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Research Article

Rooftop Rain Water Potential Assessment for Non-domestic Use: A Case of Addis Ababa Science and Technology University

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Abstract

This study investigates the efficacy of rooftop rainwater harvesting (RWH) at Addis Ababa Science and Technology University (AASTU) as a sustainable water and energy conservation strategy. The research aims to optimize water resource allocation by prioritizing harvested rainwater for non-domestic applications, thereby reducing pressure on conventional domestic water supplies. Utilizing ground measurements and ArcGIS spatial analysis, the total rooftop catchment area was quantified as 68,195.74 m^2. Annual harvestable rainwater potential, derived from Ethiopian Meteorology Agency (EMA) rainfall data (Akaki station), was estimated at 662,273.4 m^3. Concurrently, irrigation demand for AASTU's landscaping—calculated through crop water requirement assessments and standardized crop coefficients was determined to be 184,830.33 m^3/year. The results demonstrate a substantial surplus of harvestable rainwater, underscoring RWH's viability in meeting institutional non-potable demands. These findings advocate for rooftop RWH systems as a critical component of integrated water management strategies, offering a scalable model to mitigate resource scarcity in urban academic environments. The study provides actionable insights for policymakers and institutional stakeholders to advance sustainable water stewardship practices.

Keywords

Rooftop Rainwater Harvesting (RWH), Non-domestic Water Use, Water Scarcity Solutions, GIS and Ground Measurement, Sustainable Water Management

1. Introduction

1.1. Background

Water is an essential resource for sustaining life and is critical to social, economic, and environmental well-being. Despite covering a third of the planet, only 0.3% of Earth's water is fresh and accessible [1] making it a limited and precious resource. As global population pressures increase, ac-

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cess to potable water remains a challenge for many communities [2], often resulting in health risks and environmental degradation [3]. To address these challenges, sustainable solutions like rooftop rainwater harvesting have gained significance [4].

Rooftop rainwater harvesting involves capturing and storing rainwater from roof surfaces for domestic, non-domestic, and irrigation purposes [5]. This method reduces reliance on groundwater, minimizes runoff-related issues, and offers an efficient, cost-effective, and environmentally friendly alternative for water management [6]. In areas like Addis Ababa Science and Technology University (AASTU), where centralized water systems are limited, rainwater harvesting provides a practical means of addressing water scarcity while contributing to environmental conservation.

1.2. Statement of the Problem

Ethiopia, often referred to as the water tower of Africa, faces significant water resource challenges, with much of its potential remaining untapped. Nationally, water scarcity is severe, compounded by the fact that only 3% of the world's water is fresh, and merely 0.7% is usable due to climatic and geographic limitations. At AASTU, the situation is critical. Treated water, legally designated for domestic purposes under Ethiopian Water Resources Management Proclamation No. 197/2000, is being diverted for non-domestic uses, such as plant irrigation and car washing [7] This misuse results in a staggering weekly loss of approximately 352,730 liters (352.73 m^3) of treated water further straining the already insufficient supply. Such practices highlight the urgent need for sustainable alternatives like rooftop rainwater harvesting to alleviate water scarcity, reduce dependency on treated water, and ensure compliance with national water use regulations.

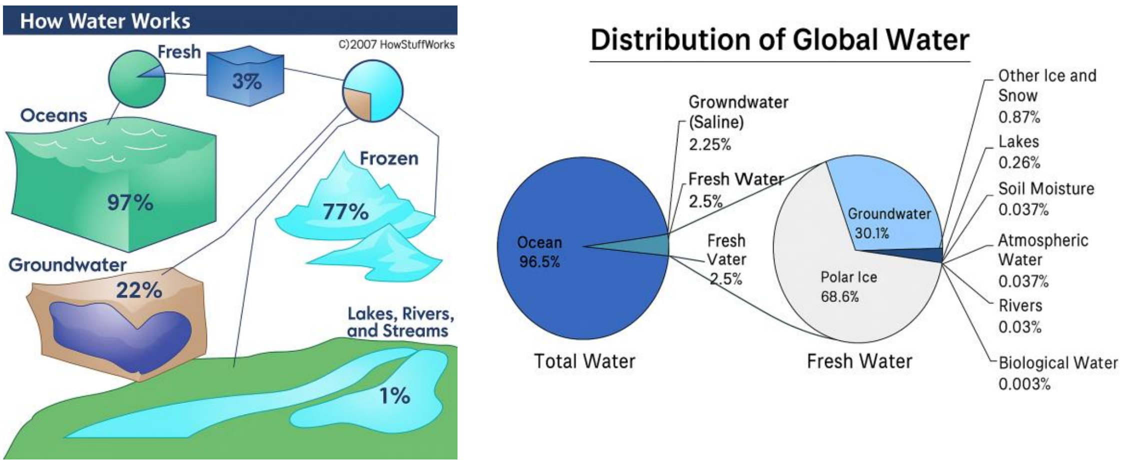


Figure 1. *Distribution of global water.*

Globally, water resources are abundant in quantity but limited in quality, making freshwater scarce. Of the 3% that is freshwater, 77% is trapped in polar ice, 22% is costly groundwater, and only 1% is readily available for living organisms and transportation [8, 9]. To address this scarcity, rooftop rainwater harvesting offers a practical solution [10]. This research aims to explore this solution and answer the following questions:

1) To what extent can the problem of water supply services at AASTU be minimized through rooftop rainwater harvesting?
2) Which method is more accurate and effective for determining the roof catchment area?
3) How can an alternative water supply be provided for non-domestic uses to reduce the pressure on treated or potable water at the AASTU campus?
4) By what percentage can rooftop rainwater harvesting decrease the water demand load on potable water?

2. Objective of the Study

2.1. General Objective

To estimate the contribution of rooftop rainwater harvesting in addressing water demand at Addis Ababa Science and Technology University (AASTU).

2.2. Specific Objectives

1) To estimate the rooftop catchment area using Google Earth procedures and ground measurements.
2) To calculate the potential amount of rainwater harvested from rooftop areas.
3) To assess the water demand for campus greenery and car washing.

4) To provide design parameters for rooftop rainwater harvesting to support future water resource management initiatives.

2.3. Significance and Scope of the Study

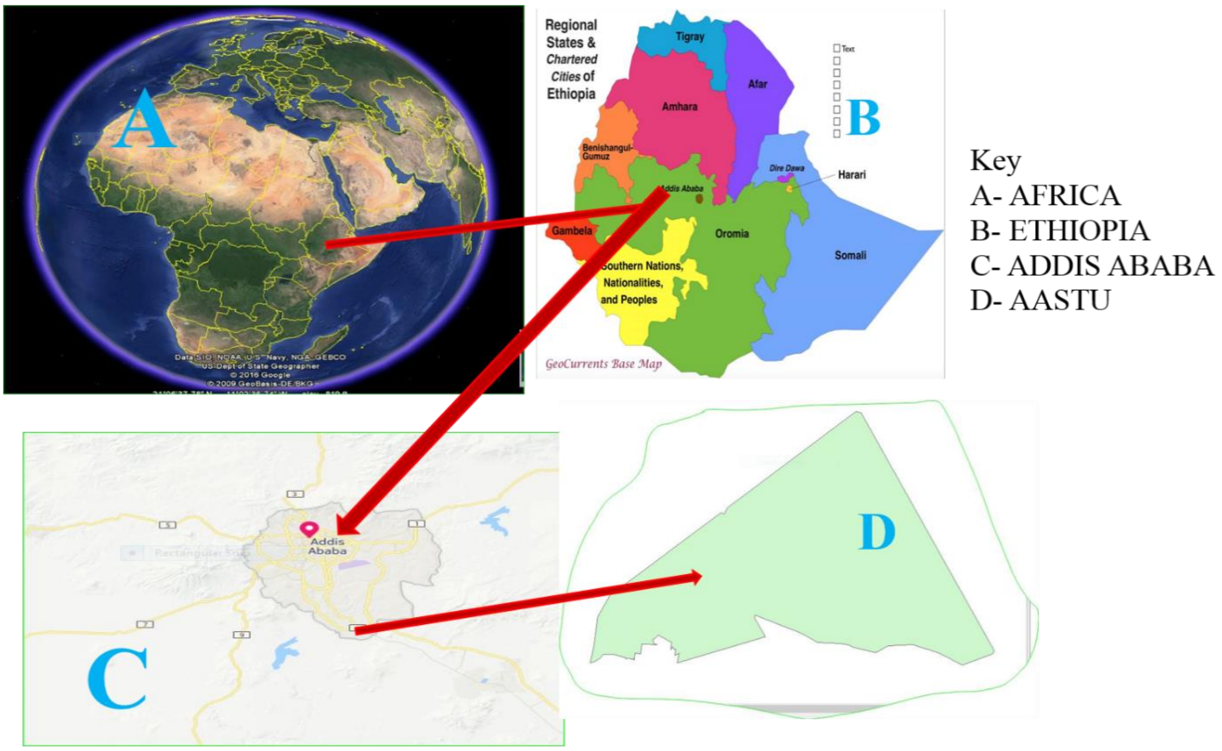
This research addresses water scarcity at Addis Ababa Science and Technology University (AASTU) by exploring rooftop rainwater harvesting as a sustainable solution to reduce reliance on treated water. It focuses on non-domestic uses such as irrigation, gardening, and car washing while promoting water conservation awareness. The study is limited to evaluating rooftop rainwater harvesting within AASTU's premises to support improved water resource management.

3. Methodology

3.1. Description of the Research Area

3.1.1. Location

Addis Ababa Science and Technology University (AASTU), established in 2011, is one of Ethiopia's two Science and Technology universities. Located in the Kilintho area of the Akaki-Kality sub-city, southeast of Addis Ababa, it is 3.6 km from Tirunesh Beijing General Hospital. AASTU is positioned at 8°53'06" N latitude and 38°48'35.63" E longitude, with an elevation of 2,148 meters.



Source (Google Earth)

Figure 2. *Addis Ababa Science Technology University location map.*

3.1.2. Climate

Addis Ababa has a temperate climate due to its high-altitude subtropical location. Rainfall peaks during the boreal summer (July-August) and is minimal in winter (December-February). The average annual temperature is 15.9℃ (60.7℉), with April being the hottest month at 20℃ and December the coldest [11]. Monthly temperatures range from 10℃ to 20℃, with a maximum range of 23.4℃ to 29.3℃. [12].

3.2. Data Collection

Primary data includes water shortage at AASTU, wilting plants, campus building numbers and areas, plant types and quantities. Rooftop area was measured using ground and ArcGIS methods. The distance between plants was measured to determine water requirements using the canopy method.

$$Area = (Length * width)/2$$

Thus,

$$ETo = \frac{WR\ (Water\ Requirement)}{Crop\ coefficient\ (Kc)*Area} \quad (1)$$

Figure 3. Measurement of distance between plants.

Secondary data includes rainfall, precipitation, and temperature from national meteorology agencies, as well as campus-specific data such as the number and types of cars, plant types, water requirements per plant, and water usage for car washes.

3.3. Data Analysis

This research uses a non-experimental approach focused on calculating the rooftop catchment areas at AASTU for rainwater harvesting. The procedures include measuring rooftop areas (via ground measurement, Google Earth, and ArcGIS), estimating annual rainfall, calculating harvested water, comparing it with plant water usage, and determining crop water requirements and evapotranspiration.

1. *Catchment Area*

This paper evaluates two methods for determining the catchment area: the Ground Area Calculation Method and Google Services (ArcGIS using Google Earth). Currently, AASTU has 91 buildings, categorized into 14 subtypes, as outlined in Table 10 (see Appendix II).

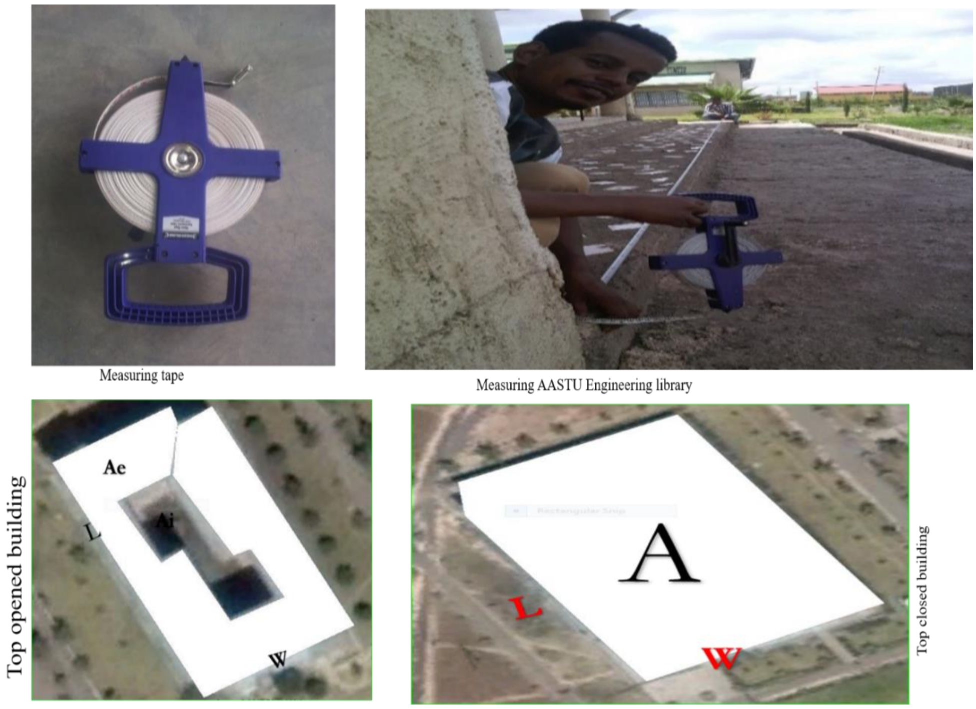


Figure 4. Measuring AASTU building's roof top area by using ground area method and different shapes of building.

Most AASTU buildings have irregular shapes, making direct measurement difficult. For accurate calculations, internal sections are subtracted for top-open buildings, and external areas are added for closed buildings. The internal and external areas are represented as Ai and Ae, respectively. Using the ground measurement method, 32 buildings were measured, totaling 61,555.644 m^2 for rooftop catchment area. Measurements were taken with a tape, and areas were calculated based on building section types.

$$Area\ of\ bldg = A\ total - A\ internal$$

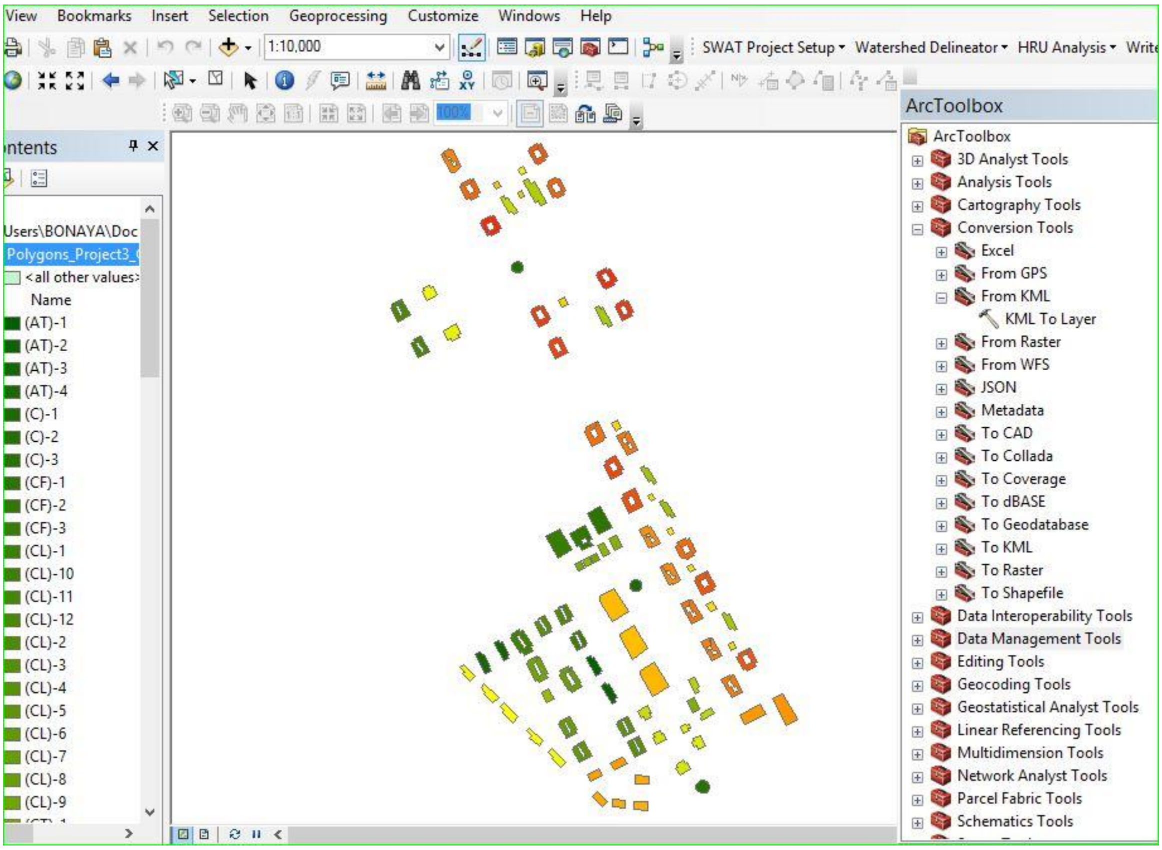
For Example: Building number seven (B-7) area calculated as follows.

Table 1. *Building Catchment Area Measurement.*

Regular part		**Area(A**	**Internal**		**2Ai**	**External**		**2Ae**	**Total Area**
L	**W**		**L**	**W**		**L**	**W**		**At=A-2Ai+2Ae**
44.5	25.6	1139.2	13.8	9.15	252.54	6	4.2	50.4	937.06

Area for Rectangle is the product length and width, for Circle square of radius multiple by Pi (Π).

The Google Earth and ArcGIS method combines satellite imagery with Geographic Information Systems (GIS) to calculate rooftop catchment areas [13]. Google Earth provides 2D and 3D visualizations of the earth's surface, with imagery resolutions ranging from 15 meters to 15 centimeters. Using Google Earth, the area is selected, and a KML file is exported to ArcGIS for analysis. The total rooftop catchment area for AASTU calculated via this method is 67,786.56 m^2 This method is cost-effective, time-saving, and efficient for large-scale calculations.



Source (Own data)

Figure 5. *Google Earth delineated ArcGIS application process.*

2. Catchment area Calculation

As try to explain in the methodology part roof top area (catchment area) calculated both by ArcGIS and ground measurement.

Table 2. *Catchment area measurement of AASTU buildings.*

Building Type	**Sample and Code**	**Measured (m^2)**	**GIS (m^2)**
Dormitory	®-1	937.06	989.9912

Building Type	Sample and Code	Measured (m^2)	GIS (m^2)
Rectangular type (7)	®-2	939.57	961.1096
	(L)-1	523.2	489.7866
L-shape (8)	(L)-2	525.1	474.5807
	(L)-3	523.5	518.0995
White House Type (14)	(W)-1	780.82	973.9228
	(W)-2	780.82	1097.238
	(W)-3	985	985.0242
	(W)-4	1061	1094.501
Clinic Type (7)	(CT)-1	238.68	257.9339
	(CT)-2	237.15	264.1241
	(CT)-3	236.36	483.0348
Cafe type (3)	(CF)-1	1580.315	1570.403
Class Type (12)	(CL)-1	693.06	257.9339
	(CL)-2	686.928	264.1241
	(CL)-3	696.35	483.0348
Administration Type (4)	(AT)-1	684	644.9455
	(AT)-2	684.1	655.488
Lecture Theatre (7)	(LT)-1	614.76	481.7134
	(LT-2)	621.36	488.8686

Building Type	Sample and Code	Measured (m^2)	GIS (m^2)
Museum Type (6)	(MT)-1	437.9	429.1614
	(MT)-2	440.8	459.2833
Circular Lounge (3)	©-1	480.81	257.9339
	©-2	490.625	264.1241
Laboratory (5)	(Lab)-1	648.74	554.01341
	(Lab)-2	641.68	497.95144
Library (3)	(Lib)-1	2086.92	2246.371
	(Lib)-2	2088.8	2271.984
Laundry (10)	(Lau)-1	163.48	148.2076
	(Lau)-2	163.35	155.3525
	(Lau)-3	161.66	159.6115
Metal work (2)	(Mw)-1	1256.96	1185.741

The rooftop area of AASTU buildings was calculated using both ground measurement (61,555.644 m^2) and ArcGIS (67,786.567 m^2). Since measuring all 91 buildings by the ground method was challenging, a trend line equation was developed from the 32 measured buildings. Using this equation, the total rooftop catchment area was estimated to be 68,195.74 m^2. Additionally, 45 vehicles were categorized into service buses, ambulances, and land cruisers to estimate water demand.

Table 3. Addis Ababa Science and Technology University transports type.

R. L	Type	Quantity	Washed cars per week	Frequency	Need water in Litter	Required demand per week in (L)
1	Ambulance type	10	3	3	30	270
2	Land Cruses Type	28	6	2	30	360
3	Services bus	7	7	3	100	2100
Total		45	16		110	2730

AASTU uses potable water for campus greening, as it is a new university under construction. In 2014, 2015, and 2016, 5,000, 3,000, and 20,000 seedlings were planted, respectively. Each seedling requires 10-15 liters of water daily, totaling 862.5 m^3 per week, assuming a 30 cm radius and 45 cm rooting depth for water application.

Table 4. AASTU plants with their type and needed water demand per week.

Year	Types of plants	Quantity in Numbers
2016	Yellow wood	800

Year	Types of plants	Quantity in Numbers
	Olive	2100
	Dire Dawa tree (pistachio)	2300
	Ebony	500
	NIMI	1250
	Jacaranda	1650
	Shewashew	2000
	Grave Lia	3000
	Bottlebrush	1350
	Amedula	2000
	Spatodia	2150
	Deciduous	900
2015	All type	3000
2014	All type	5000
Tot		28000

AASTU applies 350 m^3 of water per week for plants, costing 1,575 ETB/day. With 47 cars and 28,000 plants (23,000 needing water), the total water demand is 865,230 liters/week. The monthly water demand is 3,749,330 liters, equating to 44,991.96 m^3/year. Rooftop rainwater harvesting can reduce potable water usage.

3. Water harvesting potential analysis

To analyze the water potential, monthly rainfall data from Akaki was utilized. This secondary data, obtained from the Addis Ababa Meteorology Agency, was statistically analyzed as shown in the following table.

Table 5. *Akaki annual average rainfall data for eleven years.*

year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Sum
2006	0.95	2.54	2.69	3.1	1.58	3.69	9.52	9.34	5.66	2.1	0.9	0.9	42.970
2007	1.97	1.36	1.7	4.13	2.95	5.28	8.68	8.03	5.53	1.09	0.94	0.87	42.530
2008	0.87	0.93	0.89	2.04	2.01	4.67	8.18	8.14	6.38	0.23	2.16	0	36.500
2009	1.94	0	0.32	3.96	1.54	2.12	7.84	10.4	2.38	1.06	0.13	0.54	32.230
2010	0	2.28	4.07	5.67	3.07	5.49	11.15	5.48	5.14	0.17	0.49	0.25	43.260
2011	0	0.09	1.46	0.69	4.15	2	6.59	9.81	6.48	0	0.16	0	31.430
2012	0	0	0.97	2.03	0.87	2.69	7.35	7.87	4.1	0	0	0	25.880
2013	0	0	2.48	2.97	2.37	3.6	5.79	7.82	4.75	0.66	0	0.01	30.450
2014	0	1.41	2.45	0.46	0	1.75	5.89	9.08	3.84	1.69	0	0	26.570
2015	0	0	0.44	0	3.11	5.27	6.06	7.98	2.26	0	0.48	0	25.600
2016	0	0	1.4	6.15	4.33	3.52	7.55	5.93	3.77	0.52	0.3	0	33.470
Avg	0.52	0.78	1.72	2.84	2.36	3.64	7.69	8.18	4.57	0.68	0.51	0.23	33.720

Source (National meteorology Agency, Ethiopia)

4. Calculating Crop Water Requirements

As discussed in the literature review, the Blaney-Criddle method is the simplest and most effective for estimating reference evapotranspiration using temperature data [14]. AASTU has 23,000 plants, requiring water due to their recent planting in 2016. The canopy method calculates the area between plants covered by evapotranspiration (see Figure 3). The mean daily percentage of annual daytime hours (P) is determined using a table based on the area's latitude.

Table 6. *Mean daily percentage of annual day time hours for different latitude in North hemisphere.*

Latitude	Jan July	Feb Aug	Mar Sept	Apr Oct	May Nov	Jun Dec	July Jan	Aug Feb	Sep Mar	Oct Apr	Nov May	Dec June
60o	0.15	0.20	0.26	0.32	0.38	0.41	0.40	0.34	0.28	0.22	0.17	0.13
55	0.17	0.21	0.26	0.32	0.36	0.39	0.38	0.33	0.28	0.23	0.18	0.16
50	0.19	0.23	0.27	0.31	0.34	0.36	0.35	0.32	0.28	0.24	0.20	0.18
45	0.20	0.23	0.27	0.30	0.34	0.35	0.34	0.32	0.28	0.24	0.21	0.20
40	0.22	0.24	0.27	0.30	0.32	0.34	0.33	0.31	0.28	0.25	0.22	0.21
35	0.23	0.25	0.27	0.29	0.31	0.32	0.32	0.30	0.28	0.25	0.23	0.22
30	0.24	0.25	0.27	0.29	0.31	0.32	0.31	0.30	0.28	0.26	0.24	0.23
25	0.24	0.26	0.27	0.29	0.30	0.31	0.31	0.29	0.28	0.26	0.25	0.24
20	0.25	0.26	0.27	0.28	0.29	0.30	0.30	0.29	0.28	0.26	0.25	0.25
15	0.26	0.26	0.27	0.28	0.29	0.29	0.29	0.28	0.28	0.27	0.26	0.25
10	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.28	0.28	0.27	0.26	0.26
5	0.27	0.27	0.27	0.28	0.28	0.28	0.28	0.28	0.28	0.27	0.27	0.27
0	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27

The studied area's latitude is between 5° and 10° North, specifically at 8°53'06" North, 38°48'35.63" East, with an elevation of 2,148m above sea level. The value of P in Table 8 is calculated using the interpolation method.

Table 7. *Annual day time hours for Akaki Area.*

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
P (at latitude 8)	0.26	0.27	0.27	0.28	0.28	0.28	0.28	0.28	0.28	0.27	0.26	0.26

To calculate the total water requirements for AASTU plants:

1) ETo is calculated using Equation (1).
2) Kc is derived from the average of three plants with known Kc values (see table).
3) ETc is the product of ETo and Kc.
4) Monthly irrigation water demand is ETc minus 50% of rainfall.
5) Total monthly irrigation requirement per plant is the product of monthly demand and its area coverage.

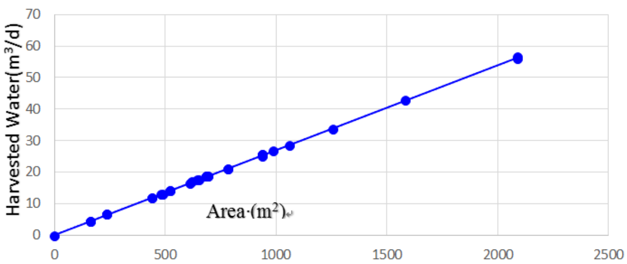


Figure 6. *Rooftop potential versus area.*

The total rooftop area of AASTU is 68,195.74m^2 with a potential to harvest 662,273.4m^3/year. From 1m^2 the volume of water that can be harvested is 0.026976m^3/day based on the average annual rainfall in the Akaki area.

4. Results and Discussions

4.1. Quantifying Catchment Area

The catchment area of AASTU buildings was calculated using both ground measurement and ArcGIS methods (see Table 2, Chapter 3). A sample of 32 out of 91 buildings was measured, while the remaining buildings' areas were estimated using a trend line equation derived from the combination of both methods and represented in a scatter chart.

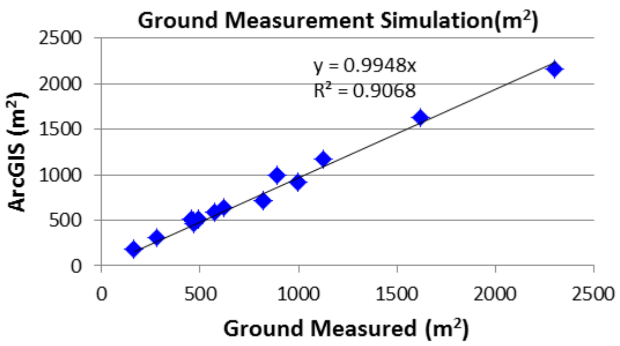


Figure 7. Ground area simulation and trend line equation.

The linear equation y = 0.9948x represents the trend between ground measurement and ArcGIS methods, with an accuracy of 90.68%, indicating a 10% error. This error results from factors such as rough ground surfaces, measurement inaccuracies, unclear satellite imagery, and topographical variations. The area of 32 measured buildings is 24,971.37 m^2 and using the trend line equation, the total rooftop catchment area for rainwater harvesting at AASTU is calculated to be 68,195.74 m^2.

4.2. Harvested Water Potentials from Rooftop Catchments

The best method for calculating roof rainwater harvesting potential is the Gould and Nissen formula (1999). Based on the calculated mean and median monthly rainfall, the harvested water from the AASTU roof catchment is determined. The mean rainfall is calculated using the formula:

Calculate the mean of rainfall

$$\bar{x} = \frac{x_1 + x_2 + \cdots x_n}{n}$$

Where, $\bar{x}$ = mean of x_i

x_i = is each of the value of the data

n = the number of data points

Table 8. Mean and Median monthly rainfall at Akaki Area of Addis Ababa.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
mean	0.522	0.783	1.716	2.836	2.363	3.643	7.691	8.170	4.572	0.636	0.479	0.234
med	0.00	0.089	1.458	2.97	2.368	3.597	7.545	8.026	4.750	0.232	0.157	0.000

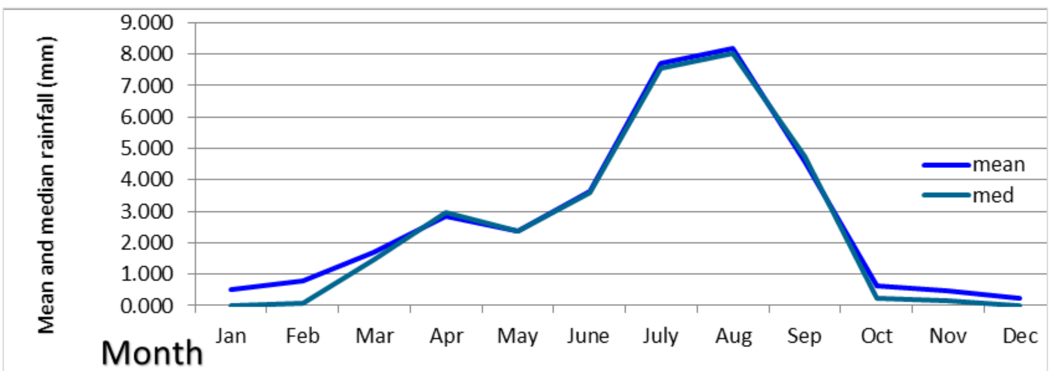


Figure 8. Mean and Median monthly rainfall at Akaki Area.

The mean rainfall method is more effective than the median for short-term rainwater harvesting. For example, in January and December, the median value is nearly zero, while the mean rainfall is positive, making the mean method more reliable [15]. Both methods show high rainfall in July and August. The choice between mean and median methods significantly influences the interpretation of long-term rainfall trends in Ethiopian highlands. However, for long-term rainfall analysis, the median method [16] is preferred because it:

1) Avoids exaggerating high rainfall events from a few days.
2) Reflects months with frequent rainfall.
3) Is more conservative and suitable for rooftop rainwater harvesting design.

Calculate potential of rooftop rainwater harvesting

The monthly mean harvested rainfall from roof top of AASTU was calculated as follows:

$Q = R\ x\ A\ x.C$ see equation (*)

$$Q = 33.72mm/day * (1m/1000mm) * 30day/month * 68195.74\text{m2} * 0.8 = 55{,}189.45m3/month$$

4.3. Demand Analysis

4.3.1. Non-domestic Use

The monthly water demand for plants and car washes at AASTU was 3,749.33 m³. Implementing this rainwater harvesting system reduced the demand for potable water, creating a surplus for other uses.

$$(((55{,}189.45.m3)/month - 3749.33\text{m3/month}))/(3749.33m3/month) * 100\% = 1371.98\%$$

Similarly, the yearly harvested rooftop rain water from the AASTU was 662273.4m^3/year.

$$(662273.4 - 44991.96/44991.96) * 100\% = 1371.98\%$$

4.3.2. Crop Water Requirements

For example, the water required for Olive, Dire Dawa tree and Deciduous for January, 2016 calculated as follows.

Table 9. Crop water requirements calculation for some trees in AASTU campus.

Plants	Kc	Area b/n plants (m^2)	Eto (mm/d)	Etc (m/d)	Qtot (m^3/d)
Deciduous tree	0.73	12.5	5.3	0.00387	0.048363
Olive tree	0.6	12.5	5.3	0.00318	0.03975
Dire dawa tree	0.58	12.5	5.3	0.00307	0.038425

Kc average for all AASTU plants according to this research paper is:

$$Kcavg\ = (0.73 + 0.6 + 0.58 + 0.5)/4 = 0.6025$$

Table 10. Overall monthly Crop water requirements of AASTU plants.

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
T min	12.3	14.6	17.6	17.3	15.8	18.5	17.7	17.4	15.7	14.5	14.6	12.2
T max	29.2	29.4	32.0	27.0	51.3	30.4	24.5	23.9	27.9	26.1	25.9	25.8
T mean	20.7	22.0	24.8	22.1	33.6	24.4	21.1	20.6	21.8	20.3	20.3	19.0
P	0.264	0.27	0.27	0.28	0.28	0.286	0.286	0.28	0.28	0.27	0.264	0.264
ET0 (mm/d)	4.63	4.89	5.24	5.09	6.56	5.50	5.06	4.90	5.05	4.68	4.57	4.42
KC	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
ETC (mm/m)	83.4	88.1	94.3	91.6	118.2	99.0	91.2	88.2	90.9	84.3	82.3	79.5
RF (mm/m)	16.2	21.9	53.2	85.1	73.2	109.3	238.4	253.3	137.1	19.7	14.4	7.2

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
plant no	23000	23000	23000	23000	23000	23000	23000	23000	23000	23000	23000	23000
Area (m2)	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
Irrigation water Dm (mm/m)	75.27	77.14	67.67	49.10	81.53	44.39	0	0	22.34	74.43	75.10	75.92
Qtotal (m3)or Ig	21641.28	22176.71	19455.37	14116.99	23440.25	12760.9	0	0	6422.62	23398.02	21592.32	21825.87

Source (own data)

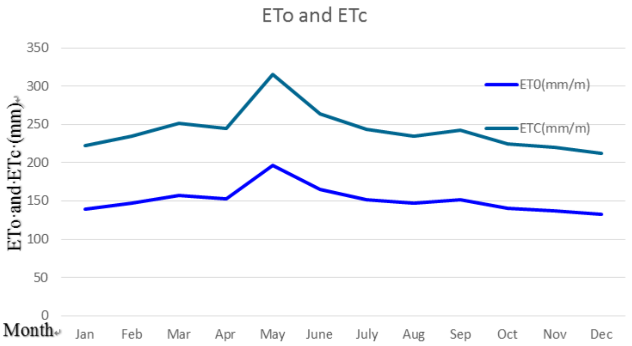


Figure 9. *Monthly Crop water requirements verse reference evapotranspiration.*

As shown in Figure 9 and Table 11, ETo and ETc were directly proportional. In May, evapotranspiration was highest, resulting in increased water requirements for plants, while in December, the water demand was lower.

Figure 10 indicated that as effective rainfall increased, irrigation water demand decreased, and vice versa. When irrigation demand reached zero, effective rainfall matched the plants' water requirements. The highest irrigation demand occurred in May. From May to July, irrigation demand decreased, while it increased from August to December. The total irrigation water demand for AASTU's plants was 184,830.33 m³/year, whereas the drinking water estimated by the GSO was 44,850 m³/year. Water stress was calculated by subtracting the GSO's water allocation from the irrigation demand.

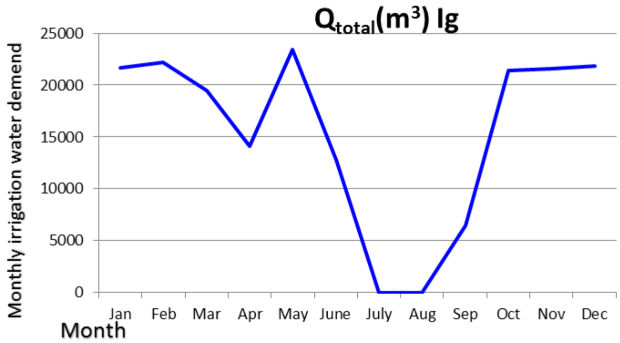


Figure 10. *AASTU Monthly gross irrigation water demand.*

$$Water\ stress\ per\ month\ = ((15402.53m3/month - 3737.5m3/month)/15402.53)) * 100\% = 75.73\%$$

The drinking water losses due to non-domestic use at AASTU were insufficient for the campus plants, resulting in visible wilting of some plants. This research provided the following design parameters:

1) The total water required for car washing was 131.04 m³/year, based on data from the AASTU General Service Office.
2) The study established that 0.026976 m³ of rainwater can be harvested per square meter of rooftop area in the Akaki region. This design parameter can be used for rooftop rainwater harvesting in the area.

5. Conclusion and Recommendation

5.1. Conclusion

This study focused on rooftop water harvesting at Addis Ababa Science and Technology University (AASTU), based on rainfall and catchment area. The catchment areas of AASTU buildings were evaluated using both ground measurement and ArcGIS techniques. ArcGIS was found to be the most efficient method for evaluating large or remote areas, saving time and costs. However, for smaller areas, ground measurement remained essential. This dual approach allowed for a comprehensive understanding of the campus's rainwater harvesting potential.

The total catchment area of AASTU buildings was 68,195.74 m^2. The highest water collection occurred between July and September, with a total potential of 55,189.45 m^3 per month and 662,273.4 m^3 per year. Despite the loss of 44,991.96 m^3 of potable water for planting and car washes, this amount did not fully meet the irrigation needs for campus plants.

The total irrigation water demand for AASTU plants was 184,830.32 m^3 per year, indicating a surplus of harvested water that could be used for other purposes.

5.2. Recommendations

To enhance the efficiency and sustainability of water usage at AASTU, the following key recommendations are made based on the findings of this study:

1) Prioritize rooftop rainwater harvesting to reduce dependency on potable water for non-domestic uses.
2) Implement a combination of ArcGIS and ground measurement methods for accurate catchment area evaluation.
3) Install a rain gauge at AASTU for precise rainfall data to improve water management strategies.

Abbreviations

AASTU	Addis Ababa Science and Technology University
ArcGIS	Aeronautical Reconnaissance Coverage Geographic Information System
EMA	Ethiopian Meteorology Agency
ETc	Crop Evapotranspiration
ETo	Reference Evapotranspiration
GIS	Geographic Information Systems
GSO	General Statistics Office

Conflicts of Interest

The authors declare no conflicts of interest.

Appendix

Appendix I. Akaki High and Low Yearly Average Rainfall of Eleven Year Both by Table and Graph

Table 11. Akaki high and low yearly average rainfall of eleven year by table.

Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
0.95	2.54	2.69	3.10	1.58	3.69	9.52	9.34	5.66	2.10	0.90	0.90
1.97	1.36	1.70	4.13	2.95	5.28	8.68	8.03	5.53	1.09	0.94	0.87
0.87	0.93	0.89	2.04	2.01	4.67	8.18	8.14	6.38	0.23	2.16	0.00
1.94	0.00	0.32	3.96	1.54	2.12	7.84	10.40	2.38	1.06	0.13	0.54
0.00	2.28	4.07	5.67	3.07	5.49	11.15	5.48	5.14	0.17	0.49	0.25
0.00	0.09	1.46	0.69	4.15	2.00	6.59	9.81	6.48	0.00	0.16	0.00
0.00	0.00	0.97	2.03	0.87	2.69	7.35	7.87	4.10	0.00	0.00	0.00
0.00	0.00	2.48	2.97	2.37	3.60	5.79	7.82	4.75	0.66	0.00	0.01
0.00	1.41	2.45	0.46	0.00	1.75	5.89	9.08	3.84	1.69	0.00	0.00
0.00	0.00	0.44	0.00	3.11	5.27	6.06	7.98	2.26	0.00	0.48	0.00
0.00	0.00	1.40	6.15	4.33	3.52	7.55	5.93	3.77	0.00	0.00	0.00
5.74	8.61	18.87	31.20	25.99	38.58	84.60	89.87	50.29	6.99	5.27	2.57
0.52	0.78	1.72	2.84	2.36	3.64	7.69	8.17	4.57	0.64	0.48	0.23
0.99	1.27	1.87	3.08	2.16	1.87	2.68	2.46	2.11	1.05	1.08	0.45

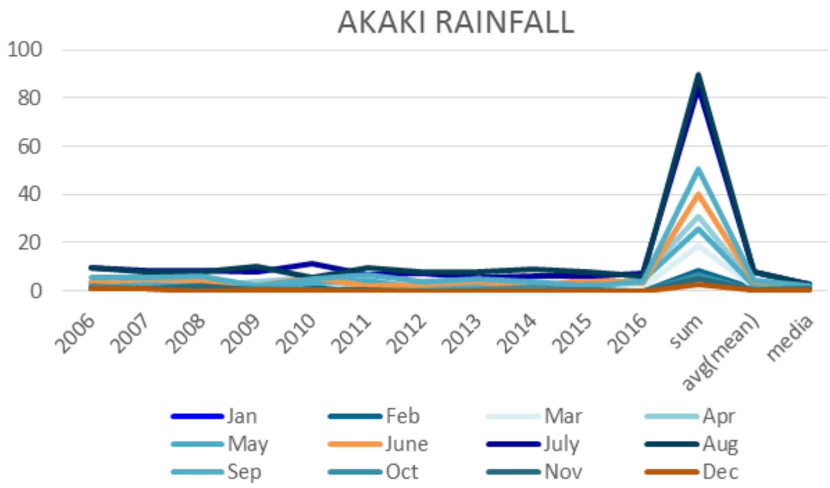


Figure 11. *Akaki high and low yearly average rainfall of eleven-year graph.*

Appendix II. Ground Method Measurement of AASTU Buildings with Respect to Their Type

Table 12. *Ground Method measurement of AASTU buildings vs type.*

		Length	**width**	**Area**		**Internal area**		**area*1**	**External Area**			**area*2**	**Tot Area**	**Avg A**	**AtRF**
BLd	**NS**				**L**	**W**			**L**	**w**					
R (7)	1	44.5	26	1139	13.8	9.15	126	252.5	6	4.2	25	50.4	937		
	2	44.4	26	1132	13.5	9.1	123	245.7	6.1	4.35	27	53.1	940	939	6575
	3	45	25	1143	13.6	9.25	126	251.6	6	4.1	25	49.2	941		
	4	44.3	26	1139	13.7	9	123	246.6	6	4	24	48	940		
L (8)	1	44.6	12	535.2	4	1.5	6	12			0	0	523		
	2	45	12	535.5	4	1.3	5.2	10.4			0	0	525	524	4191
	3	44.5	12	534	4.3	1.5	5.7	10.5			0	0	524		
W (14)	1	36.4	33	1183	19.2	13.5	259	259.2	6.5	4	26	52			
									19	1.3	25	49.9	1026		
	2	35.9	33	1192	19	13.2	251	250.8	6.8	3.8	23	45			
									19	1.3	24	47	1033		
	3	36.2	31	1122	18	12.9	232	232.2	6.4	3.5	24	48		1026	14366
				0			0	0	18	1.25	24	47	985		
	4	37	34	1240	19.4	14	272	271.6	7	3.75	23	45.8			
									19	1.28	24	47	1061		
Lib (3)	1	56.1	37	2087											
	2	56	37	2089										2088	6264
CL (12)	1	33.4	27	895.1	27.1	4.1	111	222.2	3.2	3.15	10	20.2	693		
	2	33.6	27	893.8	27	4.2	113	226.8	3.2	3.12	10	20	687		
	3	33.5	27	894.5	27.2	4	109	217.6	3.3	3	9.8	19.5	696	697	8363

		Length	width	Area		Internal area		area*1	External Area			area*2	Tot Area	Avg A	AtRF
BLd	NS				L	W			L	w					
	4	34	27	924.8	27.5	4.25	117	233.8	3.2	3.2	10	20.2	711		
AT (4)	1	43.2	15	643.7					4.8	4.2	20	40.3	684		
	2	43.1	15	646.5					4.7	4	19	37.6	684	684	2052
LT (7)	1	27.6	15	416.8					17	6	99	99	516		
	2	27.5	15	418					16	6.2	102	102	520	518	3624
Lab (5)	1	28	12	324.8					12	4	46	92.8			
									20	14.7	288	576			
									15	10.5	152	305	649		
	2	28	12	330.4					11	4.5	50	99			
									19	14.6	282	564		324	1622
									15	10.6	155	310	642		
MT (6)	1	29	15	437.9											
	2	29	15	440.8	439.4	2636									
CF (3)	1	48.7	32	1580	1580	4741									
CT (7)	1	15.6	15	238.7											
	2	15.5	15	237.2	237.4	1662									
	3	15.6	15	236.4											
Lau (10)	1	13.4	12	163.5											
	2	13.5	12	163.4	162.8	1628									
	3	13.7	12	161.7											
C (3)		radius	rad												
	1	12.4	3.1	482.8											
	2	12.5	3.1	490.6	486.7	1460									
Mw (2)	1	45.6	26	1186	1186	2371									

Appendix III. Mean and Median Average Rain Fall

Table 13. Yearly Mean and median average rain fall.

year	Jan	Feb	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	sum
2006	0.00	0.00	0.00	0.00	1.75	5.79	5.48	2.26	0.00	0.00	0.00	5.74
2007	0.00	0.00	0.46	0.87	2.00	5.89	5.93	2.38	0.00	0.00	0.00	8.61
2008	0.00	0.00	0.69	1.54	2.12	6.06	7.82	3.77	0.00	0.00	0.00	31.20
2009	0.00	0.00	2.03	1.58	2.69	6.59	7.87	3.84	0.00	0.00	0.00	25.99
2010	0.00	0.00	2.04	2.01	3.52	7.35	7.98	4.10	0.17	0.13	0.00	40/07
2011	0.00	0.09	2.97	2.37	3.60	7.55	8.03	4.75	0.23	0.16	0.00	84.60

year	Jan	Feb	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	sum
2012	0.00	0.93	3.10	2.95	3.69	7.84	8.14	5.14	0.66	0.48	0.01	89.87
2013	0.87	1.36	3.96	3.07	4.67	8.18	9.08	5.53	1.06	0.49	0.25	50.29
2014	0.95	1.41	4.13	3.11	5.27	8.68	9.34	5.66	1.09	0.90	0.54	6.99
2015	1.94	2.28	5.67	4.15	5.28	9.52	9.81	6.38	1.69	0.94	0.87	5.27
2016	1.97	2.54	6.15	4.33	5.49	11.15	10.40	6.48	2.10	2.16	0.90	2.57
mean	0.52	0.78	2.84	2.36	3.64	7.69	8.17	4.57	0.64	0.48	0.23	31.92
med	0.00	0.09	2.97	2.37	3.60	7.55	8.03	4.75	0.23	0.16	0.00	29.75

Appendix IV. ArcGIS and Ground Measurement of Some Buildings in AASTU

Table 14. *ArcGIS and Ground Measurement of some buildings in AASTU.*

	GIS (m^2)	Measured (m^2)
®-1	989.9912	937.06
®-2	961.1096	939.57
®-3	986.1535	940.6
®-4	952.2154	939.91
(L)-1	489.7866	523.2
(L)-2	474.5807	525.1
(L)-3	518.0995	523.5
(W)-1	973.9228	780.82
(W)-2	1097.238	780.82
(CT)-1	257.9339	238.68
(CT)-2	264.1241	237.15
(CT)-3	483.0348	236.36
(CF)-1	1570.403	1580.315
(CL)-1	257.9339	693.06
(CL)-2	264.1241	686.928
(CL)-3	483.0348	696.35
(AT)-1	644.9455	684
(AT)-2	655.488	684.1
(LT)-1	481.7134	614.76
(LT-2)	488.8686	621.36
(MT)-1	429.1614	437.9
(MT)-2	459.2833	440.8
©-1	257.9339	480.81
©-2	264.1241	490.625
(Lab)-1	554.01341	648.74
(Lab)-2	497.95144	641.68

	GIS (m^2)	Measured (m^2)
(Lib)-1	2246.371	2086.92
(Lib)-2	2271.984	2088.8
(Lau)-1	148.2076	163.48
(Lau)-2	155.3525	163.35
(Lau)-3	159.6115	161.66
(Mw)-1	1185.741	1256.96

Appendix V. Roof Catchment of All Current buildings in AASTU by ArcGIS

Table 15. Roof catchment by ArcGIS.

R. N	Type	shape length	GISA (m2)								
1	(Lib)-1	191.2201	2246.371	31	(W)-12	218.6802	933.4523	61	(CT)-7	85.22457	436.8803
2	(Lib)-2	191.6275	2271.984	32	(W)-13	240.8009	963.6937	62	(MT)-1	86.15216	429.1614
3	(Lib)-3	192.16726	2257.623	33	(W)-14	238.2044	1019.249	63	(MT)-2	89.27046	459.2833
4	(C)-1	82.084494	481.6573	34	(L)-1	111.43	489.7866	64	(MT)-3	93.30134	507.4882
5	(C)-2	77.265187	438.7756	35	(L)-2	112.0924	474.5807	65	(MT)-4	87.73398	430.3558
6	(C)-3	86.884574	589.142	36	(L)-3	114.3008	518.0995	66	(MT)-5	88.48456	457.0365
7	(R)-1	225.52296	989.9912	37	(L)-4	131.5234	669.8871	67	(MT)-6	92.9885	499.0285
8	(R)-2	241.24276	961.1096	38	(L)-5	166.8979	1065.645	68	(LT)-3	97.81527	544.3116
9	(R)-3	229.89705	986.1535	39	(L)-6	91.59983	398.9222	69	(LT)-1	94.4786	481.7134
10	(R)-4	237.13486	952.2154	40	(L)-7	86.4952	361.7626	70	(LT)-2	94.11391	488.8686
11	(R)-5	238.80607	911.7084	41	(L)-8	119.0793	576.6507	71	(LT)-4	95.821716	488.00339
12	(R)-6	242.19049	997.0607	42	(Lau)-1	49.1759	148.2076	72	(LT)-5	66.34447	239.41281
13	(R)-7	246.55709	1004.525	43	(Lau)-2	50.21239	155.3525	73	(LT)-6	121.91445	779.91639
14	(AT)-1	118.98633	644.9455	44	(Lau)-3	50.67253	159.6115	74	(LT)-7	103.42772	607.61888
15	(AT)-2	122.91925	655.488	45	(Lau)-4	64.60034	257.3866	75	(Lab)-1	111.64659	554.01341
16	(AT)-3	118.51212	655.9171	46	(Lau)-5	52.38267	171.2589	76	(Lab)-2	108.87459	497.95144
17	(AT)-4	124.86545	707.9665	47	(Lau)-6	63.57732	250.8794	77	(Lab)-3	121.02697	704.78225
18	(Mw)-1	147.1473	1185.741	48	(Lau)-7	62.1317	240.8813	78	(Lab)-4	114.28365	575.35789
19	(Mw)-2	175.581	1601.695	49	(Lau)-8	45.2145	126.835	79	(Lab)-5	100.34921	469.64129
20	(W)-1	218.6371	973.9228	50	(Lau)-9	52.49583	170.2777	80	(CL)-1	194.29035	734.38871
21	(W)-2	221.7639	1097.238	51	(Lau)-10	53.31835	177.0784	81	(CL)-2	196.61837	795.67598
22	(W)-3	225.7623	985.0242	52	(CF)-1	162.5199	1570.403	82	(CL)-3	196.25423	799.51836
23	(W)- 4	237.3093	1094.501	53	(CF)-2	221.9545	1276.438	83	(CL)-4	210.69589	772.40761
24	(W)-5	227.6591	981.6288	54	(CF)-3	169.5866	1721.172	84	(CL)-5	207.3078	772.40938
25	(W)-6	223.3794	834.1333	55	(CT)-1	64.26235	257.9339	85	(CL)-6	219.98418	912.35979
26	(W)-7	215.7528	827.1607	56	(CT)-2	65.13307	264.1241	86	(CL)-7	210.73302	859.20152

R. N	Type	shape length	GISA (m2)								
27	(W)-8	215.0695	840.118	57	(CT)-3	89.85337	483.0348	87	(CL)-8	264.25343	1233.2891
28	(W)-9	221.0157	937.8437	58	(CT)-4	90.41393	493.3863	88	(CL)-9	256.2666	1236.14
29	(W)-10	228.213	1002.325	59	(CT)-5	87.19588	452.3934	89	(CL)-10	251.4571	1202.743
30	(W)-11	215.7331	820.6643	60	(CT)-6	63.14444	248.2622	90	(CL)-11	210.048	852.1713
								91	(CL)-12	216.234	934.1595
								Total Area			67786.56

Appendix VI. Conversion ArcGIS Measured Area to Ground Measurement by Trend Line Equation

Table 16. Conversion ArcGIS measured area to ground measurement.

No	GIS (m2)=Y	X=Y/0.9448	No	GIS (m2)=Y	X=Y/0.9448	No	GIS (m2)=Y	X=Y/0.9448
1	2246.37	2259.93	31	933.45	939.09	61	436.88	439.52
2	2271.98	2285.70	32	963.69	969.51	62	429.16	431.75
3	2257.62	2271.25	33	1019.25	1025.40	63	459.28	462.06
4	481.66	484.56	34	489.79	492.74	64	507.49	510.55
5	438.78	441.42	35	474.58	477.45	65	430.36	432.95
6	589.14	592.70	36	518.10	521.23	66	457.04	459.80
7	989.99	995.97	37	669.89	673.93	67	499.03	502.04
8	961.11	966.91	38	1065.65	1072.08	68	544.31	547.60
9	986.15	992.11	39	398.92	401.33	69	481.71	484.62
10	952.22	957.96	40	361.76	363.95	70	488.87	491.82
11	911.71	917.21	41	576.65	580.13	71	488.00	490.95
12	997.06	1003.08	42	148.21	149.10	72	239.41	240.86
13	1004.53	1010.59	43	155.35	156.29	73	779.92	784.62
14	644.95	648.84	44	159.61	160.57	74	607.62	611.29
15	655.49	659.44	45	257.39	258.94	75	554.01	557.36
16	655.92	659.88	46	171.26	172.29	76	497.95	500.96
17	707.97	712.24	47	250.88	252.39	77	704.78	709.04
18	1185.74	1192.90	48	240.88	242.34	78	575.36	578.83
19	1601.70	1611.36	49	126.84	127.60	79	469.64	472.48
20	973.92	979.80	50	170.28	171.31	80	734.39	738.82
21	1097.24	1103.86	51	177.08	178.15	81	795.68	800.48
22	985.02	990.97	52	1570.40	1579.88	82	799.52	804.34
23	1094.50	1101.11	53	1276.44	1284.14	83	772.41	777.07
24	981.63	987.55	54	1721.17	1731.56	84	772.41	777.07
25	834.13	839.17	55	257.93	259.49	85	912.36	917.87
26	827.16	832.15	56	264.12	265.72	86	859.20	864.39

No	GIS (m2)=Y	X=Y/0.9448	No	GIS (m2)=Y	X=Y/0.9448	No	GIS (m2)=Y	X=Y/0.9448
27	840.12	845.19	57	483.03	485.95	87	1233.29	1240.73
28	937.84	943.50	58	493.39	496.36	88	1236.14	1243.60
29	1002.33	1008.38	59	452.39	455.12	89	1202.74	1210.00
30	933.45	939.09	60	248.26	249.76	90	852.17	857.32
						91	934.16	939.80
						sum	67786.56	68195.74

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