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CHARACTERIZATION OF RANOMAFANA LAKE WATER QUALITY - ANTSIRABE MADAGASCAR-

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Master thesis

CHARACTERIZATION OF RANOMAFANA LAKE WATER QUALITY – ANTSIRABE MADAGASCAR.

Thesis submitted to the ”University of Stavanger” in partial fulfillment of the requirements for the degree of Master in ”Offshore Technology”, specialization: ”Environmental control”.

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ABSTRACT

Analyses of water quality parameters in Ranomafana Lake showed that the lake is hypereutrophic. It receives untreated wastewater from Antsirabe municipality by three main inlets: the North West inlet, the North inlet and the North East inlet. And the measured values in different stations indicate that, horizontally, the water is not well mixed; peak values are recorded at station 3 located downstream the North West inlet.

For all measured parameters, daily variation was noticed. The surface water registered a temperature difference of 2°C from morning to afternoon. The water pH was slightly alkaline and ranged from 7.17 to 8.12 in the surface and from 7.1 to 7.95 in the bottom. The dissolved oxygen in the morning was between 6mg/l to 12 mg/l in the surface layer and between 4 mg/l to 8 mg/l at the bottom water. This amount increased from morning to the afternoon due to the photosynthesis. Regarding the nutrient level, the total nitrogen concentration in the lake water varied from 7.6 mg/l to 10.6 mg/l in February; from 6.6 mg/ to 10.8 mg/l in March and from 6.3 mg/l to 12.1 mg/l in April. The total phosphorus concentration ranged from 0.94 mg/l to 2.23 mg/l in February; from 0.99mg/l to 2.23 mg/l in March and from 0.94 mg/l to 3.85 mg/l in April. The quantity was always higher in the afternoon. Ranomafana Lake water also had high chlorophyll a concentration: 106 mg/m3 to 232 mg/m3 in February, 88 mg/m3 to 142 mg/m3 in March and 131 mg/m3 to 238 mg/m3 in April.

Despite its hypereutrophic state, Ranomafana Lake water does not experience oxygen depletion. The whole water column is aerobic due to high photosynthesis. The main problems are high phosphorus concentration and algae concentration. They contribute the most to the increase of water turbidity and to the decrease of Secchi disk depth in this Lake. It is then necessary to reduce the nutrient level and the chlorophyll a concentration in order to remediate the water quality. And for that purpose, our recommendations consist of reducing the nutrient loads by treating the wastewater prior to their discharge into the lake, increasing the nutrient uptake from the lake water by promoting algae growth and then removing the excess of algae to clarify the water.

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Lilia V Rasolofomanana

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INTRODUCTION

The main topic of this thesis concerns the characterization of Ranomafana Lake water quality, a tropical lake situated in Southern Hemisphere, located in Antsirabe city in Madagascar.

The lake has important roles in sanitation and tourism for Antsirabe municipality. However, the untreated wastewater discharged into it and the population growth combined with the activities development in its watersheds affect the lake water quality. Thus, Ranomafana Lake remediation has become a focus for the municipal authority of Antsirabe since 1986. The objectives are to improve the water quality, to reduce public health risk related to the use of water coming out the lake and also to improve its aesthetical value to promote its recreational vocation.

Many studies have since then already been effectuated concerning Ranomafana Lake. In 2007, Ranomafana lake renewal was integrated within the Norwegian Program for Development, Research and Education (NUFU) in collaboration with the marine institute (IHSM) of the University of Toliara Madagascar and the University of Stavanger (UIS) Norway.

Defined as an “inland body of water”, every lake is a unique ecosystem. The majority of lakes on Earth is fresh water and present in the Northern Hemisphere at higher latitudes. Worldwide, most of lakes provide recreational opportunities such as fishing, bathing and tourism. Besides, they are used for irrigation, livestock watering and navigation.

A lake is an open system which is connected to its surrounding by the streams (inlets and outlets) and its watersheds. Therefore, the use of the lake associated with population growth and technology development become a threat if the lake utilization and its water body are not well managed.

Water body management can be a very complex task and in order to design and put into preventative practice or curative water quality management programs, it is essential to have a firm understanding of the causes of water quality problems.

The present research is performed in order to fulfill a Master's thesis in offshore engineering – Environmental control in UIS. The topic is part of the lake management project that the Antsirabe municipality, NUFU program and UIS undertake. Lake water quality assessment information is useful to any one involved in lake management. It provides a knowledge base that we can use to protect and restore our lakes.

The scope of this document is to report the water quality parameters values that have been collected and analyzed within Ranomafana Lake and to try to conclude its current status. Thus, the first part of the book will concern the literature review. It will introduce generality about Lake and the existing data about the Lake of concern. The second chapter will explain the experimental methodology. And the last part will present the results and will discuss the current status of the Lake.

It is our hope that this book will help the project managers to delineate a deep modeling of the lake in order to choose appropriate remediation methods and to meet their goals.

I- LITERATURE REVIEW

1.1. General Characteristics of a lake

- **Description**

A Lake is a body of water surrounded by land and geologically defined, is temporary (Otterbine Barebo, 2003). That means, it may dry at certain time and becomes filled again under seasonal condition or heavy rain (Wikipedia.com). It is said temporary also because it undergoes an aging process and will disappear (we will describe this phenomenon in the coming paragraph).

According to Jørgensen (1980), most Lakes are of catastrophic origin that is formed by volcanic, tectonic, river activity and glacial processes, but they can also be man-made that we refer to as reservoirs.

Every Lake is a unique ecosystem. Apart from its origin, each lake has its own features such as size, drainage basin, inflow and outflow characteristics, nutrients content, dissolved oxygen content, pH, temperature and its productivity.

Lake size does affect a number of relationships. Some examples are the ratio of lake surface area and length of shoreline, the faction of the total water volume that is influenced by sunlight, and the ratio of the size of the drainage basin to size of the lake. These relationships affect how lakes function such as environmental conditions, biological productivity and ability to handle pollution. On the other hand, a small lake with a greater ratio of shoreline to water volume may be more susceptible to damage from shoreline or watershed activities as it consists of a shallow lake.

Lake morphology (shoreline configuration) varies from one to another, some of them are bowl-shape, and another has bays. The shoreline characteristics have significant impact over horizontal mixing and plant populations. In other words, bowl-shape lake is horizontally well mixed compared to lakes with bays where pollution tends to accumulate.

Another Lake feature is its morphometry which is lake shape regarding its depth, which may determine its function. It has influence on vertical mixing: deep lakes may have stratification where water surface characteristics can be very different from the bottom water. In shallow lakes, stratification does normally not occur and it is more likely to be homogeneous because water is well mixed by wind and sunlight reaches to the lake bottom. In such lakes, physical characteristics such as temperature and oxygen vary little with depth and photosynthesis and algal growth occur throughout the water column (Joy P. Michaud, 1991).

In general, lakes are described with different zones (Jørgensen, 1980):

- The littoral zone: Corresponds to the shallow water region with light penetration to the bottom and where nutrients are added by surface runoff.

- Limnetic zone: The open water zone with effective light penetration and this corresponds to the upper layer of the lake where photosynthesis occurs.

- Profundal zone: the bottom and deep water area beyond the depth of effective light penetration. This region is normally absent or very small in shallow lakes.

- Benthic zone: this includes all bottom areas and is comprised of sediment and soil and, in polluted lakes, it has a high demand for dissolved oxygen due to degradation of organic matter.

- **Classification of lakes**

Two criteria can be used to classify a lake which is the depth that determines the water stratification and the water circulation patterns and the trophic state that describes its pproductivity.

According to its depth or stratification (Jørgensen, 1980), lake is categorized as:

- Shallow lake or pond where stratification does normally not occur.
- Dimictic* lake which has two seasonal periods of overturn.
- Cold monomictic lake whose water temperature is never above 4°C, generally found in Polar Regions.
- Warm monomictic lake having water temperature always above 4°C, found in warm, temperate or subtropical regions.
- Polymictic lake: more or less continuous in circulation, located in high altitude or equatorial zones.
- Oligomictic lake: rarely or very slowly mixed. This is the case of many tropical lakes.
- Meromictic lake: permanently stratified due to chemical differences in water surface and bottom water.

The classification based on lake trophy gives the following categories:

- oligotrophic lake (or new lake)
- mesotrophic lake (middle aged lake)
- eutrophic lake (old lake)

Oligotrophic lakes are clear, cold lakes with slightly acidic to slightly alkaline water. Nutrient level is poor and few macrophytes or plants grow in. The phosphorus concentration in the water is usually less than 1µg/l and there are little or no algae present.

* Mictic means circulation

Mesotrophic lakes tend to have intermediate level of nutrient and macrophytes. These lakes have higher level of phosphorus and experience some weed and algae problems. The water pH ranges from neutral to slightly alkaline.

Eutrophic lakes are characterized by high nutrient levels, turbid water, and large algae and macrophyte plant populations. Phosphorus level is normally higher than 10µg/l. the water pH is usually alkaline.

The age and shape are two factors we must consider when managing a lake. The existing zones or regions should be well managed in order to maintain an ecological balance in the lake. Lake that is in ecological balance is a healthy lake, aging at a slow rate.

1.2. The aging process in a lake - eutrophication process

Lakes are dynamic and complex ecosystems. They are subject to a natural aging process known as eutrophication (Gilbert M. Masters, 1991). This process consists of the change from an original oligotrophic state to a eutrophic state including changes in chemical, physical and biological characteristics of the lake.

Eutrophication is caused by the increase of nutrients, especially nitrogen and phosphorus, in the ecosystem leading to an increase of primary production (photosynthesis) and an accumulation of organic matter in the lake. In addition, silt from the drainage basins will accumulate over time, which makes the lake shallower and warmer. Under natural conditions, the rate of this process is very slow and it takes hundreds or thousands of years. When human activities contribute, however, the process accelerates and we refer to it as a cultural eutrophication (Gilbert M. Masters, 1991).

Cultural eutrophication was recognized as a pollution problem in European and North American lakes and reservoirs in the mid-20th century. Since then, it has become more widespread. Surveys showed that 54% of lakes in Asia are eutrophic; 53% in Europe; 48% in North America; 41% in South America; and 28% in Africa (www.wikipedia.com).

- **Eutrophication indicators**

Jørgensen (1980) considered the total organic carbon concentration, total phosphorus, total nitrogen, and the biomass productivity in the lake water in order to determine its trophic state (Tables 1.1 and 1.2).

Table 1.1: Chemical parameters used to determine the trophic state of a lake.

Trophic state	TOC (mg/l)	TP (µg/l)	TN (µg/l)	Total inorganic Solids (mg/l)
Ologotrophic	< 1 -3	1-5	1-250	2-15
Mesotrophic	1-5	5-10	250-600	10-200
Eutrophic	5-30	10-30	500 – 1100	100 – 500
Hypereutrophic		30 -5000	500 – 15 000	400 – 60 000
Dystrophic	3 -30	1 -10	1 -500	5 - 200

Table 1.2: Biological parameters used to measure the lake trophy.

Trophic state	Mean primary productivity ($mg/cm^2/d$)	Phytoplankton biomass (mg/cm^3)	Chlorophyll (mg/m3)	Dominant phytoplankton	Light extinction coefficient ($ŋm^{-1}$)
Ologotrophic	50 – 300	20 – 100	0.3 - 3	Chrysophyceae Chryptophyceae Dinophyceae Bacillariophycea	0.05 – 1
Mesotrophic	250 – 1000	100 – 300	2 - 15		0.1 – 2
Eutrophic	>1000	>300	10 - 500	Bacillariophycea Cyanophyceae Chlorophyceae Euglenophyceae	0.5 - 4
Hypereutrophic	<50 – 500	<50 – 200	10 – 500		1 - 4
Dystrophic			0.1 - 10		

Source: Jørgensen (1980)

In most New York lakes, three important parameters are used to measure the lake trophy: total phosphorus, chlorophyll *a* (estimating the amount of algae), and Secchi disk transparency as shown in Table 1.3 (NYS Citizens Statewide Lake Association Program, 2006). These parameters are closely linked to the growth of weeds and algae and they provide insight into the status of the lake and its suitability for recreation and aesthetics.

Table 1.3: The most parameters used to determine the trophic state of a lake in New York.

	Eutrophic	Mesotrophic	Oligotrophic
P µ g/l	>20	10-20	<10
Chl a µ g/l	>8	2-8	<2
Secchi depth (m)	<2	2-5	>5

Source: NYS Citizens Statewide Lake Association Program, 2006

- **Factors influencing the eutrophication process**

As eutrophication is about increase of primary production, light and nutrients (nitrogen and phosphorus) are needed for the process to occur. Light that can penetrate the water column depends on water turbidity which is influenced by algal production that depends on nutrient availability. Thus, high algal production will cause high turbidity and reduction in light penetration and then reduction in algal production.

The major factor controlling the eutrophication process is the nutrient load into the water bodies. An analysis of mean growing season concentrations of chlorophyll, total phosphorus (TP), and total nitrogen (TN) in 228 north latitude lakes conducted by Val. H. Smith (1982) confirms previous observations that chlorophyll yield is dependent both on the phosphorus concentration and on the TN/TP ratio: the lower TN/TP ratio, the higher chlorophyll yield.

- The role of phosphorus in eutrophication

Phosphorus is essential to plant growth and is considered to be the most limiting nutrient for plant growth in natural lake (C.C. Lee & Shun Dar Lin, 2007; Tchobanoglous & Schroeder, 1987). Therefore, it has become the focus of attention in the eutrophication issue. Phosphorus has low availability in water because it has no gas phase. It is only provided from runoff. It is present in water in different forms both dissolved and particulate. Dissolved phosphorus is mainly as orthophosphate (PO_4^{3-}) and is defined as the fraction passing through 0.45 µm filter. .

- The role of nitrogen in eutrophication

Nitrogen is not considered as limiting nutrient compared to phosphorus since it can be provided by different processes in the aquatic system (refer to John J.Goering, 1972). It has gas phase which make it more soluble and algae can fix N2 from air. Therefore, it has high availability. Thus, in a lake, phosphorus is limiting more often than nitrogen. The significance of nitrogen for algal growth was studied in Lake Vesijärvi in 1979 and 1980 by algal bioassay, using *Selenastrum capricornutum* and *Anabaena cylindrica* as test organisms (J. Kanninen et al, 2004). Also, Gilbert (1991) demonstrated by a simple stoichiometry analysis, that it takes 7 times more nitrogen than phosphorus to produce a given amount of algae, and phosphorus concentration more than 0.015 mg/l and nitrogen concentration above 0.3 mg/l are sufficient to cause an algal bloom.

- **Effects of eutorphication**

Eutrophication affects greatly the dissolved oxygen concentration in water. At the surface, oxygen concentration may always be higher since it is continuously produced by photosynthesis and also provided by air-water interaction. When it comes into deeper water, its production is limited. In fact, photosynthesis occurs only in presence of sunlight and for a eutrophic lake, the water turbidity prevents the light to enter deeper into water column. In addition, the super production of algae due to nutrient abundance is associated with algal death. The dead algae sink into the bottom and are degraded there. The degradation process demands oxygen which emphasizes the diminution of oxygen concentration at that depth. Regarding the variation of dissolved oxygen within depth, oligotrophic lakes shows little variation and oxygen can always be

recorded even near the bottom. However, in eutrophic lakes, dissolved oxygen concentration diminishes considerably with depth and may become zero at a certain depth (Gilbert M. Masters, 1991).

In addition to those impacts, other consequences can be also observed depending on the eutrophication level in the water, for example:

- Apparition of noxious algae (blue, green toxic algae), scum, odor and color
- Excessive macrophyte growth causing loss of open water
- Loss of habitat for fish and fish food due to the low dissolved oxygen content
- Production of "Toxic" gases (such as ammonia, H_2S) in bottom water (more loss of fish habitat)

Knowledge of the lake's trophic state is important because it provides a reference point to view changes in a lake's water quality and help to understand how these changes may threaten the use of the lake. It is also helpful for restoration purposes.

1.3. Water quality standards for a lake

Water quality standards are the cornerstone of water quality management program. They define the use of water body and describe the specific water quality criteria to achieve that use, Table 1.4.

Table 1.4: Nitrogen and phosphorus concentrations in Lakes and reservoirs relevant to water use purposes.

Categories	Water use	TN (mg/l)	TP (mg/l)	Summer chlorophyll a (mg/m3)	Transparency (m)
I	Conservation of natural environment, and use in II - V	<0.07	<0.005	<1	>6
II	Water supply class 1, 2, and 3, fishery class 1, bathing and use III - V	<0.15	<0.01	<3	>4
III	Water supply class 3, use IV - V	<0.40	<0.03	<20	>2
IV	Fishery class 2, and use V	0.60	<0.05	<40	>1
V	Fishery class 3, industrial water, irrigation water, conservation of environment	<1	<0.10	-	-

Water supply:
- class 1: sand filtration
- class 2: coagulation/rapid filtration
- class 3: pretreatment, advanced water treatment

fisheries:
- class 1: salmon, trout, ayu
- class 2: pond smelt (wakasagi)
- class 3: carp, catfish, roach

Source: www.env.go.jp/en/water/wq/wp.pdf

Water quality standards for lakes are also established based on organic matter (COD), dissolved oxygen and suspended solids (TSS) regarding the water use, Table 1.5.

Table 1.5: COD and dissolved oxygen concentration standards for a lake regarding its use

Water use	COD (mg/l)	TSS (mg/l)	Dissolved oxygen (mg/l)
Conservation of natural environment	< 1	< 1	>2
Water supply for drinking water, fishery class 1and 2	< 3		>7.5
Fishery class 3	< 5		>6
Bathing	< 8		-

Source: http://www.emecs.or.jp

Nevada Division of Environmental Protection also set a classification of the water quality surface (class A to class D with class A being the highest quality) based on watershed occupation, the beneficial use of water, and on water quality parameters such as solids, pH, temperature, fecal coliform and total phosphorus content, Table 1.6.

Table 1.6: Lake Class according to the Nevada Administration Code

Items	Specifications			
	Class A	Class B	Class C	Class D
watershed	areas of little human habitation, no industrial development or intensive agriculture, relatively undisturbed by man's activity	areas of light or moderate human habitation, little industrial development, light-to-moderate agricultural development, only moderately influenced by man's activity	areas of moderate-to-urban human habitation, where industrial development is present in moderate amounts, agricultural practices are intensive and considerably altered by man's activity	areas of urban development, highly industrialized or intensively used for agriculture or a combination of all the above and where effluent sources include a multiplicity of waste discharges from the highly altered watershed
Beneficial uses of water	- Municipal/domestic supply with treatment by disinfection only, - aquatic life, propagation of wildlife, - irrigation, watering of livestock, -recreation including contact (or not) with the water.	- municipal or domestic supply, with treatment by disinfection and filtration only, - irrigation, watering of livestock, - aquatic life and propagation of wildlife, - recreation involving (or not) contact with the water, - industrial supply	- municipal or domestic supply, following complete treatment, - irrigation, watering of livestock, - aquatic life, propagation of wildlife, - recreation involving (or not) contact with the water, - industrial supply	- recreation not involving contact with the water, - aquatic life, propagation of wildlife, - irrigation, watering of livestock, - industrial supply except for food processing purposes
Floating solids, sludge deposits, or taste- or odor-producing substances.	None attributable to man's activities.	Only such amounts attributable to man's activities which will not make the waters unsafe or unsuitable as a drinking water source or injurious to fish or wildlife, or will not impair the waters for any other beneficial use established for this class.	Only those amounts attributable to the activities of man which will not make the receiving waters injurious to fish or wildlife or impair the waters for any beneficial use established for this class.	Only such amounts attributable to the activities of man which will not impair the receiving waters for any beneficial use established for this class.
Sewage, industrial wastes or other wastes.	None.	None which are not effectively treated to the satisfaction of the Department.	None which are not effectively treated to the satisfaction of the Department.	None which are not effectively treated to the satisfaction of the Department.
Toxic materials, oils, deleterious substances, colored or other wastes.	None.	Only such amounts which will not impair the palatability of drinking water or fish or have a deleterious effect upon fish, wildlife or any beneficial uses established for waters of this class.	Only such amounts as will not render the receiving waters injurious to fish and wildlife or impair the waters for any beneficial use established for this class.	Only such amounts as will not impair the receiving waters for any beneficial use established for this class.
Settleable solids.	Only amounts attributable to man's activities which will not make the waters unsafe or unsuitable as a drinking water source or which will not be detrimental to aquatic life or for any other beneficial use established for this class.	Only such amounts as will not render the receiving waters injurious to fish or wildlife or impair the receiving waters for any beneficial uses established for this class.		

pH.	6.5 to 9.0 SU.	6.5 to 9.0 SU.	6.5 to 9.0 SU.	6.0 to 9.0 SU.
Dissolved oxygen.	≥6.0 mg/l.	≥6.0 mg/l. ≥5.0 mg/l.	≥ 6.0 mg/l. ≥ 5.0 mg/l.	≥3.0 mg/l.
Temperature: Maximum. ΔT.	≤20°C. =0°C.	≤20°C. ≤24°C. =0°C.	≤ 20°C. ≤ 34°C. = 3°C.	
Fecal coliform (No./100ml).	≤200/400.[a]	≤200/400.[b]	The more stringent of the following apply: ≤ 1000/2400.[b] ≤ 200/400.[c] ≤ 200/400.[d]	
Total phosphorus (as P): In any stream at the point where it enters a reservoir or lake. In any reservoir or lake. In a stream or other flowing water.	≤0.05 mg/l. ≤0.025 mg/l. ≤0.10 mg/l.	≤0.10 mg/l.	≤ 0.33 mg/l.	
Total dissolved solids.	≤500 mg/l or one-third above that characteristic of natural conditions (whichever is less).	≤500 mg/l or one-third above that characteristic of natural conditions (whichever is less).	≤ 500 mg/l or one-third above that characteristic of natural conditions (whichever is less).	

Source: Nevada Administrative Code (NAC), Chapter 445A.118-445A.225

1.4. The Ranomafana Lake

A figure of Ranomafana Lake is shown in Figure 1.1.

- **Description**

Source: google map, 2009

Figure 1.1: Ranomafana Lake and its surroundings

Ranomafana Lake is a tropical lake situated in Antsirabe, a city located in the high plateau region of Ankaratra (1450m of altitude) in central Madagascar, south hemisphere. Geologically, the city lies on a Precambrian formation of crystalline (granite and gneiss) as basement rocks (British Geological survey, 2002 in Ranomafana Lake renewal project report, May 2008). The city is also recognized by its thermal springs associated with ancient volcanism. In fact, the basement rock which is volcanic rock is composed largely of basalt and let the thermal mineral water to come out when fractures are developed. The first drilling was conducted by a French geologist, H.Perrier De La Bathie in 1913. Nowadays, the thermal spring issued from this drilling is used for balneotherapy (spa center).

The Ranomafana Lake has a surface area of 14ha and a catchment area of 125ha including cress field, rice field, spa and habitation (Figure 1.1).

Originally, the lake was created to counterbalance the rise of gases (CO2 and H2S) from the bottom volcanic layer. Then it has been used for recreational purposes and as municipal wastewater receptor. Nowadays, it also serves as a fishing area for inhabitants and also for irrigation of the downstream cress field (located downstream the South outlet).

- **Pollutant sources for Ranomafana Lake**

Ranomafana Lake receives untreated wastewater and storm water runoff from surrounding watershed (Yves, 2008). From its 125ha of catchment areas, the discharged domestic wastewater into the lake was estimated to 870 m^3 per day, generated by 39 527 inhabitants, including the thermal wastewater from the spa center. The city of Antsirabe is considered as an important industrial pole of Madagascar where textile industries, food processing factories and farming are important. Untreated industrial effluents are discharged into the surrounding rivers such as Sahatsio River, and this river connects to Ranomafana Lake by its North West inlet.

The main pollutant sources to the Ranomafana Lake are:

- Oxygen- demanding wastes from human sewage and food processing factories
- Diseases-causing agents from sewage and industrial wastes
- Plant nutrients (nitrogen, phosphorus) from sewage, industrial wastes and agricultural run-off
- Organic chemicals (detergents, pesticides…) from sewage, industrial wastes and agricultural run-off
- Inorganic chemicals and minerals (salts, acids…) from drainage and from sediments

- Toxic substances
- Sediments (solids) from natural run-off
- Heat from the spa wastewater discharges.

According to Yves (2008), the BOD loading and COD loading into the lake were estimated to 790 kg/day and 1976 Kg/day, respectively.

- **Ranomafana Lake renewal project**

The importance of Ranomafana Lake is obvious both for the public health and for the municipality in tourism development in Antsirabe. However, the cultural eutrophication degrades its state.

For its remediation, studies have already conducted on the lake water[†] and influent streams (Anne-Lise, 2005, wega 2007, Yves, 2007). The results from the previous researches are reported below.

- Diagnostic of Ranomafana water quality in October – November 2006 (Yves, 2007)

Water/wastewater is discharged into the Lake through 10 inlets. The total inlet flow rate into the lake was estimated to 504.27m3/h in October and 84.36m3/h in November. The flow is higher in the North-west inlet (42.18m3/h in October and 28.38m3/h in November) and in the North-East inlet draining wastewater from the spa (410.4m3/h in October and 18.7m3/h in November). The outlet flow was very low. The recorded water temperature at that time varied significantly within the sampling station. It was between 18°C and 37°C. The highest value was registered at the North-East inlet conducting water from the thermal treatment building. Water pH ranged from 6.68 to 8.92. Conductivity showed considerable variation: it was 423µS/cm in the small East inlet while 6000µS/cm in the North- East inlet from the spa; and it ranged from 480µS/cm to 3500µSm/cm in the West side of the Lake. It was observed also that water was very turbid in the East part (134.8FTU) compared to the North – West (71.8FTU).

1.5. Lake monitoring and tested water quality parameters

There are different types of monitoring programsaccording to their purpose, such as the ambient monitoring program. It is conducted to describe existing conditions or long-term trends in water quality (seasonal variation of the water quality).

Another type of monitoring program is the baseline monitoring to describe baseline conditions in a lake or stream. Baseline conditions are those which exist before some event, that affects the water quality, occurs.

[†] Studies were only carried out within water samples collected in the streams and in the edge of the lake.

Compliance monitoring is designed to assess whether specific standards or requirements are being met. In other words, it is carried out to check if the values of the water quality parameters of a lake met the standards regarding to its use.

Whatever the type of monitoring, the most frequently tested parameters are: temperature, pH, turbidity, conductivity, dissolved oxygen, oxygen demand (organic matter), solids, nutrients, chlorophyll, and coliforms. The importance of those parameters will be discussed in the following paragraphs. For in-depth research, metals, toxic substances and biological composition of the lake may also be studied.

- **Temperature**

Temperature is an important parameter in characterization of natural water bodies. It affects the water chemistry such as saturation and concentration of dissolved gases, especially oxygen (James Vincent Quagliano & al, 1969). The rate of chemical reactions generally increases as temperature increases (rule of Vant Hoff). Temperature also affects biological activity and regulates the kinds of organisms that can live in the lake.

The most obvious reason for temperature change in lakes is the change in seasonal air temperature (David C. L. Lam, William M. Schertzer, 1999). Daily variation may also occur, especially in the surface layers, which are heated during the day and cooled at night. In deeper lakes, thermal stratification may occur during summer and winter. The temperature of the surface water will change according to the sun intensity, while the bottom of the lake remains constantly cold (Jørgensen, 1980).

- **pH**

The pH of a solution is a measure of the concentration of hydrogen ions (H^+) and it represents the negative logarithm of hydrogen ions concentration. It expresses the intensity of the acid or the alkaline condition of a solution (Sawyer & al, 1978). The pH of water determines the solubility and biological availability of chemical constituents such as nutrients and heavy metals (Rao, 1989).

One of the reasons of pH change in water is the photosynthesis. This process absorbs carbon dioxide from the water and uses the sun's energy to convert it to simple organic carbon compounds and to produce oxygen (Equation 1.1). Carbon dioxide in solution has acidizing effect as it reacts with water and forms carbonic acid (H_2CO_3). As long as plants and algae remove it, the water becomes more alkaline and the pH increases (Equation 1.1).

Equation 1.1 – Growth of algae by photosynthesis:

$106\ CO_2 + 16NH_4^+ + HPO_4^{2-} + 65\ H_2O \rightarrow C_{106}H_{181}O_{45}N_{16}P + 118O_2 + 14H^+$

Unlike the photosynthesis process, respiration has an acidizing effect as it consumes the dissolved oxygen in water and releases carbon dioxide.

With photosynthesis being dominant during the day, the plants have a net alkalizing affect during daylight hours. However, during the night, plants stop photosynthesis but normal respiration continues, so there is only oxygen removal from water and carbon dioxide release with a net pH decrease.

Other processes affecting the water pH is the bacterial degradation of organic (Equation 1.2) and conversion of inorganic matter (equation 1.3) as they utilize oxygen.

Equation 1.2 – aerobic degradation of organic matter:

$COHN + O_2 + \text{nutrients} \rightarrow CO_2 + NH_4^+ + C_5O_7H_2N + \text{other end- products}$

(Organic matter) (New cell)

Equation 1.3 - Nitrification:

$NH_4^+ + 1.86O_2 + 1.98HCO_3^- \rightarrow 0.02C_5H_7O_2N + 0.98NO_3^- + 1.88H_2CO_3 + 1.04H_2O$

- **Dissolved oxygen**

Dissolved oxygen is an important parameter in aquatic environments. It governs the majority of biological processes in aquatic ecosystems. Its concentration is the result of physical, chemical and biological processes that whether produce or consume oxygen.

Oxygen is added into water bodies by air-water exchange, diffusion and mixing in the water and by photosynthesis. It is consumed by the phenomena of photo-oxidation, chemical oxidation reactions and by aquatic organisms for respiration and bacterial degradation (Equations 1.2 and 1.3).

The biological processes have dominant influence on the concentrations of oxygen. Thus, in areas where organic matter accumulates and become degraded, those areas may become anoxic or totally anaerobic and fish death will occur. In addition, if nitrogen load is high, oxygen consumption by nitrification will also be significant (Equation 1.3). However, in eutrophic areas, major developments of phytoplankton can cause supersaturation.

The presence of dissolved oxygen is of fundamental importance in maintaining aquatic life and the aesthetic quality of water (Tchobanoglous & Schroeder, 1985).

- **Turbidity**

Turbidity indicates the amount of suspended solids in the water, either mineral (such as soil particles) or organic (like algae). The turbidity analysis is a measure of the amount of light scattered in water and more suspended particles cause greater scattering and thus high turbidity value.

Turbidity values vary for two main reasons. One reason is physical such as heavy rains and fast-moving water which causes erosion. The other reason is biological due to algae growth and bacterial degradation of organics in the water column.

- **Secchi disk depth**

The Secchi disk depth is the measure of water clarity. It indicates the light penetration in the water and will be opposite to turbidity. Clear water lets light penetrate more deeply and allows photosynthesis to occur and oxygen to be produced in that layer. Secchi disk depth is thus used as an indicator algal abundance and lake productivity.

A role of thumb is that light can penetrate 1.7 times the Secchi disk depth.

- **Conductivity and salinity**

Conductivity is a measure of the ionic activity of a solution in terms of its capacity to transmit current (Tchobanoglous & D. Schroeder, 1985). In a water sample, the electric current is conducted by the ions present in it, so when the concentration of ions increases, conductivity augments as well. This parameter relates then to the amount of dissolved solids (as it includes ions) in the water: the higher the total dissolved solids in the solution, the higher the ion concentration and conductivity.

Salinity is the dissolved salt content of water and there is relationship between the two parameters, conductivity and salinity.

- **Oxygen demand**

The oxygen demand of a water sample usually determines the impact of contaminants on oxygen resources. Both biochemical and chemical oxidations reactions take place in aquatic environments but the most dominant is the biochemical. The biochemical oxidation consists of the oxidation of organic matters by microorganisms as resumed in the Equation 1.2.

The chemical oxygen demand can be used to measure the whole amount of organic compounds in water. It is based on the fact that all organic matter can be oxidized by the action of potassium dichromate under acidic conditions (Clair N. Sawyer & Perry L. McCarty, 1978).

The comparison of the 2 variables (COD and BOD) can provide information about how much and how strength the organic materials in the water sample are.

- **Nutrient**

The significances of nutrients (nitrogen and phosphorus) in aquatic ecosystem can be evaluated by considering their sources and cycle in the aquatic environment:

- Nitrogen cycle

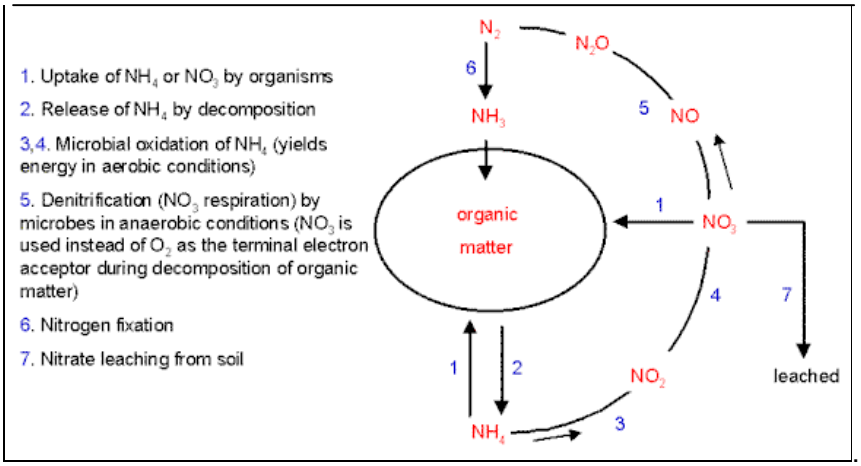


Figure 1.2: Nitrogen cycle in the environment

In lakes, nitrogen is added from external sources discharged from inlet streams or exchange with atmosphere. In addition, nitrogen ammonia (NH_4^+) result from the bacterial degradation of organic matters (ammonification). Produced ammonia is converted into nitrate (NO3-) in nitrification (equation 1.3) and nitrate can be reduced to nitrogen gas (N_2) under anoxic conditions. To complete the nitrogen cycle in the nature, nitrate is used as nitrogen source in growth of bacteria and plants.

- Phosphorus cycle

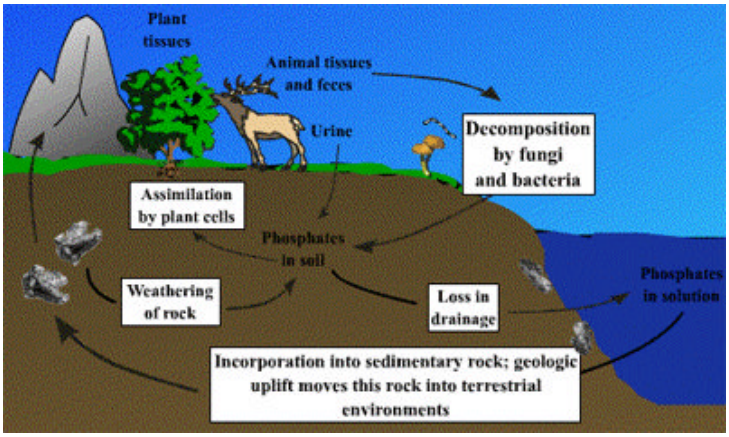


Figure 1.3: Phosphorus cycle

Phosphorus in surface water is mostly from runoff of soil particles. It also enters waterways through fertilizer runoff, sewage discharges, natural mineral deposits, and wastes from other industrial processes. Dissolved phosphate is used by algae while particulate phosphorus will settle on lake bottom. As sediments are stirred up, phosphates may reenter the phosphorus cycle in the way that they are taken up by aquatic plants and then travel up through successive stages of the aquatic food chain.

Generally, the concentration of phosphorus in many natural water is low and usually limits the algal growth (Tchobanoglous & Schroeder, 1985).

- **Chlorophyll a**

Chlorophyll is the green molecule in plant cells that carries out the bulk of energy fixation in the process of photosynthesis. Besides its importance in photosynthesis, chlorophyll is probably the most-often used estimator of algal biomass in aquatic system. Many types of chlorophyll can be found in plant such as chlorophyll *a, b, c,* and *d*, but Chlorophyll *a* is the molecule found in all plant cells and therefore its concentration is what is reported during chlorophyll analysis. It absorbs sunlight and converts it to energy, which is used to produce algae cells during photosynthesis. Its concentration can be an effective measure of the trophic status (Tables 1.2 & 1.3). Chlorophyll *a* levels may fluctuate over time. They are often higher after rainfall, particularly if the rain has flushed nutrients into the water. Higher concentrations are also observed during the summer months when water temperatures and light increase.

II- EXPERIMENTAL METHODS

In order to collect data, the experimental work had two parts:

- The field work which included the in field measurement of some parameters such as temperature, pH, conductivity, salinity, dissolved oxygen and Secchi disk depth. It also included sampling and preservation of water for laboratory testing purposes.
- The laboratory work: analysis of BOD, COD, nitrogen, phosphorus, solids, and chlorophyll in the samples.

2.1. The field work

2.1.1. Sampling design

As the objective is to characterize the entire lake which covers an area of 14Ha, five stations in the Lake and 2 stations in the inlets stream were elected to provide an adequate characterization of the lake.

Sampling locations were geographically identified using Global Positioning System (GPS) in order to locate them easily in the next sampling period. In Table 2.1 and Figure 2.1, those chosen stations (their localization and their description) are summarized.

Table 2.1: Location of sampling stations

stations	Geographic coordinate		description
	latitude	longitude	
1	19° 52’ 148” South	47° 01’ 877” East	In the North East of the Lake
2	19° 52’ 196” South	47° 01’ 861” East	East of the island
3	19° 52’ 190” South	47° 01’ 813” East	Downstream the main inlet, located at the North-west of the lake
4	19° 52’ 260” South	47° 01’ 826” East	In the midsection
5	19° 52’ 345” South	47° 01’ 817” East	Upstream the outlet, south of the lake
6	19° 52’ 114” South	047° 01’ 868” East	Main inlet in the North-west (NW) of the lake
7	19° 52’ 138” South	047° 01’ 894” East	Inlet in the North- east (NE) of the lake

Source: google map, 2009

Figure 2.1: Localization of the sampling stations

Regarding the vertical sampling, samples were taken near the surface (about 15 cm depths) as the lake is relative shallow (0.3m – 0.8m) and no significant variation in water quality can be expected from surface to bottom apart from oxygen and pH.

2.1.2. Sampling frequency

The objective of the study is to collect data which will be used as a basis for the lake restoration and the samples were collected monthly between February 2009 and April 2009.

2.1.3. Sample preservation

As some analyses were done in lab, samples had to be preserved. They were stored in plastic bottle of 1liter.

Table 2.2: Sample size and preservation for the analyzed parameters.

Parameter to be determined	container	Minimum sample size (ml)	Sample type	preservation	Maximum storage recommended	Regulatory storage
BOD	P	1000	g	refrigerate	6h	48h
COD	P	100	g	add H2SO4 to PH<2, refrigerate	7d	28d
chlorophyll	P	500	g	Unfiltered, dark, 4°C	24 – 28h	
Nitrogen Kjeldhal	P	500	g	Unfiltered, add H2SO4 to pH<2, refrigerate	7d	28d
Nitrate + nitrite	P	200	g	Filtrate, add H2SO4 to pH<2, refrigerate	1 -2d	28d
Reactive phosphorus	P	100	g	Filtrate. add H2SO4 to pH<2, refrigerate	28d	
Phosphorus	P	100	g	Add H2SO4 to pH<2, refrigerate	28d	
pH				In field measurement		
solids	P	200	g	refrigerate	7d	
temperature				In field measurement		
Turbidity				In field measurement		
Conductivity, salinity				In field measurement		

P= plastic (polyethylene or equivalent), g: grab sample; Refrigerate: storage at 4°C in the dark

Source: standards methods for the examination of water and wastewater, 20th ed (LenoreS.Clesceri, Arnold E.Greenberg, Andrew D: Eaton, 1998)

2.1.4. Field measurements

a- Temperature

Temperatures were measured during sampling using a portable WTW multi 340i pH/O2/Conductivity meter connected to an oxygen probe cellox 325 VTV. Temperatures at the surface and at the bottom were noted.

b- PH

In field, we measured this parameter by using the multi-meter 340i connected to the pH-probes C 98 07 10 21 VTV. Values were recorded at the surface and at the bottom.

c- Dissolved oxygen

Dissolved oxygen concentration was measured directly in the lake water using the oxygen probe cellox 325 VTV connected to the multi-meter 340i. It was recorded at the surface and at the bottom.

d- Turbidity (Nephelometric method)

This parameter was measured on-site with a quick and reliable instrument, a turbidimeter HI 93 703 HANNA instrument.

The sample is introduced into a transparent glass sample cell and put in the sample chamber. The device reads its turbidity value by illuminating the sample and recording the scattered light.

e- Conductivity, salinity

The determination of these parameters is done by using the conductivity probe TetraCON 3245 connected to the multimeter 340i.

f- Secchi disk depth

This parameter is measured by using a Secchi disk which is a circular plate divided into quarters painted alternatively black and white. The disk is attached to a rope and lowered into the water until it is no longer visible.

2.2. The laboratory analyses

2.2.1. Determination of chemical oxygen demand

Chemical oxygen demand (COD) is the mass of oxygen equivalents needed to oxidize the organic matter in a sample, normally expressed in milligrams per liter. It can be determined by the equivalent to the mass of dichromate consumed when treating a sample of water in a defined oxidizing condition.

Theoretically, 1 mole of dichromate (Cr2O72-) is equivalent to 1 mole of oxygen (O2)

The determination of this parameter was effectuated following the AFNOR standard T91/K, September 1971, ISO 6060. The principle consists of boiling a defined volume of sample, under acidic condition and in the presence of a known mass of potassium dichromate, silver sulfate (Ag_2SO4) (playing the role of oxidation catalyst) and sulfate of mercury (II) (Hg SO_4). Then, the excess of dichromate is determined by titration using a solution of iron sulfate (II) and Ammonium ($(NH_4)_2Fe(SO_4)\ 2.6H_2O$), and the COD value is obtained by calculating the quantity of potassium dichromate reduced using the equation 2.1.

COD = 8000 c (V1 - V2) / Vo (equation 2.1)

Where

c: concentration of the solution of iron sulfate (II) and ammonium (mol/l)

c = 5 x 0.04 x 6 / v = 1.2 / v with **v**, the used volume (in ml) of solution of iron sulfate (II) and ammonium for its titration

Vo: volume of the sample (ml)

V1: volume of the solution of iron sulfate (II) and ammonium used for the blank (ml)

V2: volume of the solution of iron sulfate (II) and ammonium used in the sample (ml)

(V1>V2)

2.2.2. Determination of the biochemical oxygen demand (BOD)

Biochemical oxygen demand (BOD) is the amount of oxygen that is consumed during biological degradation of organic matter in a water sample. Typical test time is five days at 20 ° C in darkness. Its determination was done according to the NF T90 – 103 standards (December 1970). The principle of this method is that microorganisms, mainly bacteria, degrade organic matter in the sample and the corresponding oxygen consumption is measured. The sample must be diluted to a level so that oxygen in it is sufficient to maintain degradation over 5 days.

The samples was prepared by adding appropriate amount of dilution water with seeding made from distilled water and filtered urban wastewater, phosphate buffer solution and nutrient salt solution.

Diluted samples were filled in incubation bottles of 330ml and incubated at 20 ° C. Oxygen concentration was measured both at the filling time and after 5 days incubation. The BOD of the sample is calculated from the amount of oxygen consumed during 5 days (*equation 2.2*). Each sample was analyzed with duplicates at different dilutions and BOD was the average of the duplicates.

BOD = F (To - T5) - (F - 1) (Do - D5) (equation 2.2)

Where:

- D_o the oxygen content of the blank (incubation bottle filled only with seeded dilution water) at the time of filling (mg/l).
- D_5 oxygen content of the blank after 5 days incubation (mg/l).
- T_o the oxygen content of any dilution of the sample at the time of filling of the vials (mg/l).
- T_5 oxygen content of this dilution of the sample after 5 days incubation (mg/l).
- F the dilution factor: F = V1/Vo

With V1 = the volume of the incubation bottle (330ml) and Vo the volume of undiluted sample.

2.2.3. Determination of nitrate concentration

Nitrate concentration was determined using sodium salicylate method (Jean Rodier, 2001). In the presence of sodium salicylate, nitrate is transformed into sodium paranitrosalicylate, having yellow color and sensitive to a colorimetric determination using a spectrophotometer at a wavelength of 415nm. The measured value of the sample is then subtracted to the value of the blank (distilled water). The result is calculated using the calibration curve (See appendix).

For a sample of 10ml, the curve gives directly the nitrogen content expressed as mg N/l of sample. To obtain the nitrate (NO3), multiply the result by 4.43.

2.2.4. Determination of nitrite concentration

In the nitrogen cycle, nitrite ions are relatively a fleeting intermediate compound between ammonia nitrogen and nitrate ions. Their concentrations usually found in water are the order of micromoles per liter. However, in water where oxygen content is low, the reduction of nitrate ions concentration may lead to increased concentrations of nitrite.

The concentration of this compound in the lake water sample was determined using the method described by Alain Aminot Chaussepied and Marcel (1983)

Principle of the method

Nitrites ion form a diazo (diazoïque) with sulfamide (NH2SO2C6H4-NH2) under acidic condition (pH <2) by the reaction:

$NH_2SO_2C_6H_4\text{-}NH_2 + NO_2 + 2H^+$ ----------> $(NH_2SO_2C_6H_4\text{-}N \equiv N) + + 2H_2O$

Then, the diazo reacts with N-naphthyl-ethylenediamine to form a pink dye:

$(NH_2SO_2C_6H_4\text{-}N \equiv N)^+ + C_{10}H_7 - NH - (CH_2)_2 - NH_2 \rightarrow NH_2SO_2C_6H_4\text{-}N = N - C_{10}H_6 - NH - (CH_2)_2 - NH_2 + H^+$

The pink dye absorbs at wavelength 543nm using distilled water as reference. The concentration is calculated using a calibration curve for nitrite.

2.2.5. Determination of total Kjeldhal nitrogen (TKN)

Total Kjeldhal Nitrogen (TKN) is the organic and ammoniacal nitrogen content in the sample which is determined as NH_4^+ after mineralization of organic nitrogen with sulfuric acid to form ammonium sulfate, and in the presence of selenium as a catalyst. The method is described in NF EN 25663 standards (January 1994, ISO 5663). Then the ammonia is liberated by distillation and titrated with 0.02N sulfuric acid until the indicator turns red. The volume of sulfuric acid used for the titration is then noted and used in the equation 2.3 to calculate the concentration of TKN, Q_N, expressed in mg / l.

$$\mathbf{Q_N = 0.02v\ (1000x18) / V\ (equation\ 2.3)}$$

v: volume of 0.02N sulfuric acid used to titrate the sample (ml).

V: volume of the sample (150ml).

<u>Note</u>: The total nitrogen (TN) corresponds to the sum of nitrate, nitrite and total Kjeldhal nitrogen.

2.2.6. Reactive phosphate analysis (colorimetric method)

The method consists of combining the phosphorus with Nitrovanadomolybdic made of ammonium molybdate - $(NH_4)6Mo.7O_2.4H_2O$ and ammonium metavanadate NH_4VO_3, to form a complex phosphovanadomolybdique having a molybdate yellow color. The intensity of the color is proportional to the phosphorus content and measured at wavelength 430 nm. Distilled water

was used as blank. The phosphate concentration is calculated using a calibration curve for phosphorus.

2.2.7. Determination of total phosphorus

The method for determining the total phosphorus concentration in water sample as it is described by Jamie Bartram and Richard Balance (1996) consists of converting all organically combined phosphorus and all phosphates to reactive phosphate by digestion in presence of potassium peroxydisulphate. Then the reactive phosphorus is analyzed by colorimetric method as described for reactive phosphate (section 2.2.6).

The digestion method

In 100 ml of thoroughly mixed sample, add 1 drop (0.05 ml) of phenolphthalein indicator solution. If a red color develops, add sulphuric acid solution drop by drop to just discharge the color. Then add 2 ml sulphuric acid 6N and 15 ml potassium peroxydisulphate solution. Heat the muxture for 30 minutes in a pressure-cooker at 1.1–1.4kPa cm-2. Cool and add 1 drop (0.05 ml) phenolphthalein indicator solution. Neutralize to a faint pink color with sodium hydroxide solution. Restore the volume to 100 ml with distilled water.

2.2.8. Solids analysis

a. Total suspended solids (TSS) and volatile solids (VSS)

The TSS determination is accomplished by filtration using glass fiber Whatman GF/C within 1µm pore-size and then evaporation at 105°C for 2 hours. The weigh difference between filter and the filter after evaporation corresponds to the suspended solids.

The VSS analysis consists of combusting the filter and TSS in an oven at 550°C for 30 min. This process converts the organic matter into carbon dioxide and water. The loss in weight is interpreted as the organic matter (which has volatilized).

Calculation

Let:

Mo: the initial mass of the clean filter (g)

M1: mass of the filter with suspended solids after evaporation at 105°C for 2 hours (g)

M2: mass of the filter after ignition at 550°C for 30 min (g).

Vs: volume of sample that is filtered (ml).

Assume that after combustion, the paper has lost approximately 1% of its initial weight (UiS laboratory experiment).

The concentration of the total suspended solids (TSS) and volatile suspended solids (VSS) present in the sample is given by the formula:

$$TSS = \frac{(M1 - Mo).10^6}{Vs}(mg/l) \quad \text{(Equation 2.4)}$$

$$VSS = \frac{[M2 - (M1 + 0.01Mo)].10^6}{Vs}(mg/l) \quad \text{(Equation 2.5)}$$

b. Total solids (TS) and total volatile solids (TVS)

To determine the total solids and total volatile solids, 30 ml of sample is added into a completely dry porcelain bowl (heat resistant), and then dried in an oven at 105°C during 24 hours. Cool the bowls and then weigh. Put the bowls at 550°C for 1 hour. Cool and weigh.

Expression of the results

Let:

M_p: the initial mass of the porcelain (g)

M_{p1}: mass of the bowl with solids after evaporation at 105°C during 24 hours (g).

M_{p2}: mass of the bowl after ignition at 550°C for 1 hour (g).

Vs: volume of sample (ml).

The concentration of the total solids (TSS) and total volatile solids (VSS) present in the sample is calculated using the following formula:

$$TS = \frac{(Mp - Mp1).10^6}{Vs}(mg/l) \quad \text{(Equation 2.6)}$$

$$TVS = \frac{[Mp2 - Mp1].10^6}{Vs}(mg/l) \quad \text{(Equation 2.7)}$$

2.2.9. Analysis of chlorophyll a

The analysis follows the method described by Jamie Bartram and Richard Balance (1996). It consists of filtering the sample using a glass fiber Whatman GF/C within 1µm pore-size, extracting the chlorophyll (from phytoplankton) with 8ml 90% acetone followed by

centrifugation for 15 minutes at 3,000 rpm to clarify the sample. Then the acetone extract is analyzed in a spectrophotometer at several wavelengths (750 nm, 663 nm and then 750 nm and 665 nm).

When the sample is concentrated by filtration, the phytoplankton cells die. The chlorophyll immediately starts to degrade into phaeophytin *a*. Its concentration is thus reduced. It is therefore essential to measure the concentration of phaeophytin *a* and to make appropriate corrections to analytical results.

Chlorophyll *a* concentration was determined using the equation 2.8 and the spectrophotometer was calibrated against a blank (solution of 90% acetone).

Let:

- Absorbance of the blank at 750 nm and 663 nm equals to Zero
- Then the recorded the absorbance with the samples at 750 nm and 663 nm: 750a and 663a respectively.
- After adding two drops of 1 mol l-1 HCl to sample, agitate gently for 1 minute and record absorbance at 750 nm and 665 nm (750b and 665b).

Calculation

1. Subtract absorbance: 663a-750a = corrected 663a absorbance
   665b-750b = corrected 665b absorbance
2. Use these corrected 663a and 665b absorbance to calculate:

$$chlorophyll(a) = \frac{26.73(663a - 665b).Ve}{Vs * l}(mg/l) \text{ (Equation 2.8)}$$

$$phaeophytin(a) = \frac{26.73[1.7(665b) - 663a].Ve}{Vs * l}(mg/l) \text{ (Equation 2.9)}$$

Ve: volume of acetone extracts (liters)

Vs: volume of water sample (liters)

l: path length of cuvette of the spectrophotometer, used for the absorbance measurement (cm)

III- RESULTS AND DISCUSSION

3.1. Physical characters of Ranomafana Lake

- **Depth**

The preliminary depth survey that we did in February in Ranomafana Lake recorded a depth ranging from 0.3m to 0.8m (table 3.1). The lake is shallower in its littoral zone (0.3m – 0.4m) especially in the North-West part (0.3m) and gets deeper inwards (0.8m around the point 19°52'378" latitude South and 47°01'813" Longitude East).

Table 3.1: Water depth of Ranomafana Lake (February 2009)

Position	Recorded depth (m)
19° 52' 126" S/ 047° 01' 887"E	0.6
19° 52'199" S/ 047° 01' 892"E	0.7
19° 52' 213" S/ 047° 01' 837"E	0.5
19° 52' 182" S/ 047° 01' 829"E	0.5
19° 52' 220" S/ 047° 01' 791"E	0.3
19° 52' 302" S/ 047° 01' 792"E	0.4
19° 52' 378" S/ 047° 01' 813"E	0.8
19° 52' 321" S/ 047° 01 '838"E	0.6
19° 52' 274" S/ 047° 01' 857"E	0.4
19° 52' 205" S/ 047° 01' 891"E	0.4
19° 52' 148" S/ 47° 01' 877" E	0.4
19° 52' 196" S/ 47° 01' 861" E	0.5
19° 52' 190" S/ 47° 01' 813" E	0.3
19° 52' 260" S/ 47° 01' 826" E	0.6
19° 52' 345" S/ 47° 01' 817" E	0.8

An attempt for sediment depth measurement was also done which gave a sediment depth more than 1m.

- **Lake size**

Ranomafana Lake is laying in a surface of 14Ha (14000 m^2). Its shoreline is estimated to approximately1200m (estimation using Google earth, 2009).

For Ranomafana Lake, the average depth of the lake is 0.55m which gives an average water volume of 7700 m^3. The ratio of shoreline to water volume is estimated to 0.15. Such a lake is normally not susceptible to damage from shoreline or watershed activities (Joy P. Michaud, 1991).

- **Shoreline configuration, inflows and outflows**

The shape of Ranomafana Lake shows many bays, 10 stream inlets and one main outlet. Two inlets located in North West and North East contribute most to the drainage of the lake: The North-West stream carries in water from the hospital and from the cress-field situated ahead the Lake (across the road) and has characteristics of wastewater. The North- East inlet discharges natural water from a rice field and water coming in by this inlet is apparently clean, so people do washing at this place. Table 3.2 presents some parameters value measured within samples taken from those two main inlets in March and April.

Table 3.2: Characteristics of the North West and North East Inlets

Stream	**North West inlet**		**North East inlet**	
Water quality	**March**	**April**	**March**	**April**
TSS (mg/l)	63.00	34.00	18.00	24.00
VSS (mg/l)	35.82	22.96	9.75	17.00
Reactive P (mg/l)	1.27	1.27	1.04	1.04
TP (mg/l)	1.99	2.32	1.23	1.42
N-Nitrate (mg/l)	8.66	5.21	0.88	0.63
TN (mg/l)	12.73	9.49	7.99	2.36
BOD (mg/l)	36.61	24.46	28.42	13.71
COD (mg/l)	80.97	50.38	62.08	26.99

The North West inlet appears as diluted wastewater and can be explained by the sampling site that was after the wastewater had passed a natural wetland. The North East inlet has lower value of pollutants, but do also contribute to the pollution due to its high flow rate.

Another inlet which may contribute with thermal pollution of the lake water is the central North inlet. It brings warm wastewater from the spa into the Lake in the morning. Temperature measured at that place was 34.3°C in April while the average temperature in the lake water was 23.23°C.

3.2. Physical water quality parameters

This section presents the physical characteristics of the Lake water, such as temperature, turbidity and solids content.

- **Temperature**

The temperature during sampling is presented in Figures 1a to 1d.

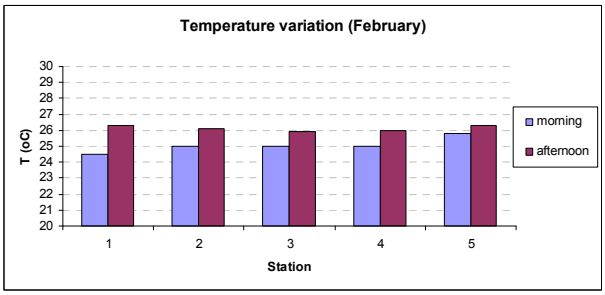


Figure 3.1a. Comparison between morning and afternoon temperatures at the surface water in February

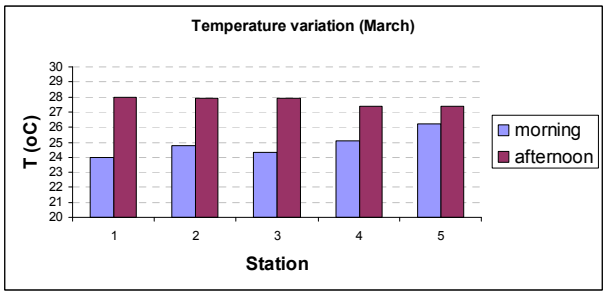


Figure 3.1b. Comparison between morning and afternoon temperatures at the surface water in March

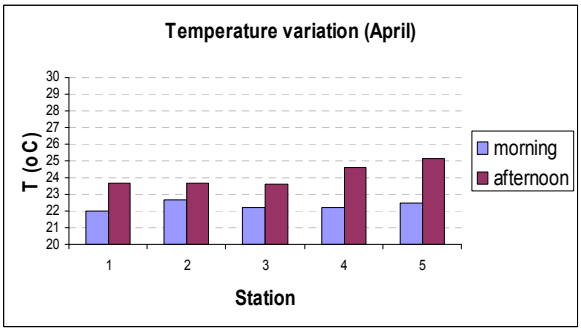


Figure 3.1c. Comparison between morning and afternoon temperatures at the surface water in April

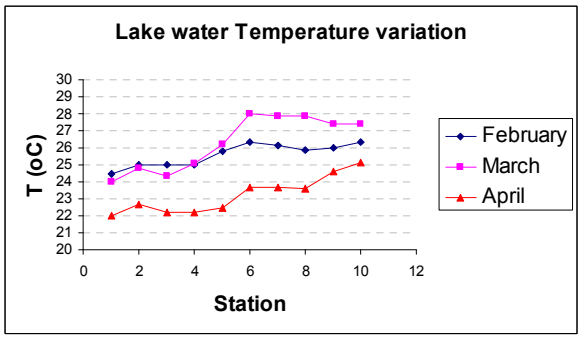


Figure 3.1d. Variation of surface water temperature from February to April

Figure 3.1: Temperature variation of Ranomafana Lake water

At the same station, daily variation of temperature was recorded at 8am and 17pm, and the temperature difference was about 2°C. Surface waters are subject to temperature variation due to fluctuation in sunlight and air temperature (George Tchobanoglous & Edwards D. Schroeder, 1985). Temperature was slightly higher in the afternoon compared to the morning due to longer exposure to sunlight. The temperature difference between surface and bottom can be explained by the difference in light penetration.

The temperatures recorded at different stations did not show big variation during the same sampling period which indicates uniform conditions with respect to temperature. However, it decreases from February to April (Figure 3.1d). This variation is due the seasonal change in air temperature.

- **Turbidity**

The turbidity was lower in the morning than in the afternoon. This is because of the waste water discharged into the lake during the day and other activities like washing and fishing which disturb the water and suspend the sediments into the water column. The algae growth also contributes to this turbidity increase: in the morning, productivity is low due to low light intensity, and then it augments during day with the increase of sunlight intensity.

Some peak values were recorded in station 3 (Figures 3.2a & 3.2c). This station is located downstream the main water inlet and so receives the major quantity of discharges prior to their spreading into the lake. Otherwise, the turbidity is relatively constant throughout the lake.

Turbidity in water is also affected by the weather, which means it increases when the water flow or currents increases due to rain or wind. That is the case in April (Figure 3.2c) when it was raining 2 days before the sampling, and consequently, the recorded water turbidity increased significantly.

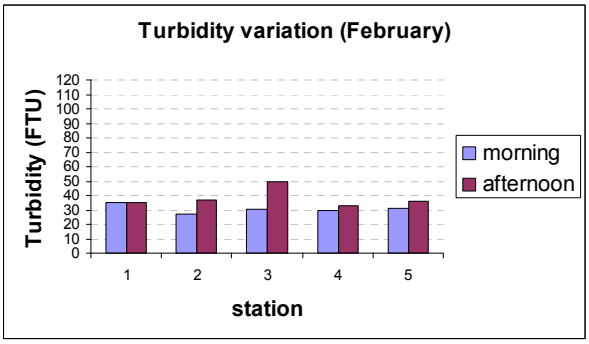


Figure 3.2a. Comparison between morning and afternoon turbidity of the surface water in February

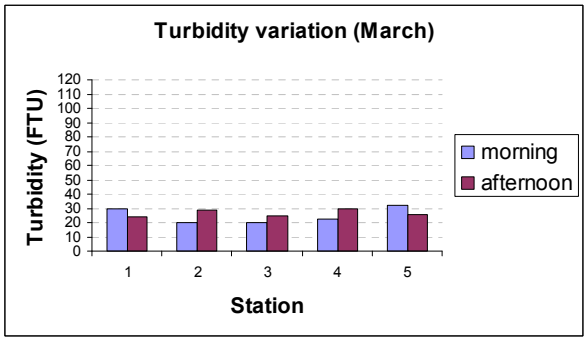


Figure 3.2b. Comparison between morning and afternoon turbidity of the surface water in March

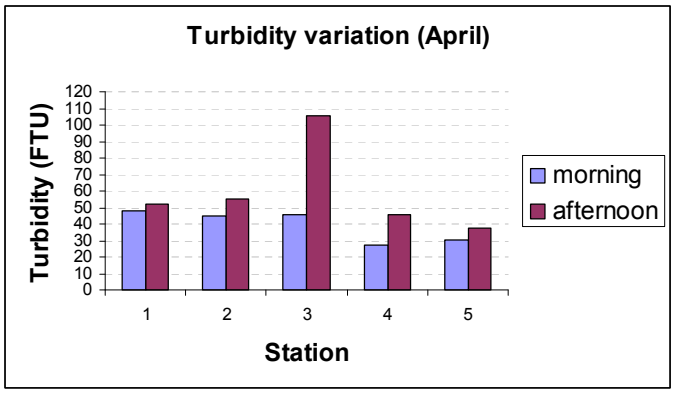


Figure 3.2c. Comparison between morning and afternoon turbidity of the surface water in April

Figure 3.2: Turbidity variation of Ranomafana Lake water

- **Solids**

Similar to turbidity, the concentration of total suspended solids generally increases from the morning to the afternoon and after rainfall (such as in April). In February, the suspended solids concentration of lake water was between 31mg/l and 54 mg/l (Figure 3.3a). In March, it

was between 22 mg/l and 36 mg/l (Figure 3.3b); while in April, it varied from 30 mg/l to 116 mg/l (Figure 3.3c).

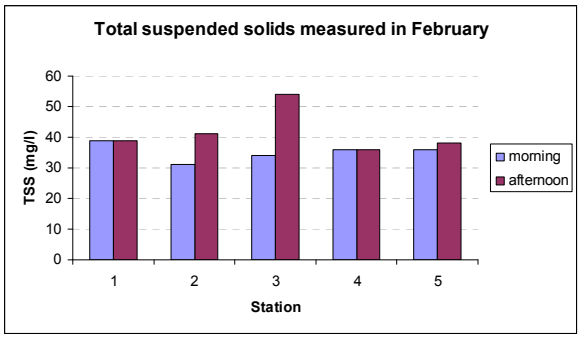


Figure 3.3a. Comparison between morning and afternoon TSS concentration of the Lake water in February

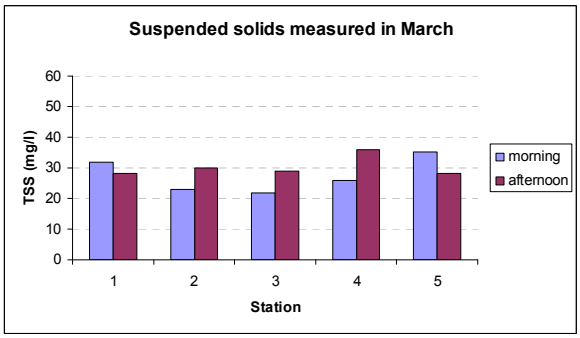


Figure 3.3b. Comparison between morning and afternoon TSS concentration of the Lake water in March

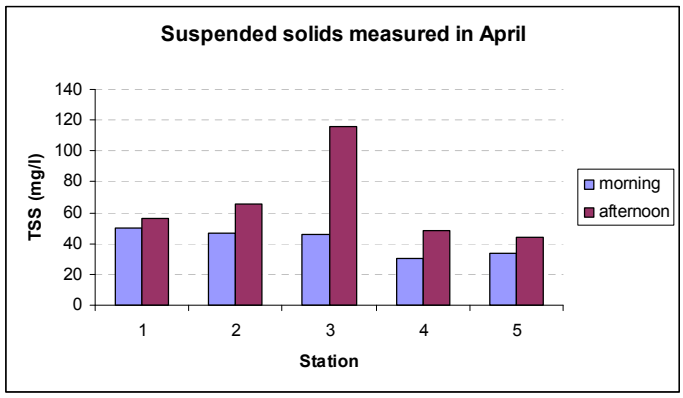


Figure 3.3c. Comparison between morning and afternoon TSS concentration of the Lake water in April

Figure 3.3: Total suspended solids content of Ranomafana Lake water

Correlations between the two parameters (turbidity and TSS) are shown by the following figures.

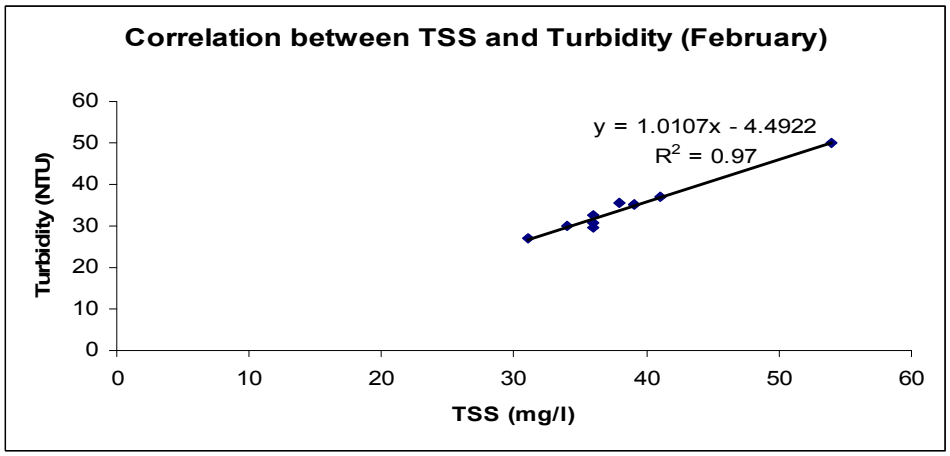


Figure 3.4a: Correlation between TSS and turbidity (data from February sampling)

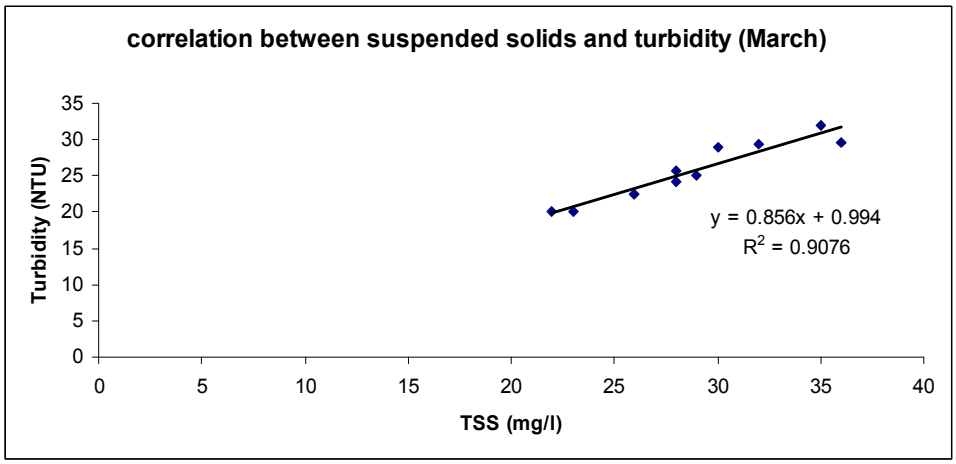


Figure 3.4b: Correlation between TSS and turbidity (data from March sampling)

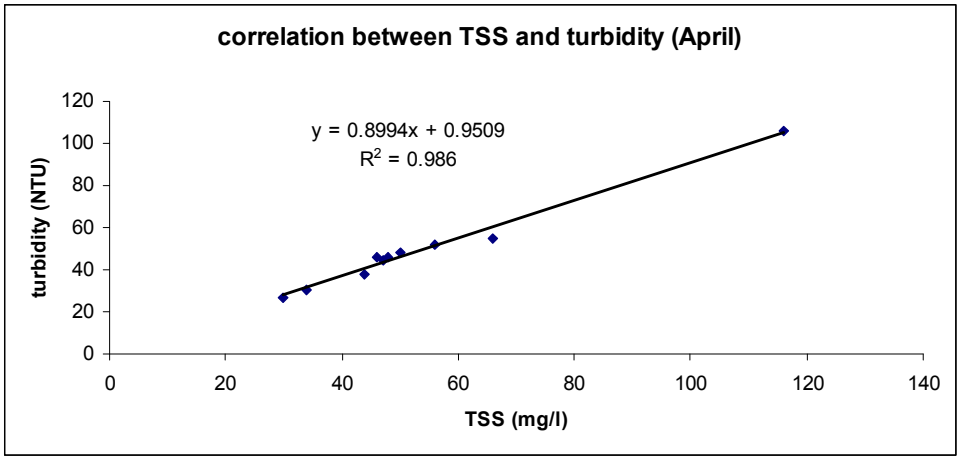


Figure 3.4c: Correlation between TSS and turbidity (data from April sampling)

Figures 3.4a - 3.4c show an average correlation coefficient of **R^2 = 0.9545 (0.907 – 0.986),** meaning that there is strong relationship between the two parameters. These correlations can be used to simplify the analyses as suspended solids can be estimated based on turbidity.

As shown in the Table 3.3, about 64.29% ± 22.46% of the determined total suspended solids are organic matter (VSS) in February. This percentage was 54.67% ± 8.04% in March and 75.89% ± 7.35% in April. They are mainly composed of algae.

Table 3.3: Suspended solids concentration at different stations in February, March and April

Station	February			March			April		
	TSS (mg/l)	VSS (mg/l)	%VSS	TSS (mg/l)	VSS (mg/l)	% VSS	TSS (mg/l)	VSS (mg/l)	%VSS
1	39	19.87	50.94	32	15.77	49.28	50	34.45	68.90
2	31	10.71	34.54	23	12.72	55.3	47	35.53	75.60
3	34	9.72	46.23	22	11.84	53.82	46	38.66	84.04
4	36	30.63	85.08	26	15.63	60.12	30	23.00	76.67
5	36	29.77	82.69	35	18.83	53.80	34	20.78	61.12

Table 3.3: Suspended solids concentration at different stations in February, March and April (continued)

Station	February			March			April		
1’	39	37.66	96.56	28	17.73	63.32	56	43.14	77.04
2’	41	33.63	82.02	30	18.72	62.40	66	56.76	86.00
3’	54	41.72	77.25	29	16.95	58.45	116	95.08	81.97
4’	36	14.70	40.83	36	19.74	54.83	48	34.74	72.38
5’	38	17.75	46.71	28	9.90	35.36	44	33.08	75.18
Mean			64.29			54.67			75.89
STDEV			22.46			8.04			7.35

Stations 1-5 are sampling in the morning and station 1’ – 5’ are sampling in the afternoon.

STDEV: Standard deviation.

Apart from the suspended solids, the total dissolved solids content (TDS) is also valuable to understand the lake functioning. It contributes to the water temperature stability throughout most of the hypolimniom zone (Thomas et. al, 1996). Those particles are those which pass through the filter and determined by subtracting the TSS from the total solids (TS). Table 3.4 shows the results of TDS.

Table 3.4: Total and dissolved solids concentration at different stations in February, March and April

Station	February			March			April		
	TS (mg/l)	TDS (mg/l)	%DVS	TS (mg/l)	TDS (mg/l)	%DVS	TS (mg/l)	TDS (mg/l)	%DVS
1	510	471	93.52	500	468	94.15	686	636	89.45
2	503	472	96.17	493	470	93.53	766	719	91.40
3	500	466	95.75	490	468	96.71	766	720	91.94
4	470	434	88.51	460	434	92.31	870	840	94.56
5	480	444	87.77	470	435	93.19	793	759	94.97
1’	523	484	90.51	513	485	95.07	863	807	89.72
2’	473	432	88.13	463	433	93.06	803	737	83.46
3’	533	479	89.39	523	494	95.45	943	827	76.23
4’	546	510	96.80	536	500	95.54	793	745	88.54
5’	466	428	94.62	456	428	96.73	816	772	89.66
Mean			92.12			94.57			88.99

Most quantity (>70%) of the dissolved solids is organic material (dissolved volatile solids – DVS) which can be used directly by microorganisms.

3. 3. Chemical characteristics of Ranomafana Lake water

3.3.1. Chemical characteristics related to inorganic matter

- **pH**

The pH measurements are presented in Figure 3.5.

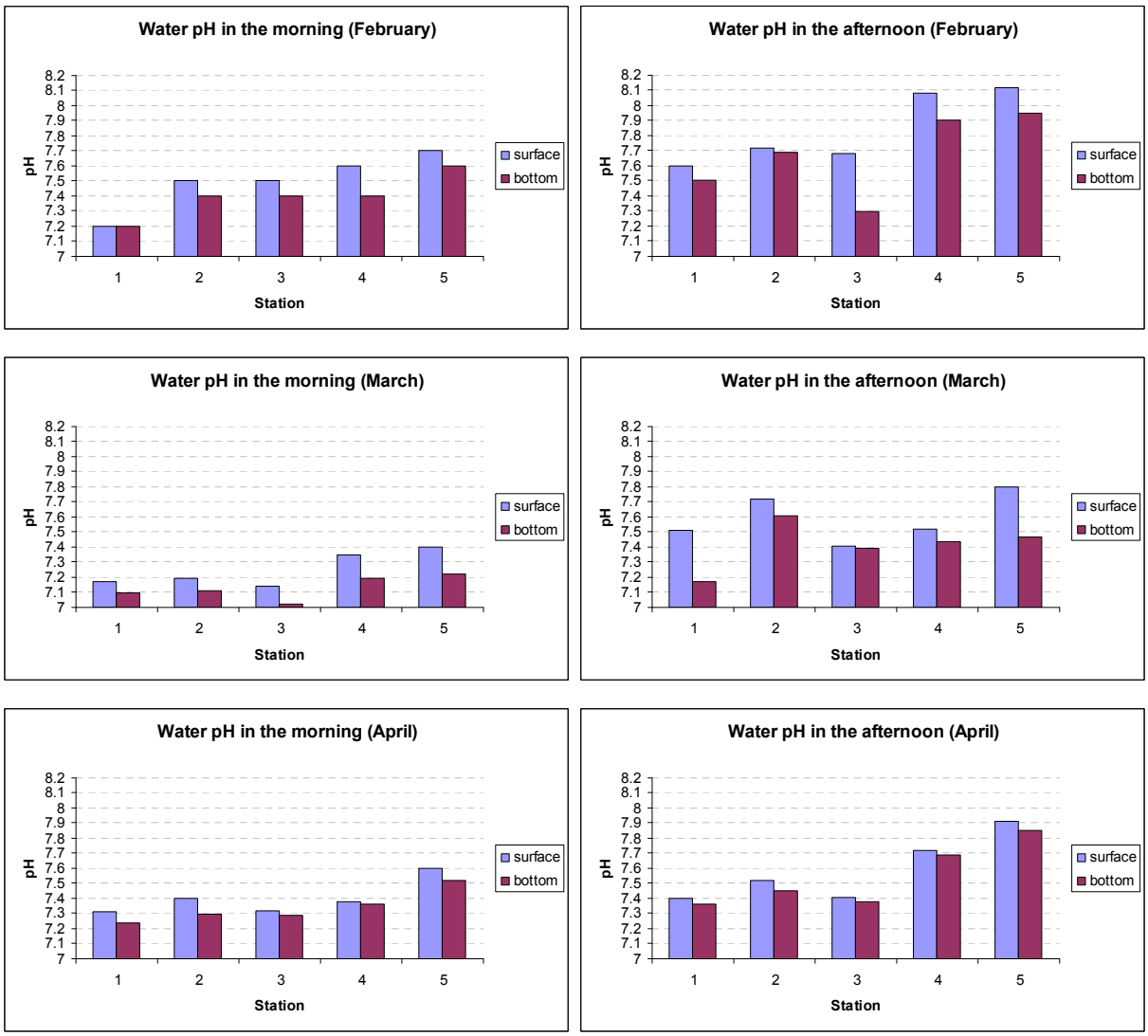


Figure 3.5: pH variation of Ranomafana Lake water

The lake Ranomafana water is slightly alkaline. During the sampling periods, the pH values varied from 7.17 to 8.12 in the surface and from 7.1 to 7.95 in the bottom. Higher pH at surface is due to more photosynthesis in that layer (more light). There was a small variation during the day and pH was lower in the morning compared to the afternoon. This is always due to photosynthesis during daytime.

- **Conductivity**

The conductivity of water is related to the concentration of ions and correlated with inorganic dissolved solids .

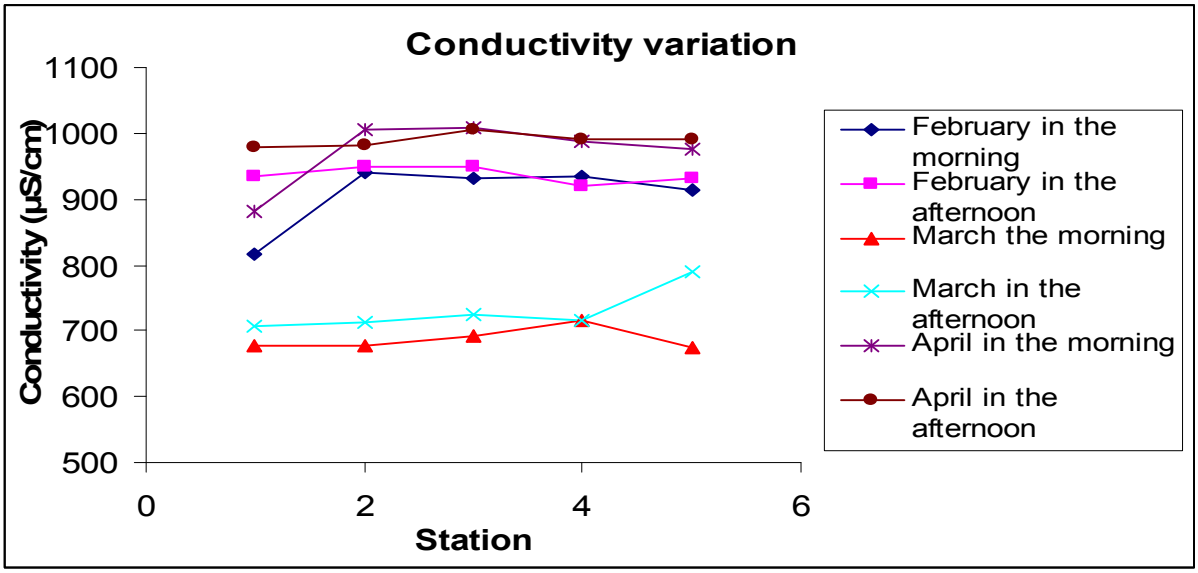


Figure 3.6: Conductivity of Ranomafana Lake water

We could not find any explanation for the low values in March but it could be due to dilution by rain.

3.3.2. Nutrient

- **Nitrogen content**

The total nitrogen concentration in the lake water varied from 7.6 mgN/l to 10.6 mgN/l in February; from 6.6 mg/ to 10.8 mg/l in March and from 6.3 mg/l to 12.1 mg/l in April with a peak concentration at station 3. It increased from the morning to the afternoon (Figure 3.7).

The water contains also a significient concentration of nitrates (NO_3^-):

- From 1.7mgN/l (≈7.4mg NO_3^-/l) to 2.1mgN/l (≈9.5mg NO_3^-/l) in the morning and from 2.1mgN/l (≈9.3mg NO_3^-/l) to 2.3mgN/l (≈10.6mg NO_3^-/l) in the afternoon in February (Figure 3.7a).
- From 2.2mgN/l (≈9.9mg NO_3^-/l) to 2.6mgN/l (≈11.8mg NO_3^-/l) in the morning and from 2.3mgN/l (≈10.3mg NO_3^-/l) to 3.3mgN/l (≈14.7mg NO_3^-/l) in the afternoon in March (Figure 3.7b).

- From 1.02mgN/l (≈4.5mg NO_3^-/l) to 1.6mgN/l (≈7.3mg NO_3^-/l) in the morning and from 1.4mgN/l (≈6.2mg NO_3^-/l) to 1.6mgN/l (≈7.2mg NO_3^-/l) in the afternoon in April (Figure 3.7c).

Nitrate results from the bacterial degradation of organic matter where nitrogen is released and converted to ammonia. The ammonia undergoes bacterial conversion, known as nitrification in aerobic conditions, producing nitrite and finally nitrate (Equations 1.2 & 1.3).

As the organic matters tend to sink into the bottom where they will be degraded and reduce the oxygen concentration in that layer (Equation 1.2).

The increase in nitrate concentration during the day indicates the ratio of its production compared to its utilization, which is reminiscent of the importance of the ammonification and nitrification in the lake. Nitrogen may also originate from atmosphere or from sediment.

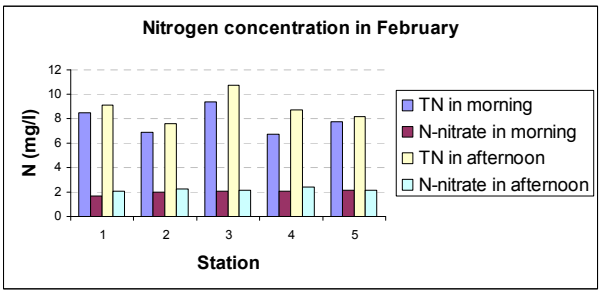


Figure 3.7a: Total nitrogen and nitrogen nitric in February

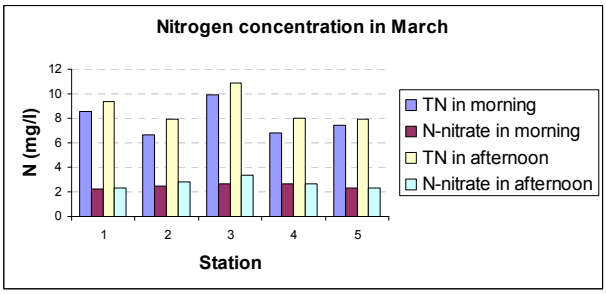


Figure 3.7b: Total nitrogen and nitrogen nitric in March

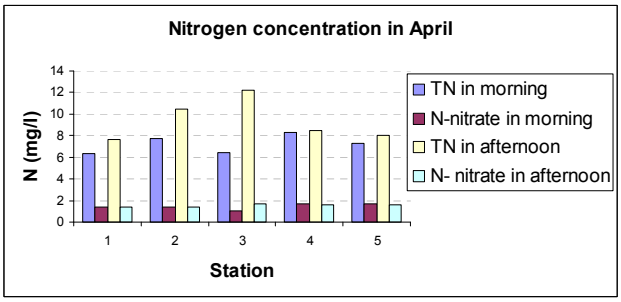


Figure 3.7c: Total nitrogen and nitrogen nitric in April

Figure 3.7: Nitrogen content of Ranomafana Lake water

- **Phosphorus content**

For Ranomafana Lake water, the total phosphorus concentration ranged from 0.94 mg/l to 2.23 mg/l in February; from 0.99 mg/l to 2.23 mg/l in March and from 0.94 mg/l to 3.85 mg/l in April. The concentration was always higher in the afternoon.

The total phosphorus (TP) concentration represents all form of phosphorus while the reactive phosphate is dissolved phosphorus, the only form of phosphorus that is directly used for the new cell synthesis. Figure 3.8 compares the fraction of the reactive phosphorus in the total phosphorus concentration.

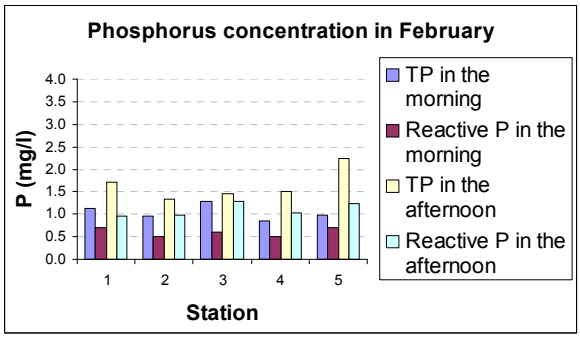


Figure 3.8a: Total phosphorus and reactive Phosphorus concentration in February

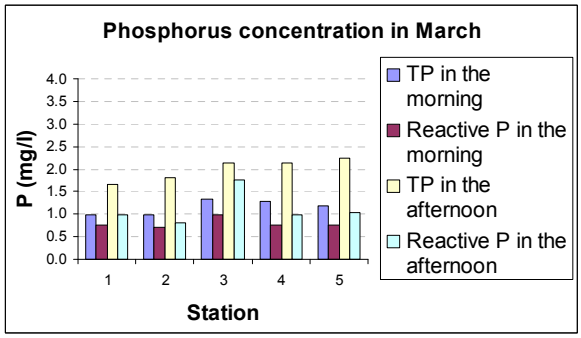


Figure 3.8b: Total phosphorus and reactive phosphorus concentration in March

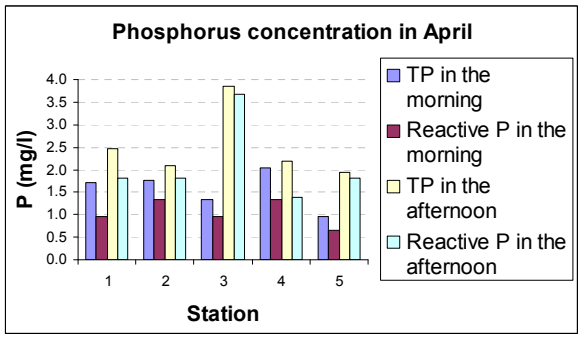


Figure 3.8c: Total phosphorus and reactive phosphorus concentration in April

Figure 3.8: Phosphorus content of Ranomafana Lake water

About 50% or more of the total phosphorus concentration in the lake water are reactive phosphates. The fraction varies: in February and March, the fraction of reactive phosphorus was higher in the morning and decreased in the afternoon. A possible explanation of this is that the new cell production increased along the day which took up a certain quantity of the reactive phosphates. In April however, the percentage augmented in the afternoon. What happened that sampling day was the water turbidity was higher which might limit the photosynthesis and cause the death of algae. The high percentage of orthophosphate in the afternoon is then probably due the release from microbial degradation of dead algae and release from the sediments.

3.3.3. Chemical characteristics related to organic matter

- **Dissolved oxygen**

The dissolved oxygen concentration in Ranomafana lake water increases from the morning to the afternoon and decline from the surface to the bottom region (Figure 3.9). The variation during the day relates to the sunlight intensity associated with the increased nutrient loads which power the photosynthesis process. Higher light intensity at the surface promotes more photosynthesis that produces oxygen.

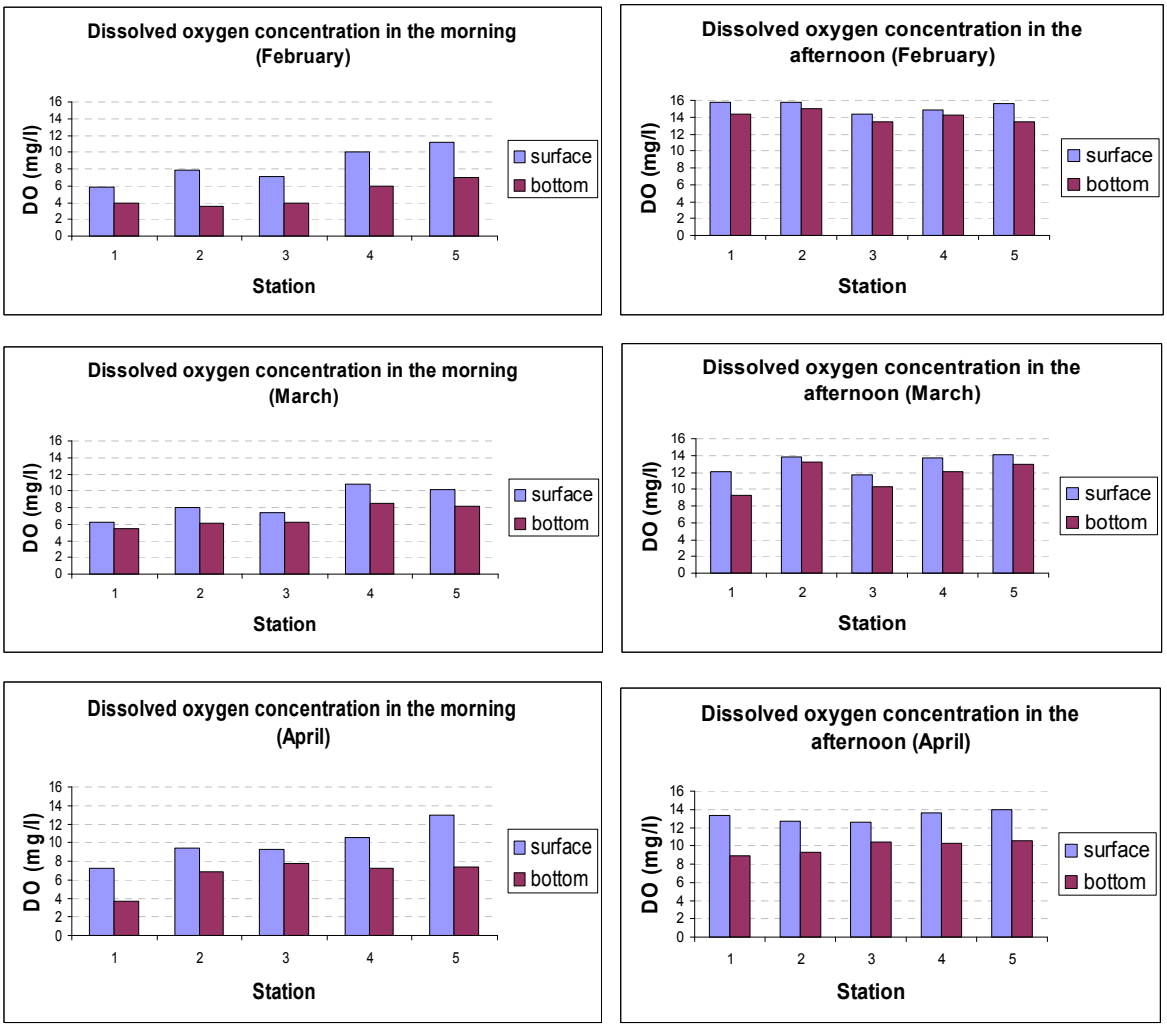


Figure 3.9: Dissolved oxygen content of Ranomafana Lake water

Concerning the decrease of the oxygen concentration from the surface to the bottom water, it can be explained by photosynthesis combined with the degradation of organic matters occurring at that depth.

The Table 3.6 shows the water depth (D) at each sampling point and the corresponding Secchi disk depth (SDD) following the depth (LD) into which light can reach.

Table 3.6: Lake water depth (D), Secchi disk depth (SDD) and depth (LD) into which light can reach.

Station	February			March		April	
morning	D (m)	SDD (m)	LD (m)	SDD (m)	LD (m)	SDD (m)	LD (m)
1	0.4	0.2	0.34	0.3	0.51	0.2	0.34
2	0.5	0.2	0.34	0.35	0.59	0.2	0.34
3	0.3	0.2	0.34	0.3	0.51	0.15	0.225
4	0.6	0.3	0.51	0.35	0.59	0.15	0.225
5	0.8	0.4	0.68	0.3	0.51	0.15	0.225
Afternoon							
1’	0.4	0.4	0.68	0.3	0.51	0.2	0.34
2’	0.5	0.4	0.68	0.3	0.51	0.2	0.34
3’	0.3	0.2	0.34	0.3	0.51	0.15	0.225
4’	0.6	0.4	0.68	0.3	0.51	0.2	0.34
5’	0.8	0.4	0.68	0.3	0.51	0.2	0.34

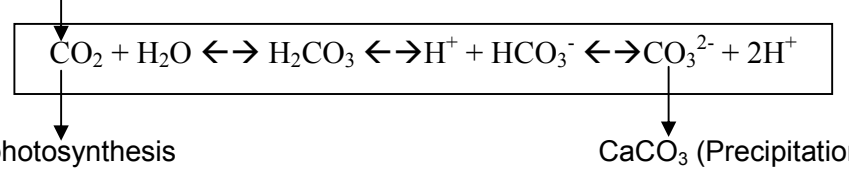
The Ranomafana Lake is shallow so light can more or less penetrate the total depth. However, at the depth where “bottom dissolved oxygen concentrations” were recorded (about 15 cm above the sediment bed); the zone is aphotic when light intensity is not so strong (such as in February and April). This fact causes an important decrease in dissolved oxygen in the bottom water since photosynthesis is significantly reduced.

- **Correlation between dissolved oxygen and pH**

According to Equation 3.1, photosynthesis influences the water pH as it removes CO_2 and thus increases pH.

Equation 3.1: The pH – Carbon dioxide - Bicarbonate system (Reynolds, 1984 in Christer Bronmark et al, 2005)

Atmosphere input and respiration



To photosynthesis $CaCO_3$ (Precipitation at pH>10)

When carbon dioxide (CO_2) is taken up by photosynthesis, free H^+ ions are associated with HCO_3^- and CO_3^{2-}, leading to fewer free H^+, and thereby a higher pH. That means, when the photosynthesis process occurs, oxygen concentration and pH increase hence the (medium) positive correlation shown in Figure 3.10.

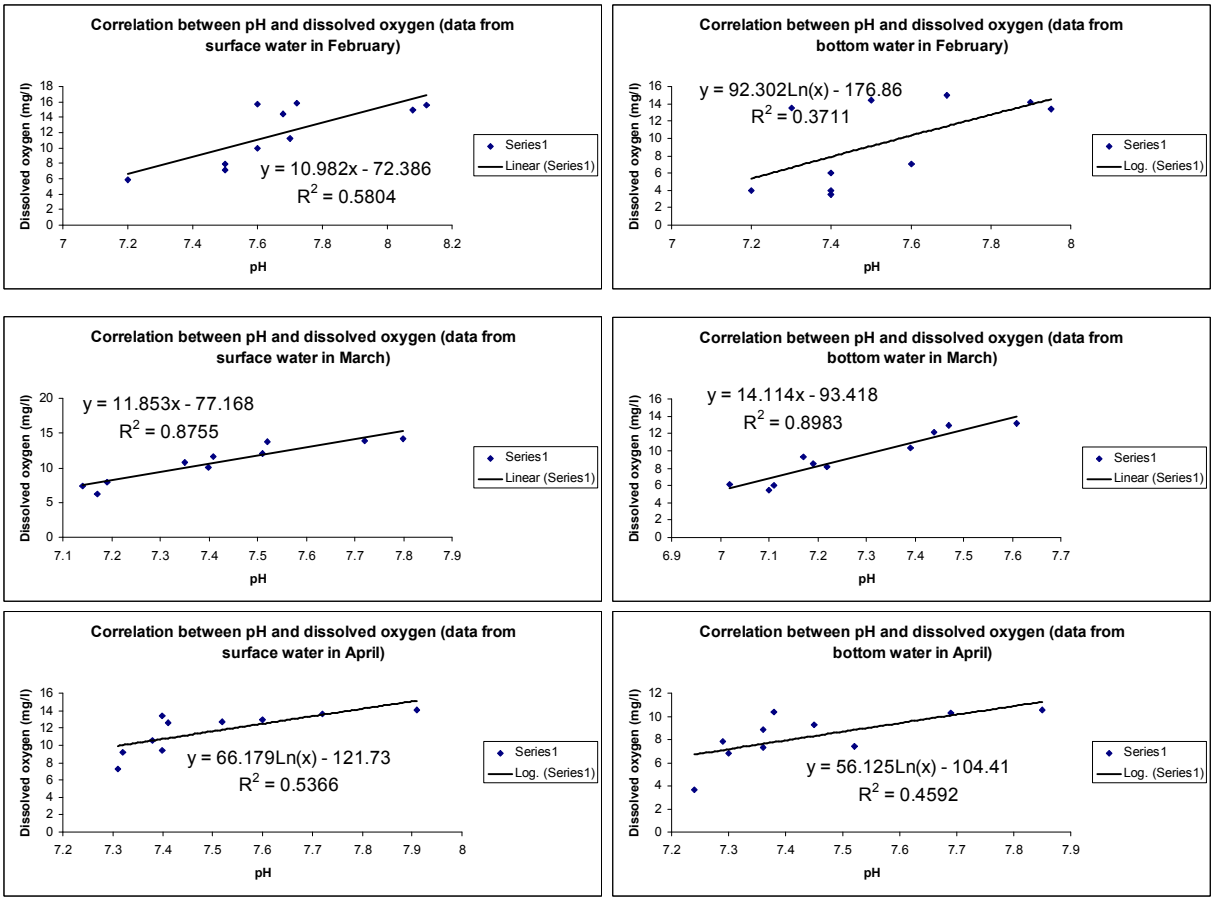
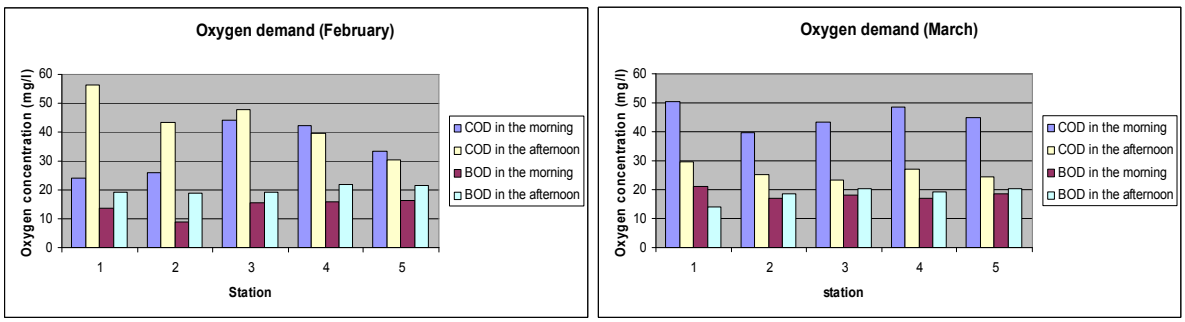


Figure 3.10: Relationship between pH and dissolved oxygen in Ranomafana Lake water.

- **Oxygen demand (COD and BOD)**



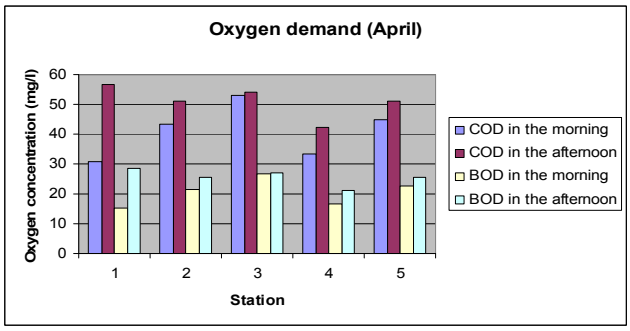


Figure 3.11: BOD and COD of Ranomafana Lake water

Referring to Figure 3.11, the BOD/COD ratio ranged from 0.3 to 0.7 in February, between 0.3 and 0.8 in March and between 0.3 to 0.5 in April.

For comparison, typical value of municipal wastewater BOD/COD ratio is between 0.3 and 0.8 (George Tchobanoglous, Franklin Louis Burton, H. David Stensel, Metcalf & Eddy, 2003). Therefore, we can conclude that the Ranomafana water lake is similar to municipal wastewater with regard to organic pollutants characteristics (biodegradability).

The increase of COD and BOD during the day is due to the primary production which yields organic matter.

3.4. Chlorophyll a concentration

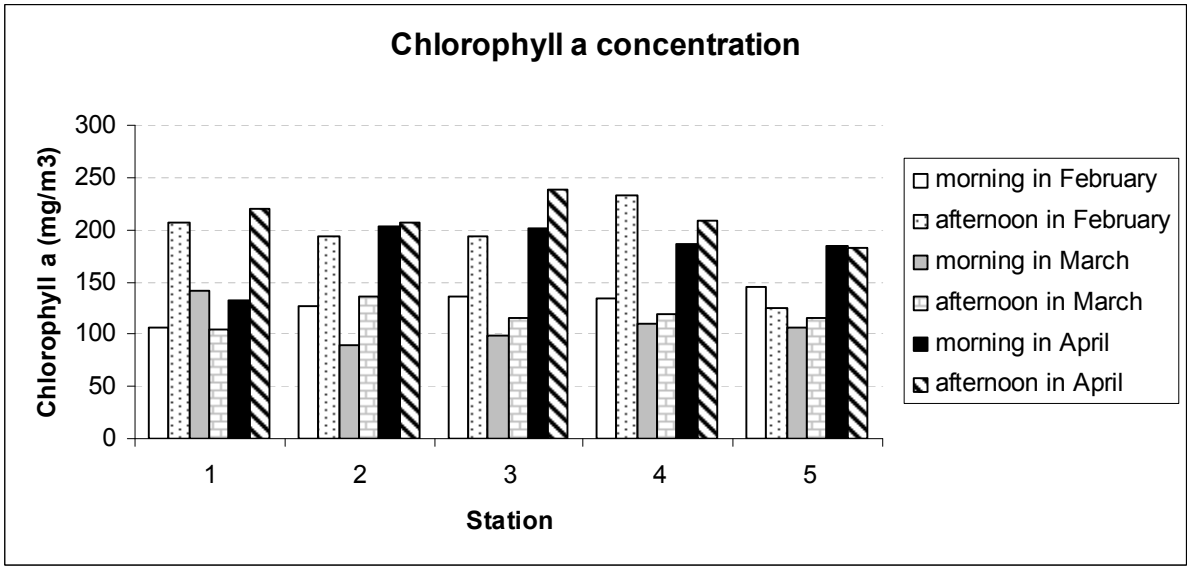


Figure 3.12: Chlorophyll a concentration in Ranomafana Lake water

Figure 3.12 shows that chlorophyll a concentration was higher in the afternoon. It can be explained by the variation of the light conditions: light intensity increases during the daytime and so photosynthesis does. That means algae are more abundant in the afternoon compared to the

morning. This fact also contributed to the increase of water turbidity (Figure 3.2) and the increase of TSS (Figure 3.3).Low chlorophyll a concentration was recorded in March which means low algal productivity. This also is the reason why turbidity and TSS concentration were the lowest that month (Figures 3.2b and 3.3b).

3. 5. General discussion

- **Stratification and classification of Ranomafana Lake**

Comparing the mean depth (0.55m) with the depth at which light can reach (0.225m – 0.68m depending on the sunlight intensity), the lake can be classified as shallow. However, the existence of a deeper zone (zone of 0.8m depth) that is not totally reached by sunlight allows us to deduce that Ranomafana Lake, in terms of light penetration, can be considered as a deep lake, but it is getting shallower due to the sedimentation and eutrophication process.

The small variation of certain parameters such as pH and dissolved oxygen concentration with depth means that stratification does not occur in Ranomafana Lake water.

- **Processes occurring in Ranomafana Lake Water**

Photosynthesis occurs at the photic zone. Light promotes the growth of algae in that zone. When algae die, they settles to the bottom and are degraded by bacteria.

The measurement of dissolved oxygen throughout the Ranomafana Lake water column shows that the water is aerobic from top to bottom; the presence of oxygen molecules allows the ammnonification and nitrification processes to take place at any depth. Algal growth mainly causes the increase of dissolved oxygen concentration in water as well as its pH while ammonification and nitrification reduce the oxygen and lower the water pH.

The increase of nitrate and phosphate concentrations in the water column along the day allows us to make assumption that there is release of those nutrients from sediments in addition to influent wastewater.

- **Water quality of Ranomafana Lake**

With regards to total solids, Ranomafana Lake water is like diluted domestic wastewater. Table 3.6 illustrates its composition expressed by its organic contaminants content.

Table 3.6: Comparison between organic contaminants in Ranomafana Lake water and in domestic wastewater

Compound	Concentration range (mg/l)		
	Ranomafana Lake water	Domestic wastewater	Typical concentration of domestic wastewater
Total solids	456 - 943	300 -1200	
TSS	18 - 116	100 -350	250
BOD	8.8 – 36.6	110 – 400	250
COD	23 - 80	250 – 1000	500
Total Nitrogen	6.3 – 12.1	20 – 85	45
Nitrate + nitrite	0.6 – 2.8	0	
Total phosphorus	0.9 – 3.8	3 - 12	8
Reactive phosphorus	0.5 – 1.8	4 – 5	6

The Ranomafana Lake water contains more dissolved and organic solids than inorganic solids. However, the values of the parameters are much lower compared to that of the domestic wastewater because of dilution and natural treatment (auto purification).

- **Trophic status of Ranomafana Lake**

On the basis of the values of TN (from 6373µg/l to 12186µg/l), TP (ranging from 849µg/l to 3852µg/l), transparency (Secchi Disk Depth ranging between 0.15m and 0.4m), and the chlorophyll a concentration (88mg/m^3 to 238mg/m^3), the lake can be classified as hypereutrophic (Tables 1.1 &1.2).

The Lake is gradually getting filled up by sediment due to the high productivity; also macrophytes grow in the shallow zone. Those facts indicate a high level of eutrophication.

The eutrophication and sedimentation occur in all of the lake but in its North West part, they are important. This is probably because of the presence of a main inlet in this North West part. Sediments have also become dry landing that part. Besides, the contaminant spreading is so slow, leading to the accumulation of pollutants and sediments in the North – West part. So, we can deduce that, horizontally, Ranomafana Lake water is not well mixed.

CONCLUSION

Located in the tropical zone, Ranomafana Lake lies on a surface area of 14Ha. The drainage area is about 125Ha and includes habitation and agricultural areas. The average depth is 0.55m and the water volume is around 7700m3. The sediment thickness is more than 1m. Two main inlets carry wastewater into the Lake: the North West inlet and the North East inlet. The outlet flow is very low even insignificant.

Water quality characterization of the Lake was carried out after monthly sampling in February, March and April. Tested parameters were temperature, pH, turbidity, Secchi disk depth, conductivity, solids, dissolved oxygen, oxygen demand (BOD and COD), nutrient and chlorophyll a.

Generally, those parameters showed variation within sampling stations. Peak values were recorded at the station located downstream the North West inlet. Also, for all stations, parameters values were higher in the afternoon compared to the morning. And similarly to all lake, weather affects Ranomafana Lake water quality: temperature changes within sunlight intensity; the difference from morning temperature and afternoon temperature was about 2°C. Turbidity, suspended solids and Secchi disk depth varied after run off loading. This later increases the nutrient input as well.

As a shallow lake, photosynthesis can occur almost throughout the depth in Ranomafana Lake. Hence, the water column is aerobic from top to bottom but the concentration of dissolved oxygen decreases with the depth, the same for pH. The presence of oxygen combined with the high content of dissolved organic matter in the lake promotes organic degradation and nitrification process.

To sum up, the Ranomafana Lake is getting shallower. Its water can be compared to a diluted untreated wastewater with regard to its solids content, the BOD and the COD.

According to the results, the main problems of the Lake concern its high nutrient concentration and resulting in high algae growth with a high chlorophyll a concentration compared to the nutrient and chlorophyll that water lakes of different use have. The

sedimentation, occurring in the North West part and at its bottom, also represents a problem. And based on the value of water quality parameters such as pH, total phosphorus, total nitrogen, water transparency, total organic carbon and chlorophyll a, Ranomafana Lake is classified as hypereutrphic.

Recommendations:

The remediation methods for Ranomafana Lake should focus on the reduction of the nutrient level in the lake water and the reduction of the algae concentration.

- Reduction of nutrient level: it can be achieved by reducing the nutrient loads and by increasing their uptake from the lake water. Treatment of water prior to their discharge into the lake is then recommended especially for the wastewater from the North West inlet. In addition, it can be a solution to reduce the number of inlets. For that the watershed areas need to be managed and all wastewater evacuation channels need to be conducted in one place for treatment before their discharge into the lake.

- Increasing the nutrient uptake in water lake body consists of promoting the algae growth. Thus, it is necessary to improve the other conditions controlling the photosynthesis such as light penetration into water. Algae harvesting is then suggested to clarify the water surface (to reduce its turbidity). Moreover, suspended solids removal upstream the inlet is needed. Increasing the gazing capacity of the fish population in the lake is also another option. It might include introduction of new planktonophage fish species which live on algae.

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Appendix 1: Collected data in February 2009

1/ Results from in-field measurement

Parameters	Latitude	Longitude	Sampling hour	Depth (m)	Secchi disk depth	Temperature °C	pH		Conductivity (µS/cm)	Turbidity	Dissolved oxygen (mg/l)	
samples			27.02.2009		(m)	surface	surface	bottom	surface	FTU	surface	bottom
Morning												
1	19° 52' 148" S	47° 01' 877" E	8h40	0.4	0.2	24.5	7.2	7.2	815	35.29	5.9	4
2	19° 52' 196" S	47° 01' 861" E	9h	0.5	0.2	25	7.5	7.4	940	27.08	7.9	3.5
3	19° 52' 190" S	47° 01' 813" E	9h12	0.3	0.2	25	7.5	7.4	933	30.03	7.1	4
4	19° 52' 260" S	47° 01' 826" E	9h30	0.6	0.3	25	7.6	7.4	935	29.52	10	6
5	19° 52' 345" S	47° 01' 817" E	9h45	0.8	0.4	25.8	7.7	7.6	915	30.9	11.2	7
Afternoon												
1'	19° 52' 148" S	47° 01' 877" E	15h20	0.4	0.4	26.3	7.6	7.5	935	35.17	15.7	14.4
2'	19° 52' 196" S	47° 01' 861" E	15h45	0.5	0.4	26.1	7.72	7.69	950	36.93	15.8	14.95
3'	19° 52' 190" S	47° 01' 813" E	16h	0.3	0.2	25.9	7.68	7.3	950	49.87	14.4	13.5
4'	19° 52' 260" S	47° 01' 826" E	16h30	0.6	0.4	26	8.08	7.9	921	32.66	14.9	14.2
5'	19° 52' 345" S	47° 01' 817" E	17h10	0.8	0.5	26.3	8.12	7.95	932	35.73	15.6	13.4

2/ Solids

- Suspended solids

Samples	mf (g)	V (ml)	m(f + s) after evaporation (g)	TSS (mg/l)	m(f + s) after ignition (g)	1% of mf	m(f+s) + 1%mf	VSS (mg/l)
1	0.0913	100	0.0952	39.00	0.0923	0.000913	0.093213	19.87
2	0.0929	100	0.096	31.00	0.094	0.000929	0.094929	10.71
3	0.0928	100	0.0962	34.00	0.0937	0.000928	0.094628	15.72
4	0.0937	100	0.0973	36.00	0.0933	0.000937	0.094237	30.63
5	0.0923	100	0.0959	36.00	0.092	0.000923	0.092923	29.77
1'	0.0934	100	0.0973	39.00	0.0926	0.000934	0.093534	37.66
2'	0.0937	100	0.0978	41.00	0.0935	0.000937	0.094437	33.63
3'	0.0928	100	0.0982	54.00	0.0931	0.000928	0.094028	41.72
4'	0.093	100	0.0966	36.00	0.0942	0.00093	0.09513	14.70
5'	0.0925	100	0.0963	38.00	0.0936	0.000925	0.094525	17.75

- Total solids

Samples	mp (g)	V (ml)	mp after evaporation 24h	TS (mg/l)	mp after ignition 1h	TVS (mg/l)	TDS (mg/l)
1	36.8167	30	36.8320	510.00	36.8228	306.67	471.00
2	45.6447	30	45.6598	503.33	45.6514	280.00	472.33
3	25.8632	30	25.8782	500.00	25.8671	370.00	466.00
4	28.9359	30	28.9500	470.00	28.942	266.67	434.00
5	27.0136	30	27.0280	480.00	27.0207	243.33	444.00
1'	28.1631	30	28.1788	523.33	28.1669	396.67	484.33
2'	28.1582	30	28.1724	473.33	28.1639	283.33	432.33
3'	25.5630	30	25.5790	533.33	25.5672	393.33	479.33
4'	27.3776	30	27.3940	546.67	27.3802	460.00	510.67
5'	26.4618	30	26.4758	466.67	26.4659	330.00	428.67

3/ Oxygen demand

- Biochemical oxygen demand (BOD)

Samples	To (mg/l)	T5(mg/l)	To - T5	Ve (ml)	F = Vt/Ve	F-1	BOD5
Blank 1	8.69	8.07	0.62	0			**BOD5= F(To-T5)-(F-1)(Do-D5)**
Blank 2	8.66	7.68	0.98	0			
1_40	8.63	6.17	2.46	40	8.25	7.25	14.50
1_70	8.6	5.16	3.44	70	4.71	3.71	13.25
2_40	8.64	7.26	1.38	40	8.25	7.25	5.59
2_70	8.62	5.43	3.19	70	4.71	3.71	12.07
3_40	8.54	5.60	2.94	40	8.25	7.25	18.46
3_70	8.64	5.35	3.29	70	4.71	3.71	12.54
4_40	8.51	5.71	2.80	40	8.25	7.25	17.30
4_70	8.58	4.93	3.65	70	4.71	3.71	14.24
5_40	8.52	5.57	2.95	40	8.25	7.25	18.54
5_70	8.6	5.04	3.56	70	4.71	3.71	13.81
1'_40	8.5	5.22	3.28	40	8.25	7.25	21.26
1'_70	8.57	4.26	4.31	70	4.71	3.71	17.35

2'_40	8.49	5.21	3.28	40	8.25	7.25	21.26
2'_70	8.49	4.31	4.18	70	4.71	3.71	16.73
3'_40	8.48	5.04	3.44	40	8.25	7.25	22.58
3'_70	8.48	4.44	4.04	70	4.71	3.71	16.07
4'_40	8.47	4.66	3.81	40	8.25	7.25	25.63
4'_70	8.47	4.00	4.47	70	4.71	3.71	18.10
5'_40	8.42	4.63	3.79	40	8.25	7.25	25.47
5'_70	8.44	4.14	4.30	70	4.71	3.71	17.30

With Vt = 330ml

- COD

Samples	Volume (V2) of (NH4)2Fe(SO4)2 used (ml)	C [(NH4)2Fe(SO4)2] (mol/l) = 1.2/ V	COD = 8000*c(V1-V2)/Vo
blanc froid (V)	10.42	0.12	
B (V1)	8.56	0.12	
1	8.3	0.12	23.95
2	8.28	0.12	25.80
3	8.08	0.12	44.22
4	8.1	0.12	42.38
5	8.2	0.12	33.17
B' (V'1)	8.52	0.12	
1'	7.91	0.12	56.20
2'	8.05	0.12	43.30
3'	8	0.12	47.91
4'	8.09	0.12	39.62
5'	8.19	0.12	30.40

With Vo = 10ml (tested volume of sample)

4/ Nutrient

- Phosphorus

	Reactive P		Total P	
Station	Absorbance	Conc-P (mg/l)	absorbance	Conc-P (mg/l)
Morning				
1	0.016	0.706	0.025	1.135
2	0.012	0.516	0.021	0.945
3	0.014	0.611	0.028	1.278
4	0.012	0.516	0.019	0.849
5	0.016	0.706	0.022	0.992
Afternoon				
1	0.021	0.945	0.037	1.707
2	0.022	0.992	0.029	1.326
3	0.028	1.278	0.032	1.469
4	0.023	1.040	0.033	1.517
5	0.027	1.231	0.048	2.232

- Nitrogen

Station	Nitrate			Nitrite			NTK		**TN**
Morning	absorbance	N- NO3 (mg/l)	NO3 (mg/l)	absorbance	N-NO2 (µg/l)	NO2 (µg/l)	V (H2SO4) used (ml)	NTK (mg/l)	N (mg/l)
1	0.517	1.691	**7.484**	0.320	101.350	332.877	2.8	6.720	8.512
2	0.601	1.966	**8.702**	0.297	94.041	308.870	2.0	4.800	6.860
3	0.638	2.087	**9.239**	0.333	105.481	346.446	3.0	7.200	9.393
4	0.627	2.051	**9.079**	0.325	102.939	338.096	1.9	4.560	6.714
5	0.654	2.139	**9.471**	0.287	90.863	298.432	2.3	5.520	7.750
Afternoon									
1	0.643	2.103	**9.311**	0.215	67.981	223.279	2.9	6.960	9.131
2	0.692	2.264	**10.022**	0.199	62.896	206.578	2.2	5.280	7.607
3	0.672	2.198	**9.732**	0.291	92.134	302.607	3.5	8.400	10.691
4	0.731	2.392	**10.587**	0.265	83.871	275.468	2.6	6.240	8.716
5	0.649	2.123	**9.398**	0.234	74.019	243.111	2.5	6.000	8.197

5/ Chlorophyll a

Stations	1	2	3	4	5	1'	2'	3'	4'	5'
Absorbance at 663a	0.02	0.546	0.39	0.378	0.411	0.595	0.514	0.529	0.482	0.413
Absorbance at 750a	0.313	0.2	0.009	0.003	0.026	0.065	0.028	0.038	0.019	0.034
correction 663a	0.293	0.346	0.381	0.375	0.385	0.53	0.486	0.491	0.463	0.379
Absorbance at 750b	0.018	0.196	0.008	0.002	0.023	0.075	0.027	0.041	0.07	0.009
Absorbance at 665b	0.211	0.424	0.262	0.252	0.272	0.412	0.331	0.35	0.316	0.272
correction 665b	0.193	0.228	0.254	0.25	0.249	0.337	0.304	0.309	0.246	0.263
chlorophyll a (mg/m3)	106.92	126.1656	135.7884	133.65	145.4112	206.3556	194.5944	194.5944	232.0164	124.0272
phaeophytin a (mg/m3)	37.52892	44.47872	54.31536	53.46	40.95036	45.86868	32.93136	36.67356	-47.9002	72.81252

Appendix 2: Collected data in March 2009

1/ Results from in-field measurement

Parameters	Latitude	Longitude	Sampling hour	Depth (m)	Secchi disk depth	Temperature °C	pH		Conductivity (uS/cm)	Turbidity	Dissolved oxygen (mg/l)	
Samples					(m)	surface	surface	bottom	surface	FTU	surface	bottom
1	19° 52' 148" S	47° 01' 877" E	8h45	0.4	0.3	24	7.17	7.1	676	29.29	6.24	5.43
2	19° 52' 196" S	47° 01' 861" E	9h20	0.5	0.35	24.8	7.19	7.11	677	20.08	7.97	6.06
3	19° 52' 190" S	47° 01' 813" E	9h38	0.3	0.3	24.3	7.14	7.02	693	20.03	7.34	6.18
4	19° 52' 260" S	47° 01' 826" E	10h03	0.6	0.35	25.07	7.35	7.19	715	22.52	10.82	8.54
5	19° 52' 345" S	47° 01' 817" E	10h22	0.8	0.3	26.2	7.4	7.22	673	31.9	10.13	8.12
1'	19° 52' 148" S	47° 01' 877" E	13h45	0.4	0.3	28	7.51	7.17	707	24.17	12.05	9.29
2'	19° 52' 196" S	47° 01' 861" E	13h55	0.5	0.3	27.9	7.72	7.61	714	28.93	13.88	13.19
3'	19° 52' 190" S	47° 01' 813" E	14h17	0.3	0.3	27.9	7.41	7.39	725	25	11.68	10.33
4'	19° 52' 260" S	47° 01' 826" E	14h30	0.6	0.3	27.4	7.52	7.44	716	29.66	13.69	12.11
5'	19° 52' 345" S	47° 01' 817" E	14h52	0.8	0.3	27.4	7.8	7.47	789	25.73	14.13	12.91

2/ Solids

- Suspended solids

Samples	V (ml)	mf (g)	m(f + s) (g)	TSS (mg/l)	mf after ignition (g)	1% of mf	m + 1%mf	VSS (mg/l)
1	100	0.0923	0.0955	32.00	0.093	0.000923	0.0939	15.77
2	100	0.0928	0.0951	23.00	0.0929	0.000928	0.0938	12.72
3	100	0.0916	0.0938	22.00	0.0917	0.000916	0.0926	11.84
4	100	0.0937	0.0963	26.00	0.0938	0.000937	0.0947	15.63
5	100	0.0917	0.0952	35.00	0.0924	0.000917	0.0933	18.83
1'	100	0.0927	0.0955	28.00	0.0928	0.000927	0.0937	17.73
2'	100	0.0928	0.0958	30.00	0.093	0.000928	0.0939	18.72
3'	100	0.0905	0.0934	29.00	0.0908	0.000905	0.0917	16.95
4'	100	0.0926	0.0962	36.00	0.0933	0.000926	0.0942	19.74
5'	100	0.0910	0.0938	28.00	0.0919	0.00091	0.0928	9.90
nw	100	0.0918	0.0981	63.00	0.0936	0.000918	0.0945	35.82
ne	100	0.0925	0.0943	18.00	0.0924	0.000925	0.0933	9.75

- Total solids

Samples	mp (g)	V (ml)	mp after evaporation 24h	TS (mg/l)	mp after ignition 1h	TVS (mg/l)	TDS
1	41.0981	30	41.1131	500.00	41.105	270.00	468.00
2	42.7034	30	42.7182	493.33	42.7123	196.67	470.33
3	51.0948	30	51.1095	490.00	51.0987	360.00	468.00
4	38.3808	30	38.3946	460.00	38.3885	203.33	434.00
5	27.0136	30	27.0277	470.00	27.0194	276.67	435.00
1'	28.1631	30	28.1785	513.33	28.1677	360.00	485.33
2'	25.5542	30	25.5681	463.33	25.56	270.00	433.33
3'	27.3776	30	27.3933	523.33	27.3821	373.33	494.33
4'	25.8863	30	25.9024	536.67	25.8891	443.33	500.67
5'	26.4449	30	26.4586	456.67	26.4495	303.33	428.67

3/ Oxygen demand

- Biochemical oxygen demand (BOD)

Samples	To (mg/l)	T5(mg/l)	To - T5	Ve (ml)	F = Vt/Ve	F-1	BOD5
B	8.25	7.35	0.90	0			**BOD5= F(To-T5)-(F-1)(Do-D5)**
B'	8.25	7.17	1.08	0			
1_40	8.13	4.33	3.80	40	8.25	7.25	24.17
1_70	8.08	3.50	4.58	70	4.71	3.71	17.91
2_40	8.12	4.88	3.24	40	8.25	7.25	19.55
2_70	8.04	4.18	3.86	70	4.71	3.71	14.52
3_40	8.14	4.75	3.39	40	8.25	7.25	20.79
3_70	8.07	3.98	4.09	70	4.71	3.71	15.60
4_40	8.18	5.12	3.06	40	8.25	7.25	18.07
4_70	8.15	3.98	4.17	70	4.71	3.71	15.98
5_40	8.16	5.02	3.14	40	8.25	7.25	18.73
5_70	8.15	3.42	4.73	70	4.71	3.71	18.62
1'_40	8.17	5.70	2.47	40	8.25	7.25	13.20
1'_70	8.16	4.18	3.98	70	4.71	3.71	15.09
2'_40	8.13	4.75	3.38	40	8.25	7.25	20.71
2'_70	8.01	3.69	4.32	70	4.71	3.71	16.69

3'_40	8.24	4.63	3.61	40	8.25	7.25	22.61
3'_70	8.25	3.69	4.56	70	4.71	3.71	17.82
4'_40	8.19	4.73	3.46	40	8.25	7.25	21.37
4'_70	8.17	3.80	4.37	70	4.71	3.71	16.92
5'_40	8.35	4.73	3.62	40	8.25	7.25	22.69
5'_70	8.47	3.86	4.61	70	4.71	3.71	18.06
NW40	7.56	1.10	6.46	40	8.25	7.25	46.12
NW70	7.13	0.60	6.53	70	4.71	3.71	27.11
NE40	7.41	2.76	4.65	40	8.25	7.25	31.19
NE70	7.04	0.82	6.22	70	4.71	3.71	25.65

With Vt = 330ml

- COD

Samples	Volume (V2) of (NH4)2Fe(SO4)2 used (ml)	C [(NH4)2Fe(SO4)2] (mol/l) = 1.2/ V	COD = 8000*c(V1-V2)/Vo
Blanc froid (V)	10.67	0.11	
B (V1)	8.78	0.11	
1	8.22	0.11	50.38
2	8.34	0.11	39.59
3	8.3	0.11	43.19
4	8.24	0.11	48.58
5	8.28	0.11	44.99
B' (V'1)	8.94	0.11	
1'	8.61	0.11	29.69
2'	8.66	0.11	25.19
3'	8.68	0.11	23.39
4'	8.64	0.11	26.99
5'	8.67	0.11	24.29
nw	8.04	0.11	80.97
ne	8.25	0.11	62.08

With Vo = 10ml (tested volume of sample)

4/ Nutrient

- Phosphorus

	Reactive P		Total P	
Station	Absorbance	Conc-P (mg/l)	absorbance	Conc-P (mg/l)
Morning				
1	0.017	0.754	0.022	0.992
2	0.016	0.706	0.022	0.992
3	0.022	0.992	0.029	1.326
4	0.017	0.754	0.028	1.278
5	0.017	0.754	0.026	1.183
Afternoon				
1	0.022	0.992	0.036	1.660
2	0.018	0.802	0.039	1.803
3	0.038	1.755	0.046	2.136
4	0.022	0.992	0.046	2.136
5	0.023	1.040	0.048	2.232
nw	0.028	1.278	0.043	1.993
ne	0.023	1.040	0.027	1.231

- Nitrogen

Station	**Nitrate**			**Nitrite**			**NTK**		**TN**
Morning	absorbance	**N- NO3 (mg/l)**	NO3 (mg/l)	absorbance	N-NO2 (µg/l)	NO2 (µg/l)	V (H2SO4) used (ml)	**NTK (mg/l)**	N (mg/l)
1	0.686	**2.244**	**9.935**	0.240	75.926	249.374	2.6	**6.240**	8.560
2	0.749	**2.451**	**10.848**	0.287	90.863	298.432	1.7	**4.080**	6.621
3	0.802	**2.624**	**11.616**	0.313	99.125	325.570	3.0	**7.200**	9.923
4	0.813	**2.660**	**11.776**	0.314	99.443	326.614	1.7	**4.080**	6.840
5	0.719	**2.352**	**10.413**	0.262	82.918	272.337	2.1	**5.040**	7.475
1’	0.712	**2.329**	**10.311**	0.197	62.261	204.491	2.9	**6.960**	9.352
2’	0.867	**2.837**	**12.559**	0.192	60.672	199.272	2.1	**5.040**	7.938
3’	1.015	**3.322**	**14.705**	0.279	88.320	290.081	3.1	**7.440**	10.850
4’	0.801	**2.621**	**11.602**	0.255	80.693	265.030	2.2	**5.280**	7.982
5’	0.713	**2.333**	**10.326**	0.212	67.028	220.147	2.3	**5.520**	7.920
nw	2.640	**8.644**	38.265	0.021	6.328	20.783	1.7	**4.080**	12.731
ne	0.271	**0.885**	3.918	0.480	152.198	499.884	2.9	**6.960**	7.997

5/ Chlorophyll a

Stations	1	2	3	4	5	1'	2'	3'	4'	5'
Absorbance at 663a	0.384	0.256	0.314	0.359	0.331	0.284	0.377	0.339	0.334	0.324
Absorbance at 750a	0.006	0.003	0.045	0.043	0.025	0.011	0.035	0.031	0.016	0.014
correction 663a	0.378	0.253	0.269	0.316	0.306	0.273	0.342	0.308	0.318	0.31
Absorbance at 750b	0	0.008	0.043	0.052	0.019	0.012	0.034	0.03	0.024	0.016
Absorbance at 665b	0.245	0.178	0.219	0.265	0.225	0.187	0.248	0.23	0.231	0.218
correction 665b	0.245	0.17	0.176	0.213	0.206	0.175	0.214	0.2	0.207	0.202
chlorophyll a (mg/m3)	142.2036	88.7436	99.4356	110.1276	106.92	104.7816	136.8576	115.4736	118.6812	115.4736
phaeophytin a (mg/m3)	41.1642	38.4912	32.28984	49.29012	47.25864	26.1954	23.30856	34.2144	36.24588	35.71128

Appendix 3: Collected data in April 2009

1/ Results from in-field measurement

Parameters	Latitude	Longitude	Sampling hour	Depth (m)	Secchi disk depth	Temperature °C	pH		Conductivity (uS/cm)	Turbidity	Dissolved oxygen (mg/l)	
Samples			22.04.2009		(m)	surface	surface	bottom	surface	FTU	surface	bottom
1	19° 52' 148" S	47° 01' 877" E	8h40	0.4	0.2	22	7.31	7.24	880	48.2	7.21	3.68
2	19° 52' 196" S	47° 01' 861" E	9h01	0.5	0.2	22.7	7.4	7.3	1005	44.61	9.4	6.8
3	19° 52' 190" S	47° 01' 813" E	9h23	0.3	0.13	22.2	7.32	7.29	1009	45.56	9.21	7.8
4	19° 52' 260" S	47° 01' 826" E	9h45	0.6	0.14	22.2	7.38	7.36	989	26.88	10.6	7.3
5	19° 52' 345" S	47° 01' 817" E	10h00	0.8	0.14	22.5	7.6	7.52	975	30.47	12.94	7.4
1'	19° 52' 148" S	47° 01' 877" E	14h	0.4	0.2	23.7	7.4	7.36	979	52	13.38	8.88
2'	19° 52' 196" S	47° 01' 861" E	14h15	0.5	0.2	23.7	7.52	7.45	983	55	12.74	9.31
3'	19° 52' 190" S	47° 01' 813" E	14h27	0.3	0.15	23.6	7.41	7.38	1005	106	12.57	10.4
4'	19° 52' 260" S	47° 01' 826" E	14h40	0.6	0.2	24.6	7.72	7.69	992	46	13.58	10.3
5'	19° 52' 345" S	47° 01' 817" E	14h55	0.8	0.2	25.1	7.91	7.85	992	37.78	14.03	10.56

2/ Solids

- Suspended solids

Samples	mf (g)	V (ml)	m(f + s) (g)	TSS (mg/l)	mf after ignition (g)	1% of mf	m + 1%mf	VSS (mg/l)
1	0.1355	100	0.1405	50.00	0.1357	0.001355	0.1371	34.45
2	0.1347	100	0.1394	47.00	0.1345	0.001347	0.1358	35.53
3	0.1367	50	0.139	46.00	0.1357	0.001367	0.1371	38.66
4	0.135	50	0.1365	30.00	0.134	0.00135	0.1354	23.00
5	0.1361	50	0.1378	34.00	0.1354	0.001361	0.1368	20.78
1'	0.1343	50	0.1371	56.00	0.1336	0.001343	0.1349	43.14
2'	0.1362	50	0.1395	66.00	0.1353	0.001362	0.1367	56.76
3'	0.1346	50	0.1404	116.00	0.1343	0.001346	0.1356	95.08
4'	0.1363	50	0.1387	48.00	0.1356	0.001363	0.1370	34.74
5'	0.1346	50	0.1368	44.00	0.1338	0.001346	0.1351	33.08
nw	0.1352	50	0.1369	34.00	0.1344	0.001352	0.1358	22.96
ne	0.1350	50	0.1362	24.00	0.134	0.00135	0.1354	17.00

- Total solids

Samples	mp (g)	V (ml)	mp after evaporation 24h	TS (mg/l)	mp after ignition 1h	TVS (mg/l)	TDS (mg/l)
1	38.3776	30	38.3982	686.67	38.3884	326.67	636.67
2	51.0887	30	51.1117	766.67	51.0993	413.33	719.67
3	41.0944	30	41.1174	766.67	41.103	480.00	720.67
4	42.6926	30	42.7187	870.00	42.706	423.33	840.00
5	27.3578	30	27.3816	793.33	27.3692	413.33	759.33
1'	28.9320	30	28.9579	863.33	28.9453	420.00	807.33
2'	27.0136	30	27.0377	803.33	27.0274	343.33	737.33
3'	26.4380	30	26.4663	943.33	26.4543	400.00	827.33
4'	25.5475	30	25.5713	793.33	25.5622	303.33	745.33
5'	28.1598	30	28.1843	816.67	28.1747	320.00	772.67

3/ Oxygen demand

- Biochemical oxygen demand (BOD)

Samples	To (mg/l)	T5(mg/l)	To - T5	Ve (ml)	F = Vt/Ve	F-1	BOD5
B	8.06	6.88	1.18	0			**BOD5= F(To-T5)-(F-1)(Do-D5)**
B'	8.12	6.75	1.37	0			
1_40	7.91	4.39	3.52	40	8.25	7.25	19.76
1_70	8	3.15	4.85	70	4.71	3.71	18.11
2_40	7.98	4.10	3.88	40	8.25	7.25	22.73
2_70	8.03	3.09	4.94	70	4.71	3.71	18.53
3_40	8.07	4.04	4.03	40	8.25	7.25	23.97
3_70	8.12	3.32	4.80	70	4.71	3.71	17.87
4_40	8.09	4.59	3.50	40	8.25	7.25	19.60
4_70	8.19	3.36	4.83	70	4.71	3.71	18.02
5_40	8.16	4.69	3.47	40	8.25	7.25	19.35
5_70	8.25	3.78	4.47	70	4.71	3.71	16.32
1'_40	8.15	4.13	4.02	40	8.25	7.25	23.89
1'_70	8.28	2.82	5.46	70	4.71	3.71	20.99
2'_40	8.16	4.14	4.02	40	8.25	7.25	23.89
2'_70	8.18	2.86	5.32	70	4.71	3.71	20.33

3'_40	8.16	4.66	3.50	40	8.25	7.25	19.60
3'_70	8.28	2.31	5.97	70	4.71	3.71	23.39
4'_40	8.33	4.15	4.18	40	8.25	7.25	25.21
4'_70	8.61	3.30	5.31	70	4.71	3.71	20.28
5'_40	8.29	4.28	4.01	40	8.25	7.25	23.80
5'_70	8.58	3.11	5.47	70	4.71	3.71	21.03
NW40	7.89	3.35	4.54	40	8.25	7.25	28.18
NW70	7.81	2.40	5.41	70	4.71	3.71	20.75
NE40	8.15	5.09	3.06	40	8.25	7.25	15.97
NE70	7.89	4.45	3.44	70	4.71	3.71	11.46

With Vt = 330ml

- COD

Samples	Volume (V2) of (NH4)2Fe(SO4)2 used (ml)	C [(NH4)2Fe(SO4)2] (mol/l) = 1.2/ V	COD = 8000*c(V1-V2)/Vo
Blanc froid (V)	10.67	0.11	
B (V1)	8.7	0.11	
2	8.22	0.11	43.19
3	8.11	0.11	53.08
4	8.33	0.11	33.29
B' (V'1)	8.17	0.11	
1'	7.54	0.11	56.68
2'	7.6	0.11	51.28
3'	7.57	0.11	53.98
4'	7.7	0.11	42.29
5'	7.6	0.11	51.28
B" (V1)	8.03	0.11	0.00
1	7.69	0.11	30.59
5	7.53	0.11	44.99
nw	7.47	0.11	50.38
ne	7.73	0.11	26.99

With Vo = 10ml (tested volume of sample)

4/ Nutrient

- Phosphorus

	Reactive P		Total P	
Station	Absorbance	Conc-P (mg/l)	absorbance	Conc-P (mg/l)
Morning				
1	0.021	0.944623	0.037	1.707
2	0.029	1.325927	0.038	1.755
3	0.021	0.944623	0.029	1.326
4	0.029	1.325927	0.044	2.041
5	0.015	0.658645	0.021	0.945
Afternoon				
1’	0.039	1.802557	0.053	2.470
2’	0.039	1.802557	0.045	2.089
3’	0.078	3.661414	0.082	3.852
4’	0.03	1.37359	0.047	2.184
5’	0.039	1.802557	0.042	1.946
nw	0.028	1.278	0.050	2.327
ne	0.023	1.040	0.031	1.421

- Nitrogen

Station	**Nitrate**			**Nitrite**			**NTK**		**TN**
Morning	absorbance	**N- NO3 (mg/l)**	NO3 (mg/l)	absorbance	N-NO2 (µg/l)	NO2 (µg/l)	V (H2SO4) used (ml)	**NTK (mg/l)**	N (mg/l)
1	0.439	**1.435**	**6.353**	0.433	137.261	450.825	2.0	**4.800**	6.373
2	0.436	**1.425**	**6.310**	0.403	127.727	419.512	2.6	**6.240**	7.793
3	0.313	**1.023**	**4.527**	0.455	144.253	473.789	2.2	**5.280**	6.447
4	0.506	**1.655**	**7.325**	0.481	152.516	500.927	2.7	**6.480**	8.287
5	0.504	**1.648**	**7.296**	0.417	132.177	434.125	2.3	**5.520**	7.300
1’	0.43	**1.406**	**6.223**	0.636	201.775	662.715	2.5	**6.000**	7.608
2’	0.431	**1.409**	**6.237**	0.648	205.588	675.241	3.7	**8.880**	10.495
3’	0.502	**1.642**	**7.267**	0.706	224.021	735.780	4.3	**10.320**	12.186
4’	0.499	**1.632**	**7.223**	0.515	163.321	536.416	2.8	**6.720**	8.515
5’	0.498	**1.628**	**7.209**	0.472	149.656	491.533	2.6	**6.240**	8.018
nw	1.592	**5.212**	**23.070**	1.381	438.536	1440.340	1.6	**3.840**	9.490
ne	0.194	**0.633**	**2.801**	0.168	53.044	174.221	0.7	**1.680**	2.366

5/ Chlorophyll a

Stations	1	2	3	4	5	1'	2'	3'	4'	5'
Absorbance at 663a	0.557	0.663	0.628	0.625	0.555	0.609	0.595	0.597	0.554	0.534
Absorbance at 750a	0.175	0.116	0.111	0.11	0.058	0.036	0.04	0.019	0.028	0.044
correction 663a	0.382	0.547	0.517	0.515	0.497	0.573	0.555	0.578	0.526	0.49
Absorbance at 750b	0.179	0.11	0.112	0.095	0.056	0.035	0.039	0.034	0.032	0.038
Absorbance at 665b	0.438	0.467	0.441	0.435	0.381	0.403	0.4	0.389	0.363	0.358
correction 665b	0.259	0.357	0.329	0.34	0.325	0.368	0.361	0.355	0.331	0.32
chlorophyll a (mg/m3)	131.5116	203.148	201.0096	187.11	183.9024	219.186	207.4248	238.4316	208.494	181.764
phaeophytin a (mg/m3)	62.33436	64.04508	45.22716	67.3596	59.3406	56.23992	62.76204	27.2646	39.23964	57.7368

Appendix 4: Calibration curves for calculating phosphorus concentration, nitrate concentration and nitrite concentration.

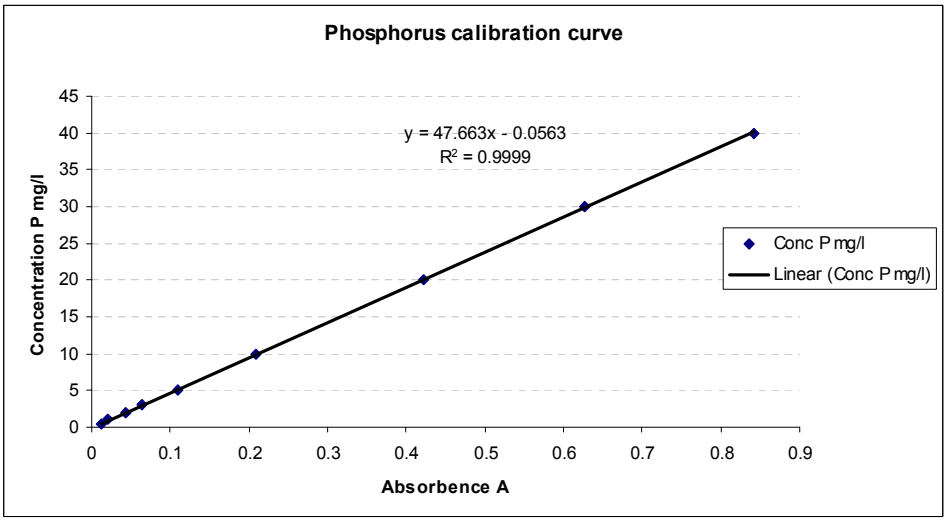

Figure i: Phosphorus calibration curve

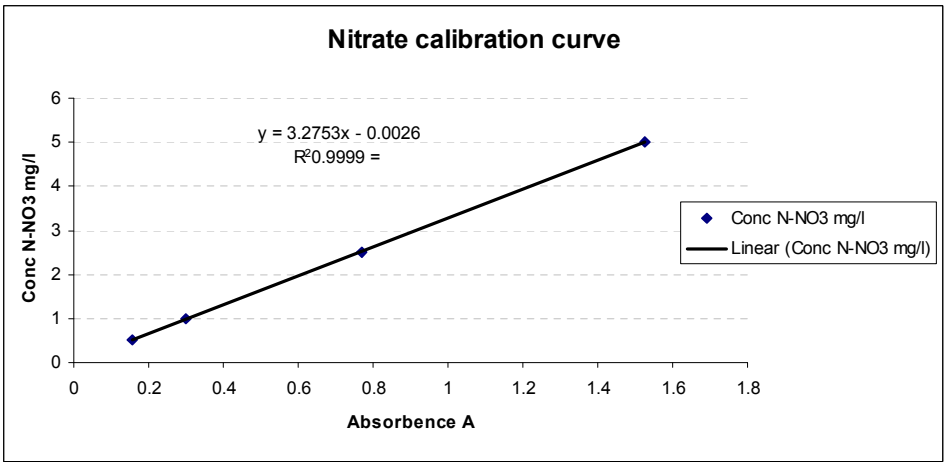

Figure ii: Nitrate calibration curve

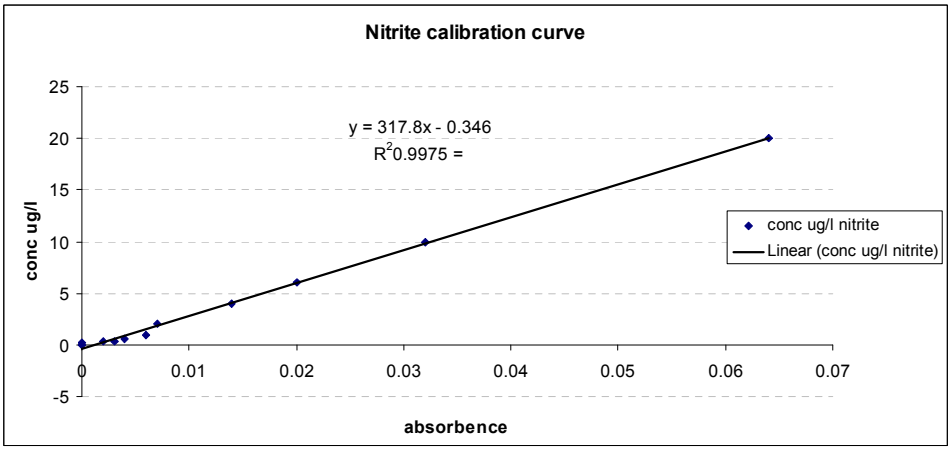

Figure iii: Nitrite calibration curve