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Full Length Research Paper

Rooftop Rainwater Harvesting as an Alternative Approach of Sustainable Water Supply: A Case Study of Addis Ababa Ethiopia

Kidist Alemu Hailemariam[1*] and Akkaraboyina Mahesh Kumar [2]

[1-]*Department of Urban management, College of Urban Development and Engineering, Ethiopian Civil Services University, Addis Ababa, Ethiopia.*

[2-]*Assistant Professor, Department of Environmental and Climate Change Management, College of Urban Development and Engineering, Ethiopian Civil Services University, Addis Ababa, Ethiopia.*

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Corresponding Author:
Kidist Alemu
Department of Urban Management, Ethiopia Civil Service University, Addis Ababa, Ethiopia.

Abstract
Due to rapid urbanization and ever increasing growth of population, fulfilling the demand of the safe water supply is always a challenge. All the countries are ensuring sustainable approaches to protect the available water resources and also to adopt newer technologies. Rainwater harvesting is one of the environmentally sound systems of gaining water. During rains, the portion of the water which falls on the roofs of buildings is collected directly from the roofs before it reaches the ground, which is called rooftop rainwater harvesting. The rationale of this research is to study about the potential of rooftop rainwater harvesting as an alternative approach to sustainable water supply in Addis Ababa, Ethiopia. Available 20 years daily rainfall data from five meteorological stations were collected and analyzed through SPSS and MS-Excel program to observe the variations and the trend in the amount of precipitation. In addition, AUTOCAD drawings and satellite images of buildings within the city of Addis Ababa were collected and Arc GIS software was used to calculate the roof areas. Exploratory research method has been applied. The study revealed that, adopting rooftop rainwater harvesting system at city level can cover 28% of the daily water demand or it can fill the deficit faced by the city water supplier AAWASA. The study necessitated the need for similar approaches towards sustainable water usage in Ethiopia, Addis Ababa in particular.

Keywords: *RWH, RRWH Potential, Demand Analysis, Rainfall Analysis, Calculation of Roof Areas.*

Introduction

Rainwater harvesting is defined as the process which involves the immediate collection of rainwater running off the surfaces upon which it has fallen directly and it excludes the run-off water from land watersheds into streams, rivers, lakes, etc (Water Aid, 2013). Until recently Addis Ababa doesn't have urban planning; the city simply grew in a natural organic way, unforced and unstructured. This unmanaged expansion of Addis Ababa has put pressure on different services and infrastructures, one of which is municipal water supply. Better living hopes attract more and more people to migrate, but the capacity to accommodate is limited. The Addis Ababa urban water supply system is characterized by a low output capacity, inadequate networks and high system losses. Water supply for both household and industry consumption is provided by Addis Ababa water and Sewerage Authority (AAWSA) only. Currently, the city has two sources of water which are surface and groundwater, and failure of whichever would result in a crisis. The city water demand met is not more than 60% (AAWSA, 2017) and it is expected to address the estimated 36.5 % leakage of water supply in the system as a way of ensuring that more potable water is made obtainable for the population (World Bank, 2015). Since the surface water dams are built out of the city jurisdiction and groundwater is being exploited without any control or limit (AAWSA, 2017), there is a need to search for an alternative water supply within the boundaries of the city which is less in economy, environmentally bearable and socially acceptable, like rainwater harvesting. This study is carried out in order to assess the potential of the city in RRWH and the main objective is to calculate how much water can be harvested from the roofs of the buildings within the city of Addis Ababa.

Materials and Methods

Study area

Addis Ababa, capital of Ethiopia and the African Union is located at 9048"N Latitude and 38044'24"E Longitude, at an elevation of 2355m (7,726ft) from mean sea level. It covers an area of 527 km2. The city is divided in to 10 Sub Cities and 116 Woredas. It will have a projected population of 4,914,474 in the year 2017 (CSA, 2007). The climate is subtropical highland with complex mix of highland climate zones. The city is at the equator which means temperatures are very constant from month to month. The long-wet

season is from June to mid-September and it is the major winter season of the country. Occasional rains occur during the months November to January and the average annual rainfall is about 1165mm (NMA, 2017). The various areas of water source include the following surface and groundwater sites; (AAWSA, 2017). It has been found that the water demand of the city is calculated by using 110L/day as a baseline.

Fig.1 Map of Addis Ababa City

Methodology

In order to determine the amount of water that can be harvested from the roofs of the buildings in the city and to analyze the effect which could be brought by applying rooftop rainwater harvesting system, four parameters were analyzed. The mean annual rainfall data, the roof area, the run of coefficient and the water demand analysis.

Rainfall

There are 5 Meteorological Stations in Addis Ababa, which monitor the climatic parameters regularly. The location of the stations is shown in the Figure 1 below. Gathering the rainfall data from these five stations shows a slight difference between them in the amounts of rainfall for annual average calculations. Taking the average rainfall of Addis Ababa as 1165mm (NMA Ethiopia) for calculation of rainwater harvesting potential. The mean annual rainfall of Addis Ababa from 2005-2015 are shown in Figure below.

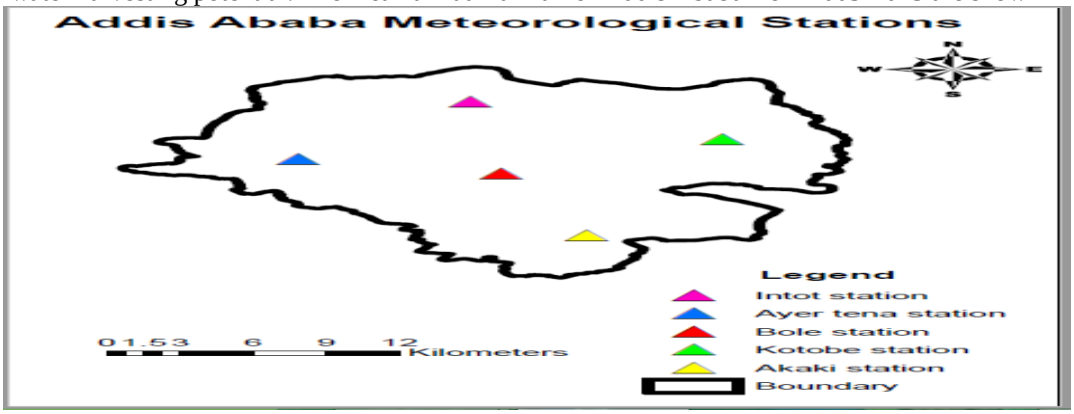

Fig. 2 Addis Ababa Meteorological Stations Location Map *(Data Source; NMA 2017)*

The rainfall data from the five meteorological stations indicated that the average annual rainfall of Addis Ababa lies between minimum of 800mm and a maximum of 1300mm. The precipitation gained from those five stations is higher around the areas of Entoto and Ayertena while the lowest amount is recorded in the area of Akaki station. This can be due to the geographical altitude and the natural preservation in Entoto and Ayertena areas. On the other side being industrial area and less in greenery landscape Akaki tends to have less rainfall. From the rainfall variations and trend analysis (Fig. 2 & 3) it was found that the amount of the rain is decreasing by 0.7% yearly and it has decreased by 5.4% through the last 8 years (2005 - 2015). Even if the rainfall trend analysis revealed that the amount has kept on going down by 0.7% each year, the minimum mean rainfall value of Addis Ababa (845mm) is significantly higher than the minimum standard requirement of rainfall for Rainwater Harvesting System which is 300mm per year (ERHA, 2017).

Calculation of Roof area

The total Roof area of the city should be determined for estimating the rainwater potential that can be harvested. It is a very sophisticated procedure to digitize every building from the satellite image of Addis Ababa city. However with help of AUTOCAD data for every wereda of the ten sub cities in the city it was possible to estimate the total roof area of buildings in the city.

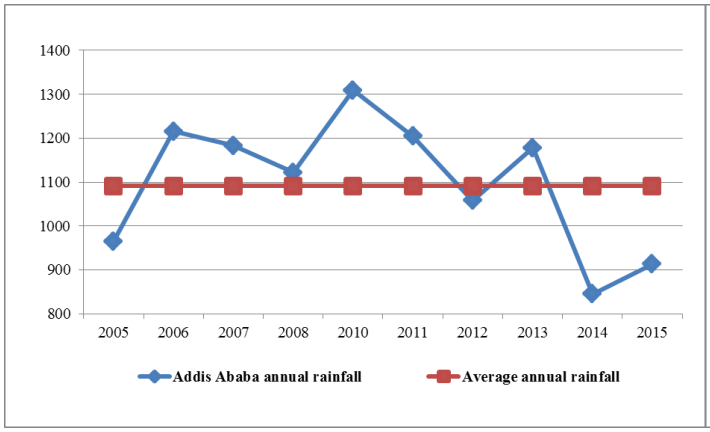

Fig.3 Average Annual Rainfall Variations of Addis Ababa *(Data Source; NMA 2017)*

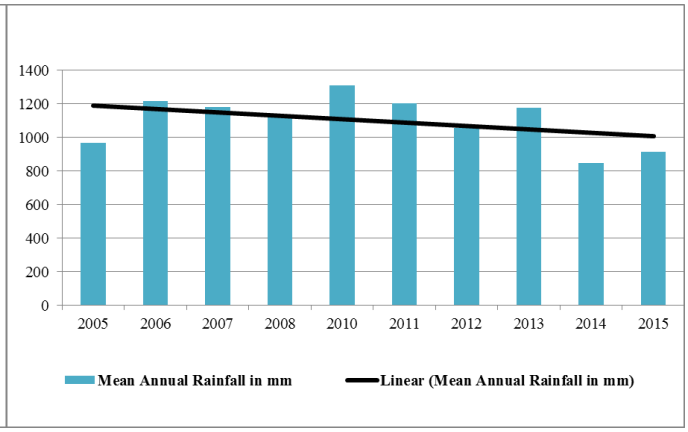

Fig.4 Mean Annual Rainfall Trends of Addis Ababa *(Data Source, NMA 2017)*

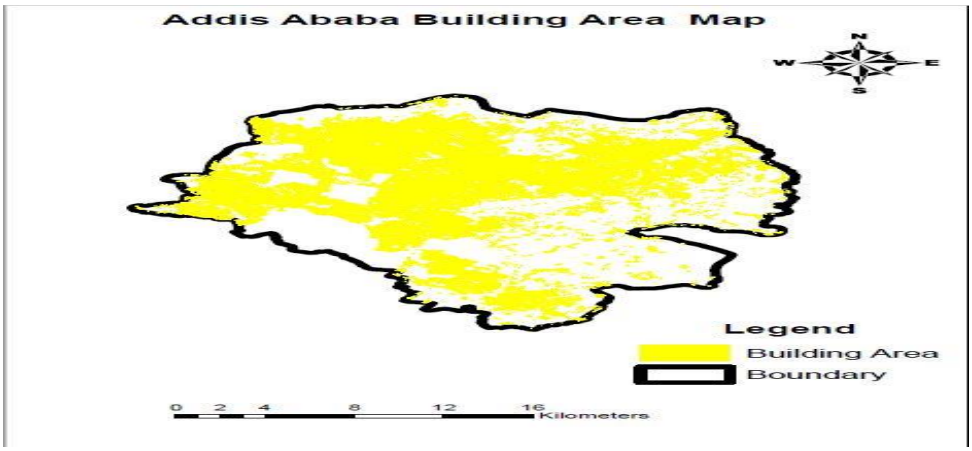

Fig.5 Building Area Map Of Addis Ababa *(Data Source, City Administration 2011)*

According to the calculation, the total roof area was found to be 5,310 Hectares or 53,097,335.00 m2.

Runoff Coefficient

During the field observations and the social survey, it has been observed that most of Addis Ababa's buildings used Galvanized Iron sheet of roofing material for which its runoff coefficient is 0.9 (UNESCO, IHE).

Calculation of Water Demand

According to CSA (2007) National Census, Addis Ababa has a population of 3,384,569 with growth rate of 3.8 %. Using this as a baseline, the projected population for the year 2017 will be 4,914,474. The AAWSA has set a minimum standard of water requirement as 110 Lts/Capita/Day for urban area. Therefore in order to meet the demand, it needs to pump 540,592 m3 per day to the city.

Results

The quantum of rainwater that can be harvested (theoretical potential) can be calculated by using the formula,

$$HR = R*A*C$$

Where; HR = for harvested water in m^3, R =Average Annual Rainfall in mm; A=Roof Area in m^2; C= Runoff Coefficient(Chao-Hsien Liaw et al; (2014)

Taking the mean annual rainfall as 1165mm, The roof area in square meter as 53,097,335.00 m2 and the runoff coefficient as 0.9, The total potentially harvestable water can be determined as HR;

$$HR = 1165mm * 53{,}097{,}335m^2 * 0.9;\ HR = 55{,}672{,}556\ m^3/\text{year or } 152{,}528\ m^3/\text{day}$$

The actual capacity and the current amount of water that is pumped by AAWSA is 414,018 m3 per day. The deficit can be calculated as 126,592 m3 per day. However if rooftop rainwater harvesting is applied 152,528 m3 / day can be supplemented which can cover the deficit that AAWSA is facing. Another issue that should be taken into consideration is the huge water transmission losses from the

water supply. According to World Bank, 2013 report, the water losses account to more than 30% of its production. Therefore by applying these systems, it can also cover the amount lost and improve the supply by more than the 30 %.

Discussion

Relma and UNEP (2006) conducted a study in the potential for rainwater harvesting in 10 African cities through GIS overview, Addis Ababa has been one of the cities with the highest potential of rooftop rainwater harvesting because of the highest number of building area. In this specific study, the findings of the study showed that from the Roof areas an approximate quantum of 152,528 m3 could be collected daily which can cover the demand deficit faced by AAWSA. Even areas with less rainfall amounting between 110-350mm annually like Yemen Senea had been proven to have potential of RRWH and contribute significantly in fighting against water scarcity (Musa'ed M. Aklan , 2011).

Chao-Hsien Liaw et al (2014) studied regarding the assessment of the potential for rooftop rainwater harvesting of Taiwan. During the study three concepts relevant to the calculation of domestic rainwater harvesting potential were discussed. They are theoretical, available and environmentally bearable potentials of the system. In theoretical potential, it assumed that all rainwater cannot be collected solely a precipitation that can be catched on the roof will be harvested. In computing the theoretical potential of RRWH climatic condition, the building roofing types and sizes were considered without the economic and ecological features.

Regarding the available potential it was thought that all the harvested water cannot be utilized because it depends on the tank size limitation, the rainwater collection competency and the rainwater demand. In order to clearly calculate the available potential, one should plan the exact storage tank size, taking into consideration the efficiency of the catchment or collection system and how much is the rainwater demand. Inadequate collection and storage volumes lead to water wastage. The third concept is environmentally bearable potential of RRWH which states that apart from home owners when the system is installed at Regional or National level, this may affect by reducing the surface runoff having a visible impact on the ecological system of the area. The impacts of RRWH on different water sources should be given a great contemplation beforehand.

Therefore in this specific study due to the fact that it has been a tedious work collecting the best available roof area by applying AUTOCAD and Arc GIS software and doesn't deeply assess the feasibility of the system, this is a theoretical assessment of the potential in rooftop rainwater harvesting of Addis Ababa. In Urban Management one of the main aspects that should be given a great focus is Resource Management and Preservation. For a sustainable urban development three major pillars should go hand in hand namely, Environmental, Economic and Social aspects. As Nicholas L Cain (2014) considering the local water crisis and rainwater harvesting, forwarded the idea of small scale rainwater harvesting which was an environmentally sustainable and newly exercised approach.

According to Water Aid Technical Brief (2013) RRWH uses relatively cheap materials for constructing the system, less maintenance cost and is close to the users which save time and money. Unlike other sources of water like surface water and groundwater, productions which need a whole lot of big dams and treatment plants, RRWH is of cheaper in economically considerations.

Conclusion

It is obvious that the city is facing water scarcity and it is explained as interruption and lack of availability. The problem is not lack of resource; it is due to lack of production. Having the rainfall amount and the wide roofing area, RRWH is found to be another option for supplying the city with water supply. By performing demand analysis and determining the available roof area, water can be harvested greatly. If rainwater harvesting is applied it will surely have a great impact in supplying the city with another source of supply. The possible amounts of water that can be harvested from the roofs of buildings have been calculated. In overview of Addis Ababa's potential towards RRWH, Arc GIS and AUTOCAD software were used in the making of the final building map of Addis Ababa. It showed an encouraging amount of water that can be harvested which is 52,566,362m3/year.

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Ethical consideration

The study was conducted as a part of Master's Thesis after academic approval by the school of graduate studies, Department of Urban Management, Ethiopian Civil Service University, Addis Ababa. Permission to carry out the study was obtained from the respective agencies before data collection process began. Respondents were treated properly and confidentiality was maintained throughout the study. Results obtained from this study were kept safely and handled with utmost care.

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