



ADDIS ABABA UNIVERSITY

Ethiopian Institute of Architecture Building

Construction and City Development

**Design and Development of Multipurpose Downpipe system
for
Rooftop Rainwater Harvesting
on
Institutional Building: The Case of EiABC Campus**

By

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Declaration

I, the undersigned, declare that this thesis is my own and original work and has not been presented for a degree or diploma in any other institution or university, and that all sources of material used for the thesis have been duly acknowledged, following the scientific guidelines of the Institute.

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Abstract

Water is necessary for human survival, essential to socioeconomic development and environmental wellbeing. Sufficient quantity, safe and affordable potable water is crucial for life and economic development. Urban water scarcity is one of the major problems among the problems induced by the current urbanization and rapid urban population growth. As a result, many urban centers are facing a problem in meeting their water demanded. Rainwater harvesting is becoming alternative solution to fill the gap between demand and supply. Even though, rainwater is naturally the purest form of water on our planets, its quality and quantity degrades due to debris and other pollutants on the potential catchment area. This research aimed to improve the quality and quantity of rooftop rainwater harvesting based on study made on all 34 buildings having corrugated iron sheet roofing in EiABC campus. Data of gutter system and downpipe collected by direct measuring and debris from gutter system collected and analyzed using sieve analysis in the laboratory. Based on these study, integrated nature based debris strainer is developed and tested on urban building of EiABC. Compared to the raw water before the device, the laboratory test result has shown that TSS, TDS, and turbidity has shown remarkable difference by 72.17%, 28.43% and 59.1%, respectively. Simultaneously, the multipurpose integrated rain chain system improve the building façade quality. Since rainwater, resource within the campus is still safe for outdoor use and bridge the gap of water supply. Institutions should have to expand this practice to cover their 70% of water demand and reduce water supply pressure on municipal supply.

Key words: *Water -supply, debris strainer, rain chain, nature-based solution*

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ACRONYMS

CIS	Corrugated Iron Sheet
EIABC	Ethiopian Institute of Architecture Building Construction and City Development
GDP	Growth Domestic Product
GIS	Galvanized iron Sheet
RWH	Rainwater harvesting
RRWH	Roof rainwater harvesting
TDS	Total dissolved solid
TSS	Total Suspended Solid
UN	United Nation
UNICEF	United Nations International Children's Emergency Fund
UN-HABITAT	United Nations Human Settlements Program
UN-HABITAT WSIB	United Nations Human Settlements Program; Water, Sanitation and Infrastructure Branch
WHO	World health organization

CHAPTER ONE

INTRODUCTION

1.1. Background

Water is one of the most commonly used naturally endowed resources on earth. According to Quentin et al., (2011), water plays a critical role in the welfare of societies around the world and affects the livelihood of every human. It is the third most abundant gas in the atmosphere and 70.7 percent of the earth's surface is covered by oceans. The global water cycle redistributes water from oceans to land through atmospheric circulation and back to the oceans, primarily through the surface and sub-surface flow (Quentin et al., 2011).

As urbanization progresses, a number of problems will be brought to the forefront including population growth, resource scarcity, and eco-environmental deterioration. A global water crisis is just one of these anticipated future problems (Biswas, 1991). According to Song et al. (2004b), global urban water utilization of living increases over 20 times within 100 years. If it continues to increase at the same rate, 55% of the people in the world will face water crises. In the 21st century, human beings will face a dilemma —whether to allow the water utilization level to continue increasing or to place a limit on the water demand (Chao & Chuang-lin, 2006). The current situation in Australia is a witness to what is going to happen in other countries in the near future; the country forced to impose restrictions on car washing, garden watering and in some states, pet washing and driveway cleaning

due to acute water shortage in Australia during the summer months (Sisuru, 2016).

Since surface water is inadequate to meet the urban water demand, the urban water supply becomes dependent on groundwater. As a result, the dependency on the groundwater led to over-extraction of groundwater resulting in groundwater depletion. This creates the imbalance between the groundwater recharge and extraction. The challenge of water scarcity requires an alternative source to bridge the gap between demand and supply urgently through RWH. RWH is the simplest and the only option that gives a solution to urban water crisis. Naturally, rainwater is the purest form of water, would be an immediate source to augment the existing water supply by "catching water wherever it falls" (UCDNRM, 2017).

According to Getachew (1999), though RWH is dating back in the antiquity, its importance has not been recognized until the devastating drought and famine of the 1980s. Run-off irrigation (run-off farming), flood spreading (spate irrigation), in-situ water harvesting (ridges, micro-basins, etc.) and roof water harvesting are the most commonly practiced techniques in Ethiopia (Getachew, 1999).

In rainwater harvesting system, gutter and downpipes are major component found under conveyance system that help to collect and convey the rainwater from the catchment to storage. it play critical role on the quality and quantity of harvested rainwater and keeping the building healthy by taking the rain water away from the building. In order to get the better quality and quantity of rainwater it is necessary to give due consideration for all component of RWHs.

1.2. Problem Statement

Water is a necessity for human survival, essential to socioeconomic and environmental life. Sufficient quantity, safe and affordable potable water is crucial for life and economic growth. However, water scarcity is currently a common challenge of all developed and developing countries, but worst in developing country such as Ethiopia, even though the country is known as the water tower of Africa (Getachew, 1999). According to Dagnachew Adugna (2018), as in many other cities, population growth worsens the water supply problem of Addis Ababa, with supply deficit of 41% in 2016 (Adugna, D. et al., 2018).

According to Suman (2017),

“RWH is receiving an increased attention worldwide as an alternative source of water supply. The rooftop RWHs is looked upon as one of the most feasible and economical ways of water conservation. With the increasing problem of water scarcity, planning and designing rooftop RWH is gaining wider importance to meet ever-increasing water demand, encouraging the use of water on more sustainable basis”
(Suman, 2017).

Even though rainwater is the purest form of water that is found on the planet earth, its quality degrades due to the catchment characteristics from where the water is harvested. In an urban area, it is strongly affected by the catchment (roof) and conveyance (gutter and downpipe) and the land use land cover of the area at a small scale. The quantity and quality of collecting rainwater depend on geographic

location, local climate characteristics, the presence of anthropic activities in the area and storage tank volume (Lorena et al., 2016).

Larger plot institution, whether governmental or private, if they adopt the RWHs and utilized at least for a non-domestic purpose, they can save 70% of water used for outdoor usage (Julia, 2008). By doing this they can reduce their water bill and spare water for other users. As a result, they can reduce the water supply pressure on the municipality.

Roof catchment is one of the best components of RWHs, especially galvanized iron sheet roof is the most suitable for RWH. The EiABC campus has high RWH potential from 34 buildings among the 37 buildings within the campus.

Generally, even though the institution has a huge amount of RWH potential the existing gutter and downpipe problems expected to reduce the quality and quantity of rainwater.

1.3. Objectives of the study

1.3.1. General objective

To develop nature-based debris controller system as an integral part of the downpipe of public buildings in order to harvest cleaner water for non-potable use from rooftops, simultaneously to enhance the visual and spatial quality of urban realm.

1.3.2. Specific objectives

1. To identify the gutter type used in the EiABC campus
2. To identify the nature of debris in the EiABC campus
3. To design and test nature-based debris strainer
4. To develop a scheme to utilize the system as a multi-function façade decorative element of public buildings in urban areas.

1.4. Research questions

1.4.1. Main question

How to develop nature-based debris controller integrated with the downpipe that enhances the visual and special quality of urban space?

1.4.2. Specific questions

1. Which types of gutter dominantly used in the buildings of EiABC campus?
2. Which types of debris are more problematic for the rainwater quality and quantity collected from the roof?
3. How can nature-based debris strainer designed and developed to improve the quality and quantity of water harvesting system?
4. How to develop a scheme to utilize the system as a multi-function façade decorative element of public buildings in urban areas?

1.5. Delimitation/ scope of the study

Thematically, the research was focused on the field of hydrology, especially on the problem of quality and quantity RWH. Spatially the research limited in Addis Ababa University at the Institute of Architecture, Building Construction and City

Development / EiABC/ campus. Moreover, temporally the research was conducted for seven months (from February to August, 2018).

1.6. The significance of the study

The study focused on solving the quality and quantity impeded on the roof RWHS due to the presence of debris in the conveyance system. Solving this problem by using nature-based debris strainer will help the community to develop trust on the quality of rainwater. It helps to utilize and fill the gap between water demand and supply. If RWHS widely practiced in Addis Ababa, it can reduce the pressure on municipal water distribution service and help to save treated water used for outdoor use and toilet flushing. If it further treated by disinfectants can be used for drinking. It can also spare treated municipal water and create an opportunity for other community to utilize it. The production and distribution of this device will help to create job opportunity and can substitute functionally similar product imported from abroad by foreign currency. This research will play significant role in solving the problems and optimize the quality and quantity of RWH in the campus. Furthermore, the integrated multipurpose downpipe system help to improve the visual and special quality of the building façade and urban space at larger scale.

CHAPTER TWO

LITERATURE REVIEW

2.1. Concept and definition of RWH

Different scholars define the term RWH differently. According to Utsav et al. (2014), RWH is defined as “the process of collecting and storing rain for later productive use”. In addition, from the same source the term “associated with other activities aimed at harvesting surface and all other hydrological studies and engineering interventions aimed at conservation and efficient utilization of the limited water enforcement of a photographic unit such as a watershed.

Sisuru (2016), also defined RWH as, "the collection, control, and utilization of rainwater close to the point it reaches the earth, this literature reveals that "RWH is an old practice throughout the world for obtaining natural soft water, potable as well as non-potable indoor usages and for sustaining livelihoods such as in agriculture. RWH also used for aquifer replenishment, erosion control as well as flood control (Sisuru, 2016). Both authors, Sisuru (2016) and Utsav et al. (2014),) the definition of RWHs commonly focuses on the collection system and the utilization of rainwater. Furthermore, according to Utsav et al. (2014), the term is associated with other activities related harvesting surface, the hydrological study, and engineering interventions.

2.2. History of RWH

Sisuru (2016), indicated as the history RWH dated back to 850BC. By taking historical evidence of Roman pools in Ajlun and Madaba. Extensive surface water harvesting was practiced India (Rajasthan) and Sri Lanka (Sigiriya, 5th Century AD) to irrigate vast tracts of agricultural lands (Sisuru,2016). According to Rolf, (1989) ancient Romans became masters in RWH and the construction of reservoirs. The urbanization within the Roman Empire around the Mediterranean, which resulted in the development of a rainwater catchment culture at all those places where water resources limited (Rolf, 1989).

Furthermore, according to the Rolf (1989), the world's largest cistern, Yerebatan Sarayi is found in Istanbul-Turkey, which constructed under Caesar Justinian (A.D. 527-565) having 140m by 70m measurement, having a capacity of storing 80,000 m³ water. And another cistern in Istanbul, Binbirdik, has a capacity of 50,000 m³. It is the oldest cisterns that constructed under Caesar Constantine (329 - 337 A.D). Both Yerebatan Sarayi and Binbirdik served as centralized storage (Rolf, 1989).

According to Rolf (1989), the water collected from roofs and paved streets and pass under a sophisticated filtration process to improve water quality. However, this technique did not continue in use for longer, due to its expensiveness of underground cisterns construction than that of a dam and fearing danger of accidental pollution through human excreta in dense urban areas and therefore a risk of epidemics. The ancient systems, rainwater catchment techniques for

housing, served to improve the microclimate through its air-conditioning effect and the water used for domestic purposes (Rolf, 1989).

As Julian (2008) revealed, the popularity of RWH practice has declined over the centuries due to the demand of a more centralized water supply system of urbanization, and watersheds and pipelines came into use and running water became one of the world's greatest inventions. However, due to modern day water pollution and drought, RWH techniques have come back into practice (Julia, 2008).

2.2.1. History of RWH in Ethiopia

The history of water harvesting in Ethiopia dated back as early as the pre-Axumite period (560 BC) (Getachew, 1999). Rainwater was harvested and stored in ponds for agricultural and water supply purposes. A roof water harvesting set up is still visible in the remains of one of the oldest palaces in Axum; the palace of the legendary Queen of Sheba (Getachew, 1999). The other evidence includes the remains of one of the old castles in Gondar, constructed in the 15-16th century, which used to have a water harvesting set up and a pool that used for religious rituals by the kings (Getachew, 1999). Furthermore, the technique also practiced for millennium by the Konso people in the southern part of Ethiopia, and it is indeed one of the wonders of this country, and it has been practiced for millennium; a symbol of struggle for survival by the Konso people against the adversaries of nature" (Getachew, 1999). Generally, the RWHs is not a new technology in the country, the practice used for agriculture, water supply and even for religious purposes.

2.2.2. Best Practice on Institutional Blocks/Plots

Water harvesting practice is currently well-known practice worldwide, large institutional plots are practicing RWHs basically for two advantages. First, they used it to fill the gap in water demand due to water scarcity. By doing so they able to cover their outdoor water demand, as a result, they reduce the water fee paid for municipal water supply. Secondly, by capturing the rainwater within the plot, they reduce runoff generated by the development. In this regard is known largescale institutional plot RWH best practice in Germany, Singapore and Tokyo-Japan are summarized in Table 1.

Table 1: Summary of institutional RWH practices in different countries

NO	Country	Type of institutional	Type of RWHs	Catchment Area in m ²	Harvest in m ³ / yr.	Use of RWH	Source
1	Frankfurt	Airport	Active	26,800	100, 000	<ul style="list-style-type: none"> • Cleaning the air conditioning 	(UN-HABITAT, 2011).
2	German	University of Darmstadt	Active RWHS	-	80,000	<ul style="list-style-type: none"> • Toilets flushing • Cooking and cleaning in laboratories 	(UN-HABITAT, 2011).
3.	Berlin	DaimlerChrysler Potsdamer Platz	ARWHS	32,000	3500	<ul style="list-style-type: none"> • Toilet flushing, • Garden Watering • Recharging of ponds 	(UN-HABITAT, 2011).
4	German (Berlin)	Belss-Luedecke-Strasse building	ARWHS PRWHs	7,000 4,200	2,430	<ul style="list-style-type: none"> • Toilet flushing • Garden watering 	(UN-HABITAT, 2011).
5	Singapore	High rise Buildings	ARWHS			<ul style="list-style-type: none"> • Toilets flushing, • Watering the plants 	(UNEP, 2017)
6	Changi	Changi Airport	PRWHs	8,400 m	28-33% its demand	<ul style="list-style-type: none"> • Fire-fighting drills • Toilet flushing 	(UNEP, 2017)
7.	Tokyo, Japan	Sumo-wrestling Arena and Sumida City Hall	ARWs	8,400	1,000	<ul style="list-style-type: none"> • Toilet flushing and air conditioning system. 	(UNEP, 2017)

2.3. Active and passive RWH

The RWHs categorized in to two basic system based on from where the water captured as passive and active RWHs. According to Tamim and Tammy (2016), the passive RWH is a system in which the rainwater captured from landscape deportation and provide water to plant through overland flow. Whereas in active RWHs rainwater is captured from the rooftop and used in-building for different uses such as toilet flushing, laundry and cooling, and other outdoor uses (Tamim & Tammy , 2016)

2.3.1. Components of RWH

RWH is a system in which different components came together as a system. According to Heather (2012), The RWHs consist of four basic components, in addition to the three basic common component; filtration system is added as one component, four basic components are:

1. Collection area – roof surfaces provide an opportunity for rainwater capture.
2. Conveyance System – used to transfer water and is comprised of gutters or flat roof drainage holes, and downspouts and piping.
3. Water storage system – may be above or below ground and can be comprised of a single container or multiple containers.
4. Filtration – to keep debris out of the system.

However, according to UN-HABITAT (2011), all RWHs comprise six basic components irrespective of the size of the system. In addition to the former

components, leaf screens, roof washers, and water treatment added as basic components of RWHs (UN-HABITAT WSIB, 2011).

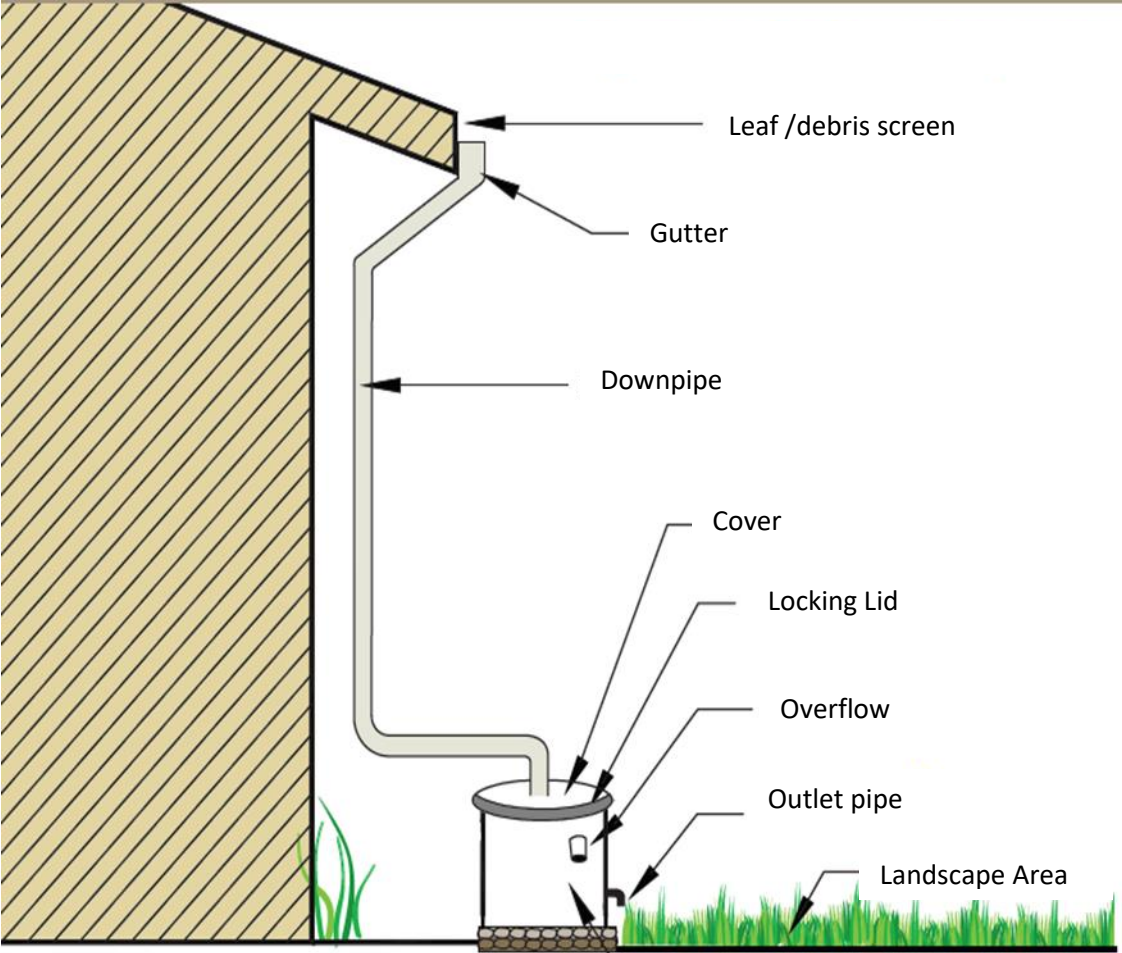


Figure 1: Component of rooftop RWHs (Source: RWH Guide city of San Diego (2015))

2.3.1.1. The catchments (roof) system

In most cases of RWHs, the collection area is the roof of a building. According to Sisuru (2016), the effective roof area and the material used in constructing the roof influence the efficiency of collection and water quality. The typical material for roofing includes corrugated iron sheet, Asbestos-Cement sheet, tiles or thatch made from a variety of organic materials. For roof rainwater harvesting all catchment surfaces must be made of a non-toxic material (Sisuru, 2016). The roof should not be painted. Otherwise, the paints should be free from heavy metals such as lead, chromium or zinc. Besides, the roof must be free from overhanging vegetation. With regard to slope of the roof, steep galvanized iron roofs have been found to be relatively efficient rainwater collectors, while flat concrete roofs are very inefficient. However, roofs covered with corrugated galvanized mild steel are found to be the easiest to use and giving the cleanest water. GI sheets also have the potential to kill bacteria because of maintaining high temperature when exposed to the sun (Sisuru, 2016).

2.3.1.2. Type and proportion gutter system

Conveyance system transports the rainwater from the catchments system to storage. It used to take the rainwater away from the building to protect from splash of water. In addition, in RWH, it conveys the rainwater to where it utilized or stored for future use. The gutter is one of the conveyance components installed horizontally along the roof eave that serves as a roof drainage system. Whereas

the downpipe is the secondary vertically erected conveyance system attached to the gutter system.

According to Rolf (1989), the efficiency of any rainwater catchment depends largely on the gutter and downpipes. To maximize the quantity of harvested rainwater, both gutters and downspouts have to be properly sized and installed on the roof catchment (UN-HABITAT WSIB, 2011). Unless it is properly designed and installed precisely on the building keeping the proper slope (0.3-0.5%). It does not properly function in draining roof rainwater and accumulates debris.

According to the UN-HABITAT WSIB (2011), depending on the shape of the gutters, there are two types of guttering; semi-circular and rectangular type. However, Allison and Kuczera (2007) categorized it into four depending on their shapes as semicircular, V-shaped, Box (rectangular) and trapezoidal gutter. Furthermore, the study reveals that semicircular gutter is the most efficient to remove debris among the four kinds of gutter type (Allison and Kuczera, 2007) as shown in Figure 2.

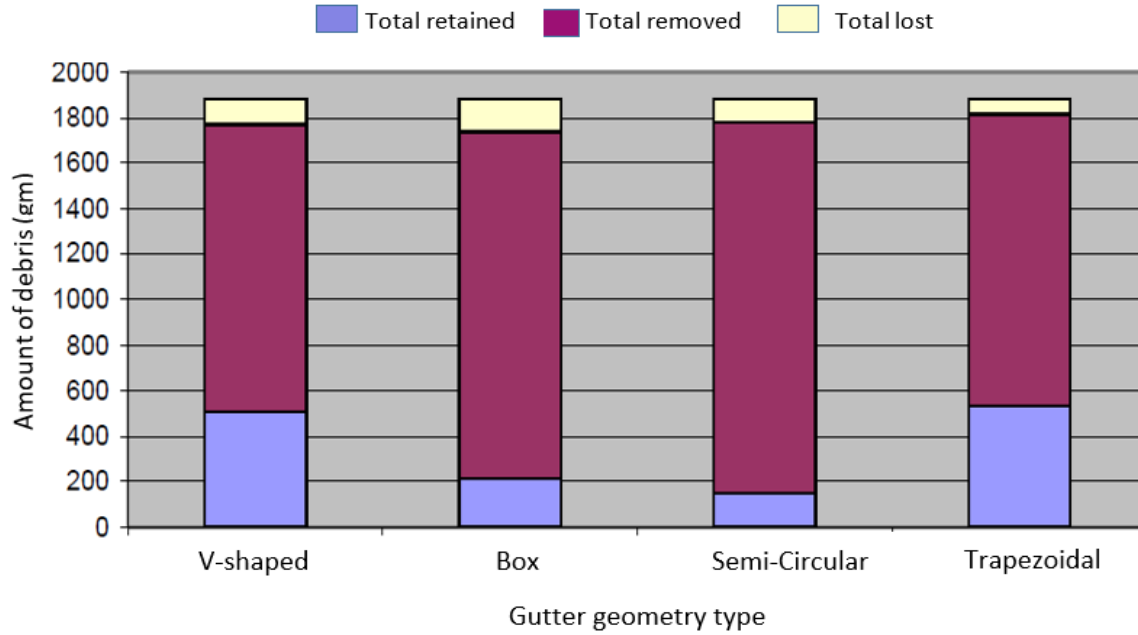


Figure 2. Comparison of gutter type on their debris removal performance

A gutter design that optimizes self-flashing potential is crucial in RWH, excluding and removing organic debris from a gutter is essential for the maintenance of water quality in water harvesting. According to Rolf (1989), there is a general rule for proper sizing of the gutter system in proportion to the catchment area, according to this rule, 1.0 cm² cross-section of gutter and downpipe per 1m² catchment (roof) area. The relation of gutter cross-section area to the catchment area and the thickness of the material described in Table 2 and 3.

Table 2: Proportion of semi-circular gutter and down pipe to the catchment area

Catchment area (m ²)	Gutter size (mm)		Cross-section (cm ²)	Thickness of material (mm)
	Height	Width		
Up to 30	41	65	21	0.65
30-40	51	85	35	0.65
40-100	75	112	70	0.70
100-150	90	140	110	0.70
150-250	115	190	196	0.80
250-450	180	225	364	0.80

Table 3: Proportion of rectangular gutter and downpipe to the catchment area

Catchment area (m ²)	Gutter diameter (mm)	Cross section (cm ²)	Thickness of sheets (mm)
Up to 25	80	25	0.65
25-40	105	43	0.65
40-60	127	63	0.70
60-100	153	92	0.70
100-150	192	145	0.70
150-250	250	245	0.80

Usually, downpipes are of smaller dimension than gutters since waterfalls more or less vertically. In rainwater catchment, this is often not the case and downpipes should be of the same dimension as the gutters attached to the downpipes (Rolf, 1989).

2.4. Type and source of debris on the rooftop

Gutters are the natural receptacle for every conceivable foreign matter carried by gravity, wind and rain runoff. Debris problem hinders the proper functioning of the gutter system. Different debris accumulate on the rooftop catchment system from internal and external sources. Since the gutter system installed along the edge or eave of the roof of a building, they exposed to debris such as leaves, twigs, eroded roof material, animal excrement and other objects. Gradually debris starts to accumulate in the rainwater gutter system, particularly at the bottleneck point of along the gutter system such as around the spikes or hangers, at the drop outlets to the downspouts, at bends in the gutter and/or downspouts (LaMorte et al., 2008). By clogging the gutter system, it reduces the quantity of rainwater harvested and the accumulation of debris within the conveyance system affect the quality of harvested rainwater.

According to Lorena et al. (2016), the source of debris are categorized in to two category as the external and internal source of debris. Leaves, twigs, animal excrement, dust are categorized under debris from external source and eroded roof materials are categorized as internal source of debris as shown in Table 4.

Table 4: Source of rooftop debris

No.	Type	Source	Remark
1	Leaves	trees	External
2	Twigs	trees	External
3	Animal excrement	Birds and rodent animals	External
4	Dust	Surrounding environment	External
5	Eroded roof material	Roof	internal
6	Other objects	Surrounding environment	External

(Source: Lorena et al., 2016)

2.4.1. Problem created by debris

The accumulation of debris in the roof and conveyance system (gutter and downpipe) has an immediate and long-term impact on RWHs. The impact varies from clogging the system up to destroying the physical structure of the system and the quantity, quality of harvested rainwater. Furthermore, because of the overflow of rainwater created over the edge of the gutter, it highly affects the aesthetics and strength of the building.

2.4.1.1. Quantity of rainwater

The quantity of RWH depends on the nature of catchment area, the property of the surface material and the quality of the conveyance system. According to the research conducted by Lamarte et al. (2008), when debris accumulated in the gutter system, the conveyance system no longer adequately drain the rainwater

captured from roof catchment. The rainwater starts overflowing over the edge of the horizontal gutter system, because of this problem the potential of rainwater harvested from the catchment is reduced (LaMorte et al., 2008).

2.4.1.2. Quality of rainwater

Even though rainwater is naturally purest form of water, its quality has been found to be dependent on both the roof type and environmental conditions, the local climate and atmospheric pollution. Representative potential sources of non-point pollution on a rooftop classified according to whether they are external or internal. External sources include airborne pollutants and organic substances from human activity, leaves, and bird-waste. Pathogens found primarily in the feces of birds and mammals that have access to the rooftop. Internal sources of non-point pollution originate in the roofing materials themselves. Rainwater reacts physio-chemically with roof materials, and the presence of lichens and mosses on the roof influences water quality over the long term. Numerous studies have analyzed the quality of harvested rainwater based on microbiological, physical and chemical parameters.

2.4.1.3. Building condition and aesthetics

Properly installed and functioned gutter and downspouts system ensure the building condition by keeping the rainwater from the roof away from the building wall and foundation. If these conveyance systems are not properly designed and installed and if not functioned due to debris accumulation, it creates rainwater overflow over the edge of the gutter. As a result, water starts to percolate into the surface of the building. This, in turn, may damage the building by leading to cracks

walls of the building, and /or the building foundation and percolate into the lower part of the building foundation and damage the building (LaMorte et al., 2008). Furthermore, according to Rolf (1989), due to improper installation and the clogging effect of the debris on the gutter system, up to 40kg of rainwater retained per meter of gutter system and this weight makes to total collapse of the gutter and downpipe system (Rolf, 1989).

2.4.2. Methods of treating rainwater

Different techniques have been used to improve the quality and quantity of rainwater harvested. According to UN-HABITAT (2011), rainwater treatment techniques are categorized into four major groups as summarized in Table 5:

Table 5: Techniques used for rainwater treatment

No	Method	Location	Result
1	Screening		
	Strainers and leaf screens (gutter guard)	Gutters and leaders	Prevent leaves and other debris from entering the tank
2	Settling		
	Sedimentation	Within tank	Settles particulate matter
3	Filtering		
	In-line/multi cartridge	After pump	Sieves sediment
	Activated carbon	On tap	Removes chlorine
	Reverse osmosis	On tap	Removes contaminants
	Mixed media	Separate tank	Traps particulate matter
	Slow sand	Separate tank	Traps particulate matter
4	Disinfecting		
	Boiling/distilling	Before use	Kills microorganisms
	Chemical treatments	Within tank or pump	Kills microorganisms
	Ultraviolet light	Should be located after activated carbon filter before the trap	Kills microorganisms
	Ozonating	Before tap	Kills microorganisms

(Source: UN-HABITAT WSIB, 2011)

2.4.2.1. Strainer or gutter guard

The history of debris removal practice for roof RWBs is dated back to 1898, Many ingenious attempts have surfaced over the year since Benjamin F. Nye, U.S. Pat. No. 603611, May 3, 1898, conceived of the deflector principle to solve debris problem. But according to Collins (1993), none of them has been successful in solving the problem (Collins, 1993). Similarly, according to Allison and Keczera (2007), even though there is an extensive debris exclusion product are available, this product only inhibit debris above greater than 2mm diameter (Allison et al., 2007). To remove smaller debris that gathers on the catchment surface, and ensures high-quality water for either potable use or to work well without clogging irrigation emitters, a series of filters are necessary. This system is known in a different name on the market, such as gutter guards, strainer, filter, screen, gutter solution, and gutter brush etc. And they use filtration, deflection, and repelling mechanism to separate the debris from rainwater. Diferent types of debris strainer found on the on the market are illustrated on Figure 3.

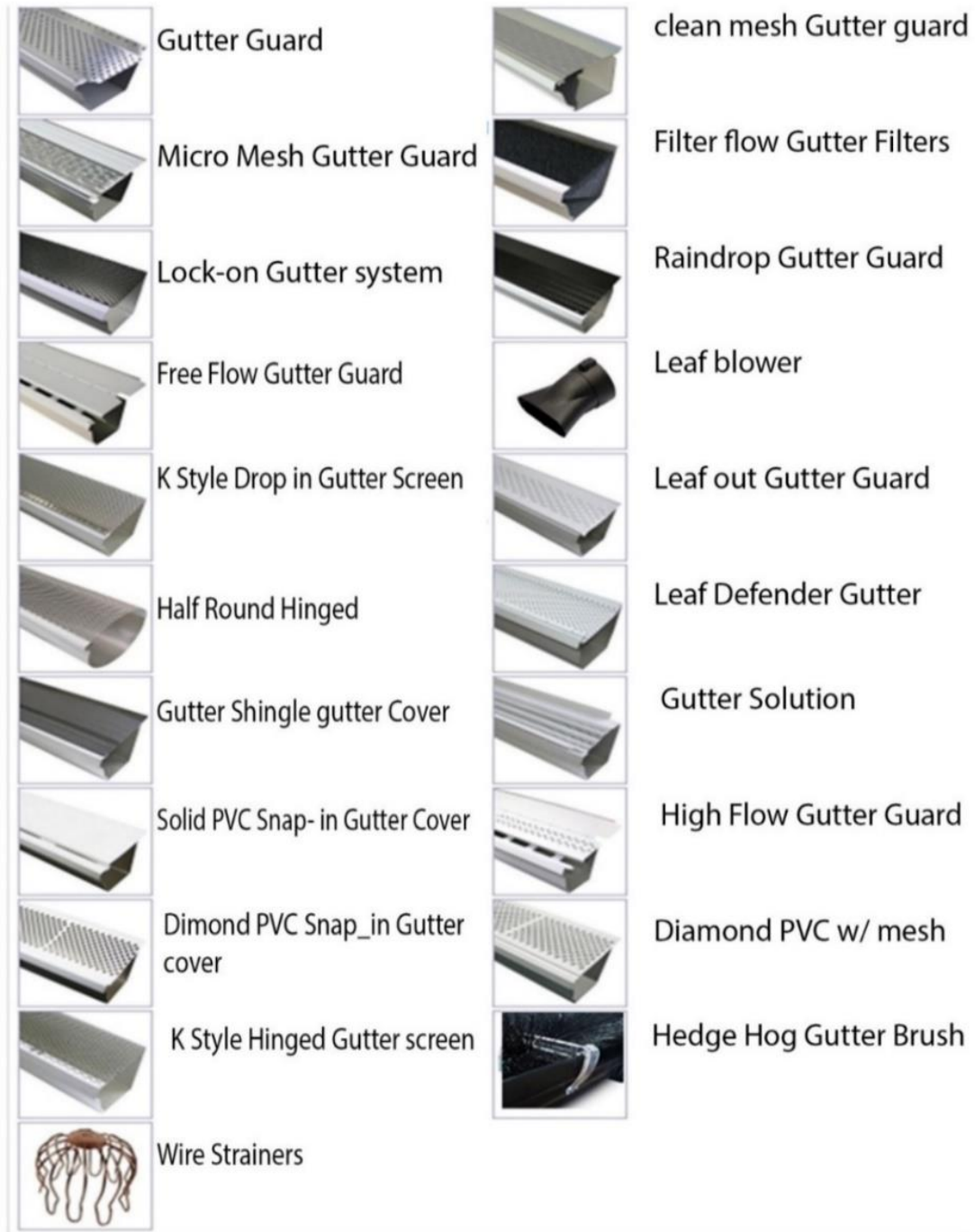


Figure 3: Types of gutter guard

(Source: <https://www.guttersupply.com/p-screens.gstml>)

2.4.3. Nature based filtration

Naturally, rivers and streams have the ability to clean themselves by removing or by sedimentation process. Running water is capable of purifying itself with distances through a process known as self-purification (Kamla-Raj, 2008). This self-purification depends upon the velocity, length of the river and the friction created between the water and the river body (Kamla-Raj, 2008)).

Water purification through sand river alluvium is a process of mechanical and physical actions that remove unwanted impurities and organic matter and leave them harmlessly within the sediment bed. Very fine particles and pathogenic organisms that are present in the raw water removed through a combination of sedimentation, filtration, adsorption and chemical and biological actions (Hussey, 2007).

As contaminated water passes through the sediment bed, the larger impurities deposited and smaller particles removed by straining. The process continues to the smallest impurities, which attached to individual grains of sediment (Hussey, 2007).

The quality of water drawn from the deep sediment of sand rivers is often of a remarkably high quality. Typically, it might be considered as safe for use of household water supply and almost certainly for use as livestock water and for irrigation and other project purposes. In effect, the percolation of water through river sediment is a huge slow-sand filter system, and as the water does not have contact with sunlight, there is little or no growth of algae (Hussey, 2007).

2.4.4. Theory and philosophy of ornament and decoration

The theory and philosophy of ornament and decoration written by Cliff Moughtin, et al. (1999), urban design is the art of city building, which concerned with the methods used to organize and structure the urban realm as distinct from the detailed design of the private domain. The role, function, and form of ornament and decoration in the city is one aspect of urban design. According to Cliff Moughtin, et al. (1999), decoration on buildings and in the city generally is the means by which varieties of visual experiences are introduced to the viewer for his/her enjoyment. Façade is an important element that comprises three main formal horizontal divisions – the base, podium or ground floor; the middle zone or main floors; and the roof or attic to present this variety of experience to the viewer (Cliff Moughtin, et al. 1999).

Ornament and decoration are taken to mean the ways in which the main elements within the city are arranged to form a pleasing and memorable pattern. The three-interrelated function of ornament and decoration are; decoration of individual buildings and to enrich the decorative themes of a locality; to enhance the physical, social and spiritual qualities of location, and thirdly to develop the 'legibility' and 'imageability' of the city. Ornament and decoration also have the capacity to unleash feelings, trigger reactions, feed the memory and stimulate the imagination.

The greatest pleasure from decoration and ornament in the urban realm will result when such embellishment is in harmony with its function, then ornament and decoration are not optional extras on a building or in a city. The city needs them

as much as it needs a transportation network, car parks or city center (Cliff Moughtin, et al. 1999). An important role of ornamentation is to give emphasis to the most important part of a building, the most important buildings or the most important civic spaces. Therefore, it is often confined to the front of the building on important elements surrounds to doors or windows. Other functions of decoration in the city relate more directly to functional necessity, such as providing shade, shelter, areas of safety, comfort or information (Cliff Moughtin, et al. 1999).

Since gutter and downpipe are elements that fall under the roof or attic, which is the third building façade division. The downpipe system also extended to the second and first division of building façade called the base and middle zone respectively. Poor quality design and placement of gutter and downpipe on buildings have a direct and indirect impact on the visual quality of the public realm. The deterioration of gutter and downpipe system by itself directly affect the visual quality of the building, whereas, as rainwater conveyance system if they are not able to convey the collected rainwater they create rainwater overflow on the building. The overflow seepage and the splash of rainwater indirectly create problems on the decorations of building façade found on the wall, doors, and windows. Designing those elements through the inclusion of water and green as integrated drainage system is a good opportunity in the tropical highland climate with intensive rain and sunlight. In this regards, if the system properly designed due considering local climatic and biophysical factors of densely developed urban areas, it will provide both drainage and decorative services simultaneously.

CHAPTER THREE

Materials and Methods

3.1. The study area

The study was conducted in one of AAU's campus, EiABC, in Ethiopia. EiABC is located in Addis Ababa city, Lideta sub-city woreda 4. Geographically it is found $9^{\circ} 00'43''$ to $9^{\circ}00'51''$ Northing and $30^{\circ}43'44''$ to $30^{\circ}43'51''$ Easting. The campus is found within altitude ranges from 2341m to 2375m above sea level. The EiABC campus covers an area of 7.8ha of land (Figure 4 and 5).

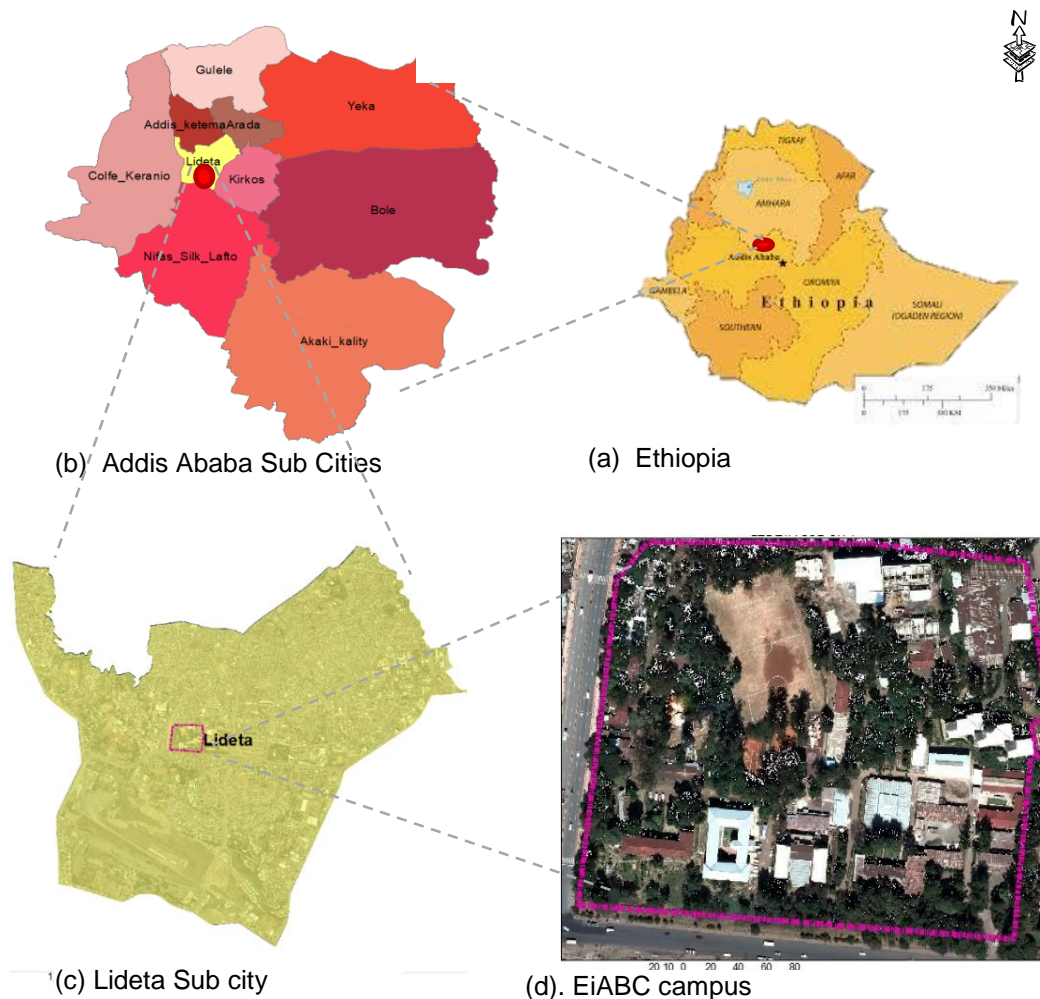


Figure 4. The study area

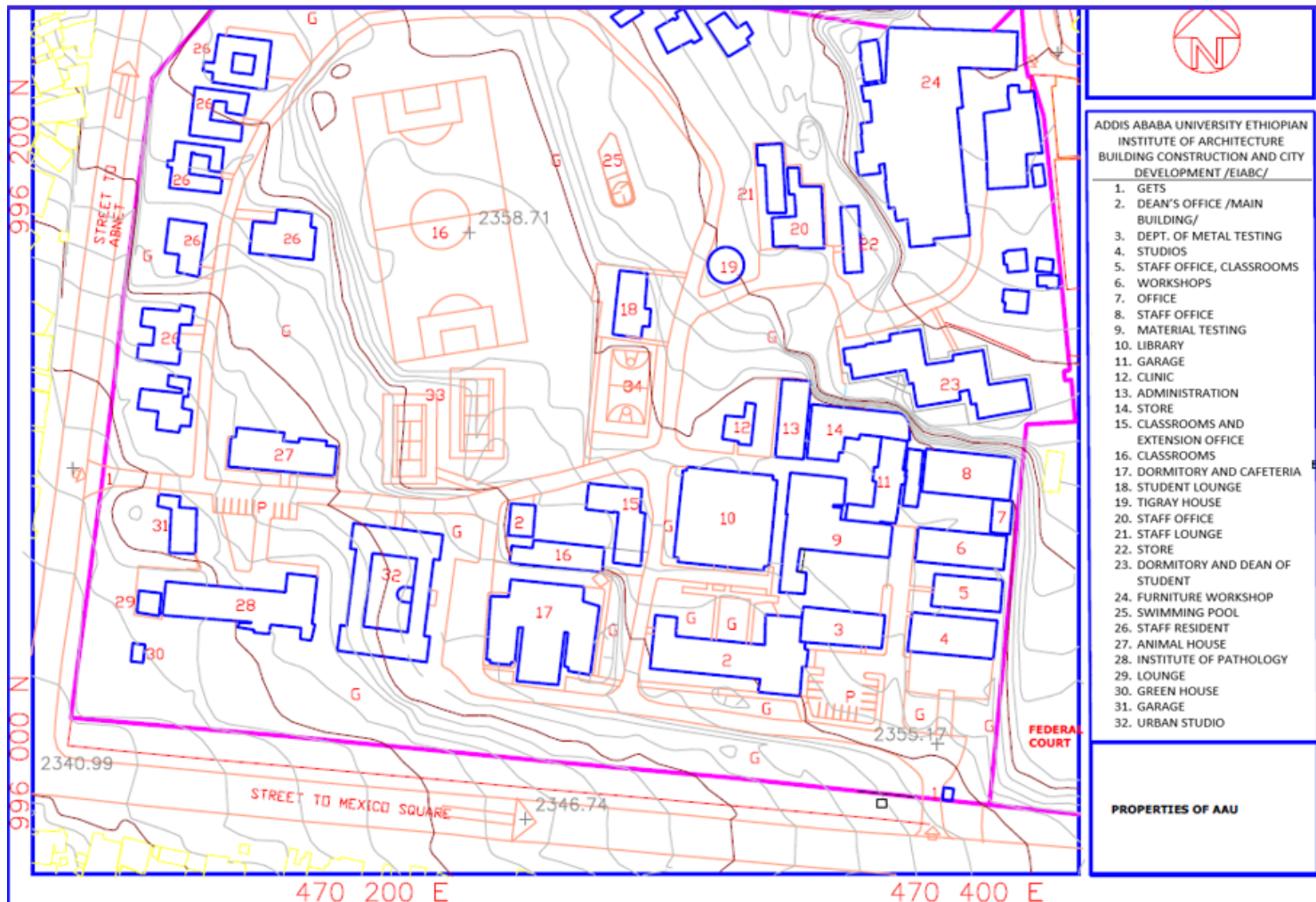


Figure 5: Site plan of EiABC Campus

The campus is found within Little Akaki watershed and drained to Lake Aba Samuel (Figure 6).

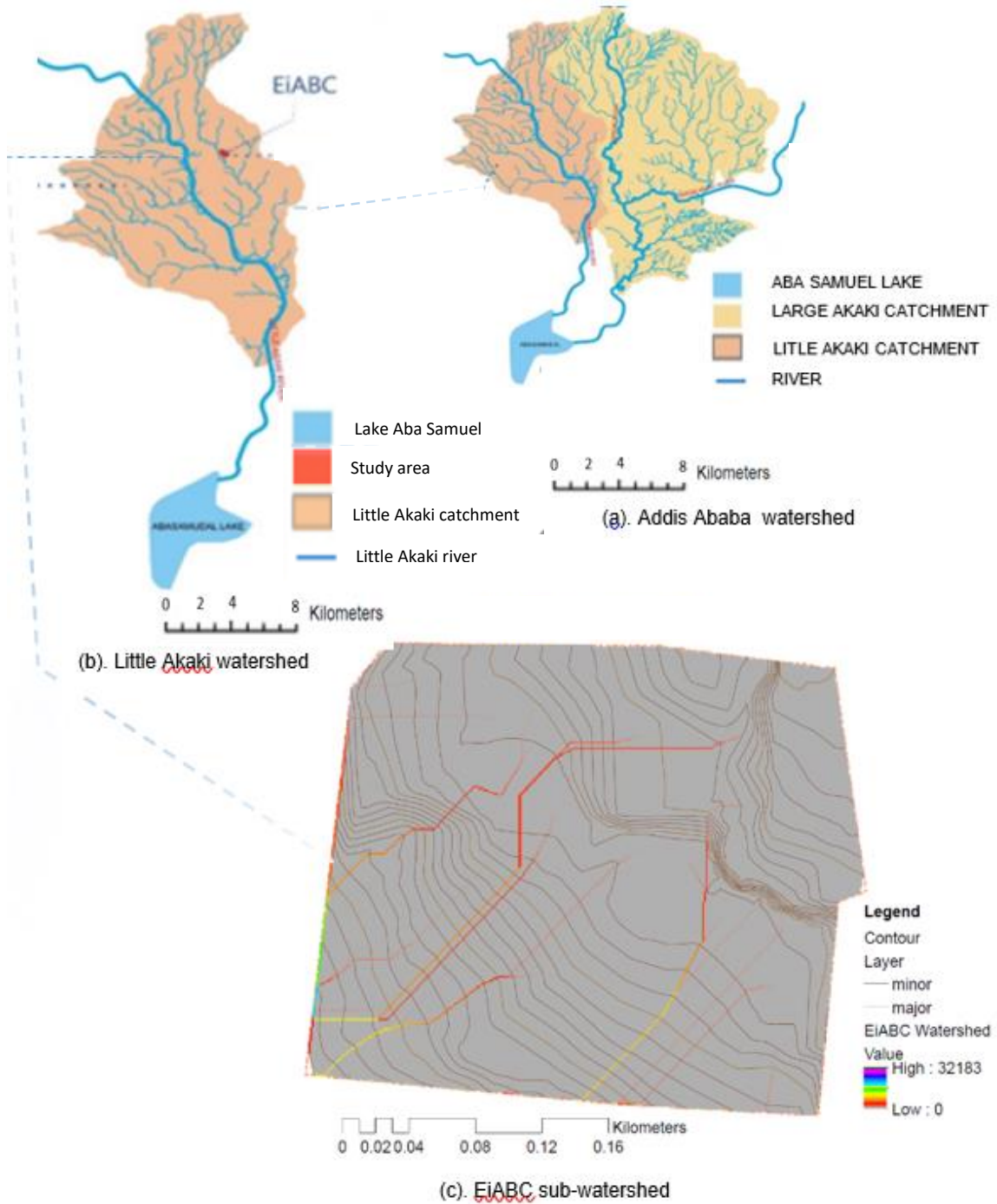


Figure 6: Watershed of the study area

3.2. Sampling technique

All building having corrugated iron sheet roofing were selected to collect data regarding the gutter system and debris. Based on this out of the 37 building found in the EiABC campus, 34 buildings are covered with corrugated iron sheet (CIS) roofing material. All the 34 buildings were fully considered for the study, the total coverage of buildings out of the campus area is 17,969m² (Table 6).

Table 6: Types of building in the EiABC campus

No	Roof type	Number of buildings	Total area (m ²)	Remark
1	Corrugated Iron Sheet	34	16,585	Target area
2	Thatched roof	1	123	Tigray house
3	Concrete roof	1	1,014	Library
4	New building	1	247	Under construction
Total		37	17,969	

The sample was taken to assess the preference of urban building users regarding the conventional downpipe and multipurpose rain chain system, and the attitude towards the multipurpose integrated building facade decorative element installed on urban building. From the 187 population, 30% (56 peoples) of urban building users were randomly selected.

3.3. Data

For this research, gutter size, the material used for the gutter, the shape of the downpipe and gutter system, types and source of debris in the gutter system were collected by field survey. Besides reports and other related documents such as plans of the buildings, the aerial photograph of the area and CAD files were used. Both qualitative and quantitative data utilized in this research, the qualitative data regarding the gutter system (types, shape, and material of gutter system) and nature of debris (types and sources of debris) were collected from the existing buildings in the EiABC campus. In addition, the quantitative data such as size of the gutter system, catchment area of each building were collected

3.4. Data collection

The primary data regarding the gutter system and the nature debris collected directly by the field survey (taking measurement) and observation. Whereas, the secondary data collected from reports, plans (soft and hard copy) of the buildings by digitizing the aerial photograph of the area. The whole methods of data collection were summarized at Table 7.

3.5. Methodology

Table 7: Summarized methodology

No	Specific objectives	Types of data	Source of data	Collection methods	Instrument used	Analysis
1	To identify the Gutter type used in the EiABC campus	Gutter shape, size and material	Buildings at the EiABC campus	Observing, Measuring	Camera, Meter tape	Comparing with the standard from literature
2	To identify and sort out the nature of debris in the EiABC campus	Type of Debris Source, Size,	Buildings at the EiABC campus	Sieving	Camera Balance, Sieve	Sort out debris using a sieve
3	To design and test landscapes-based debris strainer	Type of Debris Source, Size,	Buildings at the EiABC campus	Sieving	Sieve	Measure the performance
4	To develop a scheme to utilize the system as a multi-function façade decorative element of public buildings in urban areas.	Quality of the water from each device Infiltration rate	Recorded Experiment al results	Observing and measuring	Turbid meter Stop watch	Compare the in late amount with rate of infiltration and test the quality of water

3.6. Research design

The research designed in a way that the existing data gathered and thoroughly analyzed. The analytical procedure designed is shown in figure 7.

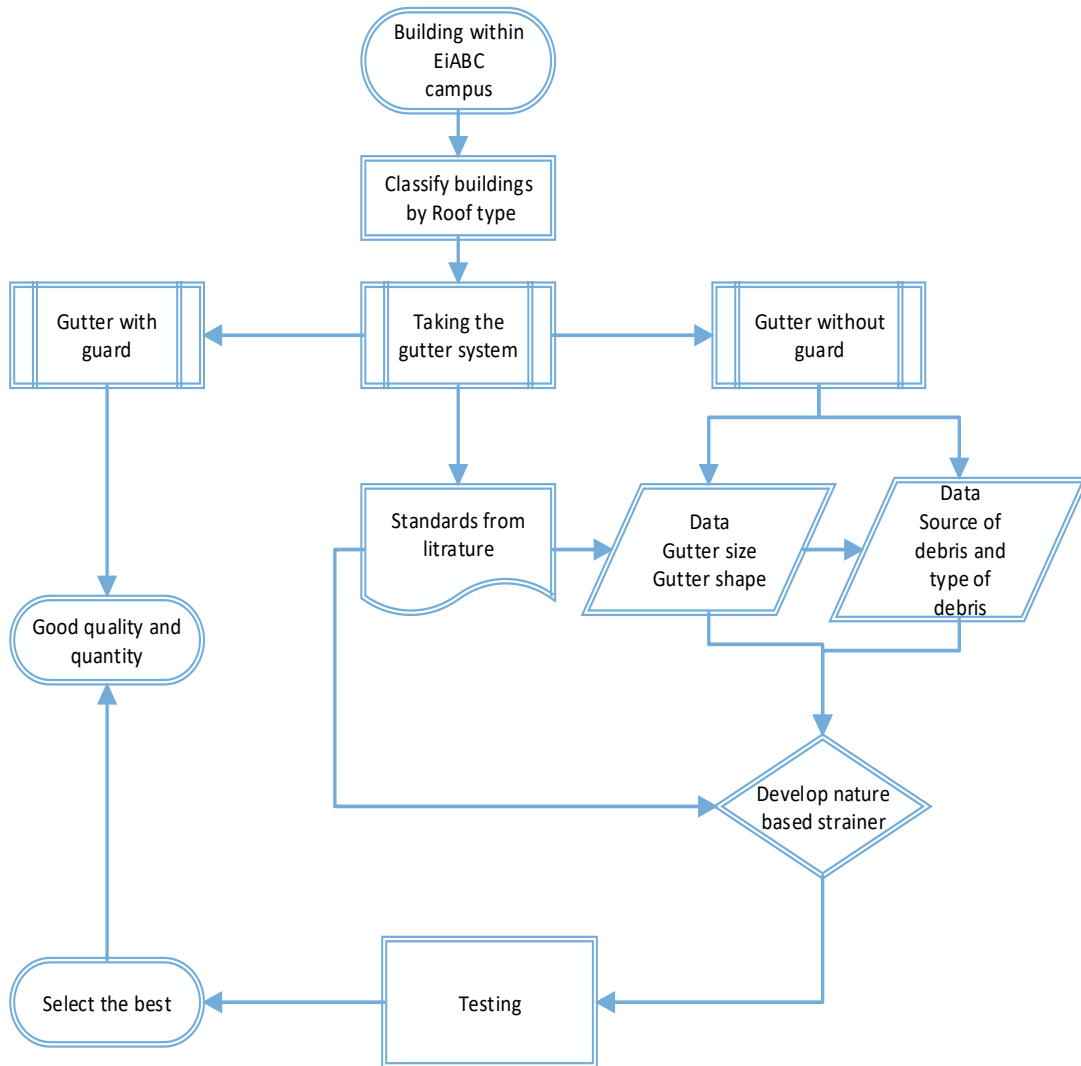


Figure 7: Research design and procedure

3.7. Experimental setup

Urban building is a building selected for experimental purpose, the building is a G+1 building found at EiABC, which has 1134.4m² roof catchment. The experiment was done on 140m² roof catchment by changing the existing rectangular gutter system to semi-circular gutter system and the conventional type of downpipe system to rain chain served as downpipe with the nature-based debris strainer. The sample was taken from rainwater collected from experimental and control group prepared on the urban building rooftop as illustrated in Figure 8. Then the pH and turbidity test were made on site, and the sample taken to laboratory for TSS and TDS test.



Figure 8: Experimental setup

The experiment was done on the quality of rainwater by measuring the amount of TSS, TDS, PH and turbidity of water before it poured to the inlet bucket and after it passes through the experimental device (from outlet bucket). Then the quality of the inlet and outlet water compared each other and results were inferred.

3.8. Data analysis and procedure

The shape of the gutter system was analyzed by the observation made on 28 selected buildings in the EiABC campus. Besides, the size of each gutter and downpipe system were directly measured, and the area of each roof catchment was taken from soft copies of building design, and their proportion was analyzed by using ARC_GIS software.

To identify the nature of debris found on 28 buildings selected for the purpose of this building, debris were collected from 1m length gutter system and made to dry under room temperature. After it dry, large and small size debris of each building were separated by using 2mm sized sieve in the laboratory. The separated debris was measured and recorded to compare the amount of debris with respect to the building height by using ARC_GIS software.

The efficiency of the device was analyzed by taking a 1lt sample of rainwater for five consecutive rainy days from the device and out of the device (the experimental group and controlled group) at the same time. The turbidity and pH of the sampled rainwater were tested immediately on site, and the sample was taken to the laboratory to test for TDS and TSS. TSS was analyzed by filtering 100 ml of the water sample using a known weight of filter paper with 47 mm diameter and 0.45 μ m pore size. Then the filter paper was dried in a dry oven at 1050C, and finally, the weight of dried filter paper (residue or total suspended particles) was measured using analytical balance. TSS was calculated using the following formula:

$$\text{TSS (mg/l)} = \frac{W2 - W1 * 1000}{V}$$

Where: W1= weight of filter paper before filtration (mg)

W2 = weight of filter paper after filtration (mg)

V= Volume of sample filtered (ml)

TDS was analyzed by evaporating filtered rainwater in known flask weight using dry oven at 1050C for 24 hours, and finally, the weight of residues remaining in the flask was measured using analytical balance. TDS was calculated using the following formula:

$$\text{TDS (mg/l)} = \frac{A - B * 1000}{V}$$

Where: A = weight of dried residue + weight of flask (mg)

B= weight of flask (mg)

V = Volume of sample filtered (ml)

The preference of the peoples about the multipurpose rain chain building façade decorative element was analyzed by using the Likert scale.

CHAPTER FOUR

RESULT

4.1. Nature of gutter system on buildings in EiABC campus

i. Gutter shape

The gutter system is one of the most important components of rooftop RWHs that used to convey the harvested water to the downpipe. The geometry or shape of the gutter system is one of the most important factors in self-debris removing capacity. The 33-buildings found in the EiABC campus have 113 CIS roof catchment having a total area of 14064.8m². Among the major four type of gutter system, three of them are found on the buildings of the EiABC. The gutter shape found are semicircular, rectangular and trapezoidal gutter systems as shown in Table 8.

Table 8: Types of gutter system in EiABC campus

NO	GUTTER TYPE	QUANTITY	CATCHMENT AREA (M ²)	PERCENTAGE
1	Semicircular	4	450.8	4
2	No Gutter	19	2555.9	17
3	Rectangular	32	4874.6	28
4	Trapezoid	58	6183.4	51
5	Total	113	14064.8	100.00

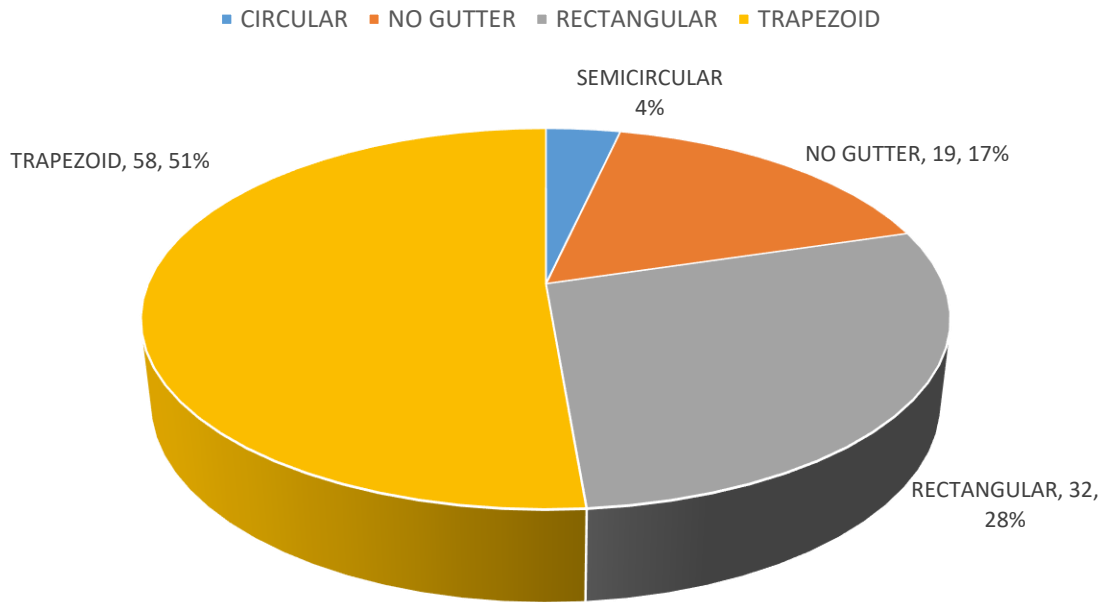


Figure 9: Gutter shape on EiABC buildings

As shown in the Figure 9 the largest portion 51% of roof catchment are installed by using trapezoidal gutter, 28.32% rectangular gutter and 4% circular gutter system. Even though 16.81 % (19 catchments) of roof catchment having an area of 2555.9 m² are suitable for RWHs, the gutter system on 3 building 10.62%(12 catchments) is not installed at all. In addition, the rest gutter system on 5 building which accounts 6.19% of the catchments has been destroyed due to debris overload. The distribution of buildings by their type of gutter system is shown in Figure-10.

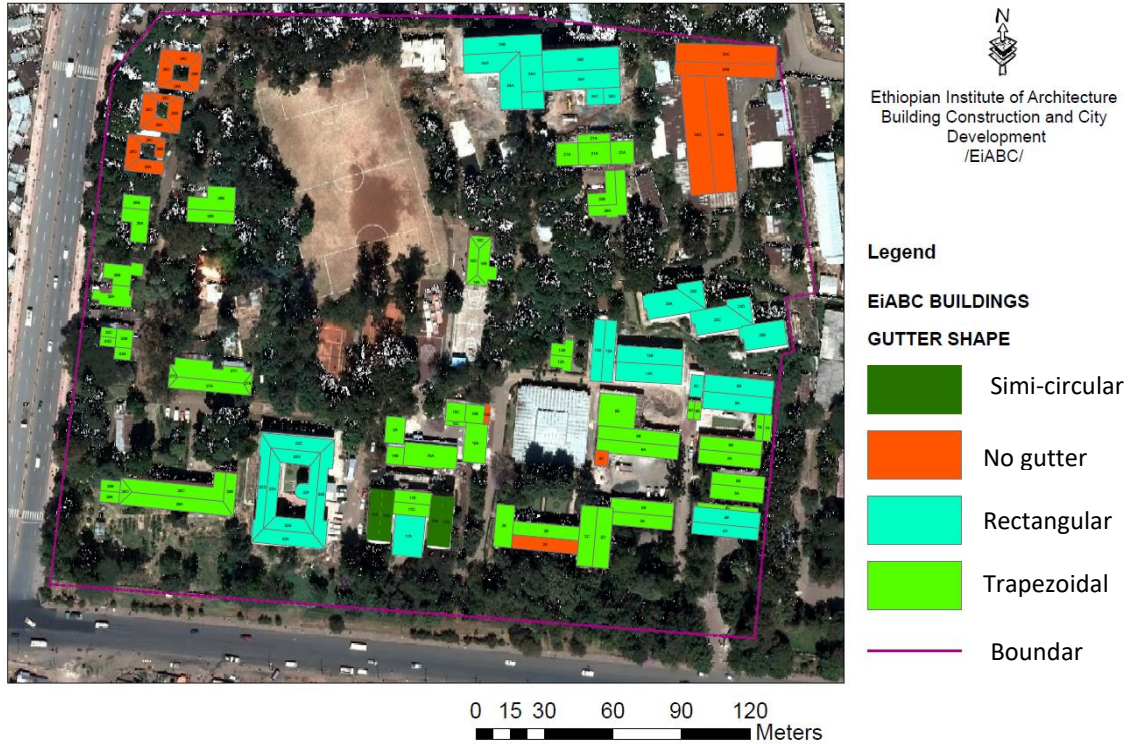


Figure 10: Buildings by gutter shape

a) Trapezoidal gutter system in EiABC campus

The trapezoidal gutter system is the poorest gutter system in self-cleaning performance, but 6183.4m²(51.33%) of the roof-catchment installed the trapezoidal gutter system. Almost all of these gutter systems found in bad condition. The debris collected on the gutter system decomposed and became plant growing media as it is seen in Figure 11 and 12 and Some of them are totally destroyed and not functional as shown in Figure 13,14 and 15.



Figure 11: Trapezoidal gutter system on Animal House

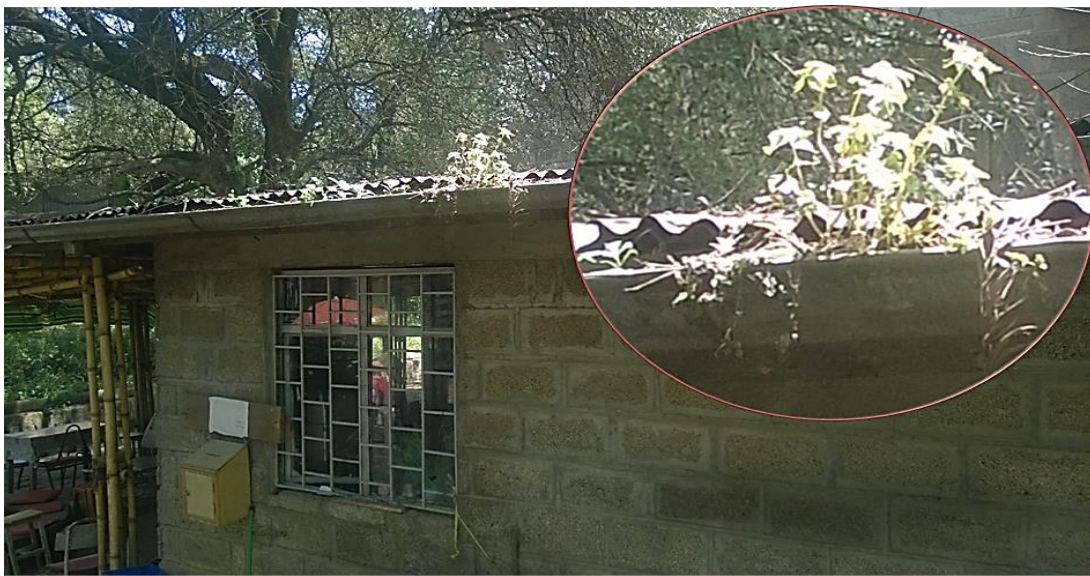


Figure 12 : Trapezoidal gutter system on pathology building



Figure 13: Trapezoidal gutter system on Animal House



Figure 14: Trapezoidal gutter system on administration building



Figure 15: Trapezoidal gutter system at pathology building

b) Rectangular gutter system at EiABC campus

The rectangular gutter system is the best gutter system in self-debris removing performance next to semi-circular gutter system. From the total roof catchments on EiABC buildings, 32(28%) gutter having 4875m² area is installed using the rectangular shaped gutter system. Even though this gutter system physically found in better condition than the trapezoidal gutter system, due to the clogging effect of debris accumulation on the gutter system, currently it is not properly functioning. The rainwater collected into the gutter system creates overflow over the gutter system due to the clogging effect of debris accumulated on it as shown in Figure 16 and 17.

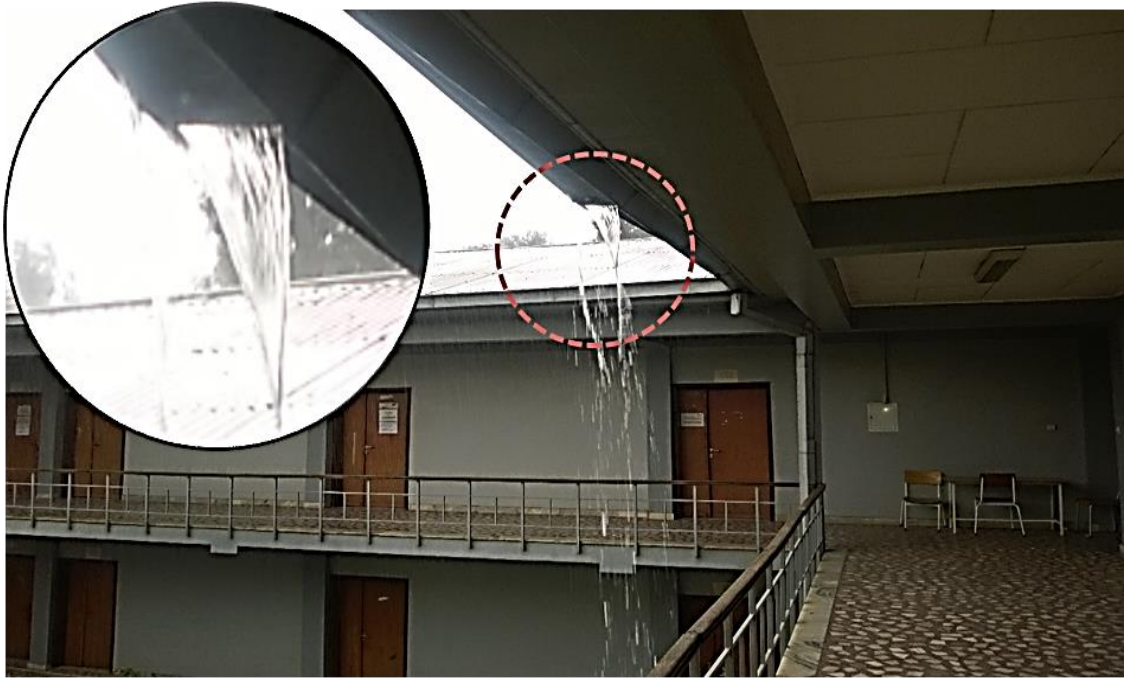


Figure 16: Rectangular gutter system on urban building



Figure 17: Rectangular gutter system on urban building

c) The semicircular gutter system

The semicircular gutter system is the most preferable gutter type by its highest self-debris removing performance. As is seen in Figure 18, only 4% (4 catchments) have semicircular gutter system, which covers an area of 450.77m². This gutter system is installed only on one building, girl's dormitory. It is the only gutter system found in good condition.



Figure 18: Semicircular gutter system(The EiABC scientific director building)

ii. Types of gutter material

The material used for the gutter system plays important role in the quality of rainwater, therefore the gutter system in the EiABC campus constructed from reinforced concrete (RC), galvanized iron sheet (GIS) and steel sheet as presented in Table 9.

Table 9: Gutter materials used on buildings of EiABC campus

No	Gutter Material	Number Of	Catchment	Percentage
		building	Area (m ²)	
1	Concrete	1	230.25	0.88
2	Galvanized Iron Sheet	89	10827.82	78.76
3	No Gutter	19	2555.94	16.81
4	Steel	4	450.77	3.54
Total		113	14064.78	100.00

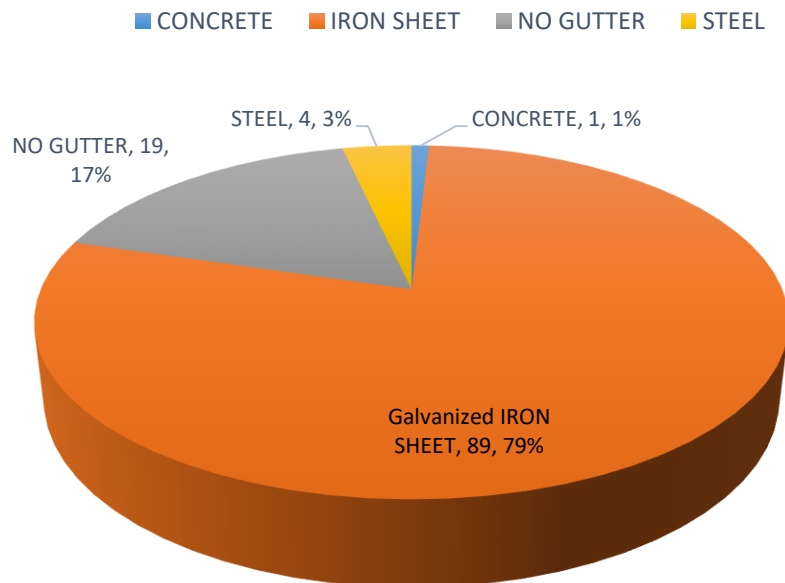


Figure 19: Gutter material used for EiABC campus

As shown in Figure 19, the gutter system on buildings in EiABC campus was made from four materials, the largest portion, 79% of the gutter system was made using galvanized iron sheet GIS material, 3% using steel material, 1% using concrete

and the rest 17% did not have any gutter system at all. The buildings by their gutter material is presented in Figure 20.

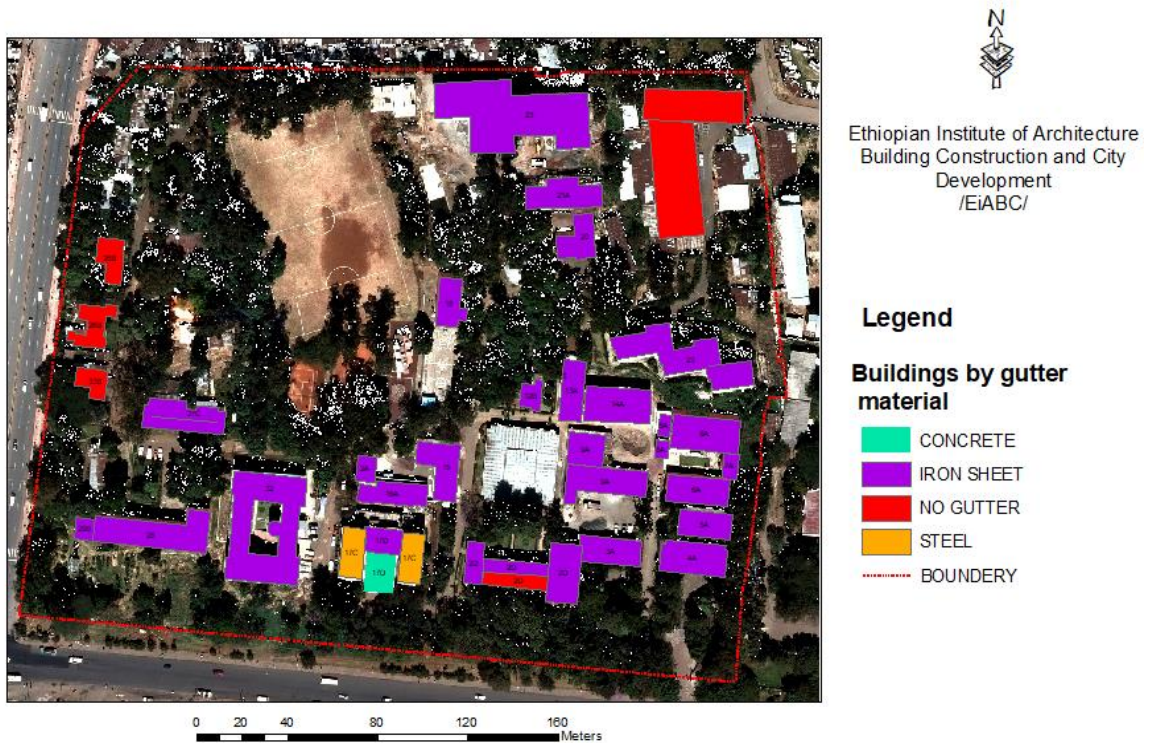


Figure 20: EiABC building by gutter material

iii. Proportion of the gutter system

The proportion of gutter system with its catchment area plays a major role in harvesting the full potential of rainwater. The proper proportion also has less exposure for debris accumulation than the excessively sized gutter system. Based on this the proportion of existing gutter system of the EiABC campus is with its catchment area is presented as follows in Table 10.

Table 10: Proportion of gutter system with its catchment area

No	Proportion	No. of Gutter	Catchment Area	Percentage
1	Less than required	32	5229.91	28.32
2	More than required	62	6278.94	54.87
3	No Gutter	19	2555.94	16.81
Total		113	14064.78	100.00

As shown in Figure 21, 55% of the gutter proportion of the gutter system to its corresponding catchment area is more than what the catchment needed, 28% of the gutter system installed on the building are less than what the system is required, and the rest 17% does not have gutter system at all. The distribution of the buildings by their gutter proportion presented in Figure 21.

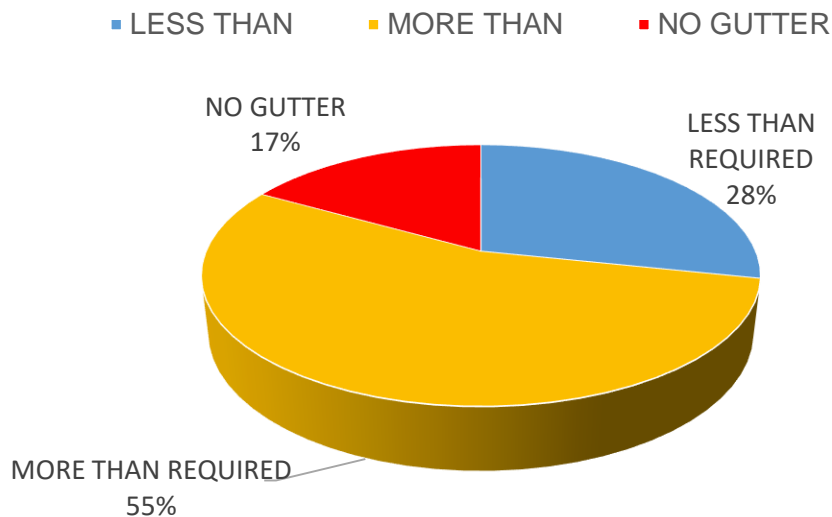


Figure 21: Proportion of gutter system with catchment area

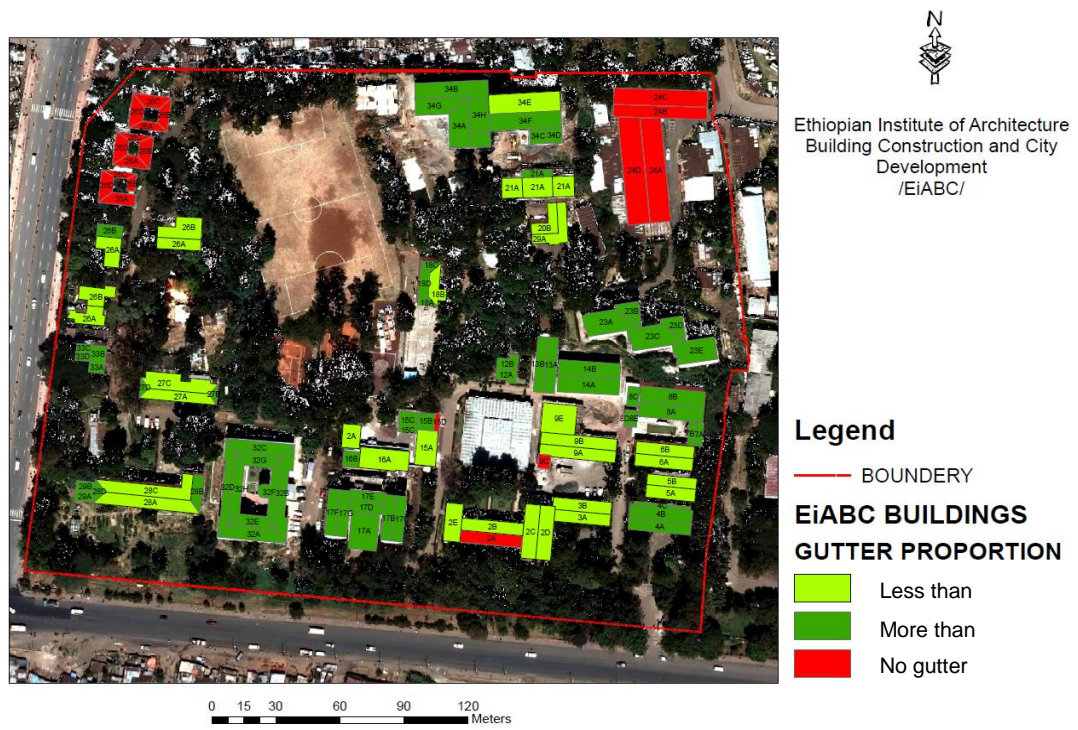


Figure 22: proportion of gutter system on EiABC buildings

iv. The nature of downpipe

a) Shape of downpipe

The downpipe system installed on EiABC buildings made using circular and rectangular shape as presented in Table 11.

Table 11: Shape downpipe installed on EiABC buildings

No	Building Name	Downpipe Shape	Catchment area	%
1	Department of Metal Testing	Circular	295.01	2.04
2	Classrooms	Circular	1590.75	10.99
3	Classrooms	Circular	365.70	2.53
4	Girl's Dormitory	Circular	415.94	2.87
Sub total			2667.4	18.41
5	Dean's Office	Rectangular	842.26	5.82
6	Studio	Rectangular	393.97	2.72
7	Staff Office Classrooms	Rectangular	259.68	1.79
8	Workshop	Rectangular	314.28	2.17
9	Office	Rectangular	76.11	0.53
10	Material Testing	Rectangular	662.49	4.58
11	Finance	Rectangular	110.08	0.76
12	Administration	Rectangular	259.80	1.80
13	Proto-Lab	Rectangular	434.24	3.00
14	Registrar	Rectangular	85.51	0.59
15	Generator house	Rectangular	94.90	0.66
16	Student Lounge	Rectangular	217.78	1.50
17	Staff Office	Rectangular	252.13	1.74
18	Dormitory And Dean Office	Rectangular	817.54	5.65
19	Staff Residence	Rectangular	239.51	1.65
20	Staff Residence	Rectangular	197.81	1.37
21	Animal House	Rectangular	427.78	2.96
22	Institute Of Pathology	Rectangular	724.45	5.01
23	Staff Residence	Rectangular	147.18	1.02
24	Classrooms	Rectangular	284.18	1.96
25	Metal and wood work	Rectangular	544.61	3.76
26	IT-department	Rectangular	249.78	1.73
27	Dormitory	Rectangular	1188.42	8.21
28	Cafeteria	Rectangular	397.26	2.75
Sub total			9221.77	63.65
29	Furniture Work Shop	No downpipe	1017.94	7.03
30	Furniture Work Shop	No downpipe	599.57	4.14
31	Staff Residence	No downpipe	280.49	1.94
32	Staff Residence	No downpipe	208.51	1.44
33	Staff Residence	No downpipe	247.75	1.71
34	Staff Residence	No downpipe	257.79	1.78
Sub total			2612.06	18.030
Total			14471.91	100

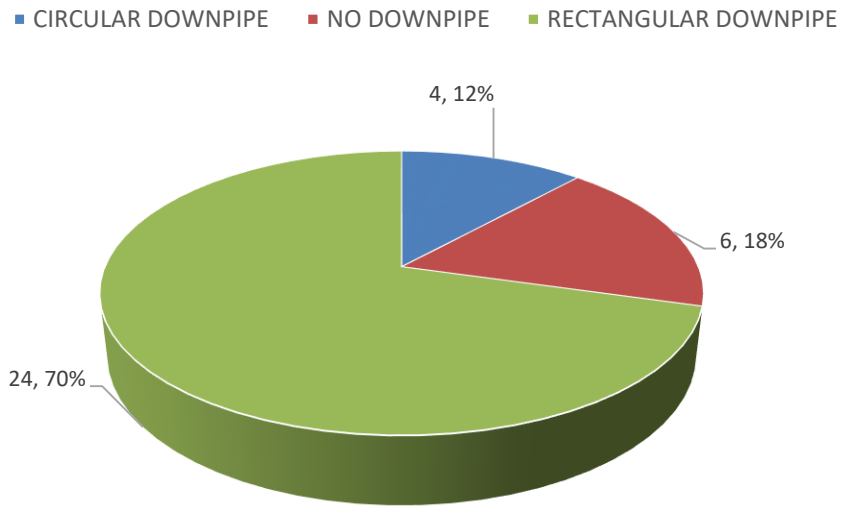


Figure 23:T types of downpipe system on EiABC building

As shown in Figure 23, the largest proportion of the downpipe installed on the EiABC building is rectangular shaped which accounts for 74% of the total building in the campus, 12% is circular shape and on the rest 18% of the building of the buildings in EiABC campus did not have downpipe system at all. The distribution buildings by shape of downpipe are presented in Figure 24.

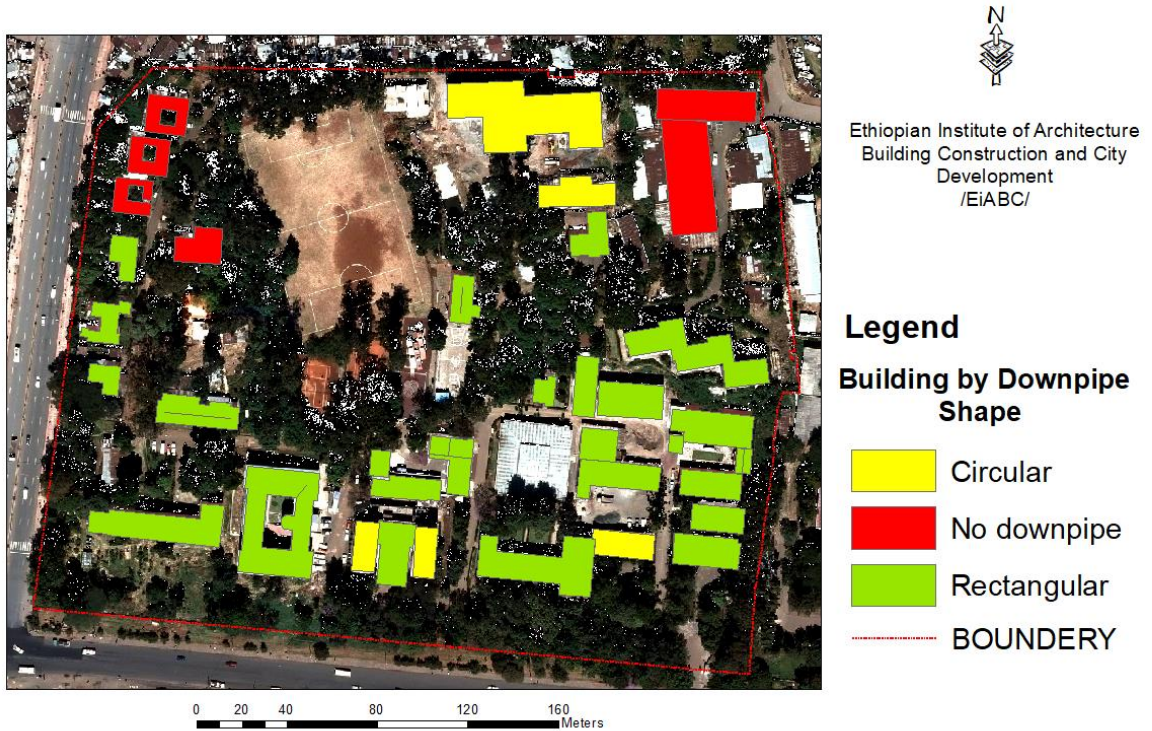


Figure 24: Buildings by shape of downpipe



Figure 25: Types of bended rectangular and circular downpipe on EiABC buildings

As it is shown in Figure 25, most of the downpipe system installed on the building are bent towards the wall to get support, and this bending effect creates a problem on the downpipe by accumulating the debris through the gutter system as it is shown in Figure 26, 27, 28.



Figure 26: Dismantled downpipe on finance buildings



Figure 27: Dismantled downpipe system on urban buildings



Figure 28: Dismantled downpipe system on student cafe

b) Downpipe by material

The materials used for downpipe system at the EiABC campus are steel, galvanized iron sheet and Polyvinyl chloride pipe (pvc) as shown in Table 12.

Table 12: Downpipe system by material of EiABC buildings

No	Building Name	Downpipe Material	Catchment Area	%
1	Dean's Office	GIS PIPE	842.26	5.8
2	Dep. of Metal Testing	GIS PIPE	304.01	2.1
3	Material Testing	GIS PIPE	662.49	4.6
4	Staff Office Classrooms	GIS PIPE	259.68	1.8
5	Workshop	GIS PIPE	314.28	2.2
6	Office	GIS PIPE	76.11	0.5
7	Metal and wood work	GIS PIPE	544.61	3.8
8	Administration	GIS PIPE	259.80	1.8
9	Proto-Lab	GIS PIPE	434.24	3.0
10	Urban building	GIS PIPE	1188.42	8.2
11	Classrooms	GIS PIPE	284.18	2.0
12	Generator house	GIS PIPE	94.90	0.7
13	IT-department	GIS PIPE	249.78	1.7
14	Registrar	GIS PIPE	85.51	0.6
15	Finance	GIS PIPE	110.08	0.8
16	Institute Of Pathology	GIS PIPE	724.45	5.0
17	Staff Residence	GIS PIPE	197.81	1.4
18	Staff Residence	GIS PIPE	239.51	1.7
19	Staff Residence	GIS PIPE	147.18	1.0
20	Dormitory And Dean Office	GIS PIPE	817.54	5.6
21	Student Lounge	GIS PIPE	217.78	1.5
22	Animal House	GIS PIPE	427.78	3.0
23	Staff Office	GIS PIPE	252.13	1.7
24	Studio	GIS PIPE	393.97	2.7
25	Dormitory	GIS PIPE	397.26	2.7
Sub Total			9525.78	65.75
26	Staff Residence	No downpipe	280.49	1.9
27	Staff Residence	No downpipe	208.51	1.4
28	Furniture Work Shop	No downpipe	1017.94	7.0
29	Furniture Work Shop	No downpipe	589.57	4.1
30	Staff Residence	No downpipe	245.75	1.7
31	Staff Residence	No downpipe	258.73	1.8
Sub Total			2601.00	17.95
29	Classrooms	PVC PIPE	376.63	2.6
30	Classrooms	PVC PIPE	1520.76	10.5
Sub Total			1897.38	13.10
31	Girl's Dormitory	STEEL PIPE	447.75	447.75
Sub Total			447.75	3.09
Total			14471.91	100

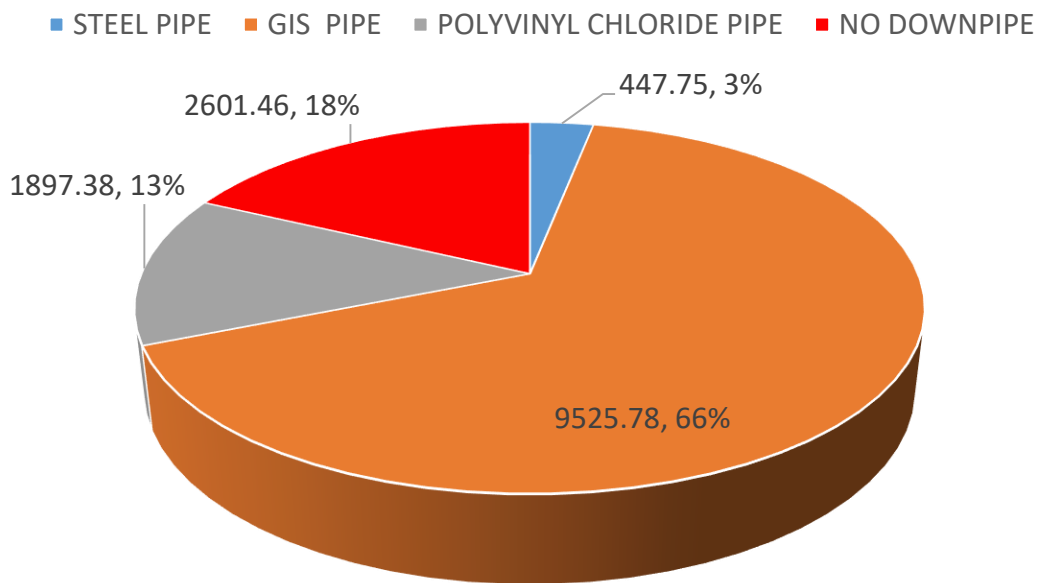


Figure 29: Materials used for downpipe system

From the total downpipe system installed at the buildings about 66% of downpipe is made of the GIS, 3% is steel downpipe, 13% is made of polyvinylchloride pipe and on the rest, 18% the catchment do not have downpipe. The distribution of the buildings by their downpipe material is presented in figure 30.

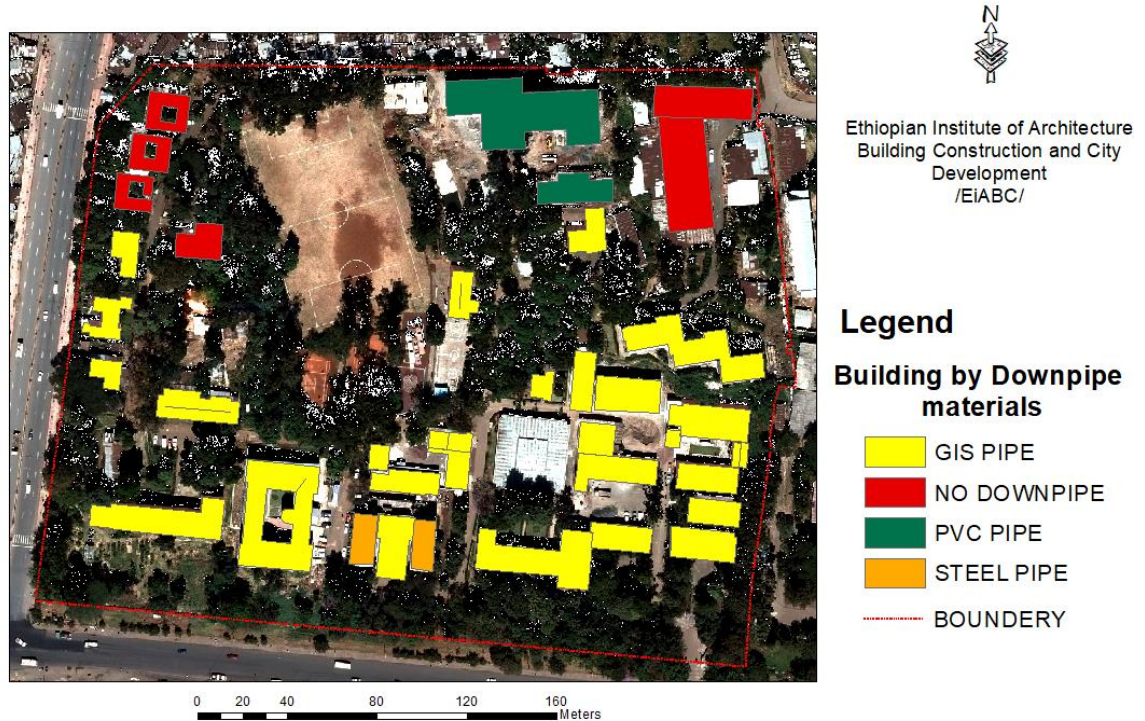


Figure 30: Building by downpipe material

4.2. Nature of rooftop debris in EiABC campus

The nature of debris is one of the most important data to decide in designing proper debris removal system. The sieve analysis made on the debris collected from 28 building having building height ranging from G+0 to G+4 revealed that, both smaller debris having the size less than 2.0mm and larger debris having the size of greater than 2.0mm are a real problem for rooftop RWH in EiABC campus. The result of sieve analysis for the collected sample debris is presented in Figure 31, 32 and 33.



(a) Debris >2.0mm size (b) Debris <=2.0mm size

Figure 31: Debris by size (Animal house)



(a) Debris >2.0mm size (b) Debris <=2.0mm size

Figure 32: Debris by size (institute of pathology building)



(a) Debris <=2.0mm (b) Debris >2.0mm size

Figure 33: Debris by size (urban building)

Larger debris (>2.0mm) debris constitutes leaves, barks, grasses, birds, plastics, feather, metals like nails pen and blades, large and small plant seeds, plant roots and growing plants. are the major problem of the gutter system as seen in Figure 34.



(a) Large plant seeds



(b) Plant roots and grasses



(c) Leaves and bird's feather



(d) Pen, key, Lead, blade and cutter



(e) Growing plant and algae



(f) Barks and Large leaves

Figure 34: sources of debris at EiABC campus building

Whereas, the result of sieve analysis showed that, the smaller debris contained dust and decayed plant as seen in Figure 35 and 36.



Figure 35: Decayed plant



Figure 36: Fine dust particles

i. Amount of rooftop debris

The amount and the type of debris accumulated on the gutter system vary from building to building. The nature of debris collected from 1m long gutter system of the 28 buildings in the campus summarized in Table 13.

Table 13: nature of rooftop debris in EiABC campus

No	Building type	Building height	Number of Building	weight of debris (kg)	Average debris weight (kg)		
					size >2.0mm	size <=2.0mm	Average weight
1	G+0	4.5	19	39.33	1.08	0.99	2.07
2	G+1	7.5	5	7.40	0.91	0.57	1.48
3	G+2	10.5	1	0.31	0.19	0.12	0.31
4	G+3	13.5	2	0.19	0.07	0.11	0.09
5	G+4	16.5	1	0.05	0.01	0.04	0.05
Total			28	47.28	2.26	1.84	1.69
percentage					55.20	44.80	100%

The average debris collected from G+0, G+1, G+2, G+3 and G+4 building is 2.07, 1.48, 0.31, 0.09 and 0.05Kg per meter of gutter length, respectively. In addition, the total average debris accumulated on the gutter system is 1.68Kg per meter gutter length.

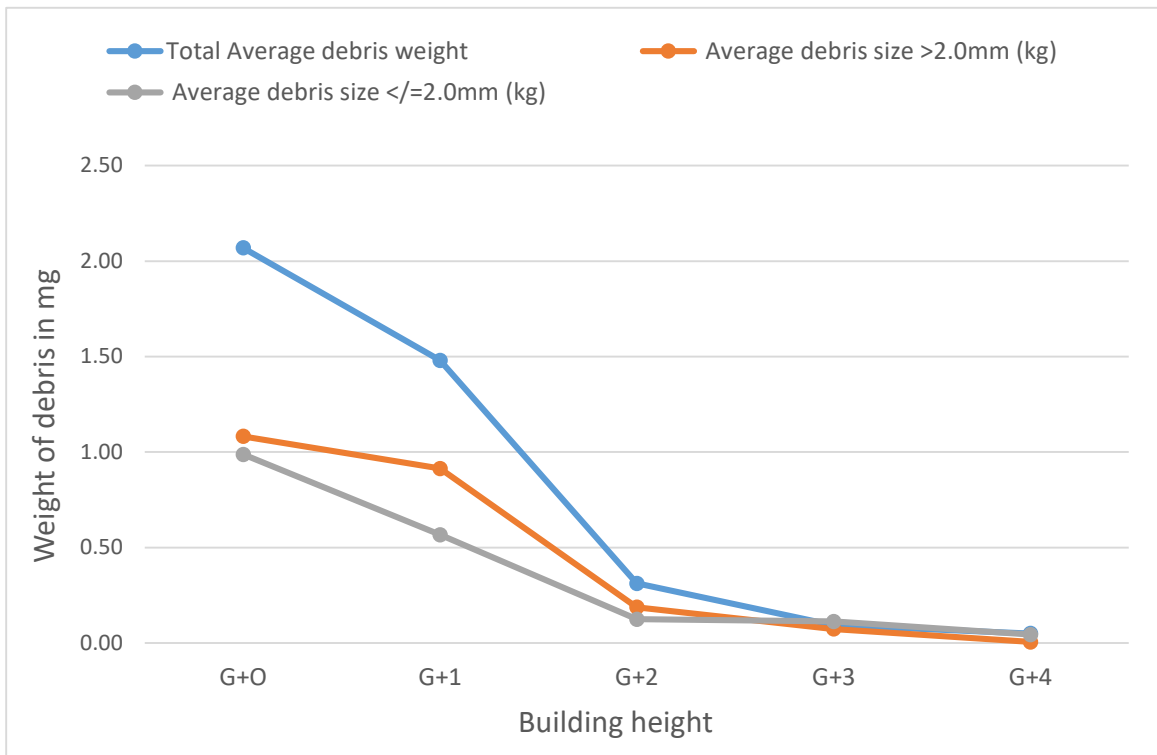


Figure 37: Average Debris Collected from buildings in EiABC campus

As it is clearly shown in Figure 37, more debris are accumulated on G+0 and G+1 buildings than that of G+3 and G+4 buildings. Even though the amount of debris decreases as the building height increases, the proportion of fine debris is greater than larger debris as the building height increases.

ii. Relation between rooftop debris and building height

As it is shown on Figure 38, since the coefficient of correlation $r = -0.93404$, it shows that the two variables have a strong inverse relationship. The amount of rooftop debris collected from the buildings decreases as the building height increases. In addition, the regression equation used to forecast the amount of debris on different building heights is:

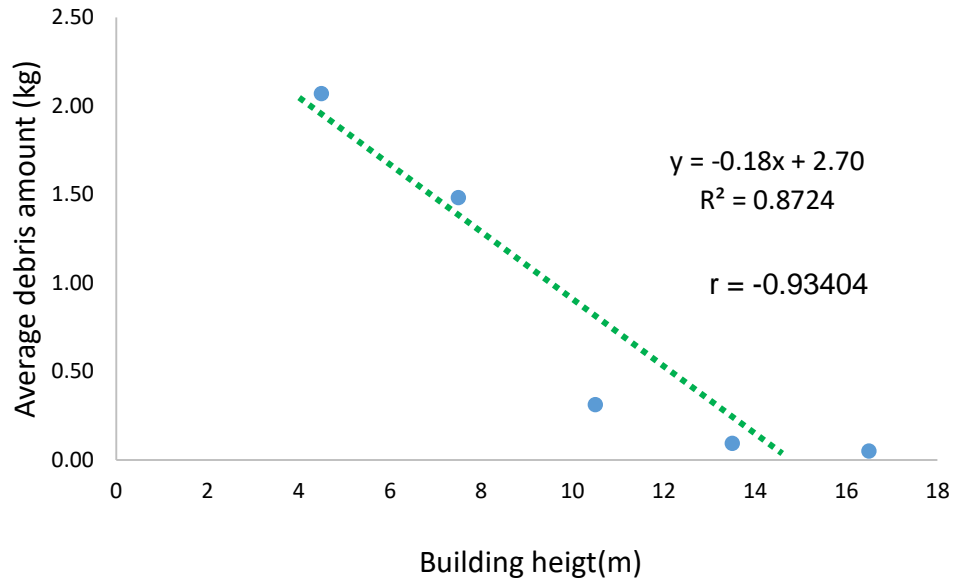


Figure 38: Relation between rooftop debris and building height

4.3. Design of nature-based debris strainer using multipurpose downpipe system

After analyzing all the debris found a nature-based debris strainer were developed and tested for both types of debris. Since it is impossible to solve large and fine debris problem with one system, integrated system were used to design and develop nature-based strainer. The bigger debris were removed by defalcation and the dust and fine debris by filtration.

i. Large debris removing system

The deflection system at the downspout is selected to remove the larger debris. Deflection principle works, while the collected rainwater poured to the curved deflector from the gutter system at the downspout, the debris deflected away from

the water and the separated rainwater follow the curved pass and enters to the filtration channel. The design and development is shown in Figure 39 and 40.

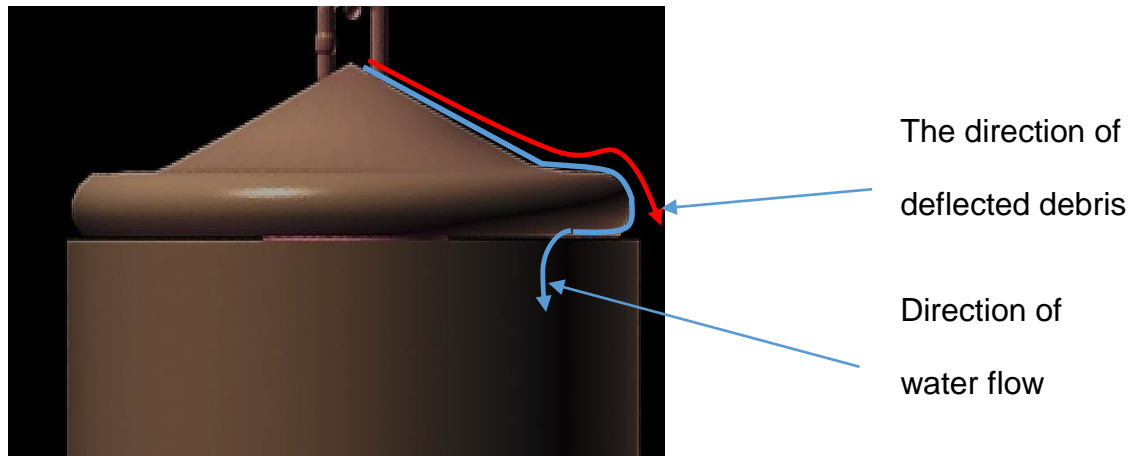


Figure 39: Design of deflector installed on the top of the downspout.

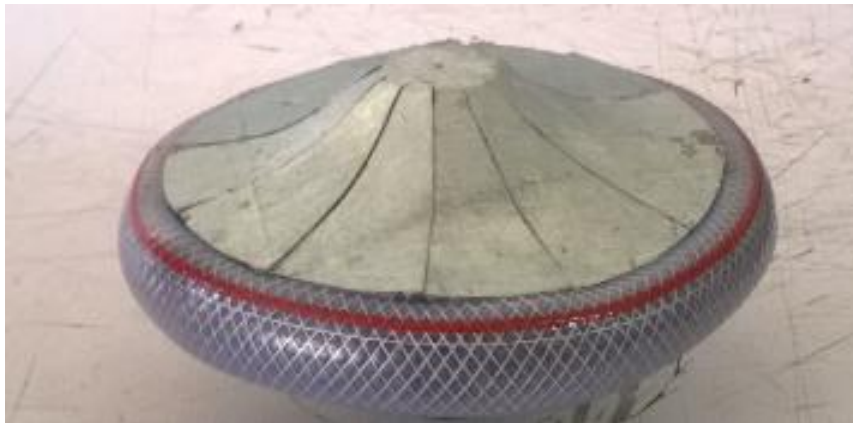


Figure 40: Developed deflector system

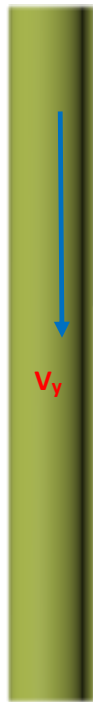
ii. Filtration principles for fine debris

As the rainwater separated from larger debris enters to the channel prepared to filter the fine debris having less than 2.0mm size. This channel designed based on principles taken from river self-purification system. In river self-purification, system slope of the riverbed, the distance traveled by water and friction between water and riverbed plays a major role in removing debris from river water. Then the

system designed to reduce the speed of the rainwater within the downpipe by reducing the slope of the flow channel and adding filtration medium to increase the friction within the channel.

a) Speed/velocity consideration

To achieve self-purification, retarding the gravitational flow of water is important. This is achieved by making spiral flow pattern within 30 cm downpipe system. This reducing the slope of conventional downpipe channel by slope of 10% is the first step, this design slope help to reduce the speed of the river water and let fine particle to settle on the spiral channel. The designed spiral channel reduces the slope at which the water flow within the conventional downpipe system from 90° to 5.71° . Therefore, free-falling collected rainwater within the conventional downpipe is forced to flow within the spiral channel having 10% slope, by doing this the speed of the rainwater is reduced to $V \cdot 0.092$. The relation between the slope and velocity presented as shown Figure 41 and 42.



For vertical channel

$$(V_y - U_y) / t = a_y$$

Where V_y = speed at any "t" along y-axis

U_x = initial speed

a_y = acceleration at any "t" along y- axis

$$a_y = g$$

$$(V_y - U_y) / t = a_y, \text{ But } u=0 \text{ and } a_y = g$$

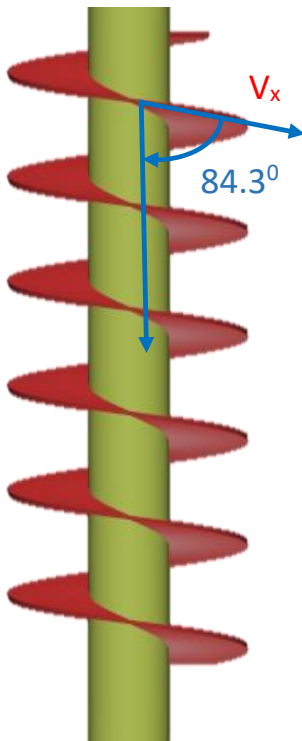
$$V_y = gt$$

$$=gt$$

$$=9.8 t$$

$$\underline{V_y = 9.8t}$$

Figure 41: free falling rainwater by gravity



$$(V_x - U_x) / t = a_x$$

Where V_x = final speed along x-axis

U_x = initial speed

a_x = acceleration along x- axis

$$a_x = g \sin \theta$$

$$(V_x - U_x) / t = a_x, \text{ But } u=0 \text{ and } a_x = g \sin \theta$$

$$v_x = g \sin \theta t$$

$$= g \sin 5.7^\circ t$$

$$= 9.8 * 0.099 t$$

$$\underline{V_x = 0.97t}$$

Figure 42: Retarded flow of rainwater by inclined spiral channel

The comparison of water speed with in the conventional down pipe and designed spiral channel for filtration device. The perpendicular speed with in the downpipe reduced by factor of $\sin 5.7^\circ$ (from $V_y = 9.8t$ to $V_x = 0.97t$) due to the slope changed by spiral channel.

b) Length of water flow

In river self-purification system, the length of the water travel plays a major role in removing debris from the water by increasing the time of interaction between water and the river media. The filtration media having a vertical length of 30 cm and 16 cm diameter pipe used to prepare the filtration media within the downpipe. To maximize the path of the water flow by providing the spiral channel within 30 cm vertical pipe, the travel distance of the water within the downpipe increase maximum from 30cm to 301cm (1005%). On average from 30cm to 188.5cm (628.3 %) as shown in Figure 43 and 44.

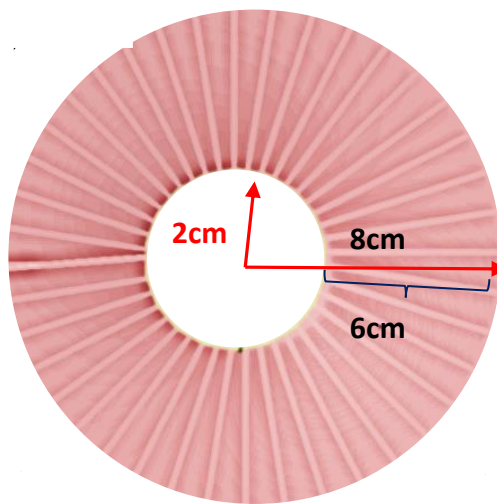


Figure 43: Top view of the spiral channel

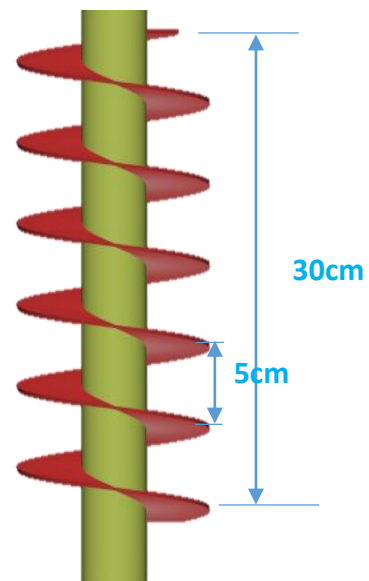


Figure 44: Side view of the spiral channel

Table 14: Distance increased by spiral channel

S. No	Distance traveled	Radius (cm)	Number of turn	Total length (cm)	Percentage increased
1	Interior circle	2	6	75.4	251.3
2	Exterior circle	8	6	301.6	1005.3
3	Average	5	6	188.5	628.3
vertical length				30	

As it is shown in the table 14, the minimum lengthen traveled water in the spiral channel is 75.5 cm ($2 \cdot \pi r_1$), the maximum length is 301.6 cm ($2 \cdot \pi r_2$) and the average length is 188.5cm ($2 \cdot (\pi r_1 + r_2) / 2$). By doing so the water travel along the 30cm length downpipe is maximized minimum by 251.3%, maximum 1005.3% and in average 628.3%.

c) The filtration medium

The filtration medium is made of pumice stone to reduce the load of the filtration device. The device divided into three compartments and in average 188.5cm long filtration media filled with gravel having different gravel size, the first course filled with gravel with size 20 to 30mm, the middle course filled with gravel size having 10 to 20mm and the last course filled with fine gravel having the size of less than 10mm. Generally, the device designed in a way that able to solve both problems of large debris by using a deflection and fine debris by using the filtration system as shown in Figure 45. (Refer the detailed design of the device on annex-1.)

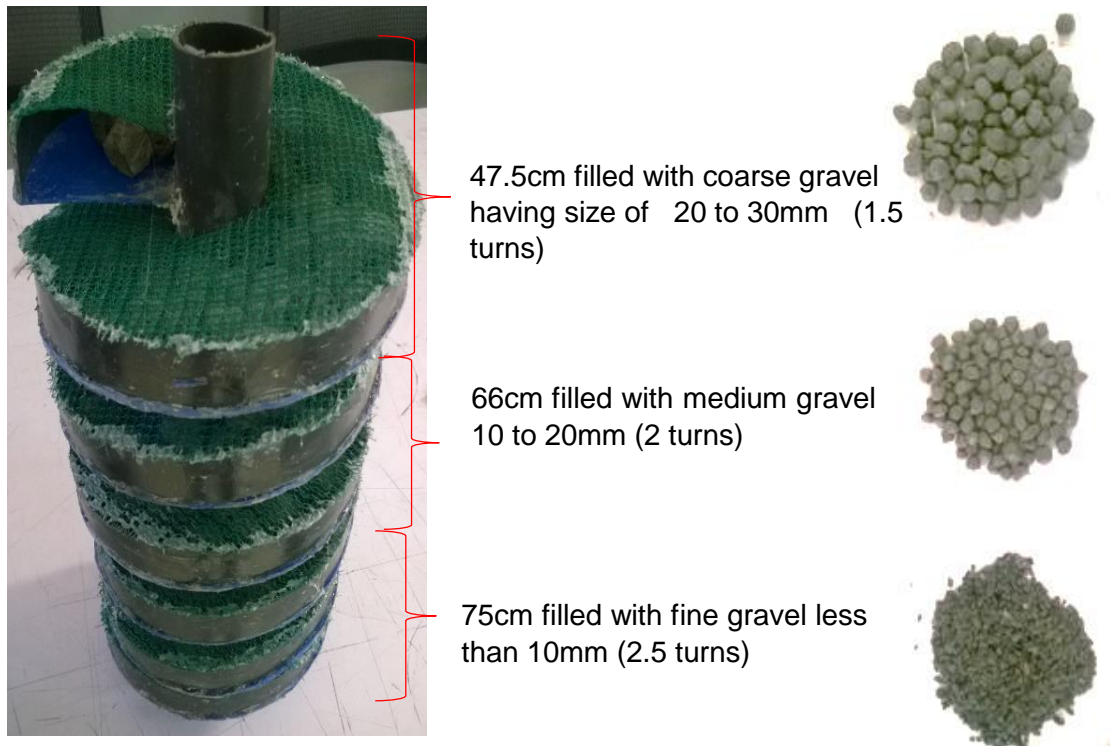


Figure 45: Developed filtration system

The nature based debris removal system have four-major component. (Refer annex-2.)

- The system holder or external body is a part of the device, which hold the whole system.
- The internal body is the inner part of the device installed in the system holder and it contains debris receiver, overflow controller, soil holder, and filtration holder tube,
- The filtration channel is the inner part of the device which filter the fine debris
- Deflector: the most top part of the device, which used to deflect the larger debris.

The major four components of nature-based debris removal system are assembled as shown in Figure 46, to form the total system.

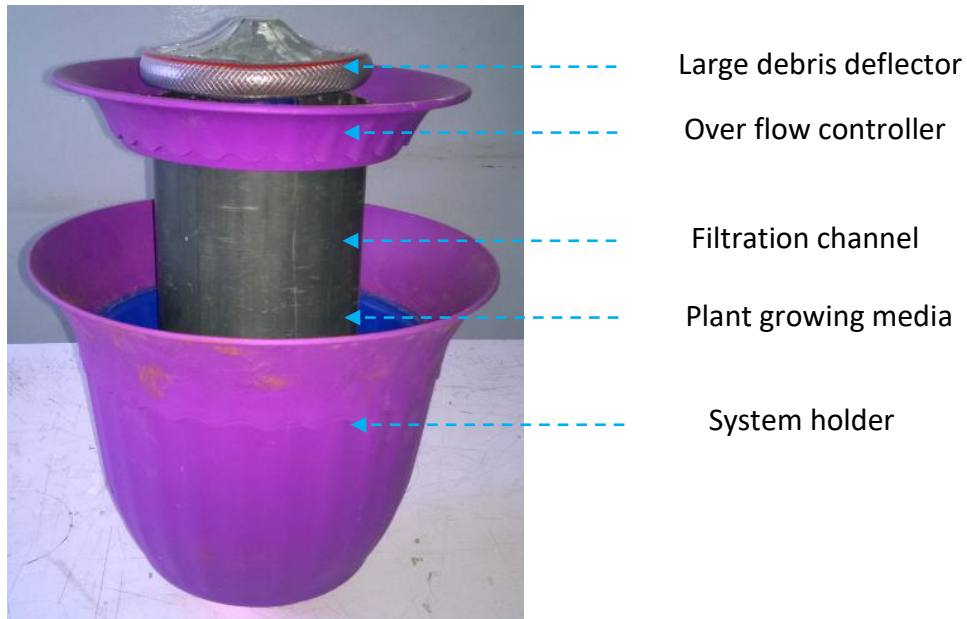


Figure 46: Assembled nature based debris removal device

d) The efficiency of the nature-based debris removal device

The laboratory test made on a sample taken has shown the total dissolve solids (TDS), total suspended solids (TSS), turbidity and pH after the rainwater pass through the device and out of the device are measured and the result is tabulated as shown in Table 15.

Table 15: laboratory result of sample water taken for five consecutive rainy days

No	Days	TDS (gm/l)			TSS (gm/l)			TURBIDITY (NTU)			pH		
		Before	After	% Removal	Before	After	% Removal	Before	After	% Removal	Before	After	% Removal
1	1 st	1.3	0.9	30.77	0.9	0.3	66.67	0.11	0.05	54.5	5.633	5.621	-0.21
2	2 nd	1.6	1	37.50	0.9	0.2	77.78	0.14	0.06	57.1	6.048	6.042	-0.10
3	3 rd	1.7	1.5	11.76	1	0.3	70.00	0.10	0.05	50.0	6.001	6.000	-0.02
4	4 th	1.3	0.8	38.46	0.7	0.2	71.43	0.24	0.06	75.0	5.631	5.621	-0.18
5	5 th	1.31	1	23.66	0.4	0.1	75.00	0.17	0.07	58.8	6.023	6.020	-0.05
Average		1.442	1.04	28.43	0.78	0.22	72.175	0.152	0.058	59.1	6.2712	6.2986	-0.11
		P-value = 0.0023			P-value = 0.00085			P-value = 0.0077			P-value = 0.0181		

The total suspended solid (TSS) reduces on average by 72.16%, since P-value = 0.00085 which is less than 0.05 it shows that there is significant difference between before and after result. The total average total dissolved solid is reduced by 28.43%, and the average turbidity reduced by 59.1%, and the p value of TDS and turbidity is 0.00085 and 0.0077 respectively. This shows that there is a significant difference between before and after result. Therefore, the device can highly purifies the rainwater. pH ranges from 5.631 to 6.048 before and 5.621 to 6.042 after, the average is 6.023 and 6.02 before and after respectively. Which show that there is no significant change in the pH of harvested rainwater.

4.4. Integrating the downpipe with the building façade

On the building façade, roof and roof details including the gutter and downpipe system are one part of building façade, which plays a great role in conveying rainwater away from the building. The beauty and the aesthetics of the building affected by the impact of destroyed gutter and downpipe system due to the debris accumulated inside. One of the major problem identified in the EiABC campus building is the visual quality problem created due to destroyed gutter and downpipe system.

Therefore, in addition to their function of transporting harvested rooftop rainwater, downpipe system designed in a way to have an additional role in building decoration and beautification. In this multifunctional downpipe system, the conventional closed downpipe system replaced by rain chain integrated with a flowerpot. The designed multipurpose downpipe system functionally serves as

filtration media, like a flowerpot and serve as downpipe system to convey the filtered water to the storage system. (Refer annex 4 and 5 for the detail design).

The developed integrated multipurpose rain chain system was tested by installing on EiABC urban building for rooftop RWHs and enhance the visual and spatial quality of the courtyard environment of the building. The test was made on 118.8m² roof catchment on the urban building, the 26m rectangular gutter system was changed to a semicircular gutter system, and the two conventional downpipes were replaced by multipurpose rain chain system connected to a storage having a capacity of 20,000lt (Refer annex 6).

The assessment was made on people's preference on the conventional down pipe system and multipurpose rain chain system installed on urban building of EiABC campus. 56 peoples were asked about their preference and the result is presented on Table16

Table 16: Preference of people for conventional downpipe and rain chain system

No	Response	No of responses	Percentage (%)
1	Conventional down pipe	1	1.8
2	Rain chain system	54	96.4
3	Non respond	1	1.8
Total		56	100.0

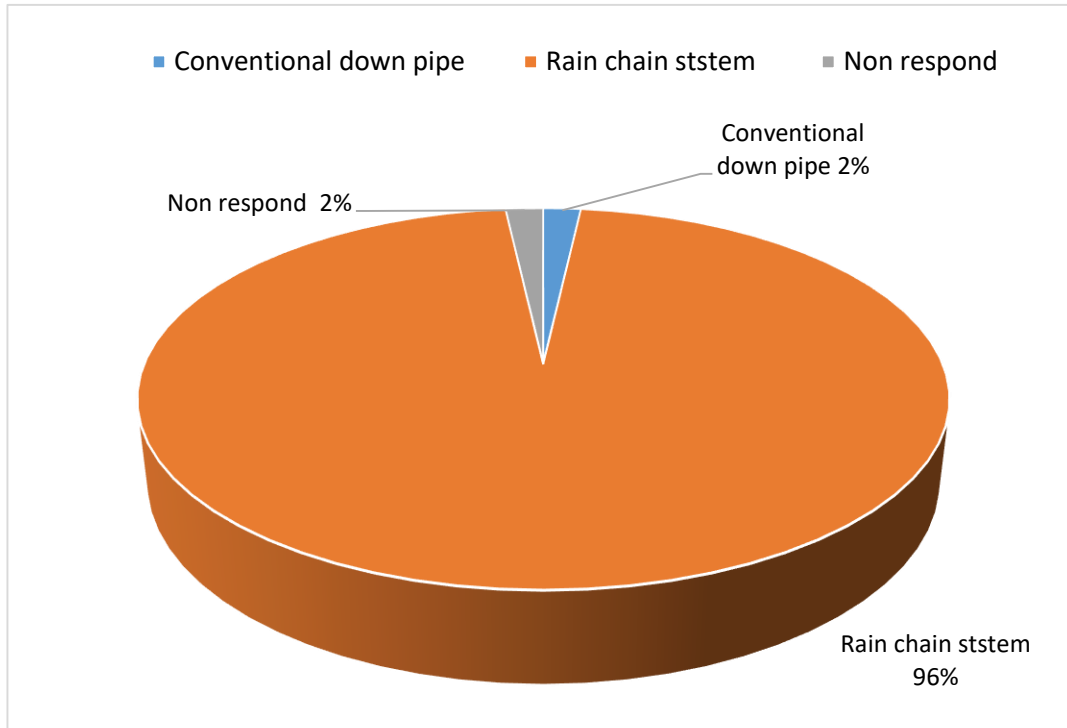


Figure 47: Preference of people for conventional downpipe and rain chain system

As described In Figure 47, from the total respondent 96% were prefer to the multipurpose rain chain system, 2% were prefer to the conventional downpipe system and 2% does not have any idea about it.

Regarding the multipurpose building façade decoration element, the assessment was made on 56 urban building user's. They were asked to reflect their feeling about the multipurpose building façade element installed on urban building and the result is presented on Table17.

Table 17 people's attitude about multipurpose building façade decorative element installed on the urban building

No	Respond	Number of respondent	Percentage (%)
1	Most like	31	55%
2	More like	21	38%
3	Neutral	4	7%
4	Less like	0	0%
5	Don't like	0	0%
6	Non-respondent	0	0%
Total		56	100%

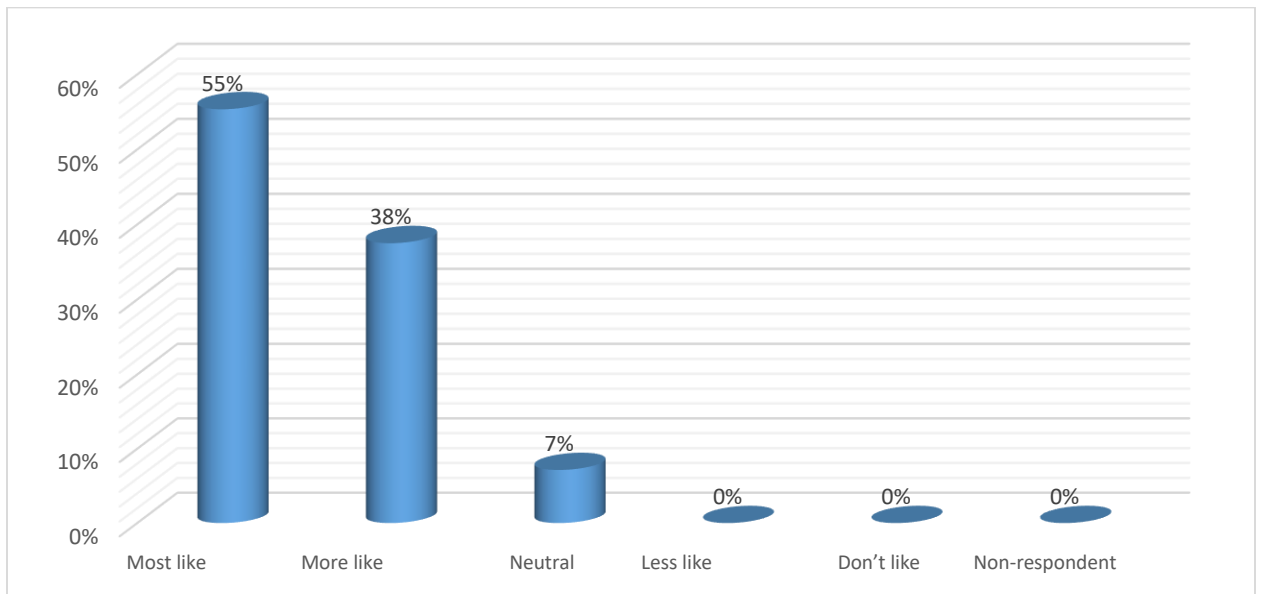


Figure 48: Peoples feeling about the multipurpose building facade decoration element

As shown in Figure 49 from the total respondent, 55% were respond to “most like”, 38% “more like” & 7% to “neutral”. There was no respond to “less like” and “don't like”.

CHAPTER FIVE

Discussion

The research designed based on four specific objective, three of them are strongly related with problems on active RWH practice, and one is related with improving the urban building façade quality through multipurpose downpipe system. The experiment is done on the urban building to answer the following research question that arises from its specific objectives the research.

1. Which types of gutter are dominantly used in the buildings of EiABC campus?
2. Which types of debris are more problematic for the rainwater quality and quantity collected from the roof?
3. How can nature-based debris strainer be designed and developed to improve the quality and quantity of water harvesting system?
4. How to develop the scheme to utilize the system as a multi-function façade decorative element of public buildings in urban areas?

5.1. Gutter type used at EiABC campus

Under this objective, the research tried to identify the gutter shape, gutter material, the size of the gutter system with respect to their catchment and the downpipe system.

The shape of the gutter system plays the most important role in self-debris removing performance. The semicircular gutter is the most preferable gutter shape, due to its high self-debris removing performance. The study identifies that

three type of gutter system on the building of EiABC campus and only 83% of the total catchment have the gutter system. In addition, the result show that, the semicircular gutter system, which is best gutter type, is installed only on 3.54% of the catchment system (one building). The rectangular gutter system, which has better debris removing capacity next to the semi-circular gutter installed only on 28.32 % of the catchment area and more than half of the catchment system is installed by using the trapezoidal gutter shape, which is the poorest gutter system in self-debris cleaning capacity. Except the semicircular gutter, all of the gutter systems installed on EiABC buildings found in poor condition. Even though the rectangular shaped gutter system have better debris removing performance, it has also had the same problem with the trapezoidal gutter system due to lack of frequent cleaning.

Regarding the materials recommended for gutter system, steel and galvanized iron sheet (GIS) is the most preferable materials due to the surface heating effect by solar radiation for bacteria self-purifying mechanism. Steel material the most preferable material due to its additional property in resisting corrosion. Therefore 82.14% of the gutter system in EiABC building made from steel and GIS (steel 3.54% and GIS 78.6%). This reveals that only 3.54% of the gutter system made using the best quality of material, and this gutter system is the only gutter system found in better condition. Even though GIS preferable material for gutter system, the largest portion of this gutter is found in bad condition due to debris accumulation.

The proportion of gutter system with respect to their catchment area analyzed by taking the measurement from buildings having the gutter system and analyzed using GIS software. Since the proportion of gutter cross-section area with respective catchment area is 1cm^2 for 1m^2 , the result shows that none of the gutter systems is proportional to its corresponding catchment area. 54.87% of the gutter system is larger than what the catchment needs, so it is vulnerable to debris accumulation due to larger surface area and lower flow depth of water to carry the debris. In addition, the disproportion of gutter element affect visual quality of the building façade, and 28.32% is leaser than what the catchment area needs, which create overflow problem that affect the building quality. In addition, even though the building roof catchment is the best for RWH, 16.81% of the catchment does not have any the gutter to harvest full potential RWHs.

Downpipe is a part conveyance system that takes the collected rainwater from the gutter system. This conveyance system found in critical problem due to the debris accumulated at the downspout. Especially the problem is serious on the building those having downpipe bent towards the wall. From the two types of downpipe shape, the rectangular downpipe having an angular elbow have a critical problem. The bending effect of the downpipe halts the flow of debris and gradually accumulate within the downpipe. Because of the accumulated debris within the downpipe, the system clogged and destroyed due to resting effect caused by the decayed debris. As a result, it affects the quality and quantity of harvested rainwater. Furthermore, the destroyed downpipe and gutter system affect the visual quality of the building façade (the roof or attic). Whereas the circular

downpipe having curved bending point is free from this kind of problem and found in better condition.

5.2. Nature of debris of debris in the EiABC campus

The nature and amount of debris on the building strongly dependent on location, climate, and human activity. The samples of debris collected from the 1m long gutter system. Depending on their size rooftop debris are categorized as larger debris and fine debris. The result of research reveals that both fine debris (debris having less than 2.0mm size) and large debris (debris having greater than 2.0mm size) is the real problem for RWH in the campus. Furthermore, the research reveals that, even though the total amount of debris decreases as the building height increases, the proportion of larger debris greater than fine debris on low-rise building and the proportion of fine debris is greater than large debris on high-rise building.

Regarding the source of debris, the result of the study revealed that the source of rooftop debris are similar to that of identified in literature part. Both internal and external sources were identified by the study. The external source of debris found in the campus includes; trees and plant on the surrounding, human activities, animals which has access to the rooftop and other wind born objects. The debris found from these external sources were Barks, leaves, large and small seeds, blades, key, cutters, plastic, pens, leads thrown to the gutter and bird's feathers, and wind-borne dust particles are some of the large and fine debris generated from external environment. The internal source is mainly generated from plants grown

in the gutter system including stems, roots, and leaves of small plant and grasses and parts of the destroyed gutter system.

5.3. Design and develop nature-based debris strainer

To design and develop nature-based debris strainer, since both fine and larger debris are identified problem by this study, based on this finding deflection and filtration system are used to design and develop nature-based debris removal system. The developed device able to remove 100% of larger debris having the size of greater than 2.0mm diameter. On average, the efficiency of this device especially in removing TSS and TDS is 72.2% and 28.43%, respectively. Since the turbidity is the result of TSS and TDS in the rainwater, the result shows that the turbidity reduced by 59.1%. The pH value of unpolluted rainwater ranges 5-6 (Olmsted & Williams, ,2004). Even though the device did nothing to bring change on the pH value, the average pH value of before and after (6.27 and 6.299) while compared with the standard (5-6) it is found in a very good condition that allows the water to use for a wider range of uses.

5.4. Develop a scheme to utilize the system as a multifunction façade decorative element of public buildings in urban area.

To create integrated debris removal system by changing the conventional type of downpipe system, which is one element of facade element in a way that it enhances the visual quality of building façade. The main characteristics that makes the device different is, the designed system has integrated debris removal system, rain chain for the conveyance system and suspended flowerpots on the rain chain

as building façade decorative element to make single multifunctional system. By doing this, the conventional downpipe system became changed to multifunctional rain chain system. As a result the flowerpot suspended on the rain chain decorate the building as integrated façade decoration element and filter the splashed water by the gravel under the soil before it drained.

In addition to the rainwater harvesting, the system is used to improve the quality and quantity of harvested water and as integrated decorative façade element, it improves the visual and quality of the public building. The preference assessment made on the conventional downpipe and rain chain system revealed that, the rain chain system installed on urban building was chosen by 96.4% of the total respondents. Similarly, 93% of the respondents were very good feeling about the multifunctional building façade decorative element installed on urban building of EiABC campus.

CHAPTER SIX

FINDINGS, CONCLUSION AND RECOMMENDATION

6.1. Findings

There are three types of gutter systems installed on the buildings in the EiABC campus, and 19% (2556 m²) of the CIS catchments do not have the gutter system at all. Steel, GIS, and concrete are materials used for the gutter system, 89% of the total gutter system was made by GIS-material.

From the total roof catchment areas, 79% of the gutter system (trapezoidal and rectangular) was found in poor condition, which needs replacement. The installed gutter systems were not proportional to what the catchment is required, 55% of the gutter system is more than what the catchment is needed and the rest 28% is less than what the catchment needs and the rest 19% do not have the gutter system.

Circular and rectangular shaped downpipe system were the two types of downpipe systems made of GIS and PVC that were installed on buildings in the campus. The bent rectangular downpipe system was made of the GIS is found in a very poor condition.

Large debris and fine debris were identified as a problem for rooftop RWHs in the EiABC campus. The amount of debris on the building decrease as the building height increases. Therefore, the amount of debris and building height do have an inverse relationship. Trees, wind born matters, birds and small animals those have

an access to the rooftop, human activities surrounding the buildings were identified as sources of debris.

The nature-based multipurpose debris strainer can remove 100% of large debris, and TDS, TSS, and turbidity by 28%, 72%, and 59% respectively. Furthermore, the 6.29 pH value of harvested rainwater test result shows that the quality of the water was found within the acceptable range for non-potable uses.

The integrated multipurpose rain chain system became effective in conveying the harvested rainwater as conveyance system, as a filtration system and in decorating the building façade as building façade decorative element on the urban building of EiABC campus.

6.2. Conclusion

EiABC is one of the large institution found in Addis Ababa, which covers about 7.8 ha of land. The campus has 37 building. Among this, 34 buildings having 1.45ha of roof catchment area covered with corrugated iron sheet, which is the best material for rainwater harvesting system. Even though the campus has huge rooftop rainwater harvesting potential, currently, only 3.54% (0.0451 ha) of roof catchment has good gutter and downpipe system that is ready to harvest rainwater. The rest needs replacing the gutter and downpipe system. Trees found around the buildings are major reason for the deterioration of the gutter and downpipe system due to debris generated from them.

Since debris are the major problem that impede the quality and quantity of rooftop rainwater harvesting system, the study have got solution that able to remove 100%

of larger debris and TSS, TDS and turbidity by 72%,28.4% and 59% respectively. The other important issue that strongly limit the use of urban rainwater is the level of acidity of the rainwater, regarding this, the study reveal that the pH is 6.299 which is beyond the range of unpolluted urban rainwater (5-6). This indicate that, the rainwater is not polluted and it can be used to bridge the gap between demand and supply by covering the outdoor water demand and toilet fleshing.

The full rainwater-harvesting scheme developed, as a demonstration site on urban buildings is one indicator how much it is use full and show how the rainwater harvesting system components are integrated with building façade element for decorating the frontage of the building. The replaced 26m rectangular gutter by semicircular gutter system and the conventional closed type downpipe system to multifunctional rain chained system became functional on urban building in the EiABC campus. In addition to transporting the harvested rainwater, the system it playing major role in filtration and decoration as a decorative element, to enhance visual and space quality of the building

Generally, urban water scarcity is becoming a critical issue as populations grow. The Current climate change aggravates the problem by affecting rain patterns. As the urban population increase simultaneously institutions like universities, colleges, hospitals, governmental administrative offices became established to give service to the grown population. In addition, these institutes attracts additional population and employees that add additional burden on water supply. Furthermore, such types of institutions by their nature, they have very large plots

of land used for landscaping and utilize the treated municipal water for watering. As a result, they aggravate the urban water scarcity.

Since from their total demand about 60% of their water consumption is used for non-potable usage, such as gardening, toilet flushing, and car wash etc. Currently, almost all governmental and private institutions found in our urban centers, they are dependent on the municipal water supply system for indoor and outdoor water consumption. It is a waste of resource using the scarce treated municipal water for above mention institutional activities. Since our urban centers are naturally endowed rainwater, every institution should have to cover their non-potable water demand by harvesting rainwater from their rooftop. If the RWH practice widely applied throughout the institutions, it reduces the pressure of water supply on the municipality and helps to utilize the spare treated water for drinking purpose for other users. On the other hand, as the institutions involve in RWH and cover their outdoor demand, they can save their budget used to pay for municipal service and fill the gap between their water demand and supply. Government should have to give due attention to existing institutions and newly developed institution to have their RWH scheme.

6.3. Recommendation

Based on the finding of the study, the following recommendations are given to promote RWH, improve the quality and quantity of rainwater harvesting and to improve visual and spatial quality of public space through integrated multifunctional rain chain system.

- As the result of this study depict, the quality of the rainwater in the EiABC campus is found within the acceptable range to use it for different outdoor like watering the landscape, care washing, and toilet fleshing. Therefor the EiABC campus should have to utilize this potential resource to save the treated municipal water supply and budget spent for it.
- To improve the quality of rainwater harvested in the campus, both the deteriorated gutter systems and the catchment, which do not have a gutter system (68.14% of roof catchments) needs replacement by a semicircular gutter system.
- Gutter system have to be semi-circular shaped gutter to get rid of of debris accumulated on it.
- Installing gutter guard and regular debris cleaning before the rainy season begins is necessary to harvest better quality of rainwater and to keep the building and the gutter system healthy.
- Since steel material the most preferable gutter material due to its higher rust resisting and bacteria killing property, It recommended that the gutter system should have to made from steel for the better quality of rainwater.
- Maintain the rule of thumb, 1cm^2 gutter cross-section area for 1m^2 catchment area for better efficiency and to keep the proportion of the gutter system and to minimize the impact of the debris by reducing oversizing and enhance the beauty of the building by creating proportionality with the roof system as one element of building Facade

- Avoided bent on the downpipe system specially for rectangular downpipe system. if it is the only option to use it, it is advisable to use circular curved type downpipe system.
- In the case of EiABC campus, both fine debris and large debris are the problem in rooftop RWHS; therefore, it is recommended that the gutter system should be cleaned every time especially before the rainy season begin.
- Gutter guard and filtration system should have installed to improve the harvested rainwater quality before it enters to the storage system.
- It is advisable to harvest rooftop rainwater from high-rise building (above G+1) for better quality of harvested rainwater due to less debris on their gutter system
- Rooftop rainwater harvesting components have to be multifunctional to have additional use as the rain chained system, which have integrated flowerpot, filtration system, and conveyance system.

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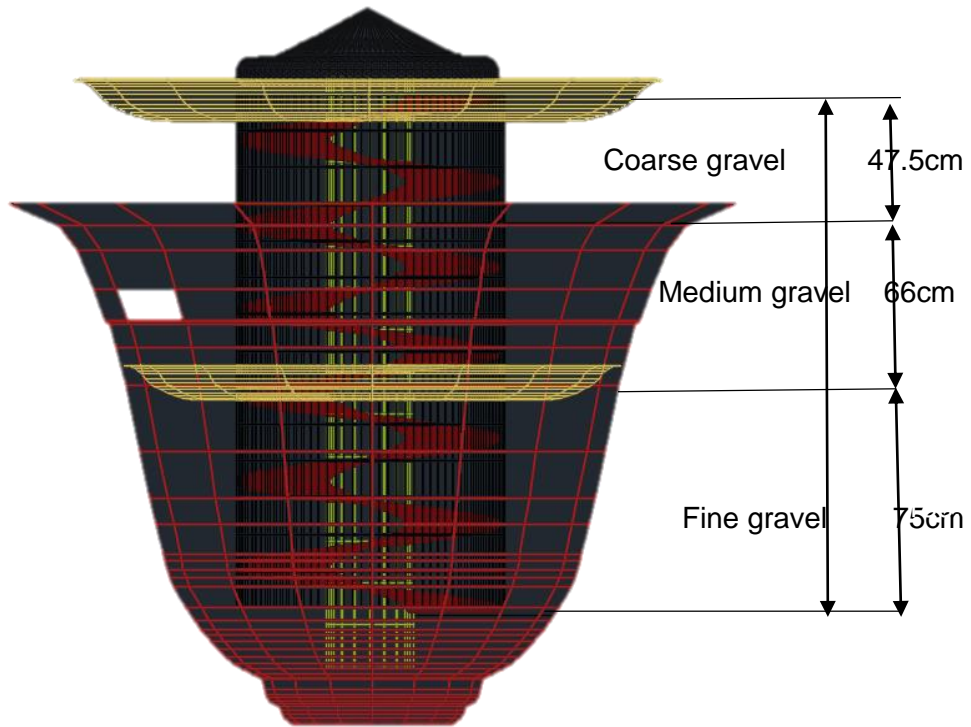
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Appendix

Annex 1: Detailed design of nature-based debris removal system



Annex 2: Component of nature based debris strainer



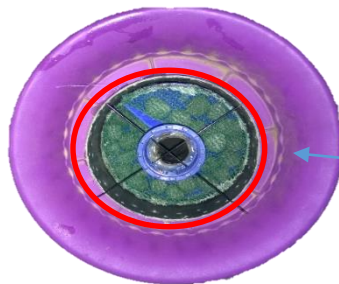
(a) Exterior part or System holder (b) The inner part or Filtration media (c) Filtration channel (d) Deflector

(a) Components of the debris-removing device



The deflector used to deflect larger debris away from the water.

(b) Top view of Deflector



The filtration system found under the deflector used to further filtration of fine debris

(c) Top view of inner part of filtration device

Annex 3: p-test value

P- test for TBS

t-Test: Paired Two Sample for Means

	<i>Before</i>	<i>After</i>
Mean	1.442	1.04
Variance	0.03732	0.073
Observations	5	5
Pearson Correlation	0.821911476	
Hypothesized Mean Difference	0	
df	4	
t Stat	5.740514554	
P(T<=t) one-tail	0.00228137	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.00456274	
t Critical two-tail	2.776445105	

P- test for TSS

t-Test: Paired Two Sample for Means

	<i>Before</i>	<i>After</i>
Mean	0.78	0.22
Variance	0.057	0.007
Observations	5	5
Pearson Correlation	0.901127114	
Hypothesized Mean Difference	0	
df	4	
t Stat	7.483314774	
P(T<=t) one-tail	0.000852579	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.001705157	
t Critical two-tail	2.776445105	

P- test for Turbidity

t-Test: Paired Two Sample for Means

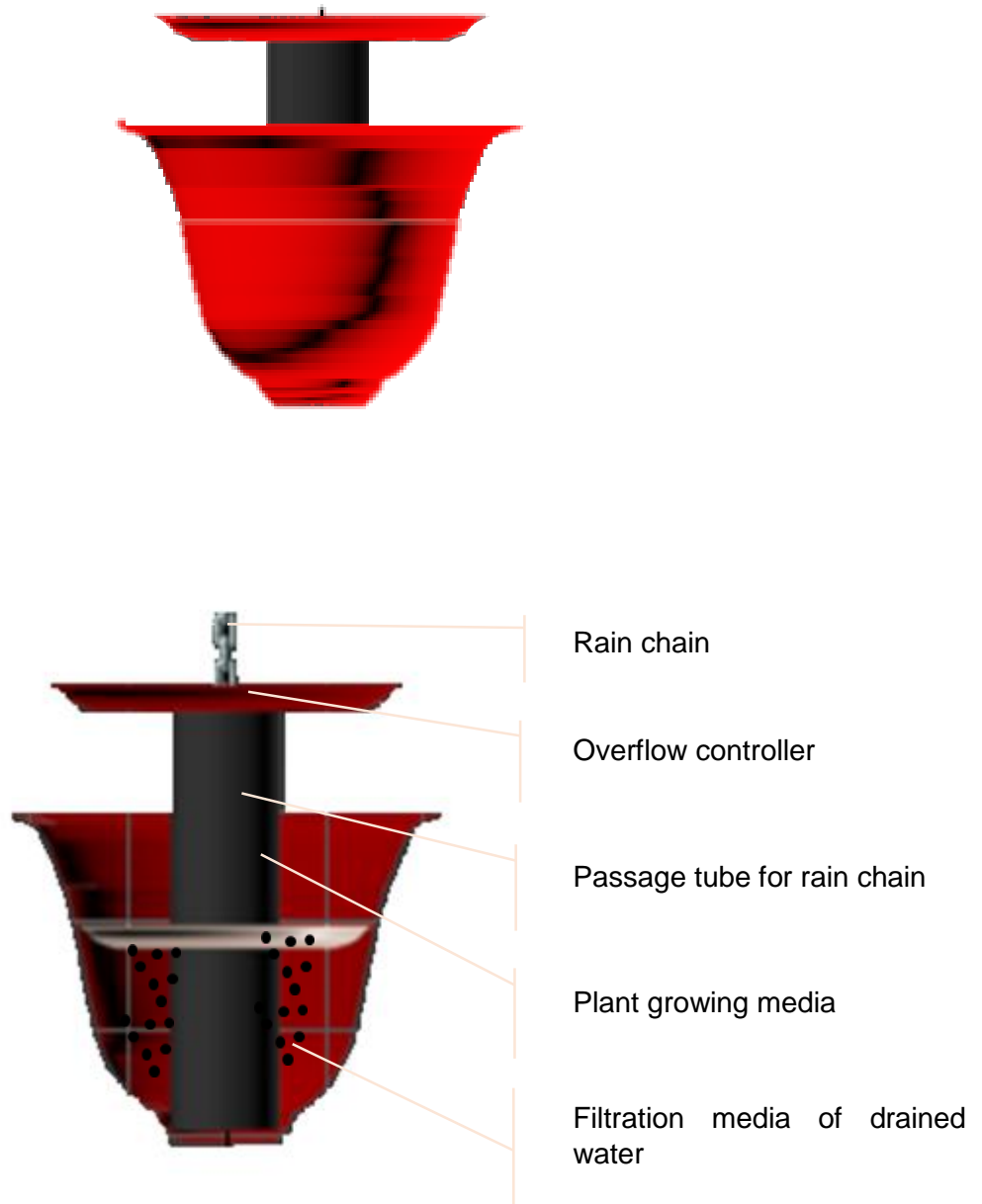
	<i>Before</i>	<i>After</i>
Mean	0.152	0.058
Variance	0.00317	7E-05
Observations	5	5
Pearson Correlation	0.59440	
Hypothesized Mean Difference	0	
df	4	
t Stat	4.06018	
P(T<=t) one-tail	0.00767	
t Critical one-tail	2.13184	
P(T<=t) two-tail	0.01534	
t Critical two-tail	2.77644	

P- test for pH

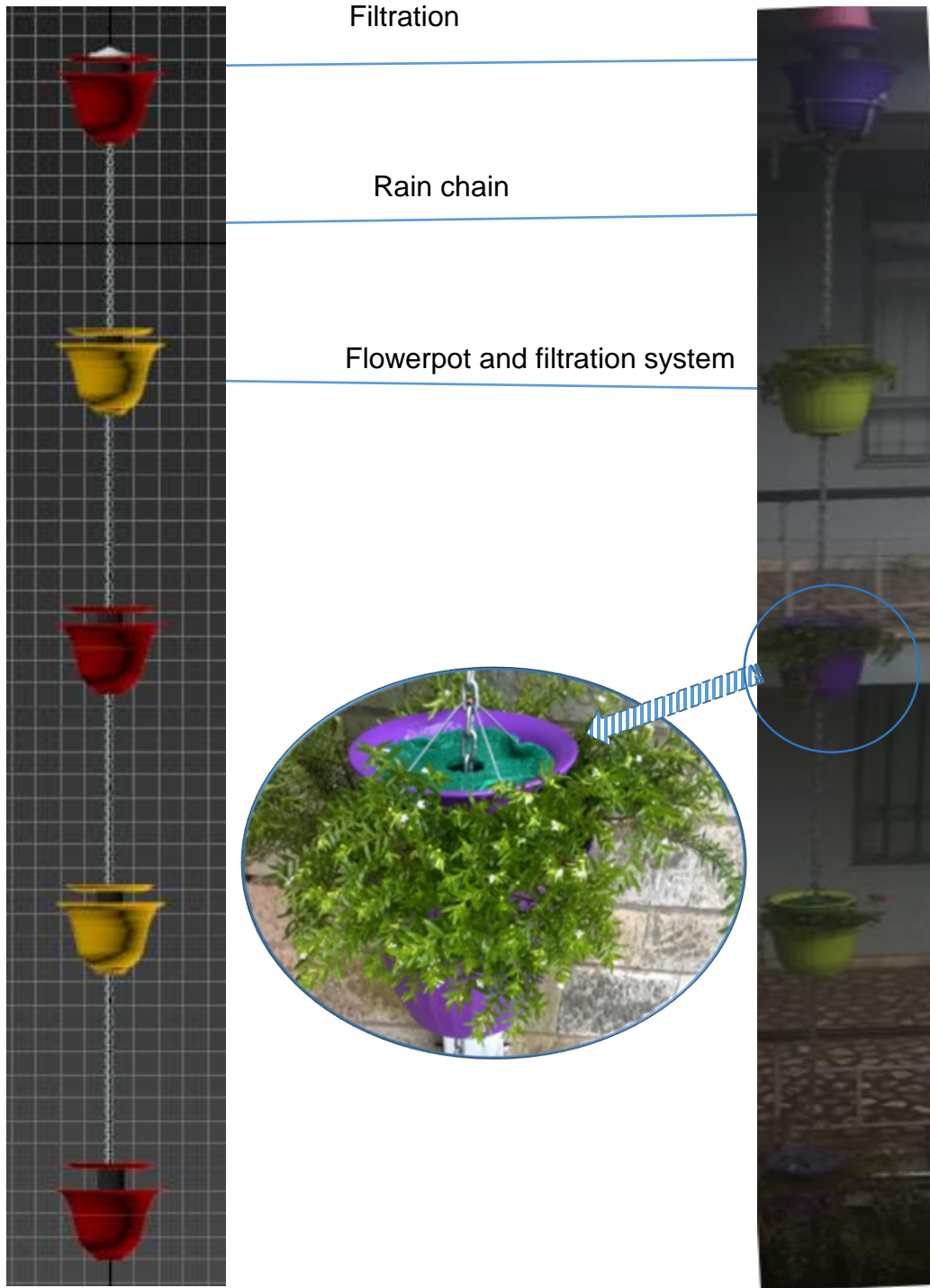
t-Test: Paired Two Sample for Means

	<i>Before</i>	<i>After</i>
Mean	5.8672	5.8608
Variance	0.0463762	0.0481407
Observations	5	5
Pearson Correlation	0.9999	
Hypothesized Mean Difference	0	
df	4	
t Stat	3.1008	
P(T<=t) one-tail	0.0180	
t Critical one-tail	2.1318	
P(T<=t) two-tail	0.03619	
t Critical two-tail	2.77645	

Annex: 4 Detail design of the flowerpot



Annex: 5 Design and development of full multifunctional rain chain system for G+1 building (urban building)



Annex 6: Design of Multifunctional rain chain building façade decorative elements for urban building



Annex: 7 Multifunctional rain chain system installed on urban building



Annex: 8 questioner developed for preference assessment

ADDIS ABABA UNIVERSITY
Ethiopian Institute of Architecture Building
Construction and City Development

Questioner

The purpose of this Questionnaire is to assess the visual quality of multipurpose rain chain system installed on the urban building. The results of this questionnaire will only be used as input for the thesis titled “**Design and Development of Multipurpose Downpipe system for Rooftop Rainwater Harvesting on Institutional Building: The Case of EiABC Campus**”, for Partial Fulfillment for Master’s Degree in urban design and development program.

1. Would you think that the multipurpose rain chain system installed on urban building is better than the conventional downpipe system?

Yes No

2. How do you see the multipurpose rain chain building façade decorative element installed on the urban building?

a) Most like

b) More like

c) Neutral

d) Less like

e) Don’t like

3. If your answer for question number 2 is “do not like” please explain why?

Thank you in advance