Urban Metabolism Analysis: A Case Study of Addis Ababa, Ethiopia

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Abstract Urbanization has been spreading across the globe and today, 55% of the world's population lives in the cities. These numbers are small in Africa; however, the urbanization rates are rapidly increasing. An urban metabolism study is an analysis of the energy, material, water, wastes and emissions coming in and out of an urban area that can provide a framework for examining the environmental impact of daily socio-economic activities in cities. The study serves as a basis for more research in urban sustainability, energy efficiency, emission control and more by looking at the analysis of the specified region as if it were an ecosystem. This research paper focuses on the water supply and distribution, and wastewater treatment and collection of Addis Ababa, Ethiopia for an urban metabolism study. Water leakage, being a persistent problem in the city, is included in the study as the water outflow. It was found that 32% of the total water produced was lost due to water leakage in 2005. In addition, a big gap was found between the total water inflows and outflows of the study. Detailed information in the amounts of water losses and causes of water leakage are needed for future research directions.

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I. Introduction

Due to urbanization, developing countries with quickly growing populations face a great challenge in water supply coverage with increasing consumption and meeting the demand for wastewater treatments. One fifth of Ethiopia's population resides in cities today compared to a 55% urban population in the world; however, the population in Ethiopian cities is expected to increase to 40% by 2050 (UN Population Division 2018). Major cities in Ethiopia lack the necessary infrastructure to host their current populations and are not prepared for the immediate hikes expected. Hence, an urban metabolism study has become imperative now more than ever.

Urban metabolism is a way of evaluating the energy, water, food, and material flows to provide a framework of changes in the overall metabolic flow of a city due to socioeconomic activities for sustainable urban planning and policy analysis. The analysis is affected by elements including climate, affluence, and population density (Fernández 2013). Initially developed by Wolman in 1965, the urban metabolism concept has grown to include socioeconomic factors, health issues and additional environmental impacts. It has been since used in major cities of the world including Tokyo, Brussels and Hong Kong as the future of energy efficiency, material recycling, emission control and waste management can be guided through urban metabolism studies (Farzinmoghadam 2014). The results of an urban metabolism study can serve as a basis for more understanding of many urban sustainability themes, including energy efficiency, pollution mitigation, and equity issues in resource access when spatial modeling is employed.

This paper focuses on estimating an urban metabolism study of water flows in the capital city of Ethiopia, Addis Ababa. In addition, it covers issues of water leakage and climate vulnerability both at the city and country level. As mentioned before, Ethiopian cities are growing in density due to increasing urbanization and population growth rates. It was important to choose Addis Ababa for this case study because 25% of the Ethiopian urban population reside in the capital and the city has become one of the fastest growing economies in Africa.

All necessary data collection was made from peer-reviewed journal articles and Thesis or Dissertations that focused on water supply and distribution and wastewater treatments in Addis Ababa. Hence, the biggest challenge in creating this framework was organizing the data available. The study years of interest for this paper were 2003, 2004 and 2005. The economic growth and population increase has brought significant changes in the inflows and outflows of water distribution and wastewater collection in these years.

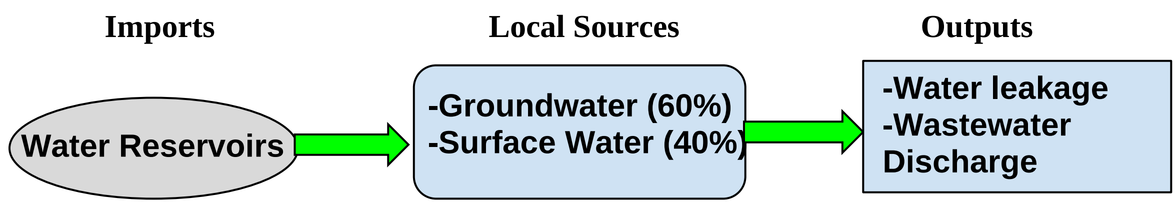

Figure 1 Diagram for urban water metabolism of Addis Ababa

All inflows and outflows that are discussed in this report are outlined in Figure 1 above.

II. Literature Review

As environmental and social issues arose around the world, the United Nations gathered for the Earth Summit in 1992 to draft sustainability development programs to be implemented across the globe. Developing economies, facing much larger issues of poverty and low growth rate of agricultural productivity, were additionally provided with Millennium Development Goals. Hence, there have been an increasing number of parties getting involved in implementing Africa's Sustainable Development Goals. When the summit met again in 2012, Africa had made notable progress despite the poor political engagement and limited investments from local stakeholders in the efforts made for the two decades reported (RIO+20 2012). According to the Progress towards Sustainability Development in Africa report, six African countries were placed in the top 10 growing economies in the world including Ethiopia (2012). To maintain the rapid economic growth and the support from United Nations, African countries should take an assessment of the urbanization rates as it correlates to the cities' metabolisms.

Conducting an urban metabolism analysis in a developing country is a difficult task due to low data availability and scarce pre-existing studies in the field. However, that didn't stop Paul Currie and his colleague Josephine Musango from conducting an urban metabolism study on 120 African cities (2016). The study included "consumption of biomass, fossil fuels, electricity, construction materials, and water, as well as emissions of carbon dioxide" (Currie 2016). Most importantly the article provides a comparison between the total material consumption of a city and the material consumption per capita of ten different categories of resources including water (Currie 2016). This helps draw an urban metabolism analysis of how a high amount of inflow to a city can be limited when distributed amongst its inhabitants.

In October 2017, Currie and Musango alongside Nhlanhla May conducted additional research on resource consumption in Cape Town. Flows including water, food, transportation, housing, energy and solid waste were navigated as they relate to each other in the concept of nexus. The study also examined the consumption levels in impoverished communities in the city as they compare to better served areas. The paper recommends an integrated approach in devising new infrastructure developments and urban planning and shows that efforts have been made by the city of Cape Town.

III. Purpose and Scope

The purpose of this paper is to calculate the annual water production and consumption levels and compare it with water outputs including water leakage and wastewater. The analysis is based on the city of Addis Ababa both at the Woreda (sub-city) and Kebele (sub-division) levels.

IV. Materials and Methodology

The inputs of the urban metabolism study were calculated and compared to results from the outputs. Values were converted to daily averages for the purpose of the comparison.

Method

The methodology employed in this report for water inflow was adapted from the work done by Desalegn in his thesis, "Water Supply Coverage and Water Loss in Distribution Systems: The case study of Addis Ababa" (2005). The amount of water consumption was calculated in average daily consumption per capita of inhabitants in each Kebele, which is a subdivision of the city.

$$\text{Per capita Consumption } (\text{m}^3/\text{person}/\text{day}) = \frac{\text{Annual consumption}(\text{m}^3)}{\text{Population in each Kebele} * 365 \text{ days}}$$

Out of the 303 kebeles located in 28 former Woredas in Addis Ababa, about 50% were selected for the study. Statistical analysis including a box plot and histogram is provided to assess the distribution of water consumption in each of the 144 kebeles (Desalegn 2005). The average daily per capita water consumption is then converted back to daily consumption averages to compare the values with the outputs.

The total annual water loss of the city between July 2003 and June 2004 was calculated in m^3 and expressed in percentage (Desalegn 2005). Amount is converted to annual average from the two years recorded. The wastewater effluent going into the Kaliti Wastewater Treatment plant was estimated to be 7,500 m^3/d in 2007 (Abiye 2008). Amount is converted into annual values as well. The sum of the two amounts is the output of the study.

$$\text{Total water loss } (\%) = \frac{(\text{Total water produced} - \text{Total water billed}) * 100}{\text{Total water produced}}$$

Case Study

Addis Ababa is the headquarters of the African Union and the capital city of Ethiopia, located in east Africa. It is home to over 3.3 million people as of 2016 (UN Population Division 2016). Covering 647 km^2 of land area, the capital has a 14% economic growth rate contributing for 50% of the national GDP (The World Bank Group 2015). Merkato, located on the northwestern part of the city, is one of the largest open-air markets in Africa (Hean et al. 2016). The Addis Ababa Water and Sewerage Authority (AAWSA) is the public institution providing potable water and collecting and treating wastewater and sludge (Desalegn 2005). Surface and groundwater are the two main sources of water in the city totaling for 450,000 m^3/day; however, 36.5% is lost because of pipe leakage and other factors denying 54% of the residents from access to clean water (The World Bank Group 2015). This is due to water traveling long distances from the Gafarsa and Legedadi water reservoirs with design capacity of 30,000 m^3/d and 150,000 m^3/d respectively. Water travels a combined 18.3 km of pipelines with gravity requiring no energy until it arrives to the city where it is pumped for distribution (Desalegn 2005). The two major wastewater treatment facilities are Kality and Kotebe with treating capacity of 7,600 m^3/d and 2,000 m^3/d respectively (The World Bank 2015). Addis Ababa faces water scarcity due to growing population and rising urbanization rates. In addition, the city suffers from poor wastewater management with the Kaliti wastewater treatment plant processing close to 10,000 m^3/d as of 2015 (The World Bank Group 2015). This is leading to contamination of the Akaki river and posing health risks to inhabitants in the area.

Data collection and calculation methods

For the water consumption and water loss calculations, data recorded by the AAWSA for monitoring purposes was utilized (Desalegn 2005). Annual wastewater effluent value from the Kaliti wastewater treatment plant for 2007 was obtained from the article in Environmental Geology, "Use of treated wastewater for managed aquifer recharge in highly populated urban centers: a case study in Addis Ababa, Ethiopia" (Abiye 2008). Data on total wastewater effluent in the 144 kebeles under study was not found in google scholar or the UC Davis Library database. In addition, an overall wastewater effluent of the city that would've provided a comparison with additional limitations was not found either. The average water leakage was calculated by subtracting the total water billed to the consumer from the total water produced. Average water loss was presented in percentage of the total water produced (Desalegn 2005). Microsoft excel was used to summarize findings and draw conclusions.

V. Results

The distribution of water consumption is presented using statistical analysis of a box plot and histogram.

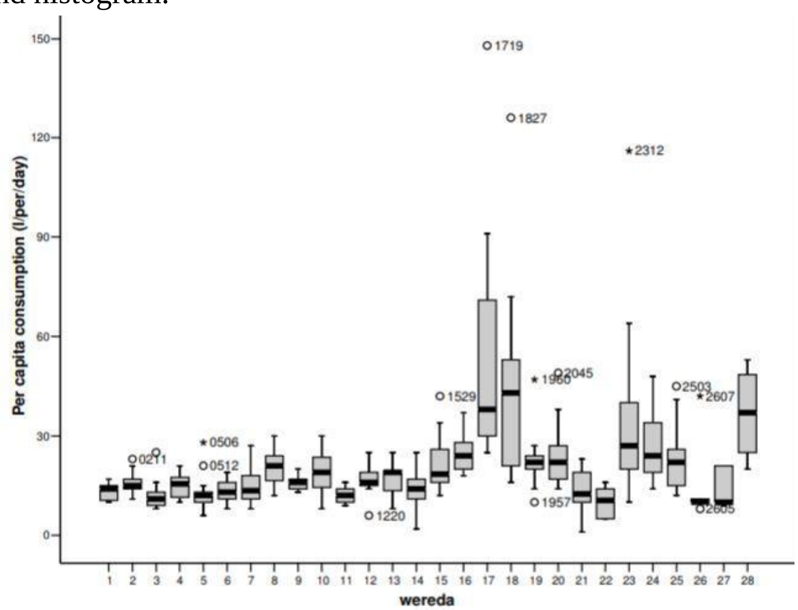

Figure 2 Consumption of water in 144 Kebeles in Addis Ababa (Desalegn 2005)

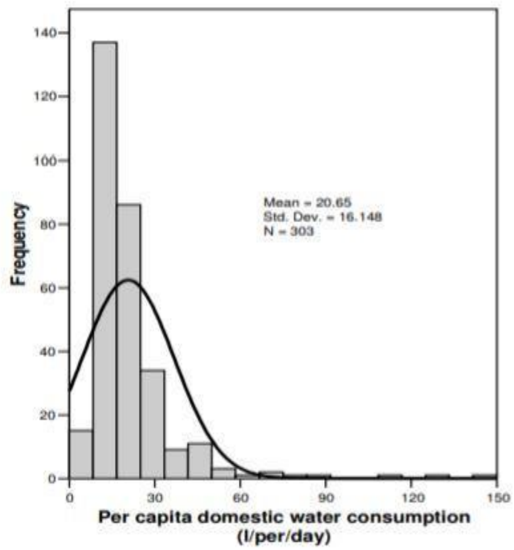

Figure 3 Histogram of per capita consumption (Desalegn 2005)

As shown on figure 3, the water consumption varies with each Woreda and kebeles in each Woreda. Woredas 17, 18, 23 and 28 have much higher consumption averages compared to the other 24 Woredas (Desalegn 2005). This gap in average values is brought to light on figure 4 with the skewed histogram. For a better analysis, the Woredas with outlying averages should be excluded. Figure 4 below shows the difference between consumption average of all 28 Woredas and the new consumption average without the outlying Woredas (Desalegn 2005). A histogram is then plotted using the new consumption averages found in figure 5.

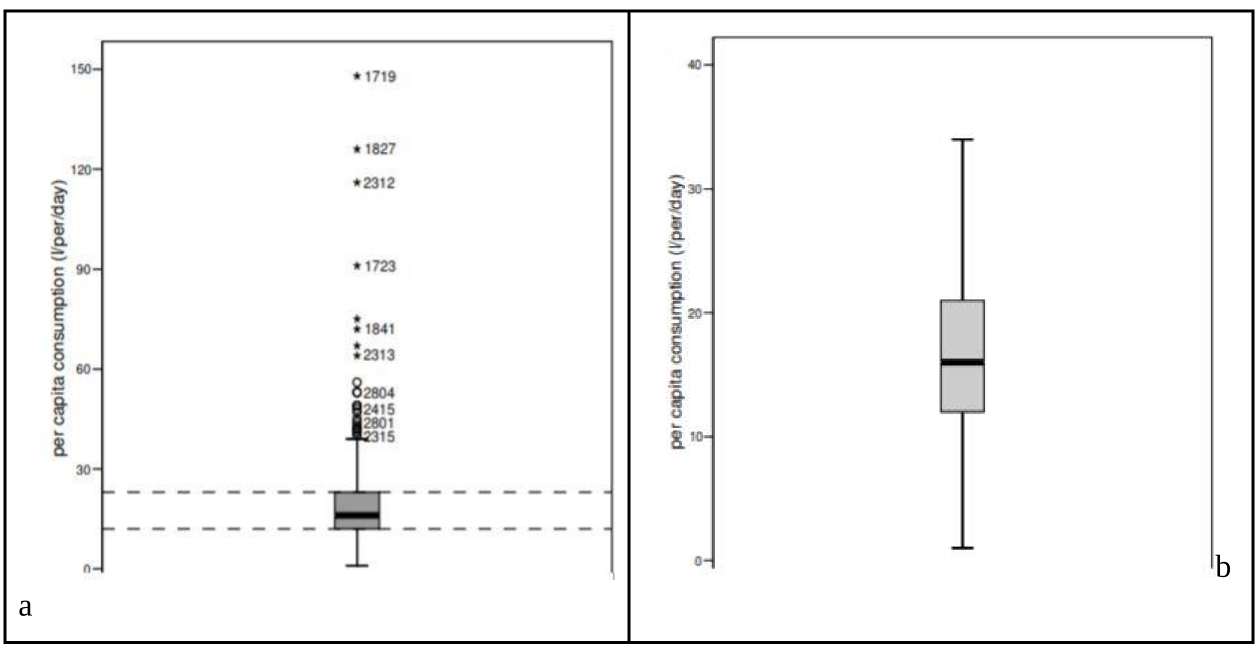

Figure 4 (a) Box plot for all Kebeles (b) Box plot after excluding outliers (Desalegn 2005)

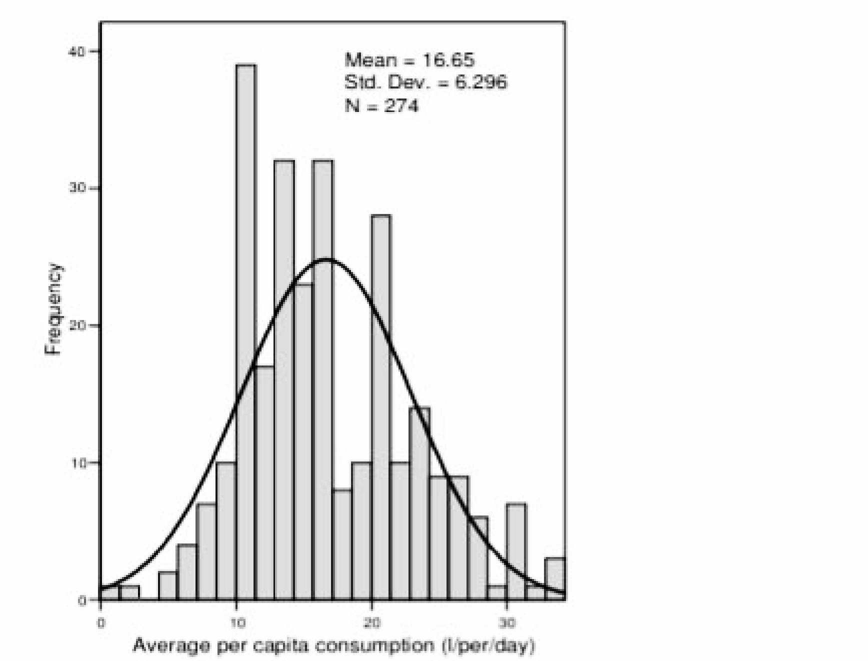

Figure 5 Histogram of per capita consumption excluding outliers (Desalegn 2005)

Calculating the mean consumption, the average water consumption of the city comes out to be 16.65 L/person/day (~0.01651 $\mathrm{m}^3/\mathrm{person}/\mathrm{day}$).

The cumulative average water loss was calculated by finding the difference of the total water produced and the total water consumed (Desalegn 2005). The annual water produced in the specified year was 73,293,783 $\mathrm{m}^3$and the annual water loss was calculated to be 23,399,155 m^3. This gives a water loss percentage of 32% (Desalegn 2005). Using the average water billing in Addis Ababa of 1.95 Birr, the leakage will sum up to 45.4 million Birr, which is estimated to be 5.25 million USD at the time (Desalegn 2005). However, for a city with increasing water consumption and demand facing water sacristy, the money is a problem of least concerns.

The wastewater discharge considered in this study was the 7,600 m^3/d coming into the Kality wastewater treatment plant in 2005 (Abiye 2008).

Table 1 Summary of Results

		Annual values
Inputs	Groundwater	164250000
	Surface Water	
Outputs	Water leakage	23399155
	Wastewater	2774000
Difference		138076845
Consumption		19886295

As shown on table 1 above, there is a large difference in the amount of inputs and outputs that were studied.

Findings presented in this report are not guaranteed to be accurate and complete. This is due to limitations in data collection and analysis. The study only considers around 50% of the Kebeles in Addis Ababa; as a result, the average consumption rates are potentially going to be different if calculated for the all 303 Kebeles. During the water loss analysis, water consumption in firefighting use and water authorities was not included. According to the 1996 Ethiopian Fiscal Year report of AAWSA, annual water used in firefighting and the water authorities is only 0.1% of annual water production in Addis Ababa (Desalegn 2005). Hence, this limitation could've only affected our results very slightly unlike the limitations due to data collection.

VI. Discussion

Due to limitations in data collection and analysis, it would be hard to draw possible causes of water leakage. Possible causes can include but are not limited to pipe aging, ground elevation differences, and use of comparison of meter records to determine water loss (Desalegn 2005).

Water consumption levels mostly followed trends of number of population in the area. However, some areas with lower populations were consuming much higher than other areas. This shows that these areas are relatively rich and better served communities (Desalegn 2005). Another reason could be because some regions in Addis Ababa receive water from the tap 2 to 3 times a week. This has created a sense of water conservation habits; hence, resulting in lower consumption levels despite a higher number of populations.

Addis Ababa's rapidly growing economy is 43% dependent on the agricultural sector, adding economic vulnerability (Hean 2016). The country is among the top 10 African countries with an annual growth rate of higher than six percent in agricultural productivity (RIO+20). This makes Ethiopia vulnerable to climate changes. In addition, the country only has a water storage capacity of about 43 m^3/person/year compared to North America that has an average water storage capacity of 5,961 m^3/person/year (The World Bank 2010). Hence, a slight variation in rainfall can easily cause change in the economy as shown in figure 6 below.

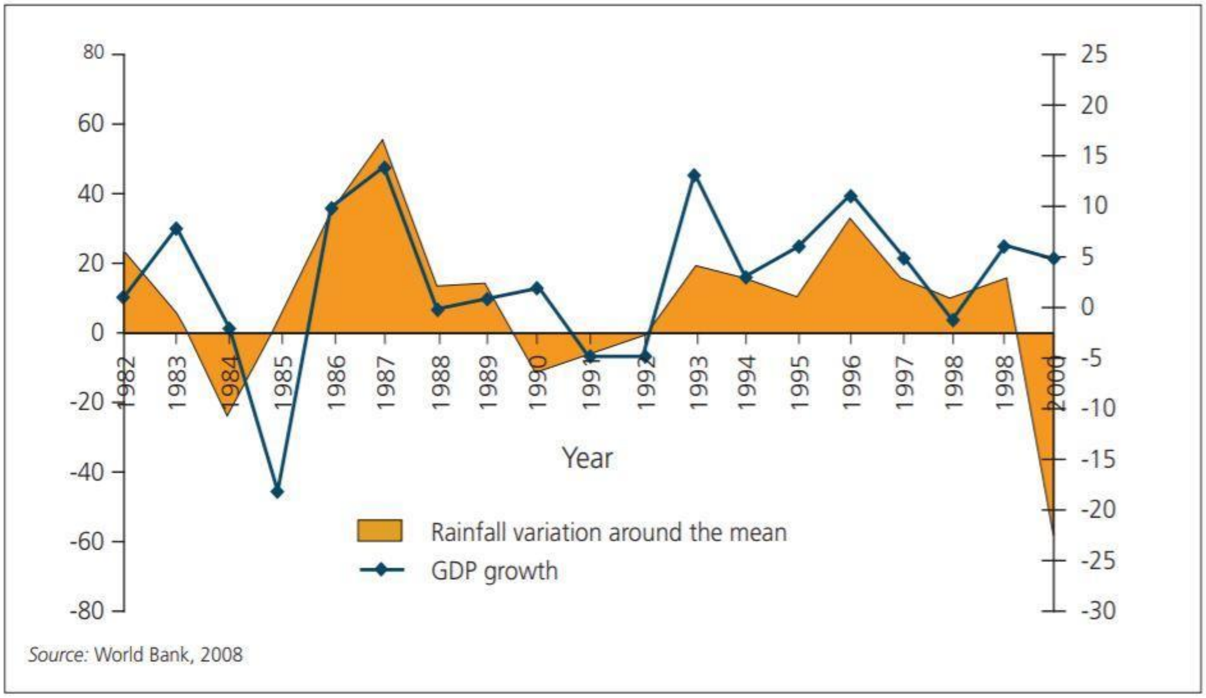

Figure 6 Change in GDP due to rainfall (The World Bank 2010)

Awash River, one of the major rivers in Ethiopia, is contaminated everyday through effluent coming from residential, commercial and industrial facilities in Addis Ababa. Nitrogen, Lead and BOD (Biological Oxygen Demand) levels were found to be three times as high as WHO's (World Health Organization) maximum standards raising Public Health concerns (Harvey 2010). The city is located in the western part of the Awash Basin as shown in figure 5 below making the Awash river easily susceptible to contamination (Van Rooijen and Tadesse 2009).

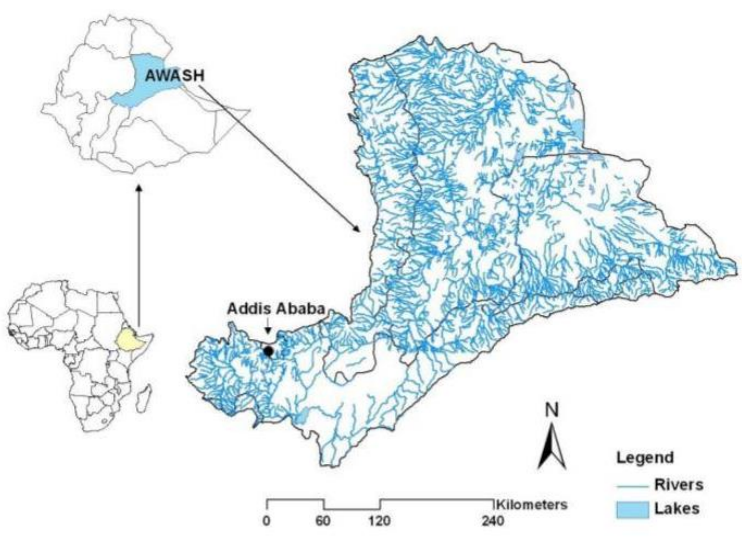

Figure 5 Location of Ethiopia, the Awash Basin and Addis Ababa (Van Rooijen and Tadesse 2009).

AAWSA has recognized the issue of water leakage and has been working towards a solution since 1995 (Desalegn 2005). The agency has conducted studies to quantify water loss and identify causes of leakage. It has also established a new research department with responsibilities including the reduction of water loss. In addition, the authority will work towards controlling illegal pipelines in the city (Desalegn 2005).

VII. Conclusion

The urban metabolism study found that water outflow is mainly due to water leakage rather than in the form of wastewater. There is little infrastructure to handle the amount of wastewater in the city Addis Ababa; hence, a significant amount directly enters rivers. Findings also showed that there is a big gap between tracked inflow and outflow elements. This shows that the limitations in data collection and analysis need to be resolved and additional elements of inflow and outflow need to be considered in the analysis. Upgrading Addis Ababa's water infrastructure will help AWWSA better the city's water budget. In addition, it will decrease economic vulnerability due to rainfall and improve public health concerns arising from water leakage and wastewater release into water bodies. On site data collection and Interviewing methodologies are recommended for future research in the area.

VIII. Acknowledgements

I would like to thank Professor Alissa Kendall for encouraging me to do this independent research project on Addis Ababa when I was worried of having little resources and providing me with a few online research articles to get started with my work. I'd also like to thank the McNair Scholars program and Professor Frank Loge for guiding me in my first steps of navigating Undergraduate Research at UC Davis.

IX. References

1. Abiye, T.A. et al. 2008. Use of treated wastewater for managed aquifer recharge in highly populated urban centers: a case study in Addis Ababa, Ethiopia. Environmental Geology.
2. Currie, P. K., & Musango, J. K. 2016. African urbanization: Assimilating urban metabolism into sustainability discourse and practice. Journal of Industrial Ecology.
3. Desalegn W.B. 2005. Water Supply Coverage and Water Loss in Distribution Systems: The case of Addis Ababa. MSc. thesis, International Institute for Geo-information Science and Earth Observation, Enschede, The Netherlands.
4. Enhancing Urban Resilience: Addis Ababa, Ethiopia. 2015. Resilient Cities Program. The World Bank Group, Washington D.C.
5. Farzinmoghadam, M. 2014. Urban metabolism and land use modeling for urban designers and planners: A land use model for the Integrated Urban Metabolism Analysis Tool. Ph.D. thesis, University of Massachusetts-Amherst, Amherst, MA.
6. Harvey, M. 2010. Water Supply and Sanitation. *Water Resources Management in Ethiopia: Implications for the Nile Basin*, edited by H. Kloos et al. Cambria Press.

7. Hean C. et al. 2016. Addis Ababa City Report. JLL Sub-Saharan Africa.
8. Report on the Status of Disaster Risk Reduction in Sub-Saharan Africa. 2010. The World Bank, Washington D.C.
9. RIO+20 (United Nations Conference on Sustainable Development). 2012. Progress Towards Sustainable Development in Africa. Addis Ababa: United Nations Economic Commission for Africa.
10. UN Population Division. 2018. World Urbanization Prospects: the 2018 revision. UN Population Division, Department of Economic and Social Affairs. New York, NY.
11. UN Population Division. 2016. The World's Cities in 2016 - Data Booklet. UN Population Division, Department of Economic and Social Affairs. New York, NY.
12. Van Rooijen D. and Tadesse G. 2009. Urban sanitation and wastewater treatment in Addis Ababa in the Awash Basin, Ethiopia. 34th WEDC International Conference, Addis Ababa Ethiopia.