



Contamination of Rivers and Water Reservoirs in and Around Addis Ababa City and Actions to Combat It

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Abstract

This work focuses on intensive review of various documents, research papers and reports to identify the main source; impact and trend of river and water reservoirs pollution in and around Addis Ababa city, the capital city of Ethiopia. Water is a vital resource needed for the survival of humans and cities. Ethiopia is often referred to as the "water tower" of eastern Africa because of the many rivers. Addis Ababa is endowed with numerous seasonal and perennial small streams that flow to the little and great Akaki rivers, then feeding into the Awash basin and so forth into the lakes of the Rift Valley. As result of fast population growth, uncontrolled urbanization and industrialization and poor waste management practices Addis Ababa water resource highly polluted which threaten human health and ecosystem function as whole. The rivers in Addis Ababa are simply used as a receptacle of all kinds of wastes released in the city. There is a high amount of waste disposal in the river and riverbanks from municipal source (municipal solid and liquid wastes), liquid wastes from toilet, open urination and defecation. Other waste sources come from construction buildings, fuel stations, garage operations and congested settlements. Addis Ababa hosts about 65% industries of the country and more than 90% of the industries discharge their waste to nearby river without proper treatment.

Keywords: Addis Ababa city rivers; River pollution; Source of pollution; Impact of pollution

Introduction

In Ethiopia, there are 12 river basins (Figure 1). Addis Ababa, the capital city has many rivers which are the tributary of main Akaki river (Teleku or Big and Tinishu or Little) [1].

The tributaries of the Akaki River includes Kebena, BancheYekeku, Kortame, Bulbula, LequSoramba and kotebe and Fincha rivers etc. (Figure 2). Akaki river consists of two main branches, the confluence of which at the Aba-Samuel reservoir. Little Akaki flows through the western part of the city, rises north-west of Addis Ababa on the flanks of Wechacha Mountain and flows for 40 km before it reaches the reservoir and the Big Akaki river flows through the eastern part of the city which rises from north-east part of Addis Ababa (Entoto Kidane Miheret) area and flows into Aba-Samuel reservoir after 53 km. The main water resources that provide the city by man-made water reservoirs in the Awash basin, namely Legedadi, Gefersa, Dire and Aba Samuel. With the exception of Aba Samuel, all reservoirs supply domestic and industrial water. The Aba Samuel Reservoir was constructed in the late 1930s for electricity generation, and today some of the municipal and industrial effluents are discharged into this reservoir. Water is being supplied from these reservoirs (80%) and one well system (20%) with a total volume of 210,000 m³ day or 77 million cubic meters (MCM) year [2]. In the previous study done by Alemayehu et al. [3], reported that the Akaki well field provides 30% of the water supply of Addis Ababa and it requires a proper aquifer management.

In Ethiopia, from the increasing human population, uncontrolled urbanization and inadequate sanitation infrastructure cause serious quality degradation of surface waters. Now a day's water pollution from disposal of industrial wastewater is becoming an environmental concern in Addis Ababa city and its vicinity areas, where most (More than 40% of large and medium scale manufacturing industries are located [4]. As a result, many rivers and streams are heavily polluted as they flow through major cities and towns [5]. Pollutants can enter surface waters from point sources such as single source industrial discharges

and waste water treatment plants. However, most pollutants result from non-point source pollution activities including runoff from agricultural lands, urban areas, construction and industrial sites, and failed septic tanks [6]. Thus, Environmental pollution of the Addis Ababa rivers particularly Akaki river has been a subject of concern for many scholars, institutions, the affected community and many environmental groups [7].

Both solid and liquid waste generated from previously mentioned sources contribute for the pollution of Addis Ababa Rivers. Even though Addis Ababa is the only city with sewer networks, it has a very limited sewer network coverage that accounts for 7.5% of the built-up areas. Since only parts of the older sections of the city are connected to the central sewer system, both residential and business premises use septic tanks [8]. Currently there are efforts to control and treat the river in Addis Ababa by city administration including the recent huge river and riverside development project and few private sectors. But these efforts are very limited and not address the whole pollution problem in the city.

Trends and Current Status of Water Pollution in the Rivers and Reservoirs in and around Addis Ababa City

Sources of river pollution in Addis Ababa

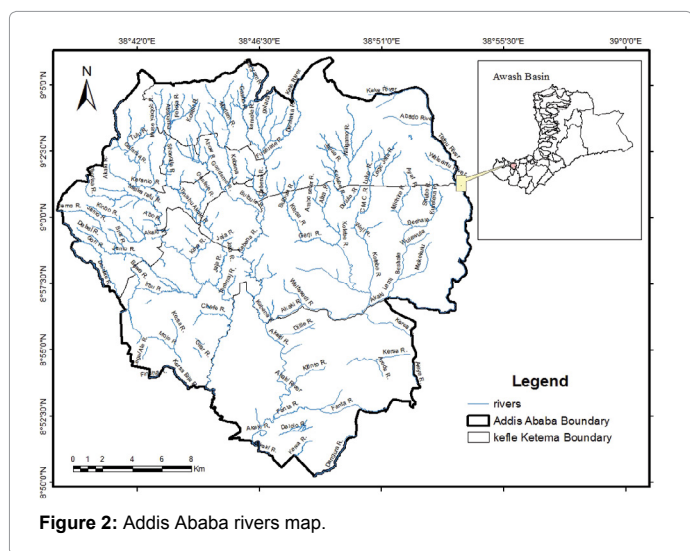
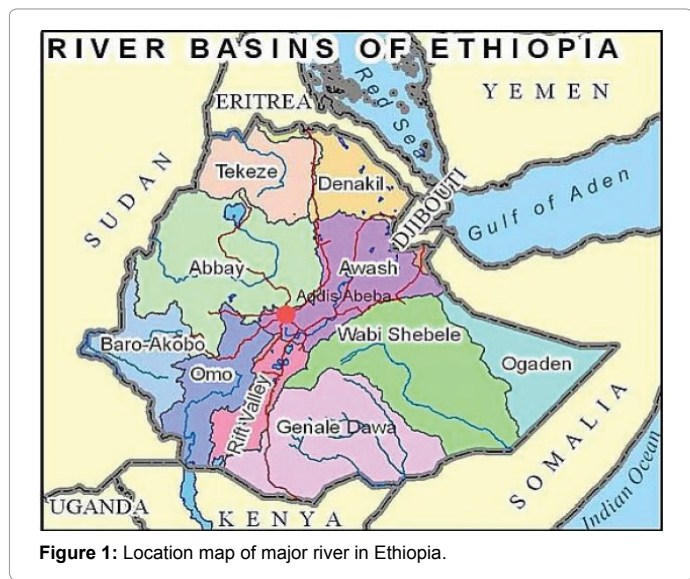
River and Water reservoirs quality can be affected by pollution from point sources and non-point sources. Point sources are identifiable

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locations (such as a factory, often with a pipe or channel leading from them) that discharge directly into a body of surface water. Groundwater is also affected by point sources where contaminants seep into the soil and rock from an identifiable source, for example, underground fuel tanks, septic tanks or pit latrines. Municipal and industrial discharge pipes are good examples of point sources [9]. Non-point or diffuse sources are those where pollution arises over a wide area and it is often difficult to locate the exact place of origin and also difficult to manage and control. For example, fertilizer or pesticide that has been widely spread may be washed from a field by rain into a river or stream at many places, or seep into groundwater; urban and industrial runoff and erosion associated with construction; mining [10]. These activities introduce harmful sediments, nutrients, bacteria, organic wastes, chemicals, and metals into surface waters [6].

Since the city has inadequate and inefficient solid and liquid waste management facilities, all point and nonpoint sources in the city discharge their effluents directly or indirectly to the nearby rivers [11]. Solid waste that is generated is often disposed of in open spaces, where it is washed by runoff during rains, and flows into rivers and seeps

into shallow groundwater. According to the Sanitation Beautification and Parks Development Agency (SBPDA), a city total of 2,256 m³ or 851 tonnes of solid waste is being generated daily of which 65% is collected and disposed in to Repi dump site, about 10 % of the waste is composted and recycled while the remaining 25% is dumped into open spaces, ditches and water bodies (CGASBPDA, 2003). On other study by Alebel et al. [12], about 35% of the solid waste generated in Addis Ababa is dumped on open sites, drainage channel and rivers. City of Addis Ababa generates a solid waste of 0.5 kg per capita per day [13]. Larger sources of solid waste generated from households (76%), from institutions, commercial, factories, hotels (18%) and 6% is street sweeping [14]. In addition to solid waste, waste water is a major contributor to water pollution in Addis Ababa. Discharging of untreated domestic, industrial, commercial and institutional liquid waste in to the rivers and agricultural land use were the observed major environmental stressors that affected the water quality of the rivers [15]. Addis Ababa generates an estimated annual volume of 49 million m³ total wastewater from which about 4 million m³ is industrial wastewater [16]. All wastes dumped in other places eventually end up to rivers during run offs [12].

Thus, the rivers and water reserves of Addis Ababa are polluted by industrial and municipal solid and liquid wastes. The polluted river water is used by downstream residents to grow vegetables, which are sold and consumed by inhabitants of the city [1]. The city's rivers are contaminated with different organic and inorganic pollutants. The shallow groundwater and springs are also contaminated [17].

The Main Sources of Contamination of River in Addis Ababa

Industrial wastes

Addis Ababa is home to more than 2,000 industries which comprises 65% of all industries in the country and most of them located along the river banks which are mostly found in the western and southern parts of the city and discharge these effluents directly to the river, as much as 90% of these industries do not have any kind of treatment plant and discharge their solid, liquid and gaseous wastes untreated into the environment [18]. Others have some degree of on-site treatment plant, and subsequently discharge effluents into adjacent streams (Table 1). Rivers in Addis Ababa are contaminated with heavy metals due to different industrial waste [18]. Therefore, depositing solid and liquid wastes and dangerous substances in rivers and riversides has been a common practice in Addis Ababa [19].

Municipal wastes

Despite generating large amounts of solid waste from domestic activities, Addis Ababa does not have adequate waste management facilities. As a result solid waste is often piled on available open grounds, stream banks and near bridges, where it is washed off into rivers. The Ethiopia Mini Demographic and Health Survey (EMDHS) showed

No.	Type of Factories	Pollutant Substances
1	Food and Beverages	NaOH, detergents fuel combustion
2	Textile, Leather and Leather products	Water pollutants, e.g. Chromium, sulphides, ammonium salts, chlorides, etc.
3	Steel and Wood products	Paint, iron rusts, Varnish, etc.
4	Paper and paper products	Printing chemicals, Lead
5	Non-metal Materials	Air Pollutants: Dust and Particulates, fuel combustion, etc.

EPA [72]

Table 1: Major pollutant substances that are discharged into rivers from factories.

that only 4.5% Percentage of population with access to flush toilet, ventilated improved pit latrine in 2014 [20]. And 65% of the societies have pit latrine. 25% of the city's residence do not have toilet. As a result, the residents use the river as toilet. In addition, houses that are built at the edges of the city's rivers link their toilets directly to them (Figure 3). Therefore, status of river pollution is increasing as time elapsed. Therefore, the city's rivers are lacking aquatic animals and plants (aquatic diversity). Moreover, most of the residential houses, service giving institutions, commerce and the like have directly linked their liquid waste systems including their latrines and septic tanks to the main rivers and their tributaries without any treatment.

Furthermore, most of the river surrounding of the city are occupied by illegal settlers and quarry developers. According to Eyob [21], 90% of surrounding of rivers crossing the major east-west axis are encroached by illegal settlers and riversides are becoming zones of stone excavation [19]. The community also exposed for flood because they settle very close to the river (Figure 4).

Medical waste

A study by FEPA [22] found that 430.7 tons of contagious waste is generated by the 29 hospitals located in Addis Ababa [23]. Examples of the contagious clinical waste include laboratory cultures, wound dressings, blood and other body fluids, and needles. Although most of the hospitals have waste treatment facilities, some of the clinical waste finds its way into the nearby streams that are tributaries [22].

Pollution Trend of Addis Ababa Rivers and Water Reservoirs

Akaki river

Akaki river is the most polluted river system in the country (Figure 5). Mersha [1], reported that water quality in almost all the assessed sites along the Akaki rivers was found to be deteriorated and not meeting the river water quality standard. Such deterioration derived from different sources of pollutants both point (factories discharge, urban waste water discharges, garage wastes, hospital wastes, etc.) and non-point sources (e.g. different sewages runoff, agricultural runoff). Industrial wastes are the dominant sources. Hunde [24], also reported that Akaki River catchment aquifers undergo a serious pollution and proper attention is important.

The overall classification of the water quality of the Akaki river is very bad. Parameters such as different ions, heavy metals, fecal coliforms were found as the major treats impairing the water quality for different uses such as irrigation, swimming and aquatic ecosystem preservation [1].

In particular, the little Akaki river is more polluted than big Akaki river and has a characteristics greenish-dark colour, pitch dark sediment and a peculiar pungent odour which is associated to the industrial and domestic waste discharged to the system. Most of the industries are established along the course of the Little Akaki river and its major tributaries. These include tanneries, breweries, wineries, distilleries, pharmaceutical and national alcohol liquor factories. According to Aschale et al. [25], Toxic trace elements in Little Akaki River exceed the permissible limits of WHO (World Health Organization), European Community and the Ethiopian Standards of drinking water, irrigation and other uses and the river further degraded in quality as compared to the previous study.

Hydrological investigation carried out in the Akaki area have shown that out of the total amount of water supplied to Addis Ababa



Figure 3: People discharge toilet and domestic waste water to Little Akaki river.



Figure 4: Improper settlement near to the rivers in Addis Ababa.

city, 70% return as sewage of which 60% flows in to the Akaki River [26]. Water quality at Akaki river basin changed remarkably over the last ten years (Table 2). Most of the original aquatic life in the two rivers has disappeared over the years due to high level of pollution [8]. Many illegal settlers have settled around Akaki River without obtaining a legal permit from the government [27]. About 10,000 ha of the green frame are already used for other purposes: residential, industrial developments, etc. [28].

Kebena river

Kebena river is a tributary of the Awash River. Alemayehu [29], found that most of the parameters in upstream were low such as water pH, Sodium, Calcium, Magnesium, COD and Manganese and some parameters were high as compared to the lower stream such as sulphate, nitrate and Aresenic (Table 3).

Beyene et al. [30] also reported that upstream site of Kebena River was relatively free from anthropogenic sources of pollutant and located within relatively protected area. Furthermore, most physical and chemical parameter values are above the recommended value and biological components are almost loss therefore, it indicate that Kebena river is has poor quality classes though it has a better status as compared to Akaki River (Table 4). One can conclude that high habitat degradation and loss in the local rivers.

As shown in Figure 6 below, In Kebena river, there is also organic pollution from domestic, commercial, agricultural and institutional wastes and residential pollutant sources were the main cause of pollution for Kebena River followed by institutional and agricultural sources as reported by Alemayehu et al. and Beyene et al. [3,30].

parameters (mg/l)	Study in				Standard limits			
	2008 ^a	2011 ^b	2013 ^c	2015 ^d	WHO	EU	MoWR	AAWSA
BOD5	130	84.35	3980.00	-		70-90		650
COD	356	219.11	11546.6	-		75		
TDS		432.58		-	1000	500	2175.9	1000
TSS		123.41	3835.33	-		90		
Nitrate	7.59	38.49	1513.33	-	50	50	130.57	50
T. Phosphate	3.94	24.07		-	0.54	-	-	-
T. Ammonia		0.495	103.33	-	1.5	-	2.08	1.5
chromium	0.029	78.41	-	67.04	0.05	0.05	-	0.05
cadmium	0.009	0.098	-	0.06	0.3	0.005	0.003	0.003
Arsenic		0.43	-	1.46	0.05	0.05	-	0.1
Iron		2437.5	-	1075.9	0.3	0.2	0.38	0.3
copper		24.96	-	67.04	1	0.1-0.3	1.93	1
mercury		0.40	-	<0.05	0.001	0.01	-	0.001
cobalt	0.048	36.55	-	3.13	NM	NM		
zinc	-	-	-	25.50	5	0.1-5.0	6.05	3
Manganese			-	1540.04	0.1	0.05	0.13	0.5
Biological parameters								
Fecal coliform/100 ml	6.68 × 10 ⁹	1613666.58	-	2.08 × 10 ⁵	0	0	0	0
Total coliform/100 ml		5660433	-	1.35 × 10 ⁶	0	0	0	0

(Extracted from: Mersha [69]; Gebremedehin [70]; Mulu et al. [4]; Aschale et al. [25]; NM=Not Mentioned)

Table 2: Trend of pollution status in Little Akaki river.

Selected physiochemical parameters	Kebena stream		
	Up stream	Near German Embassy	Near Ureal Church
pH	6.08	7.22	7.48
Sodium (mg/l)	15	74	28
Calcium (mg/l)	6	21	17
Magnesium (mg/l)	15	67	36
Sulphate (mg/l)	23	19.7	9.26
Phosphate (mg/l)	Nd	Nd	2.09
Nitrate (mg/l)	531	188.14	8.96
COD (mg/l)	14.4	27.2	20
Chromium (µg/l)	0	0	0
Manganese (µg/l)	12.3	6531.6	1219.01
Nickel (µg/l)	0	0	0
Zinc (µg/l)	0	0	0
Arsenic (µg/l)	1.24	0	0.59
Lead (µg/l)	0	0	0

(Extracted from Alemayehu [29] and zero values represent below detection limit)

Table 3: Measured physiochemical parameter in Kebena river.

Physiochemical components		Biological components		
Parameters	Average value	Parameters	Diatoms	Macro-invertebrates
Temperature (°C)	18.64	Abundance	644.2	400.4
pH	6.36	Richness	15.4	3.6
DO (mg/l)	4.04	Evenness	0.58	0.28
TDS (mg/l)	373.8	Simpson	1.164	0.076
BOD (mg/l)	335.56	Alpha	2.92	0.56
Salinity (PSS)	0.3	% Pollution Tolerance taxa	41.5	96.76
Alkalinity (mg/l)	306	Diversity	2.24	----
Ammonia (mg/l)	5.38	IBD: Diatom biological index	8.58	----
Nitrate (mg/l)	3.06	% DT: Percent dominant taxa;	----	95.88
Phosphate (mg/l)	0.41			

(Extracted from Beyene et al. [30])

Table 4: Summarized physiochemical and biological components in Kebena river.

Bulbula river

Bulbula river is one of the rivers that flow through the inner section of the city, which receive large amount of liquid and solid wastes along their course. The streams serve as the main dumping sites for all forms of wastes from household, construction, garages, fuel station, construction wastes, hospitals, congested settlements and others [31]. Itanna [32], also reported that Ethiopian Metal Tools Factory with a daily domestic and industrial discharge of 21 m³ is the major source of river pollution of Bulbula River, which is used to irrigate part of the Peacock Park vegetable farm. Workalemahu [33], also reported that vegetable grown near to Bulbula river are highly exposed to pollution (Figure 7).

As shown in Table 5, in the soil of Bulbula river Ni (74.13 mg/kg) and Zn (2985.50 mg/kg) become above recommended maximum permissible level which is 50 mg/kg and 300 mg/kg [32].

Tilahun [31], also reported that Bulbula river is highly polluted with trace metals and some excessive nutrients, which are hazardous to human health and natural ecosystem. The middle and lower zones of the Bulbula river are highly polluted than the upper zone of the stream (Table 6).

Fincha river

Fincha river is a tributary of Kotebe River. It located in in Yerer, Bole Sub-city, around Future Park. The river has highly degraded water quality. The possible sources of this pollution are related with different land uses around the river. The land uses include residences, mixed uses, commerce, social services, open spaces and small scale industries (Figure 8). These land uses have contributed to the pollution of the river. This is because, they discharge their liquid and solid wastes into the river through drainage systems without any treatment. Especially, the houses that are constructed along the river directly link their toilets with the river. And the pollution of the river increased as time elapsed [19].

Water reservoirs

Aquifers in and around the city of Addis Ababa are showing signs of increasing contamination by chemicals including nitrate [34]. Alemayehu et al. [35] showed that there is an increasing concentration of heavy metal pollution, coliform and pathogen pollution in the water of Aba Samuel reservoir and its tributaries. Bekele [36] also shows that input of the metals in to the lake is increasing from time to time. Moreover as it contains higher level of dissolved Cd and Mn than the maximum recommended level, the water is unfit to be used

for household consumption. Point source of pollution on Aba Samuel reservoir comes from construction and mining sites in its watershed in and around the city, urban waste, domestic (raw) sewage and factory effluents and contaminants from the tributaries of Akaki river which drain the city of Addis Ababa. The non-point source pollutants come from agricultural sediments.

Impacts of River Pollution

Addis Ababa holds more than 65 percent of the country's all industries [20]. Since the majority of the industries are in Addis Ababa, they have significant negative and positive impacts in terms of socio-economic, political and environmental aspects of the city dwellers' [37]. The odour of sewage is common in in most road side drains of the cities and towns, and most rivers along the main industry zones are excessively polluted. These all generates water borne diseases, decreases the quality of life, and undermines the attractiveness of cities to foreign investors, and the competitiveness of tourism (FDRE, 2015).

Environmental impact

Pathogens, organic compounds, synthetic chemicals, micro-plastics, nutrients and heavy metals are some elements that pollute fresh water. Unregulated discharge of wastewater undermines biological diversity, natural resilience and the capacity of the planet to provide fundamental ecosystem services [11]. Addis Ababa City Rivers highly affected by pollution and has significant impact on macro-invertebrates composition since water quality deteriorates [30]. The contamination of surface water by heavy metals is a serious ecological problem as many heavy metals such as Hg, As, Pb, Sb, Ni, Sr and Cd are toxic even at low concentrations. They are non-degradable and can accumulate in the human body and causing damage to nervous system and internal organs [38,39]. Though some metals such as Cu, Fe, Mn and Zn are essential as micronutrients for living organisms, they can be detrimental to their physiology at higher concentrations [40,41]. Heavy metal affects highly the water biota [42]. Anthropogenic sources of heavy metal are associated mainly with industrial and domestic effluents, surface runoff, landfill leachate, mining of coal and ore, atmospheric sources and inputs from agricultural activities [43].

As surface and groundwater are intimately linked to each other, there might be leakage from the highly polluted River. In the area, where large-scale industries have been expanding, pollution due to disposal of untreated industrial waste seems to be forthcoming [29,44]. Different studies point out that quality of surface water is affected by waste disposal and these would have also potential impact on the quality of groundwater. The ministry of water and energy (2011) report



Figure 5: Akaki river pollution (Source: Alemayehu et al. [3]).



Figure 6: Organic pollution in Kebena river (Source: Alemayehu et al. [3]).

Parameters	Concentration in water (µg/L)	Concentration in soil (mg/kg)
As	1.70	5.19
Cd	0.07	0.71
Co	2.69	27.95
Cu	12.4	38.96
Ni	2.26	74.13
Pb	14.10	46.74
Zn	50.37	2985.50

Table 5: Heavy metal accumulation in water and soil of Bulbula river.

Parameters	Symbol	Sampling Sites		
		Upper Zone	Middle Zone	Lower Zone
Electrical Conductivity	EC (mmhos/cm)	0.069 ± 10.3	0.8 ± 23.3	0.91 ± 82.3
pH	pH	6.37 ± 0.16	7.49 ± 0.1	7.37 ± 0.06
Chloride	Cl ⁻	0.75 ± 0.07	90.11 ± 3.7	71.5 ± 6.45
Sulfate	So ₄ ⁻²	0.04 ± 1.5	0.48 ± 1.2	0.61 ± 2.98
Nitrate	No ₃	5.75 ± 3.31	3.45 ± 2.66	0.23 ± 0.4
Phosphate	Po ₄ ⁻³	1.03 ± 0.28	6.29 ± 1.12	18.44 ± 7.9
Zinc	Zn ²⁺	0	0	0
Copper	Cu ²⁺	0	0	0
Chromium	Cr ²⁺	0	0	0
Lead	Pb ²⁺	0	0	0
Iron	Fe ²⁺	0.1 ± 0.0	0.17 ± 0.05	0.38 ± 0.11
Manganese	Mn ²⁺	0	0.38 ± 0.45	0.096 ± 0.46

^{**}Values are in mg/l except for So₄⁻², EC and pH
^{*}Zero values represent below detection level

Table 6: Bulbula river bank water quality at different zone.



Figure 7: Vegetation near the Bulbula river bank (Source: Workalemahu [33]).

shows that, shallow aquifers to the south of Addis Ababa are most prone to contamination, whereas the pollution risk for the very shallow aquifer to the north of the city is less. For example, Sewage, garbage and toxic pollutants are continually disposed into Akaki River. The contaminants may eventually enter into the aquifer system through porous, permeable media cut by numerous structures or clay materials that lose their filtration capacity [29].

Another environmental effect of the pollution of the water sources of Addis Ababa is eutrophication. Caused by excessive use of phosphorous and nitrogen in agriculture, and effluents from sewerage and pit latrines and municipal wastes, eutrophication causes growth of algae and weeds, which deplete the oxygen level of the water bodies, and in turn affect aquatic fauna and flora. Gizaw et al. and Solomon [45,46] reported that the concentration of nutrient in Aba Samuel lake is very high, which trigger algal bloom (Figure 9). Similarly, AAEP (2002), the pollution of the Akaki River is blamed for the emergence of water hyacinth weed in the Aba Samuel Lake. According to Tasew [47], about 48% of the lake surface area is covered by water hyacinth weed.

Social impact

Industries are contributing to the loss of the well-being of society and are one of the causes for society's health problems. In principle,

development activities of a country are meant to make the lives of citizens better off. But if the benefits people get out of development activities such as the development of industries is overwhelmed by the problems they face, it is considered as undesirable to society. The harmful industrial waste liquids when mixed with rivers and streams endanger public health through different uses [48].

Heavy metals has a capacity to accumulate in the food web especially in fishes and vegetables and threat living organisms [49]. The number of researches has so far been conducted in vegetable grown in polluted soil and irrigated by waste water in Addis Ababa and the results shows that the vegetables have a capacity to accumulate large concentration of heavy metals above the recommended maximum limit [32,50,51]. Since the 1940s, a variety of vegetables have been produced within and around the city, mainly using water from the Akaki River [52]. In Akaki river around 390 hectares of land irrigates vegetables such as potatoes which have some toxic elements such as zinc, nickel, mercury, copper, cadmium and chromium, as does red beet and onions containing chromium [15]. For a long time, it has been known that intake of food



Figure 8: Dumped solid waste and pollution in Finicha river (Source: Tesfaye [19]).



Figure 9: Aba Samuel Lake covered by water hyacinth (left) and Eutrophication in Aba Samuel Lake (right) (Source: Solomon [46]).

that contains high levels of heavy metals, poses risks to human health as shown in Table 7. Report says that high accumulation of heavy metal (beyond maximum limit) in most vegetables from sample taken; high arsenic in carrot, cadmium and chromium in lettuce, iron and zinc in Swiss chard, mercury in kale and high concentration of lead in cabbage. These vegetables directly consumed by the people, which could affect the health of the consumers. Itanna [32] reported that Cabbage was in general the least accumulator of metals/metalloids. Lettuce and Swiss in a few cases, As, Cr, Fe and Pb in these vegetables have surpassed maximum permitted concentrations. The intake of most of the metals constitutes less than 10% of the TMDI (theoretical maximum daily intake) at present, and hence health risk is minimal. But with increase in vegetable consumption by the community the Situation could worsen in the future. Furthermore, Bekele [36] point out that the increasing level of the metals in the sediment of the Aba Samuel lake may pose potential risk on the people residing around the reservoir. This is because large number of people use the water to water their livestock and for other household purposes.

Aregawi [53] found that around Akaki Kality industrial zone most people affected by cough, diarrhea, typhoid and typhus due to serous pollution of the nearby river, Akakai river (Table 8).

Aregawi [53] also reported that vegetable farmers are the most vulnerable groups for the industrial waste related problems (Figure 10).

Economic impact

Polluted water bears two kinds of economic costs: Firstly, pollution reduces the total amount of adequate water available for household consumption or agricultural and industrial usage. Thus, there are economic costs of water held back from supply. Secondly, there are costs related to the use of polluted water for consumption and production. The costs of using contaminated water for production refer to the decrease in both quality and quantity of products [54]. In Africa, due to water pollution and lack of sanitation, the overall economic loss is estimated to be 5% of the gross domestic product (UNESCO, 2009). Teshager [11] reported that there is no study that reveal economic impact of pollution in Addis Ababa rivers and he study willingness to

Potential Health Effects	
Arsenic	Gastrointestinal, skin and nerve damage, cancer
Cadmium	Gastrointestinal, kidney and lung damage
Chromium	Lung and skin damage, cancer
Lead	Nervous and immune system and kidney damage embryo/feto toxic
Mercury	Brain and kidney damage, embryo/feto toxic
Nickel	Lung, brain, kidney, liver, spleen and skin damage, cancer

(Source: Kassa [71])

Table 7: Selected heavy metal of potential health effects.

Health problems	Percentage
Cough	76.5
Diarrhea	58.8
Typhoid	51
Typhus	45.1
Skin problem	41.2
Gastro intestinal	39.2
Asthma	33.3
Eye problem	29.4
Bronchitis	3.9

Source: Aregawi [53]

Table 8: Peculiar disease occurrence around Akaki Kality industrial zone.

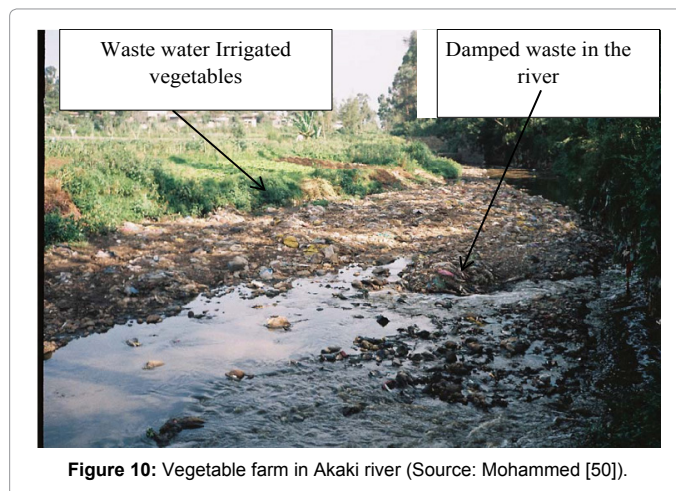


Figure 10: Vegetable farm in Akaki river (Source: Mohammed [50]).

pay of the Addis Ababa city residents for the protection of urban river water pollution and revealed that most of the community live around Akaki river willingness to pay for river protection.

Current approach to Manage River Pollution

Governmental and private investors are participating in the development activities of environmental sanitation in Addis Ababa city [8]. Environmental Protection Authority put wonderful policies and standards to control pollution of the environment including river. Particularly, Addis Ababa city Environmental Protection Authority has a mandate to control pollution in river of the Addis Ababa city. Though this organization does different research study pollution status of rivers in the city particularly in Akaki river, the implementation of the policies especially to penalize industries who does not follow the rules and discharge waste without treatment to rivers is none. According to AAEP report, the organization focuses in awareness creation and working together with the industries to improve their production system as supported by Aregawi [53]. Similarly, Experts in AAEP explained that it is very difficult to take measures since the source of the pollution is difficult to identify.

Currently, city administrations are the main service providers of liquid waste collection services although there are private operators that provide septic tank emptying services. Therefore, liquid waste of the city mainly managed by AAWSA, According to AAWSA expert Mr. Nuri Mohammed personal communication, currently, the organization treats or sewer less than 10 percent of city's liquid waste. This figure is similar with AAWSA [55], report and the remaining are a pit latrines are use d that dispose their wastewater in the storm water drainage network. Mr. Nuri Mohammed also mentioned that they use hybrid waste treatment method, i.e., combination of centralized and decentralized waste water treatment. Centralized waste water treatment means handling wastewater treatment residuals and industrial process by-products that come from other industries. When waste management services are not provided or accessible in unplanned areas through conventional means, the responsibility to manage solid waste becomes the responsibility of individuals. A decentralized waste management system becomes an option. This is an approach is based on the concept of integrating decentralized peri-urban systems within urban planning initiatives and centralized waste concepts (<http://www.borda-africa.org/basic-needs-services/decentralised-solid-waste-management.html>). Thus, Mr. Nuri Mohammed explained that it is important to combine this approaches based on different situation. He continues

to explain, currently the centralized system used in three sites namely, Kality treatment plant, Akaki treatment plant and Eastern treatment plant (Kotebe) having the capacity of 7,600 m³/day (currently work above its capacity about 10, 000 m³/day); 12,500 m³/day and 80,000m³/day (only plan), respectively. The Eastern treatment plant not functional except serve as drying bed then changed to stabilizing pond and receives only sludge from vacuum trucks that empty septic tanks. The main treatment method here is secondary treatment.

In the city, the majority of the population uses on-site sanitation facilities and a very minor proportion use off-site facilities while a significant proportion use open fields and storm water drains for liquid waste disposal [56]. Currently, this situation remains the same. For decentralized or on site treatment, AAWSA usually use oxidation tank but it takes more space so start to use membrane technology which is advanced and there is experienced in nine condominium. Therefore, somewhat conventional treatment method is implemented to treat the waste which includes physical, biological and chemical treatment as supported by [56,57].

According to Mr. Nuri Mohammed, for industrial waste, Upflow Anaerobic Sludge Blanket (UASB) technology is used. UASB reactor is considered to be one of the most successful anaerobic systems, capable of forming dense aggregates by auto immobilization and consequently allowing high-rate reactor performance [58]. Because of its simple design, easy construction and maintenance, low operating cost and ability to withstand fluctuations in pH, temperature and influent substrate concentration, it has gained popularity. UASB reactor as a unit for waste water treatment, under appropriate conditions is quite remarkable [59] study on St George Brewery reported that after UASB reactor treat the waste, the TP, PO₄³⁻, TSS, EC and BOD₅ of the final effluents exceeded the EEPA guidelines; however PH, temperature, TN, NH⁴-N, NO³-N, S²⁻, SO²⁻ and COD could be discharged into nearby river without causing water pollution.

In general, Mr. Nuri Mohammed confirmed that waste water treatment capacity of the organization is limited. Similarly, According to Krishna [60], in Addis Ababa, the daily wastewater discharge from industries is increasing, while, on the other hand, the amount of wastewater treated has decreased annually from 6% to 4% as shown in Table 9.

The solid waste management services provided by city administrations generally focus on the collection and disposal of solid wastes that fall under the category of municipal waste [8]. The solid waste management of the city is very poor. In Addis Ababa the main solid waste management is open dumping. The city has a single open dumping site located about 13 km away from the city center names as 'Koshe', which was established in 1950s. Due to the horizontal expansion of the city now the site become center and more institutions and residences found round it. Currently, the site reach to its maximum full level, yet the city still utilize the site as the only open disposal location. This site affects the surrounding environment including the inhabitants [13]. According to City Solid Waste Recycling and Disposal Project Office, Currently new sanitary landfill already built in Sendafa, Oromia state, but not operational due to some conflict. This new landfill is expected to process solid waste for the coming 30 years generated from the City, when it became fully functional.

Addis Ababa city administration also start some effort, in order to improve the mismanagement and development of the city's riparian zones, the city developmental plan designated 15 m of width for riparian zones that are located in inner city. Also along the expansion

Indicators	Annual Trend					
	2005	2006	2007	2008	2009	2015
Daily wastewater generated in m ³ day ⁻¹	136,893	136,027	149,392	155,013	161,668	404,170
Daily wastewater treated in m ³ day ⁻¹	8,530	8,592	8,768	8,024	6,728	8,129
Percent (%)	6%	6%	6%	5%	4%	2%

Source: CSA (2010)

Table 9: Amount of wastewater released and treated trend in Addis Ababa.

areas of the city, 50-100m width are assigned. The City Development Plan of Addis Ababa also allocated 22,000 ha of land for the green frame thereby expected to cover 41% the city's territory if successfully implemented. It is expected for no settlement or any other sort of physical interventions to happen other than green development [61]. This effort approved by watershed expert in the riverside rehabilitation project in AAEP and also mentioned that this project is undergoing with collaboration of Addis Ababa University and Addis Ababa city administration. The project start working in Kebena river and they start to identify specific source of pollution stating from its initial point as explained by pollution control expert in Addis Ababa University river and riverside development project.

Possible Options and Area of Improvement

Low cost pollution control and waste water treatment

Establish riparian vegetation buffers: Non-point source pollution can be difficult to control, measure, and monitor. Riparian vegetation plays a key role in mitigating non-point source pollution as bio-accumulators. Tilahun [31] reported that the grass species *Arundo donax*, which is the dominant vegetation type along the river bank, found out to be an excellent sink (absorbent) of much of trace metals along the riverbank. This riparian forest buffers could be considered as phytoremediation measure since it is known as an innovative use of green plants to clean up our environment. A number of different plants, trees and grasses are used to stimulate microbial degradation of organic contaminants in soil [31]. Vetiver (*Vetiver zizanioides*) grass installation also could be one option to vegetate the riversides. It is an extremely hardy grass species with a number of characteristics that make it ideal for use in environmental protection measures such as vegetative buffer strips and it is unlikely to be adversely affected by runoff and low cost measures [62].

This option is low cost as compared to the mechanical measures and it should get priority. According to Dunfa and Krishna [60], the amount of waste treated decrease and waste generation rate increase from time to time. This indicates that, it is becoming a crucial issue requiring the introduction of low-cost treatment techniques that use local abundantly available raw materials.

Addis Ababa should be clean and beautiful as capital city. Therefore, this option not only control pollution but the riverside aesthetic value will increase.

Adsorption method: Among the possible techniques for water treatments, the adsorption process by solid adsorbents shows potential as one of the most efficient methods for the treatment and removal of organic contaminants in wastewater treatment. Adsorption has advantages over the other methods because of simple design and can involve low investment in term of both initial cost and land required. The adsorption process is widely used for treatment of industrial

wastewater from organic and inorganic pollutants and meets the great attention from the Researchers. In recent years, the search for low-cost adsorbents that have pollutant-binding capacities has intensified. Materials locally available such as natural materials, agricultural wastes and industrial wastes can be utilized as low-cost adsorbents. Activated carbon produced from these materials can be used as adsorbent for water and wastewater treatment. Rashed [63], Zeinu and Sahu [64] reported that bio-adsorption method by using Eucalyptus bark, Coffee husk, and Sawdust was found to be suitable for tannery wastewater treatment in Ethiopia. As we know tannery wastewater holds dangerous chromium which have carcinogenic effect.

Cleaner production: UNEP defines Cleaner production as means the continuous application of an integrated preventive environmental strategy to processes and products to reduce risks to humans and the environment. For production processes, cleaner production includes conserving raw materials and energy, eliminating toxic raw materials, and reducing the quantity and toxicity of all emissions and wastes before they leave a process. For products, the strategy focuses on reducing impacts along the entire life cycle of the product, from raw material extraction to the ultimate disposal of the product. Cleaner production is being increasingly accepted around the world [65]. Therefore, the industries found in Addis Ababa could incorporate this concept since it creates triple win-win-win situation for environment, community and business (UNEP, no date). There are successful industries by following this approach such as DuPont chemical industry in US, polyethylene plant at Altona and NEEASAE Fluorescent lamps manufacturing industry in Egypt. Ethiopia already has cleaner production policy in EPA proclamation that states the prime option to control pollution is to use cleaner production. Thus, the only thing left is enforcement.

Area of improvement

Improve the existing waste water treatment plant: AAWSA [66] confirmed that treated wastewater effluent can be used for: irrigation, industrial, recreation, groundwater recharge, potable water reuse, and discharge in to surface water. But the issue of the use of reclaimed water for drinking purposes has been approached with extreme caution because of public rejection and because of health, safety and aesthetic concerns. At present, the option of direct potable use of reclaimed municipal waste-water is limited to extreme situations.

Land use planning: For effective urbanization and organized urban development, a well thought urban planning exercise is a prerequisite. Even though land is the largest economic resource of Addis Ababa, the land use pattern is characterized by haphazard development which mainly geared towards horizontal expansion (Finance and economic development office report, 2010). Particularly, most of the riverside areas in the city are not well kept and utilized as per the acceptable standard [67].

In addition to Environmental regulation of Ethiopia which prohibit to use buffer areas for any purpose except greening. The master plan of the city that was developed in 2002 and is currently at work has put a particular setback of a minimum of 15 m buffer zone in both sides of the river course for areas located in the inner city and developed areas of the city. The 15 m setback should also incorporate 2-5 m width walk way/circulation along the river corridor. The delineation of the buffer zones along the rivers is expected to stretches to 50-100 m in the peripheries (ORAAMP, 2002). Within this zone at least on a principal basis, for environmental and ecological reasons, it is expected for no settlement or any other sort of physical interventions to happen other than green development [61].

Addis Ababa City Administration with collaboration of AAEPa and AAU starts to rehabilitate the riverside and delineate buffer zone in every river found in Addis Ababa by allocating huge investment. But their activities appear weak and unorganized. Therefore, they need to improve their by including more experts from different field to undertake reliable research and bring significant output.

Holistic multi-sectoral approach: To tackle multilateral problem of the environment, there should be collaboration of different Responsible institutions should work in collaboration to solve this serious environmental problem [68]. It is important these institutions strictly implement industrial pollution control measures and apply guidelines to mitigate further contamination of water, soils and crops with especially heavy metals.

Conclusion and Recommendation

Conclusion

Currently, Addis Ababa City Rivers are highly polluted as a result of increasing human population, uncontrolled urbanization and inadequate sanitation infrastructure and system. The main cause of this pollution is domestic waste, industrial as well as hospital wastes from point and non-point sources. Little Akaki river among other river is the most polluted river due to it surrounded by industries and largest market of the country as well as east Africa (Merekato).

The degradation of water quality poses serious impact on the environment, social and economic sector. Heavy metal accumulation in Akaki river call critical attention because around the river there is large urban agriculture activities to grow mainly vegetables. Vegetables have a capacity to accumulate large concentration of heavy metals and pass to human body through food chain which affects the health of the community. The biota of the river already destroyed. Most studies agreed that the river water should not be used for irrigation, drinking, livestock drinking and washing. In addition, though there is estimated economic loss of Addis Ababa river pollution, it is obvious it put huge negative impact in economic loss and even affects countries GDP.

To control river pollution and rehabilitate the affected river and riversides, there are different efforts by mainly government organization including AAWSA sewage management and the new project launched in 2016 with the collaboration of AAU, City administration and AAEPa and policy formulation principally by EPA to control pollution of rivers. But still the management status/implementation is limited in general due to different challenges as mentioned by different researches. Therefore, Low cost appropriate pollution control and waste water treatment such as buffer zone vegetation, Adsorption method by using locally available materials are very important based on the country's economy.

Recommendations

- Based on the intensive appraisal of different scientific papers and reports, the following recommendations are forwarded:
- The city administration should focus on treating the polluted rivers by adoption of adequate measures and initiate and expand cleaner production system to avoid further deterioration of the river water quality.
- Strength decentralized waste management system for already urbanized area like upgrading waste treatment plants and considers centralized waste management system for any new construction.

- There should be capacity building for every stakeholders stating from the government bodies like AAWSA, AAEP, EPA, etc., up to the city communities who lives near to the river and far from it.
- Strict policy implementation should be placed in different industrial effluents to avoid the contamination of the rivers water.
- There should be collaboration among the organization who involve in pollution control and rehabilitation of river and riversides, to avoid repetition of efforts.
- There should be affordable waste management strategy for every society.

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