THE IMPACT OF URBAN STORM WATER RUNOFF AND DOMESTIC WASTE EFFLUENT ON WATER QUALITY OF LAKE TANA AND LOCAL GROUNDWATER NEAR THE CITY OF BAHIR DAR, ETHIOPIA

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ABSTRACT

In urban areas, the main task of town planners and engineers is providing drainage structures to prevent flooding. Recently the effect of these drainage structures on water quality has become a concern. However, little is known about the magnitude of the pollution. There fore the objective of this study is to characterize pollution loads from one Ethiopian urban area, Bahir Dar, on the southern end of Lake Tana which is experiencing dramatic expansion. In particular this research measured the quantity and quality of storm runoff and ground water. To determine the pollutant concentration and its effect on the quality of ground water, three shallow wells were installed. Urban storm water runoffs at six storm drains, which empty to Lake Tana, were instrumented for discharge and water quality measurements. The quality parameters considered were the total coliform, dissolved oxygen, total solids (TS), total suspended solids (TSS), biological and chemical oxygen demand (BOD/COD), total nitrogen (TN), total phosphorus (TP), pH, and conductivity. Three-rainfall event samples were taken in each month during rainy season (July, August, September and October) for a total of 9 rainfall events. Magnitude of pollutant load concentration flowing in to Lake Tana during low and high storm flow and contributions to groundwater were determined. In addition low flow characteristics (base flow) was determined once in a month. The results indicate that the water quality parameters like total nitrogen; total phosphorus and total suspended solids are found to be high with an average concentration load of 22.8mg/l, 0.46mg/l and 365mg/l respectively. The average concentration for dissolved solid, electric conductivity, dissolved oxygen COD, and total coliform are178mg/l, 338µ/cm, 2.8mg/l, and 3.28mg/l and169coli/100ml respectively. From the six sub watersheds assessed in this study, the sub watershed that drains the hotel discharge (station-5) had the elevated concentration for all

pollutant except dissolved oxygen. All runoff concentration means found in this study area except the mean recorded for chemical oxygen demand, are higher than the means found in the data base for North American cities (CDM and NURP) and it shows that the Bahir Dar storm water runoff pollutant load is in excess of the North American cities.

BIOGRAPHICAL SKETCH

Tenagne Addisu Wondie was born in Gojjam, Ethiopia to his mother, Asinakech Yalew Gebiru, and father, Addisu Wondie Tesemma, in 1970.

He received an Advanced Diploma in Irrigation Engineering & Drainage from Arbaminch Water Technology Institute in 1990 and his first degree in Hydraulics Engineering from Arbaminch University in 2005. He has been working as a water engineer for the last 17 years in Amhara Region, Ethiopia and carried out many water development projects in the rural part of the country.

Tenagne is very keen for new ideas, especially problem solving and researchable issues, and he believes that every success is a reflection of hard work.

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I am very grateful to Amhara Region Water Resource Development Bureau, Bahir Dar Town Water Supply and Sewerage Service Office and Bahir Dar University for providing me their water quality laboratory to carry out the required laboratory analysis work. Many thanks to all my friends, they have enriched my life with new, different, good and bad experiences, all part of life, which made my stay in BDU.

Last but certainly not the least, my very special, warm and deep thanks to my family for offering me their perpetual love, support, and encouragement throughout my life and mainly during the last 2 years. To my wife Asmeret thanks for your commitment and patience. To my children, Betty, Tigist and Eueal, thanks for bring us happiness and innocence.

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CHAPTER ONE

1. INTRODUCTION

1.1 Background

The city of Bahir Dar in Amhara region of Ethiopia is the study area. Lake Tana is the water body receiving most of the urban runoff and sanitary effluents drained from this city. The city of Bahir Dar is situated on the southern shore of Lake Tana at latitude of $11^0$35'N and longitude of $37^0$23'E. It is a rapidly expanding city and has no particular parts where commercial or other activities are concentrated. Shops and residences are generally present in all sectors. There are no major industries in the contributing areas; the textile factory and two tanneries are located outside the watershed that contributes to the urban storm water and sanitary sewer joining the lake. In 2005, the city of Bahir Dar had approximately 250,000 inhabitants. According to the Ethiopian Meteorology Agency the annual mean precipitation for Bahir Dar is 900 mm. The urban storm runoff and domestic waste effluent receiving water body, Lake Tana, with surface area of 3150 km2 is the largest fresh water body in the country and the source of Blue Nile (Eshetie Dejen, 2003).

In the last few years, the lake has undergone large changes in chemistry and biology as a result of growing human interferences. Currently the lake ecosystem is in danger due various factors like deforestation, erosion, sedimentation in the catchment, water level reduction, erratic rain fall, pressure of growing population and the connected impact of urban storm runoff and other unmanaged domestic wastes.

The degradation of Lake Tana water quality caused by urban storm runoff is a serious problem and affecting the ecosystem of the lake and significant portion of the community living around the gulf principally Bahir Dar city residents. In the study area, human activities are directly and indirectly generating a drastic change in the ecosystem of the lake. For instance the dramatic expansion of the city has resulted in increase of the area that does not have the capacity to store and infiltrate water (impervious surface). The transformations of these natural land surfaces in to impervious surfaces (like streets, parking lots, foot path and other pavements etc) are radically decreasing the rate of infiltration and thereby increasing surface runoff volume from precipitation. This change in land use increases impervious cover lead to flooding, erosion, habitat degradation, and water quality impairment. Researches have identified storm water runoff as a major contributor to water quality degradation in urbanizing water shed (Field & Pitt, 1990). Every day activities such as excavation at construction site, driving, maintaining vehicles, disposing of wastes, collecting wastes in failed septic systems and sewer structures contribute substantial amount of contaminant to runoff. Sediment that comes from active construction sites and wash-off of particulate materials from impervious surface is one of the most common and potentially damaging pollutants found in urban runoff (Earl Shaver, Richard Horner, Joseph Skupien, Chris May, Graeme Ridiey, 2007). Generally discharge of large storm event may shock the receiving water body many times greater than the small but steady sanitary effluent (Loehr, 1974; Bedient et al., 1978; WEF and ASCE, 1998: Lee and Bang, 2000).

Another factor for the degradation of water quality assessed in this urban catchment is seepage of liquid wastes from septic tanks and its impact on ground water quality. Most of the domestic waste collecting tanks in Bahir Dar are constructed using dry masonry without any lining materials that can leak all the liquid waste to the ground and can be a cause for nitrate pollution of ground water or over flow to open ditches when the ground water rises to the surface during the rainy season. The mass movements of these wastes together with urban storm water runoff to the lake may cause significant change in the ecosystem and water quality of the lake.

All these stresses on the lake and ground water will have serious and irreversible effect on the ecosystem and water quality in the future. To remedy this situation, this study proposes critical pollution source assessment of the lake of an urban area.

1.2 Objectives of the research

The general objective of this research is to assess the non-point pollution source and characterizing the water quality of urban runoff at both high and low flow condition. Our specific objectives are:

1. To assess the magnitude of the pollutant load in urban runoff imposed by Bahir Dar city on Lake Tana
2. To asses the magnitude of ground water pollution
3. To provide recommendations for improving urban storm water runoff disposal practices and develop effective methods for mitigation of storm and domestic waste water pollution on Lake Tana ecosystem

CHAPTER TWO

2. LITERATURE REVIEW

2.1 General concept

Urban runoff is not simply clean rain that falls on the urban landscape and subsequently flows away. Rain falling upon a catchment collects pollutants from the air, road way surfaces, other catchment surfaces, and storm drains, and is thereafter transformed into a type of municipal wastewater (Chambers et al. 1997; Adams and Papa 2000). The most recent Water Quality Inventory reports that runoff from urbanized areas is the leading source of water quality impairments to surveyed estuaries and the third-largest source of impairments to surveyed lakes EPA (February, 2003). Increasing urbanization has led to significant changes in the natural systems of the receiving water bodies. These changes include alterations in the hydrologic flow regime as well as shifts in the chemical and biological makeup of storm water runoff from these developing areas. As an area is developed, the natural ability of the catchments to withstand natural hydrologic variability is removed. Infiltration capacity is decreased due to the increase in impervious surface and disrupted native soils and vegetation. Anthropogenic activity also introduces chemical and biological constituents to the catchment. Trace metals, suspended solids, nutrients, pesticides, petroleum products, and E. coli and fecal coliform bacteria are generally found in higher concentrations in urbanized and urbanizing areas than in natural systems, due to increased numbers of people, vehicles, roads, and building materials introduced into the landscape. These constituents that storm water runoff carries is found to be a major source of pollution to surface water quality and groundwater resources

2.2 Constituents of Urban Storm water runoff

2.2.1 Conventional Water quality Parameter /constituents/

pH: pH is the measure of the acidity or alkalinity of the water on a scale from 1 –14 (1 is very acidic, 7 neutral and 14 very alkaline). The pH of water affects the solubility of many toxic and nutritive chemicals; therefore, the availability of these substances to aquatic organisms is affected. As acidity increases, most metals become more water soluble and more toxic. Toxicity of cyanides and sulfides also increases with a decrease in pH (increase in acidity). Ammonia, however, becomes more toxic with only a slight increase in pH (Environment Canterbury; Resource care guide -2005). Runoff, sewage, geology (limestone is associated with more alkaline conditions); high nutrient levels are some of the causes to acidity or alkalinity. High nutrient levels cause excessive growth of algae and plants that will lift pH values. Outside what is considered the normal pH range there may be a loss of sensitive species. If extremely high or extremely low pH values occur, it would result in the death of all aquatic life. Alkaline conditions can also increase the toxicity of other pollutants such as ammonia. The safe aquatic habitat range is between 6.5 and 8.5.

Electric conductivity: The electric conductivity is the ability of a substance to conduct electricity. The conductivity of water is a more-or-less linear function of the concentration of dissolved ions. Conductivity itself is not a human or aquatic health concern, but because it is easily measured, it can serve as an indicator of other water quality problems (It is used to give an indication of the amount of inorganic materials in the water including, calcium, bicarbonate, nitrogen, phosphorus, iron, sulfur and others). If the conductivity of a stream suddenly increases, it indicates that there is a source of dissolved ions in the vicinity. Therefore, conductivity measurements can be used as a quick way to locate potential water quality problems. Conductivity is measured in terms of conductivity per unit length, and meters or micro siemens/cm. Storm water runoff, sewage effluent, catchment geology and agricultural effluent running into streams have a significant influence on the conductivity of stream water

- Good for drinking by people and livestock 0-800ms/cm
- Drinkable but with salty taste. Some plants will not tolerate over 1500ms/cm (grapes/peas/apricots) 800 – 2,500
- Unsuitable for people, most livestock and crops 2,500 – 10,000

Temperature: Many of the physical and biological characteristics of waterways are directly affected by temperature. Temperature is highly dependent on the depth of the water, season, time of the day, cloudiness of the sky and the air temperature. Discharges can also affect temperature e.g. cooling water. Changes in temperature alter dissolved oxygen. (Higher temperatures mean the water holds less dissolved oxygen). The distribution and number of aquatic species also changes as temperature varies. A short period of high temperatures each year can make the water body unsuitable for sensitive species even though during the rest of the year the temperature is acceptable.

Optimal temperature range for trout 13-15°C

Critical temperature which if exceed will harm or kill fish 23°C

Total coliform: Total coliform include species that may inhabit the intestines of warm-blooded animals or occur naturally in soil, vegetation, and water. They are usually found in water polluted with fecal matter and are often associated with disease outbreaks. Although they are not usually pathogenic themselves, their presence in drinking and recreation water indicates the possible presence of pathogens. E. coli, one species of the coliform group, is always found in feces and is, therefore, a more direct indicator of fecal contamination and the possible presence of enteric pathogens (USEPA, Sep, 2002). Some of the recommended coliform limits based on the median value are:

- Drinking water < 1.0 *E.Coli*/100ml
- Contact recreation 126 *E.Coli*/100ml or 200 FC/100ml

2.2.2 Aggregates

Dissolved oxygen: Fish and other aquatic animals depend on dissolved oxygen (the oxygen present in water) to live. The amount of dissolved oxygen in streams is dependent on the water temperature, the quantity of sediment in the stream, the amount of oxygen taken out of the system by respiring and decaying organisms, and the amount of oxygen put back into the system by photosynthesizing plants, stream flow, and aeration. Dissolved oxygen is measured in milligrams per liter (mg/l) or parts per million (ppm). The temperature of stream water influences the amount of dissolved oxygen present; less oxygen dissolves in warm water than cold water. For this reason, there is cause for concern for streams with warm water. Trout need DO levels in excess of 8 mg/liter, striped bass prefer DO levels above 5 mg/l, and most warm water fish need DO in excess of 2 mg/l.

Solids

Solids in storm water runoff are classified using various methods, with most dependent on size. Total solids (TS) encompass all solids found in runoff, both suspended and dissolved. Solids enter storm water runoff through erosion of natural soils. Both the amount of total solids present and the size distribution of those solids depend on catchment land use, the extent of construction activities, and the time since initial disturbance of the catchment (Minton, 2002). Solids also enter the runoff stream from vehicle emissions, vehicle tire, engine and brake wear, as well as through pavement wear and atmospheric deposition (Sansalone, 1998).

Total suspended solids (TSS) and total dissolved solids (TDS) are separated by what does and does not pass through a 0.45-µm filter (APHA, 1998). A PSD analysis further categorizes solids into size ranges. The American Association of State Highway and Transportation Officials (AASHTO) divide size classes for solids into gravel, sand, silt, and clay. Solids larger than 2,000 µm are referred to as gravel, between 75 and 2000 µm as sand, 2 and 75 µm as silt, and less than 2 µm as clay, with all particles less than 75 µm commonly referred to as fines (Das, 1998). Particles in storm water runoff are referred to as colloidal if they are less than 1.0 micrometer (µm) in diameter and macro colloidal if they are between 0.45 and 20 µm in diameter (Characklis and Wiesner, 1997). The sizes of particles in storm water runoff can significantly affect various physical and chemical processes. Fine particles may agglomerate, causing PSD to vary along the longitudinal path of storm water runoff (Minton, 2002). Larger particles settle faster than smaller particles. This settling mechanism affects the relative concentrations of different sizes of particles depending on runoff velocity and depth of flow.

Total Dissolved solids: “Dissolved solids” refer to any minerals, salts, metals, cations or anions dissolved in water. This includes anything present in water other than the pure water molecule and suspended solids. (Suspended solids are any particles/substances that are neither dissolved nor settled in the water.) In general, the total dissolved solids concentration is the sum of the cations (Positively charged) and anions (negatively charged) ions in the water. Parts per million (PPM) is the weight to weight ratio of any ion to water. Conductivity is usually about 100 times the total cations or anions expressed as equivalents. Total dissolved solids (TDS) in mg/l usually range from 0.5 to 1.0 times the electrical conductivity. Some dissolved solids come from organic sources such as leaves, silt, plankton, and industrial waste and sewage. Other sources come from runoff from urban areas, and fertilizers and pesticides used on lawns and farms. Dissolved solids also come from inorganic materials such as rocks and air that may contain calcium bicarbonate, nitrogen, iron phosphorous, sulfur, and other minerals. Many of these materials form salts, which are compounds that contain both a metal and a nonmetal. Salts usually dissolve in water forming ions. Ions are particles that have a positive or negative charge. Water may also pick up metals such as lead or copper as they travel through pipes used.

Total Suspended solid: Suspended solids refer to small solid particles, which remain in suspension in water as a colloid or due to the motion of the water. Generally the amount of particles that suspend in a sample of water is called total suspended solids (TSS). It is used as one indicator of water quality. It is sometimes abbreviated SS, but is not to be confused with settle able solids also abbreviated SS, which contribute to the blocking of sewer pipes. Suspended solids are important as pollutants and pathogens are carried on the surface of particles. The smaller the particle size, the greater the surface area per unit mass of particle, and so the greater the pollutant load that is likely to be carried. To remain permanently suspended in water (or suspended for a long period of time), particles have to be light in weight (they must have a relatively low density or specific gravity), be relatively small in size, and/or have a surface area that is large in relation to their weight (have a shape like a sheet of paper). The greater the TSS in the water, the higher its turbidity and the lower its transparency (clarity).

2.2.3 Nutrients

Urbanization generally leads to higher nutrient concentration in storm runoff (Omernik, 1976). Nutrients such as phosphorous and nitrogen are essential for the growth of algae and other plants. Aquatic life is dependent upon these photo synthesizers, which usually occur in low levels in surface water. Excessive concentrations of nutrients, however, can over stimulate aquatic plant and algae growth. Bacterial respiration and organic decomposition can use up dissolved oxygen, depriving fish and invertebrates of available oxygen in the water (eutrophication).

Phosphorus: Phosphorus occurs naturally in low concentrations and is essential for all forms of life. It comes from processes such as weathering of rock and the decomposition of organic matter. Phosphorus indicates nutrient status, organic enrichment and the consequent health of the water body. Increased levels may result from erosion, discharge of sewage or detergents, urban runoff, and rural runoff containing fertilizers, animal and plant matter. When concentrations are too high problems such as algal blooms, excessive weed growth and the loss of species diversity can occur. Abundant plant growth such as algal blooms leads to increased pH and turbidity and sometimes to the production of toxins and odor.

- Algal growth in streams may occur 0.01 – 0.1mg/L (Total Phosphorus)
- Recreational use 0.006 mg/L (Dissolved Reactive Phosphorous)
- Aquatic ecosystem balance 0.001 mg/L (Dissolved Reactive Phosphorous)

Nitrogen: Nitrogen in urban runoff/streams occurs in three forms:

- Gaseous form (Nitrogen and Ammonia)
- Inorganic form (Nitrates, nitrites and Ammonium)
- Organic form (biological material e.g. protein)

Natural breakdown of vegetation, run-off from lawn and crop fertilizers and effluent can contain nitrates. Run-off from feedlots can have concentrated ammonia and nitrates. Inadequately treated sewage, poor septic tank systems and streams fed by nitrate rich groundwater can all increase nitrogen in waterways. Ecosystems can be affected when nitrogen concentrations become too high. This may result in algal blooms and an overabundance of oxygen-dependant bacteria that deplete the water of oxygen. Nitrate in high concentrations may be harmful to stock. Excessive nitrates in drinking water can cause methaemoglobinaemia (blue baby) in bottle-fed infants. High concentrations of ammonia are also very toxic to aquatic animals.

- Limit for algal growth 0.1- 0.75mg/l (Total Nitrogen)
- Limit for human consumption 11.3mg/l (Nitrate-nitrogen)

2.2.4 Biochemical Oxygen Demand/ Chemical oxygen Demand

Natural organic detritus and organic waste from urban and agricultural runoff, waste water treatment plants, and failing septic systems acts as a food source for water-borne bacteria. Bacteria decompose these organic materials using dissolved oxygen, thus reducing the DO present for fish. Biochemical oxygen demand (BOD) is a measure of the amount of oxygen that bacteria will consume while decomposing organic matter under aerobic conditions. Biochemical oxygen demand is determined by incubating a sealed sample of water for five days and measuring the loss of oxygen from the beginning to the end of the test. Samples often must be diluted prior to incubation or the bacteria will deplete all of the oxygen in the bottle before the test is complete. The main focus of wastewater treatment plants is to reduce the BOD in the effluent discharged to natural waters. Wastewater treatment plants are designed to function as bacteria farms, where bacteria are fed oxygen and organic waste. The excess bacteria grown in the system are removed as sludge, and this “solid” waste is then disposed of on land. Chemical oxygen demand (COD) does not differentiate between biologically available and inert organic matter, and it is a measure of the total quantity of oxygen required to oxidize all organic material into carbon dioxide and water. COD values are always greater than BOD values, but COD measurements can be made in a few hours while BOD measurements take five days. If effluent with high BOD levels is discharged into a stream or river, it will accelerate bacterial growth in the river and consume the oxygen levels in the river. The oxygen may diminish to levels that are lethal for most fish and many aquatic insects. As the river re-aerates due to atmospheric mixing and as algal photosynthesis adds oxygen to the water, the oxygen levels will slowly increase downstream. The drop and rise in DO levels downstream from a source of BOD is called the DO sag curve.

2.3 Urban runoff and Best management practices (BMPs)

BMPs are any measure, practice, or control implemented to protect water quality and reduce the pollutant content in storm water runoff. Legal entities are required to define and implement a selection of BMPs to reduce the discharge of pollutants from their storm drain system. The Permit requirement is applicable to both permanent and temporary (construction) BMPs. Additionally; the BMPs may be applied to special circumstance sites where there is a direct discharge into impaired receiving water with an established TMDL for example in US.

BMP Categories

The general categories of BMPs are:

Permanent BMPs: Permanent controls are designed to control erosion and sediment after construction and fulfill the general requirements in the Permit. Permanent BMPs are either designed to control the pollution at the source or treat storm water runoff by removing contaminates. The two types of permanent BMPs are:

a. Source Control Measures or Soil Stabilization BMPs: measures of control to prevent pollutants from being entrained in runoff, thereby curtailing pollution at the source. Most literature refers to these BMPs as Soil Stabilization BMPs.

b. Treatment Control Measures: Control measures to treat storm water runoff and remove pollutants of concern before discharging into conveyance systems or receiving water.

Temporary BMPs: Temporary or construction BMPs are the Best Conventional Technology/Best Available Technology (BCT/BAT) based BMPs and are consistent with the BMPs required under the General Permit.

CHAPTER THREE

3. METHODS

3.1 Study Area and climate

The city of Bahir Dar in Amhara region of Ethiopia is the study area (fig 3.1). Lake Tana, which is found at the northern end of the city, is the water body receiving most of the urban storm water run off and domestic waste effluents. Bahir Dar is a rapidly expanding city and an important center where tourism and commercial activities are taking place. There are no particular parts of the city where commercial or other activities are concentrated. Shops and residences are generally present in all sectors. Most of the houses especially old residential houses found in the city are not sewered. People in this area collect their excreta and domestic wastes using dry pit latrine prepared in their back yard. There are no major industries in the contributing areas; the textile factory and two tanneries are located outside the watershed that contributes to the urban storm water and sanitary sewer joining the lake. Most part of the city is established on the vertisol found at the periphery of Lake Tana and Blue Nile. The city has flat topography having a poor drainage network. According to the data obtained from the city administration, the total road length in Bahir Dar is estimated to be 71km, of which about 26% asphalted, 57% graveled and the remaining17% is unsurfaced. In 2005, the city had approximately 250,000 inhabitants. According to the Ethiopian Meteorology Agency, Bahir Dar area has a mean annual rain fall is 900mm, where 54% of the rain falls in July and August and only 3% falls during the dry months, the rest fall in the remaining months. The mean annual temperature is 160C. The maximum temperature usually occurs from March to May and at its lowest from November to February.

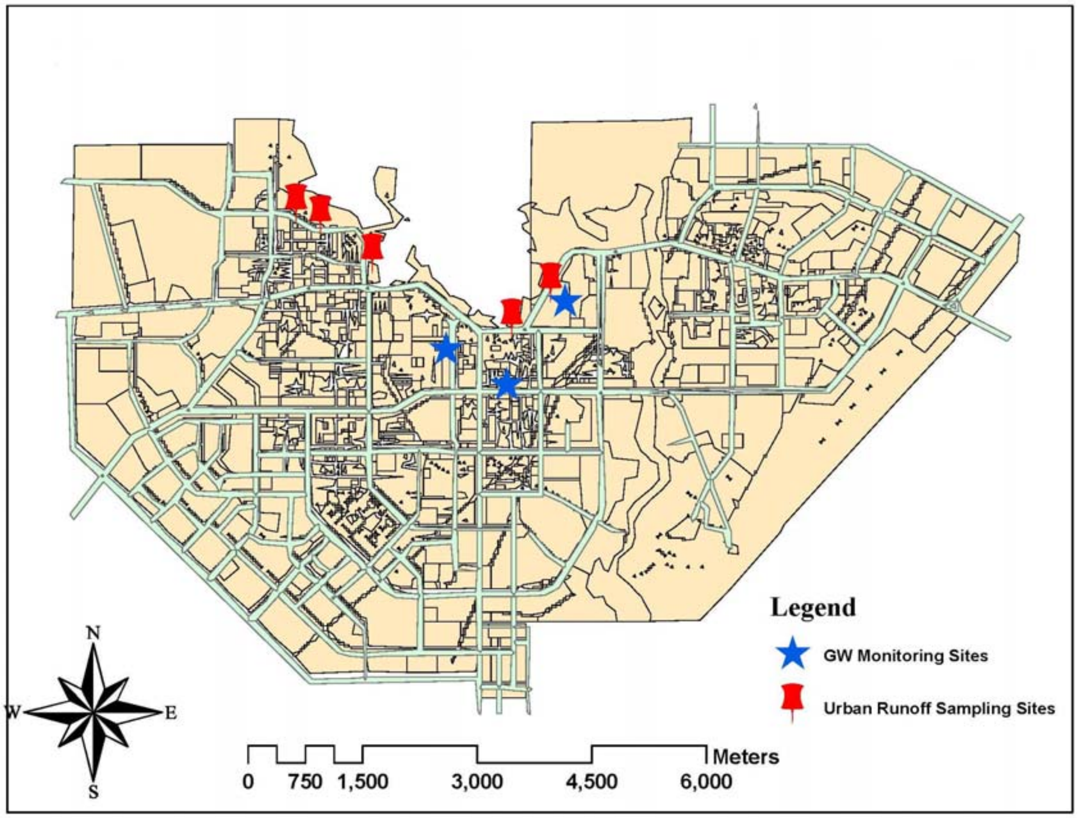

Figure 3-1: Urban storm runoff and ground water sampling station within the City of Bahir Dar (the study area).

3.2 Study methodology and approach

3.2.1 Data Availability

Data considered in this study obtained from direct measurements, field assessments and from different institution in the region and consists of primary, secondary, and experimental or metadata .The primary data includes:

1. Rainfall and other hydrological data to estimate runoff flow rate during sampling.
2. The urban runoff and ground water quality data.
3. Direct measured values from field survey.
4. Metadata consists of information on the data, such as maps and satellite images of the city and the gulf to delineate the study area and the sub drainages.

5. Other data collection were achieved through

- Intensive literature review
- Inspection of the pollution source points

3.2.2 Area characterization and Site Selection

The city of Bahir Dar has different topographical urban catchments that each convey the urban storm runoff to separate outfalls. The storm collection network of the city is a mixture of open and closed storm drains. Currently the urban runoff with other domestic effluent is joining the lake at six identified outfalls. The pollution source assessment & the magnitude of urban run off pollution & water quality at each drainage outlet and the lake, will apply methodologies for the translation of the data in to conclusion that could contribute to the recommendation of effective urban runoff pollution control approach. Some of the procedure /activities that were carried out in study area characterization and site selection include:

- GIS based watershed delineation was carried out to identify and delineate parts of the town that contributes runoff and domestic waste to the established monitoring sites/ sampling stations/.
- Six sampling stations were established to monitor the urban storm water runoff quality and three piezometers were installed as ground water monitoring site at appropriate site that ground water is expected to be found at shallow depth. The sampling stations are shown above on Figure 3-1 and the locations are described in Table 3-1.

Table 3-1: Description of the Monitoring Stations

S.No	Name of the station/ID of the stations	Location (GPS coordinate of the station)
1	SO S (station-1)	N 11^{0}36'31.4'' & E 37^{0}21'54.7''
2	Hospital (station- 2)	N11^{0}36'26.2'' & E 37^{0}22'05.1''
3	N.Fueldepot (station-3)	N11^{0}36'09.9'' & E 37^{0}22'27.9''
4	Summerland (station-4)	N11^{0}35'42.5'' & E 37^{0}23'28.3''
5	Ethiostar (station-5)	N11^{0}35'42.5'' & E 37^{0}23'28.3''
6	Shumabo (Station-6)	N11^{0}35'57.7''& E 37^{0}23'44.95''
	GW monitoring sites	
1	Red cross (station-1)	N11^{0}35'29.8'' & E 37^{0}23'00''
2	M. college (station-2)	N11^{0}35'14.6'' & E 37^{0}23'26.2''
3	BDU/EF (station-3)	N11^{0}35'50.46''&E37^{0}23'51.18''

The first sampling station located at the North-western end of the city collects most of the urban runoff from new residential area and small farms. The storm water run off at this sampling station is supplied by mixed type of drainage ditches. The drainage ditches run from the airline Main Street to this outfall point is earthen open ditches where as the other feeder ditches are rectangular masonry open ditches. The sampling station No.2 represents the total runoff exiting in the sub-basin around the city Referral Hospital. Most run off transporting ditches in this sub basin are grassed open ditches and rectangular masonry storm drains. The only concrete pipe found in this sub catchment is the one that is laid along the street to Bahir Dar Referral hospital where commercial activities and hotels are found. In the other and most part of the sub catchment, new residential houses are dominant. In some cases when there is high storm event the flood that normally flows to other sub catchment over tops the main road that takes to airplane station and join the ditch that guide floods to this sub catchment. There are two monitoring station (station 4 and 5) located at the main street that stretches between the Saint George Church to the regional council bureau where hotels are concentrated. In these sub catchments most of the urban runoff transporting system is carried out with closed concrete pipe. At sampling station four (Summerland) the western and central part of the sub catchments is monitored. The concrete pipe laid along the street in this sub catchment carries most of the storm water runoff in the area. The fifth sampling station found near the two big hotels (Ethiostar and Summerland hotel) carries the waste discharged by these hotels and has continues flow in the dry period. These sampling stations enabled an assessment of the quantity and quality of runoff from the north eastern portion of this catchment area and discharges from hotels. The two sampling station represents the total surface runoff exiting in the sub-basin. In the other sub catchment run off quantity measurements and samples for laboratory analysis were collected from the Shumabo site (sampling station-6) at the outlet of a 90 cm diameter concrete pipe at the site down stream of the fourth and fifth sampling station. Like the neighborhood stations, shumabo monitoring sites is laid with concrete storm water pipes that collects the runoff to the out fall point. There are no residential and commercial buildings in this sub catchment and the urban runoff collected in this catchment is mainly from the Engineering faculty Bahir Dar University and the streets found between the regional council bureau and Shumabo recreation center.

3.2.3 Runoff Quantity Measurement

Water level data were used to calculate the average flow rate using Manning's equation at all sampling stations. The depth of flow (and, thus the related section properties) in the storm runoff drainage pipe was physically measured with simple scale during the runoff event simultaneously with sampling process, and pipe slope were determined from record drawings and confirmed by field measurements. Manning's roughness coefficient has been taken the same for sampling station that have similar pipe material (concrete pipes) except for the stations 1 and 2 which have water ways composed of rectangular masonry. Table 3-2 contains parameters associated with these flow calculations.

$$Q = \frac{1}{n} A R^{2/3} S^{1/2} \qquad \text{Equation 1}$$

Where: Q is the flow rate (m^3/s), n is the Manning's roughness coefficient, A is the cross-sectional area of the channel (m^2), R is the hydraulic radius (m), and S is the channel slope (%).

The runoff monitored at each sampling station site varies because of spatial differences in the rain fall, which may have produced measurable runoff at one site but not all sites. Higher measurements of runoff during the study period were recorded consistently at sampling station two and four.

Table 3-2: Parameters for Flow Calculations

Station Id	Method	Shape & material	Parameters
SOS (Station- 1)	Manning's Eqn.	Masonry & rectangular	Width=0.9m Slope= 0.0032, n=0.018
Hospital (Station- 2)	Manning' eqn.	Masonry & rectangular	Width=2.3m Slope= 0.0032, n=0.018
National-fuel Depot(staion-3)	>>	Circular concrete pipe	Diameter=1m Slope= 0.006, n=0.014
Summerland (station-4)	>>	>>	Diameter=1.10m Slope= 0.0046, n=0.014
Ethiostar (station-5)	>>	>>	Diameter=1.2m Slope= 0.0046, n=0.014
Shumabo (Station-6)	>>	>>	Diameter=0.9m Slope= 0.006, n=0.014

3.2.4 Runoff Water Quality Sampling and Analysis

Urban runoff water quality characteristics has been determined in both low and high flow conditions .The samples were gathered from six different runoff outfalls for one rain fall-run off event simultaneously with the runoff discharge. The urban runoff sampling was done by collecting the runoff sample manually using PVC scoop that received the entire flow and where then transferred to sampling bottles. For bacteriological analysis, BOD/COD and other WQ parameters; 200-ML sterilized plastic sampling bottles, 200ml Winkler standard bottle (black glass bottles) and 1-L plastic sampling bottles that are free from any chemicals were used respectively. The preparation of composite sample for one rainfall event was done by calibrating the sampling bottle with equal volume for three grab samples and preparing one event composite sample on site for that specific runoff event and sampling station. In each month, three-runoff event were sampled during the 2008 rainy season (July, August, September and October) for a total of 9 rainfall events. Grab samples in each runoff event were collected at the start of the runoff, middle of the run off event and finally when the storm water flows decreased significantly.

The composite samples were shipped to the Water Resource Development Bureau Water Laboratory in Bahir Dar, Amhara Region, for water quality analyses. This laboratory is used for much of the regulatory analyses required within the Region, and thus maintains high test standard protocols. The Regional Laboratory provided a complete water quality analysis of each composite sample throughout the three month research program that consists of the following water quality characteristics: the total coliform dissolved oxygen, total dissolved solids (TS), total suspended solids (TSS), total nitrogen (TN), total phosphorus (TP), BOD/ COD, pH and conductivity. The water quality analyses were generally conducted according to standard methods appropriate for turbid samples. All samples were preserved in the laboratory under 4^0C until analyzed. When the time between sample collection and analysis (the sample holding time) exceeded that set out by standard methods, no test was conducted by this

Laboratory. Samples collected in September were analyzed by the Bahir Dar University water quality laboratory for the same water quality parameter as the regional laboratory performed.

For the whole water quality parameter analyses, cost considerations dictated that only a composite sample would be used for analysis purposes. As a composite sample provides only a mean concentration over the sampling interval, it was recognized and accepted that less information could be derived using such a sample analysis protocol. (e.g., it is not possible to generate a pollution load versus time graph from the results of a composite analysis).

CHAPTER FOUR

4. RESULT

Result of water quality parameter analyses for nine selected urban runoff and ground water sampling station from the study catchment area are depicted in Table 4-1, Table 4-2, Table 4-3, Table 4-4, and Table 4-5. The results for urban runoff indicate that the water quality parameters like total nitrogen; total phosphorus and total suspended solids are found in excess of the specific level of permit discharge defined by the environmental regulations.

Table 4-1: Water quality data and average concentration load collected in July, 2008

Sampling stations	Temp (^{0}C)	pH	WQ Parameters							
			EC	DO	COD	TN	TP	TSS	TDS	Total colifor /100ml
			µ/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
Staion-1	18.4	6.57	271	2.47	0.00	18.0	0.43	337	161	142
Station- 2	18.5	6.57	346	4.01	0.00	29.6	0.25	271	164	178
Station-3	18.3	6.70	173	2.80	0.00	17.8	0.56	356	89.3	101
Station-4	18.8	6.53	182	3.10	0.00	27.8	0.56	436	86.7	164
Station-5	18.6	6.30	798	0.62	0.00	40.6	0.59	205	417	187
Station-6	17.8	6.60	107.7	5.27	0.00	40.8	0.27	394.3	51.0	200

Table 4-2: Water quality data & average concentration load collected in August, 2008

Sampling stations	Temp (^{0}C)	pH	**WQ Parameters**							
			EC	DO	COD	TN	TP	TSS	TDS	Total coli/ 100ml
			µ/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
Station- 1	17.5	6.67	367	2.03	0.00	19.0	0.36	286	197	130
Station- 2	17.5	6.83	450	2.68	0.00	49.1	0.25	255	218	157
Station-3	18.1	6.87	179	2.37	0.00	26.9	0.34	257	95.7	97.0
Station-4	18.3	6.57	222	2.27	0.00	19.6	0.65	405	118	126
Station-5	18.4	6.33	780	0.82	0.00	24.4	0.49	137	389	168
Station-6	17.9	6.67	70.2	3.66	0.00	29.5	0.24	312	38.0	141

Base flow samples were collected from four stations that have flow during dry weather periods to establish an average base flow concentration of the various water quality pollutants i.e., the same parameters as for the rainfall–runoff event composite samples. Dry weather periods were defined by a minimum duration of 36 to 48 hour rainfall that produce a with no rainfall prior to sample collection. Base flow samples were manually collected using standard sampling bottles held below the end of the storm sewer at the lake side and analyzed for the same WQ parameters of urban runoff. The storm water drainage pipes that empty its discharge to Summerland (station 4) and Shumabo (station 6) have no measurable base flow.

As it is indicated in the preamble one of the objectives of this study was to assess the pollution magnitude of ground water by installing piezometer and analyzing samples, especially for nitrogen and phosphorus load. For the purpose of ground water monitoring, samples were collected from the three piezometer sites. The average pollutant concentration of the base flow and ground water samples collected at sampling stations are shown in Table 4-4 and Table 4-5.

Table 4-3: Water quality data and average concentration load collected in September - October, 2008

Sampling stations	Temp (^{0}C)	pH	**WQ Parameters**							
			EC µ/cm	DO mg/l	COD mg/l	TN mg/l	TP mg/l	TSS mg/l	TDS mg/l	Total colif./ 100ml
Staion-1	19.2	6.79	294	3.33	2.67	15.7	0.43	577	144	145
Station- 2	19.7	7.00	244	3.51	4.00	7.30	0.49	428	106	180
Station-3	19.5	6.99	531	1.41	1.67	18.1	0.80	248	266	186
Station-4	19.7	7.02	180	4.20	3.33	3.60	0.41	798	132	180
Station-5	20.1	7.13	782	0.94	7.33	21.0	0.91	145	430	240
Station-6	19.7	6.91	121	4.96	0.67	3.00	0.23	717	98.1	175

Table 4-4: The average pollutant concentrations of the base flow collected in the study period at four stations

Sampling stations	Temp (^0C)	pH	Parameters						
			EC	DO	TN	TP	TSS	TDS	Total coliform/ 100ml
			μ/cm	mg/l	mg/l	mg/l	mg/l	mg/l	
Station-1	20.5	6.80	422	1.49	9.03	0.73	12.3	226	108
Station- 2	20.0	6.86	490	0.93	22.5	0.47	12.7	255	160
Station-3	20.3	6.82	347	1.84	12.7	0.24	3.33	191	59.0
Station-5	20.5	6.78	855	0.45	33.7	1.14	38.7	451	187

Table 4-5: The average pollutant concentrations in ground water collected in the study period at three stations

Sampling stations	Temp (^0C)	pH	WQ Parameters				
			Conductivity	TN	TP	TDS	Total coliforms/ 100ml
			μ/cm	(mg/l)	(mg/l)	(mg/l)	
BDU/EF Pez. site-1	23.4	7.32	1110	Nill	0.16	625	181
Red cross deep well site-2	23.3	7.06	1229	11.7	0.19	732	78.0
Keyamed college Pez.Site-3	23.7	7.39	1026	17.0	0.26	591	109

In this paper, for the whole water quality parameter analyses the composite samples were prepared from three grab samples taken at the runoff start, at the middle and when the runoff peak declines significantly in the event and the concentration is determined only once for one storm event. To determine the event mean concentration for such samples, the data lack series record of time and runoff concentration for one rain fall event since the concentration could not be determined for each grab sample. There fore the pollutant load found from the composite sample analysis for one storm event in each month is taken as the event mean concentration for that specific event and catchment and the site mean concentration (SMC) is taken to be suitable measure of central tendency (i.e. average) of the EMC's for a particular site (Adams and Papa 2000). The SMCs for the study catchments at the six urban runoff sampling stations during the study period are found in Table 4-6.

Table 4-6: The mean concentration (SMC's) for the study catchments at six urban runoff sampling stations during the study period (June-October).

Sampling stations	Av.Q m^3/s	pH	Parameters							
			EC	DO	COD	TN	TP	TSS	TDS	Total colif./ 100ml
			μ/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
Staion-1	0.18	6.67	311	2.61	2.67	17.6	0.41	400	167	147
Station- 2	0.36	6.80	347	3.40	4.00	28.7	0.33	318	163	171
Station-3	0.16	6.85	295	2.20	1.67	20.9	0.56	287	150	145
Station-4	0.32	6.71	195	3.19	3.33	17.0	0.54	546	112	167
Station-5	0.26	6.59	787	0.79	7.33	28.7	0.67	162	412	200
Station-6	0.10	6.73	99.7	4.63	0.67	24.4	0.25	474	62.4	183

From the statistical summary of urban storm water runoff quality data for the study catchment shown in Table 4-7, the mean values for some water quality parameters like chemical oxygen demand (COD), TDS and electric conductivity are found to be lower when compared to the permit values. The runoff concentration load value for total nitrogen and phosphorus are found relatively greater than the permit value.

Table 4-7: Statistical summary of SMCs of water quality characteristics for the study catchment (June-October).

	Temp (^{0}C)	pH	**Parameters**							
			EC	DO	COD	TN	TP	TSS	TDS	Total Colif./ 100ml
			μ/cm	Mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
MaxSMC	19.0	6.85	787	4.63	7.33	28.7	0.67	546	412	200
MinSMC	18.4	6.59	99.7	0.79	0.67	17.0	0.25	162	62.4	145
S.D	0.26	0.23	237	1.35	2.31	5.22	0.16	138	121	21.0
Mean	18.7	6.72	339	2.80	3.28	22.9	0.46	365	178	169

The event mean concentrations (EMCs) of the study area storm water runoff are compared to those of NURP (USEPA, 1983) and CDM (Smullen et al., 1999) data bases of the US and Droste and Hartt (1975) of Canada in Table 4-8 and **Figure 4-1** illustrates the water quality characteristics between EMCs of Bahir Dar storm water runoff and these data sources. All runoff concentration means found in this study are higher than the means found in the data base for North American cities (CDM and NURP) and it shows that the pollutant loads of Bahir Dar storm water runoff are relatively higher than runoff pollutant load for North American cities except for chemical oxygen demand. This is because of more littering, more unsewered houses, more unpaved road and manual street sweeping activities in Bahir Dar.

Table 4-8: Comparison of the study catchment and North America EMC estimates

Quality parameter	Unit	Study catchment runoff	Droste & Hartt (1975)	NURP (USEPA 1983)	CDM (smullen et al.,1999)
PH		6.72	7.40	---	---
EC	µ/cm	339	300	---	---
TSS	mg/l	365	300	174	78.4
COD	mg/l	3.28	150	66.1	52.8
TN	mg/l	22.9	2.98	2.51	2.39
TP	mg/l	0.46	0.52	0.34	0.32

4.1 Statistical comparison between sampling station results

One-way analysis of variance (ANOVA) performed in SPSS software was used to compare and discuss the runoff concentrations obtained in each outfall. The summary of the statistical analysis results are presented in Table 4–9 and the statistical comparison and discussion between station results is based on the data tabulated that follows.

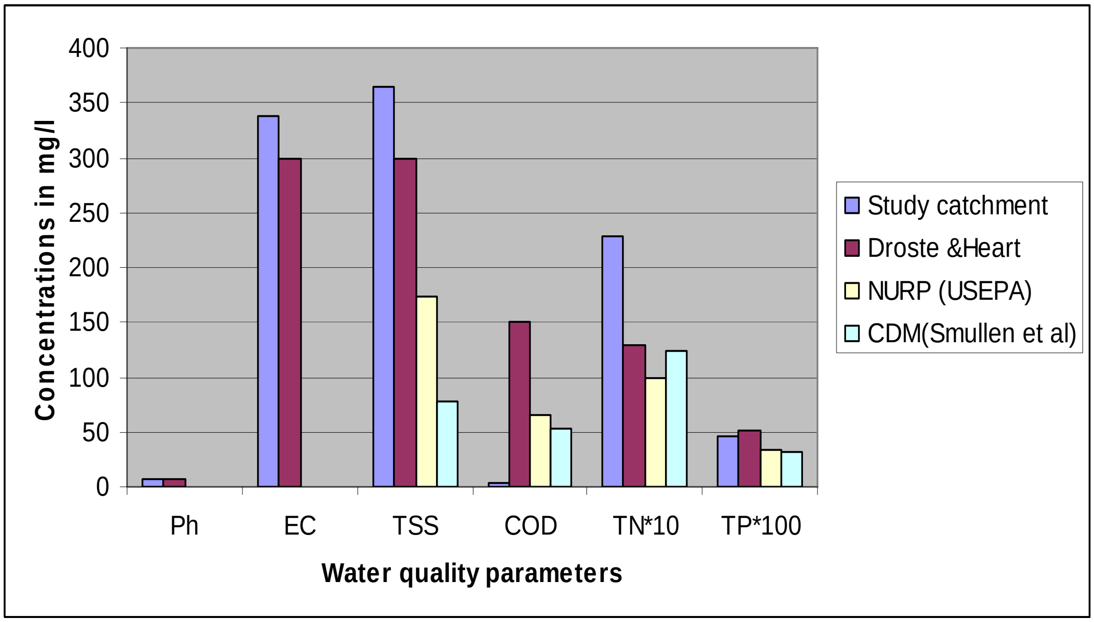

Figure 4-1: Comparison of water quality characteristics between Bahir Dar storm water runoff and other data sources

Table 4-9: Statistical comparison of runoff sampling station for each quality parameter

Sampling stations	Temp (^{0}C)	pH	WQ Parameters EC μ/cm	DO mg/l	COD mg/l	TN mg/l	TP mg/l	TSS mg/l	TDS mg/l	Total colif/ 100 ml
Staion-1	18.4[a]	6.67[a]	311[a]	2.61[a]	2.67[a]	17.6[a]	0.41[a]	400[a]	161[a]	147[a]
Station- 2	18.6[a]	6.80[a]	347[a]	3.40[ac]	4.00[a]	28.7[a]	0.33[ab]	318[a]	163[a]	171[a]
station-3	18.6[a]	6.85[a]	295[a]	2.20[a]	1.67[a]	20.9[a]	0.50[ab]	287[a]	150[ac]	145[b]
Station-4	18.9[a]	6.71[a]	195[ac]	3.19[a]	3.33[a]	17.0[a]	0.54[abce]	546[ab]	112[ac]	167[a]
Station-5	19.0[a]	6.59[a]	787[b]	0.79[b]	7.33[a]	28.7[a]	0.67[ac]	162[ac]	412[b]	200[a]
Station-6	18.5[a]	6.73[a]	99.7[c]	4.63[c]	0.67[a]	24.4[a]	0.25[ad]	474[abd]	62.4[c]	183[a]

*Similar small letter superscripts indicates that there is no significant difference between station value while for different letters the reverse is true

CHAPTER FIVE

5. DISCUSSIONS

5.1 Statistical comparison of water quality parameters between sampling stations

pH: By definition, pH is the negative logarithm of the hydrogen ion concentration. Most natural waters will have pH values from pH 5.0 to pH 8.5. Fresh rainwater may have a pH of 5.5 to 6.0. In this study the measurements carried out for pH in each sampling station have the minimum value of 6.59 and a maximum value of 6.85. The statistical results showed that there is no significant difference between the six sampling stations. This result refers that the pH value for all analyzed samples were with in the range of the acceptable limits.

Total coliforms: Total coliform counts in water bodies are an important parameter for checking possible sewage contamination. Laboratory measurements at the beginning of July sampling showed that the counts of total coliform were considerably high. The laboratory result of the total coliform for all six stations on average basis was above 145colony/100ml and this is a clear evidence of domestic wastewater contamination in all monitoring sites. For the month August there was a slightly decrease in total coliform count but in September the total coliform counts again showed an increasing trend in connection with the flow rate reduction that leads to concentrated pollutant load. The minimum coliform count was recorded consistently through out the study period for samples collected at station 3 (National fuel depot) and this station was significantly different from the other 5 sampling stations. The total coliform for station 5 showed the highest value though there is no significant difference with station 1, 2, 4 and 6.The high values in coliform counts most probably arise from untreated domestic wastewater that most hotels discharged in to the storm draining ditch.

Dissolved oxygen: WHO standards indicate that the acceptable range for dissolved oxygen for fresh water is 10-12mg/l. The analyzed water quality data showed that the dissolved Oxygen levels measured in all monitoring stations were not in the acceptable range according to WHO. The three months measurements in Ethio-star outfall (station 5) showed that the dissolved oxygen levels were consistently below the limit. In contrast at Shumabo (station 6), the DO levels were found higher than the other stations. As it can be shown in the statistical summary (Table 4-9), the result found in stations 5 and 6 were significantly different from the other four stations .The runoff water in all monitoring sites was not suitable to support aquatic life in terms of DO levels.

Conductivity: The monthly conductivity values were not significantly different between the stations. Laboratory measurements for conductivity showed an average value of 786μ/cm levels in the highest measured stations of Ethiostar. The lowest conductivity was recorded at Shumabo monitoring site in all rainfall events (100 μ/cm). After the laboratory analysis, the result of electric conductivity and total dissolved solid were found to be highly correlated (correlation coefficient equal to 0.99). The increase in electric conductivity is completely associated with the amount of dissolved solid in the analyzed samples. The conductivity of station 5 had a value which is significantly greater than the other five sampling stations.

Total dissolved and Suspended Solids: The maximum total dissolved solid pollution loads comes from the Ethiostar (station- 5) with an average load of 412mg/l and the second highest load is from Hospital value of 162 mg/lit which is almost half of the TDS of Ethiostar. Of course, for the third and second rainfall event sampling of July and September, the TDS measurement at this station was above the recommended value (500mg/l) (USEPA).The minimum load is recorded at Shumabo sampling station with a load of 62 mg/l. There is a strong correlation between the total dissolved solid and the conductivity. When the sample has high measurement of conductivity, the TDS is also high with almost half and above the value of electric conductivity consistently at all station .It is observed that total dissolved solids (TDS) in mg/l ranges from 0.5 to 1.0 times the electrical conductivity in µ/cm. As it is indicated in statistical summary the TDS of station 5 showed significance difference with the TDS recorded for other five sampling stations. The TDS for station 6 was also significantly different from station 1, 2 and 5 but not with station 3 and 4. As discussed above the maximum and minimum conductivity TDS value was found in station 5 and 6 respectively.

The suspended solid (SS) pollution loads in all monitoring sites except in Ethiostar sampling station are above 200mg/l, which exceeds the permit level of water quality standard of 50mg/lit (USPCD, Vol. 113 Part 13 D, dated February 13, B.E.2539 (1996). The reason for such a high amount of SS from the five sampling station would possibly originate from the erosion coming from active road construction sites from the immediate vicinity. Because areas along the main streets that feed runoff to this outfall points are excavated for pavement construction, therefore, the adverse effects of surface runoff may cause increase in SS levels. The presence of unpaved roads in this sub catchment may also be the other cause for high value of suspended solids. The lowest suspended solid load recorded in station-5 carries the waste water from Ethiostar hotel in a buried closed pipe. Therefore the runoff that sweeps most of the main roads and walkways found in the sub watershed have no chance to join this sewer line. Higher values of suspended solid were found in sampling stations where urban storm runoff flow in open ditches or along the street curve stones. Except the station-5 value that has significant difference with station 4 and 6, no significance difference was observed in the remaining stations for total suspended solids.

Total phosphorus: The sampling station at Ethiostar was the highest with a phosphorus load of 0.67mg/l. The elevated total P levels in the Ethiostar sampling station could possibly result from soaps used by the hotels that discharge their domestic effluents to the sewer pipe which drains the storm water runoff to this out fall point (sampling station). The second highest level found in Summerland monitoring site could be due to the closely located hotels, public housing wastewater and detergent discharges to this drainage ditch. In the SOS and National fuel depot sampling station the phosphorus levels measurements were also elevated. The average total phosphorus levels recorded at each sampling station and summarized in Table 4-6 were in excess of 0.1mg/l limit for eutrophication (European Community (80/778/EEC) Guide Level.

Total nitrogen: Nitrogen, generally as the two oxidized states nitrate and nitrite, is a nutrient for algal and plant growth in streams; it can be deleterious, especially to infants, when present at high levels in drinking water. Excess nitrogen in urbanized catchment generally results from waste water (failing septic system), over-fertilization of lawns, and fine sediment from erosion or street runoff. For surface waters the acceptable value of nitrogen is 10 mg/ml. The nitrogen loads in all runoff and ground water sampling station were found to be quite high. The average total nitrogen levels in all sampling station were much higher than the surface water nitrogen level. The high level of nitrogen would possibly arises from the direct discharge of house holds, restaurants and other public service giving centers like recreation sites located in the near by of the monitoring sites. Though there is no significant difference observed between the six sampling stations, higher value of nitrogen was recorded at station 2 and 5 with load of 28.7 and 28.6 mg/l respectively.

CHAPTER SIX

6. CONCLUSION, MANAGEMENT IMPLICATION AND RECOMMENDATIONS

6.1 Conclusion

This study was conducted with the main objective of assessing the magnitude of urban storm runoff pollutant load and its impact on Lake Tana. From the result found during the study period, major conclusions were drawn. Conclusions drawn from the site assessment, data analyses, and assessment of results include the following:

1. The runoffs collected from areas where hotels and other commercial centers are located have elevated value of nitrogen and phosphorus which are in excess of concentration that causes eutrophication of the lake.
2. Sampling location in catchments with open drains had greater suspended solids (TSS) concentration than those catchments with closed drains or grassed water way
3. The strongest correlation was observed among the parameters associated with dissolved minerals (electric conductivity and dissolved solids).
4. The concentration of colliforms and other pollutant loads were found to be very high when the discharge is low and there was a long dry period before the sample was taken.
5. The conductivity and total dissolved solids found in ground water was greater than in the urban runoff.
6. Generally the results found from sampled and analyzed runoff during the study indicate that there is domestic wastewater contamination.
7. Pollutant concentrations in all mean except for COD were greater than the average pollutant concentration for the cities in US.

6.2 Management implication and recommendations

Currently the city of Bahir Dar does not effectively manage its storm water. The city service office constructed open ditches that collect the urban runoff that empty in Lake Tana without any treatment and quality control. In view of the relatively large pollutant load to Lake Tana from urban runoff, more attention should be given to the water quality of this urban runoff and the source of pollution. This will require further testing to quantify the load more precisely involving continuous water quality monitoring programs consisting of standardized sampling and runoff measurement. Obtaining reliable data is a prerequisite to implementing best management practices to reduce these loads.

Tentative recommendations for improving urban storm water runoff quality using management practices are summarized into the following two scenarios.

Scenario-1

Expensive treatment plants to treat the runoff water are feasible but can’t be practical because they require a high initial investment, more importantly maintenance costs are high and the necessary expertise for the plants is not available. Therefore under this scenario an immediate option is proposed for improving the storm water quality using natural wetlands. Bahir Dar is surrounded by wetlands and low laying lands that easily can be converted to natural wetlands. Diverting the current storm water that drains into Lake Tana will not only help conserve these wetlands from development pressures, but at the same time treat the wastewater.

Scenario-2 (Future Scenario)

Improvement of storm water quality can also be obtained with urban best management practices. These BMPs are either designed to control the pollution at the source or treat storm water runoff by removing contaminates. This includes:

1. Construction of vegetated swales to promote infiltration and detention of runoff.
2. Remove pollutants before discharging into conveyance systems or Lake Tana. The two tannery factories are of special concern though they are found outside the runoff contributing area to Lake Tana since they uses toxic chemical to treat the hides. Tanneries in the USA have a legacy of polluting river systems decades after they are closed and have been proven.
3. There should be an institute responsible to set legal measures that minimize impact from construction activities.

CHAPTER SEVEN

7. REFERENCES

Adams, B. J., and Papa, F. (2000). *Urban storm water management planning with analytical probabilistic models,* Wiley, Toronto, Ont., Canada.

Chambers, P. A. (1997). "Impacts of municipal effluents on Canadian waters: A review." *Water Qual. Res. J. Canada,* 32(4): 659–713.

Characklis, G.W., and Wiesner, M.R. (1997). Particles, Metals, and Water Quality in Runoff from Large Urban Watershed. *Journal of Environmental Engineering,* 123(8): 753-759.

Das, B.M. (1998). *Principles of Geotechnical Engineering*. PWS Publishing, Boston, Ma, 712 pp.

Droste, R.L., Hartt, J.P. (1975). Quality and variation of pollutant loads in urban storm water runoff. *Cdn J Civ Eng*; 2:418 –429.

Shaver E., Horner R., Skupien J, Chris M., and Ridiey G. (2007). *Fundamentals of Urban runoff management*.

Eshetie Dejen. (2003). *Lake Tana biodiversity potential and treats,* ARARI, Bahir-Dar, Ethiopia.

Field, Pitt. (1990). Water research: Effects of urban runoff from a detention pond on water quality.

Field, Pitt. (1990). Water research: The impact of sediment fecal coliform in reservoirs.

Lee, J.H., Bang, K.W. (2000). *Characterization of urban storm water runoff*. Water res; 34:1773-1780

Loehr. (1974), Bedien. (1978), WEF and ASCE. (1998) and Lee and Bang. (2000). Science of the total Environment: *Pollution loads in urban runoff.*

Minton, G.R. (2002). Storm water Treatment: *Biological, Chemical, and Engineering Principles.* G. Minton, Seattle, Washington, 416 pp.

Nix, S.J. (1994). *Urban storm water modeling and simulation*. Boca Raton, FL: Lewis Publishers

Omernik, J.M. (1976). *The influence of land Use on Stream Nutrient Level*.US-EPA-600/2-76-014.Washington, DC.

Smullen, J.T., Shallcross, A.L., Cave, K.A. (1999). Updating the US nationwide urban runoff quality data base. *Water Sci. Technol.*, 39(12), 9 –16.

CHAPTER EIGHT

8. APPENDIXES:

8.1 Appendix A: Laboratory Analytical Results

Arithmetic mean of urban runoff water quality data collected in July 2008

	Temp (°C)	PH	Parameters EC μ/cm	DO mg/l	COD mg/l	TN mg/l	TP mg/l	TSS mg/l	TDS mg/l	Total coliforms/ 100ml
Staion-1	18.43	6.57	271.27	2.47	0.00	18.03	0.43	337.33	160.67	142.00
Station- 2	18.50	6.57	346.33	4.01	0.00	29.63	0.25	270.67	164.00	178.00
Station-3	18.33	6.70	173.27	2.80	0.00	17.83	0.56	356.33	89.33	101.00
station-4	18.80	6.53	181.67	3.10	0.00	27.77	0.56	436.33	86.67	164.00
Station-5	18.60	6.30	797.67	0.62	0.00	40.60	0.59	204.67	417.33	187.00
Station-6	17.83	6.60	107.73	5.27	0.00	40.80	0.27	394.33	51.00	200.00

Arithmetic mean of urban runoff water quality data collected in August 2008

Sampling stations	Temp (°C)	pH	Parameters Conductivity μ/cm	DO mg/l	COD mg/l	TN mg/l	TP mg/l	TSS mg/l	TDS mg/l	Total coliforms/ 100ml
Staion-1	17.53	6.67	366.73	2.03	0.00	18.99	0.36	285.67	197.33	130.00
Station- 2	17.53	6.83	450.00	2.68	0.00	49.13	0.25	255.33	218.33	157.00
Station-3	18.07	6.87	179.23	2.37	0.00	26.86	0.34	257.33	95.73	97.00
station-4	18.33	6.57	222.13	2.27	0.00	19.57	0.65	405.33	118.33	126.00
Station-5	18.43	6.33	779.67	0.82	0.00	24.37	0.49	136.67	389.00	168.00
Station-6	17.87	6.67	70.20	3.66	0.00	29.48	0.24	312.07	38.00	141.00

Arithmetic mean of urban runoff water quality data collected in September & October 2008

Sampling stations	Temp (^oC)	pH	Parameters							
			Conductivity	DO	COD	TN	TP	TSS	TDS	Total coliforms/100ml
			μ/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
Staion-1	19.2	6.8	294.0	3.3	2.6	15.7	0.4	577.0	144.0	165.00
Station- 2	19.7	7.0	244.0	3.5	4.0	7.3	0.5	428.4	105.6	200.00
Station-3	19.5	7.0	531.5	1.4	1.7	18.1	0.8	248.0	266.0	104.00
station-4	19.7	7.0	180.3	4.2	3.3	3.6	0.4	797.8	132.2	157.00
Station-5	20.1	7.1	782.5	0.9	7.3	21.0	0.9	145.0	430.0	156.00
Station-6	19.7	6.9	121.1	5.0	0.7	3.0	0.2	717.0	98.1	171.00

Arithmetic mean for base flow water quality Data collected in August and September

Sampling stations	Temp (^oC)	pH	Parameters						
			Conductivity	DO	TN	TP	TSS	TDS	Total coliforms/100ml
			μ/cm	mg/l	mg/l	mg/l	mg/l	mg/l	
SOS (staion-1)	20.47	6.80	422.00	1.49	9.03	0.73	12.33	225.67	108
Hospital (Station-2)	20.00	6.86	490.33	0.93	22.53	0.47	12.67	255.33	160
N. Fuel D-epot (station-3)	20.33	6.82	346.67	1.84	12.70	0.24	3.33	191.33	59
Summer land (station-4)									
Ethiostar (station-5)	20.53	6.78	855.00	0.45	33.67	1.14	38.67	451.00	187
Shum Abo (Station-6)									

The average pollutant concentrations in ground water collected at three stations

Sampling stations	Temp (0C)	pH	WQ Parameters Conductivity μ/cm	TN (mg/l)	TP (mg/l)	TDS (mg/l)	Total coliforms/100ml
BDU/EF Pez. site-1	23.4	7.32	1110	Nill	0.16	625	181
Red cross deep well site-2	23.3	7.06	1229	11.7	0.19	732	78.0
Keyamed college Pez.Site-3	23.7	7.39	1026	17.0	0.26	591	109

WQ data arranged for SPSS analysis

Sampling stations	Temp (^oC)	pH	Parameters result EC μ/cm	DO mg/l	COD mg/l	TN mg/l	TP mg/l	TSS mg/l	TDS mg/l	Total coliforms/100ml
Station -1	18.43	6.57	271.27	2.47	0.00	18.03	0.43	337.33	160.67	142.00
Station -1	17.53	6.67	366.73	2.03	0.00	18.99	0.36	285.67	197.33	130.00
Station -1	19.20	6.79	294.00	3.33	2.61	15.70	0.43	577.00	144.00	165.00
Station -2	18.50	6.57	346.33	4.01	0.00	29.63	0.25	270.67	164.00	178.00
Station -2	17.53	6.83	450.00	2.68	0.00	49.13	0.25	255.33	218.33	157.00
Station -2	19.70	7.00	244.00	3.51	4.00	7.30	0.49	428.40	105.60	200.00
Station -3	18.33	6.70	173.27	2.80	0.00	17.83	0.56	356.33	89.33	101.00
Station -3	18.07	6.87	179.23	2.37	0.00	26.86	0.34	257.33	95.73	97.00
Station -3	19.45	6.99	531.50	1.41	1.67	18.10	0.80	248.00	266.00	104.00
Station -4	18.80	6.53	181.67	3.10	0.00	27.77	0.56	436.33	86.67	164.00
Station -4	18.33	6.57	222.13	2.27	0.00	19.57	0.65	405.33	118.33	126.00
Station -4	19.65	7.02	180.30	4.20	3.33	3.60	0.41	797.80	132.20	157.00
Station -5	18.60	6.30	797.67	0.62	0.00	40.60	0.59	204.67	417.33	187.00
Station -5	18.43	6.33	779.67	0.82	0.00	24.37	0.49	136.67	389.00	168.00
Station -5	20.10	7.13	782.50	0.94	7.33	21.00	0.91	145.00	430.00	156.00
Station -6	17.83	6.60	107.73	5.27	0.00	40.80	0.27	394.33	51.00	200.00
Station -6	17.87	6.67	70.20	3.66	0.00	29.48	0.24	312.07	38.00	141.00
Station -6	19.70	6.91	121.05	4.96	0.67	3.00	0.23	716.95	98.05	171.00

8.2 *Appendix B: Statistical summary*

Multiple Comparisons

Dependent Variable	(I) ID	(J) ID	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
PH	1	2	-.12333	.21144	.570	-.5840	.3374
		3	-.17667	.21144	.420	-.6374	.2840
		4	-.03000	.21144	.890	-.4907	.4307
		5	.09000	.21144	.678	-.3707	.5507
		6	-.05000	.21144	.817	-.5107	.4107
	2	1	.12333	.21144	.570	-.3374	.5840
		3	-.05333	.21144	.805	-.5140	.4074
		4	.09333	.21144	.667	-.3674	.5540
		5	.21333	.21144	.333	-.2474	.6740
		6	.07333	.21144	.735	-.3874	.5340
	3	1	.17667	.21144	.420	-.2840	.6374
		2	.05333	.21144	.805	-.4074	.5140
		4	.14667	.21144	.501	-.3140	.6074
		5	.26667	.21144	.231	-.1940	.7274
		6	.12667	.21144	.560	-.3340	.5874
	4	1	.03000	.21144	.890	-.4307	.4907
		2	-.09333	.21144	.667	-.5540	.3674
		3	-.14667	.21144	.501	-.6074	.3140
		5	.12000	.21144	.581	-.3407	.5807
		6	-.02000	.21144	.926	-.4807	.4407
	5	1	-.09000	.21144	.678	-.5507	.3707
		2	-.21333	.21144	.333	-.6740	.2474
		3	-.26667	.21144	.231	-.7274	.1940
		4	-.12000	.21144	.581	-.5807	.3407
		6	-.14000	.21144	.520	-.6007	.3207
	6	1	.05000	.21144	.817	-.4107	.5107
		2	-.07333	.21144	.735	-.5340	.3874
		3	-.12667	.21144	.560	-.5874	.3340
		4	.02000	.21144	.926	-.4407	.4807
		5	.14000	.21144	.520	-.3207	.6007
EC	1	2	-36.11000	79.25050	.657	-208.7820	136.5620
		3	16.00000	79.25050	.843	-156.6720	188.6720
		4	115.96667	79.25050	.169	-56.7053	288.6387
		5	-475.94667*	79.25050	.000	-648.6187	-303.2747
		6	211.00667*	79.25050	.021	38.3347	383.6787
	2	1	36.11000	79.25050	.657	-136.5620	208.7820

		3	52.11000	79.25050	.523	-120.5620	224.7820
		4	152.07667	79.25050	.079	-20.5953	324.7487
		5	-439.83667*	79.25050	.000	-612.5087	-267.1647
		6	247.11667*	79.25050	.009	74.4447	419.7887
	3	1	-16.00000	79.25050	.843	-188.6720	156.6720
		2	-52.11000	79.25050	.523	-224.7820	120.5620
		4	99.96667	79.25050	.231	-72.7053	272.6387
		5	-491.94667*	79.25050	.000	-664.6187	-319.2747
		6	195.00667*	79.25050	.030	22.3347	367.6787
	4	1	-115.96667	79.25050	.169	-288.6387	56.7053
		2	-152.07667	79.25050	.079	-324.7487	20.5953
		3	-99.96667	79.25050	.231	-272.6387	72.7053
		5	-591.91333*	79.25050	.000	-764.5853	-419.2413
		6	95.04000	79.25050	.254	-77.6320	267.7120
	5	1	475.94667*	79.25050	.000	303.2747	648.6187
		2	439.83667*	79.25050	.000	267.1647	612.5087
		3	491.94667*	79.25050	.000	319.2747	664.6187
		4	591.91333*	79.25050	.000	419.2413	764.5853
		6	686.95333*	79.25050	.000	514.2813	859.6253
	6	1	-211.00667*	79.25050	.021	-383.6787	-38.3347
		2	-247.11667*	79.25050	.009	-419.7887	-74.4447
		3	-195.00667*	79.25050	.030	-367.6787	-22.3347
		4	-95.04000	79.25050	.254	-267.7120	77.6320
		5	-686.95333*	79.25050	.000	-859.6253	-514.2813
DO	1	2	-.79000	.58576	.202	-2.0663	.4863
		3	.41667	.58576	.490	-.8596	1.6929
		4	-.58000	.58576	.342	-1.8563	.6963
		5	1.81667*	.58576	.009	.5404	3.0929
		6	-2.02000*	.58576	.005	-3.2963	-.7437
	2	1	.79000	.58576	.202	-.4863	2.0663
		3	1.20667	.58576	.062	-.0696	2.4829
		4	.21000	.58576	.726	-1.0663	1.4863
		5	2.60667*	.58576	.001	1.3304	3.8829
		6	-1.23000	.58576	.058	-2.5063	.0463
	3	1	-.41667	.58576	.490	-1.6929	.8596
		2	-1.20667	.58576	.062	-2.4829	.0696
		4	-.99667	.58576	.115	-2.2729	.2796
		5	1.40000*	.58576	.034	.1237	2.6763
		6	-2.43667*	.58576	.001	-3.7129	-1.1604
	4	1	.58000	.58576	.342	-.6963	1.8563
		2	-.21000	.58576	.726	-1.4863	1.0663
		3	.99667	.58576	.115	-.2796	2.2729
		5	2.39667*	.58576	.001	1.1204	3.6729
		6	-1.44000*	.58576	.030	-2.7163	-.1637

	5	1	-1.81667*	.58576	.009	-3.0929	-.5404
		2	-2.60667*	.58576	.001	-3.8829	-1.3304
		3	-1.40000*	.58576	.034	-2.6763	-.1237
		4	-2.39667*	.58576	.001	-3.6729	-1.1204
		6	-3.83667*	.58576	.000	-5.1129	-2.5604
	6	1	2.02000*	.58576	.005	.7437	3.2963
		2	1.23000	.58576	.058	-.0463	2.5063
		3	2.43667*	.58576	.001	1.1604	3.7129
		4	1.44000*	.58576	.030	.1637	2.7163
		5	3.83667*	.58576	.000	2.5604	5.1129
COD	1	2	-1.33333	5.51429	.813	-13.3479	10.6813
		3	1.00000	5.51429	.859	-11.0146	13.0146
		4	-.66667	5.51429	.906	-12.6813	11.3479
		5	-4.66667	5.51429	.414	-16.6813	7.3479
		6	2.00000	5.51429	.723	-10.0146	14.0146
	2	1	1.33333	5.51429	.813	-10.6813	13.3479
		3	2.33333	5.51429	.680	-9.6813	14.3479
		4	.66667	5.51429	.906	-11.3479	12.6813
		5	-3.33333	5.51429	.557	-15.3479	8.6813
		6	3.33333	5.51429	.557	-8.6813	15.3479
	3	1	-1.00000	5.51429	.859	-13.0146	11.0146
		2	-2.33333	5.51429	.680	-14.3479	9.6813
		4	-1.66667	5.51429	.768	-13.6813	10.3479
		5	-5.66667	5.51429	.324	-17.6813	6.3479
		6	1.00000	5.51429	.859	-11.0146	13.0146
	4	1	.66667	5.51429	.906	-11.3479	12.6813
		2	-.66667	5.51429	.906	-12.6813	11.3479
		3	1.66667	5.51429	.768	-10.3479	13.6813
		5	-4.00000	5.51429	.482	-16.0146	8.0146
		6	2.66667	5.51429	.637	-9.3479	14.6813
	5	1	4.66667	5.51429	.414	-7.3479	16.6813
		2	3.33333	5.51429	.557	-8.6813	15.3479
		3	5.66667	5.51429	.324	-6.3479	17.6813
		4	4.00000	5.51429	.482	-8.0146	16.0146
		6	6.66667	5.51429	.250	-5.3479	18.6813
	6	1	-2.00000	5.51429	.723	-14.0146	10.0146
		2	-3.33333	5.51429	.557	-15.3479	8.6813
		3	-1.00000	5.51429	.859	-13.0146	11.0146
		4	-2.66667	5.51429	.637	-14.6813	9.3479
		5	-6.66667	5.51429	.250	-18.6813	5.3479
NO3	1	2	-11.11333	11.07861	.336	-35.2516	13.0249
		3	-3.35667	11.07861	.767	-27.4949	20.7816
		4	.59333	11.07861	.958	-23.5449	24.7316
		5	-11.08333	11.07861	.337	-35.2216	13.0549

		6	-6.85333	11.07861	.548	-30.9916	17.2849
	2	1	11.11333	11.07861	.336	-13.0249	35.2516
		3	7.75667	11.07861	.497	-16.3816	31.8949
		4	11.70667	11.07861	.311	-12.4316	35.8449
		5	.03000	11.07861	.998	-24.1082	24.1682
		6	4.26000	11.07861	.707	-19.8782	28.3982
	3	1	3.35667	11.07861	.767	-20.7816	27.4949
		2	-7.75667	11.07861	.497	-31.8949	16.3816
		4	3.95000	11.07861	.728	-20.1882	28.0882
		5	-7.72667	11.07861	.499	-31.8649	16.4116
		6	-3.49667	11.07861	.758	-27.6349	20.6416
	4	1	-.59333	11.07861	.958	-24.7316	23.5449
		2	-11.70667	11.07861	.311	-35.8449	12.4316
		3	-3.95000	11.07861	.728	-28.0882	20.1882
		5	-11.67667	11.07861	.313	-35.8149	12.4616
		6	-7.44667	11.07861	.514	-31.5849	16.6916
	5	1	11.08333	11.07861	.337	-13.0549	35.2216
		2	-.03000	11.07861	.998	-24.1682	24.1082
		3	7.72667	11.07861	.499	-16.4116	31.8649
		4	11.67667	11.07861	.313	-12.4616	35.8149
		6	4.23000	11.07861	.709	-19.9082	28.3682
	6	1	6.85333	11.07861	.548	-17.2849	30.9916
		2	-4.26000	11.07861	.707	-28.3982	19.8782
		3	3.49667	11.07861	.758	-20.6416	27.6349
		4	7.44667	11.07861	.514	-16.6916	31.5849
		5	-4.23000	11.07861	.709	-28.3682	19.9082
TP	1	2	.07667	.12339	.546	-.1922	.3455
		3	-.16000	.12339	.219	-.4289	.1089
		4	-.13333	.12339	.301	-.4022	.1355
		5	-.25667	.12339	.060	-.5255	.0122
		6	.16000	.12339	.219	-.1089	.4289
	2	1	-.07667	.12339	.546	-.3455	.1922
		3	-.23667	.12339	.079	-.5055	.0322
		4	-.21000	.12339	.115	-.4789	.0589
		5	-.33333*	.12339	.019	-.6022	-.0645
		6	.08333	.12339	.512	-.1855	.3522
	3	1	.16000	.12339	.219	-.1089	.4289
		2	.23667	.12339	.079	-.0322	.5055
		4	.02667	.12339	.833	-.2422	.2955
		5	-.09667	.12339	.449	-.3655	.1722
		6	.32000*	.12339	.024	.0511	.5889
	4	1	.13333	.12339	.301	-.1355	.4022
		2	.21000	.12339	.115	-.0589	.4789
		3	-.02667	.12339	.833	-.2955	.2422

		5	-.12333	.12339	.337	-.3922	.1455
		6	.29333*	.12339	.035	.0245	.5622
	5	1	.25667	.12339	.060	-.0122	.5255
		2	.33333*	.12339	.019	.0645	.6022
		3	.09667	.12339	.449	-.1722	.3655
		4	.12333	.12339	.337	-.1455	.3922
		6	.41667*	.12339	.006	.1478	.6855
	6	1	-.16000	.12339	.219	-.4289	.1089
		2	-.08333	.12339	.512	-.3522	.1855
		3	-.32000*	.12339	.024	-.5889	-.0511
		4	-.29333*	.12339	.035	-.5622	-.0245
		5	-.41667*	.12339	.006	-.6855	-.1478
TSS	1	2	81.86667	1.20981E2	.511	-181.7275	345.4608
		3	112.78000	1.20981E2	.370	-150.8141	376.3741
		4	-146.48667	1.20981E2	.249	-410.0808	117.1075
		5	237.88667	1.20981E2	.073	-25.7075	501.4808
		6	-74.45000	1.20981E2	.550	-338.0441	189.1441
	2	1	-81.86667	1.20981E2	.511	-345.4608	181.7275
		3	30.91333	1.20981E2	.803	-232.6808	294.5075
		4	-228.35333	1.20981E2	.084	-491.9475	35.2408
		5	156.02000	1.20981E2	.221	-107.5741	419.6141
		6	-156.31667	1.20981E2	.221	-419.9108	107.2775
	3	1	-112.78000	1.20981E2	.370	-376.3741	150.8141
		2	-30.91333	1.20981E2	.803	-294.5075	232.6808
		4	-259.26667	1.20981E2	.053	-522.8608	4.3275
		5	125.10667	1.20981E2	.321	-138.4875	388.7008
		6	-187.23000	1.20981E2	.148	-450.8241	76.3641
	4	1	146.48667	1.20981E2	.249	-117.1075	410.0808
		2	228.35333	1.20981E2	.084	-35.2408	491.9475
		3	259.26667	1.20981E2	.053	-4.3275	522.8608
		5	384.37333*	1.20981E2	.008	120.7792	647.9675
		6	72.03667	1.20981E2	.563	-191.5575	335.6308
	5	1	-237.88667	1.20981E2	.073	-501.4808	25.7075
		2	-156.02000	1.20981E2	.221	-419.6141	107.5741
		3	-125.10667	1.20981E2	.321	-388.7008	138.4875
		4	-384.37333*	1.20981E2	.008	-647.9675	-120.7792
		6	-312.33667*	1.20981E2	.024	-575.9308	-48.7425
	6	1	74.45000	1.20981E2	.550	-189.1441	338.0441
		2	156.31667	1.20981E2	.221	-107.2775	419.9108
		3	187.23000	1.20981E2	.148	-76.3641	450.8241
		4	-72.03667	1.20981E2	.563	-335.6308	191.5575
		5	312.33667*	1.20981E2	.024	48.7425	575.9308
TDS	1	2	4.69000	42.09380	.913	-87.0245	96.4045
		3	16.98000	42.09380	.694	-74.7345	108.6945

		4	54.93333	42.09380	.216	-36.7812	146.6478
		5	-244.77667*	42.09380	.000	-336.4912	-153.0622
		6	104.98333*	42.09380	.028	13.2688	196.6978
	2	1	-4.69000	42.09380	.913	-96.4045	87.0245
		3	12.29000	42.09380	.775	-79.4245	104.0045
		4	50.24333	42.09380	.256	-41.4712	141.9578
		5	-249.46667*	42.09380	.000	-341.1812	-157.7522
		6	100.29333*	42.09380	.035	8.5788	192.0078
	3	1	-16.98000	42.09380	.694	-108.6945	74.7345
		2	-12.29000	42.09380	.775	-104.0045	79.4245
		4	37.95333	42.09380	.385	-53.7612	129.6678
		5	-261.75667*	42.09380	.000	-353.4712	-170.0422
		6	88.00333	42.09380	.059	-3.7112	179.7178
	4	1	-54.93333	42.09380	.216	-146.6478	36.7812
		2	-50.24333	42.09380	.256	-141.9578	41.4712
		3	-37.95333	42.09380	.385	-129.6678	53.7612
		5	-299.71000*	42.09380	.000	-391.4245	-207.9955
		6	50.05000	42.09380	.257	-41.6645	141.7645
	5	1	244.77667*	42.09380	.000	153.0622	336.4912
		2	249.46667*	42.09380	.000	157.7522	341.1812
		3	261.75667*	42.09380	.000	170.0422	353.4712
		4	299.71000*	42.09380	.000	207.9955	391.4245
		6	349.76000*	42.09380	.000	258.0455	441.4745
	6	1	-104.98333*	42.09380	.028	-196.6978	-13.2688
		2	-100.29333*	42.09380	.035	-192.0078	-8.5788
		3	-88.00333	42.09380	.059	-179.7178	3.7112
		4	-50.05000	42.09380	.257	-141.7645	41.6645
		5	-349.76000*	42.09380	.000	-441.4745	-258.0455
Coliform	1	2	-32.66667	16.03699	.064	-67.6083	2.2749
		3	45.00000*	16.03699	.016	10.0584	79.9416
		4	-3.33333	16.03699	.839	-38.2749	31.6083
		5	-24.66667	16.03699	.150	-59.6083	10.2749
		6	-25.00000	16.03699	.145	-59.9416	9.9416
	2	1	32.66667	16.03699	.064	-2.2749	67.6083
		3	77.66667*	16.03699	.000	42.7251	112.6083
		4	29.33333	16.03699	.092	-5.6083	64.2749
		5	8.00000	16.03699	.627	-26.9416	42.9416
		6	7.66667	16.03699	.641	-27.2749	42.6083
	3	1	-45.00000*	16.03699	.016	-79.9416	-10.0584
		2	-77.66667*	16.03699	.000	-112.6083	-42.7251
		4	-48.33333*	16.03699	.011	-83.2749	-13.3917
		5	-69.66667*	16.03699	.001	-104.6083	-34.7251
		6	-70.00000*	16.03699	.001	-104.9416	-35.0584
	4	1	3.33333	16.03699	.839	-31.6083	38.2749

		2	-29.33333	16.03699	.092	-64.2749	5.6083
		3	48.33333*	16.03699	.011	13.3917	83.2749
		5	-21.33333	16.03699	.208	-56.2749	13.6083
		6	-21.66667	16.03699	.202	-56.6083	13.2749
	5	1	24.66667	16.03699	.150	-10.2749	59.6083
		2	-8.00000	16.03699	.627	-42.9416	26.9416
		3	69.66667*	16.03699	.001	34.7251	104.6083
		4	21.33333	16.03699	.208	-13.6083	56.2749
		6	-.33333	16.03699	.984	-35.2749	34.6083
	6	1	25.00000	16.03699	.145	-9.9416	59.9416
		2	-7.66667	16.03699	.641	-42.6083	27.2749
		3	70.00000*	16.03699	.001	35.0584	104.9416
		4	21.66667	16.03699	.202	-13.2749	56.6083
		5	.33333	16.03699	.984	-34.6083	35.2749

*. The mean difference is significant at the 0.05 level.

8.3 *Appendix C: Data of Environmental Features*

8.3.1 I Rain fall

STATION	Bahirdar
ZONE	gmw
LONG.	37.3875
LAT.	11.58972
ELEV.	1770
CLASS	1
Element	Rain fall depth

Date	Jun	Jul	Aug	September	October
1	0	0.1	1.8	33.3	0
2	1.4	0	10.7	1.8	0
3	10.1	2.6	5.6	TR	0.5
4	8.3	13.1	23.7	0	0
5	0	30.8	16.4	3.7	0
6	0	7.3	9.6	TR	0
7	23.7	23.7	tr	9.9	0
8	2.7	12.6	*18.4	9.8	0
9	1	0	19.5	6.4	0
10	9.7	5.3	10.5	1.2	*30.9
11	13.5	26	16.6	0	
12	tr	2.2	31.2	*19.3	
13	0	3.1	22.7	3.5	
14	0	18.2	5.4	7.4	
15	6.5	5.7	3.2	0	
16	4.5	12.6	*20.9	0	
17	22.8	19.6	1.1	23.4	
18	0	24.2	0	0.5	
19	7.1	6	2.3	0	
20	0	*46.1	4.8	4.9	
21	8.6	7.2	7.4	9.7	
22	6.2	2.5	*8.3	1.2	
23	0	9.9	tr	0	
24	0.4	*20.5	2.6	tr	
25	7.4	68.3	19.4	tr	
26	0.3	9.2	8.5	0.6	
27	0	1	17.1	6.2	
28	2.2	18.1	5.6	8.6	
29	14.6	19.3	tr	0.3	
30	24.6	*10.3	4.6	5.6	
31		56	39.7		

* Monitored rain fall events