it was not possible to put a concrete value about sediment yield effects on GHGs emission level. Rather it was discussed what can be the emission level by raising the possible effects of sediment yield in the organic carbon budget of the reservoir and retention time of the inflow water due to the displaced reservoir volume by sediment deposition.

Sediment yield with organic carbon content

The simulation results of GHGs emission given in figure 6.4a and 6.4b over the reservoir lifetime indicates the continuity of the emission despite less in an amount compared to the initial value following the impoundment. This is an indication of the continuous supply of organic matter by the eroded soil from the catchment. And land use types in the watershed have a significant influence on sediment yields and then amount of organic matter.

The resulted organic carbon estimation for 2001 and 2010 land use scenario were 1.48 and 1.82 Mton/year. This shows that the 2010 land use condition has more organic carbon yield compared to the 2001 land use scenario. The emission of both CO_2 and CH_4 are expected to be high by 2010 land use scenarios regarding the organic carbon contribution. But all the organic carbon may not be decomposed and readily available to join the greenhouse gas production processes. The most degradable type of organic carbon is the liable organic carbon than semi-liable and refractory type. To which extent the organic carbon from the sediment involved depends on the organic matter nature which needs lab analysis. The land use can also influence the organic matter nature in the soil. But, regarding the organic carbon amount, the 2010 land use scenario which has around 23% more organic carbon than 2001 scenario is expected to have high GHGs emission potential.

The impact of sediment yield on greenhouse gases emission is not only by the directly carried organic carbon content but also by the long-term effect in nutrient contribution such as phosphorous and nitrates. Sediments that usually come from the watershed particularly agricultural land are highly enriched with nutrients and flushed inorganic fertilizers. From the two scenarios, it is obvious that the 2010 land use condition has more nutrient addition than 2001 scenario from the result of sediment yield even if there was no analysis of nutrient content. These nutrients addition to the reservoir water causes eutrophication which leads to excess organic matter and depletion of dissolved oxygen in the water. Regarding the organic matter addition, the emission level is expected to be high for both CO_2 and CH_4. But looking at the possibility of the creation of anoxic region due to high biomass addition, it may favor towards high methane (CH_4) production and emission than CO_2. In both ways, the emission level of GHGs (CO_2 and CH_4) is expected to be high by 2010 land use scenario than 2001 land use condition.

In the contrary, even if the organic matter added from sediment increase the organic carbon budget in the reservoir, the deposited sediment in the reservoir bottom may have a positive effect on reducing the potential greenhouse gas emissions. This might happen if the deposited sediment burying permanently the potential carbon sources from the inundated vegetation surface. But this effect may depend on the distribution pattern of sediments and by how much the deposited sediment is enough to inactive the ground surface permanently which needs further research as well. According to Tardieu and Pigeon (2005), the long-term sequestered carbon don't involve in the system of greenhouse gases emission from artificial reservoirs (cited from UNESCO/IHA, 2012). So, if there is a significant effect of sediment on emission level by this way, the 2010 land use scenario will have less emission potential than 2001 land use scenario.

Therefore, from the different directions that have been looked at to see the trend of emission with sediment addition, it may not be possible to conclude absolutely whether it increases or decreases the emission level. Further studies should be carried out to see the overwhelmed direction of sediment contribution on emission level of greenhouse gases. But from the author point of view, the more sediment yield by 2010 land use scenario may have more potential of increasing the GHG emission level than 2001 land scenario. Because the effect of burying the biomass in the flooded area by deposited sediment may not be that much influential. In the initial period following the impoundment, the cumulative deposited sediment amount is less than what could be for example after 30 years. At the same time, the potential biomass in the inundated vegetation will decompose rapidly in the early age of dam. Once it gets fully decomposed in the early age, even if a huge sediment deposited and covered the original ground surface after three 10 years of reservoir life, there might be nothing to lose for reservoir regarding carbon budget from flooded biomass. Because according to (UNESCO/IHA, 2012), reservoirs do not bring new carbon to the hydrosphere-biosphere-atmosphere system, rather changing the short term carbon cycle.

Sediment yield on the retention time of water in the reservoir

The retention time of water is actually one of the most important factors that differentiate post-impoundment from the pre-impoundment condition of the river water. Damming the river stored water behind and gives more time for different biological, physical and chemical processes than the river water in the pre-impoundment condition which keeps going to downstream. Reservoirs with retention time less than 10 days resemble a river zone with a complete mixture of water column while reservoir with retention time more than 100 days can create a stratified layer (StrašKraba 1973; Straškraba et al 1993 cited from De Faria et al., 2015). This leads to the depletion of dissolved oxygen inside the water since there is no frequent water refreshment in the dam by river water which is saturated with dissolved oxygen compared to the reservoir water.

Sediment yield and retention time in the reservoir has an absolutely linear correlation as it is given in figure 6.7 for 2010 land use scenario. As the result of retention time with the change in sediment yield indicates, the 2010 land use condition has less retention time than 2001 land use scenario (table 6.13). This is due to high sediment yield in 2010 land use scenario and the displacement of more volume of the reservoir storage by sediment. From the result of retention time analysis (see Appendix 1), 2001 land use condition is expected to have more greenhouse gases emission than 2010 land use scenario. Because of the reservoir can able to store water for many years in 2001 land use scenario than 2010 condition. By the 2010 land use condition, the retention time at 2079 is almost zero but in 2001 land use condition the dam still has a retention time of approximately 0.49 years which is equivalent to 178 days. According to StrašKraba, (1973) and Straškraba et al., (1993) report where reservoirs which have more than 100 days can create a stratified layer (cited from De Faria et al., 2015), the reservoir water by 2001 land use scenario can create a stratified layer in 2079. But for 2010 land use scenario, the river water will pass the dam like runoff water with relatively no residence time after 2077.

Despite the high possible emission of both CO_2 and CH_4 in 2001 land use scenario, CH_4 has a relatively high potential of emission than CO_2 compared with the possible emission of the two gases by 2010 land use scenario. Because the detention time of river water in the reservoir is very important parameters for CH_4 production in particular. Thus due to more retention time in 2001 scenario, methane has a relatively high possibility to be produced and emit than CO_2.

Table 6.13: Projected retention time of water with land use scenarios

year	2009	2016	2029	2038	2045	2059	2077
Retention time (year)_LUS_2010	2.79	2.5	1.97	1.6	1.32	0.75	0.05
Retention time (year)_LUS_2001	2.79	2.56	2.13	1.83	1.6	1.14	0.55

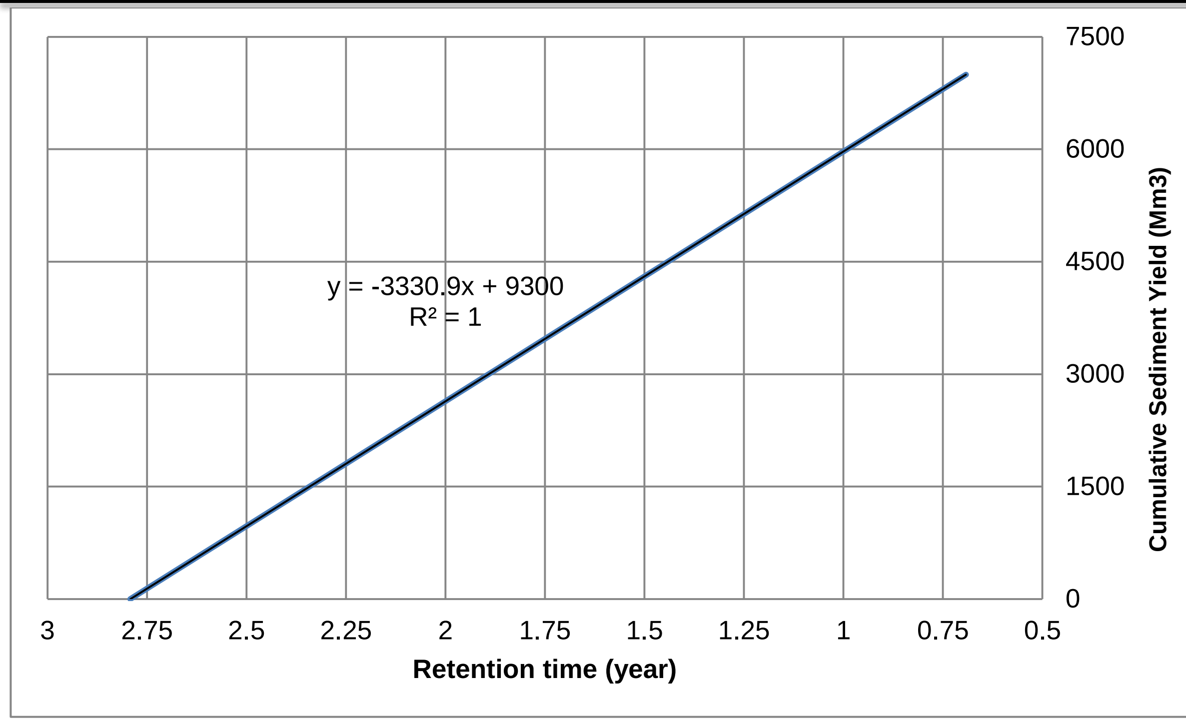


Figure 6.7: Correlation of retention time vs. cumulative sediment yield in the reservoir

In the retention time computation, the information's that have been used were the outflow data and net reservoir capacity. Thus reservoir operation policy has an influence on the retention time of the reservoir water since it determines the outflow discharge rate. In this research, it was assumed that the annual outflow water is equal to the annual inflow volume except for evaporation loss from the reservoir surface. Because it is obvious that the annual outflow water cannot be more than annual inflow volume in the long term. But the annual water demand from the dam might be less than the water potential in the river or inflow volume. This will not bring a problem in the result. Because even if the user did not let the water pass through the turbine, as long as the reservoir capacity is limited, the excess water in the dam will find a way through spillways. From this, the maximum annual outflow rate was assumed to be the annual inflow rate minus the evaporation loss from the reservoir surface. The assumption is in an annual basis and did not consider the monthly variation of inflow and outflow of water. However, in reality, the retention time might vary from month to month due to the seasonal river flow variation which obviously affects the outflow rate.

Chapter Seven. CONCLUSION AND RECOMMENDATION

7.1 Conclusion

Soil erosion and downstream sedimentation problem are the major challenges worldwide for the water resources development particularly for reservoirs by reducing the storage capacity and power generating capacity in case of hydropower dams. Land use change in the watershed is the main factor by which anthropogenic influence is reflected to the risk of soil erosion problem. Secondary data from different open sources have been used to estimate the effect of land use change on sediment yield in the study area. As the sediment yield analysis using universal soil loss equation (USLE) by the two land use scenarios indicated, the expansion of cultivation land at the expense of other land uses from 2001 to 2010 land use condition increase the rate of soil erosion by around 23.6%. This result shows the role of land cover in the watershed to the risk of soil erosion.

However, the difference in trap efficiency of the dam by the two scenarios was not significant due to high reservoir storage capacity compared to the difference in sediment yield volume. Almost above 95% of the incoming sediment can be trapped even after 50 years of dam life in both scenarios. Using the average TE value and dry bulk density of the sediment, the rate of reservoir sedimentation were estimated to 110.2Mm^3/year and 136.2 Mm^3/year for 2001 and 2010 land use condition respectively. This has changed the projected reservoir lifetime from 36 years that could exist by 2001 land use scenario to 29 years which was projected by 2010 land use scenario since impoundment.

Regarding the greenhouse gases emission, the simulated result showed that the gross CO_2 emission amount is 722 mg C-CO_2 m^{-2} d^{-1} and 312 mg C-CO_2 m^{-2} d^{-1} for the current reservoir age and averaged over 100 years respectively. While CH_4 gross emission was estimated to be 114 mg C-CH_4 m^{-2} d^{-1} and 82 mg C-CH_4 m^{-2} d^{-1} for the current reservoir age and averaged over 100 years respectively. Compared to the dataset that has been used to calibrate the model, the current level of CO_2 and CH_4 emission were high and needs consideration of assessing the net GHG emission.

However, since the dam expected lifetime by 2010 land use condition is almost 68 years, the emission level averaged over 68 years were computed and found to be 366.26 mg C-CO_2 m^{-2}

d^{-1} and 85.6 mg C-CH_4 m^{-2} d^{-1} for CO_2 and CH_4 respectively. According to the threshold value given for comparison with the distributed datasets, the CH_4 emission level averaged over 68 years needs net assessment but for CO_2 emission it does not need net assessment of GHG emission unless it is indicated by other measurement tool. The level of emission is very high at the early age of the dam which can coincide with the presence of huge biomass potential following the dam impoundment. However, the above-simulated value is expected to be underestimated compared to the potential emission from Tekeze dam through bubbling and degassing in particular.

The approaches that have been used to see the trends of GHGs emission amount with sediment yield change were by estimating the organic carbon content change and amount of retention time with the two land use scenarios. This was due to the absence of no empirical model or software so far that used sediment yield as an input parameter and estimate greenhouse gas emission from reservoirs. Thus, regarding organic carbon content, GHG emission is expected to be high by 2010 land use condition than 2001 scenario, because of more organic matter addition proportionally with high sediment yield in 2010 scenario. In this case, which gas will be highly produced and emitted depends on other circumstances in the reservoir which determine their production and emission rate. On the other hand, the deposited sediment might have an influence in burying the inundated biomass permanently from being involved in the GHGs production processes.

Regarding the retention time, emission of both CO_2 and CH_4 is expected to be high in 2001 land use scenario due to more retention time than 2010 land use condition. This is because of more reservoir storage volume displaced by sediment in 2010 land use scenario than 2001 land use condition which reduces the retention time of inflow water. Looking at the proportional increment in production and emission rate between the two gases, CH_4 emission is expected to be in high proportion than CO_2 in 2001 land use scenario. Because the retention time is highly significant in particular for CH_4 production than CO_2 and this might give more chance for CH_4 to be produced.

Using the averaged emission value over 68 years of dam lifetime, the emission level of Tekeze dam is estimated to be 171.5gCO_2/kwh by assuming that the dam operates for 12 hours a day at full installed capacity and by using 25 as the conversion factor of CH_4 global warming potential than CO_2. Compared with the coal and gas combustion energy sources which have an averaged emission level of 900 and 400 gCO_2/kwh respectively (J. Dermaut and B. Geeraert (n.d.) cited from Steen M., n.d), the estimated value from Tekeze dam is very low. However, other potential emission sources such as bubbling and degassing were not considered that may potential increase the level of emission. Even compared to the 2006 Kyoto's Protocol Clean Development Mechanism (CDM) proposed limit of power density (10 W/Km^2) for the reservoir emission to be set zero, the power density of Tekeze dam which is 2 W/km^2 is by far lower than the limit which might indicate the high potential contribution of the reservoir to the anthropogenic greenhouse gases emission to the atmosphere.

Despite the perception of hydropower dams as a clean and renewable energy sources since long time ago, they have a contribution to the greenhouses concentrations in the atmosphere. Hydropower dams are renewable energy sources as they are non-consumptive water users but not pollution-free energy sources. The huge inundated vegetation following impoundment of dams and prolonged retention time of river water in the reservoir are highly responsible for emissions of GHGs to the atmosphere. The impact is not only by producing GHGs from the available organic carbon, rather also by diminishing the potential carbon sequestration by the vegetation in the inundated area. These cumulative effects make the importance of greenhouse gases emission from the reservoir has no doubt and needs attention in the effort of climate mitigation.

The continuously flushed sediments by the runoff water and settled to the reservoir bottom have also a contribution to the carbon budget in the reservoir. It is a continuous and renewable carbon source to the reservoir organic carbon budget as long as erosion is a natural process that cannot be totally removed. But of course, it is possible to reduce either from the catchment using watershed management activities like afforestation or from the dam itself through different sediment management techniques. However, the effect of land use changes on GHGs emission due its effect on sediment yield is in two contrary directions which need further in the field with detail numerical simulation in order to know the most influential relation of sediment yield and greenhouse gases emission from reservoirs.

The rugged topographic nature of Ethiopian highlands, inappropriate farming practice, together with high human population pressure are the main drivers for the severe land degradation problem in the study area. It is the most susceptible area for soil erosion which threats the use full lifetime of Tekeze dam significantly. The land use changes in the study area have a significant influence on the catchment responses to sediment yield and sediment related problems in downstream. Due to change in sediment yield between the two scenarios, the rate of reservoir sedimentation and then the useful lifetime of the dam have been changed significantly. If the land uses change to continue with the expansion of cultivation land, the dam uses can be ended even before 2038 which can cause a huge economic crisis compared to the design lifetime which was expected to end at 2059.

Regarding the greenhouse gases emission amount, the reservoir contribution is not insignificant due to the potential emission by bubbling and degassing which were not considered in the simulation and expected to be significant in Tekeze dam reservoir. Despite the exact effect of sediment yield change on emission level was not estimated quantitatively, it is expected to have a significant influence to an emission level of GHGs from reservoir due to its relation to carbon budget and retention time of water which are the most influential factor in GHGs production.

7.2 Recommendation

- ✓ Sustainable watershed management activities should be practiced in order to mitigate any sediment related problems in downstream together with other sediment management option within the structure.
- ✓ The estimated sediment yield from Tekeze dam basin should be verified by the observed data in the field.
- ✓ Due to the complexity of greenhouse gas emission processes, field measurement is required to cross-check the accuracy of the GHGs risk assessment tool and to see its applicability in another area as well.
- ✓ The potential emissions by ebullition and degassing should also be addressed in order to know the actual effect of dams on the GHGs concentration to the atmosphere.
- ✓ Reservoir operating policy should consider not only water demand and supply in the system for optimized water use but also the possible greenhouse gas emission level from the dam due to its influence in retention time and siltation rate.
- ✓ Innovative idea towards continuous sediment transportation technique and their implementation is highly recommended to keep the sediment in the movement from the reservoir bottom which may have an advantage of reducing the available carbon source from the catchment to GHGs production and also to avoid sediment starvation in the downstream ecosystem.
- ✓ In the future planned dam, site selection should consider the potential greenhouse gases emission from the dam, for example, vegetation condition in the inundated area and the size of the inundated area itself is very important.
- ✓ Finally, due to the complexity of the greenhouse gas emission processes, further studies in the field with detail numerical simulation should be carried on to adequately investigate the overall processes, to identify the sensitivity of emission level with each factor involving in the process which is a first step in the way of thinking towards mitigation measure.

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Appendix

Appendix 1, Projected retention time of river water in the reservoir by the two land use scenarios

Scenario	year	2009	2016	2019	2029	2038	2045	2049
LUS_ 2001	Retention time_ 2001 (year)	2.79	2.56	2.46	2.13	1.83	1.60	1.47
LUS_ 2010	Retention time_2010 (year)	2.79	2.50	2.38	1.97	1.60	1.32	1.16

Scenario	year	2059	2069	2077	2079	2089	2094	2095
LUS_ 2001	Retention time_ 2001 (year)	1.14	0.81	0.55	0.49	0.17	0.04	0.01
LUS_ 2010	Retention time_2010 (year)	0.75	0.36	0.05	0.00	0.00	0.00	0.00

Appendix 2, Simulated results of CH_4 and CO_2 emission using GHG risk assessment tool from Tekeze dam over 100 years

UNESCO/IHA GHG RESEARCH PROJECT

Greenhouse Gas Status of Freshwater Reservoirs

GHG Risk Assessment Tool (Beta Version)

Predicted values

Time (years)	CH_4 (mg C-CH_4 m^{-2} d^{-1})	CO_2 (mg C-CO_2 m^{-2} d^{-1})	lower limit CO_2 (mg C-CO_2 m^{-2} d^{-1})	Upper limit CO_2 (mg C-CO_2 m^{-2} d^{-1})	lower limit CH_4 (mg C-CH_4 m^{-2} d^{-1})	Upper limit CH_4 (mg C-CH_4 m^{-2} d^{-1})
0	148.53	1229.25	534.46	2827.27	41.84	527.26
1	142.39	1134.07	493.07	2608.36	40.11	505.49
2	136.69	1047.71	455.53	2409.74	38.51	485.27
3	131.40	969.37	421.46	2229.54	37.01	466.47
4	126.48	898.28	390.56	2066.05	35.63	448.99
5	121.90	833.79	362.52	1917.71	34.34	432.74
6	117.64	775.27	337.07	1783.12	33.14	417.63
7	113.69	722.18	313.99	1661.02	32.02	403.59
8	110.01	674.01	293.05	1550.23	30.99	390.54
9	106.59	630.31	274.05	1449.71	30.03	378.40
10	103.42	590.66	256.81	1358.52	29.13	367.14
11	100.47	554.68	241.17	1275.77	28.30	356.68
12	97.74	522.04	226.98	1200.70	27.53	346.98
13	95.21	492.43	214.10	1132.59	26.82	337.99

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	A	B	C	D	E	F	G
20	10	103.42	590.66	256.81	1358.52	29.13	367.14
21	11	100.47	554.68	241.17	1275.77	28.30	356.68
22	12	97.74	522.04	226.98	1200.70	27.53	346.98
23	13	95.21	492.43	214.10	1132.59	26.82	337.99
24	14	92.86	465.56	202.42	1070.79	26.16	329.67
25	15	90.70	441.19	191.82	1014.73	25.55	321.98
26	16	88.70	419.07	182.20	963.86	24.99	314.89
27	17	86.86	399.00	173.48	917.70	24.47	308.36
28	18	85.17	380.80	165.56	875.83	23.99	302.37
29	19	83.63	364.28	158.38	837.84	23.56	296.89
30	20	82.22	349.29	151.87	803.37	23.16	291.90
31	21	80.95	335.69	145.95	772.09	22.80	287.37
32	22	79.80	323.36	140.59	743.72	22.48	283.28
33	23	78.77	312.16	135.72	717.97	22.19	279.63
34	24	77.86	302.01	131.31	694.62	21.93	276.39
35	25	77.05	292.79	127.30	673.43	21.71	273.54
36	26	76.36	284.43	123.67	654.20	21.51	271.09
37	27	75.78	276.85	120.37	636.75	21.35	269.02
38	28	75.30	269.97	117.38	620.93	21.21	267.31
39	29	74.92	263.72	114.66	606.57	21.10	265.97
40	30	74.64	258.06	112.20	593.54	21.03	264.99
41	31	74.47	252.92	109.97	581.72	20.98	264.36
42	32	74.39	248.26	107.94	570.99	20.95	264.08
43	33	74.39	244.03	106.10	561.26	20.95	264.08
44	34	74.39	240.19	104.43	552.43	20.95	264.08
45	35	74.39	236.71	102.92	544.42	20.95	264.08
46	36	74.39	233.55	101.54	537.16	20.95	264.08

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A	B	C	D	E	F	G
35	74.39	236.71	102.92	544.42	20.95	264.08
36	74.39	233.55	101.54	537.16	20.95	264.08
37	74.39	230.68	100.30	530.56	20.95	264.08
38	74.39	228.08	99.16	524.58	20.95	264.08
39	74.39	225.72	98.14	519.15	20.95	264.08
40	74.39	223.58	97.21	514.23	20.95	264.08
41	74.39	221.63	96.36	509.76	20.95	264.08
42	74.39	219.87	95.60	505.71	20.95	264.08
43	74.39	218.27	94.90	502.03	20.95	264.08
44	74.39	216.82	94.27	498.69	20.95	264.08
45	74.39	215.51	93.70	495.66	20.95	264.08
46	74.39	214.31	93.18	492.92	20.95	264.08
47	74.39	213.23	92.71	490.42	20.95	264.08
48	74.39	212.24	92.28	488.16	20.95	264.08
49	74.39	211.35	91.89	486.11	20.95	264.08
50	74.39	210.54	91.54	484.25	20.95	264.08
51	74.39	209.81	91.22	482.56	20.95	264.08
52	74.39	209.14	90.93	481.03	20.95	264.08
53	74.39	208.54	90.67	479.64	20.95	264.08
54	74.39	207.99	90.43	478.38	20.95	264.08
55	74.39	207.49	90.21	477.23	20.95	264.08
56	74.39	207.04	90.02	476.20	20.95	264.08
57	74.39	206.63	89.84	475.25	20.95	264.08
58	74.39	206.26	89.68	474.40	20.95	264.08
59	74.39	205.92	89.53	473.62	20.95	264.08
60	74.39	205.62	89.40	472.92	20.95	264.08
61	74.39	205.34	89.28	472.28	20.95	264.08

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A	B	C	D	E	F	G
60	74.39	205.62	89.40	472.92	20.95	264.08
61	74.39	205.34	89.28	472.28	20.95	264.08
62	74.39	205.09	89.17	471.70	20.95	264.08
63	74.39	204.86	89.07	471.18	20.95	264.08
64	74.39	204.65	88.98	470.70	20.95	264.08
65	74.39	204.46	88.90	470.27	20.95	264.08
66	74.39	204.29	88.82	469.88	20.95	264.08
67	74.39	204.14	88.76	469.52	20.95	264.08
68	74.39	204.00	88.69	469.20	20.95	264.08
69	74.39	203.87	88.64	468.90	20.95	264.08
70	74.39	203.76	88.59	468.64	20.95	264.08
71	74.39	203.65	88.54	468.40	20.95	264.08
72	74.39	203.56	88.50	468.18	20.95	264.08
73	74.39	203.47	88.46	467.98	20.95	264.08
74	74.39	203.39	88.43	467.80	20.95	264.08
75	74.39	203.32	88.40	467.63	20.95	264.08
76	74.39	203.25	88.37	467.49	20.95	264.08
77	74.39	203.20	88.35	467.35	20.95	264.08
78	74.39	203.14	88.32	467.23	20.95	264.08
79	74.39	203.10	88.30	467.12	20.95	264.08
80	74.39	203.05	88.28	467.02	20.95	264.08
81	74.39	203.01	88.27	466.93	20.95	264.08
82	74.39	202.98	88.25	466.84	20.95	264.08
83	74.39	202.94	88.24	466.77	20.95	264.08
84	74.39	202.91	88.22	466.70	20.95	264.08
85	74.39	202.89	88.21	466.64	20.95	264.08
86	74.39	202.86	88.20	466.58	20.95	264.08

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A	B	C	D	E	F	G
76	74.39	203.25	88.37	467.49	20.95	264.08
77	74.39	203.20	88.35	467.35	20.95	264.08
78	74.39	203.14	88.32	467.23	20.95	264.08
79	74.39	203.10	88.30	467.12	20.95	264.08
80	74.39	203.05	88.28	467.02	20.95	264.08
81	74.39	203.01	88.27	466.93	20.95	264.08
82	74.39	202.98	88.25	466.84	20.95	264.08
83	74.39	202.94	88.24	466.77	20.95	264.08
84	74.39	202.91	88.22	466.70	20.95	264.08
85	74.39	202.89	88.21	466.64	20.95	264.08
86	74.39	202.86	88.20	466.58	20.95	264.08
87	74.39	202.84	88.19	466.53	20.95	264.08
88	74.39	202.82	88.18	466.49	20.95	264.08
89	74.39	202.80	88.17	466.44	20.95	264.08
90	74.39	202.79	88.17	466.41	20.95	264.08
91	74.39	202.77	88.16	466.37	20.95	264.08
92	74.39	202.76	88.16	466.34	20.95	264.08
93	74.39	202.74	88.15	466.31	20.95	264.08
94	74.39	202.73	88.14	466.29	20.95	264.08
95	74.39	202.72	88.14	466.26	20.95	264.08
96	74.39	202.71	88.14	466.24	20.95	264.08
97	74.39	202.71	88.13	466.22	20.95	264.08
98	74.39	202.70	88.13	466.21	20.95	264.08
99	74.39	202.69	88.13	466.19	20.95	264.08
100	74.39	202.68	88.12	466.18	20.95	264.08

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