The Status of Harmful Cyanobacteria Bloom in Amuddee (Lake Koka-Ethiopia)

Aquatic Ecology and Water Quality Management

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AQWA Aquatische ecologie Waterkwaliteitsbeheer

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Abstract

In order to understand the status and threat of harmful cyanobacteria in the Amuddee area of Lake Koka- Ethiopia a three-month survey was carried out from May 20, 2009 to July 17, 2009. In this study, several data collection methods were used: literature review, interview, e-mail, field observation, collection of water samples and their analyse (spectrophotometrically and microscopically), digital photographs and video. Moreover relevant information from newspapers, magazines and internet were also included in the report. Inorganic nutrients were analyzed using standard methods for water quality. Ammonia (NH_3-N), nitrate (NO_3-N) and orthophosphate (PO4 - P) were determined by titration, HACH spectrophotometer (Cadmium Reduction method) and Ascorbic Acid methods, respectively. Biomass was determined as chlorophyll-a concentration using a spectrophotometer. Field observations and Compound Microscope 40X result showed that in Amuddee area heavy algal blooms especially at the near-shore were dominated by a single cyanobacteria species of *Microcystis*. Potentially harmful *Microcystis* species might be the cause for deterioration of lake quality, serious ills to human and animals in the surrounding of Amuddee (Lake Koka). Due to time and financial limitations I did not generate adequate scientific information on water column. Thus it is very difficult to determine the causes and impact of algal blooms in Amuddee area. Nitrate, phosphate, and ammonia concentrations of this study were by far higher than the standards given by Wisconsin (2008). Based on Wisconsin (2008) standards, Amuddee is classified as hypereutrophic (very poor lake quality). There are extensive lake experiments results that justify rising temperatures favour cyanobacteria than other eukaryotic phytoplankton. Considering this scientific information (Global warming) holds true on Lake Koka combined with high concentrations of the macronutrients nitrogen and phosphorus, and the micronutrient iron, it is not surprising that potentially harmful *Microcystis* species have been observed on the Amuddee side of Lake Koka. In the light of what the residents said (assuming that their assessment and description of the situation is accurate), it is tempting to think that the health problems of the residents of Amuddee and the death of their livestock may have been associated with the toxins released by *Microcystis* spp.

Key words: **Amuddee, Lake Koka, cyanobacteria, harmful cyanobacteria bloom, *Microcystis*, eutrophication, nitrate, phosphate, chlorophyll 'a'**

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1 Introduction

Natural eutrophication was originally identified as an inevitable natural process that usually takes thousands of years to progress and eventually reaching an end point as the lake is converted to a wetland (Deevey, 1942; Lindeman, 1942). However, in recent decades, due to human activities, (anthropogenic factors such as nutrient pollution from industry and agricultural practices) this natural process is speeded up and become an indisputable fact, as we can clearly observe extensive harmful algal blooms world wide (WHO, 1999; UNEP, 2005).

There are several factors that influence the freshwater bloom dynamics. Among these nutrient enrichment play the most important role in fresh water algal bloom (Scheffer, 2004; Eisenreich, 2005; Perovich et al., 2008; Lopez et al., 2008; Johnk et al., 2008;); cited in Teffera, 2009). According to UNEP (2005), nowadays many lakes and reservoirs from Africa, Europe, North and South America, Asia and Oceania encounter the problem of nutrient enrichment. Anthropogenic eutrophication caused by excess nutrient input from industry, agricultural and municipal wastewater discharges has detrimental effects on the aquatic ecosystem (Fig 1).

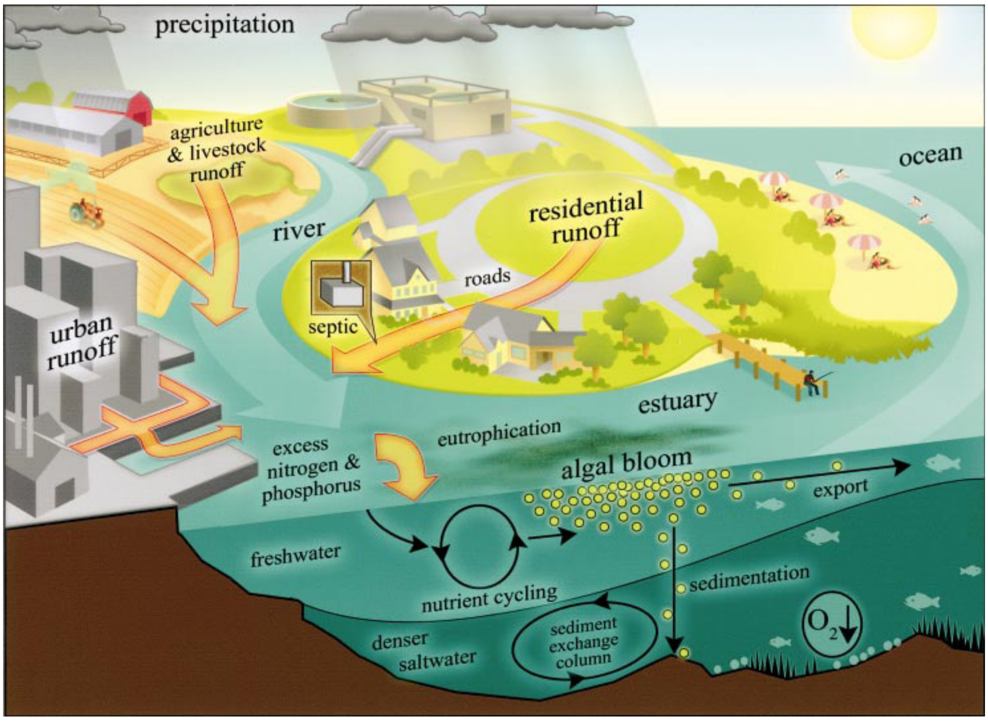

Figure 1 "Conceptual diagram showing the various watershed and airshed anthropogenic nutrient Sources" (Paerl, Valdes & Peierls, 2006)

Phosphorus is an important micronutrient for plant and animal growth and is often limits phytoplankton growth in aquatic systems. "As a result, small increases in phosphorus in lake water can cause substantial increases in aquatic plants and algae. When phosphorus levels in lakes increase due to human activities (e.g. fertilizer, animal waste, soil erosion) eutrophication can occur. Nitrogen is second only to phosphorus in importance to aquatic plant and algal growth. Nitrogen concentrations can vary widely temporally and spatially but are often related to local land use. Humans can increase nitrogen in the watershed through waste treatment plants, fertilizers and runoff" (Wisconsin, 2008).

Lakes and reservoirs, which contain high levels of phosphate and nitrate, are liable for freshwater harmful algal bloom since concentrations of phosphorus as low as (0.1 mg l^{-1}) are sufficient to induce a cyanobacterial bloom (WHO, 1999; UNEP, 2005; IPCC, 2007; Steinman, 2007). Algal growth is not only limited by the macronutrients nitrogen and phosphorus, but also by the micronutrients such as iron; they play an important role in controlling photosynthesis and eventually the growth of cyanobacteria (Kathleen et al., 2006; Lurling, 2008). "All plants require iron for photosynthesis and the enzymatic processes responsible for NO_2^- and NO_3^- reduction to NH_4^+ (nitrite and nitrate reductases)" (Kathleen et al., 2006).

Common total phosphorus values for Lake quality (Wisconsin, 2008):

Oligotrophic (Good):	< 0.020 mg\L
Mesotrophic (Fair):	0.020 – 0.050 mg\L
Eutrophic (Poor):	0.050 – 0.150 mg\L
Hypereutrophic (Very Poor)	>0.150 mg\L

Common total nitrogen values for Lakes quality (Wisconsin, 2008):

Oligotrophic:	< 0.4 mg\L
Mesotrophic:	0.4-0.6 mg\L
Eutrophic:	0.6-1.5 mg\L
Hypereutrophic:	> 1.5 mg\L

1.2 Linking climate change and harmful algal blooms

Global warming in recent decades is an indisputable fact, as we can clearly observe extensive melting of ice and increased average global temperature (IPCC, 2008). By investigating enormous scientific findings, IPCC reported that in the period between 1861 to 2000 the average global temperature over land surfaces has risen by 0.6 ± 0.2°C (Eisenreich, 2005; IPCC, 2001). Furthermore according to the IPCC full set of scenarios the projected increased temperature over the 21st Century were in the range of 1.4 to 5.8 ºC (Eisenreich, 2005; IPCC, 2001, 2007b). The increased global temperature over land surfaces has a significant impact on the surface water temperature, however up to now the relationship among climate change, global warming problems and freshwater resources have not been sufficiently dealt with in water resources analyses (IPCC, 2008). IPCC (2008) clearly stated that "Since the 1960s, surface water temperatures have warmed by between 0.2 and 2.0°C in lakes and rivers in Europe, North America and Asia". And several scientific investigations agree on the significant increase of surface water temperature (Fang & Stefan, 1999; Scheffer et al., 2001; NWO, 2004; Eisenreich, 2005; IPCC, 2001, 2004, 2007a, 2008).

Such a significant increase in global temperatures combined with higher nutrient enrichment in lakes, rivers and reservoirs, leads to a significant change in the amount and distribution of algae in the aquatic system which certainly enhances freshwater harmful algal bloom (HAB) (Adams et al., 1998; Arnell, 1996; Eisenreich, 2005; IPCC, 2001, 2007a, 2008; Lopez et al., 2008).

Most studies addressing cyanobacteria agree cyanobacteria have well experienced adverse environmental conditions, they evolved under anoxic conditions along with high UV exposure, high temperature, and fluctuations in nutrient availability (Johnk et al., 2008; Paerl & Huisman, 2008; Paul, 2008; Perovich et al., 2008). In addition, some species have gas vesicles which enables to change their buoyancy state under influence of light (Walsby, 1994). So they have a superior access to light and nutrient compared to the non-buoyant green algae and diatom species (Paul, 2006; Paerl & Huisman, 2008; Perovich et al., 2008)

One of the recent studies by Johnk et al (2008) on the competition of the harmful cyanobacterium *Microcystis* against diatoms and green algae reveals that "a high temperature favors cyanobacteria directly, through increased growth rates. Moreover, high temperatures also increase the stability of the water column, thereby reducing vertical turbulent mixing, which shifts the competitive balance in favor of buoyant cyanobacteria".

1.3 Characteristics of Cyanobacteria

Cyanobacteria make up the Division Cyanophyta, and this Division contains about 150 genera and 2000 species worldwide (Steinman, 2007). Blue green algae (cyanobacteria) are a major risk to water quality and are the most studied group compared to other freshwater harmful algal blooms (UNEP, 2005; Donald & Judy, 2007; Lopez et al., 2008); cited in Teffera, 2009). Green algae may bloom by producing excessive biomass in eutrophic water, but they might not form dangerous scum as cyanobacteria do (WHO, 2003).

Cyanobacteria, show both characteristics of bacteria and algae that drive scientists to argue whether they are really algae or bacteria (WHO, 2003; Lansing et al., 2007; Steinman, 2007). Similar to other prokaryotes, cyanobacteria do not have membrane - bounded organelles such as nuclei, chloroplasts and mitochondria. And unlike bacteria, Cyanobacteria have internal membranes (thylakoids), which contain chlorophyll a (Steinman, 2007). Similar to algae and higher plants, they carry out the same photosynthetic pathway via chlorophyll a and blue-green pigments. Sometime in the late Proterozoic, or in the early Cambrian (UCMP, 1995) through the process of endosymbiosis, cyanobacteria started to live inside the cells of some eukaryotic algae, and providing oxygen and food for the eukaryotic hosts, and in return receiving protection (UCMP, 1995). Thus, the chloroplast with which algae and green plants make food for themselves and feeding the rest of world actually came from the cyanobacteria (UCMP, 1995; Prescott et al., 2007).

Cyanobacteria are both beneficial and harmful to ecosystems and human beings. They are beneficial because cyanobacteria have been on earth since 3 billions of years ago (UCMP, 1995; Paul, 2008). They are also the basic reason for our existence, since they were the pioneer organisms able to carry out oxygenic photosynthesis which means they are the first to produce oxygen as a by-product of photosynthesis (WHO, 2003; Verspagen, 2006; Williams et al., 2006). Over millions of years, cyanobacteria gradually added oxygen to the carbon dioxide-rich atmosphere of the early earth, essentially changing the chemistry of atmosphere towards the present day oxygen rich atmosphere (Prescott et al., 2007; Perovich et al., 2008). Thus we may call them “the architects of the atmosphere” (UCMP, 1995). Cyanobacteria are also beneficial for agriculture because some heterocyst-forming species are able to fix atmospheric nitrogen (N_2) and change to plant available form of Nitrogen (ammonia ($NH3$), nitrites ($NO2-$) or nitrates ($NO3$))(WHO, 1999; Steinman, 2007).

However, in recent decades, cyanobacteria became harmful since these tiny important creatures become a critical enemy of mankind and the aquatic environment, because they respond to eutrophication and global warming (Hallegraeff, 1993; Eisenreich, 2005; Havens, 2006; IPCC, 2008; Lopez et al., 2008; Paerl & Huisman, 2008; Perovich et al., 2008).

Cyanobacteria proliferate rapidly when temperature is high, nutrients are at high level and the weather is calm (IPCC, 2008; Johnk et al., 2008; Lopez et al., 2008; Paerl & Huisman, 2008). “Where such proliferation is dominated by a single (or a few) species, the phenomenon is referred to as an algal or cyanobacterial bloom” (WHO, 1999). These harmful cyanobacterial blooms may cause serious water quality problems either through the production of toxins or by their accumulated biomass (IPCC, 2008; Lopez et al., 2008). Their excessive accumulated biomass (scum) is harmful to lake ecosystems since the over-shading effect blocks photosynthesis (sunlight energy) that nourishes other phytoplankton (base of the food chain) and macrophytes growing on the bottom of lakes, which results in a serious problem in the complex aquatic food web. When blooms end, algal cells die and release toxins which are responsible for several human illnesses, mortality of fish and terrestrial organisms. The decomposition of dead algal cells by other microbes also consumes much of the oxygen in the water that lead to severe oxygen depletion which might cause a massive fish kill (IPCC, 2008; Lopez et al., 2008).

1.4 Cyanobacteria toxins

From the time of the late 19th century, cyanobacteria toxicity has been described typically from poisonings in freshwater environments (Paul, 2008). Since that time, several articles and reports mentioned animal and human poisoning with cyanobacteria intoxication (Paul, 2008). However, it is only recently that diversification of cyanotoxins and their impact became clear. Therefore, in recent times toxins produced by algal bloom become one of the primary concerns throughout the world in fresh water and coastal water environments (UNEP, 2005; Paul, 2008). Almost all freshwater toxins are produced by cyanobacteria (UNEP, 2005).

According to Sivonen and Jones (1999), there are at least 46 species that can cause toxic effects on vertebrates. The most widespread toxic cyanobacteria in fresh water are "*Microcystis spp., Cylindrospermopsis raciborskii, Planktothrix (syn. Oscillatoria) rubescens, Synechococcus spp., Planktothrix (syn. Oscillatoria) agardhii, Gloeotrichia spp., Anabaena spp., Lyngbya spp., Aphanizomenon spp., Nostoc spp*., some *Oscillatoria spp., Schizothrix spp.* and *Synechocystis spp.*"(WHO, 2003). The toxins produced by cyanobacteria are called cyanotoxins. These toxins are water-soluble compounds typically classified into five major classes based on damage caused on body organ or tissue: hepatotoxins, neurotoxins, cytotoxins, dermatotoxins and irritant toxins (WHO, 2003; UNEP, 2005; Williams et al., 2006) (Table 1).

Table 1 General feature of the cyanotoxins (Sivonen and Jones, 1999).

TOXIN GROUP [1]	PRIMARY TARGET ORGAN IN MAMMALS	CYANOBACTERIAL GENERA [2]
Cyclic peptides		
Microcystins	Liver	Microcystis, Anabaena, Planktothrix (Oscillatoria), Nostoc, Hapalosiphon, Anabaenopsis
Nodularin	Liver	Nodularia
Alkaloids		
Anatoxin-a	Nerve synapse	Anabaena, Planktothrix (Oscillatoria), Aphanizomenon
Anatoxin-a(S)	Nerve synapse	Anabaena
Aplysiatoxins	Skin	Lyngbya, Schizothrix, Planktothrix (Oscillatoria)
Cylindrospermopsins	Liver [3]	Cylindrospermopsis, Aphanizomenon, Umezakia
Lyngbyatoxin-a	Skin, gastro-intestinal tract	Lyngbya
Saxitoxins	Nerve axons	Anabaena, Aphanizomenon, Lyngbya, Cylindrospermopsis
Lipopolysaccharides (LPS)	Potential irritant; affects any exposed tissue	All

1 *Many structural variants may be known for each toxin group*

2 *Not produced by all species of the particular genus*

3 *Whole cells of toxic species elicit widespread tissue damage, including damage to kidney and lymphoid tissue(Sivonen & Jones, 1999)*

Many scientists agree that Microcystis *aeruginosa* is one of the most common species of cyanobacteria which is able to dominate eutrophic lakes all over the world (Sivonen & Jones, 1999; WHO, 2003; UNEP, 2005; Lürling & Roessink, 2006; Verspagen, 2006; Williams et al., 2006; NHMRC, 2008) (Fig 2). *Microcystis* is a non - heterocyst-forming genus that usually dominates under nutrient-rich conditions (especially where there is significant supply of ammonia) (WHO, 1999). They cause a serious problem in the production of safe drinking water and recreational sites, because of their production of microcystins.

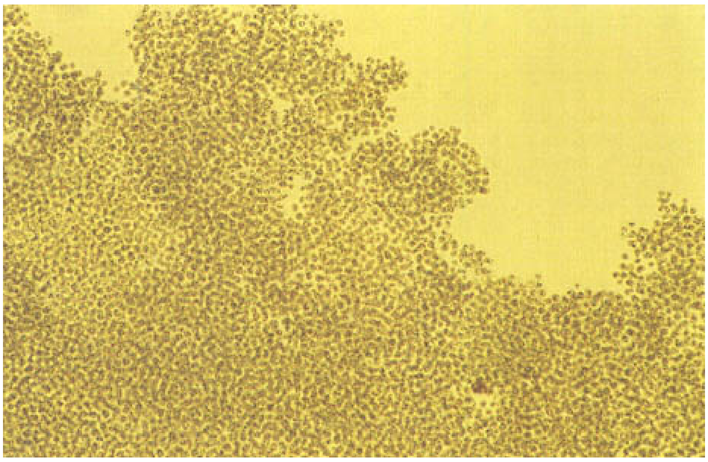

Figure 2 Micrograph of *Microcystis aeruginosa* (WHO, 1999)

Microcystins have 7 amino acids in their cyclic peptide ring system. Variations occur primarily at positions 1 and 2 (Fig 3). For example, microcystin– LR contains the amino acids leucine (L) and arginine (R) at positions 1 and 2 respectively while microcystin–RR has arginine at both positions (Fristachi & Sinclair, 2008) (Fig 3).

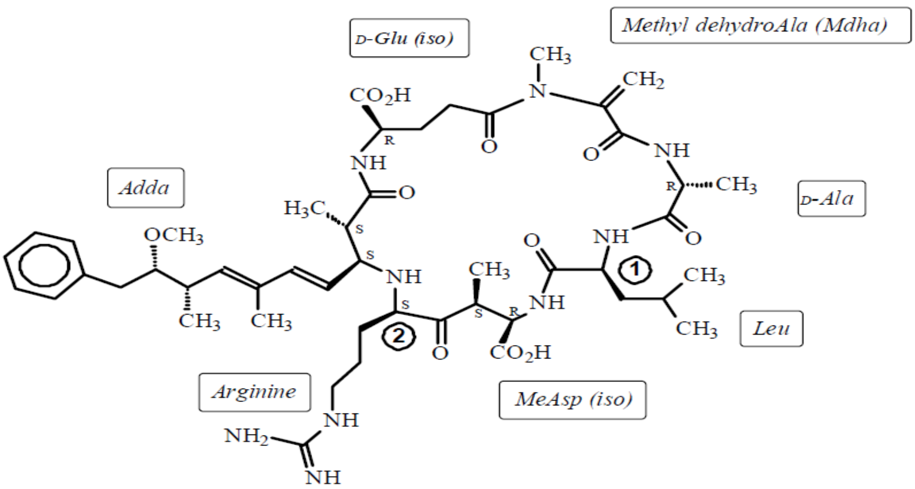

Figure 3 The generic structure of a microcystin (Fristachi & Sinclair, 2008)

According to WHO (1999) Gastro-enteritis epidemic & liver toxic blooms have been observed throughout the world. The following box information is taken directly from (WHO, 1999)

Gastro-enteritis epidemic in the area of the Itaparica Dam, Bahia, Brazil

A severe gastro-enteritis epidemic in the Paulo Afonso region of Bahia State in Brazil followed the flooding of the newly constructed Itaparica Dam reservoir in 1988. Some 2,000 gastro-enteritis cases, 88 of which resulted in death, were reported over a 42-day period.

Clinical data and water sample tests were reviewed, blood and faecal specimens from gastroenteritis patients were subjected to bacteriological, virological and toxicological testing and drinking water samples were examined for micro-organisms and heavy metals. The results demonstrated that the source of the outbreak was water impounded by the dam and pointed to toxin produced by cyanobacteria present in the water as the responsible agent. No other infectious agent or toxin was identified, and cases occurred in patients who had been drinking only boiled water. The cases were restricted to areas supplied with drinking water from the dam. Cyanobacteria of the *Anabaena* and *Microcystis* genera were present in untreated water at 1,104 to 9,755 units per ml (conversion of colony units to cells per ml depends on colony size, but a minimum of 100 cells per colony is likely in a mixed bloom of these genera).

1.5 Cyanobacteria Bloom Control

The first step to control cyanobacterial bloom should be eliminating the cause (algal nutrients). These include the macronutrients phosphorus and nitrogen, and the micronutrient iron (CLEAN-FLO, 2005). There are various algicides that remove algae from the lakes. However, these methods use aluminium salts, ferric salts and synthetic polymers as coagulants that can cause health problem both to human and animals. A number of studies showed that excess copper algicides and alum can kill fish and other aquatic animals and ultimately destroying the lake water quality (CLEAN-FLO, 2005). Moreover, the cost of these chemicals is not affordable for developing countries. Thus, natural algal bloom control methods that are affordable and environmentally friendly are very crucial. One of the most promising natural algal bloom control is the use of *Moringa oleifera,* the miracle tree of hope, to control cyanobacteria growth. Several laboratory studies have shown that, the seed extract of *Moringa oleifera* has valuable coagulating properties. Moreover, they are not toxic both to human and animals.

This miraculous tree of hope received attention from the renowned senior Scientist Dr. Miquel Lurling (Aquatic Ecology and Water Quality, the University of Wageningen- Netherlands). Recently, he conducted a preliminary study on the effect of *Moringa oleifera* seed extract on *Microcystis aeruginosa* growth rate. The results were promising; *Microcystis aeruginosa* was completely removed from the flask. This promising result was also reconfirmed by his M.Sc students (Getahun Tolla and Fassil Eshetu Ethiopia). Currently, intensive laboratory studies are undergoing in Aquatic ecology and water quality management laboratory, the Netherlands.

2 General description of the project area

Lake Koka is located about 90 km south of Addis Ababa (Fig 4). The lake covers a surface area of 220 km^2 at an altitude of 1660 m (Zinabu G/Mariam & Pearce, 2003; Tesfay, 2007). The lake is man-made, which was constructed in the course of Awash River for the purpose of hydropower. Awash River is the major river that flows into the lake, although Mojo River also flows to into it in its western part (Tesfay, 2007).

Figure 4 Satellite image of lake koka, Ethiopia (Google Earth, 2008)

There is lack of literature regarding the limnology of Lake Koka, but some of the physical, chemical and biological characteristics studied by different instigators were listed by Tesfaye (2007) (Table 2).

Table 2 "Some Physical, Chemical and biological Characteristics of Koka Reservoir"(Tesfay, 2007)

Parameters		**Sources**
Location	8° 23'N; 39° 5'E	Welcomme (1972)
Secchi depth (cm)	28	Wood and Talling (1988)
pH	8.3	Elizabeth Kebede *et al.*(1994
Conductivity (µS cm^{-1})	200	Melaku Mesfin *et al.* (1988) and FLDP (1998)
Salinity (g l^{-1})	0.319 0.2	Wood and Talling (1988) Elizabeth Kebede *et al.*,(1994)
Total Alkalinity (meq l^{-1})	2.6 3.22	Elizabeth Kebede *et al.*,(1994) Wood and Talling (1988)
Na (meq l^{-1})	1.35	"
K (meql^{-1})	0.14	"
Ca (meq l^{-1})	1.16	"
M (meq l^{-1})	0.43	"
Cl (meq l^{-1})	0.22	"
SO_4 (meq l^{-1})	12.5	"
Total P(µg)	224	"
SiO_2(mg l^{-1})	2.5	"
Chlorophyll a(µg l^{-1})	22.4 16	Melaku Mesfin *et al.*, (1988) Ellizabeth Kebede *et al.*,(1994)

Figure 5 Lake Koka in Amuddee area (photo taken by F.E Teffera)

Amuddee is one of the most affected areas by harmful cyanobacteria in Lake Koka (Fig 5). It is located 161 km South of Addis Ababa. To reach Amuddee area, you have to travel to Nazreth City (99 km) then take the road to Assela and drive 37 km by passing two small towns, Awash Melekassa and Diera. Then, turn to your right after you find the road sign Koka, and finally drive the pebbly road about 25km.

Cyanophyceae, Chlorophyceae and Bacillariophyeae are the most dominant taxa in the phytoplankton community of Koka Reservoir. Among these taxa, Cyanophyceae (mainly *Microcystis* and *Anabaena*) are the most abundant and persistent phytoplankton (Tesfay, 2007). "The dominance of the phytoplankton community in Koka Reservoir by *Microcystis spp*, particularly *Microcystis aeruginosa*, was reported earlier by (Melaku Mesfin *et al.,* 1988) cited in Tesfaye 2007). The persistent harmful cyanobacterial bloom mainly of *Microcystis aeruginosa* in Lake Koka that was obviously responsible for the death of livestock is primarily related to nutrient pollution from shore-line agriculture, highly expanded floriculture (excess

N-P) and tanning industry (excess Fe) (Zinabu G/Mariam & Pearce, 2003; Tesfay, 2007). Similarly, a scientist from U.K University (Durham) analysed a water sample from Amuddee (Lake Koka) and reported the occurrence of *Microcystis*. He argued that it was "one of the worst he had seen anywhere in the world" (Power & People, 2009).

3 Research objectives and questions

3.1 Research objectives

- The aim of this study was to determine the occurrence and extent of harmful cyanobacteria bloom in Lake Koka (Amuddee) side and assess its threat.
- Raising awareness about harmful cyanobacteria blooms and its threat to the general public especially to Amuddee's people.
- Generate base line information for further research.

3.2 Research questions

- How is the status of cyanobacteria bloom in Lake Koka (Amuddee) side?
- What are the potential threats of harmful cyanobacteria blooms on Amuddee's people and on the ecology of Lake Koka?

4 Methodology

In this study, several data collection methods were used: literature review, interview, e-mail, field observation, collection of water samples and their analyse (spectrophotometrically and microscopically), digital photographs and video. Moreover, relevant information from newspapers, magazines and internet were also included in the report. Field visits have been made to Lake Koka (Amuddee) on May 20, 2009, June 2, 2009 and July 17, 2009. In order to create awareness about harmful cyanobacteria and get information on the existing situation, two meetings and interviews were made with the residents of Amuddee including the respected elder residents (Fig 6).

Figure 6 photos taken after meeting in Amuddee (by F.E Teffera)

To study the status of harmful cyanobacteria bloom in Lake Koka (Amuddee), water samples were taken from near-shore station on June 2, 2009 and July 17, 2009 (Fig 7).

Figure 7 Water quality sampling in Amuddee (Lake Koka) (photo taken by F.E Teffera)

Inorganic nutrients were analyzed using standard methods for water quality (Greenberg et al., 1985). Ammonia (NH_3-N), Nitrate (NO_3-N) and Orthophosphate (PO4 - P) were determined by titration, HACH spectrophotometer (cadmium Reduction method) and Ascorbic Acid methods respectively (Greenberg et al., 1985;

HACH, 2000). Biomass was determined as Chlorophyll-a concentration using spectrophotometer (Greenberg et al., 1985) (Fig 8).

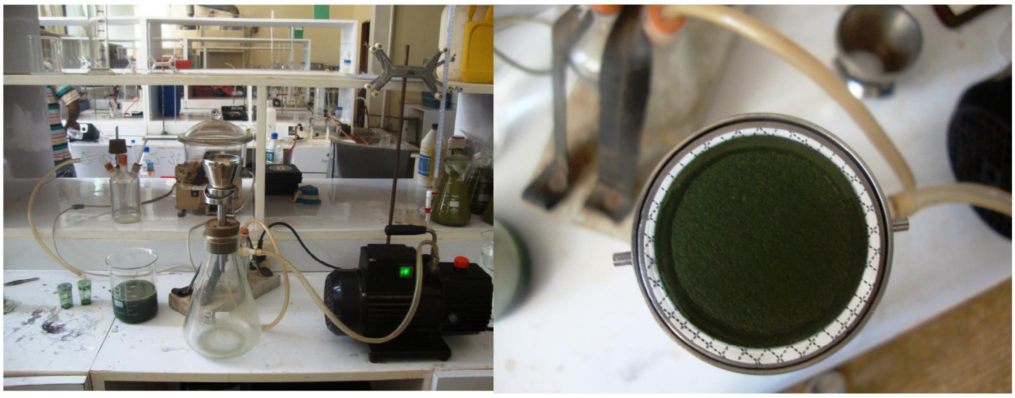

Figure 8 Determination of Chl-a in water quality lab (Arbaminch University) photo taken by F.E Teffera

4.1 Problem faced

During the field trip I have faced financial constraint to arrange for vehicle, fuel and allowance. The problems were later somehow lessened since Arbaminch University arranged for vehicle and fuel for the 2nd field trip. Due to lack of Whatman Glass Fiber filter (GF/C, 47 mm), a membrane filter (Endo, SM 13906) was used to determine Chlorophyll-a concentration (Fig 8).

4.2 Statistical analysis

The data generated for the lake were analyzed statistically using SPSS 15.0.1 for windows and Microsoft excel 2003.

5 Result and Discussion

Observations made in Amuddee area on May 20 & June 2, 2009 showed that there was a heavy harmful algal bloom (Fig. 9).

Figure 9 Harmful algal bloom in Koka Lake in Amuddee area (photos taken by F.E Teffera)

The identification of the phytoplankton taxa with Compound Microscope at magnification of 40X confirms that the heavy algal blooms especially at the near-shore were dominated by a single cyanobacterium species of *Microcystis* (Fig. 10). This agrees with the result of Prof. Brian Whitton from U.K University (Durham) who analysed a water sample from Amuddee area of Lake Koka and reported the dominance of toxic *Microcystis sp*. (Power & People, 2009)(Fig 11).

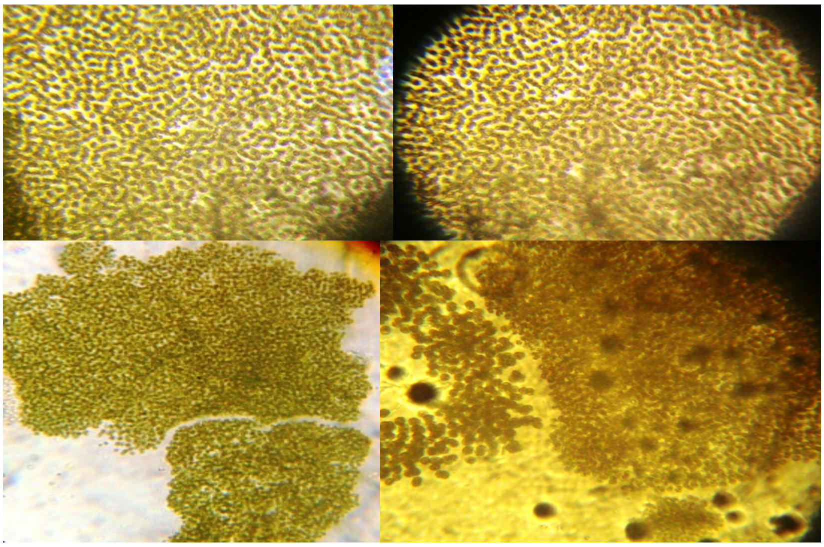

Figure 10 Proliferation of *Microcystis* in Amuddee area of Lake Koka (Compound microscope photos taken by F.E Teffea in Biology Lab at Arbaminch University).

Figure 11 Prof. Brian Whitton and his well magnified microscope photo of *Microcystis from Amuddee sample*

Moreover, the photographs of colonies taken from temporally mounts and samples under microscopic examination are similar to the micrograph *Microcystis aeruginosa* given by WHO (1999) (Fig 2 & 10). To identify the harmful cyanobacteria at species and strain level is beyond the scope of this study. In agreement with this study, previous studies stated that *Microcystis spp*, particularly *Microcystis aeruginosa* is often the dominant species in Lake Koka (Melaku Mesfin *et al.,* 1988 cited in Tesfaye 2007). Such heavy cyanobacterial blooms of *Microcystis* in Amuddee may have a significant impact on human health and on the ecosystem of Lake Koka.

Most of the randomly interviewed residents of Amuddee associate these problems with the health problems they experienced. The residents indicated that this bloom-forming alga is different from what they locally call algae in that it is notoriously difficult to remove from the lake water; it is like a green paint in the water (Fig.9). It grows luxuriously in the lake, especially in the littoral zone. The residents also expressed their concern about the aforesaid algal bloom as follows:

"Our livestock are dying and we are suffering from stomach disorders, diarrhea, vomiting and other complicated problems which we don't know for sure. You can understand our problem only if you drink the lake water. We don't see the bloom after complete mixing by wind or during rainy season. Under such conditions, we drink the Lake water easily although we know we think we are ingesting a disease-causing organism. However, when the weather is calm and there is no rainfall, algal scum reappears within a few hours or days."

In the light of what the residents said (assuming that their assessment and description of the situation is accurate), it is tempting to think that the health problems of the residents of Amuddee and the death of their livestock may have been associated with the toxins released by *Microcystis* spp. The severe liver damage observed by the residents in most of the cattle they slaughtered seems to suggest a causal relationship between bloom of *Microcystis* and death of domestic animals in the Amuddee area. The residents further stated that fishes were seen exhibiting strange behaviours including jumping above and floating on the water surface hereby facilitating their catch by humans. The observations made by the residents seem to be consistent with the symptoms of microcystin-poising in humans and animals (Arnell, 1996; WHO, 1999; IPCC, 2001; NWO, 2004; Eisenreich, 2005; Havens, 2006; Johnk et al., 2008; Lopez et al., 2008; Paerl & Huisman, 2008; Paul, 2008).

Figure 12 Lake Koka (Amuddee) during rainy season and when there is wind for mixing the lake

Even if several residents of the Amuddee area claim to have suffered from health problems following consumption of lake water in which there was an algal bloom, it is difficult to establish a causal relationship between human health problems and death of livestock and cyanotoxins in the absence of the quantitative assessment of the latter. Fortunately, if the responsible bodies of Ethiopian government are prepared to organize and facilitate research activities, a renowned senior Scientis Dr. Miquel Lurling of the University of Wageningen, the Netherlands, are willing to make tests for cyanotoxins and develop control measures that involve the use of *Moringa oleifera* through further studies both in Ethiopia and the Netherlands.

Table 3 Biomass in terms of Chlorophyll-a from Amuddee area of Lake Koka

Date	Chl-a µg/l	Remark
06/02/2009	815.7	Sample taken in early morning at 5:58 a.m. from littorial zone, the water column was calm no mixing.
07/02/2009	77.4	Sample taken in early morning at 6:10 a.m. from littorial zone, there was heavy rainfall 1 day before the sampling, the water column was calm no mixing.
Average	446.5	

5.1 Biomass (Chlorophyll-a)

The algal biomass values (chlorophyll-a, 446.55 µg/l) of this study in the Amuddee area of Lake Koka are by far higher than those recorded in lake koka " (22.4 µg/l, Melaku Mesfin *et al.*, 1988; 16 µg/l, Elizabeth Kebede *et al.*, 1994; cited in Tesfay, (2007) (Table 3).

5.2 Inorganic Nutrients

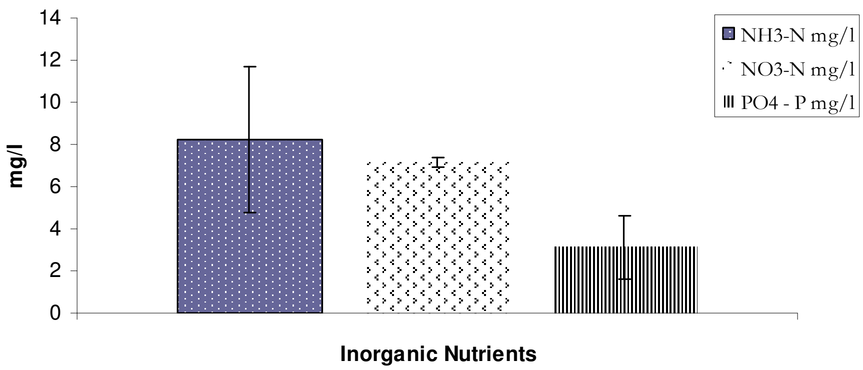

Figure 13 Inorganic nutrients in Amuddee (Lake Koka)

Figure 13 and Table 4 show the concentrations of inorganic nutrients and the sampling conditions during the study period. It is not reasonable to make comparisons between concentrations of nutrients measured in the present study and those recorded in previous investigations because different analytical methods were employed. However, I have made the comparisons to present a wakeup call for further detail scientific studies. Nitrate (NO_3-N, 7.15 mg/l), phosphate (PO_4 – P, 3.13 mg/l), and ammonia (NH_3-N, 8.21 mg/l) concentrations of this study were by far higher than those reported in Lake Koka. In the Amuddee area of Lake Koka, the concentration of Soluble Reactive Phosphate (SRP, PO_4-P, 3.13 mg/l) alone was much higher than the total P concentration reported by (Wood & Talling, 1988; Elizabeth Kebede et al, 1994; cited in Tesfaye, 2007).

Due to time and financial limitations I did not generate adequate scientific information on water column. Thus it is very difficult to determine the causes and impact of algal blooms in Amuddee area. In order to establish a causal relationship between environmental factors and dynamics of biological systems, variables should be measured over an extended period of time (Demeke Kifle, Pers. Comm.). In my opinion, the reason for consistent bloom of *Microcystis* in Amuddee area might be high level of Phosphate, since concentrations of phosphorus as low as 0.1 mg l^{-1} are sufficient to induce a cyanobacterial bloom WHO, (1999).

Moreover; according to Wisconsin (2008), a total phosphorus concentration > 0.150 mg\L is regarded as an indicator of very poor lake quality. Thus, Lake Koka water quality around Amuddee is very poor and creates a conducive condition for the proliferation of harmful *Microcystis* bloom. The concentrations of nitrogen in the form of nitrate (NO_3-N, 7.15 mg/l) and ammonia (NH_3-N 8.21 mg/l mg/l) were also very high compared to those of previous studies (NO_3-N, 0.04- 0.0267 mg/l) (Tesfay, 2007). Therefore, according to Wisconsin (2008), Amuddee (Lake Koka) is classified as Hypereutrophic (very poor lake quality) since the concentrations of nitrate (NO_3-N, 7.15 mg/l) and ammonia (NH_3-N, 8.21 mg/l) alone are by far grater than total Nitrogen (1.50 mg\L, Wisconsin, 2008).

According to the finding of Zinabu G/Mariam & Pearce (2003) "The effluent from the tannery, that eventually enters Lake Koka through its inflow River Mojo, contained 0.523 mg/l of Fe". This result is higher than the maximum allowable concentration (0.3 mg/l, WHO, 1999).

Table 4 Inorganic nutrients in (mg/l) from Amuddee area of Lake Koka

Date	Replication	PO_4-P mg/l	NH_3-N mg/l	NO_3-N mg/l	Remark
		Inorganic nutrients			
05/25/2009	I	10	14	-	Sample taken at 6:15 p.m. from littorial zone, there was strong wind that mixed the sediments with water column
	II	2.02	16.8	-	
	III	4.74	9.8	-	
07/02/2009	I	0.56	0.26	6.9	Sample taken early in the morning at 6:10 a.m. from littorial zone , there was heavy rainfall 1 day before the sampling , the water column was no mixing.
	II	0.68	0.22	7.4	
	III	0.77	-	-	
	Mean	**3.13**	**8.21**	**7.15**	
	STDES	3.71	7.69	0.35	
	SE(±)	1.51	3.44	0.25	

There are extensive lake experiments results that justify rising temperatures favour cyanobacteria than other eukaryotic phytoplankton (Paerl & Huisman, 2008; 2009). Considering this scientific information (Global warming) holds true on Lake Koka combined with high concentrations of the macronutrients nitrogen and phosphorus, and the micronutrient iron, it is not surprising that potentially harmful *Microcystis* species have been observed on the Amuddee side of Lake Koka. High temperature, high concentrations of the macronutrients nitrogen and phosphorus, and the micronutrient iron, play a very important role in regulating the *Microcystis* bloom dynamics ultimately causing deterioration of lake water quality, serious disorder in humans and animals of the surrounding area.

6 Conclusion and Recommendation

Based on the findings from this study and other earlier studies, the following preliminary conclusions can be drawn: If macronutrients (N & P) and micronutrients (Fe) are transported from Floriculture, watershed, near-shore Agriculture and Tanneries into Lake Koka, persistent increases in harmful cyanobacteria bloom can occur under conducive environmental conditions (no wind, higher temperature and lake stratification).

However, to understand the bloom dynamics of harmful cyanobacteria further research is needed with a view to answer the following questions.

- What is the interrelationship among *Microcystis* bloom, nutrients, water temperature, light, rainfall, and groundwater and catchments runoff?
- What causes the persistence of *Microcystis* bloom in the Amuddee side of Lake Koka?
- What is the biomass and seasonality of *Microcystis* in the Amuddee side of Lake Koka?
- Do the cyanobacteria found in Amuddee side of Lake Koka toxic?
- What is the concentration of Microcstin in the Amuddee side of Lake Koka?
- What are the controlling and monitoring mechanisms?
- Which controlling and monitoring mechanisms are cost effective and biofriendly for Amuddee (Lake Koka) ?

These are some of the questions that need to be answered at PhD level studies in collaboration with senior Scientist like Dr. Miquel Lurling from the University of Wageningen the Netherlands.

The following points were made as the summarized recommendations;

1. Harmful cyanobacterial bloom in the Amuddee side of Lake Koka should be approached as a problem and then Government, NGOs, farmers, the public and the private sector need to take ownership, since it may have destructive consequences on the lake ecosystem and presents a serious threat to the health of Amuddee's residents.

2. Increased awareness of harmful cyanobacterial bloom at grass root level should be the first step towards the control measure.

3. Appropriate harmful cyanobacterial bloom control strategy and monitoring project should be developed and implemented.

4. Human activities along the Awash River, Mojo River and their tributaries (nutrient pollution from shore-line agriculture, highly expanded floriculture (excess N-P) and tanning industry (excess Fe) are increasing with an alarming rate. These human activities simply discharge their waste into the rivers with out any treatments, thus the responsible bodies of the government must take urgent action to save human life and their environment in Lake Koka especially to Amuddee residence.

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