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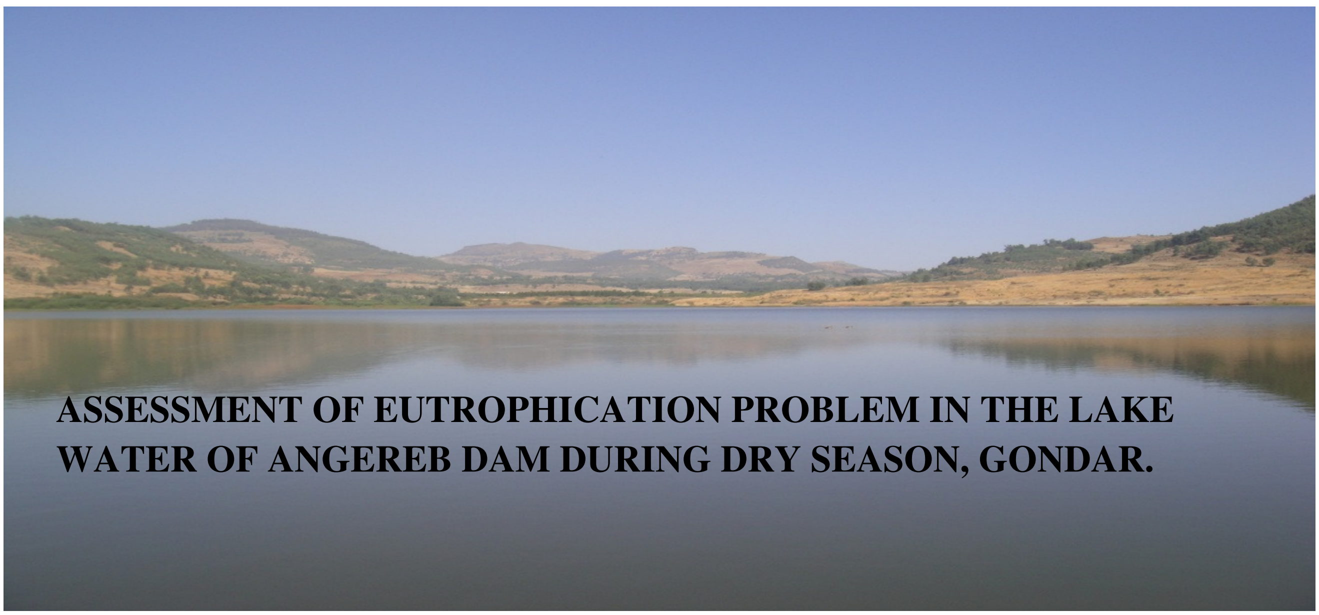

# ASSESSMENT OF EUTROPHICATION PROBLEM IN THE LAKE WATER OF ANGEREB DAM DURING DRY SEASON, GONDAR.

**M.Sc. thesis**

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**Declaration**

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

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## Abbreviations and Acronyms

| | |
|---|---|
| ANOVA | Analysis of Variance |
| APHA | American Public Health Association |
| AR | Angereb River |
| ARL | Angereb River Lower |
| ARM | Angereb River Middle |
| ARU | Angereb River Upper |
| a.s.l. | Above sea level |
| AWWA | American Water Works Association |
| BMPs | Best Management Practices |
| Chl-a | Chlorophyll-a |
| DO | Dissolved Oxygen |
| DS | Defecha Stream |
| DSL | Defecha Stream Lower |
| DSM | Defecha Stream Middle |
| DSU | Defecha Stream Upper |
| EC | European Commission |
| FAO | Food and Agricultural Organization |
| Fig. | Figure |
| GPS | Global Positioning System |
| GS | Gesite Stream |

| | |
|---|---|
| GSL | Gesite Stream Lower |
| GSM | Gesite Stream Middle |
| GSU | Gesite Stream Upper |
| LSD | Least Significant Difference |
| LWE | Lake Water Edge |
| mg/L | Milligram per Liter |
| NTU | Nephlometric Turbidity Unit |
| OSPAR | Oslo and Paris convention |
| ppm | Parts per million |
| SD | Standard Deviation |
| SPSS | Statistical Package for Social Sciences |
| t/ha/y | Tone per haectare per year |
| THMs | Trihalomethanes |
| TKN | Total Kjeldahl Nitrogen |
| TN | Total Nitrogen |
| $T^o$ | Temperature |
| TP | Total Phosphorus |
| TUR | Turbidity |
| µg/L | Microgram per Liter |
| UNEP | United Nations Environmental Program |
| USEPA | United States Environmental protection Authority |

| | |
|---|---|
| UV/VIS | Ultraviolet per Visible |
| WHO | World Health Organization |

## *Abstract*

*Eutrophication is one of the pollution problems of aquatic environments. Nitrogen and phosphorus are the causal factors for eutrophication, and are creating a problem of algal growth in Angereb Dam. This research was carried out to assess the trophic status of the water in Angereb Dam. A systematic sampling approach was used to select sampling sites from which sediment, soil and water samples were collected and analyzed using standard methods. The results of the study revealed that the trophic status of the water in Angereb Dam was found at the level of mesotrophic condition (4.2µg/L of chlorophyll-a). Total nitrogen and total phosphorus were also found in the water of the Dam at the level that could support the production of algae. Dissolved oxygen, pH and temperature of the water in the Dam were found at the level that could not be harmful to aquatic inhabitants. On the other hand, the turbidity level was high. Sediments and soils of all the selected sub watersheds contained substantial amount of total nitrogen and total phosphorus that could be the source of nutrients to the water in the Dam. Particularly, Angereb and Defecha sub watersheds could be the main sources of nutrients to the water in the Dam. Therefore, appropriate soil and water conservation measures are needed to reduce the overflow of nutrients to the Dam. Additionally, bio-manipulation techniques should be undertaken to impede further growth of algae.*



*Keywords: Angereb Dam, Eutrophication, Nitrogen, Phosphorus*

# 1 Introduction

## 1.1 Background

Water pollution is one of the main problems in the globe. It has been suggested that it is the leading worldwide cause of deaths and diseases. In developing, non-industrialized countries, water pollution is predominantly caused by human and animal wastes, and unsound farming and timbering practices. Similarly industrialized countries are also the victim of this problem. Especially, their modern and extravagant lifestyles and numerous industries are responsible for the improper disposal of hazardous pollutants to the environment particularly to water bodies (Chiras, 2001).

Many authors define water pollution as the degradation of water quality as measured by biological, chemical or physical criteria. This implies the presence of pollutants in water in sufficient quantity that can change the biological and physico-chemical characteristics of the water and makes it unsuitable for desired uses (Botkin and Keller, 1987; Turk and Turk, 1988; Chiras, 2001; Cunningham and Ann, 2008).

Pollutants may come from single or a variety of dispersed sources. They may be released from point sources at specific locations into surface water bodies through ditches, drain pipes or sewer lines. Municipal wastes, industries, sewage treatment plants and oil tankers are the typical point sources of pollution. It is not as such difficult to control and reduce the discharge of pollutants from these sources since they have definite source and can be easily identified. On the other hand, there are also pollutants discharged from diffuse sources which are much more difficult to identify and control. These pollutants are mainly come from agricultural land, urban paved surfaces, livestock feedlots, logged forests and others (Botkin and Keller, 2005; Enger and Smith, 2008).

Among the sources, agricultural activities are the most responsible source for surface water pollution. This is due to excessive utilization of fertilizers and pesticides for the enhancement of productivity. This creates a chance for nutrients to enter streams, rivers, reservoirs and other freshwaters through runoff and results in accumulation of them in that water bodies. Nitrogen and phosphorus are the two important nutrients that cause the water to be polluted (Miller, 2006).

Nitrogen and phosphorus are major nutrients that are needed largely by plants. They promote the growth and development of plants and maintain plants survival and in turn sustain animals. But due to over fertilization of croplands far more nitrogen and phosphorus are applied to fields than are removed by crops. This causes the transport of nutrients (nitrogen and phosphorous) to freshwaters through runoff. Excessive accumulation of these nutrients in water bodies leads to the undesirable plant growth which is commonly called algal bloom (eutrophication).

According to WHO and EC (2002), the term eutrophication has been derived from two Greek words; “eu” -which means well, and “trophy”- to mean food or nutrient. Thus it is the enrichment of water bodies with nutrients. Eutrophication is the process of accumulation of nutrients specially nitrogen and phosphorus in water bodies and stimulate undesirable growth of photosynthetic blue green bacteria and algae (Goel, 2006).

Basically eutrophication is a natural phenomenon which gets accelerated by increased nutrient supply through human activities. Due to rapid urbanization, industrialization, and intensifying agricultural production, humans in the watershed can cause the loss of excessive nutrients and create a chance to enter streams, rivers, reservoirs and other water bodies (Wright, 2008).

These human activities bring the occurrence of cultural eutrophication which worsens the growth rate of algae and causes to bloom within a short period of time and finally results in deaths. Consequently, other aquatic plants and animals are adversely affected. Moreover, the quality of water deteriorates and becomes unsuitable for use (O’Riordan, 2000).

Although the primary cause of eutrophication is related to excessive load of nutrients (nitrogen and phosphorus), nutrient enrichment by itself is only the necessary but not the sufficient condition for algal bloom. This implies that eutrophication is not likely to occur if the water contained low concentrations of nitrogen and phosphorus. Similarly, eutrophication may not happen though the water has high concentration of nutrients unless other conditions are being under favorable conditions. Temperature, light and others are also some of the factors which are needed by and affect the process of eutrophication (Dauvin *et al*., 2007).

## 1.2 Statement of the problem

Recently eutrophication has become a serious problem in the world. Its severity is increasing especially in the developing countries because of the rapid population growth and expansion of agriculture. According to a study conducted by UNEP which is cited in Yang *et al*. (2008), about 30%- 40% of the lakes and reservoirs have been affected by eutrophication all over the world.

Eutrophication can be manifested by the reduction of dissolved oxygen, increasing of turbidity, coloring of water, odor and loss of biodiversity. This quality loss of water will bring subsequent negative impacts on the ecosystem. Due to the formation of dense algal bloom, sufficient amount of light does not reach to the bottom of water bodies. Thus, the productive activities of photosynthetic plants will be significantly disrupted which in turn affect other aquatic animals (Khan and Ansari, 2005). In addition to this, eutrophication also induces the shortage supply of drinking water by degrading its quality. This happens when the blooming algae die, a lot of algae toxins which are harmful to human health will be produced. In order to supply clean tap water to the people, this polluted water needs to be purified which requires high cost of treatment (USEPA, 2000).

Among the water bodies which are affected by eutrophication, Dams are one of them which are susceptible and exposed to the problem (Cunnigham and Ann, 2008). Particularly, this problem can be augmented when the Dam is located in agricultural fields where there are poor management practices.

In line with this, Angereb Dam is the source of domestic water supply to the people of Gondar town. It is surrounded by agricultural fields that use fertilizers and pesticides and from which nutrients flow excessively to the Dam. As a result, the Dam is suffering from sedimentation and eutrophication.

A study conducted by Admasu Amare (2005) indicated that on average 152.5 t/ha/y of soil was eroded and carried to the Dam. This affects the storage capacity of the Dam, and results in shortage of domestic water supply to the people. Additionally, because of eutrophication and turbidity problems, the town water supply and sanitation office is also expensing considerable amount of costs for its treatments. According to the information given by the technician of the treatment plant, Copper sulphate is added to the Dam for algae destruction. Besides, in order to reduce the turbidity status of the water, during rainy season 400 kg Aluminum sulphate, and during winter 150 kg Aluminum sulphate is added per a day.

Although the erosion problem of the watershed is studied, there is no available data related to the eutrophication status of the water in the Dam. Thus, providing scientific information regarding the eutrophication condition of the Dam is vital in taking any corrective actions. Therefore, this study attempts to examine and provide the general trophic status of the water in the Dam.

## 1.3 Scope of the study

This study is intended to deal with the current eutrophication status of Angereb Dam. The study has emphasized in examining the current level of nitrogen, phosphorus and algal biomass in the water of the Dam. Moreover, the levels of dissolved oxygen, pH, temperature and turbidity status of the Dam have also been evaluated within the study period. However, this paper would not give seasonal variations of the selected parameters due to time and cost limitations.

## 1.4 Significance of the study

It is obvious that soil erosion is one of the greatest challenges that hinder developmental activities of a given country. It has, especially, adverse effects on countries that depend on agriculture. Ethiopia which has high agrarian population is one of the victims of this problem. It was suggested by several studies that Ethiopia loses high amount of soil by erosion each year. This erosion does not only carry the soil but also nutrients which cause eutrophication are transported together. This results in the reduction of crop productivity, sedimentation of water bodies and excessive growth of algae.

As a result of this, many people are exposed to starvation, lack of enough water accessibility and high cost of treatments. In order to alleviate such type of critical problems, both the government and the people should be aware of the problem and have the mechanisms to solve it. This can be accompanied by conducting researches (studies) that can clearly show the causes and consequences of the problem on different aspects. Therefore, assessment of the extent (levels) of nutrients and algal biomass in Angereb Watershed and suggestion of possible management practices will be the contribution of the study to take corrective actions.

## 1.5 Objectives

### 1.5.1 General objective

The general objective of this study is to examine the trophic status of the lake water of the Dam, and to determine the main source areas of sediments in the Dam so as to recommend possible management measures.

### 1.5.2 Specific objectives

- To assess the level of phosphorus and nitrogen in the water and sediment of the Dam.
- To assess the level of phosphorus and nitrogen in the sediments of the selected streams.
- To assess the level of phosphorus and nitrogen in the soils of the selected sub watersheds.
- To assess the level of algal biomass and trophic status in the lake water of the Dam.
- To examine the level of dissolved oxygen in the lake water of the Dam.
- To examine the turbidity of the water in the Dam.
- To measure the acidity and basicity, and temperature of the water in the Dam.
- To assess the sources of nutrients to the Dam.

# 2 Review of literature

## 2.1 Water pollution

Water pollution occurs when a body of water is adversely affected by the addition of large amounts of materials to the water. As a result, when it is not fit to its intended use, the water is considered polluted. In general, water pollution is the change of its physical, chemical and biological characteristics so that it is not longer used for the designated uses. The loss of water quality can be natural or anthropogenic, or a combination of the two. Natural cause of water pollution can happen when the water bodies are exposed to pollutants (materials) released from natural hazards such as landslides, floods, erosion and volcanoes. The occurrence of these disasters would have the potential to release toxic gaseous or particulate pollutants (materials) into the water bodies. However, the natural cause of water pollution can be accelerated by the activities of humans (Pennington and Cech, 2010).

According to Zinabu G/Mariam (1998), the rapid growth of human populations and the expansion of agricultural activities which seeks deforestation, fertilizers, pesticides and irrigation, and industrialization are the major causes of water quality degradation. Land use and modification is one of the important anthropogenic activities that causes water pollution by facilitating natural factors like soil erosion, sediment loading, deposition of plant and animal debris. The occurrence of erosion carries soil particles enriched with nutrients and end up in water bodies and leads to eutrophication. Nutrients particularly nitrogen and phosphorus become pollutants in a water body when they are supplied in large quantity.

### 2.2 Eutrophication

Eutrophication is one of the serious and the leading causes of water quality impairment within the last 50 years (Selman *et al.*, 2008). Many authors have given different definitions for eutrophication and one differs fundamentally from others. One of the differences is with respect to whether eutrophication is only the processes of nutrient enrichment or whether it should include the problems associated with such enrichment. Hence, the definition given by Beeton and Edmondson (1972) cited in Welch (1992), reflects this differences. Based on their definition, eutrophication refers only to the quantity of nutrients in a water body and does not necessarily indicate the response in production and associated problems. Thus a water body can become eutrophic from the increment of nutrients though productivity cannot be enhanced due to some factors such as light.

On the contrary, another definition has been given by Steele (1974) who is cited in Karydis (2009), eutrophication is the rapid growth of algae due to excess supply of nutrients and leads to adverse impacts. Another definition has been given by OSPAR (2003) as the enrichment of nutrients which causes the accelerated growth of algae, and other higher forms of plant life and produce undesirable disturbance to the balance of organisms living in the water as well as to the quality of water.

However, the most comprehensive definition of eutrophication is given by Vollenweider (1992), and Khan & Ansari (2005) as eutrophication is the plant growth promoting process resulting from accumulation of nutrients. It is due to enrichment of water bodies with plant nutrients, mainly nitrogen and phosphorus that can stimulate the production of aquatic plants with manifestations of visible algal blooms, and enhanced benthic algal growth.

Therefore, eutrophication is a process driven by enrichment of water with nutrients, especially compounds of nitrogen and phosphorus, which causes an accelerated growth of algae and other aquatic plants. As a result, changes in the balance of organisms, reduction of dissolved oxygen, turbidity and other water quality degradations become the manifestations of it (Ferreira *et al*., 2010).

Depending on the source of nutrient supply, eutrophication can be natural or cultural. Water bodies have always received nutrients from natural sources in the watershed and from others. Hence, eutrophication can happen naturally in the normal succession of some fresh water ecosystems. However, under normal conditions, it is a time consuming phenomenon that can be a problem after a long period of time (Zheing and Paul, 2007). Thus, eutrophication is a natural ageing process of water bodies and this gradual process can ultimately transforms aquatic environments into terrestrial environments (Landner and Wahlgren, 1988; Bricker *et al*., 1999).

However, in recent years, human activities have substantially increased the rate of delivery of nutrients to aquatic ecosystems. As a result, algal production in many water bodies has increased (intensified) much faster than would occur under natural circumstances. This accelerated algal growth is termed as cultural or anthropogenic eutrophication. Thus, cultural eutrophication is associated with human activities that facilitate the eutrophication process beyond the rate of the natural process by increasing the load of nutrients into aquatic ecosystems (Chris *et al*., 2001).

Population growth, food production (agriculture, animal operation and aquaculture) and production and consumption of energy have exacerbated the enrichment of water bodies with nutrients (Glibert *et al*., 2005).

## 2.3 Causes of eutrophication

### 2.3.1 Nutrients

Nutrients are essential elements for the metabolic activities of organisms and become the major cellular components. Photosynthetic plants require these essential nutrients such as magnesium, calcium, phosphorus, nitrogen and others in sufficient amount. Of these essential nutrients, nitrogen and phosphorus are the most required elements by producers. In aquatic ecosystems, nitrogen and phosphorus are the two nutrients that commonly limit the maximum growth of algal biomass and other aquatic plants (Carr and Neary, 2008). These happen when the concentrations of the two elements are below the level of requirement for optimal growth of aquatic producers. Therefore, the availability of these elements is usually less than the biological demand of organisms and consequently, productivity of aquatic systems is regulated by other environmental sources of these elements. However, in excessive amounts they cause proliferation of primary producers which in turn results in increase of secondary biological production at all levels of the food chain. Thus, nitrogen and phosphorus are considered to be the primary drivers of eutrophication of aquatic ecosystems (Walker *et al*., 2006; Carr and Neary, 2008).

These driver elements can be released from different sources into the environment. Natural source of nitrogen and phosphorus is one of the responsible factors that enables the elements to enter water bodies either by serving as a source or facilitating the process (nutrient cycles). Natural weathering of minerals in the drainage basin and, the process of biological decomposition are the principal natural sources of phosphorus (Jong, 2006).

Although natural factors have their own contribution for the transportation of nitrogen and phosphorus into aquatic ecosystems and enhancing their levels to some extent, the process is mainly exacerbated by anthropogenic activities. Urbanization, industrialization and agricultural expansions are the principal sources from which nutrients are discharged into the environment.

Effluents from wastewater and septic systems, fossil fuel, fertilizers runoff and animal wastes are the major factors that promote the concentrations of nitrogen and phosphorus in aquatic environment (Rast and Thornton, 1996).

Once nitrogen and phosphorus have been received in a water body, they can be taken up by algae, adsorbed to organic or inorganic particles in the water and sediment, accumulated or recycled in the sediment or transformed and released as a gas from the water body. Biological and other-activities can re-introduce the nutrients into a water body. The movement of nutrients from sediments and microbial transformation would have the potential to result in a long recovery period even after the reduction of pollutant sources (USEPA, 2000).

After nutrients (nitrogen and phosphorus) enter aquatic ecosystems, the dissolved forms are immediately utilized by the plants whereas the particulate forms of these nutrients are less readily available and may provide a long term source of nitrogen and phosphorus for the growth of aquatic plants. Thus, measurement of the particulate forms of these nutrients together with their dissolved forms is very important and enables to estimate more accurately the impact of agricultural management practices on biological productivity of surface water (Sharpley and Smith, 1992).

### 2.3.2 Supporting factors

Besides to the input of nutrients, there are also other factors that enhance the development of eutrophication. The most important physical factors that support biomass production of algae are temperature, and light (Mcilroy *et al*., 2009).

#### 2.3.2.1 Temperature

Temperature is one of the major factors that can affect the speed of chemical reactions in a water body. The rate at which algae and aquatic plants photosynthesize, the metabolic rate of other organisms as well as the interaction of pollutants with their environment are highly determined by the intensity of temperature (Wierenga, 2004). In addition, temperature can also affect the solubility of chemical compounds and influence the effect of pollutants on aquatic life. It escalates the releasing of nutrients from sediments to water column through molecular movements and activities of microorganisms. Temperature is a measurement of the intensity of heat stored in a volume of water (Boqiang *et al*., 2006).

Even if water bodies have the ability to buffer against atmospheric temperature extremes, temperature fluctuations have serious impacts on aquatic life. In general at high temperature, the activities of organisms are facilitated so that their consumption rate of nutrients would be high. This would increase the biomass of algae and leads to eutrophication. According to Chorus and Bartram (1999), the maximum growth and production of phytoplankton usually attained when the temperature is more than 25$^{o}$C . In addition, aquatic animals have low temperature tolerances and can be at risk and may leads to deaths. This on the other hand increases proliferation of algae by reducing the pressure of grazing (Biggs, 2000).

#### 2.3.2.2 Light

Light is a principal physical factor that can control the rate of photosynthesis. Aquatic producers require sufficient amount of light for their survival. Thus, the availability of light in a desired level enables aquatic algae and other producers to utilize nutrients excessively. This over consumption of nutrients by producers can leads to excessive production of biomass of algae (Rast and Thornton, 1996). Growth of algae increases with an increase in light intensity until the optimal value is reached. Fluctuation in either direction from the optimal light intensity can reduce the growth rate of phytoplankton (Gurung, 2007).

However, the availability of sufficient amount of light can be influenced by several factors. The presence of suspended materials can reduce the amount of light penetrating and reaching to the middle and bottom of the water body. In addition, the amount of light can be also influenced by the bloom of algae. Blooms of algae can reduce the amount of light available to organisms and plants beneath the surface layer. The bloom often makes the surface layer very turbid and attenuates light (Rast and Thornton, 1996).

Besides, light availability is also affected by riparian canopy covers (Biggs, 2000). According to Lowe *et al.* (1986) cited in Zheing and Paul (2007), algal biomass can be 4 or 5 times higher in water bodies with open canopies than at sites with more closed canopy cover.

## 2.4 Trophic status

Trophic state is a description of the biological condition of the water body (USEPA and MDEP, 2007). Carlson and Simpson (1996) also define trophic state as the total weight of living biological material (biomass) in a water body.

Different authors and researchers have not taken fixed number of parameters that measure the trophic status of a given water body. Some of them take only chlorophyll- a to indicate the trophic status of a water body; others have also taken nutrients only (Walker *et al*., 2006). Hence, considering more than one criterion is important for the determination of trophic status and helps to come up with better conclusion (Xiao *et al.*, 2007).

However, eutrophication is a complex process that several factors have their own contribution for the development of it. As a result, assessment of more trophic criteria is crucial and provides reliable information for the status of the water body. Chlorophyll-a is the principal parameter used to characterize the trophic status of water bodies. In addition, total phosphorus and total nitrogen are also used to characterize the eutrophication condition of water bodies (Donia and Hussien, 2004).

### 2.4.1 Chlorophyll- a

Chlorophyll- a is a major and predominant photosynthetic green pigment in plant and used to capture energy from the sun. It is the most important parameter when any estimate of the photosynthetic capacity of an ecosystem is desired. Therefore, chlorophyll-a is considered as an appropriate surrogate measurement for primary production and used as an estimator of algal biomass due to strong correlation values between chlorophyll-a and biomass (Walker *et al*, 2006).

Most algae are dependent on chlorophyll-a for their survival and it is often the molecule of preference due to its primary role in photosynthesis. Measuring the concentration of this pigment found in water sample can be used to estimate the amount of free-floating algae. Therefore, chlorophyll-a is one of the biological parameters used to characterize the trophic status of a water body (Gibson *et al*, 2000).

### 2.4.2 Phosphorus and Nitrogen

Phosphorus is often the most important nutrient in freshwater for the growth of aquatic plants. It has a significant role for the production of algae in freshwater. As a result, it is often the variable of concern with regards to lake and reservoir eutrophication. Thus, phosphorus is used to estimate the trophic status of lakes and reservoir as one criterion. Besides, nitrogen can also affect the trophic status of water body (ILMB, 1998; Gibson *et al*., 2000).

### 2.4.3 Turbidity

Turbidity refers to water clarity and it is the measurement of the suspended particulate matter in a water body. A number of materials from different natural and anthropogenic sources in a watershed can contribute for the occurrence of turbidity. Silt, clay, organic material, micro organisms and other suspended solids from soil erosion in agricultural fields, construction, urban runoff, industrial effluents, disturb the clarity of water. Besides, excessive growth of algae which forms bloom (scum) directly affects the clarity of the water (Carr and Neary, 2008). Eventhough the acceptable standards depend on the water body use, a turbidity reading higher than 10NTU is indicative of potentially undesirable water quality (ENSR, 2002).

### 2.4.4 Dissolved oxygen

Dissolved oxygen is one of the most important characteristics of water bodies and it is a measure of the amount of oxygen dissolved in water. It is controlled by consumption of aquatic organisms, consumption of plants, natural re-aeration, and water temperature. Oxygen is needed by aerobic aquatic organisms to carry out their metabolic activities properly. Hence, it affects the solubility and availability of nutrients and therefore the productivity of aquatic ecosystems. The presence of low level of dissolved oxygen in a water body facilitates the release of nutrients from the sediments (ILMB, 1998). The amount of dissolved oxygen in a water body depends on temperature and photosynthetic activity. As temperature increases, the level of dissolved oxygen decreases, and thus dissolved oxygen is inversely proportional to temperature. Excessive growth of algal biomass may lead to a depletion of dissolved oxygen. The productivity of the water body in turns stimulates the biomass of aquatic animals that uses oxygen so that over production of algal contribute the reduction of oxygen. Furthermore, at the time of death of producers, they are subjected to decomposition by aerobic microorganisms. As a result, the required amount of oxygen may not exist so that aerobic dwellers are impacted and leads to deterioration of water quality (Walker *et al*., 2006; Carry and Neary, 2008). Reduced levels of dissolved oxygen can cause changes in the types and numbers of aquatic macro invertebrates in the water ecosystem. On the other hand, the level of dissolved oxygen can increase when the there is production of algae. Unless there is excessive organic matter, the probability of dissolved oxygen level is high up to a certain level of algal growth (UNEP, 2008). Majority of aquatic organisms need a minimum of dissolved oxygen in the range of 5-6 mg/L (Pennington and Cech, 2010).

### 2.4.5 pH

The pH of water is a measure of its acid base condition that can be determined by the production of hydrogen and hydroxyl cons. The pH of an aquatic ecosystem is closely linked to biological productivity and hence, fluctuation of water column pH can be caused by excessive primary production (Carr and Neary, 2008).

In line with this, during photosynthesis, the pH of water column tends to be more basic. Because, carbon dioxide and water are converted to sugar and oxygen, and during sugar formation hydroxyl ions are produced and raise the pH of the water (make it more basic). Moreover, the removal of carbon dioxide lowers the level of carbonic acid in the water which causes a shift to less acid condition. However, more acidic conditions occur at night when there is no photosynthesis. The absence of photosynthesis and the continuity of respiration results in the release of carbon dioxide into the water and thus increases the production of carbonic acid (Walker *et al*., 2006).

The availability of phosphorus for the intake (consumption) of algae is affected by the pH of water column. Phosphorus cannot be available at high and low values of pH and impact on the production of algae. Moreover, these extreme values of pH can damage the gills, skin and eyes of fish, and interfere with fish reproduction (Ibid). Lethal effects of pH on aquatic life can occur in pH values below 4.5 and above 9.5. Therefore, appropriate value of pH is very important to maintain the quality of water body as well as biodiversity of aquatic environment (ILMB, 1998).

## 2.5 Classification of trophic status

The concept of trophic status as a system of classification was introduced by early limnologists like Nauman (Donia and Hussien, 2004). Due to the complex interaction of parameters with each other and their own contribution to eutrophication, it is difficult to develop strict boundaries between trophic classes (FAO, 1996). Based on the biomass of algae and the concentration of nutrients, the degree of eutrophication in aquatic environment can be classified as oligotrophic, mesotrophic and eutrophic (Rast and Thornton, 1996). In addition, other physical and chemical parameters also characterize the trophic classes.

An oligotrophic environment of a water body is characterized by clear water, little suspended materials or sediments and low production. They are poorly supplied with plant nutrients and support little plant growth. As a result, biological productivity is generally low (Ansari, 2010).

Mesotrophic ecosystems are the second classes of the trophic state and are moderately well supplied with phosphorus and nitrogen and support moderate growth of phytoplankton. Therefore, it occupies an intermediate position (classes) of the trophic state and it shows an increasing signs of water quality problems (Ansari, 2010).

To the contrary, eutrophic environments have high concentration of nutrients and are characterized by high biological productivity (Rast and Thornton, 1996).

The classes of trophic states and the parameters exhibited by each trophic class are given (summarized) in the following tables. However, different authors give different values for the parameters which enable to group whether that water body is oligotrophic, mesotrophic or eutrophic. According to Mackie *et al*. (2006), the trophic states of lakes are characterized in the following Table.

Table 2.1 Characterization of trophic status of lakes (Mackie *et al*., 2006)

| Features | Oligotrophic lakes | Mesotrophic lakes | Eutrophic lakes |
|---|---|---|---|
| Total nitrogen (µg/l) | <300 | 300-600 | >600 |
| Total phosphorus (µg/l) | <10 | 10-30 | >30 |
| Chlorophyll-a (µg/l) | <2 | 2-5 | >5 |

Besides, scientists also use only chlorophyll-a to identify the trophic status of lakes. Thus, the USEPA and MDEP (2007), have put the values of chlorophyll-a given by different scientists.

Table 2.2 Characterization of trophic status of fresh water bodies using chlorophyll-a

| Trophic Status | Ryding and Rast (1989) | Novotny and Olem (1994) | Wetzel (2001) |
|---|---|---|---|
| Oligotrophic | 0.8 to 3.4µg/l | 0.3 to 3µg/l | < 4µg/l |
| Mesotrophic | 3 to 7.4µg/l | 2 to 15µg/l | 4 to 10µg/l |
| Eutrophic | 6.7 to 31µg/l | >10µg/l | >10µg/l |

## 2.6 Impacts of eutrophication

Occurrence of algal biomass on surface of water brings serious ecological, social and economical impacts (USEPA, 2000).

### 2.6.1 Ecological impacts

The increment of nutrients in water bodies assists the rapid growth of algae and other short-living macrophytes. This enrichment of water with nutrients causes an intensification of all biological activity and typically leads to dramatic changes in the composition and structure of aquatic food webs. Thus, a shift in algal species composition and an increase in the frequency and intensity of nuisance algal blooms are the two most effects of eutrophication (Smith *et al*., 2006). The excessive accumulation of aquatic algal and other plants prevents the penetration of large proportion of light from reaching the bottom. This affects the activities of bottom aquatic plants and animals (Khan and Ansari, 2005).

Furthermore, as primary producers die, they are subjected to decomposition by aerobic micro organisms. Large populations of decomposers consume more dissolved oxygen which increases the severity of dissolved oxygen depletion. Specially, the process of decomposition gets accelerated when there is high temperature, which normally occurres in non- rainy season (Zheing and Paul, 2007). The loss of dissolved oxygen in turn can cause the release of toxic metals from sediments. In addition, low level of dissolved oxygen in the water body causes the availability of toxic substances like ammonia and hydrogen sulfide and this makes the habitat unsuitable for aquatic organisms.

Moreover, toxic substances are also released by some species of algae that are harmful to animals. The blue- green algae are known in releasing the toxic substances cyanotoxins into the water (especially when their cells are ruptured by decaying or algaecides) (Mssanzya, 2010). Cyanotoxins are the main harmful substances that cause the death of wild animals, farm livestock, pets, fish and birds in eutrophicated water bodies (USEPA, 2000).

The presence of high algal biomass also causes the water pH either to increase or decrease. This fluctuation of pH has adverse impacts on aquatic organisms (Boquiang *et al*., 2006). Extremely high or low pH values are harmful to aquatic organisms. High pH value damages the gills of fish, eyes and skin, and thus affects fish reproduction. In addition, a high pH level also enhances the toxicity of some substance like ammonia. On the other hand, low levels of pH in a water body can make heavy metals in the sediments more bio-available. Moreover, extreme pH values increase the availability of some nutrients so that it further exacerbates the problem of enrichment (Boquiang *et al*., 2006; Zheing and Paul, 2007).

Besides, the formation of large clogs of mats of algae which either floats or attached to substrata prevents the services (Swimming, fishing and boating) provided by the water body. Moreover, due to the decay of algae and production of chemicals such as 2 methyligoborneol and geosmin causes the taste and odour problem of the water body. As a result, aesthetical and recreational values of the aquatic ecosystem would be deteriorated (Boquiang *et al*., 2006).

### 2.6.2 Social impacts

The enrichment of nutrients in drinking water supply could have adverse impacts on the health of people. In connection with this, one of the serious human health problems associated with nutrient enrichment is the formation of Trihalomethanes (THMs). These compounds are carcinogenic compounds that are produced when certain organic compounds are chlorinated and bromated as part of the disinfection process in a drinking water treatment facility. Algal metabolites, algal decomposition products as well as humic substances are responsible for the formation of THMs and associated compounds (Paul and Ashton, 2008).

Besides this, chronic ill-health effects are also common for those people who are exposed to odours from water bodies polluted with excessive algal blooms (WHO and EC, 2002). Excessive concentration of nitrate and/or nitrite (> 10 mg/L-$NO_3$) can be harmful to humans. Nitrate is broken down in human intestine to become nitrite. After conversion, the nitrite reacts with hemoglobin in the blood to produce methemoglobin which limits the ability of red bloods to carry oxygen. This condition is termed as methemoglobinemia or blue baby syndrome which is very serious especially to infants due to lack of enzyme necessary to correct it. This problem does not only occurr in humans but it is also a serious problem for wild animals like fish (Ribaudo and Johansson, 2006).

### 2.6.3 Economical impacts

Directly or indirectly, the ecological and social impacts of eutrophication have significant negative impacts on the economic aspects of the people living in a eutrophicated area.

Human, domestic and wild animal health impacts due to cyanotoxins in water for instances have a direct economical impact. In addition, the loss of biodiversity in the water bodies such as fish can affect the income generation of fishing-based people and others. Moreover, the loss of aesthetic and recreational values can also have negative impacts on the tourism sector (Lee *et al*., 2005).

Furthermore, one of the most expensive problems caused by the enrichment of nutrients is related to the cost of treatments for drinking water. People have to be supplied with clean drinking water. Therefore, in order to supply clean drinking water, the odor, taste and toxic substances and algal cells should be removed from the water. This can be achieved by treating the water before provision. However, in order to treat this eutrophicated water, it requires high investment costs of treatment. It needs greater volume of water treatment chemicals, increased back-flushing of filters and additional settling times to attain acceptable drinking water quality. Additionally, algal-bloomed water commonly causes the drinking water treatment plant filters to clog with algae and can increase maintenance costs. Moreover, it can contribute to the corrosion of intake pipes (USEPA, 2000).

## 2.7 Mechanisms to control eutrophication

Although eutrophication is a natural phenomenon that takes place over geological time, it becomes a serious problem for the impairment of water quality. Basically, it is not the natural eutrophication process that currently is a problem of water quality degradation rather it is the human activities which accelerates the natural process of eutrophication that makes the problem serious (cultural eutrophication) (Lee *et al*., 2005).

Thus, in order to control eutrophication of water bodies, the most appropriate mechanism is the reduction of nutrient loads to aquatic ecosystems (Boqiang *et al*., 2005). In line with this, controlling erosion is an essential aspect of preventing nutrient pollution of surface waters (Cestti *et al*., 2003).

Thus, one of the most important effective tools in preventing or reducing the load of nutrients to water bodies is the program of watershed management. Integrative management of the activities within a watershed can affect the amount and transport of pollutants to the water bodies. Watershed management activities aims at preventing eutrophication from occurrence as well as it provides management options which are designed to remediate water bodies once eutrophication has occurred. Therefore, it is possible to control and solve problem of eutrophication before and after the occurrence of it by taking appropriate preventative and mitigation measures (Piehler, 2008).

### 2.7.1 Preventative measures

Preventative measures are the most often preferred approach to control the occurrence of eutrophication. Hence, in order to control the flow of nutrients, appropriate measurements have to be put in place. However, similar measurements may not be applied in both urban and agricultural watersheds since their sources of nutrients are different. Therefore, for each of them taking appropriate management actions are essential (Piehler, 2008).

Thus, in order to reduce the flow of nutrients from urban watersheds, one of the measurement actions is reduction of the impact of imperviousness. Impervious layers most of the time prevents the infiltration of water and as a result, it promotes the transport of materials to water bodies through runoff. Therefore, the reduction of imperviousness by using pervious pavement and decreasing the connection of impervious areas plays a significant role in minimizing the amount and movement of pollutants to adjacent waters. Additionally, the flow of pollutants can also be decreased by increasing surface storage using retention structures and storm water treatment and engineering for increased infiltration in urban watershed (Piehler, 2008).

However, in agricultural watershed, other best management practices are needed to minimize the overflow of nutrients and hence maximize the retention of nutrients on the landscape. Best management practices (BMPs) are individual or combinations of management, cultural and structural practices that are identified as the most effective strategies and reduce environmental degradation (Novotny, 2003).

These BMPs can be either structural or managerial measures that help to address agricultural-induced pollution of water. Structural measures are the best environmental practices that intercept and transform nutrient fluxes from agricultural lands to water bodies. These include tree planting along water bodies, buffer zones, natural and constructed wetlands, terraces, fencing and others. On the other hand, managerial measures have also great contribution in the reduction of excessive flow of nutrients from farmlands. Nutrient budgeting, rotational grazing, conservation tillage and others are managerial practices (measures) (Kuusemets *et al.*, 2000; Cestti *et al.*, 2003). Besides, agro-forestry activity is also the other most critical and successful management practice in preventing and reducing excessive erosion of soil.

### 2.7.2 Mitigation measures

Mitigation measures are also another ways of practices which are designed to remove the bloom after it has occurred. These measures are most of the time applied in drinking water supply because of the higher risk of human exposure.

Eutrophication could result from the top-down effect besides to the bottom-up effect of nutrient enrichment. The absence of zooplankton predation has its own contribution for the rapid enhancement of eutrophication. However, this excessive bloom of algae can be remediated by applying different techniques. Of the techniques, application of chemicals is the most effective mechanism. Application of algaecides, oxidants and coagulants are used to remove the bloom of algae (Chorus and Bartram, 1999).

Beside to the application of chemicals, bio-manipulation (biological restoration) is another biological option for rehabilitating turbid lakes and reservoirs characterized by high algal biomass. It is an intentional action to reduce algal biomass through encouraging the interaction of the components of aquatic ecosystems. Zooplankton grazing is one of the powerful bio-manipulation means of controlling high population density of algae in lakes and reservoirs. Zooplankton feeds on algae and reduces the excess accumulation of the blooms on the surface of water. Moreover, there are also algae-eating fish species in reservoirs that can control the rapid growth of algal biomass (Smolders *et al*., 2006; Osomon, 2008; Mustapha, 2010).

In addition, aquatic macrophytes have also a significant impact in controlling and remediating high production of algal biomass. Macrophytes usually compete with algae for nutrients, and provide refuge (habitat) for algae-feeding fish so that they contribute for the reduction of algal biomass. Furthermore, during the growth of aquatic macrophytes, they release allelopathic substances that can inhibit the growth of algae (Osomon, 2008).

Sometimes aquatic macrophytes can be a nuisance, their total eradication can promote high production of algal biomass due to the absence of competition for nutrients and light. During the dense growth of macrophytes in a water body, many of the planktonic algal species decline. Therefore, plantation of macrophytes in reservoirs and other water bodies can reduce (remediate) the already accumulated algal biomass. In addition, they can also prevent the occurrence of algal biomass by limiting nutrients, light and other resources (Mustapha, 2010).

### 2.7.3 Mechanisms to control internal load of nutrients

Minimizing the discharge of nutrients at the source is the most effective method of controlling eutrophication. The sources can be external from watersheds or internal from sediments. Nutrients can be discharged from agricultural watersheds and enter water bodies together with sediments. Some of them are utilized immediately by aquatic plants and others settle down to the bottom of the water. Lake sediment is one of the main accumulation pools of nutrients and therefore it is the internal source of nutrients. Hence, these nutrients can be released from the sediments to the overlying water and become available for phytoplankton and other aquatic plants (Boqiang *et al*., 2006).

Lake sediments can be disturbed by different factors that initiate the sediment to release nutrients. Dynamic disturbance induced by wind and wave, bio-disturbance by benthic organisms, transmission of aquatic plant roots and molecular diffusion which mainly rely on the nutrient concentration gradient between the interstitial and overlying water are the major factors that disturbs the sediment. As a result, nutrients could be easily moved from the sediment to the overlying water. In addition, temperature, pH and redox condition are also responsible in disturbing the sediments of water bodies specially shallow lakes are very vulnerable to such type of activities and the exchange rate is very high (Xie, 2006).

Thus, controlling the movement of nutrients from the sediment to the overlying water is very important in reducing excessive growth of algae. One of the techniques to hinder the availability of nutrients to algae is taking physico-chemical measures. Sediment oxidation, chemical precipitation and sediment capping are the physico-chemical measures that reduce the internal loading of nutrients. These measures can be applied on small lakes in which their hydrodynamic action is weak and their sediment surface is in anaerobic condition. By changing the sediment redox conditions that can increase the ability of sediments to adsorb nutrients, it is possible to reduce the internal loading. Additionally a capping layer on the sediment surface can be made and can inhibit the releasing of phosphorus (Charboneau, 1999).

Besides, application of chemicals such as Aluminum, Ferrous and Calcium can change the redox action at the sediment-water interface. These chemicals play key role in precipitating and inactivating of nutrients specially phosphorus. Such type of activities results in the creation of oxidative conditions and formation of sensitive phosphate metallic compounds like ferrous phosphate. The precipitation process using chemicals removes inorganic phosphorus from the water column by forming insoluble compounds that can settle to the lake bottom. Then after, phosphorus is inactivated by further chemical reactions that prevents its release from the sediment (Charboneau, 1999).

Similarly, the formation of aerobic conditions could greatly reduce the releasing of nutrients from the sediments. According to Goel (2006), nutrients in anaerobic condition can be released from the sediment 10 times more than in aerobic condition. Thus, aerobic condition can be created by injecting chemicals like calcium nitrate into sediments. The injected chemicals can stimulate denitrification and oxidation of organic matter. As a result, oxidation of organic matter can enhance the greater binding of phosphorus with some compounds such as ferric hydroxide complexes.

However, the application of chemicals can bring some negative impacts on the aquatic environment. But the possibility of harming aquatic organisms and habitats can be minimized by using proper dosing and timing of treatments besides to the appropriate selection of chemicals (Charboneau, 1999; Rahman and Bakri, 2000).

Sediment dredging is also another measure to intercept the internal load of nutrients. This measure can improve the quality of water for short period of time. However, sediment dredging cannot be applied for a long-term controlling of internal nutrient load (Goel, 2006; Smolders *et al*., 2006).

Some aquatic macrophytes such as isoetid species release large amounts of oxygen from their roots and so maintain an oxidized state in the sediments. As a consequence, phosphate is bound to iron hydroxide and remains highly immobile (Smolders *et al*., 2006).

# 3 Materials and methods

## 3.1 Description of the study area

### 3.1.1 Location

Angereb watershed lies in the north central massif which is characterized by rugged mountains and valleys. The watershed is located on the eastern side of Gondar town between 328000 to 338000m E and 1393500 to 1407000m N and has an area of 7653.73ha (Figure 3.1). It belongs to the Blue Nile basin. Angereb Dam is an earthen Dam constructed by the Ethiopian Water Works Construction Authority (EWWCA) in 1990. The Dam is located at an average altitude of 2125m a.s.l.

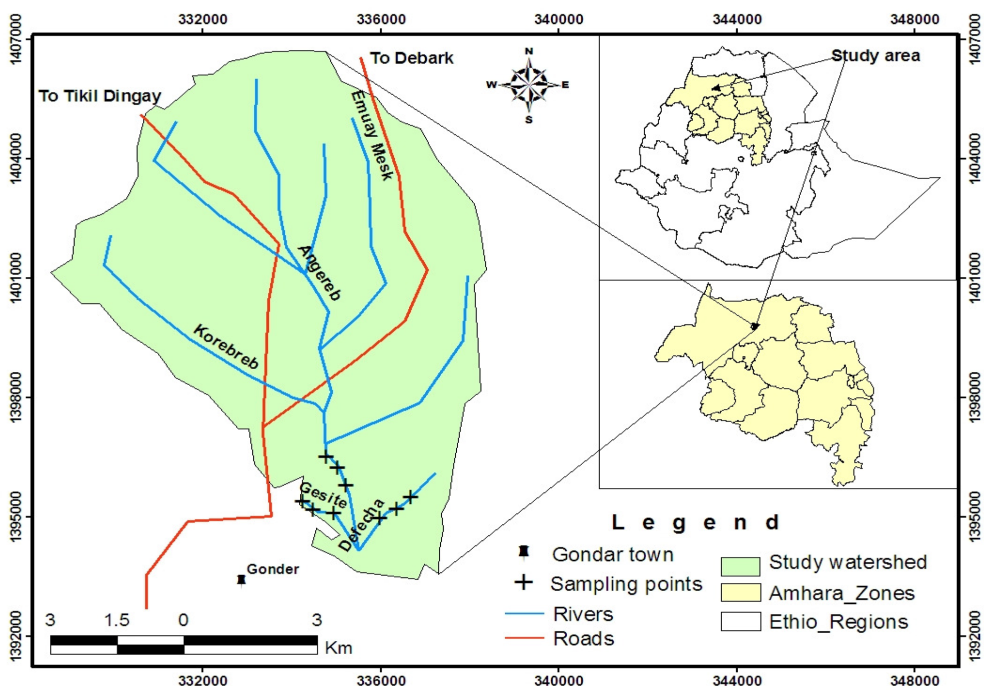



Fig.3.1.Map of the study area

### 3.1.2 Topography

Angereb watershed is mainly characterized by high mountains and steep slopes. The watershed has steep mountainous boundary at the edges, numerous convex hills inside the watershed and steep gorges. The topography of the watershed is generally characterized by 46.09% of mountainous, 16.11% of hilly, 10.57% of undulating plain, 27.57% of rolling plain, and 0.96% of flat plain ( Teshager Admasu, (?).

### 3.1.3 Climate

The rainfall pattern of Gondar is characterized as mono-modal type. The annual rainfall varies from 711.8 to 1822.42 mm with a mean annual value of 1200 mm. Long-term distribution of rainfall data indicates that most of the rain occurs in July followed by August. The rainfall in May and June is also quite significant. The mean annual temperature in Gondar town varies between 16$^{o}$C and 20°C which makes it in Weina Dega Zone. Maximum temperature occurs in March and April and minimum temperatures are at their lowest in November to February (Draft design report, 2010).

### 3.1.4 Land use and land cover

Angereb watershed is characterized by different sizes of bushes and trees. Indigenous species such as, *Combretum collinum, Apodytes dividiata, Carisa edulis, Olea africana, Dodoma viscosa, Croton macrostachys,* and *Acanthus arobresus* are the common vegetation coverage of the area. In addition, poorly managed state and community eucalyptus plantation (predominantly *Eucalyptus globules*) forest is also the common land cover of the watershed. Farmland is the major land use of the watershed (Admasu Amare, 2005).

### 3.1.5 Socio-economic features

There is no significant variation in the overall socio-economic activities of the watershed from other neighboring rural Kebeles**.** The rural community in the watershed is mainly practicing mixed farming system; cereal cropping and livestock production. Other inhabitants of the watershed are also engaged in unskilled labor and government works. The high population growth causes shortage of land which leads to the cultivation of steep slopes. All marginal and grazing lands are brought under cultivation. Besides, the communities are also utilizing commercial fertilizers to enhance their crop production (Admasu Amare, 2005).

## 3.2 Study design

A systematic study designed was employed in order to achieve the required objectives of the study. Field observation and reconnaissance survey was carried out so as to identify the sampling sites.

### 3.2.1 Reconnaissance survey

A preliminary reconnaissance survey was conducted to assess the existing situations of the study area. The streams and river that drains directly to the Dam were identified. In connection with this, the flow condition of these streams was observed besides to the information obtained from the local people and the office of water supply and sanitation service of the town. Additionally, physical observation was made on slope differences in each stream. The different amounts of sediment deposition in the different sections of the streams were also an indicative of slope differences. These all made identifying the sampling sites simple.

### 3.2.2 Sampling methods

#### 3.2.2.1 Selection of sampling sites

Sampling points were selected from identified sub watersheds based on sediment deposition differences (for streams) using a systematic sampling approach. Thus, sediment and soil samples were taken from Angerb river, Defecha and Gesite streams. Accordingly, for Angereb river, the first sampling site had a distance of 100 m from the Dam; the second site was far 200 m from the first sampling point; and the third site was 200 m apart from the second sampling point. The same was true for Defecha and Gesite streams. Similarly, in the lake water of the Dam, 3 sampling sites (Lake water edge-1 (LWE-1); Lake water edge-2 (LWE-2); and Lake water edge-3 (LWE-3)) were selected at the edges of the dam that had 100m interval with each other.

#### 3.2.2.2 Sediment sampling

A total of 18 sediment samples were taken from all sampling sites of streams. From Angereb river, 2 sediment samples from each of the 3 different sites were taken. In the same manner, from each of the 3 sites of Defecha stream, 2 sediment samples were taken. Likewise, from Gesite stream, 2 sediment samples were taken from each 3 sites.

In the lake water of the Dam, 3 replicate sediment samples were taken from December 24, 2010 to February 17, 2011 (once a month). Thus, a total of 9 sediment samples were taken from the 3 sites of the Dam.

Surface sediments were collected using a scoop sampler to obtain the recent sediment deposition (Smodis *et al*., 2003). In the streams, sediments were taken at the middle, and on both sides of the internal bank of the stream, and become mixed (composited), and placed in clean plastic bags. Composite samples were duplicated for each of sampling sites of the streams. The scoop was washed with distilled water throughout the sampling sites to avoid contaminations.

#### 3.2.2.3 Soil sampling

Soil samples were collected from the top 20cm depth. The samples were taken parallel to the sites where sediment samples are taken. A total of 18 composite soil samples were taken from all sites. From the 20m x 20m plotting area, soil samples were taken at the nodes and middle of it using a tube auger, and become composited.

#### 3.2.2.4 Water sampling

Water samples were taken from December 24, 2010 to February17, 2011 (once a month) for the analysis of total nitrogen (TN), total phosphorus (TP), and chlorophyll-a (Chl-a). For the analysis of TN and TP, grab water samples were taken (once a month) from the lake water of the Dam sites where sediments were taken using 1L polyethylene bottle. The samples were preserved using concentrated sulfuric acid ($pH < 2$) for those which were not analyzed immediately. For chlorophyll-a analysis, water samples were also taken from the same sites of the Dam (once a month), and transported to the laboratory and analyzed immediately. For the measurement of turbidity, water samples at the same sites of the Dam were taken, and measured immediately. Dissolved oxygen, pH, and temperature were measured on site at the same sites of the Dam. Altitude and geographical positions were taken for each of the sampling sites using GPS.

### 3.2.3 Analytical methods

The chemical analyses of water, sediment and soil samples were carried out in Gondar Soil and Water Laboratory for total nitrogen and total phosphorus. Algal biomass was analyzed in the laboratory of Biology in Gondar University.

Total phosphorus (TP) in the water sample was analyzed using Digestion and Ascorbic acid spectrophotometric method (APHA and AWWA, 1995). 100 mL of thoroughly mixed water samples were digested using 0.4 g Ammonium per sulphate solution. It was boiled gently on a pre-heated hot plate for 30 to 40 minutes. The digested samples were cooled and make up to 100 mL with deionized water. Calibration curve was prepared before the measurement of samples. This was done using standard phosphate solution (2.5 mg/L). To each of the 50 mL deionized water containing flasks, 2 mL, 4 mL, 8 mL, 10 mL, 15 mL and 20 mL standard phosphate solutions were added. The blank which did not contain phosphate solution was also prepared from deionized water that serves as a control group. To each of the flasks, 8 mL combined reagent was added. After 30 minutes, the absorbance's of each solution was measured at 880 nm using spectrophotometer. The calibration curve was prepared by plotting the absorbances of solutions against phosphate concentrations. In order to verify the proper calibration of the instrument, the correlation coefficient was calculated which is 0.9969. After the preparation of calibration curve, 8 mL combined reagent was added to the digested samples. After 30 minutes, the absorbances of samples were measured at 880 nm. Finally, the concentration of total phosphorus in each sample was computed using linear regression calculation.

Since due to the absence of applicable analytical methods in the laboratory of Gondar that can measure total nitrogen (TN) once at a time, the forms of nitrogen were analyzed separately and at the end were added together. Hence, TKN (Organic nitrogen + Ammonia) was analyzed using the procedures of USEPA method No.351.3 (EPA-600/4-79-020). According to this procedure, 50 mL digestion solution was added to 100 mL water samples and digested under block digester. The digestion was continued until colored or turbid samples were turning clear. After the digestion was completed, the samples were cooled and diluted back to 300 mL with deionized water. Few drops of phenolphthalein indicator and 50 mL Sodium hydroxide-thiosulphate reagent were added. After the completion of digestion, the digested samples were distilled. 200 mL distillate was collected below the surface of 50 mL of 2% boric acid solution. Finally, the concentration of TKN was determined using titration.

Nitrate was analyzed using UV spectrophotometric method (APHA and AWWA, 1995). The samples were pre-treated using filtration. Thus, water samples were filtered through 0.45 μm pore size membrane filters to avoid suspended materials. The calibration curve was prepared by using standard nitrate solution. To each of the 50 mL deionized water containing flasks, 1 mL, 2 mL, 4 mL, 7 mL, 10 mL, 15 mL, 20 mL, 25 mL, 30 mL, and 35 mL of standard nitrate solutions were added. The blank was also prepared using re-distilled water that serve as quality control measures. The absorbances were measured at 220 nm to obtain nitrate reading and at 275 nm to determine interferences due to dissolved organic matter. The absorbance reading at 275 nm was subtracted two times from the reading at 220 nm to obtain absorbance due to nitrate. The calibration curve was prepared as absorbances against concentration of nitrate, and the correlation coefficient was calculated which is 0.9991. The concentrations of nitrate from the samples were computed using linear regression calculation.

Nitrite was analyzed using UV spectrophotometric method (APHA and AWWA, 1995).water samples were filtered through 0.45 µm pore size membrane filters. Calibration curve was prepared using standard nitrite solution. 0.5 mL, 1 mL, 2 mL, 4 mL, 5 mL, 10 mL of standard solutions of nitrite was added to each of the 50 mL deionized water containing flasks. 2 mL of color reagent was added to each standard to develop color. The absorbances were read after 15 minutes at 540 nm by calibrating the spectrophotometer using the blank. The calibration curve was prepared and its acceptance was checked by calculating the correlation coefficient which is 0.9982. After the preparation of calibration curve, the samples were also treated in the same manner as the standards were treated. The concentrations of samples were calculated using linear regression calculation. Finally TKN, nitrate and nitrite were sum up and gave total nitrogen.

The sample preparation for sediment and soil samples involved air drying, crushing, grinding, and sieving. Total nitrogen was determined using the procedures of modified kjeldahl method (Jaiswal, 2003). Thus, air dried and sieved samples of soils and sediments were digested with Sulphuric acid-salicylic acid mixture in the presence of sodium-thiosulphate and the catalyst mixture namely anhydrous Sodium sulphate and Mercuric oxide with external heat. During digestion, carbon of organic fraction is oxidized to carbon dioxide, and organic nitrogen is initially converted into amino form which on oxidation by Sulphuric acid is converted into Ammonium sulphate. Nitrates in the soil form nitric acid in the presence of Sulphuric acid. The Nitric acid react with salicylic acid to form Nitro-salicylic acid which is reduced by Sulphorous acid produced by the action of Sulphuric acid on Sodium thiosulphate to form Amino-salicylic acid. Amino-salicylic acid is oxidized by Sulphuric acid to convert Amino nitrogen into Ammonium sulphate. Then, the digested material was distilled using kjeldahl nitrogen distillation assembly after making it strongly alkaline using Sodium hydroxide. The Ammonium distilled was collected into Boric acid solution containing mixed indicator. Ammonia reacts with Boric acid to form Ammonium borate which was titrated by a standard Sulphuric acid.

Similarly, TP was analyzed based on the method of AOAC (Association of Official Agricultural Chemists) of USA. Sulphuric acid was used to digest phosphorus in soil and sediment samples. The digestion was carried out for 3 hours at 300$^oC$ using block digester under a hood. The phosphorus extracted from the soil and sediment was first made alkaline by adding Ammonium hydroxide. Thereafter, it was made acidic by adding Nitric acid. In Nitric acid medium, Ammonium molybdate was added to precipitate phosphorus as yellow compound of Ammonium phosphomolybdate. The precipitate was collected on a filter paper and washed to make it free from acid using Potassium nitrate. The precipitate also washed with cold water to remove Potassium nitrate. Thereafter, the precipitate was dissolved by adding standard sodium hydroxide solution. The alkali added in excess was back titrated by standard 0.1 N Sulphuric acid to the phenolphthalein end point. Finally, the concentration of total phosphorus was calculated from the titration.

The turbidity was measured using a method of nephlometric unit. 4000 NTU stock solution was prepared by mixing solution-1 and solution-2. Solution-1 contained 1 g of Hydrazine sulphate dissolved in distilled water. Solution-2 also contained 10 g of Hexamethylenetetramine dissolved in distilled water. The standards were prepared from the 4000 NTU stock solution that serves for quality controls. Samples were agitated gently and wait until air bubbles were disappeared, and then samples were poured into the cell and the turbidity was taken from the instrument directly.

Algal biomass was determined as chlorophyll-a using Acetone extraction spectrophotometric method (APHA and AWWA, 1995). One liter water sample was filtered with the aid of electrically operated vacuum and suction pump (Model AP-9925) through 0.45µm pore size filter paper. Then after, the pigment was extracted from the filter through maceration (grinding), steeping and centrifugation in 90% acetone. The extracted pigment was then analyzed using a T60 UV/VIS spectrophotometer at 664nm and 750nm, and again after acidification at 665nm and 750nm. All the activities were performed under subdued light. The change in optical density after acidification was used to determine the corrected values for chlorophyll-a. The concentration of chlorophyll-a was calculated using the following formula.

$$\text{Chlorophyll-a } (\mu g/L) = \frac{26.7(664_B - 665_A)xV_1}{V_2 x L}$$

Where, $V_1$ -Volume of extract in mL.

$V_2$ -Volume of sample in L.

L- Width of cuvette.

$664_B$ -Corrected optical density before acidification.

$665_A$ -Corrected optical density after acidification.

The value 26.7 is the absorbance correction and equals $A \times K;$

$A$ –Absorbance coefficient for chlorophyll-a at 664nm = 11

$K$ – Ratio expressing correction for acidification, 2.43

Dissolved oxygen was measured on site using Hana model H1-9143 DO meter. The temperature was also recorded using this instrument. A digital pH meter (Model H1-8314) was used to measure the acidity and basicity of the water.

### 3.3 Data analysis

Computer programs were used for data interpretation and analysis. SPSS version 13.0 was used for descriptive, correlation and ANOVA tests. Descriptive statistics were used for mean computation. Correlation test has been carried out to assess the relations of physico-chemical characteristics of the water in the dam with its biological characteristics. In addition, one way ANOVA was also used to see the spatial variations of physical, chemical and biological characteristics of the water in the dam. Microsoft excel spreadsheet was employed for graphical illustrations.

# 4 Results and discussion

## 4.1 Nutrients status of the water in the Dam

### 4.1.1 Total Nitrogen (TN) in the lake water of the Dam

As shown in the Table below (Table 4.1), sufficient amount of TN was found in the lake water of the dam. The presence of nitrogen in the water of Angereb Dam showed the existence of management problems in the upland area of the watershed. When the level of nitrogen in a water body increases, there will be a corresponding increment in the growth of algae and aquatic plants. However, the presence of this nutrient below and above the requirement level could affect the growth and distribution of aquatic organisms.

Table 4.1TN of the water in the Dam

| Parameters | Mean ± SD |
|---|---|
| TN (mg/L) | 0.805 ± 0.137 |

A study conducted by Chu cited in Pfafflin and Ziegler (2006), the growth of algae appears to be inhibited if the concentration of total nitrogen is below 0.2 ppm. Likewise, the same reduction in growth can happen if TN concentration is raised above 20 ppm. Moreover, according to Khan and Ansari (2005), maximum growth of algae can be attaining when TN is less than 1.0 mg/L. Thus, the amount of total nitrogen of the water in Angereb Dam was sufficient for supporting the growth and development of algae and other aquatic plants. Therefore, according to Mackie *et al.* (2006), depending on the level of nutrients, the lake water of the Dam could be characterized as having high enrichment of nitrogen.

### 4.1.2 Total Phosphorus (TP) in the lake water of the Dam

Total phosphorus in the water of the Dam was found at a level that can initiate and proliferate the growth and development of aquatic plants especially algae. As shown in the Table below (Table 4.2), there was high concentration of TP in the water of the Dam (0.11 ± 0.057 mg/L).

Table 4.2 TP of the water in the Dam

| Parameters | Mean ± SD |
|---|---|
| TP (mg/L) | 0.11 ± 0.057 |

The production of algae can be hindered if the concentration of TP is below 0.05 ppm (Chu cited in Pfafflin and Ziegler, 2006). Additionally, production of algae can be accelerated when the concentration of TP is between 0.1-0.75 mg/L especially when it is less than 1.0 mg/L (Khan and Ansari, 2005). As a result, the amount of TP in the water of the dam is found in the range of requirement and can cause algal production. However, if TP is not found in the range of optimum level, it can reduce the growth of algae. Hence, if the amount of TP is above 20 ppm, the production of algae will be substantially decreased (Chu cited in Pfafflin and Ziegler, 2006). Thus, depending on Mackie *et al.* (2006), the lake water of Angereb Dam could be characterized by high level of TP.

### 4.1.3 Spatial distribution of TN and TP of the water in the Dam

Table 4.3 below shows both TN and TP vary significantly from site to site. Therefore, as LSD test has indicated (Appendix-1), with respect to TN, there was a significant difference between LWE-1 and LWE-3 (at P= 0.01) but there was no significant variation between LWE-1 and LWE-2 (at p= 0.145). Similarly, LWE-2 and LWE-3 do not show any significant difference between them (p= 0.186). On the other hand, with respect to TP, there was a statistical significant difference between LWE-1 and LWE-2 (at p= 0); LWE-1 and LWE-3 (at p= 0); and LWE-2 and LWE-3 (at p= 0).

Table 4.3 Spatial variation of TN and TP of the water in the Dam

| Parameters | Sites LWE-1 Mean ± SD | LWE-2 Mean ± SD | LWE-3 Mean ± SD | p-value |
|---|---|---|---|---|
| TN (mg/L) | 0.905 ± 0.132 | 0.802 ± 0.127 | 0.708 ± 0.084 | 0.034 |
| TP (mg/L) | 0.178 ± 0.024 | 0.103 ± 0.021 | 0.05 ± 0.013 | 0.000 |

(LWE-1: Lake Water Edge-1; LWE-2: Lake Water Edge-2; LWE-3: Lake Water Edge-3)

The possible reason for the variation of TN and TP in the three aforementioned sites could be the activities of zooplanktons, microorganisms, roots of macrophytes and others. According to USEPA (2000), the concentration of nutrients in the water body can be affected by the activities of aquatic organisms. The activities of these organisms cannot be uniform throughout the different sites of a single lake. These different activities therefore could have the potential impact on the level of nutrients both in the sediment and overlying water throughout the various sites of a lake. Thus, as it is shown from Table 4.3, LWE-1 seems to have (relatively) high disturbance of sediments which causes the releasing of nutrients to the water column and results in high concentrations of TN and TP, followed by LWE-2 and LWE-3.

## 4.2 Total Nitrogen (TN) and Total Phosphorus (TP) in the sediments of the Dam

Table 4.4 below shows that there is high concentration of total nitrogen and total phosphorus in the sediments of the Dam. The presence of TN and TP in high concentrations was an evidence for the existence in management interventions in the watershed.

Table 4. 4 TN and TP of sediments in the Dam

| Parameters | Mean ± SD |
|---|---|
| TN (%) | 0.037 ± 0.026 |
| TP (%) | 0.516 ± 0.371 |

These nutrients can also be released from the sediments to the water column and become available to algae and macrophytes. Sediments are internal storage pools of nutrients and cause nutrient dynamics in the water column. Therefore, sediments in the Dam of Angereb can be the long-term potential source for the nutrients even if the discharging of nutrients from the external source can be decreased. So, aquatic plants will grow and reproduce at their preferential time without the limitation of nitrogen and phosphorus.

### 4.2.1 Spatial distribution of TN and TP in the sediments of the Dam

There were statistical significant differences of TN and TP in the sediments of the selected sites of the Dam (Table 4.5). The statistical LSD analysis (Appendix-2) showed that in relation to TP, there was a significant difference between LWE-1 and LWE-2 (P= 0.043). In the same way, LWE-1 and 3; and LWE-2 and 3 varies significantly (p= 0). Similarly With respect to TN, except LWE-1 and 2 (p= 0.273), the remaining sites had significant variations i.e. the concentration of TN in LWE-1 significantly varies to the LWE-3 (at p= 0.004); and the concentration of TN in LWE-2 differ significantly to LWE-3 (P= 0.04).

Table 4.5 Spatial variation of TN and TP in the sediment of the Dam

| Parameters | Sites | | | |
|---|---|---|---|---|
| | LWE-1 | LWE-2 | LWE-3 | p-value |
| | Mean ± SD | Mean ± SD | Mean ± SD | |
| TN (%) | 0.0198 ± 0.009 | 0.030 ± 0.008 | 0.060 ± 0.033 | 0.013 |
| TP (%) | 0.317 ± 0.045 | 0.218 ± 0.035 | 1.013 ± 0.12 | 0.000 |

(LWE-1: Lake Water Edge-1; LWE-2: Lake Water Edge-2; LWE-3: Lake Water Edge-3)

The high concentrations of TN and TP in the sediment of LWE-3 as compared to the remaining sites could be associated with the low disturbance of sediments by aquatic organisms.

## 4.3 Algal biomass and trophic status of the water in the Dam

The biomass of algae was measured as chlorophyll-a depicted in table below.

Table 4.6 Algal biomass of the water in the Dam

| Parameter | concentration is Mean ± SD |
|---|---|
| Chlorophyll-a (µg/L) | 4.20 ± 0.918 |

The biomass of algae as chlorophyll-a is one of the principal biological response of nutrient enrichment. Hence, the biomass of algae estimated as chlorophyll-a in the water of Angereb Dam was 4.20 ± 0.918 µg/L. The Trophic status of water bodies is mainly determined by the level of algal biomass. Total nitrogen and total phosphorus are also used to classify the trophic state.

Table 4.7 Mean concentrations of TN, TP and Chlorophyll-a of the water in the Dam

| Parameters | Concentrations |
|---|---|
| TN (mg/L) | 0.805 ± 0.137 |
| TP (mg/L) | 0.11 ± 0.057 |
| Chl-a (µg/L) | 4.20 ± 0.918 |

According to the trophic state classification system of Mackie *et al*. (2006), in the concentrations of TN and TP, Angereb Dam could be classified as being eutrophic condition. However, with respect to algal biomass which was 4.20µg/L, the Dam is not under the category of eutrophic level rather it is under the level of mesotrophic. On the other hand, others considered only the concentration of chlorophyll-a to determine the trophic status of the water. Thus, based on the classification of Ryding and Rast (1989), the trophic state of Angereb Dam falls under mesotrophic condition. Similarly, according to Novotny and Olem (1994), the dam is under the category of mesotrophic level. In addition, based on the classification system of Wetzel (2001), the trophic status of Angereb Dam still falls under the category of mesotrophic conditions.

Although, there were high concentrations of phosphorus and nitrogen in the water, these concentrations could not bring excessive bloom of algae. Rather, the biomass as it is depicted in Table (4.7) was 4.2 µg/L. But, this does not mean that phosphorus and nitrogen were available below the requirement level of algae. The result is in agreement with the result of Cloern (1999). As he tried to elucidated, eutrophication is not simply a matter of nutrient loading; but the pathways through which nutrients impact on productivity are numerous and varied. It can be governed by other physical and biological processes. Moreover, Yonas Ugo (2008) has also found that algal bloomed did not occurr even if there was high concentration of phosphorus (0.74 ± 0.74 mg/L).

The transformation of nutrients to algal biomass requires solar radiation. Turbidity which is one of the physical factors that can affect the intensity of light could be one of the causes for algae to not bloom on the surface of water in Angereb Dam. The Dam had a mean turbidity measurement of 18.55 ± 2.068 NTU within the study period which was sufficient to block (attenuate) the incoming radiation. Thus, light limitation due to turbidity limits the capacity of algae to assimilate and transform dissolved phosphorus and nitrogen into new algal biomass.

In addition, the proliferation of algae in the water of Angereb Dam could also be limited by the grazing activities of zooplanktons. According to Walker and his co-workers (2006), grazing by snails, caddisfly larvae, mayfly larvae, filter feeding organisms, and by other aquatic organisms, can control algal growth and production even under high levels of nutrients. Little concentration (0.3 to 0.015 ppm) of nitrates and phosphates can produce blooms of certain species of algae if other environmental conditions are favorable (Pfafflin and Ziegler, 2006). To sum up, unless other environmental conditions are favorable, it is very difficult to algae to flourish on surface water easily.

### 4.3.1 Spatial distribution of algal biomass of the water in the Dam

As it is shown in Table 4.8 below, there was no statistically significant difference of algal biomass across the three sites of the water in the Dam ($p= 0.058$). However, the multiple comparison LSD test (Appendix-3) has indicated that there was a statistical significant difference between LWE-2 and LWE-3 ($p= 0.023$) which is probably due to the presence of floating macrophytes in LWE-3.

Table 4.8 Spatial distribution of algal biomass as chlorophyll-a concentration

| Parameter | Sites | | | |
|---|---|---|---|---|
| | LWE-1 | LWE-2 | LWE-3 | P-value |
| | Mean ± SD | Mean ± SD | Mean ± SD | |
| Chlorophyll-a (µg/L) | 4.34 ± 0.842 | 4.95 ± 0.67 | 3.31 ± 0.387 | 0.058 |

(LWE-1: Lake Water Edge-1; LWE-2: Lake Water Edge-2; LWE-3: Lake Water Edge-3)

Macrophytes are the main competent of algae in aquatic ecosystems with respect to nutrients. Thus, in LWE-3, the available nitrogen and phosphorus in the water column may be consumed by macrophytes at a higher rate than algae. Furthermore, the presence of macrophytes may also release toxic substances that hinder the growth and production of algae (Osomon, 2008).

Plate 4.1 Macrophytes around the edge of the dam ( LWE-3) Macrophytes

## 4.4 Physical and chemical characteristics of the water in the Dam

Besides to the nutrients and biomass of algae, other physical and chemical characteristics have also been assessed in the lake water of the Dam. The parameters are dissolved oxygen, pH, temperature and turbidity. The Table shown below (Table 4.9) displays the results of these parameters.

### 4.4.1 Dissolved oxygen

Dissolved oxygen is one of the indicators of the health of aquatic environments. In the lake water of Angereb Dam, the level of dissolved oxygen (6.654 ± 0.521 mg/L) was found at a level that can support most aquatic organisms. According to Pennington and Cech (2010), most aquatic ecosystems require minimum dissolved oxygen in the range of 5-6 mg/L to support living organisms. Warm water fishes can survive within a level of dissolved oxygen ranging from 5-9 mg/L, and cold water fishes require a minimum amount of 6.5 mg/L to a maximum of 9.5 mg/L (Alabaster and Liyod, 1982). Thus, the concentration of dissolved oxygen in the lake water of Angereb Dam (6.654 ± 0.521 mg/L) was favourable for the majority of aquatic dwellers.

Table 4.9 Physico-chemical characteristics of the water in the Dam

| Parameters | Measured values (Mean ± SD) |
|---|---|
| Dissolved oxygen (mg/L) | 6.654 ± 0.521 |
| pH | 8.402 ± 0.147 |
| Temperature ($^oC$) | 22.57 ± 0.384 |
| Turbidity (NTU) | 18.55 ± 2.068 |

### 4.4.2 pH

The pH of the water in the Dam was found at the level of basic conditions (8.402 ± 0.147) which could be linked to the photosynthetic activities of producers. According to Carr and Neary (2008), the value of pH between 6.5 to 8.5 usually indicates good water quality though the tolerance of individual species varies. pH values less than 4.5 and greater than 9.5 are lethal to aquatic life (ILMB, 1998). Therefore, pH status of the lake water of Angereb Dam is found in a condition that can support the inhabitants of the water ecosystem.

### 4.4.3 Temperature

The temperature of water in the Dam (22.57 ± 0.384$^oC$) was found to be favorable for fishery activities since it was in the recommended range (22 - 31$^oC$) that can support the growth of fishes (Korai *et al.,* 2008). But this temperature (22.57 ± 0.384$^oC$) might not be favorable for the maximum growth of algae rather they become bloomed when the temperature is 30$^oC$ (Shen, 2002 cited in Khan and Ansari, 2005).

### 4.4.4 Turbidity

Turbidity is another physical factor that can affect the survival of organisms. The turbidity level of the water in Angereb Dam was 18.55 ± 2.068 NTU which could have resulted from the disturbance of internal sediments by the movement of zooplanktons. Tidal movement through the aid of wind action may also have its own impact in disturbing internal sediments. In addition, algae could have also an effect on the enhancement of turbidity level. According to ENSR (2002), water bodies having turbidity measurement of above 10 NTU are categorized under low level of water quality and can be risk to aquatic life. Hence, the quality of the lake water of Angereb Dam with respect to turbidity did not meet the required status so that it could be detrimental to its inhabitants especially to fishes.

### 4.4.5 Spatial variation of physical and chemical characteristics of the water in the Dam

Table 4.10 below shows the physical and chemical characteristics of the water at the different sites of the Dam. With respect to the selected sites of the water in the dam, all of the parameters significantly varied from one site to another site with the exception of temperature.

Table 4.10 Range and mean of physico-chemical parameters across sites of the water in the Dam

| Parameters | LWE-1 | | | LWE-2 | | | LWE-3 | | | P-value |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean ± SD | Min. | Max. | Mean ± SD | Min. | Max. | Mean ± SD | Min. | Max. | |
| DO (mg/L) | 6.64 ± 0.295 | 6.3 | 6.82 | 7.22 ± 0.111 | 7.12 | 7.34 | 6.1 ± 0.195 | 5.91 | 6.3 | 0.002 |
| pH | 8.42 ± 0.011 | 8.4 | 8.43 | 8.55 ± 0.03 | 8.52 | 8.58 | 8.24 ± 0.115 | 8.11 | 8.33 | 0.004 |
| $T^o$ ($^oC$) | 22.67 ± 0.577 | 22 | 23 | 22.47 ± 0.451 | 22 | 22.9 | 22.57 ± 0.153 | 22.4 | 22.7 | 0.855 |
| TUR (NTU) | 19 ± 1.0 | 18 | 20 | 20.33 ± 1.53 | 19 | 22 | 16.33 ± 1.154 | 15 | 17 | 0.02 |

(DO-Dissolved Oxygen; $T^o$-Temperature; TUR-Turbidity)

Dissolved oxygen had a statistical significant difference among sites (p= 0.002). The multiple comparisons LSD test showed that there were statistically significant differences between LWE-1 and LWE-2 (P= 0.016); LWE-1 and LWE-3 (p= 0.021); and LWE-2 and LWE-3 (P= 0.001) (Appendix-4). Similarly, pH had a general significant difference in all sites (p= 0.004). The multiple comparison test has indicated that there was statistically significant variation between LWE-1 and LWE-3 (at p= 0.02). In the same way, LWE-2 and LWE-3 differ significantly at p= 0.002. But, LWE-1 and LWE-2 did not show any statistical significant difference (p= 0.056) unlike their dissolved oxygen. The most likely source of the significant variations of dissolved oxygen and pH in these sites could be their relatively spatial variation of algal biomass.

With respect to turbidity variation, all of the three sites showed significant variation at p= 0.02 level. There was a statistical significant difference between LWE-2 and LWE-3 (P= 0.008); LWE-1 and LWE-3 (P= 0.04). But there was no significant difference between LWE-1 and LWE-2 (P= 0.238). The variation may be due to the activities of aquatic organisms like microbial activities, fishes, root movement of benthic algae and others could disturb the water to be turbid especially, in the sites of LWE-1 and LWE-2 (because of disturbance in sediments, TN and TP were low in the sediments and high in the water column). In addition, the presence of relatively high algal biomass in LWE-2 (4.95 ± 0.67 µg/L), and LWE-1 (4.34 ± 0.842 µg/L) caused the presence of high turbidity than in LWE-3 (3.31 ± 0.387 µg/L). As it is observed from Table 4.9, temperature did not show any significant variation among the sites (p= 0.855).

### 4.4.6 Relations of algal biomass with physical and chemical characteristics of the water in the Dam

Algal biomass is one of the principal biological responses of other physical and chemical factors. It has also great contribution for fluctuation of other physical and chemical characteristics in aquatic ecosystems. Some of the factors control the proliferation of algae and others become the manifestation of it. As a result, each of the selected parameters has its own relationship with each other, and for this reason a statistical correlation test has been carried out (Appendix-5).

Table 4.11 Correlations of algal biomass with DO, pH and turbidity

| Parameters | | DO | pH | TUR |
|---|---|---|---|---|
| Chl-a | r | 0.919 | 0.824 | 0.692 |
| | p | 0.000 | 0.006 | 0.039 |

(Chl-a-Chlorophyll-a; DO-Dissolved oxygen; TUR-Turbidity)

As shown in Table 4.11 above, there is strong relationship of dissolved oxygen with the biomass of algae. The statistical correlation test has indicated that the biomass of algae had significant correlation with dissolved oxygen (r= 0.919; P= 0). This implies that flourishment of algae on the water surface has a considerable positive effect on the level of dissolved oxygen. However, this does not mean that excessive growth of algae causes high production of dissolved oxygen. But, it means that the biomass of algae is found at the level that produces more oxygen than at the level that can reduce oxygen through decomposition meaning there is no excessive growth of algae in the water of Angereb Dam that can cause significant reduction of oxygen through decomposition.

Likewise, pH and Chlorophyll-a had a significant positive correlation with each other (r= 0.824; P= 0.006 level). Such type of strong relationship is due to the fact that pH is closely linked to the biological productivity of water (ILMB, 1998; Carr and Neary, 2008). The photosynthetic activities of algae remove carbon dioxide from the water and releases hydroxyl ions during sugar formation that enhances the pH of water. The removal of carbon dioxide lowers the level of carbonic acid in the water which causes a shift to less acidic condition (Walker *et al*., 2006). Thus, as the biomass of algae increases, the level of pH also increased (became more basic).

Turbidity which can be the manifestation of the large magnitude of producers was also correlated with algae (r= 0.692; P= 0.039). Although other suspended particulate matter have a considerable effect on turbidity, algae could also have their own contribution on the level of turbidity (Carr and Neary, 2008). This can be the possible justification why it had a significant positive correlation with the biomass of algae in Angereb Dam. Moreover, the presence of high turbidity whether it is caused by algae or suspended sediments can have a significant impact on the production of algae by restricting the amount of available sun light. This could be the probable reason why high level of eutrophic condition was not created in the water of Angereb Dam.

Temperature is the other most important environmental factors that can regulate the growth of aquatic organisms.

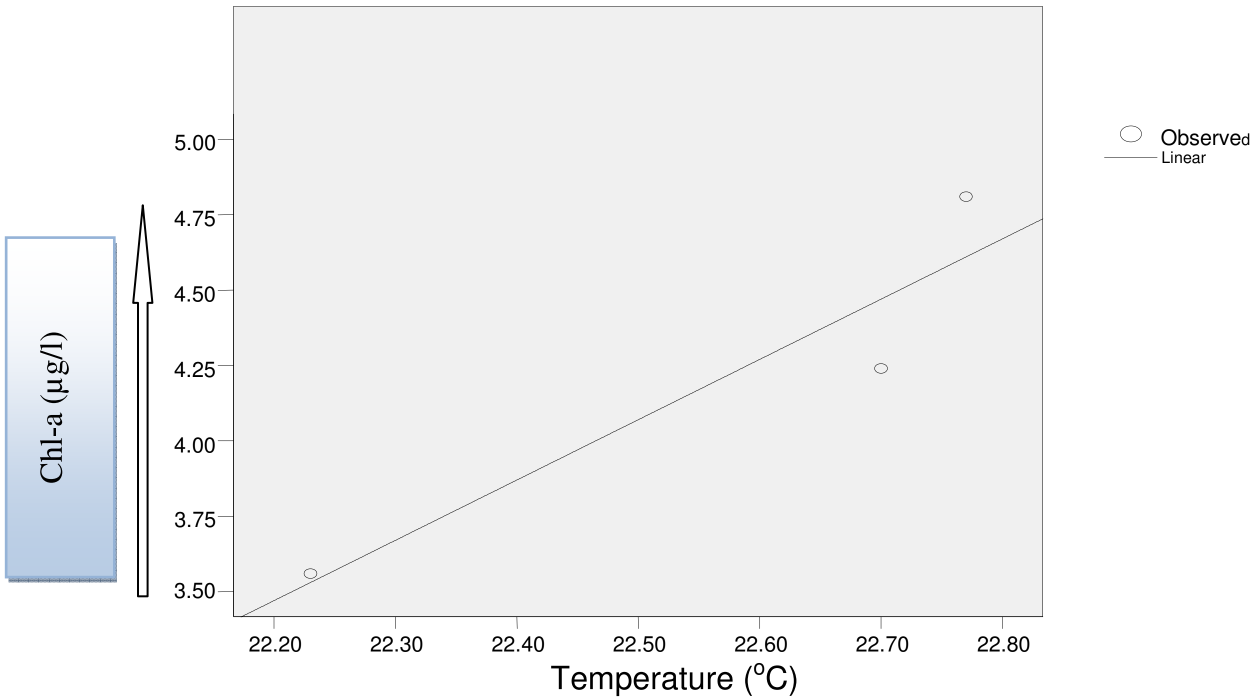



Fig.4.1 Relationship of algal biomass and temperature

The statistical correlation test indicated that temperature and algae had a positive correlation (r= 0.435). As it is indicated from the graph (Figure 4.1), as temperature increases, the production rate of algae also increases. Hence, the presence of high temperature in a water body initiates and increases the physiological activities of algae. Consumption of nutrients by algae would be accelerated usually when the temperature is high (Khan and Ansari, 2005). However, the temperature of the water in the dam was not found in the range that can cause algae to bloom on the surface of the water though other factors (like grazing) play significant role. Majority of algae seek a temperature above 25°C to undergo maximum growth and development (Chorus and Bartram, 1999). On the other hand, Robarts and Zohary (1987) suggested that algal blooms can occur at a temperature above 20°C. Although the temperature of water in the dam was found in the range of Robarts and Zohary (1987) suggestion, the algae did not bloom. The most likely reason for this could be the presence of grazing activities of zooplanktons, and in addition macrophytes might release toxins that hinder the growth of algae.

Nitrogen and phosphorus are the causal factors for the survival of algae, and hence the proliferation of algae is controlled by availability of these nutrients in the water. Although the production of algae is mainly controlled by these nutrients, according to Ponader and Charles (2003), it is very difficult to establish a strong correlation between nutrients and algal biomass. This is mainly because of the profound effect of other environmental conditions on the accumulation of algae. Therefore, in order to establish the proper nutrient-biomass relationships, other environmental factors should be taken into account. That is why the presence of high amount of nitrogen and phosphorus in the water of Angereb Dam could not bring excessive accumulation of algae. Thus, in evaluating the effects of nutrients on the biomass of algae, the interaction between nutrients and other physical, chemical or biological conditions should be taken into consideration. Accelerated growth of algae may be stimulated more by factors such as sunlight, temperature, pH, than by the abundance of nutrient material (Pfafflin and Ziegler, 2006).

The Pearson correlation analysis revealed that TN and chlorophyll-a had a positive correlation ($r= 0.735$) at $p= 0.024$. Correspondingly, TP was also correlated with chlorophyll-a ($r= 0.583$; $p= 0.099$), and therefore the enrichment of nutrients enhance algal production. However, it is possible to understand that the presence of high amount of TN and TP are not the sufficient factors for the blooming of algae and therefore, the biomass of algae could only be explained through a combination of other factors including nutrients.

## 4.5 Sources of nutrients to the Dam

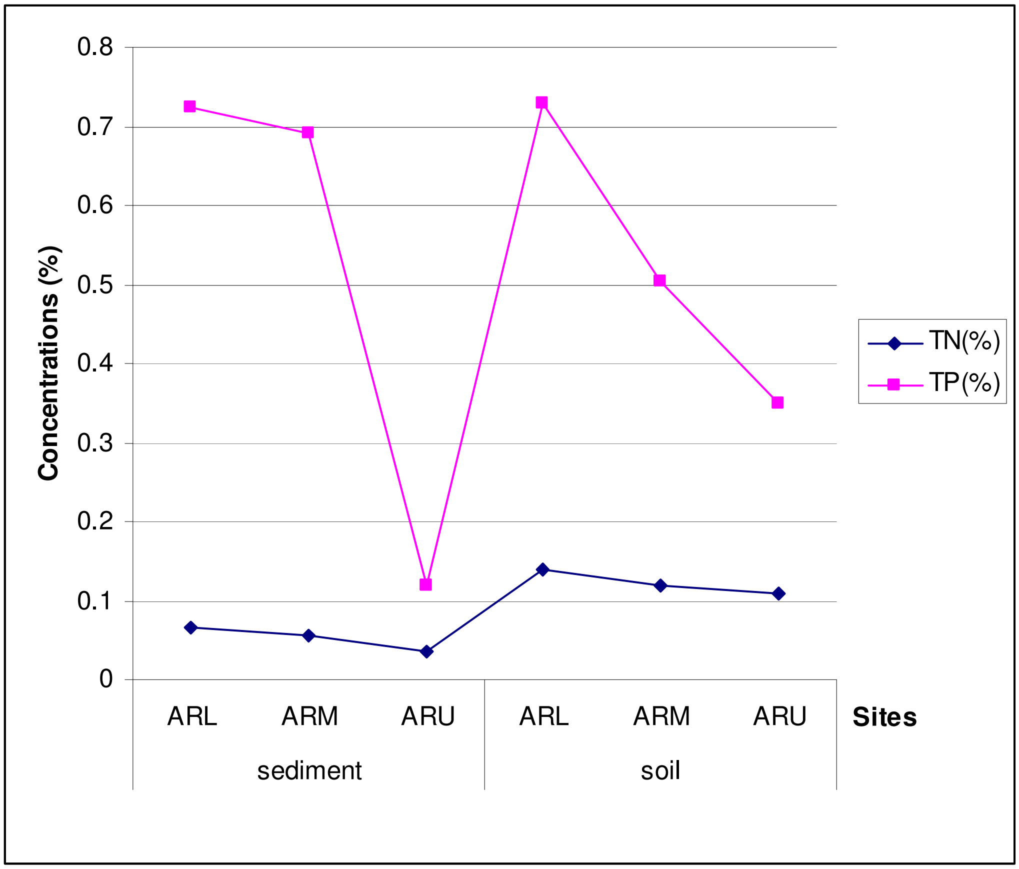
In order to assess the sources of nutrients of water in Angereb Dam, sediment samples along the streams, and soil samples were taken from the selected sites of the watershed. The following results have been obtained.

Table 4.12 Concentrations of TN and TP in the sediments of the streams

| Parameters | Sites | Mean ± SD |
|---|---|---|
| TN (%) | AR | 0.052 ± 0.015 |
| | DS | 0.105 ± 0.024 |
| | GS | 0.077 ± 0.021 |
| TP (%) | AR | 0.512 ± 0.307 |
| | DS | 0.543 ± 0.361 |
| | GS | 0.817 ± 0.318 |

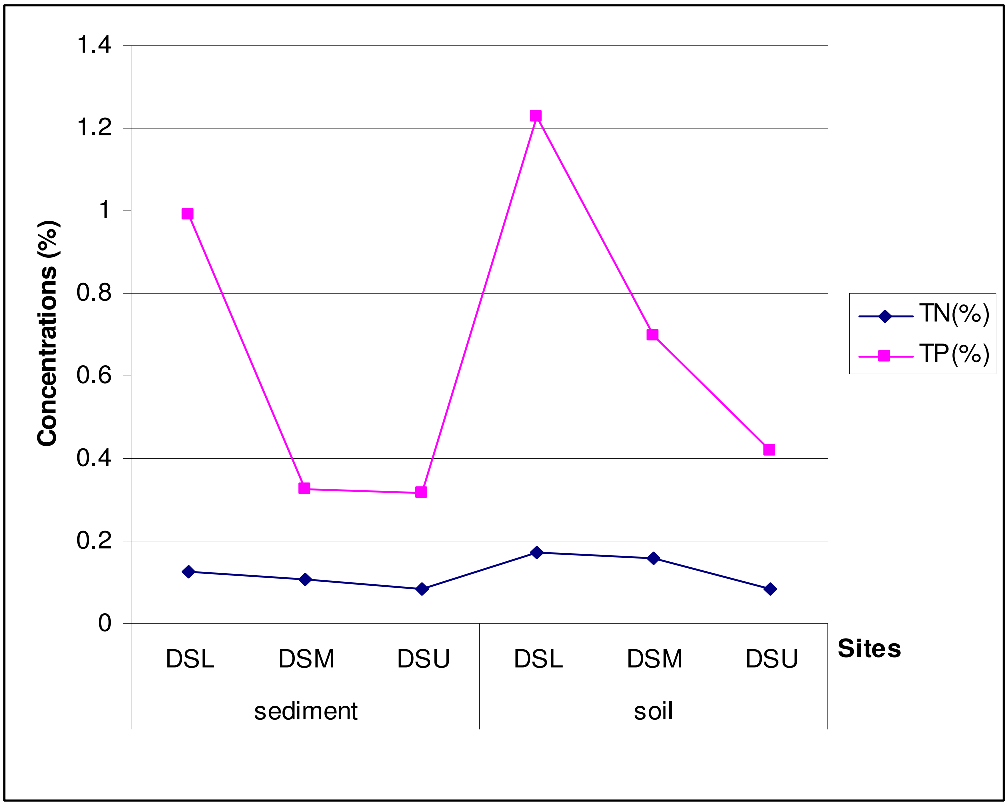
(AR-Angereb River; DS-Defecha Stream; GS-Gesite Stream)

As it can be seen in Table 4.12, there were high amounts of total nitrogen and total phosphorus in the sediments of the selected streams. This is one of the evidences for the removal of these nutrients from the watershed. Thus, the presence of TN and TP in large amounts (Table 4.12) in the sediments of streams was an indicator of the absence of proper soil and water conservation practices in the watershed. Especially, the absence of stream buffer zones and tillage of stream banks accelerates the stream bank erosion and results in the immediate erosion and deposition of soils on the bed of streams. According to Ritter and Shirmohammadi (2001), the presences of stream buffers minimize the flow velocities of runoff that ensures the water to be stay longer in the buffer. Long retention time of the water in buffer zone enhances the removal of nutrients through plant uptakes (Phyto-extraction). It also helps to reduce erosion from buffer zones. Therefore, the absence of conservation practices in general in Angereb watershed caused the accumulation of high concentration of nitrogen and phosphorus both in the water and sediment of the dam and streams.



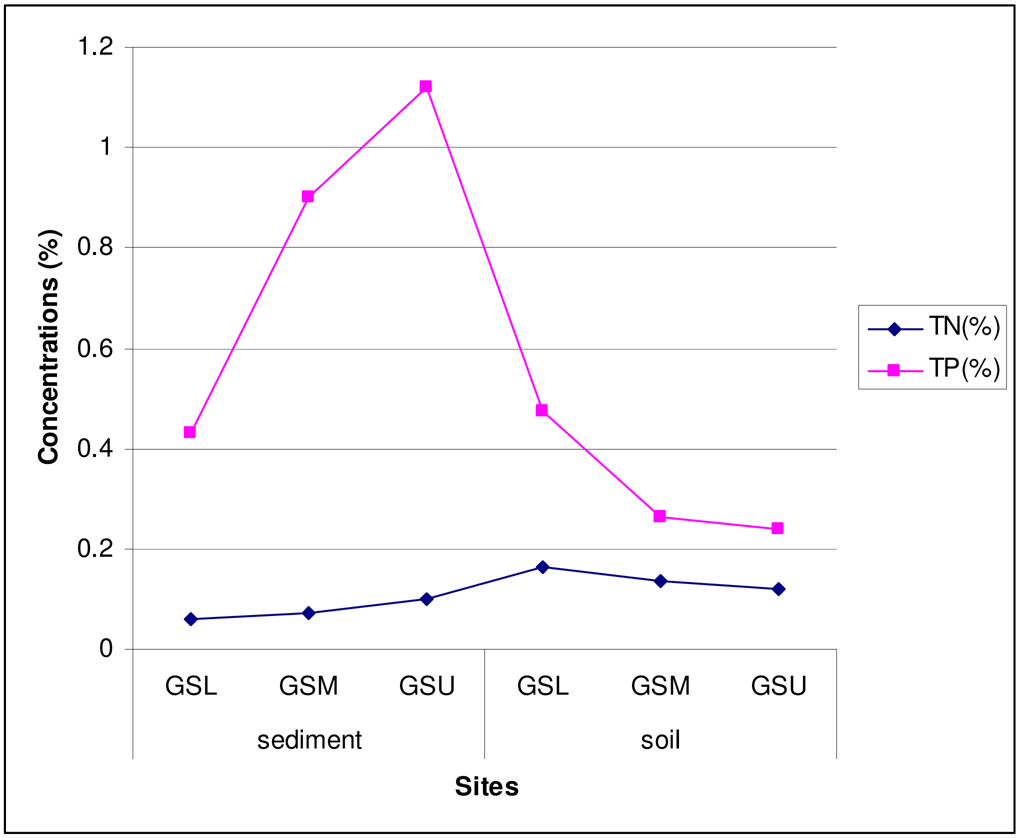

(ARL-Angereb River Lower; ARM-Angereb River Middle; ARU-Angereb River Upper)

Fig. 4.2 Concentrations of TN and TP in the sediment and soil of Angereb sub watershed at different positions




(DSL-Defecha Stream Lower; DSM-Defecha Stream Middle; DSU-Defecha Stream Upper)

Fig. 4.3 Concentrations of TN and TP in the sediment and soil of Defecha sub watershed at different positions




(GSL-Gesite Stream Lower; GSM-Gesite Stream Middle; GSU-Gesite Stream Upper)

Fig.4.4 Concentrations of TN and TP in the sediment and soil of Gesite sub watershed at different positions

As it is shown from the figures above (Figures 4.2 and 4.3), concentrations of TN and TP in the sediments were reducing from the lower part of Angerb river and Defecha stream to the upper parts. Whereas, in the case of Gesite stream (Figure 4.4) the amount of the two nutrients in the sediment have shown increment from the lower part to its upper part. Such type of variations could have resulted from slope differences that cause fine sediments to reach in the lower parts of the streams. Fine sediments are easily carried and transported to down streams than coarse sediments, and for this reason large deposition of fine sediments are found in down streams. Most of the time, fine sediments have strong tendency of attachment to nutrients than coarse sediments (Smodis *et al*., 2003). So, in Angerb and Defecha rivers due to large deposition of fine sediments, high amount of TN and TP are found in the lower parts than the upper parts.

However, to the contrary, the concentrations of TN and TP in Gesite stream increases from the downstream to the upper part of the stream. This may be because of the presence of retention structure like gabions across the stream at a certain intervals. The presence of gabions could store substantial amount of sediments and prevents its passage to the downstream that is why the amount of TN and TP is higher in the upper part of the stream than the lower part.

Plate 4.2 Deposition of sediments at the upper part of Gesite Stream due to Gabions

Table 4.13 Range and mean of TN and TP in the sediments of the three streams

| Parameters | Sites | Mean ± SD | Min. | Max. | P-value |
|---|---|---|---|---|---|
| TN (%) | AR | 0.052 ± 0.015 | 0 .03 | 0.07 | |
| | DS | 0.105 ± 0.024 | 0.07 | 0 .14 | 0.001 |
| | GS | 0.077 ± 0.021 | 0 .05 | 0 .10 | |
| TP (%) | AR | 0.512 ± 0.307 | 0 .07 | 0.75 | |
| | DS | 0.543 ± 0.361 | 0.21 | 1.05 | 0.243 |
| | GS | 0.817 ± 0.318 | 0 .37 | 1.14 | |

(AR-Angereb River; DS-Defecha Stream; GS-Gesite Stream)

As shown in Table 4.13, there was a statistical significant difference (p= 0.001) between the streams in their TN level. High concentration of TN is found in Defecha stream and followed by Gesite stream and Angereb river. Since Angereb river flows throughout the year, and there was high bloom of algae in this river (Plate 4.3). Subsequently, the low amount of TN in Angereb river could be attributed to the consumption of it by phytoplankton, and for this reason the concentration of TN is small as compared to the two streams. On the other hand, in the two streams, there was no water during the sampling period, and as a result, the accumulated nutrients in the sediments did not disturbed and consumed by algae. This most probably makes the streams to have high amount of nitrogen and phosphorus than Angereb river. However, in their TP levels, all of them did not have significant variation with each other (p= 0.243).

Plate 4.3 Algal bloom in Angereb River

The Table below shows the amount of nitrogen and phosphorus in the soil of the selected sub watersheds.

Table 4.14 Concentrations of TN and TP in the soils of the selected sub watersheds

| Parameters | Sites | Mean ± SD |
|---|---|---|
| TN (%) | AR | 0.123 ± 0.014 |
| | DS | 0.138 ± 0.047 |
| | GS | 0.140 ± 0.029 |
| TP (%) | AR | 0.528 ± 0.175 |
| | DS | 0.783 ± 0.391 |
| | GS | 0.327 ± 0.194 |

(AR-Angereb River; DS-Defecha Stream; GS-Gesite Stream)

The soils of all sub watersheds had high amount of TN and TP. Thus, the presence of nitrogen and phosphorus in the selected sub watersheds could be good indicative of the source of the watershed to the nutrients of the Dam

In addition, the figures above (4.2, 4.3 and 4.4) have also revealed the reduction of TN and TP concentrations in the soil from the downstream to upper stream in all the selected sub watersheds. This variation could be an indication of the presence of erosion which most probably resulted from the absence of proper conservation measures. The presence of high erosion rate in the watershed was studied by Admasu Amare (2005). Based on his study, there was gross annual erosion of 269,586 and 36,871.1 tones in Angereb and Gesite sub watersheds respectively. Defecha sub watershed also had a gross soil erosion of 20,841 tones. Hence, from these figures, it is not difficult to understand the seriousness of the erosion problem and the absence of management interventions in the watershed. Accordingly, the present study has confirmed that nutrients are also the components of the erosion process. The deposition of sediments in the streams is also an indicative of high removal of soil from the watershed (Plate 4.4).

Plate 4.4 Deposition of sediments in Angereb River

# 5 Conclusion and recommendations

## 5.1 Conclusion

This study has indicated that Angereb Dam had high amounts of total nitrogen and total phosphorus in its water and sediment in which the sediments could become the potential source of internal loading. The trophic status of the Dam was found at the level of mesotrophic condition which is an indication of the presence of pollution by algae. Due to the presence of high concentrations of nitrogen and phosphorus in the water and sediments, the trophic status of the Dam will be transformed from the current mesotrophic condition to eutrophic condition when other environmental factors are found in favorable conditions. Besides, the level of dissolved oxygen in the water of the Dam was found to be at a level that could support aquatic zooplanktons, but its turbidity status might be risk to zooplanktons, and also needs high treatment costs for purification. The pH of the Dam is also found in a condition that could not be harmful to aquatic organisms. High concentrations of total nitrogen and total phosphorus were found in the sediments and soils of the selected sub watersheds which are the principal sources of nitrogen and phosphorus to the water in the Dam. In addition, the presence of high concentrations of these nutrients in the water and sediments of the Dam and the streams is an indicative of low soil and water conservation practices in the watershed.

## 5.2 Recommendations

In order to reduce the threat of Angereb Dam with eutrophication, the following recommendations are proposed on the basis of the findings.

- Immediate soil and water conservation measures should be undertaken in the watershed to reduce sediment and nutrient delivery to the lake.
- Agro-forestry practices should be introduced into the watershed to lessen the erosion of soil and nutrients, and as well improve the livelihood of the local people.
- Sediment trap structures should be designed and placed just upstream of the inlet of the main Angereb river and the two streams. These structures will remove sediments and nutrients just before they enter the reservoir.
- Bio-manipulation techniques such as planting of macrophytes around and in the lake water of the Dam, and introducing of algae-eating fishes will be helpful in reducing further growth and production of algae.
- This study gives a clue for further investigation to have a full picture on the eutrophication status of the water in the Dam. Thus, further research needs to be conducted on the trophic status of the dam by including other physico-chemical and biological parameters.

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## Appendices

Appendix-1 LSD test of TN and TP of the water in the Dam among the three sites

| | | | | | | 95% Confidence Interval | |
|---|---|---|---|---|---|---|---|
| Dependent variable | (I) SITES | (J)SITES | Mean D/ce (I-J) | Std. Error | Sig. | Lower bound | upper bound |
| TN | 1.000 | 2.000 | .103333 | .067283 | .145 | -.04008 | .24674 |
| | | 3.000 | .196667(*) | .067283 | .010 | .05326 | .34008 |
| | 2.000 | 1.000 | -.103333 | .067283 | .145 | -.24674 | .04008 |
| | | 3.000 | .093333 | .067283 | .186 | -.05008 | .23674 |
| | 3.000 | 1.000 | -.196667(*) | .067283 | .010 | -.34008 | -.05326 |
| | | 2.000 | -.093333 | .067283 | .186 | -.23674 | .05008 |
| TP | 1.000 | 2.000 | .075000(*) | .011369 | .000 | .05077 | .09923 |
| | | 3.000 | .128333(*) | .011369 | .000 | .10410 | .15257 |
| | 2.000 | 1.000 | -.075000(*) | .011369 | .000 | -.09923 | -.05077 |
| | | 3.000 | .053333(*) | .011369 | .000 | .02910 | .07757 |
| | 3.000 | 1.000 | -.128333(*) | .011369 | .000 | -.15257 | -.10410 |
| | | 2.000 | -.053333(*) | .011369 | .000 | -.07757 | -.02910 |

* The mean difference is significant at the .05 level.

Appendix-2 LSD test of TN and TP in the sediment of the Dam among the three sites.

| | | | | | | 95% Confidence Interval | |
|---|---|---|---|---|---|---|---|
| Dependent variable | (I) SITES | (J)SITES | Mean D/ce (I-J) | Std. Error | Sig. | Lower bound | upper bound |
| TN | 1.000 | 2.000 | -.013500 | .011864 | .273 | -.03879 | .01179 |
| | | 3.000 | -.040167(*) | .011864 | .004 | -.06545 | -.01488 |
| | 2.000 | 1.000 | .013500 | .011864 | .273 | -.01179 | .03879 |
| | | 3.000 | -.026667(*) | .011864 | .040 | -.05195 | -.00138 |
| | 3.000 | 1.000 | .040167(*) | .011864 | .004 | .01488 | .06545 |
| | | 2.000 | .026667(*) | .011864 | .040 | .00138 | .05195 |
| TP | 1.000 | 2.000 | .098333(*) | .044360 | .043 | .00378 | .19288 |
| | | 3.000 | -.696667(*) | .044360 | .000 | -.79122 | -.60212 |
| | 2.000 | 1.000 | -.098333(*) | .044360 | .043 | -.19288 | -.00378 |
| | | 3.000 | -.795000(*) | .044360 | .000 | -.88955 | -.70045 |
| | 3.000 | 1.000 | .696667(*) | .044360 | .000 | .60212 | .79122 |
| | | 2.000 | .795000(*) | .044360 | .000 | .70045 | .88955 |

* The mean difference is significant at the .05 level.

Appendix-3 LSD test of chlorophyll-a among the sites of the water in the Dam

| Dependent variable | (I) SITES | (J) SITES | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|---|
| | | | | | | Lower Bound | Upper Bound |
| Chlorophyll-a | 1.000 | 2.000 | -.606667 | .539245 | .304 | -1.92615 | .71282 |
| | | 3.000 | 1.033333 | .539245 | .104 | -.28615 | 2.35282 |
| | 2.000 | 1.000 | .606667 | .539245 | .304 | -.71282 | 1.92615 |
| | | 3.000 | 1.640000(*) | .539245 | .023 | .32051 | 2.95949 |
| | 3.000 | 1.000 | -1.033333 | .539245 | .104 | -2.35282 | .28615 |
| | | 2.000 | -1.640000(*) | .539245 | .023 | -2.95949 | -.32051 |

* The mean difference is significant at the .05 level

Appendix-4 Multiple comparisons (LSD test) of physical and chemical characteristics of the water in the Dam among the sites.

| | | | | | | 95% Confidence Interval | |
|---|---|---|---|---|---|---|---|
| Dependent variable | (I) SITES | (J)SITES | Mean D/ce (I-J) | Std. Error | Sig. | Lower bound | upper bound |
| DO | 1.0000 | 2.0000 | -.5833333(*) | .1745683 | .016 | -1.010486 | -.156180 |
| | | 3.0000 | .5400000(*) | .1745683 | .021 | .112847 | .967153 |
| | 2.0000 | 1.0000 | .5833333(*) | .1745683 | .016 | .156180 | 1.010486 |
| | | 3.0000 | 1.1233333(*) | .1745683 | .001 | .696180 | 1.550486 |
| | 3.0000 | 1.0000 | -.5400000(*) | .1745683 | .021 | -.967153 | -.112847 |
| | | 2.0000 | 1.1233333(*) | .1745683 | .001 | -1.550486 | -.696180 |
| pH | 1.0000 | 2.0000 | -.1333333 | .0564374 | .056 | -.271431 | .004764 |
| | | 3.0000 | .1766667(*) | .0564374 | .020 | .038569 | .314764 |
| | 2.0000 | 1.0000 | .1333333 | .0564374 | .056 | -.004764 | .271431 |
| | | 3.0000 | .3100000(*) | .0564374 | .002 | .171903 | .448097 |
| | 3.0000 | 1.0000 | -.1766667(*) | .0564374 | .020 | -.314764 | -.038569 |
| | | 2.0000 | -.3100000(*) | .0564374 | .002 | -.448097 | -.171903 |
| TEMPERATURE | 1.0000 | 2.0000 | .2000000 | .3527668 | .591 | -.663189 | 1.063189 |
| | | 3.0000 | .1000000 | .3527668 | .786 | -.763189 | .963189 |
| | 2.0000 | 1.0000 | -.2000000 | .3527668 | .591 | -1.063189 | .663189 |
| | | 3.0000 | -.1000000 | .3527668 | .786 | -.963189 | .763189 |
| | 3.0000 | 1.0000 | -.1000000 | .3527668 | .786 | -.963189 | .763189 |
| | | 2.0000 | .1000000 | .3527668 | .786 | -.763189 | .963189 |
| TURBIDITY | 1.0000 | 2.0000 | -1.3333333 | 1.0183502 | .238 | -3.825146 | 1.158480 |
| | | 3.0000 | 2.6666667(*) | 1.0183502 | .040 | .174854 | 5.158480 |
| | 2.0000 | 1.0000 | 1.3333333 | 1.0183502 | .238 | -1.158480 | 3.825146 |
| | | 3.0000 | 4.0000000(*) | 1.0183502 | .008 | 1.508187 | 6.491813 |
| | 3.0000 | 1.0000 | 2.6666667(*) | 1.0183502 | .040 | -5.158480 | -.174854 |
| | | 2.0000 | 4.0000000(*) | 1.0183502 | .008 | -6.491813 | -1.508187 |

* The mean difference is significant at the .05 level.

Appendix-5 Correlations among physical, chemical and biological characteristics of the water in the Dam.

| | | Chl-a | DO | pH | T$^{o}$ | TUR | TN | TP | MONTHS |
|---|---|---|---|---|---|---|---|---|---|
| Chl-a | Pearson Correlation | 1 | .919(**) | .824(**) | .435 | .692(*) | .735(*) | .583<br>.588 | Chl-a |
| | Sig. (2-tailed) | | .000 | .006 | .242 | .039 | .024 | .099<br>.096 | |
| | N | 9 | 9 | 9 | 9 | 9 | 9 | 9 9 | |
| DO | Pearson Correlation | .919(**) | 1 | .935(**) | .128 | .861(**) | .506 | .449<br>.308 | DO |
| | Sig. (2-tailed) | .000 | | .000 | .743 | .003 | .164 | .225<br>.420 | |
| | N | 9 | 9 | 9 | 9 | 9 | 9 | 9 9 | |
| pH | Pearson Correlation | .824(**) | .935(**) | 1 | -.082 | .865(**) | .487 | .491<br>.274 | pH |
| | Sig. (2-tailed) | .006 | .000 | | .833 | .003 | .184 | .180<br>.475 | |
| | N | 9 | 9 | 9 | 9 | 9 | 9 | 9<br>9 | |
| T$^{o}$ | Pearson Correlation | .435 | .128 | -.082 | 1 | -.100 | .688(*) | .375<br>.601 | T$^{o}$ |
| | Sig. (2-tailed) | .242 | .743 | .833 | | .799 | .040 | .319<br>.087 | |
| | N | 9 | 9 | 9 | 9 | 9 | 9 | 9<br>9 | |
| TUR | Pearson Correlation | .692(*) | .861(**) | .865(**) | -.100 | 1 | .362 | .497<br>.07 | TUR |
| | Sig. (2-tailed) | .039 | .003 | .003 | .799 | | .338 | .174<br>.858 | |
| | N | 9 | 9 | 9 | 9 | 9 | 9 | 9<br>9 | |
| TN | Pearson Correlation | .735(*) | .506 | .487 | .688(*) | .362 | 1 | .812(**)<br>.701 | TN |
| | Sig. (2-tailed) | .024 | .164 | .184 | .040 | .338 | | .008<br>.035 | |
| | N | 9 | 9 | 9 | 9 | 9 | 9 | 9<br>9 | |
| TP | Pearson Correlation | .583 | .449 | .491 | .375 | .497 | .812(**) | 1<br>.271 | TP |
| | Sig. (2-tailed) | .099 | .225 | .180 | .319 | .174 | .008 | .481 | |
| | N | 9 | 9 | 9 | 9 | 9 | 9 | 9<br>9 | |
| MONTHS | Pearson Correlation | .588 | .308 | .274 | .601 | .070 | .701(*) | .271<br>1 | MONTHS |
| | Sig. (2-tailed) | .096 | .420 | .475 | .087 | .858 | .035 | .481 | |

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

**Appendix -6 Laboratory results of all parameters and geographical description of sampling sites**

Appendix -6A Laboratory results of TN and TP in the sediments of streams

| Sample code | $H_2SO_4$ (mL) | TN (%) | NaOH (mL) | $H_2SO_4$ (mL) | TP (%) |
|---|---|---|---|---|---|
| ARA1 | 0.39 | 0.06 | 120 | 16.25 | 0.7 |
| ARA2 | 0.46 | 0.07 | 122.6 | 11.2 | 0.75 |
| ARB1 | 0.36 | 0.05 | 109 | 0.84 | 0.73 |
| ARB2 | 0.41 | 0.06 | 110 | 13.2 | 0.65 |
| ARC1 | 0.23 | 0.03 | 50 | 25.41 | 0.17 |
| ARC2 | 0.27 | 0.04 | 60 | 50.18 | 0.07 |
| DSA1 | 0.76 | 0.11 | 158.6 | 2.63 | 1.05 |
| DSA2 | 0.95 | 0.14 | 145.8 | 8.06 | 0.93 |
| DSB1 | 0.83 | 0.12 | 50 | 17.6 | 0.22 |
| DSB2 | 0.61 | 0.09 | 72 | 7.84 | 0.43 |
| DSC1 | 0.47 | 0.07 | 50 | 19.16 | 0.21 |
| DSC2 | 0.65 | 0.1 | 89.2 | 26.2 | 0.42 |
| GSA1 | 0.35 | 0.05 | 87.3 | 14.59 | 0.49 |
| GSA2 | 0.47 | 0.07 | 62.5 | 7.03 | 0.37 |
| GSB1 | 0.52 | 0.08 | 150 | 12.98 | 0.92 |
| GSB2 | 0.42 | 0.06 | 150 | 20 | 0.88 |
| GSC1 | 0.65 | 0.1 | 172 | 3.53 | 1.14 |
| GSC2 | 0.7 | 0.1 | 170 | 6.3 | 1.1 |

Appendix-6B Laboratory results of TN and TP in the soil of the subwatersheds

| Sample code | $H_2SO_4$ (mL) | TN (%) | NaOH (mL) | $H_2SO_4$ (mL) | TP (%) |
|---|---|---|---|---|---|
| ARA3 | 0.95 | 0.14 | 150 | 42.75 | 0.72 |
| ARA4 | 0.92 | 0.14 | 150 | 40 | 0.74 |
| ARB3 | 0.84 | 0.12 | 79.1 | 12.69 | 0.45 |
| ARB4 | 0.82 | 0.12 | 99.7 | 16.5 | 0.56 |
| ARC3 | 0.74 | 0.11 | 60.5 | 10.49 | 0.34 |
| ARC4 | 0.75 | 0.11 | 61.5 | 8.6 | 0.36 |
| DSA3 | 0.96 | 0.14 | 200 | 20.4 | 1.21 |
| DSA4 | 1.35 | 0.2 | 200 | 14.96 | 1.25 |
| DSB3 | 1.06 | 0.16 | 100 | 13.75 | 0.58 |
| DSB4 | 1.08 | 0.16 | 130 | 9.06 | 0.82 |
| DSC3 | 0.45 | 0.07 | 91 | 3.34 | 0.59 |
| DSC4 | 0.7 | 0.1 | 50 | 12.64 | 0.25 |
| GSA3 | 1.29 | 0.19 | 50 | 15.32 | 0.23 |
| GSA4 | 0.96 | 0.14 | 107.7 | 1.5 | 0.72 |
| GSB3 | 0.92 | 0.14 | 50 | 14.42 | 0.24 |
| GSB4 | 0.85 | 0.13 | 63.5 | 20.41 | 0.29 |
| GSC3 | 0.68 | 0.1 | 50 | 14.1 | 0.24 |
| GSC4 | 0.93 | 0.14 | 48 | 12.39 | 0.24 |

Appendix-6C Laboratory results of TN and TP in the sediments of the Dam

| Date | Sites | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LWE-1 | | | | | LWE-2 | | | | | LWE-3 | | | | |
| | $H_2SO_4$ (mL) | TN (%) | NaOH (mL) | $H_2SO_4$ (mL) | TP (%) | $H_2SO_4$ (mL) | TN (%) | NaOH (mL) | $H_2SO_4$ (mL) | TP (%) | $H_2SO_4$ (mL) | TN (%) | NaOH (mL) | $H_2SO_4$ (mL) | TP (%) |
| Dec.24 ,2010 | 0.24 | 0.03 | 70 | 16.47 | 0.36 | 0.29 | 0.04 | 50 | 9.93 | 0.27 | 0.59 | 0.09 | 179.4 | 6.25 | 1.17 |
| | 0.21 | 0.03 | 68 | 16.1 | 0.35 | 0.28 | 0.04 | 45 | 8.11 | 0.25 | 0.64 | 0.09 | 167.4 | 5.7 | 1.09 |
| Jan.18, 2011 | 0.17 | 0.02 | 70 | 20.12 | 0.34 | 0.29 | 0.04 | 42 | 10.83 | 0.21 | 0.56 | 0.08 | 169.8 | 0.33 | 1.07 |
| | 0.13 | 0.01 9 | 57 | 8.04 | 0.33 | 0.21 | 0.03 | 41 | 9.84 | 0.21 | 0.43 | 0.06 | 169 | 20.63 | 1.00 |
| Feb.12 ,2011 | 0.07 | 0.01 | 45.3 | 4.94 | 0.27 | 0.21 | 0.03 | 38.7 | 12 | 0.18 | 0.21 | 0.03 | 146 | 16.92 | 0.87 |
| | 0.07 | 0.01 | 45 | 7.92 | 0.25 | 0.14 | 0.02 | 38 | 9.8 | 0.19 | 0.07 | 0.01 | 146 | 15.44 | 0.88 |

Appendix-6D Laboratory results of TP of water in the Dam

| Date | Sites | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | LWE-1 | | | LWE -2 | | | LWE -3 | | |
| | Sample Absorbances | Blank Absorbances | calculated TP (mg/L) | Sample Absorbances | Blank Absorbances | Calculated TP (mg/L) | Sample Absorbances | Blank Absorbances | Calculated TP (mg/L) |
| Dec.24, 2010 | 0.096 | 0.014 | 0.16 | 0.063 | 0.014 | 0.08 | 0.043 | 0.014 | 0.03 |
| | 0.111 | 0.009 | 0.14 | 0.062 | 0.009 | 0.08 | 0.029 | 0.009 | 0.04 |
| Jan.18, 2011 | 0.122 | 0.012 | 0.19 | 0.07 | 0.012 | 0.11 | 0.031 | 0.012 | 0.05 |
| | 0.113 | 0.023 | 0.2 | 0.059 | 0.023 | 0.1 | 0.038 | 0.023 | 0.06 |
| Feb.12, 2011 | 0.123 | 0.017 | 0.2 | 0.086 | 0.017 | 0.12 | 0.059 | 0.017 | 0.06 |
| | 0.093 | 0.012 | 0.18 | 0.064 | 0.012 | 0.13 | 0.024 | 0.012 | 0.06 |

Appendix -6E Laboratory results of TN of water in the Dam.

| | Sites | Sample absorbance's (220nm) | Sample absorbance's (275nm) | Corrected absorbance (220-275nm) | **$NO_3$ (mg/L)** | $H_2SO_4$ (mL) | Blank (mL) | **TKN (mg/L)** | **$NO_2$ (mg/L)** | **TN (mg/L)** |
|---|---|---|---|---|---|---|---|---|---|---|
| Dec.24, 2010 | LWE-1 | 0.343 | 0.007 | 0.336 | 0.42 | 0.12 | 0.01 | 0.31 | 0.00 | 0.73 |
| | | 0.443 | 0.02 | 0.423 | 0.46 | 0.13 | 0.03 | 0.28 | 0.00 | 0.74 |
| | LWE-2 | 0.302 | 0.009 | 0.293 | 0.37 | 0.11 | 0.01 | 0.28 | 0.00 | 0.65 |
| | | 0.435 | 0.02 | 0.423 | 0.46 | 0.09 | 0.03 | 0.17 | 0.00 | 0.63 |
| | LWE-3 | 0.311 | 0.009 | 0.302 | 0.38 | 0.09 | 0.01 | 0.23 | 0.00 | 0.61 |
| | | 0.344 | 0.015 | 0.329 | 0.37 | 0.11 | 0.03 | 0.22 | 0.00 | 0.59 |
| Jan.18,2011 | LWE-1 | 0.549 | 0.01 | 0.529 | 0.527 | 0.19 | 0.04 | 0.42 | 0.00 | 0.99 |
| | | 0.353 | 0.005 | 0.348 | 0.67 | 0.15 | 0.04 | 0.32 | 0.00 | 0.99 |
| | LWE-2 | 0.514 | 0.013 | 0.488 | 0.53 | 0.17 | 0.04 | 0.364 | 0.00 | 0.89 |
| | | 0.318 | 0.01 | 0.308 | 0.59 | 0.13 | 0.04 | 0.25 | 0.00 | 0.84 |
| | LWE-3 | 0.425 | 0.008 | 0.409 | 0.45 | 0.15 | 0.04 | 0.308 | 0.00 | 0.75 |
| | | 0.26 | 0.008 | 0.252 | 0.48 | 0.14 | 0.04 | 0.28 | 0.00 | 0.76 |
| Feb.12, 2011 | LWE-1 | 0.561 | 0.012 | 0.537 | 0.58 | 0.19 | 0.04 | 0.42 | 0.00 | 1.00 |
| | | 0.294 | 0.006 | 0.288 | 0.556 | 0.19 | 0.04 | 0.424 | 0.00 | 0.98 |
| | LWE-2 | 0.51 | 0.009 | 0.492 | 0.536 | 0.17 | 0.04 | 0.364 | 0.00 | 0.9 |
| | | 0.266 | 0.003 | 0.263 | 0.505 | 0.18 | 0.04 | 0.395 | 0.00 | 0.9 |
| | LWE-3 | 0.413 | 0.008 | 0.397 | 0.43 | 0.16 | 0.04 | 0.336 | 0.00 | 0.77 |
| | | 0.61 | 0.004 | 0.257 | 0.493 | 0.14 | 0.04 | 0.277 | 0.00 | 0.77 |

Appendix-6F Chlorophyll-a absorbance's and its measurements

| Date | Sampling sites | Volume ofsample ( L) | Volume of extract (mL) | Absorbance's before acidification | | Absorbance's after acidification | | Corrected values | | After corrected value | Chl-a values (µg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 664nm | 750nm | 665nm | 750nm | 664nm-750nm | 665nm-750nm | 664nm-665nm | |
| Dec.29, 2010 | LWE-1 | IL | 8 | 0.468 | 0.214 | 0.409 | 0.171 | 0.254 | 0.238 | 0.0160 | 3.42 |
| | LWE-2 | IL | 8 | 0.541 | 0.275 | 0.512 | 0.266 | 0.266 | 0.246 | 0.0200 | 4.27 |
| | LWE-3 | IL | 8 | 0.499 | 0.263 | 0.427 | 0.205 | 0.236 | 0.222 | 0.0140 | 2.99 |
| Jan.23, 2011 | LWE-1 | IL | 6 | 0.674 | 0.314 | 0.6 | 0.268 | 0.36 | 0.332 | 0.0283 | 4.54 |
| | LWE-2 | IL | 6 | 0.695 | 0.343 | 0.623 | 0.302 | 0.352 | 0.321 | 0.0310 | 4.97 |
| | LWE-3 | IL | 6 | 0.562 | 0.295 | 0.521 | 0.274 | 0.267 | 0.247 | 0.0200 | 3.2 |
| Feb.17, 2011 | LWE-1 | IL | 10 | 0.385 | 0.295 | 0.278 | 0.207 | 0.09 | 0.071 | 0.0190 | 5.07 |
| | LWE-2 | IL | 10 | 0.382 | 0.307 | 0.355 | 0.301 | 0.075 | 0.054 | 0.0210 | 5.61 |
| | LWE-3 | IL | 10 | 0.357 | 0.288 | 0.313 | 0.258 | 0.069 | 0.055 | 0.0140 | 3.74 |

Appendix-6G Results of onsite measurements

| Date | Sites | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LWE-1 | | | | LWE-2 | | | | LWE-3 | | | |
| | DO | pH | T$^{o}$ | TUR | DO | pH | T$^{o}$ | TUR | DO | pH | T$^{o}$ | TUR |
| Dec.29, 2010 | 6.3 | 8.41 | 22 | 18 | 7.12 | 8.52 | 22 | 22 | 5.91 | 8.11 | 22.7 | 15 |
| Jan.23, 2011 | 6.82 | 8.43 | 23 | 20 | 7.21 | 8.55 | 22.5 | 19 | 6.09 | 8.28 | 22.6 | 17 |
| Feb.17, 2011 | 6.8 | 8.41 | 23 | 19 | 7.34 | 8.58 | 22.9 | 20 | 6.3 | 8.33 | 22.4 | 17 |

Appendix-6H Geographical description of sampling sites

| Sampling sites | Location | Altitude |
|---|---|---|
| LWE-1 | 1395504N 0335343E | 2139m |
| LWE-2 | 1395431N 0335317E | 2130m |
| LWE-3 | 1395402N 0335281E | 2129m |
| ARS-1 | 1396229N 0335042E | 2131m |
| ARS-2 | 1396400N 0334931E | 2139m |
| ARS-3 | 1396527N 0334784E | 2149m |
| DSS-1 | 1395111N 0336161E | 2131m |
| DSS-2 | 1395219N 0336364E | 2156m |
| DSS-3 | 1395394N 0336581E | 2177m |
| GSS-1 | 1395161N 0334530E | 2156m |
| GSS-2 | 1395291N 0334426E | 2166m |
| GSS-3 | 1395395N 0334239E | 2181m |

LWE-Lake Water Edge; ARS-Angereb River Site; DSS-Defecha Stream Site; GSS-Gesite Stream Site